ICUS REPORT 2009-02

ICUS ACTIVITY REPORT
Summarizing
the Activities of a Triennium
(2006-2008)

International Center for Urban Safety Engineering

IIS, The University of Tokyo

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ICUS の活動の記録
(2006-2008)

ICUS

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2009. 8

東京大学生産技術研究所 都市基盤安全工学国際研究センター

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付録　ICUS の活動を振り返る関連資料

1. はじめに

東京大学生産技術研究所国際都市基盤安全工学研究センター（ICUS: International Center for Urban Safety Engineering）は，大学の研究機関として，国際的な視野から都市基盤施設の整備と維持管理を含めた安全工学の研究を目的に，2001 年 4 月に設立された．国際災害軽減工学研究センター（INCEDE: International Center for Disaster-Mitigation Engineering, 1991(平成３）年 4 月～2001(平成 13）年３月）の時限に際し，研究領域を拡大し設立された研究センターである．設立時の 2001(平成 13)年度より 2006(平成 18)年度までは魚本健人教授が，それ以降は私がセンター長を勤めている．

都市基盤安全工学国際研究センター(ICUS)は，10 年間の時限付で，設立当時，教授 2，助教授 3，助手 2，客員教授 2，外国人客員教授 1 の合計 10 名で構成され，これまでに生産技術研究所で蓄積された研究成果を融合することによって，上記の目的を達成できる研究センターとして具体化された．

ICUS では，(1)サステナブル・エンジニアリング部門，(2)(都市防災・安全工学部門，(3)都市基盤情報・ダイナミクス部門を掲げ，21 世紀の安全かつ安心して生活できる都市の実現に向けて活発な研究活動を展開している．具体的には，「サステナブル・エンジニアリング分野」では，構造物の材料から構造全体までの基盤設備等の経年劣化による構造安全性の評価と維持管理技術を開発するための研究を，「都市防災・安全工学分野」では，地震や洪水等により基盤設備の構造安全性，ならびに災害時の使用安全性を確保するための管理技術の開発を目指す．また，「都市基盤情報・ダイナミクス分野」は，都市基盤に関する様々な情報を常にモニタリングし，常時及び非常時の都市基盤施設の安全な運用を確保するための動的制御技術の開発と評価を行っている．

ICUS は設立以来，都市の安全性を向上させる「先端研究」，「ネットワークの形成」，「情報収集と配信」を活動の根幹として様々な活動を展開してきた．こららの活動に関して，ICUS Report 2006-02 (No.15)では設立以来の 5 年間の活動をまとめた．本報告では，2006 年度から 2008 年度までの活動をまとめる．

2 大学における都市基盤安全工学と ICUS

現在社会は，環境問題・少子化・社会基盤の整備や管理・高度情報化による格差など，様々な問題を内包している．これらの問題は，国民全体に影響を与える問題から個人のみに影響を与える問題まで存在し，異なったスケールの問題が複雑に絡み合った結果，さらに新しい問題を発生させている．そのため，都市基盤の安全性に関しても，従来の考え方・対応方法では解決が困難になってきている．

安全･安心かつ豊かな社会を実現しようと, 中央省庁の直轄付置研究所, 民間機関, NGO, NPO などの組織が活動を始めているが，短期的な研究成果だけでなく，教育を通して社会に貢献する人材の育成・輩出を行う大学に対して，特に，社会の期待も高い．

他の研究組織と大学が異なる点は，人材の育成だけはない．基礎的な研究成果や実社会に反映させる応用研究も，長い時間スケールで進めるべきものである．多くの直轄付置研究所が，短期的な解決や時代の政策に沿った研究課題の解決を求められるのに対し，大学は，中立な立場で長期的なテーマに関する研究を進めることが出来る．この点は，都市基盤の安全や安心を考える分野では特に重要である．さらに，応用研究，例えば，耐震設計の考え方の統一に関わるような複数の研究分野を横断するような研究分野であり成果を求められた場合，縦割り社会の直轄付置研究所のような組織ではすばやく成果まとめることは難しい．けれども，中立的な立場である大学ならは，より早く成果をまとめることが可能である．

しかしながら，都市基盤の安全・安心を実現するためには，大学だけの活動では不可能である．研究者と実務者，研究機関と防災組織など協力体制が不可欠であること，都市基

盤の安全・安心に関する知識者が社会の様々な分野で活躍することなどの必要がある.

東京大学生産技術研究所　都市基盤安全工学国際研究センター(ICUS)は, 大学に期待されることに対して応える組織体制を有しており，基礎から応用までの研究を進めるだけでなく，社会が求める人材を育成し，輩出することを使命として活動している.

3.　ICUS の取り組んできた活動

3.1　ICUS の 2006 年 4 月から現在に至る 3 年間の活動年表

ICUS の 2006 年 4 月から現在に至る 3 年間の学内，学外活動を示す．ICSU では，都市基盤の安全・安心に関する最新の研究報告や一般の方々への情報提供，さらに，海外の研究者との情報交換や人的ネットワークの構築のため，国内において年に数回，公開講演会（オープンレクチャ)，国外において，アジア地域の巨大都市における安全性向上のため新技術に関する国際シンポジウムを年に 1 回開催している．下記に ICUS の 2006 年 4 月から現在に至る 3 年間の学内，学外活動を示す.

ICUS の 2006 年 4 月から現在に至る 3 年間の活動

2006 年	・第 10 回 ICUS オープンレクチャ「科学・安全技術のコミュニケーション」(2006 年 3 月 16 日) ・生研公開(2006 年 6 月 1-3 日) ・タン博士が日本学術振興会の 2006 年研究者交流事業で ICUS に短期滞在(2006 年 6 月 10-24 日) ・バングラデシュ工科大学訪問(2006 年 6 月 14〜19 日) ・国立高雄第一科技大学營建工程系研究所訪日団が ICUS を見学(2006 年 8 月 15 日) ・第 11 回 ICUS オープンレクチャ「建築物衛生の危機管理のあり方」(2006 年 9 月 25 日) ・タイ王国工学部長会議一行が ICUS を訪問(2006 年 10 月 23 日) ・タイ王国タマサート大学国際工学部との協力協定締結(2006 年 10 月 25 日) ・千葉実験所公開(2006 年 11 月 10 日) ・第 5 回アジア地域の巨大都市における安全性向上のための新技術に関する国際シンポジウム(2006 年 11 月 16〜17 日)
2007 年	・ICUS の連携ネットワークの拡大 ・第 1 回生研同窓会がバンコクで開催される(2007 年 2 月 26 日) ・生研公開(2007 年 5 月 31 日，6 月 1〜2 日) ・チュラロンコン大学チュラユニサーチでワークショショップ開催(2007 年 2 月 27 日) ・第 12 回 ICUS オープンレクチャ(2007 年 4 月 25 日) ・清華大学代表団が ICUS 訪問(2007 年 6 月 29 日) ・タイ科学週間に出展(2007 年 8 月 8〜19 日) ・芝浦工業大学 ICUS ルーム見学(2007 年 8 月 31 日) ・東大病院総合防災訓練実施(2007 年 9 月 4 日) ・第 13 回 ICUS オープンレクチャ(2007 年 10 月 2 日) ・千葉実験所公開(2007 年 11 月 9 日) ・第 6 回アジア地域の巨大都市における安全性向上のための新技術に関する国際シンポジウム(2007 年 12 月 9〜10 日)
2008 年	・ALOS 利用協議会(2008 年 4 月 22 日) ・第 14 回 ICUS オープンレクチャ(2008 年 5 月 9 日) ・生研公開(2008 年 5 月 29〜31 日) ・日韓タイ合同セミナ(2008 年 7 月 3〜4 日) ・港湾技術研究所(2008 年 8 月 22 日) ・東大病院総合防災訓練実施(2008 年 9 月 9 日) ・第 15 回 ICUS オープンレクチャ(2008 年 10 月 6 日) ・世界地震工学会議に出店(2008 年 10 月 12〜17 日) ・第 7 回アジア地域の巨大都市における安全性向上のための新技術に関する国際シンポジウム(2008 年 10 月 21〜22 日) ・都市における交通工学ワークショップ(2008 年 11 月 11 日) ・第 2 回生研同窓会がバンコクで開催 (2008 年 11 月 12 日)

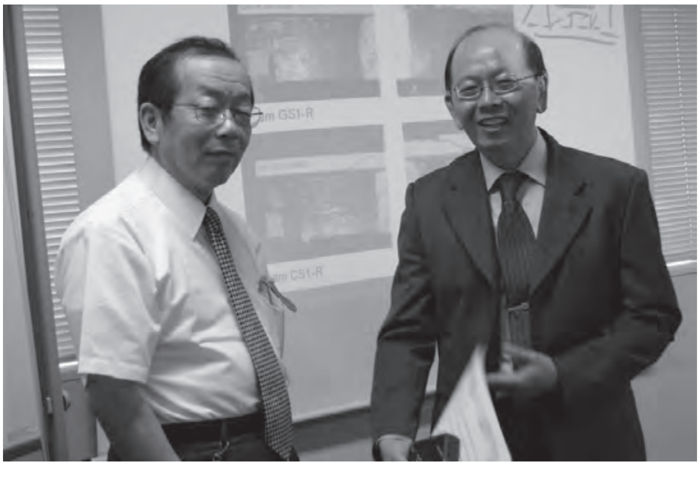

大島まり教授


吉川肇子助教授


田中弥生客員助教授

- 第 10 回 ICUS オープンレクチャ「科学･安全技術のコミュニケーション」
  (2006 年 3 月 16 日)

- 生研公開
  (2006 年 6 月 1～3 日)



- 魚本センター長(左)とタン博士
  日本学術振興会 2006 年研究者交流事業で ICUS に短期滞在
  (2006 年 6 月 10～24 日)

- バングラデシュ工科大学訪問
  (2006 年 6 月 14〜19 日
  ﾀﾞｯｶ・ﾊﾞﾝｸﾞﾗﾃﾞｼｭ)

- 国立高雄第一科技大学營建工程系研究所訪日団が来所
  (2006 年 8 月 15 日)

池田耕一氏

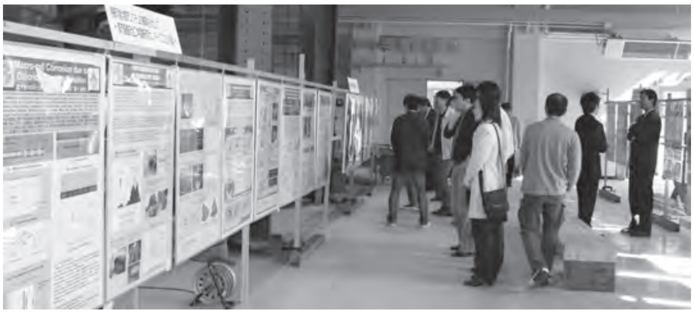
加藤信介教授

伊藤雅喜氏

柳　宇氏

- 第 11 回 ICUS オープンレクチャ
  「建築物衛生の危機管理のあり方」
  (2006 年 9 月 25 日)

・タイ王国工学部長会議一行来所
(2006年10月23日)



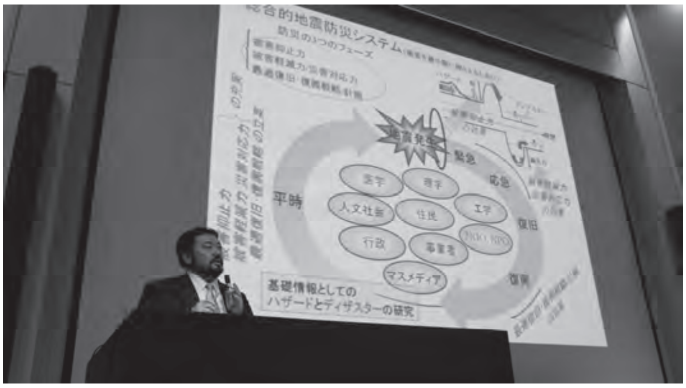
・千葉実験所公開
(2006年11月10日)

・第5回アジア地域の巨大都市における安全性向上のための新技術に関する国際シンポジウム
(2006年11月16-17日
ﾊﾟｰｸｶﾝﾜﾎﾃﾙ,ﾌﾟｰｹｯﾄ,ﾀｲ王国)

・第 1 回生研同窓会
(2007 年 2 月 26 日ﾊﾞﾝｺｸ･ﾀｲ王国)

・生研公開
(2007 年 5 月 31 日～6 月 2 日)

・ワークショップ
(2007 年 2 月 27 日
ﾁｭﾗﾛﾝｺﾝ大学ﾁｭﾗﾕﾆｻｰﾁ、
ﾊﾞﾝｺｸ・ﾀｲ王国)



・第 12 回 ICUS オープンレクチャ
「ICUS の活動—これまでの道のり、これからの展望」
(2007 年 4 月 25 日)

・清華大学代表団の来所
(2007 年 6 月 29 日)

・タイ科学週間への出展
(2007 年 8 月 8-19 日)

・芝浦工業大学 ICUS ルームの見学
(2007 年 8 月 31 日)

- 東大病院総合防災訓練の実施
  (2007 年 9 月 4 日)

森川博之教授

東方幸雄氏

上原美都男氏

- 第 13 回 ICUS オープンレクチャ
  「都市基盤の安全のために
  －危機管理・防災と情報－」
  (2007 年 10 月 2 日)

- 千葉実験所公開
  (2007 年 11 月 9 日)

・第 6 回アジア地域の巨大都市における安全性向上のための新技術に関する国際シンポジウム
(2007 年 12 月 9-10 日
ﾀﾞｯｶｼｪﾗﾄﾝﾎﾃﾙ､ﾀﾞｯｶ､ﾊﾞﾝｸﾞﾗﾃﾞｼｭ)

・ALOS 利用協議会
(2008 年 4 月 22 日)

花木啓祐教授

三村信男教授

沢田治雄教授

- 第 14 回 ICUS オープンレクチャ「地球温暖化は都市にどのような影響を及ぼすか？」
  (2008 年 5 月 9 日)

- 生研公開
  (2008 年 5 月 29～31 日)

- 日韓タイ合同学生セミナー
  (2008 年 7 月 3～4 日)

・港湾技術研究所見学
(2008 年 8 月 22 日)

・東大病院総合防災訓練実施
(2008 年 9 月 9 日)

梅山和成氏

横田弘教授

難波喬司氏

・第 15 回 ICUS オープンレクチャ
「交通･物流拠点としての港湾･
空港戦略」
(2008 年 10 月 6 日)

・第 14 回世界地震工学会議に出展
(2008 年 10 月 12～17 日)

・第 7 回アジア地域の巨大都市における安全性向上のための新技術に関する国際シンポジウム
(2008 年 10 月 21-22 日北京･中国)

・都市における交通工学ワークショップ
(2008 年 12 月 11 日)

・第 2 回生研同窓会がバンコクで開催される
(2008 年 12 月 12 日)

3.2　都市基盤安全工学に向けた研究活動

3.2.1　ICUS 活動分野とメンバー

ICUS の目的である国際的な視点から都市基盤技術の整備及び維持管理を含めた安全工学に関する研究を戦略的に進めるため，研究課題別に 3 部門に分かれている．また，学際的な研究を迅速に進めるため，ICUS の研究者以外に国内・国外から第一線の研究者を招聘している．ここに，各部門別の設立時からの現在に至る構成員とそれぞれの在籍期間を示す．

各部門の位置づけ

1)　サステナブル・エンジニアリング部門

・魚本　健人	教授／センター長	(2001 年 4 月 1 日〜2007 年 3 月 31 日)
・天野　玲子	客員教授	(2005 年 4 月 1 日〜2007 年 3 月 31 日)
・横田　弘	客員教授	(2007 年 11 月 1 日〜　　)
・加藤　佳孝	准教授	(2002 年 4 月 1 日〜　　)
・桑野　玲子	准教授	(2006 年 4 月 1 日〜　　)


魚本　健人


天野　玲子


横田　弘


加藤　佳孝


桑野　玲子

2)　都市防災・安全工学部門

・目黒　公郎　教授　(2001年4月1日～2007年3月31日)
　　センター長　(2008年4月1日～　)
・林　省吾　客員教授　(2004年7月1日～2006年9月30日)
・大原(吉村)美保 助教　(2003年6月1日～2007年3月31日)
　　准教授　(2008年4月1日～　)


目黒　公郎


林　省吾


大原(吉村)美保

3)　都市基盤情報・ダイナミクス部門

・沢田　治雄　教授　(2008年4月1日～　)
・大岡　龍三　准教授　(2001年4月1日～2008年3月31日)
・宮崎　早苗　客員准教授　(2006年8月1日～2009年3月31日)
・腰原　幹雄　准教授　(2008年4月1日～　)
・黄　弘　准教授　(2008年8月1日～　)
・田中　伸治　講師　(2007年3月1日～　)
・遠藤　貴宏　助教　(2003年4月1日～　)


沢田　治雄


大岡　龍三


宮崎　早苗


腰原　幹雄


黄　弘


田中　伸治


遠藤　貴宏

4)　研究員

・金田　尚志　特任助手　(2005年8月1日～2007年 3月31日)
・Paola Mayorca　特任助教　(2006年4月1日～2008年10月31日)
・Pranab J. Baruah 特任助教　(2008年11月1日～
・Raktipong Sahamitmonkol 特定プロジェクト研究員　(2005年10月1日～2007年7月31日)
・Kawin Worakachana　特定プロジェクト研究員　(2007年7月1日～　)


金田　尚志


Paola Mayorca


Pranab J. Baruah


Raktipong Sahamitmonkol


Kawin Worakachana

5) 秘書

・吉本　英子	(2002年9月1日〜　　)


吉本　英子

6)顧問研究員

・魚本　健人	芝浦工業大学　教授	(2007年4月1日〜)
・林　省吾	財団法人　地域創造　理事長	(2006年8月1日〜)
・高橋　健文	不動産協会　理事	(2006年10月1日〜)


魚本　健人


林　省吾


高橋　健文

7)研究員

・瀬戸島　政博	日本測量協会理事	(2004年9月1日〜)
・天野　玲子	鹿島建設株式会社土木管理本部部長	(2007年4月1日〜)
・Sudhir Misra	IIT Kanpur 教授	(2004年4月1日〜)
・Ansary Mehedi Ahmed	Bangladesh University of Engineering and Technology 教授	(2006年5月1日〜)
・Dushmanta Dutta	Monash University Senior lecture	(2005年10月1日〜)
・須崎　純一	京都大学大学院工学研究科	(2006年4月1日〜)
・徳田　俊夫	株式会社大林組　タイ事務局長	(2005年5月1日〜)
・鶴田　俊	総務省消防庁消防大学校消防研究センター技術研究部特殊災害研究室長	(2006年5月1日〜)
・Tan kiang	シンガポール大学　教授	(2006年8月1日〜)
・Worsak Kanok-nukulchai	アジア工科大学院　教授	(2007年6月1日〜)
・加藤　絵万	（独）港湾空港技術研究所 主任研究官	(2007年6月1日〜)


瀬戸島正博


天野 玲子


Sudhir Misra


Ansary Mehedi Ahmed


Dushmanta Dutta


須崎 純一

徳田　俊夫

鶴田　俊

Tan kiang
Hwee

Worsak
Kanok-nukulchai

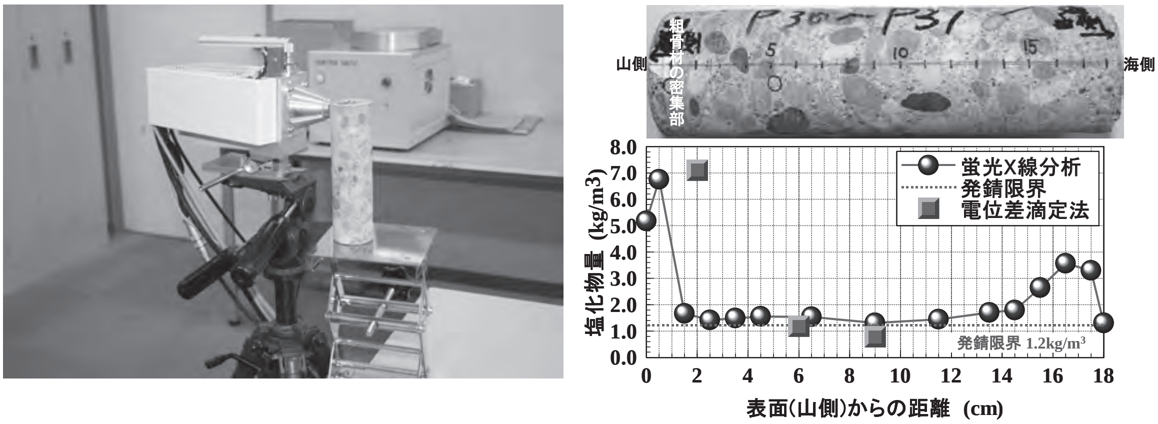
加藤　絵万

3.2.2　各部門および ICUS としての活動

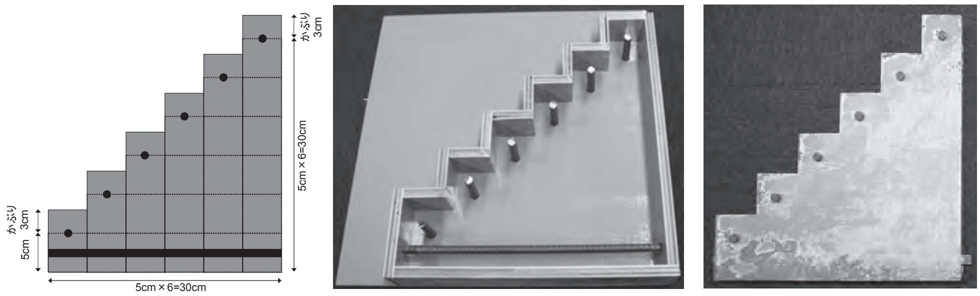
3.2.2.1　サステナブル・エンジニアリング部門

1) 魚本研究室　(都市基盤安全工学)

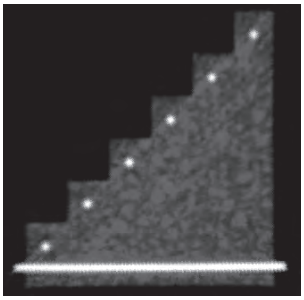
都市基盤を支えているコンクリート構造物の安全性は非常に重要であるが，昨今，コンクリートの早期劣化や，耐震強度偽造問題などコンクリート構造物への不信が拡大している．これらの問題を解決するためには正確な診断とその診断結果を踏まえて適切な対応を行う必要がある．当研究室では，放射線(エックス線，ガンマ線)を用いたコンクリートの元素分析や内部調査方法の開発を行っている．



蛍光 X 線分析によるコンクリート中の塩化物量測定



供試体寸法　**供試体型枠**　**供試体打設後**



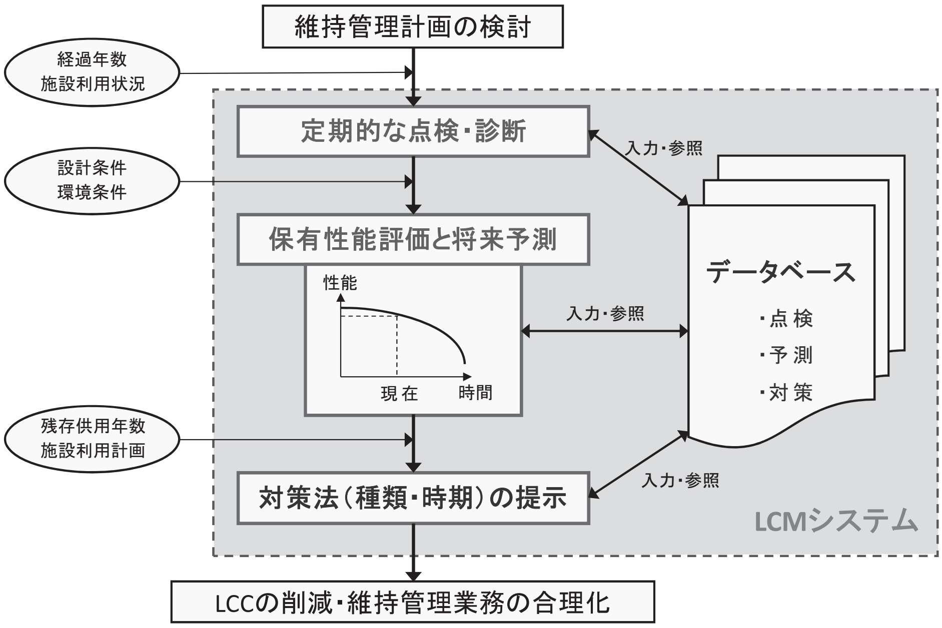
CT 画像

レーザー逆コンプトン□線によるコンクリート内部の調査

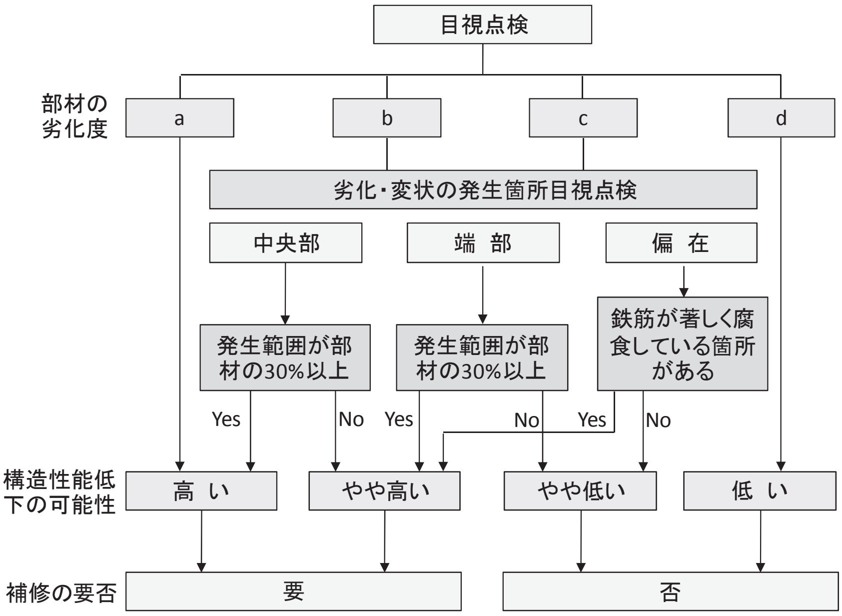
2) 横田研究室　(都市インフラのライフサイクルマネジメント)

都市インフラの性能を合理的かつ戦略的に維持するための考え方の一つに，ライフサイクルマネジメントがある．ライフサイクルマネジメントは，定期的な点検診断の結果に基づいてインフラ（構造物）の性能を客観的に評価するとともに，性能の将来

にわたる経年的な低下を予測し，最適の対策を立案する一連のシステムである．ライフサイクルマネジメントのシステムを確立するには，この「性能」をキーワードとして，上述の点検から対策に至る個別技術に内在する課題を解明し，実務に取り入れる価値のある有用な手法を提案していかねばならない．この一環として，材料の経年劣化等に起因するインフラの老朽化に伴う性能低下を高精度に評価する技術の確立およびコンクリート構造物の劣化進行の空間的分布を表現し，予測に取り込む技術の確立を目指した研究を実施している．



ライフサイクルマネジメントの流れ



目視点検の結果による簡易的な構造性能評価の流れ

3) 天野研究室　(都市防災工学)

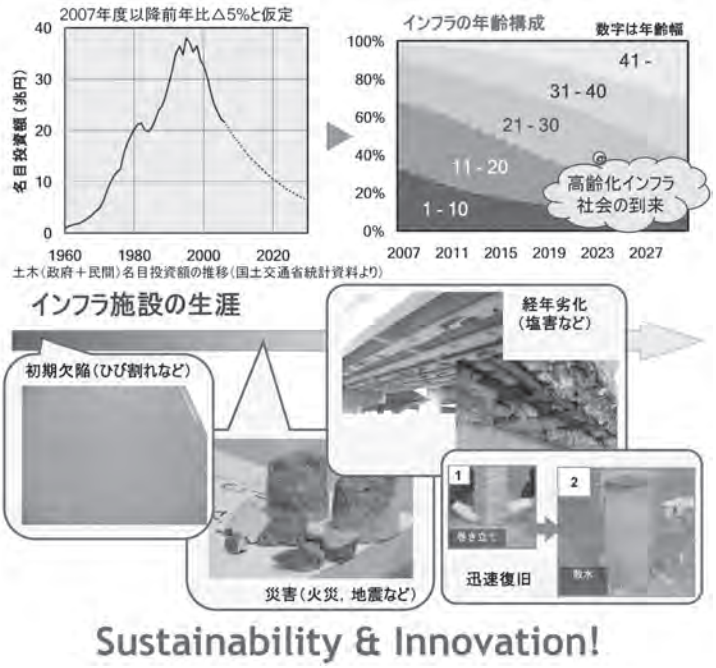
天野研究室は，東京大学生産技術研究所で蓄積された研究成果をより効果的に社会に還元する目的で，産官学連携の場として，2004 年 3 月～2007 年 3 月に設立された研究室である．天野研究室では，特に防災拠点として重要な自治体の耐震化を促進するための資料作成に力を注いでいる．2004 年 10 月に発生した新潟県中越地震では，防災拠点となるべき施設の耐震化の必要性が示された．そのため，産官学連携事業の先駆けとして，総務省消防庁･鹿島建設と連携して，地方公共団体担当者のための「防災拠点の耐震化促進資料」をまとめた．さらに，和歌山市を対象に，津波ハザードマップを等の作成を行い，「地震被害想定調査結果報告書」も作成した．また，地域の防災力を向上させる目的で，「地震を知り地震に備える～みんなで高めよう地域防災力～」というビデオを作成した．

和歌山市の地域防災力を向上させるために作成したﾋビデオ

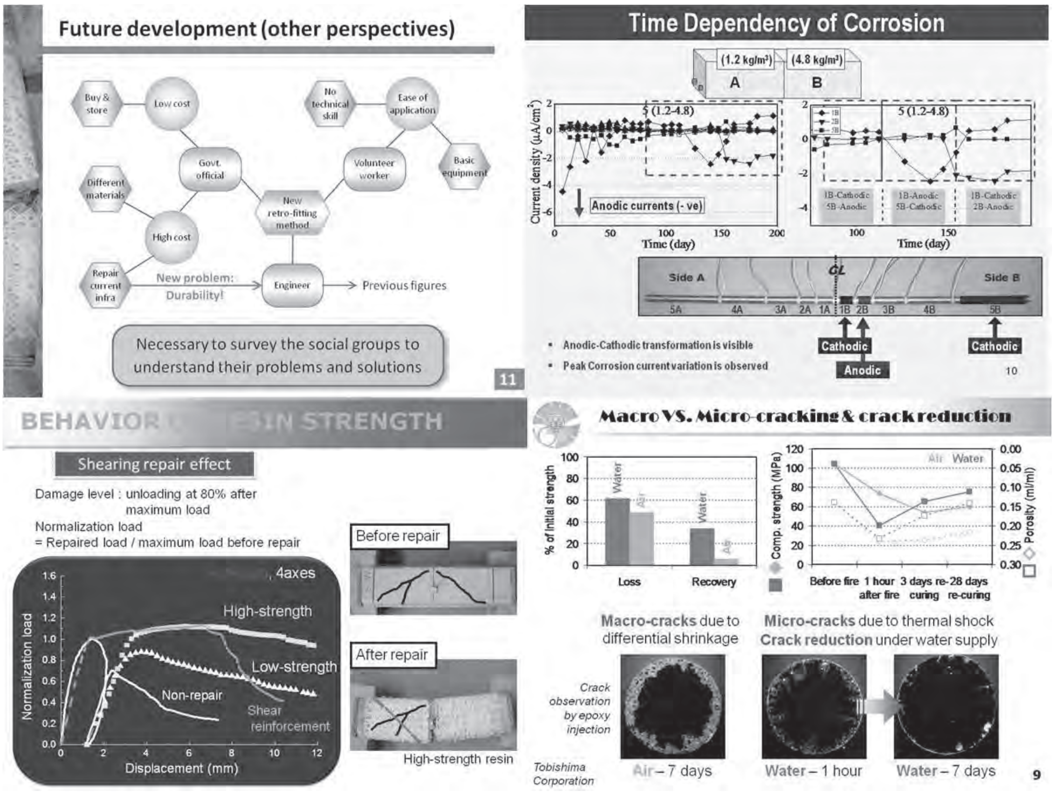
4) 加藤研究室　(建設材料マネジメント)

加藤研究室では，膨大な都市基盤ストックを戦略的に維持管理するために必要な技術開発，現象の解明，計画論に関する研究を行っている．都市基盤施設の劣化(エイジング)は，地震や台風に代表される災害のように，局所的な時空間軸で甚大な被害をもたらす現象ではないが，全ての施設で必ず生じる現象である．都市基盤施設にとって，災害をフィニッシュブローに例えれば劣化はボディーブローに，また，事故死に例えれば病死に例えることができる．人間の健康管理と同じように，施設の維持管理も，検査，診断，将来予測，対策等の様々なアクションを適切な時期に実施することが極めて重要である．特に，都市基盤施設において主要なコンクリート構造物の劣化は，環境，施工，材料非均質性などの影響による不確定性が多いため，適切な維持管理を実施することが難しいとされている．我々の研究室では，リスク評価による効率的な

維持管理計画論，劣化外力評価，施工の定量評価，劣化機構解明とモデル化，効果的な検査手法の開発等の検討を実施している．



加藤研究室の研究対象



Necessary to survey the social groups to understand their problems and solutions

- Anodic-Cathodic transformation is visible
- Peak Corrosion current variation is observed

Damage level : unloading at 80% after maximum load
Normalization load
= Repaired load / maximum load before repair

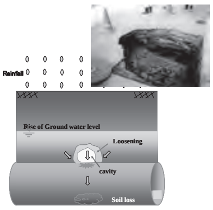
研究成果の一例

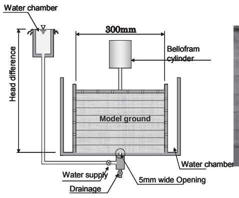
5) 桑野研究室　(地盤機能保全工学)

桑野研究室は 2006 年 4 月に開設し，保有する高精度な室内土質試験や模型実験のノウハウを生かして，種々の地盤材料の力学特性の解明という基礎的研究と，地中構造物や土構造物の長期挙動や更新手法という持続性社会の確立に向けた実務的研究に加えて，微生物機能を利用した新しい地盤強化手法の開発などに取り組んでいる.

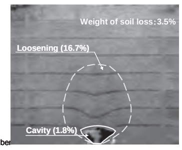
地盤内空洞・ゆるみの発生・進展メカニズムの解明

地中埋設管の破損に起因する浅層部の地盤空洞　→　小規模陥没



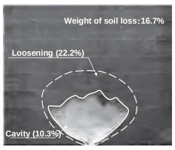


豊浦砂（3サイクル）



小さな空洞：大きなゆるみ
ゆるみ程度15%

山砂（13サイクル）



大きな空洞：小さなゆるみ
ゆるみ程度50%

深層部の地盤空洞　→　大規模陥没

GL－3m以深の空洞を確実に探査する方法は今のところない。そこで、空洞上部に生成するゆるみの類型化により深部空洞の探知を目指す。

大型土槽に作成した模擬空洞・ゆるみの探査実験（2008年12月）

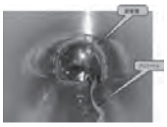
大阪府阪南市
2008年5月

陥没発生：2/15、2/19、5/5
陥没は繰返す！

地中埋設管の合理的維持管理および更新

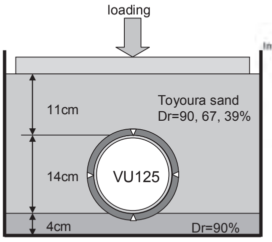
地中埋設管の非開削更新：
老朽埋設管の内部にライニングを施工することにより、開削工事をすることなく管を延命または更新する方法。既設管とライニングの荷重分担機構が未解明。

老朽下水管

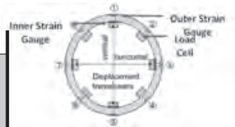


ライニングによる更新

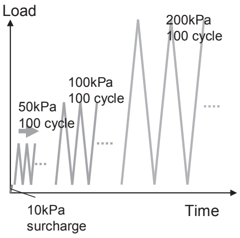
老朽既設管およびライニングの模型実験



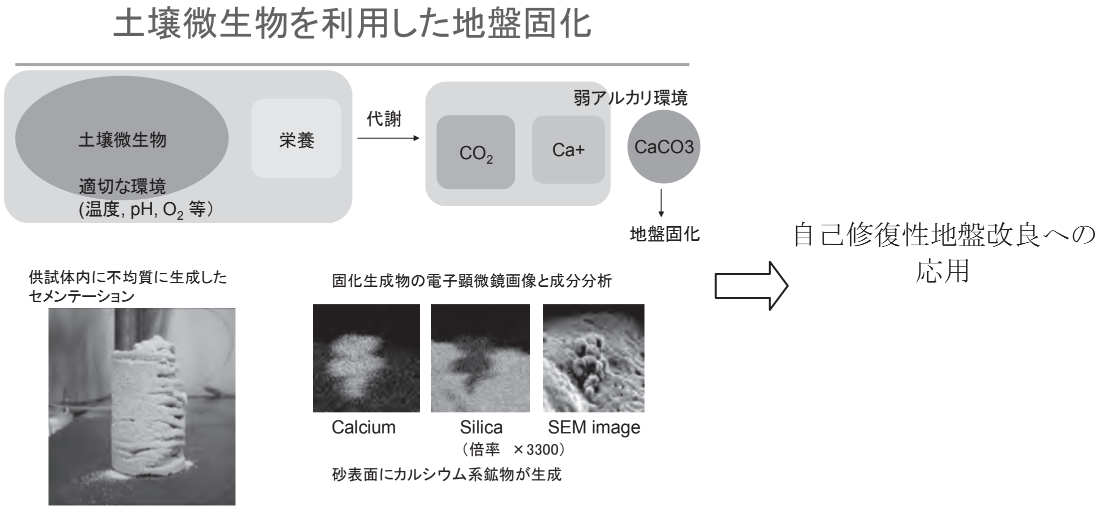
内部ライニング模型



繰返し荷重



土構造物・地中構造物の長期挙動及び合理的維持管理に関する研究



新しい地盤強化手法の開発

3.2.2.2　都市防災・安全工学部門

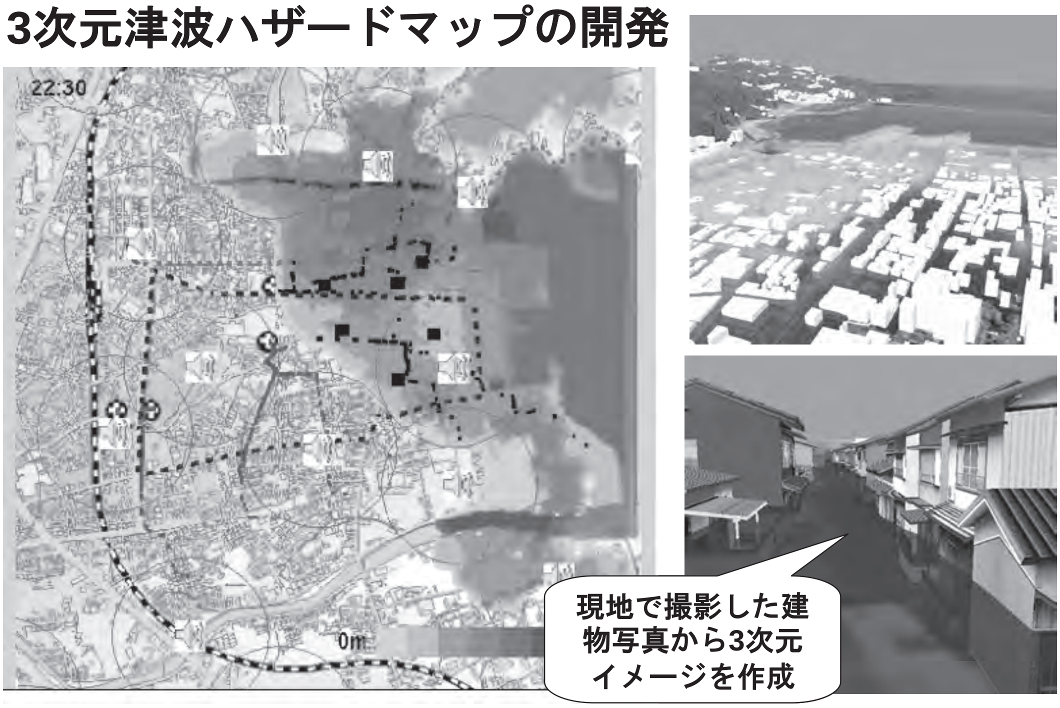
1)目黒研究室　(都市震災軽減工学)

目黒研究室研究テーマは，地震を中心としたハザードを原因として発生する人的・物的な被害や社会機能の障害を，ハードとソフトの両面からのバランスのとれた対策で，最小限に押さえる戦略研究である．目黒研究室では，「現場を見る」「実践的な研究」「最重要課題から取り組む」を研究上のモットーに，被害や事故の現地調査を実施するとともに，その結果に基づいて表に示す様々なテーマの研究を行っている．

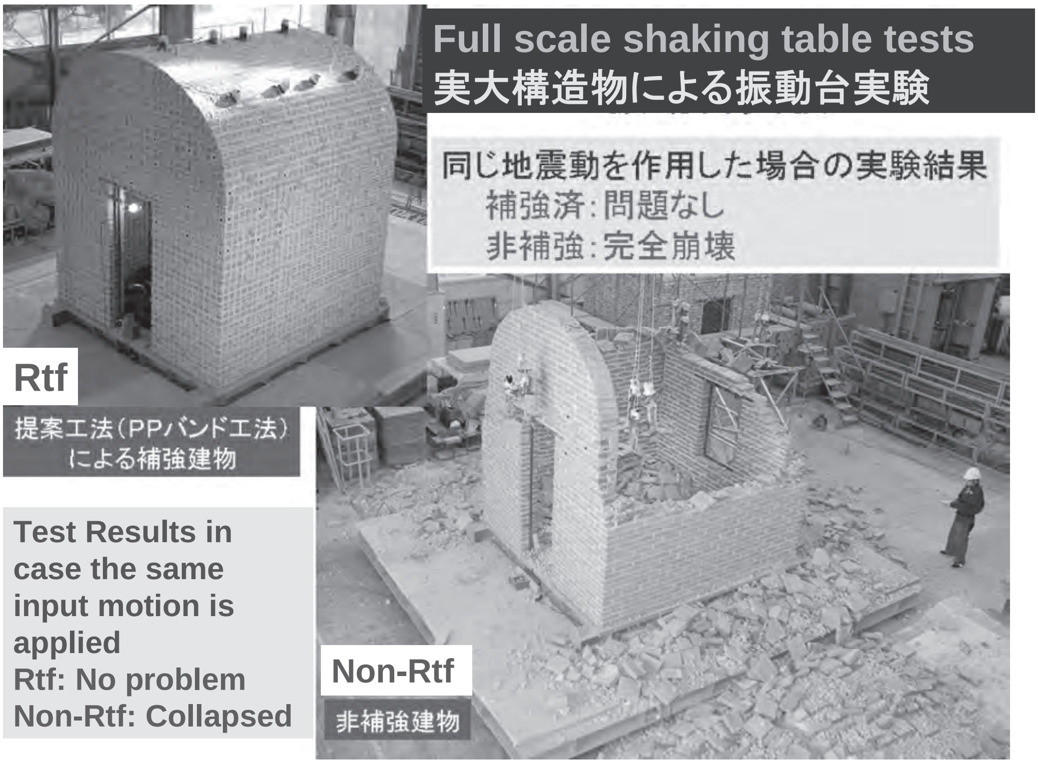
目黒研究室の研究テーマ

ハードに関係するもの
□構造物の高精度破壊解析手法の開発，□地震時の構造物の破壊/崩壊メカニズム， □地震断層と地表断層の関係の解明と活断層法の可能性検討， □高信頼性・高精度耐震診断法の開発，□非連続体の力学， □組積造構造物の地震被害メカニズム，□100 ドル耐震補強策， □インド洋沿岸諸国の地域特性を踏まえた津波被害軽減システムなど
ソフトに関係するもの
□都市ライフラインの災害対策（電力，ガス，水道，etc.）， □利用者の避難安全性に基づく新しい都市空間設計法と安全管理システム， □緊急地震情報システム，□最適「事前」「最中/直後」「事後」災害対策システム， □既存不適格構造物の耐震補強対策の推進制度/システム、□次世代危機管理/防災マニュアル， □災害時の最適人材運用法，□電力需要モニタリングによる高精度被害・復旧/復興過程評価， □相互影響を考えた最適復旧・復興戦略のあり方，□日本社会に適した BCP/BCM のあり方， □地震予知情報の工学的な利用法，□防災拠点病院の地震対策， □災害情報プラットフォーム(オール霞ヶ関＋霞ヶ関～末端市町村)，など
研究全体の基礎検討と成果の集大成として
□災害と事故の現地調査， □災害イマジネーション向上ツールの開発， □危機管理/防災情報ステーションの開発

3次元津波ハザードマップの開発



津波災害と避難シミュレーションを組み合わせた 3 次元津波ハザードマップ



Full scale shaking table tests
実大構造物による振動台実験

同じ地震動を作用した場合の実験結果
補強済：問題なし
非補強：完全崩壊

Rtf

提案工法（PPバンド工法）による補強建物

Test Results in case the same input motion is applied
Rtf: No problem
Non-Rtf: Collapsed

Non-Rtf

非補強建物

組積造の簡便で効果的な耐震補強法の研究と普及に関する研究
（アーチ形屋根の実大組積造を対象とした振動破壊実験：補強済(左)，未補強構造物(右)）

2) 林研究室　(防災行政学)

林研究室では，都市の安全や防災力の向上と，危機管理体制の充実を実現するために，関連施策や制度設計と，その効果的な実現に向けた研究と教育を行っている．研究テーマは，1)効果的な防災対策の立案と実施方法，2)災害対応の実践的なマニュアル化，3)防災行政と学術調査機関の効果的な連携スタイル，4)防災行政と防災 NGO との効果的なスタイルの 4 点である．これらに注目し，研究が推進するよう活動しています．さらに，消防防災行政の課題と改革の方向—総点検による総合的戦略の構築—に注目し，すべての行政の原点は「安心・安全の確保」であり，その運営の基本も「安心・安全の確保」でなければばならないと結論するに至った。地域のリーダーは，このことを改めて確認し，そのための戦略を構築し，地域間で競争しながら，それぞれの地域の総合的な防災力の強化になるよう活動をしている。

3) 大原研究室　(総合防災管理工学)

近年，首都直下地震をはじめとして，東海地震・東南海地震，南海地震などの大地震の発生が危惧されている．地震以外にも，都市が抱える災害リスクは洪水・土砂災害などの自然災害，テロなどの人為災害と多岐に渡る．大原美保研究室では，情報を活用して災害発生過程を管理し，災害による被害を最小化するための方法論の研究を目指している．

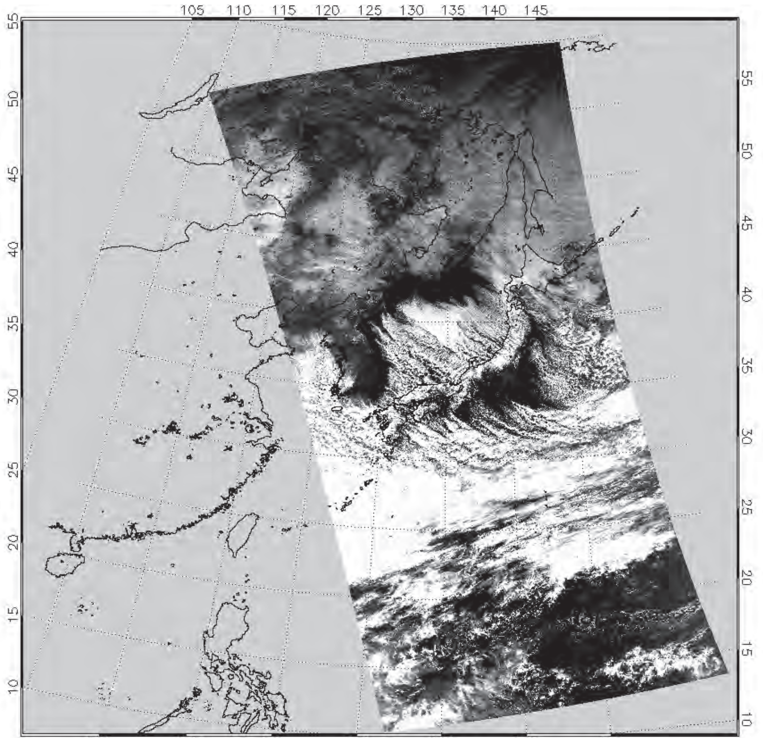
他分野と連携した総合的な防災研究の一環として，近年は病院の防災管理の研究に力を入れている．災害拠点病院では，災害直後に多数の患者の搬送が予想されるため，職員の災害対応力の向上と事前対策の実施が必須である．研究室では，災害拠点病院の一つである東京大学医学部附属病院との共同により，医師・看護師向けの災害対応 e ラーニングシステムを開発している．事前の e ラーニング学習と防災訓練の併用により，一人一人の災害対応力の向上を目指している．医師約 300 人，看護師約 800 人による学習結果からは，e ラーニングは災害対応マニュアルの周知や訓練への動機付けに有用であることが示されており，引き続き，コンテンツの拡充と改良も行っている．

病院職員の災害対応力向上の流れ

3.2.2.3　都市基盤情報・ダイナミクス部門

1)沢田研究室　(応用リモートセンシング工学)

沢田研究室ではリモートセンシング技術を利用し，陸域生態系や都市環境の評価手法の開発を行っている．これには，対象物に応じた様々なセンサによる計測(モニタリング)と，取得したデータから有用な情報を抽出するためのモデル構築(モデリング)が含まれる．対象としている空間スケールは，実験室レベルから都市・地域レベル，さらには大陸・全球レベルまで幅広いものとなっている．また，高波長分解能のハイパースペクトルセンサによる計測や，レーザースキャナによる計測，高解像度航空デジタル写真，可視・近赤外・熱赤外の波長帯を用いた計測など対象物に応じて様々な波長帯のデータを利用している．

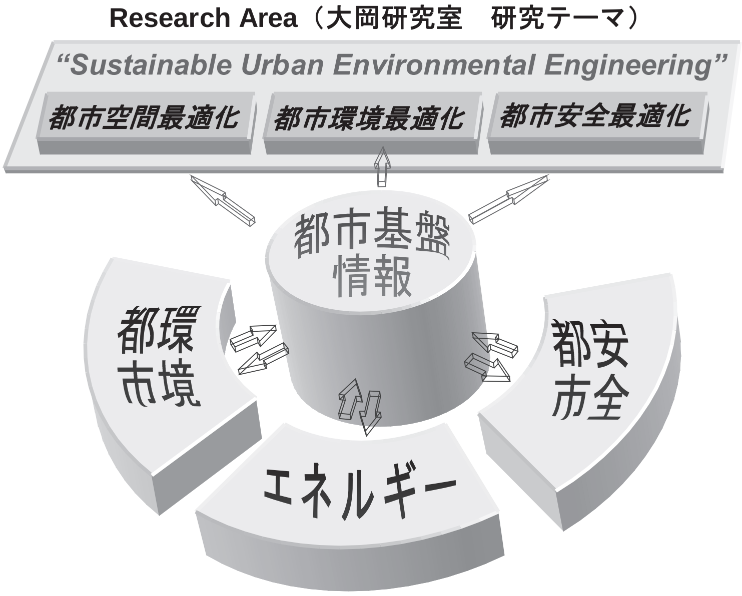


Aqua MODIS 2008/12/31 04:03 UTC　IIS/U-Tokyo/Japan

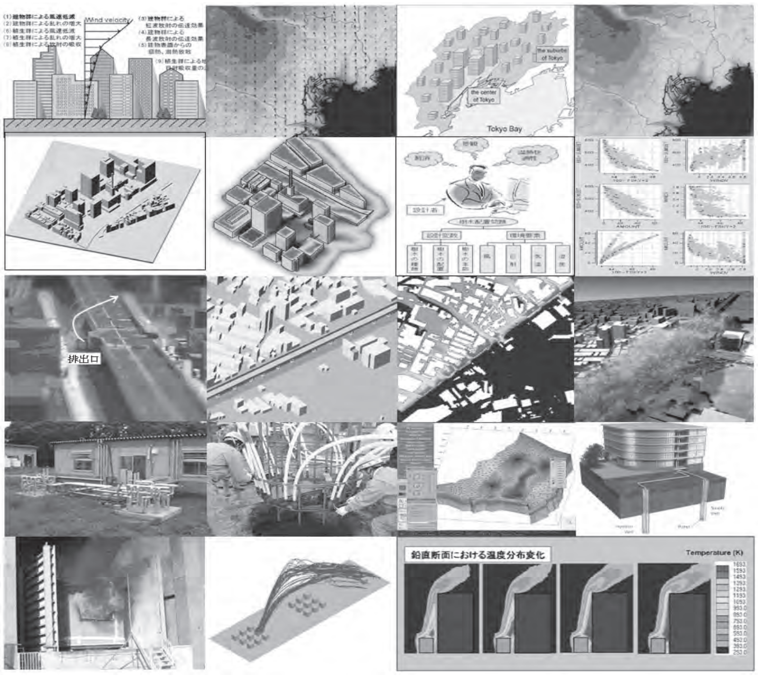
Aqua 人工衛星　MODIS センサによる大陸レベルの衛星画像
（生産技術研究所受信データ）

2)大岡研究室　(サステナブル都市環境工学)

近年，都市化の進行に伴い，ヒートアイランド現象，大気汚染，都市火災を含め都市安全問題等様々な環境・社会・安全問題を深刻化しており，都市環境の改善が急務な課題になっている．そこで，当研究室では，サステナブル都市を達成することを目指し，実験とコンピュータシミュレーションの両方に基づく都市・建築環境工学分野において，特に 1）都市大気・熱環境，2)都市エネルギー代謝，3)都市火災を含め都市安全等のテーマについて研究を行っている．



大岡研のテーマ

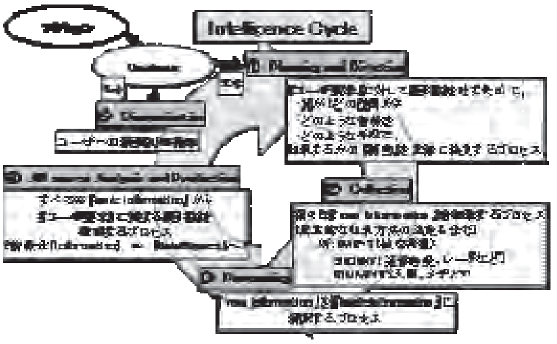


研究設備及び解析結果

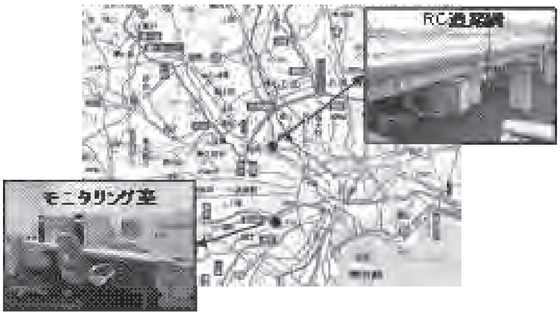
3) 宮崎（早）研究室　(都市基盤情報システム工学)

近年，各分野において情報システムの存在は無視出来ないものになってきているが，本研究室では，特に災害分野での情報システムのあり方について検討を進めてきた．主な研究テーマは以下の通りである．

(1)災害における情報基盤システムのあり方に関する研究
(2)橋梁健全性モニタリングシステムに関する研究
(3)4D 災害情報可視化システムに関する研究



災害における情報基盤システムのあり方に関する研究

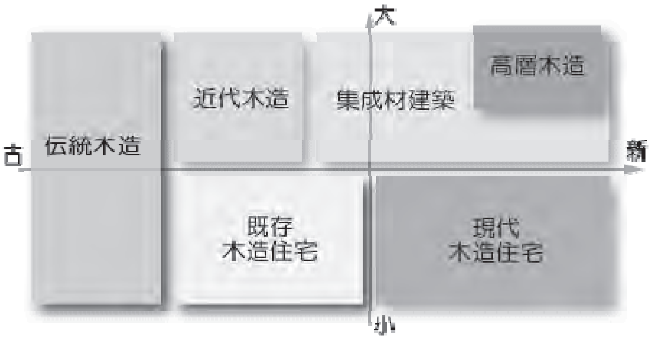


橋梁健全性モニタリングシステムに関する研究

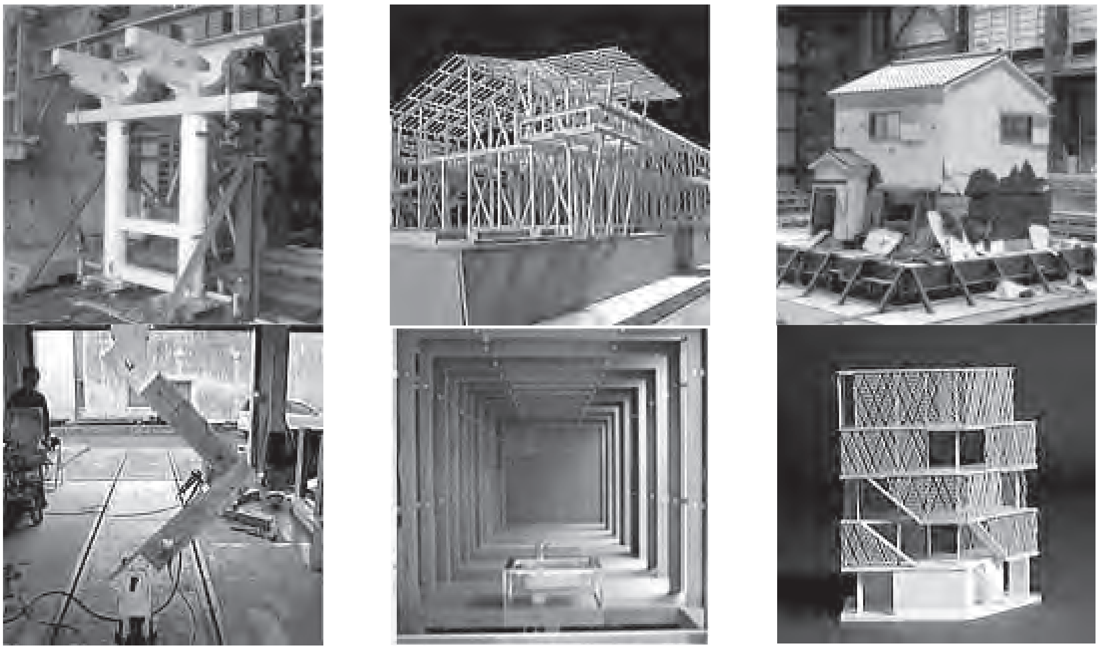
4D 災害情報可視化システムに関する研究

4)腰原研究室　(木質構造学)

日本では，古くから木材を使用して構造物を建築し続けてきたため，構造工学でありながら時間軸を持っている．古い技術は伝統技術（文化）として，新しい技術と同様に評価する必要がある．一方で，社会的には，地震災害など木造建物の耐震性能の向上が望まれている．当研究室では，伝統木造建築などの文化財の保存・改修や既存木造住宅の耐震診断・耐震補強技術の開発・整備を行うとともに，森林資源の有効活用としての新しい木質構造建築の可能性を探求している．



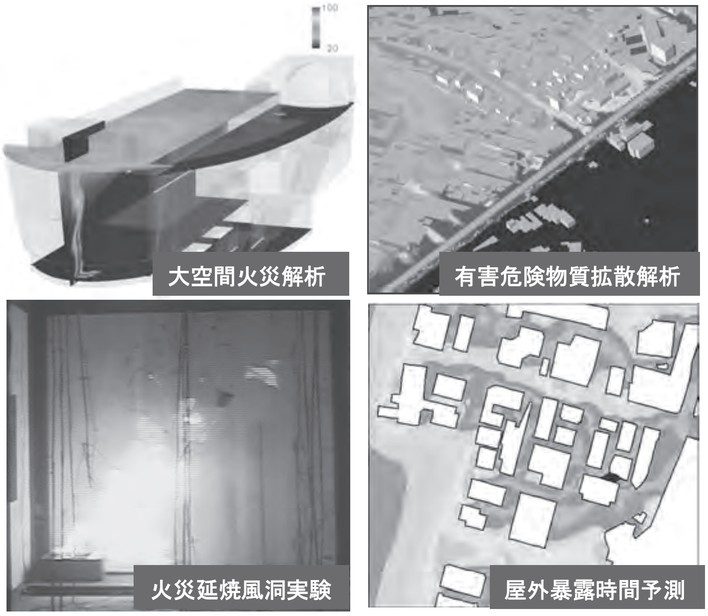
腰原研究室の研究テーマ



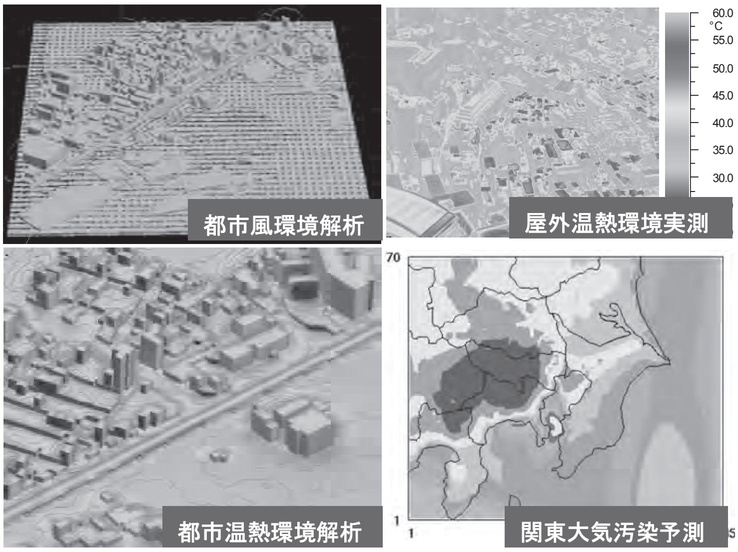
木質構造建築

5) 黄研究室　(都市建築安全環境工学)

近年，グローバルな気候変動，高度な都市化の進展，内外情勢等により，都市自然災害，人為災害，ヒートアイランド，大気汚染等様々な都市安全・環境・社会問題が深刻化になっており，その改善が緊急な課題になる．そこで，当研究室では，数値流体力学と実測・実験を中心とした物理環境シミュレーションによる都市・建築空間の温熱･空気･風環境･火災安全解析に関する研究を行っており, 21 世紀へ向かう安全,健康，快適，省エネ的で，持続性のある都市社会のデザインを目指している．マルチスケール・マルチマルチフィジックスに渡る都市・建築内外空間の安全と環境に関する研究をチャレンジしている．



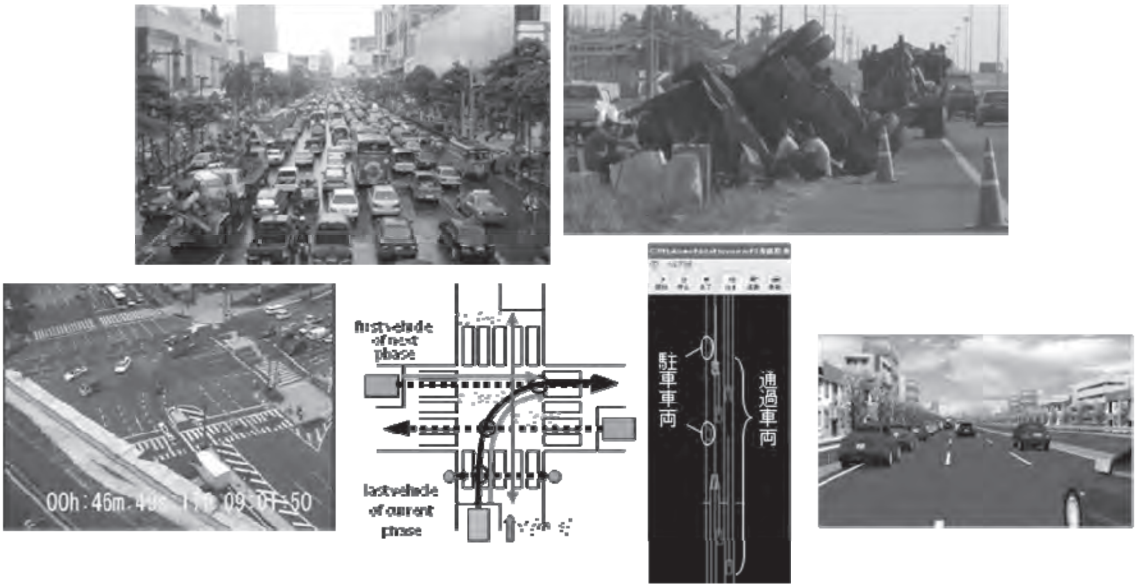
都市建築安全



都市建築環境

6) 田中研究室　(都市交通マネジメント)

交通は都市を支える非常に根源的な活動であり，事故・渋滞・排出ガスなど解決すべき課題は多い．加えて，近年の社会情勢の変化に伴い，交通基盤施設を「つくる」技術のみならずそれをうまく「つかう」工夫が求められている．また，交通は多くの利用者の行動が集積したものであるため，ある状況・ある施策に対して利用者がどのような反応をし行動をするかを考慮することが不可欠である．当研究室では交通施設の管理・運用や利用者の誘導などを通じて交通に関わる諸問題を解決する方策を見出すための研究を実施している．また，交通施設を有効に活用するための有力なツールである，ITS に関する研究にも積極的に取り組んでいる．



研究対象と分析の一例

3.2.3　産学連携研究の活動

3.2.3.1　RC39

ICUS では(財)生産技術研究奨励会の特別研究会として「RC39 サステナブル都市システム研究委員会」を発足し，平成 14 年度から平成 18 年度まで活動を民間企業 14 社(平成 18 年度)とともに実施した。

20 世紀の我が国は欧米諸国に追いつくことを最大目標に，産業の育成，設備の拡充，新製品の製造等に全力を尽くしてきた．その結果，経済は高度に成長し，我が国は世界的に見ても裕福な国に変貌した．都市基盤設備のストック状況として，橋梁を例にとると，1950 年からピーク時の 1970 年頃まで年平均約 2500 の橋梁が新設され，現在約 13.6 万橋のストックが存在しているといわれている．これは，日本の全人口で考えれば，約1000 人に1橋の割合で存在していることとなる．年平均2500 橋が新設されてきたということは，今後，同程度の割合で維持管理(長寿命化)あるいは更新をすることを物語っており，更新は大量の建設廃棄物が発生することに直結してくる．更に，高度経済成長の代償として地球温暖化に代表される環境破壊が問題視され，温室効果ガスの大幅な削減，最終処分場の逼迫や天然資源の消費抑制のために循環型社会形成が急務であるとされている．今後，日本の人口が減少していく状況で，これまでの大量生産･大量消費型から脱却し，全く異なる視点で膨大な社会資本ストックを管理していかなければならない．

都市基盤設備は，大量の資源(天然，リサイクル)が投入され，製造･施工過程を経て建造されるサービスを開始する．このとき，全ての場面において環境負荷が発生すると考えられる．例えば，天然資源を利用すること，製造･施工時の環境汚染，都市基盤設備を利用することによる環境負荷，更新時に発生する産業廃棄物など．また，都市基盤設備は，供用期間中に様々な環境作用(荷重，炭酸ガス，塩化物イオンなど)を受けることにより，構造性能が低下し，社会情勢の変化に伴いユーザーニーズに合致しなくなるなど，その機能は経時的に変化する．更に，地震，洪水，火災などの突発的に発生する環境作用によって，その機能が著しく低下することがある．

このように，都市基盤の観点から考えると，「都市基盤設備自体に関する問題」とそれが与える「環境インパクトに関する問題」を解決していくことが，持続的な生存を可能とするためには必要不可欠であるといえる．そこで，本委員会では，都市基盤設備自体の問題として「老朽化構造物」，「防災」，「環境」を取り上げ，検討している．都市基盤設備自体の問題は，膨大な社会資本ストックの有効活用および災害に強い社会システムの形成により，常時･非常時への対策を検討し，環境インパクトは，都市基盤設備のライフサイクルにおける環境への影響を検討している．平成 17 年度は，「老朽化構造物 WG」，「防災 WG」，「環境 WG」の 3 つワーキングを軸に以下の研究テーマに取り組んできた．

1. 老朽化構造物の寿命予測，簡易で精度の高い管理手法の構築
2. 災害情報データベースの構築，耐震補強推進のための地震リスクファイナンス金融商品の開発
3. 都市環境指標の調査，持続可能な都市形成のための環境総合評価指標

各年度にその成果を報告書にまとめ，また，その研究成果を学会等で発表している．それに合わせ，情報交換を目的に各分野の方に講演をして頂いている．ここに，過去 3 年間の内本報告書の年度に関係する RC39 での特別講演の講演者，講演題目および参加企業一覧を示す．

研究報告会　(その１)

研究報告会　(その２)

参加企業一覧

平成 18 年度

アジア航測 株式会社
株式会社大林組
有限会社 K&T コンサルタント
株式会社 計測リサーチコンサルタント
株式会社 建設企画コンサルタント
株式会社 建設技術研究所
国際航業 株式会社
清水建設 株式会社
大成建設 株式会社
株式会社 竹中土木
東京電力 株式会社
東電設計 株式会社
三協 株式会社
三井住友建設 株式会社

14 社

講演題目と講演者所属

日時	氏名・所属	講演題目
2006 年 5 月	橘　秀樹 千葉工業大学情報科学部	道路交通騒音の現状・予測・対策
7 月	浦　環 東京大学生産技術研究所	海の中で観測する自立型海中ロボット一釜石湾沖合防波堤から明神礁カルデラまで一
10 月	桑野　玲子 ICUS 宮崎　早苗 ICUS	地盤陥没の原因とメカニズム これまでの研究と ICUS での研究
2007 年 1 月	山口　彰夫 横浜市水道局　建設部橋梁課	横浜市の道路橋におけるアセットマネジメントについて一2007 新春に想う一

3.2.3.2　RC58

ICUS では(財)生産技術研究奨励会の特別研究会として「RC58 日本社会に適した BCM(Business Continuity Management)研究会 RC-58」を発足し，民間企業 15 社(平成 19 年度)とともに平成 19 年度から下記の趣旨のもと，活動を開始した．

我が国は，地球科学的な立地条件を背景に，実に様々な自然災害が多発する地域に存在している。特に最近では，活動期に入ったといわれる地震をはじめ，風水害や環境悪化の危険性の高まりが指摘され，我が国の自然災害リスクへの内外の関心が高まっている。このような状況を背景に，有事においても重要業務の継続を確保する事業継続計画(BCP)や，そのマネジメント手法である事業継続管理(BCM)の重要性が認識され，企業を中心としてその検討が進められつつある．しかし従来の BCP や BCM は欧米の先進国での検討事例を基本として，これをほぼそのまま我が国に適用されているのが現状であり，日本の社会環境や企業事情，BCM の対象として，考えるべき災害や危機的事例を十分踏まえたものとはいいがたい．このままでは，BCP や BCM は整備されたとしても，これが実質的な事業継続能力の向上に関与して

いるかどうかは不明な点も多い．

そこで本特別研究会は，日本社会に適した真に事業継続能力の向上に貢献するBCMのあり方に関して検討する。具体的には，我が国の各種の組織(行政，企業，教育・研究機関，病院など)が，自然災害リスクと人為的リスクや悪意による事故・事件に対するリスクを対象に，事業やサービスの適切な継続が可能となるBCMを検討する．

参加企業一覧

平成19年度

アジア航測 株式会社
㈱インターネットイニシアティブ
㈱エヌ・ティ・ティ・データ
㈱大林組
鹿島建設㈱
㈱K&Tこんさるたんと
㈱建設技術研究所
清水建設㈱
三協㈱
CPC㈱建設企画コンサルタント
㈱損保ジャパン・リスクマネージメント
東京ガス㈱
東京電力㈱
東電設計㈱
三菱化学エンジニアリング㈱

15社

平成20年度

アジア航測 株式会社
㈱エヌ・ティ・ティ・データ
㈱大林組
鹿島建設㈱
㈱K&Tこんさるたんと
㈱建設技術研究所
清水建設㈱
三協㈱
㈱損保ジャパン・リスクマネージメント
東京海上日動リスクコンサルティング㈱
東京ガス㈱
東電設計㈱
三菱化学エンジニアリング㈱

13社

講演題目と講演者所属

	氏名・所属	講演題目
2007年10月	丸谷　浩明 京都大学経済研究所　先端政策分析研究センター	事業継続計画(BCP)の意義と最新動向
12月	副島　紀代 大林組技術研究所	地震時の事業継続マネジメント(BCM)に資する被害予測手法と効果的な役割に関する基礎的研究
2008年 3月	市川　啓一 ㈱レスキューナウ・ドット・ネット	今すぐできる事業継続(BC)対策　その時，情報が自社の命運を決める
9月	鍵屋　一 板橋区総務部契約管財課長	自治体BCPのありかたについて　～事業継続計画から地域継続戦略へ～
11月	野田　健太郎 日本開発銀行公共ソリューション部CSR支援室長	BCP/BCMの推進に関する日本政策投資銀行の取り組み

研究会　(その 1)

研究報告会　(その２)

3.2.3.3　RC62

ICUS では(財)生産技術研究奨励会の特別研究会として｢RC62 社会基盤施設の老朽化に伴う性能低下の評価技術に関する研究会 RC-62｣を発足し，民間企業 16 社(平成 20 年度)とともに平成 20 年度から下記の趣旨のもと，活動を開始した．

我々の生活を支える社会基盤施設には，コンクリート構造物，土構造物，鋼構造物など，様々な材料・構造形式が存在する．これらの施設は，高級化や使用方法の変化に伴い，必要な構造性能(以下，性能と言う)が，失われた施設が散見される．また，現時点では要求性能を満足している施設も，将来に渡ってその性能を保証するた mw には，性能評価に基づいた的確な維持管理が必要である．従来，各種計測技術を活用して，構造物の性能評価が試みられているが，構造物の性能を適切に評価できる技術は未だ確立されていない．さらに，地盤から構造物までを包括した全体構造の性能を評価する技術に関しては，全くと言っていいほど検討されていないのが現状である．

本研究会では，劣化したコンクリート構造物および土構造物の性能を定量的に評価する技術，および地盤から構造までを包括した全体構造の性能を評価する技術に関する調査・検討を行う．各分野(コンクリート構造物，土構造物，地盤等)における既存の計測・評価技術の整理を行い，特定の分野で用いられている最新の技術の応用やそれらの統合も視野に入れ，将来技術の方向性を模索する．

・塩害，アル骨，疲労などにより劣化したコンクリート構造物の性能評価における計測・評価技術の整理
・土構造物の性能評価における計測・評価技術の整理
・地中埋設コンクリート構造物の性能評価の視点からの地盤計測･評価技術の整理
・他分野の計測・評価技術の応用の可能性の調査
・地盤と構造物の計測・評価技術の統合による全体構造の性能評価

参加企業一覧

平成 20 年度

OSMOS 技術協会
㈱建設技術研究所
ジオ・サーチ㈱
㈱ジャスト
住友大阪セメント㈱
中央開発㈱
東急建設㈱
㈱保全工学研究所
㈱K&T こんさるたんと
三協㈱
清水建設㈱
大成建設㈱
㈱竹中土木
東亜建設工業㈱
東電設計㈱
りんかい日産建設㈱

16 社

講演題目と講演者所属

	氏名・所属	講演題目
2008 年 12 月	勝木　太 芝浦工業大学	コンクリート構造物の構造ヘルスモニタリング
2009 年　3 月	加藤　絵万 独）港湾空港技術研究所	港湾RC構造物の劣化と構造性能に関する研究

RC62 研究会の様子

3.2.3.4　多分野防災研究会

ICUS では，防災の実務に携わる行政職員と工学・法学・社会学等の多分野の研究者との意見交換を図るため，2003 年 2 月に ICUS 多分野交流防災研究会を発足した．研究会では，防災に関わる様々な議分野の実務者を招き，最新の動向に関する話題を提供してもらった後に，参加者善意による討議を行っている．2003 年度から 2005 年度にかけて, 計 27 回の研究会を開催した. 各会の議題ならびにゲスト講師は以下の通りである.

表　2006 年度に開催した研究会一覧

No.	日時	議題	話題提供者	
1	6 月 12 日 18:00-20:00	首都直下地震対策について	内閣府参事官 (地震・火山対策担当)	上総 周平氏
2	7 月 4 日 18:00-20:00	大阪府の防災・危機管理対策	大阪府危機管理官	小河 保之氏
3	12 月 11 日 18:00-20:00	首都高速道路の災害への備え	首都高速道路株式会社 保全・交通部長	和泉公比古氏
4	1 月 23 日 18:00-20:00	今後の防災対策のあり方	国土交通省国土地理院長	藤本 貴也氏

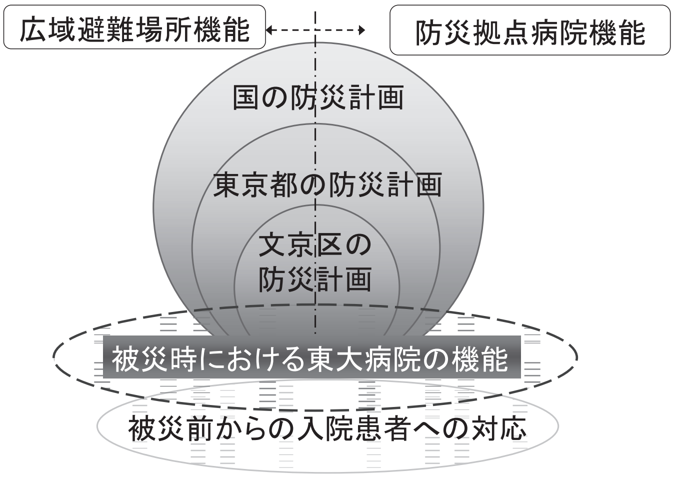
表　2007 年度に開催した研究会一覧

No.	日時	議題	話題提供者	
1	10 月 24 日 18:00-20:00	首都直下地震対策（中央省庁業務継続計画、帰宅困難者対策等	内閣府参事官内閣府政策統括官（防災担当）付きの地震・火山担当参事官	池内 幸司氏
2	11 月 20 日 18:00-20:00	首都高中央環状新宿線の総合的なトンネル防災安全対策	首都高速道路株式会社常務取締役	日月 俊昭氏
3	2 月 25 日 18:00-20:00	防災行政の最近の動き	内閣府防災総括担当参事官	上田　健氏
4	1 月 23 日 18:00-20:00	今後の防災対策のあり方	国土交通省国土地理院長	藤本 貴也氏

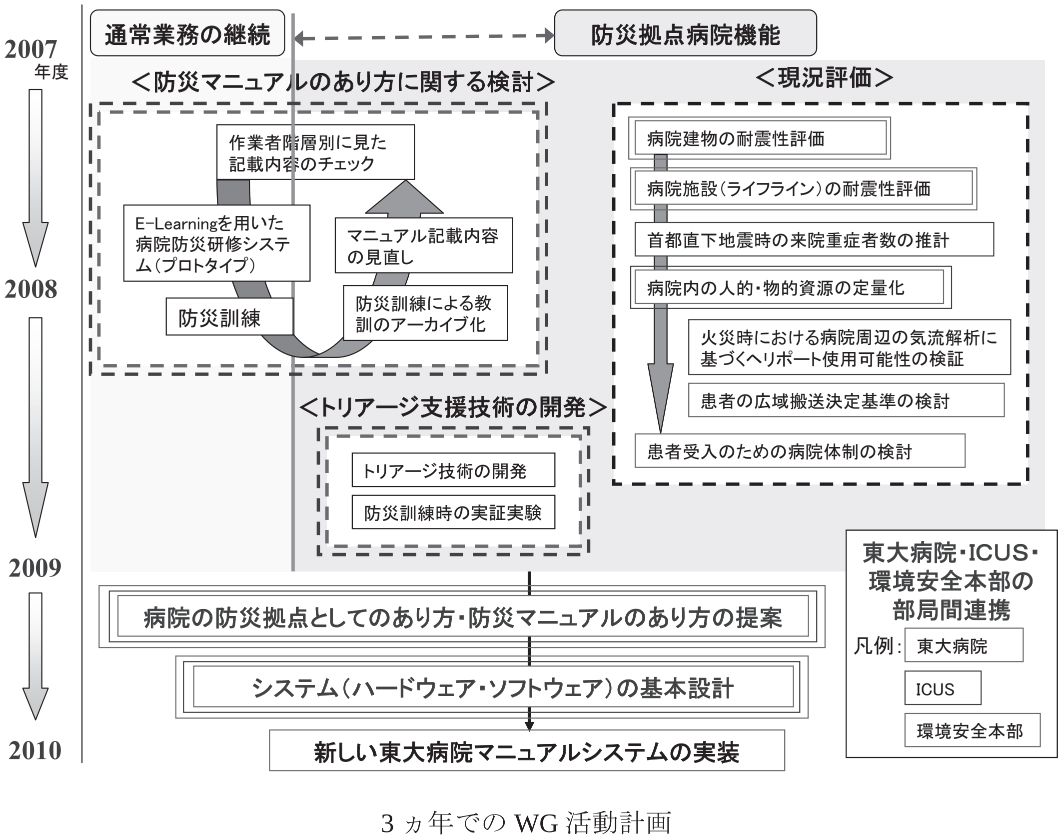
3.2.3.5　東大病院・環境安全本部と連携した病院防災マニュアルに関する検討

ICUS では，東京大学医学部附属病院(以下，東大病院とする)・環境安全本部とともに「防災対策マニュアル及び地震時の東大病院の防災拠点としてのあり方に関するワーキンググループ(WG)を結成し，医学部附属病院の災害拠点病院としての機能を高めるための実行力のある防災マニュアルの開発を行っている．本 WG は，東京大学 安全管理委員会防火・防災対策部会下に設置されており，東大病院が災害時の広域避難場所である東京大学キャンパス内にある災害拠点病院であるという特殊性を考慮しながら，東大病院に求められる機能(下図)と望ましい防災マニュアルの検討を行っている．

本 WG は 2007 年から 2009 年度までの 3 ヵ年での活動を予定しており，活動計画は下記に示すフロー図の通りである．



東大病院に求められる機能



3 ヵ年での WG 活動計画

災害発生時は，通常診療とは異なり，患者数に対して医療従事者が極端に不足する状況となる．震災時には，病院施設やライフラインの被災により，病院の機能が通常時と比較して大幅に低下する可能性もある．2007年度は，首都直下地震時に来院が想定される重症患者数の推計を行うと共に，東大病院の人的(マンパワー)･物的(施設面)の評価を行い，災害により発生する重症患者の受け入れのための院内体制を検討した．

また，防災マニュアルの医師・看護師一人一人への浸透を目指して，災害対応をシミュレーションするeラーニングコンテンツを開発し，毎年9月に実施する病院一斉防災訓練前の事前研修として運用した．内容は東大病院の防災マニュアルに即したものとし，実際の防災訓練の写真などを活用した実践的なものとした．医師約250名，看護師約800名による学習結果および感想アンケートからは，eラーニングによるマニュアルの浸透，防災対策の動機付け効果が確認された．

2008年度は，2007年度に引き続き，災害対応eラーニングの機能拡充を行った．2007年度版は職員全員を対象としており病棟での災害直後対応を学ぶ教材であったが，2008年度版は主に救急外来職員を対象とし，院外からの傷病者のトリアージ・受け入れに関わるプロセスを学習する教材とした．

数年間に及ぶ防災訓練計画の立案，eラーニングコンテンツの開発により，現行の病院防災マニュアルの記載内容についての課題が明確になってきた．2009年度は，これらの知見を踏まえた上で，東大病院の防災マニュアルのあり方を提案するとともに，次世代型の防災マニュアルシステムの基本設計を行う予定である．

3.3　ICUSとしての情報の共有化

3.3.1　調査・モニタリング

3.3.1.1　災害の調査

日本ならびに海外で災害が発生した際には，被害状況に関する情報収集と現地への研究成果の普及を目的として，災害被害調査を実施している．2006年度から2008年度にかけて実施した災害調査の実施期間，対象地域，調査参加者は以下の通りである．

調査内容	調査期間	対象地域	参加者
新潟中越沖地震被害調査	2007.7.21-22	新潟県柏崎市内	目黒公郎，佐藤芳仁，竹内雅彦、蛭間芳樹(目黒研究室)
新潟中越沖地震被害調査	2007.7.28	新潟県柏崎市内	大原美保
中越沖地震による斜面崩壊地調査(聖ヶ鼻，ＪＲ青海川駅付近の斜面崩壊地の踏査)	2007.9.4	新潟県	古関，桑野玲子，堤(古関研)，杉本(桑野研大学院生)，桑野二郎(埼玉大)，応用地質より2名
ペルー地震被災地で,実態把握及び被害調査	2007.9.13-28	ペルー	Paola Mayorca, Torress Acosta Angela Tatiana
メコン川中流の現地調査	2007.11.05-24	ビエンチャン・パクセ(ラオス)	川崎昭如(目黒研究室)
岩手宮城内陸地震被災調査(秋田県側道路の被災調査)	2008.6.19	秋田県	古関，桑野，堤(古関研)，三上(古関研大学院生)，清田(東京理科大)

岩手・宮城内陸地震における行政対応と被害調査	2008.6.27-29	宮城県栗原市，岩手県一関市及び地震計設置箇所	目黒公郎，秦康範，蛭間芳樹，藤枝拓海， 井上雅志(目黒研究室)
岩手宮城内陸地震被災調査(岩手県側道路の被災状況と荒砥沢ダム崩壊地の調査)	2008.7.1	岩手県一ノ関	古関，桑野，堤(古関研)，三上(古関研大学院生)， 内村(東大本郷)
岩手・宮城内陸地震時の緊急地震速報放送に関するヒアリング調査	2008.8.1	山形県東田川郡庄内町	大原美保
岩手宮城内陸地震被災調査(荒砥沢ダム崩壊地と胆沢ダム周辺の調査)	2008.8.29	岩手県一ノ関	桑野，杉本(桑野研大学院生)，Ngo(古関研大学院生)，久保(東大本郷)，桑野二郎(埼玉大)， 橘(埼玉大)
小千谷市荷頃地区における被災住宅調査	2008.12.8	新潟県小千谷市荷頃地区	大原美保
岩手宮城内陸地震調査(荒砥沢ダム崩壊地の試料採取)	2008.12.10	岩手県一ノ関	桑野，Adriana(桑野研大学院生)，青山(東大本郷大学院生), 田中(東大本郷大学院生)， Carlos(東大本郷大学院生)，中央開発より１名
2008年8月末岡崎水害時の医療対応に関するヒアリング調査	2008.12.14-16	愛知県岡崎市	大原美保
四川大地震の被害調査及び被災地復興支援	2009.01.02-05	中華人民共和国	目黒公郎・Navaratnarajah Sathiparan(目黒研究室)
岩手・宮城内陸地震時の医療対応に関するヒアリング調査	2009.2.6	宮城県栗原市・大崎市	大原美保
インドネシア・チラチャップの津波被害調査とアンケート・道路整備等の調査	2009.03.20-30	インドネシア	Rahman Hydayat(目黒研究室)
安平町陥没孔調査(警察による現場検証（ゴルフ場陥没孔の開削調査）の立会い)	2009.5.21-22	北海道苫小牧	桑野，木幡(室蘭工大)，警察より多数
銀座空洞調査(路面下空洞が危ぶまれる箇所にて， レーダー探査及びボーリング調査)	2009.6.14	東京都中央区銀座	桑野が国土交通省路面保全検討委員会メンバーとして参加

3.3.1.2　メモリコーダによる土材料の変形特性の調査

様々な土材料の変形特性を調べるために，土質試験中に供試体内を伝播する弾性波速度の測定を実施し，その送受信の波形を記録するために用いている．また，その知見を模型実験で応用するために，現在模型実験土槽内における弾性波トモグラフィー，および電気探査トモグラフィーの試行を計画している．多点同時の波形サンプリングが必要になるため同機種を追加購入した．本機種を用いた成果の例をいくつか示す．

Kuwano, R., Wicaksono, R.I and Mulmi, S. (2008), “Small strain stiffness of coarse granular materials measured by wave propagation”, Proc. of 4th international symposium on deformation characteristics of geomaterials, IS-Atlanta 2008, Vol.2, pp.749-756.

Wicaksono, R.I. and Kuwano,R. (2009), "Small Strain Shear Stiffness of Toyoura Sand obtained from various wave measurement techniques"Bulletin of Earthquake Resistant Structure Research Center, No.42, March 2009, 107-119.

桑野玲子、Wicaksono,R.I.、古関潤一（2009）、"弱く固結した砂の粘着力測定のための三軸圧縮試験"、第 44 回地盤工学研究発表会、横浜、2009 年 8 月.

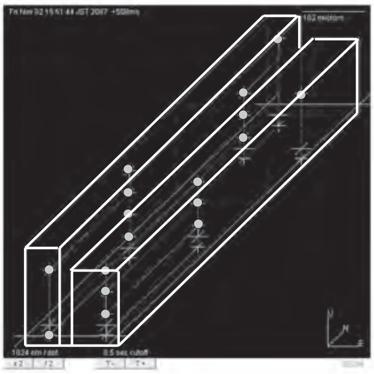
杉本大輔、桑野玲子（2009）、"微生物を利用した砂供試体固化の試行実験"、第 44 回地盤工学研究発表会、横浜、2009 年 8 月.

Beltran-Galvis, A.L.., Kuwano,R. (2009)、"Volume change of sandy soil during saturation process under isotropic stress state ", the 64th annual conference of JSCE, Fukuoka, September 2009.

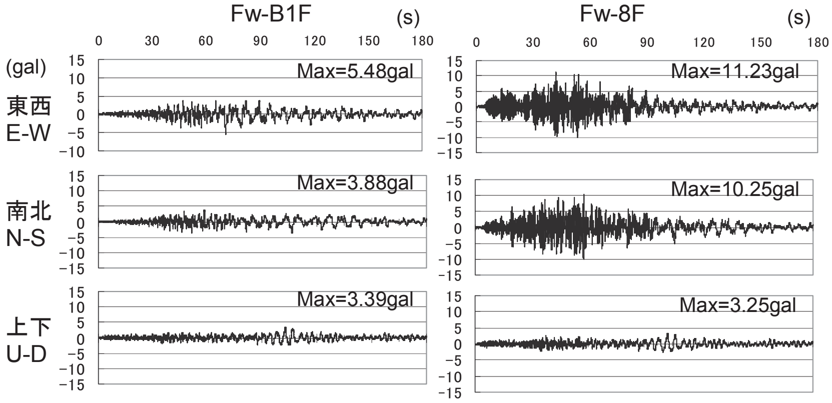
3.3.1.3　生研建物の地震モニタリングシステム

ICUS では, 2007 年度から IT 強震計による生研建物の地震時挙動モニタリングシステムを導入した．生研建物は，B・C・D 棟と E・F 棟，および高層棟(西側)と中層棟(東側)の 4 つに分けられる．これらの建物の地震時の挙動を把握するため，B1・2・4・6・8 階の共有スペースに合計 18 個の IT 強震計を設置した．測定されたデータは，LAN を介して ICUS モニタリング室内のサーバーに転送され，各階での揺れをリアルタイムに把握することができる．

2007 年 7 月 16 日午前 10 時 13 分に発生した新潟県中越沖地震の際に，現地で観測された最も大きな揺れは震度 6 強だった．下記の図は，F 棟の地下(左)と 8 階(右)で観測された地震動である．地下での揺れは震度 2(計測震度 2.3)，８階では震度 3(計測震度 2.8)となり，高層階で大きな揺れが観測されている．建物の揺れの常時モニタリングの状況と各強震計で計測された地震波形，過去の地震の際の生研建物の変形アニメーションを HP(http://icus-eq.iis.u-tokyo.ac.jp/)上で公開している．



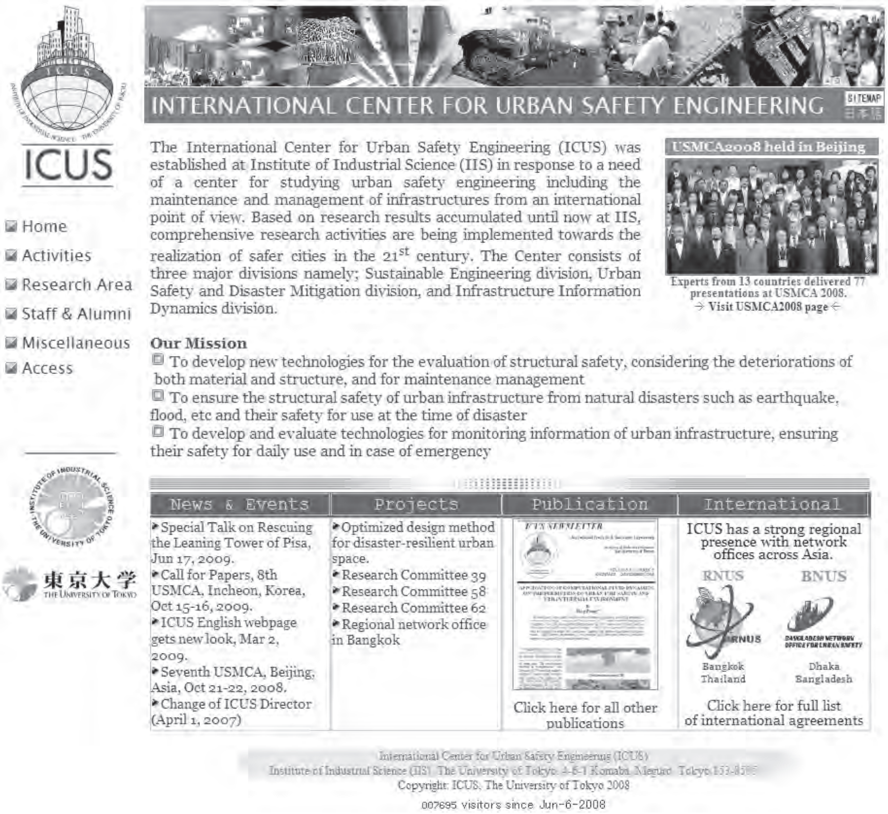
建物の変形表示



F 棟地下（左）と 8 階（右）で観測された地震動

3.3.2　インターネットを活用した都市基盤安全工学情報の発信

ICUS の Activities を Web サイトで公開している．日本語版と英語版が準備されており，国内外で災害が発生した際の情報提供，各種行事の案内，活動報告，出版物の案内，Newsletter の配布を行っている．　RNUS の Web サイトともリンクし，海外拠点での成果も閲覧可能となっている．ICUS のホームページ：http://icus.iis.u-tokyo.ac.jp/，RNUS のホームページ：http://www.sce.ait.ac.th/rnus/．一ヶ月の国別アクセス数の例を下記に示す．国別アクセス数に示す通り，日本国外から多数のアクセスがある．アジアはもちろんであるが，欧米諸国からの注目が高いことが確認できる．



The International Center for Urban Safety Engineering (ICUS) was established at Institute of Industrial Science (IIS) in response to a need of a center for studying urban safety engineering including the maintenance and management of infrastructures from an international point of view. Based on research results accumulated until now at IIS, comprehensive research activities are being implemented towards the realization of safer cities in the 21st century. The Center consists of three major divisions namely; Sustainable Engineering division, Urban Safety and Disaster Mitigation division, and Infrastructure Information Dynamics division.

USMCA2008 held in Beijing

Experts from 13 countries delivered 77 presentations at USMCA 2008.
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Our Mission

☐ To develop new technologies for the evaluation of structural safety, considering the deteriorations of both material and structure, and for maintenance management

☐ To ensure the structural safety of urban infrastructure from natural disasters such as earthquake, flood, etc and their safety for use at the time of disaster

☐ To develop and evaluate technologies for monitoring information of urban infrastructure, ensuring their safety for daily use and in case of emergency

News & Events	Projects	Publication	International
▸Special Talk on Rescuing the Leaning Tower of Pisa, Jun 17, 2009. ▸Call for Papers, 8th USMCA, Incheon, Korea, Oct 15-16, 2009. ▸ICUS English webpage gets new look, Mar 2, 2009. ▸Seventh USMCA, Beijing, Asia, Oct 21-22, 2008. ▸Change of ICUS Director (April 1, 2007)	▸Optimized design method for disaster-resilient urban space. ▸Research Committee 39 ▸Research Committee 58 ▸Research Committee 62 ▸Regional network office in Bangkok	Click here for all other publications	ICUS has a strong regional presence with network offices across Asia. Click here for full list of international agreements

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ICUS　ホームページ

3.3.3　公開講演会

2001 年 5 月 22 日に，ICUS として最初の ICUS 公開講座を生産技術研究所にて開催した．公開講座は，ICUS の前身である INCEDE の時代に開始されたもので，10 年間の継続されていたプログラムである．公開講座の目的は，一般の市民と直接知識と情報を共有することである．INCEDE の時代，主要なテーマは，天災に関する知識を共有し，何が危険であるのか，災害の後何が起こるのかを理解することであった．ICUS では，さらにその考えを進め，我々の生活圏として，特に都市の安全に関する問題を取り上げ，年に約 2 回の頻度で公開講座を続けている．2006 年から 2008 年の 3 年間では，「建築物衛生の危機管理のあり方」，「ICUS の活動ーこれまでの道のり，これからの展望ー」，「都市基盤の安全のためにー危機管理･防災と情報ー」，「地球温暖化は都市にどのような影響を及ぼすか？」，「交通・物流拠点としての港湾・空港戦略」という幅広いテーマで，都市を取り巻く問題に関して公開講演会を開催した．

第1回ICUS公開講座で講演する前魚本センター長(2001年)

ここに，今までに開催されたICUS公開講座の講演題目および講演者リストを示します.

日時	主催タイトル	講演者氏名	所属	題目
2006年 9月25日	建築物衛生の危機管理のあり方	池田耕一	国立保健医療科学院建築衛生部長	建築物衛生の危機管理のあり方
		加藤信介	東京大学生産技術研究所 教授	建築内における健康影響危険物の拡散
		伊藤雅喜	国立保健医療科学院水道工学部水道計画室長	飲料水の安全確保
		柳宇	国立保健医療科学院建築衛生部建築物衛生室長	建築内における生物化学テロ対策
2007年 4月25日	ICUSの活動 －これまでの道のり,これからの展望－	魚本健人	芝浦工業大学工学部土木工学科 教授	都市防災とコンクリート
		安岡善文	東京大学生産技術研究所 教授	都市環境と災害の観測と評価
		目黒公郎	東京大学生産技術研究所 教授	これからの都市防災：ハードとソフト，国内と国際の視点から
2007年 10月2日	都市基盤の安全のために －危機管理･防災と情報－	森川博之	東京大学先端科学技術研究センターセンター長	ユビキガスが拓く安心・安全ICT基盤
		東方幸雄	東日本電信電話株式会社 災害対策室長	NTT ｸﾞﾙｰﾌﾟの災害対策－災害･防災に活かす情報通信技術ー
		上原美都男	横浜市危機管理監	横浜市危機管理戦略について
2008年 5月9日	地球温暖化は都市にどのような影響を及ぼすか？	三村信男	茨城大学 教授	地球温暖化の影響とその適応策
		花木啓祐	東京大学 教授	温室効果ガス削減のための都市の対策
		沢田治雄	東京大学生産技術研究所ICUS教授	地球温暖化の森林への影響とその対策
2008年 10月6日	交通・物流拠点としての港湾・空港戦略	難波喬司	国土交通省港湾局計画課長	港湾を核とした物流システムの効率化を通じた環境負荷の軽減
		横田弘	港湾空港技術研究所研究主監 ICUS客員教授	港湾・海岸におけるｲﾝﾌﾗﾏﾈｼﾞﾒﾝﾄ
		梅山和成	国土交通省関東地方整備局副局長	東京国際空港再拡張プロジェクト

3.3.4　国際シンポジウムの開催

世界人口の半分以上が地球表面の約4パーセントしかない都市部に集中して暮らしている．その傾向はアジア地域で著しく顕著であり，2015年までにはアジア地域が世界の巨大都市(1000万の人口を超える)の50%以上を有する地域になるとの報告もある．アジア地域の巨大都市の特徴は，高い人口密度を支えるだけの社会基盤資本やシステムが脆弱であることである．現時点においてアジア地域の巨大都市で災害が発生した場合，人命，社会基盤施設，社会基盤ネットワークに甚大な被害を与えることは明白である。

一方，科学技術の進歩は著しく，最先端の材料や補強技術，災害低減技術，地理空間情報システムなどの様々な技術がアジア地域でも利用可能になりつつある．

それら技術を効率よく活用できる技術的，人的ネットワークをアジア地域で構築することが，巨大都市での災害被害を低減できる最善の方法であると我々は考えている．つまり，研究者，実務担当者，意思決定者を含むグループ間で関心と専門後術を共有できた時だけ，災害被害を低減できる。

そこで，ICUSは，2002年から毎年，アジア地域の巨大都市における安全性向上のため新技術に関する国際シンポジウムを国内外の学術的な研究機関と共にアジア地域で開催している．本シンポジウムでは，下記のテーマに特に注目して開催している．

- Urban Disaster Mitigation
- Safety and Security Assessment of Urban Infrastructure
- Space Technologies and GIS for Monitoring and Assessment of Urban Safety
- Planning and development of urban infrastructure
- Threat reduction and consequence management
- Environmental impact assessment of urbanization
- Rehabilitation and retrofitting of structures against natural and manmade disasters

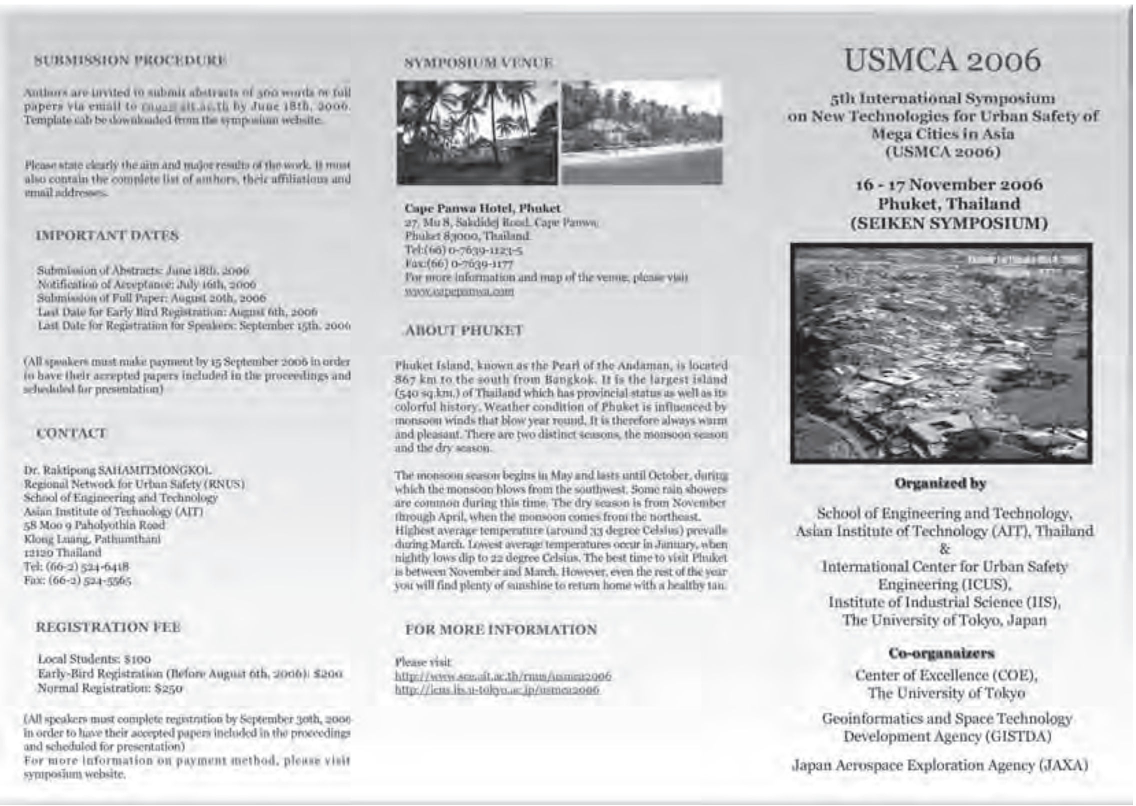
以下に，2006 年から 3 年間に開催したシンポジウムの概要を記す.

・2006 年

・概要

第 5 回　アジア地域の巨大都市における安全性向上のため新技術に関する国際シンポジウム	
Venue	Cape Panwa Hotel Phuket, Thailand
Date	Nov. 16-17,2006
Co-organizers	・ School of Civil Engineering Asian Institute of Technology
Sponsors	・ Center for Sustainable Urban Regeneration, The University of Tokyo ・ 21st Century Center of Excellence Program, The University of Tokyo ・ Geo-Informatics and Space Technology Development Agency ・ Japan Aerospace Exploration Agency

・第 5 回　ICUS シンポジウム開催案内パンフレット



SUBMISSION PROCEDURE

Authors are invited to submit abstracts of 300 words or full papers via email to rnus@ait.ac.th by June 18th, 2006. Template can be downloaded from the symposium website.

Please state clearly the aim and major results of the work. It must also contain the complete list of authors, their affiliations and email addresses.

IMPORTANT DATES

Submission of Abstracts: June 18th, 2006
Notification of Acceptance: July 16th, 2006
Submission of Full Paper: August 20th, 2006
Last Date for Early Bird Registration: August 6th, 2006
Last Date for Registration for Speakers: September 15th, 2006

(All speakers must make payment by 15 September 2006 in order to have their accepted papers included in the proceedings and scheduled for presentation)

CONTACT

Dr. Raktipong SAHAMITMONGKOL
Regional Network for Urban Safety (RNUS)
School of Engineering and Technology
Asian Institute of Technology (AIT)
58 Moo 9 Paholyothin Road
Klong Luang, Pathumthani
12120 Thailand
Tel: (66-2) 524-6418
Fax: (66-2) 524-5565

REGISTRATION FEE

Local Students: $100
Early-Bird Registration (Before August 6th, 2006): $200
Normal Registration: $250

(All speakers must complete registration by September 30th, 2006 in order to have their accepted papers included in the proceedings and scheduled for presentation)
For more information on payment method, please visit symposium website.

SYMPOSIUM VENUE

Cape Panwa Hotel, Phuket
27, Mu 8, Sakdidej Road, Cape Panwa,
Phuket 83000, Thailand
Tel:(66) 0-7639-1123-5
Fax:(66) 0-7639-1177
For more information and map of the venue, please visit
www.capepanwa.com

ABOUT PHUKET

Phuket Island, known as the Pearl of the Andaman, is located 867 km to the south from Bangkok. It is the largest island (540 sq.km.) of Thailand which has provincial status as well as its colorful history. Weather condition of Phuket is influenced by monsoon winds that blow year round. It is therefore always warm and pleasant. There are two distinct seasons, the monsoon season and the dry season.

The monsoon season begins in May and lasts until October, during which the monsoon blows from the southwest. Some rain showers are common during this time. The dry season is from November through April, when the monsoon comes from the northeast. Highest average temperature (around 33 degree Celsius) prevails during March. Lowest average temperatures occur in January, when nightly lows dip to 22 degree Celsius. The best time to visit Phuket is between November and March. However, even the rest of the year you will find plenty of sunshine to return home with a healthy tan.

FOR MORE INFORMATION

Please visit
http://www.sce.ait.ac.th/rnus/usmca2006
http://icus.iis.u-tokyo.ac.jp/usmca2006

USMCA 2006

**5th International Symposium
on New Technologies for Urban Safety of
Mega Cities in Asia
(USMCA 2006)**

**16 - 17 November 2006
Phuket, Thailand
(SEIKEN SYMPOSIUM)**

Organized by

School of Engineering and Technology,
Asian Institute of Technology (AIT), Thailand
&
International Center for Urban Safety
Engineering (ICUS),
Institute of Industrial Science (IIS),
The University of Tokyo, Japan

Co-organaizers

Center of Excellence (COE),
The University of Tokyo

Geoinformatics and Space Technology
Development Agency (GISTDA)

Japan Aerospace Exploration Agency (JAXA)

・総参加人数：88 名

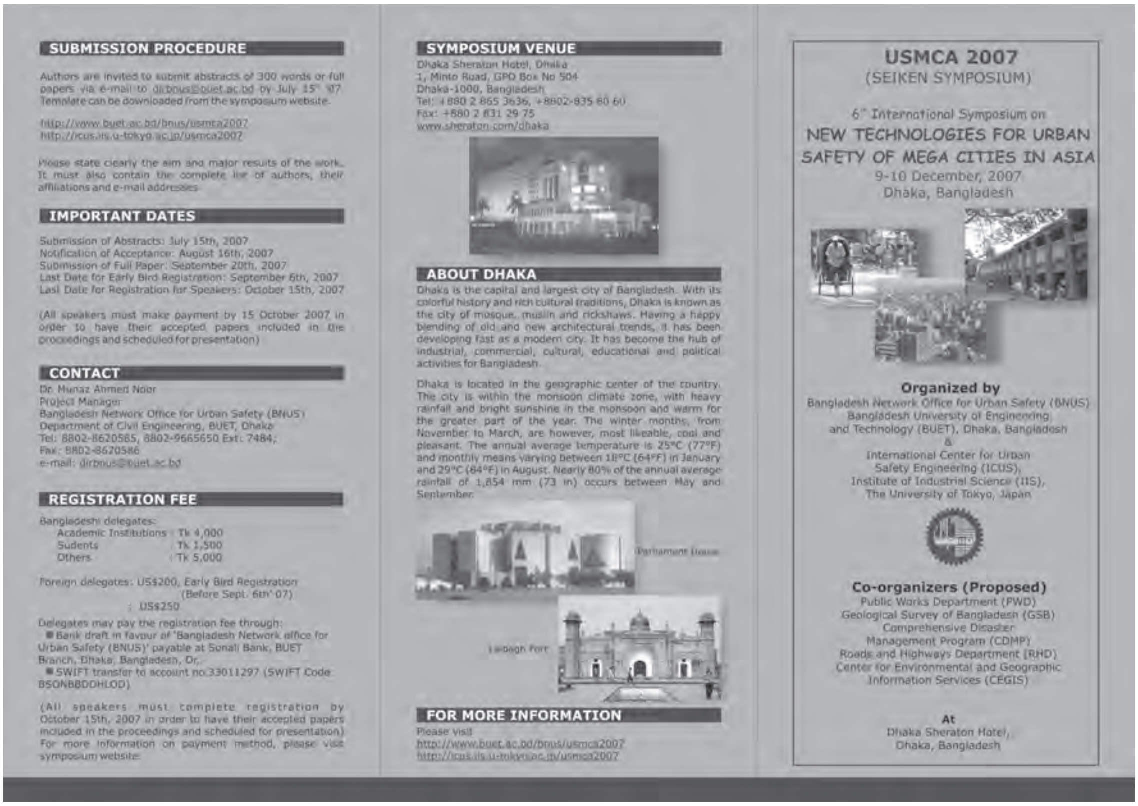
日本：29 名　　他国：59 名

・2007 年

　・概要

第６回　アジア地域の巨大都市における安全性向上のため新技術に関する国際シンポジウム	
Venue	Dhaka Sheraton Hotel, Dhaka Bangladesh
Date	Dec. 9-10, 2007
Co-organizers	•Bangladesh University of Engineering and Technology
Sponsors	• Center for Sustainable Urban Regeneration, The University of Tokyo • 21st Century Center of Excellence Program, The University of Tokyo

・第 6 回　ICUS シンポジウム開催案内パンフレット



SUBMISSION PROCEDURE

Authors are invited to submit abstracts of 300 words or full papers via e-mail to dirbnus@buet.ac.bd by July 15th '07. Template can be downloaded from the symposium website.

http://www.buet.ac.bd/bnus/usmca2007
http://icus.iis.u-tokyo.ac.jp/usmca2007

Please state clearly the aim and major results of the work. It must also contain the complete list of authors, their affiliations and e-mail addresses.

IMPORTANT DATES

Submission of Abstracts: July 15th, 2007
Notification of Acceptance: August 16th, 2007
Submission of Full Paper: September 20th, 2007
Last Date for Early Bird Registration: September 6th, 2007
Last Date for Registration for Speakers: October 15th, 2007

(All speakers must make payment by 15 October 2007 in order to have their accepted papers included in the proceedings and scheduled for presentation)

CONTACT

Dr. Munaz Ahmed Noor
Project Manager
Bangladesh Network Office for Urban Safety (BNUS)
Department of Civil Engineering, BUET, Dhaka
Tel: 8802-8620585, 8802-9665650 Ext: 7484;
Fax: 8802-8620586
e-mail: dirbnus@buet.ac.bd

REGISTRATION FEE

Bangladeshi delegates:
　Academic Institutions : Tk 4,000
　Sudents : Tk 1,500
　Others : Tk 5,000

Foreign delegates: US$200, Early Bird Registration (Before Sept. 6th' 07)
　: US$250

Delegates may pay the registration fee through:
■ Bank draft in favour of 'Bangladesh Network office for Urban Safety (BNUS)' payable at Sonali Bank, BUET Branch, Dhaka, Bangladesh, Or,
■ SWIFT transfer to account no 33011297 (SWIFT Code BSONBDDHLOD)

(All speakers must complete registration by October 15th, 2007 in order to have their accepted papers included in the proceedings and scheduled for presentation) For more information on payment method, please visit symposium website.

SYMPOSIUM VENUE

Dhaka Sheraton Hotel, Dhaka
1, Minto Road, GPO Box No 504
Dhaka-1000, Bangladesh
Tel: +880 2 865 3636, +8802-835 60 60
Fax: +880 2 831 29 75
www.sheraton.com/dhaka

ABOUT DHAKA

Dhaka is the capital and largest city of Bangladesh. With its colorful history and rich cultural traditions, Dhaka is known as the city of mosque, muslin and rickshaws. Having a happy blending of old and new architectural trends, it has been developing fast as a modern city. It has become the hub of industrial, commercial, cultural, educational and political activities for Bangladesh.

Dhaka is located in the geographic center of the country. The city is within the monsoon climate zone, with heavy rainfall and bright sunshine in the monsoon and warm for the greater part of the year. The winter months, from November to March, are however, most likeable, cool and pleasant. The annual average temperature is 25°C (77°F) and monthly means varying between 18°C (64°F) in January and 29°C (84°F) in August. Nearly 80% of the annual average rainfall of 1,854 mm (73 in) occurs between May and September.

FOR MORE INFORMATION

Please visit
http://www.buet.ac.bd/bnus/usmca2007
http://icus.iis.u-tokyo.ac.jp/usmca2007

USMCA 2007
(SEIKEN SYMPOSIUM)

6th International Symposium on
NEW TECHNOLOGIES FOR URBAN SAFETY OF MEGA CITIES IN ASIA
9-10 December, 2007
Dhaka, Bangladesh

Organized by
Bangladesh Network Office for Urban Safety (BNUS)
Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh
&
International Center for Urban Safety Engineering (ICUS),
Institute of Industrial Science (IIS),
The University of Tokyo, Japan

Co-organizers (Proposed)
Public Works Department (PWD)
Geological Survey of Bangladesh (GSB)
Comprehensive Disaster Management Program (CDMP)
Roads and Highways Department (RHD)
Center for Environmental and Geographic Information Services (CEGIS)

At
Dhaka Sheraton Hotel,
Dhaka, Bangladesh

・　総参加人数：77 名

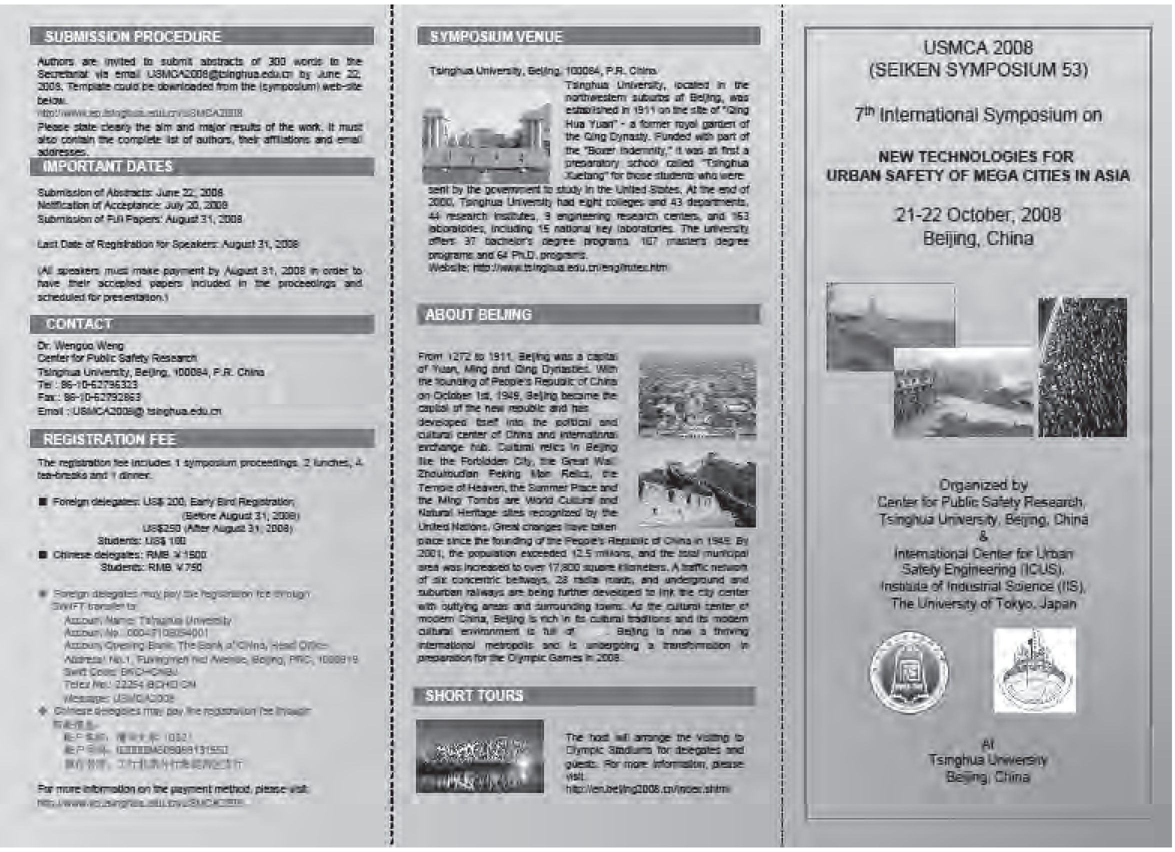
　日本：23 名　他国：54 名

・2008 年

・概要

第 7 回　アジア地域の巨大都市における安全性向上のため新技術に関する国際シンポジウム		
	Venue	Tsinghua University Beijing
	Date	Oct. 21-22, 2008
	Co-organizers	Center for Public Safety Research, Tsinghua University, Beijing, China
	Sponsors	• The Foufation for the Promotion of Industrial Sciences, JapanTOKYO GAS Corporate, JapanGlobal Center of Excellent (GCOE), The University of TokyoNational Natural Sciene Foundation of China, ChinaIllinois Fire Service Institute, University of Illiois at Urbana-Champaign, USAHomeland Security Research Center, Illinois, USAChina National Institute of Standardization, ChinaBeijing Global Safety Technology Co.LT, China

・第 7 回　ICUS シンポジウム開催案内パンフレット



SUBMISSION PROCEDURE

Authors are invited to submit abstracts of 300 words to the Secretariat via email USMCA2008@tsinghua.edu.cn by June 22, 2008. Template could be downloaded from the (symposium) web-site below.

http://www.ep.tsinghua.edu.cn/USMCA2008

Please state clearly the aim and major results of the work. It must also contain the complete list of authors, their affiliations and email addresses.

IMPORTANT DATES

Submission of Abstracts: June 22, 2008
Notification of Acceptance: July 20, 2008
Submission of Full Papers: August 31, 2008

Last Date of Registration for Speakers: August 31, 2008

(All speakers must make payment by August 31, 2008 in order to have their accepted papers included in the proceedings and scheduled for presentation.)

CONTACT

Dr. Wenguo Weng
Center for Public Safety Research
Tsinghua University, Beijing, 100084, P.R. China
Tel : 86-10-62796323
Fax : 86-10-62792863
Email : USMCA2008@ tsinghua.edu.cn

REGISTRATION FEE

The registration fee includes 1 symposium proceedings, 2 lunches, 4 tea-breaks and 1 dinner.

■ Foreign delegates: US$ 200, Early Bird Registration;
(Before August 31, 2008)
US$250 (After August 31, 2008)
Students: US$ 100
■ Chinese delegates: RMB ¥1500
Students: RMB ¥750

◈ Foreign delegates may pay the registration fee through SWIFT transfer to:
Account Name: Tsinghua University
Account No.: 000-71080054001
Account Opening Bank: The Bank of China, Head Office
Address: No.1, Fuxingmen Nei Avenue, Beijing, PRC, 100818
Swift Code: BKCHCNBJ
Telex No.: 22254 BCHO CN
Message: USMCA2008
◆ Chinese delegates may pay the registration fee through [illegible]
[illegible]
[illegible]
[illegible]
[illegible]

For more information on the payment method, please visit:
http://www.ep.tsinghua.edu.cn/USMCA2008

SYMPOSIUM VENUE

Tsinghua University, Beijing, 100084, P.R. China

Tsinghua University, located in the northwestern suburbs of Beijing, was established in 1911 on the site of "Qing Hua Yuan" - a former royal garden of the Qing Dynasty. Funded with part of the "Boxer Indemnity," it was at first a preparatory school called "Tsinghua Xuetang" for those students who were sent by the government to study in the United States. At the end of 2000, Tsinghua University had eight colleges and 43 departments, 44 research institutes, 9 engineering research centers, and 163 laboratories, including 15 national key laboratories. The university offers 37 bachelor's degree programs, 107 master's degree programs and 64 Ph.D. programs.
Website: http://www.tsinghua.edu.cn/eng/index.htm

ABOUT BEIJING

From 1272 to 1911, Beijing was a capital of Yuan, Ming and Qing Dynasties. With the founding of People's Republic of China on October 1st, 1949, Beijing became the capital of the new republic and has developed itself into the political and cultural center of China and international exchange hub. Cultural relics in Beijing like the Forbidden City, the Great Wall, Zhoukoudian Peking Man Relics, the Temple of Heaven, the Summer Place and the Ming Tombs are World Cultural and Natural Heritage sites recognized by the United Nations. Great changes have taken place since the founding of the People's Republic of China in 1949. By 2001, the population exceeded 12.5 millions, and the total municipal area was increased to over 17,800 square kilometers. A traffic network of six concentric beltways, 28 radial roads, and underground and suburban railways are being further developed to link the city center with outlying areas and surrounding towns. As the cultural center of modern China, Beijing is rich in its cultural traditions and its modern cultural environment is full of . Beijing is now a thriving international metropolis and is undergoing a transformation in preparation for the Olympic Games in 2008.

SHORT TOURS

The host will arrange the visiting to Olympic Stadiums for delegates and guests. For more information, please visit.
http://en.beijing2008.cn/index.shtml

USMCA 2008
(SEIKEN SYMPOSIUM 53)

7th International Symposium on

NEW TECHNOLOGIES FOR URBAN SAFETY OF MEGA CITIES IN ASIA

21-22 October, 2008
Beijing, China

Organized by
Center for Public Safety Research,
Tsinghua University, Beijing, China
&
International Center for Urban Safety Engineering (ICUS),
Institute of Industrial Science (IIS),
The University of Tokyo, Japan

At
Tsinghua University
Beijing, China

・総参加人数：　106 名
日本：28 名　他国：78 名

3.3.5　ICUS の刊行物

ICUS では，国内外のより多くの研究者と最新の情報を共有するために，多くの刊行物を発行している．その中でも 1 年に 4 回発行される ICUS Newsletter と不定期の研究レポートは，世界 150 余ケ国，在日本大使館・領事館および約 3000 の研究者と研究機関に送付している．これらは，ICUS のホームページ(http://icus.iis.u-tokyo.ac.jp/)からもダウンロードすることができるようにしている．

また，ICUS の活動を理解して頂くために ICUS 活動報告(日本語版／英語版)および ICUS 紹介ビデオ(日本語版／英語版)を作成している．

以下に 2006 年 4 月から現在までに発行した刊行物のリストを記す.

・ICUS Newsletter Volume 6 Number 1－ Volume 8 Number 4
・ICUS Report　No. 13-36
・SEIKIEN SYMPOSIUM
・RC39
・RC58
・Annual Report
・ICUS パンフレット
・ICUS カレンダー
・その他
  - 第 6 回比較防災学ワークショップ　みんなで防災の知恵を共有しよう
  - 第 7 回比較防災学ワークショップ　みんなで防災の知恵を共有しよう
  - ICUS 紹介ビデオ(日本語／英語)

ICUS NEWSLETTER

International Center for Urban Safety Engineering

Institute of Industrial Science
The University of Tokyo

VOLUME 6 NUMBER 1
APRIL – JUNE 2006

COMMUNICATING RISKS TO THE PUBLIC

By

Toshiko KIKKAWA *

WHAT IS RISK COMMUNICATION?

Definitions of risk and risk communication

Although there are some variants of the definition of risk and risk communication, the most accepted one was given by the National Research Council in the United States which is part of the National Academies providing science, technology and health policy advice under a congressional charter. In its epoch-making report on risk communication, it is stated that "an act or phenomenon is said to pose a hazard when it has the potential to produce harm or other undesirable consequences to some person or thing" and that "the concept of risk further quantifies hazards by attaching the probability of being realized to each level of potential harm." In short, risk can be defined as a probability of hazard occurrence.

The report defined risk communication as: "an interactive process of exchange of information and opinion among individuals, groups, and institutions. It involves multiple messages about the nature of risk and other messages, not strictly about risk, that express concerns, opinions, reactions to risk messages or to legal and institutional arrangements to risk management."

The emphasis of the definition is on the interactive process of communication among interested parties. Risk communication is not a one-way message that delivers the results of scientific risk assessments and the political decisions based on the assessments from risk experts to the general public. The risk experts, e.g. scientists, governmental officials, or business persons, are those who have more and detailed information about risks.

Risk communication failure: Warnings about tobacco related health problems are hidden by price tags

ICUS Newsletter
2006

VOLUME 6 NUMBER 1, APRIL - JUNE 2006	
Communicationg Risks to the Public	Toshiko Kikkawa, Associate Professor, Keio University
VOLUME 6 NUMBER 2, JULY - SEPTEMBER 2006	
Hidden Cavities under the Ground –Their Causes and Conwequences-	Reiko Kuwano
VOLUME 6 NUMBER 3, OCTOBER - DECEMBER 2006	
Healths Risk Management in the Field of Building Hygiene	Koichi Ikeda, Director, Department of Architecture, Hygiene and Housing, National Institute of Public Health
VOLUME 6 NUMBER 4, JANUARY - MARCH 2007	
Tsunami Risk in Thailand	Absornsuda Siripong, Professor, Marine Science Department, Faculth of Science Chulalongkorn University Bangkok, Thailand
Drought Monitoring Using Remote Sensing and Memories of Stay at the Asian Institute of Technology, Thailand	Junichi Susaki, Graduate School of Engineering, Kyoto University

ICUS NEWSLETTER

International Center for Urban Safety Engineering

Institute of Industrial Science
The University of Tokyo

VOLUME 7 NUMBER 1
APRIL – JUNE 2007

IMPORTANCE OF TECHNICAL AND SOCIAL PROBLEMS TO PREVENT FALSE STRUCTURES FOR URBAN SAFETY

By

Taketo Uomoto*

INTRODUCTION

In November 2005, a big shock struck Japanese society through newspapers, radios and TV programs. Mr. Hidetsugu Aneha, a first-class certified architect confessed that he faked records to make substandard buildings look like they met Japan's anti-earthquake requirements. He mentioned that he began faking earthquake safety data around 1998, when a developer asked him to cut costs by reducing the amount of steel reinforcement below the compulsory minimum in a Tokyo apartment project. The newspapers mentioned that at least 99 structures which he designed may collapse even in a moderate earthquake.

Such news had never been reported in Japan. The people, who bought houses paying large amounts of money, lost everything except the commitment to return the bank loan. If such a disaster was caused by a natural hazard (earthquake, tsunami, flood, fire, etc.), Japanese people and government would surely try to help the victims by all means. But in this faked design case, it is not easy to persuade the people of our country to support the victims.

PROBLEMS RELATED TO FALSE WORKS

The problems related to false works reported by newspapers, magazines, etc. can be classified as follows:

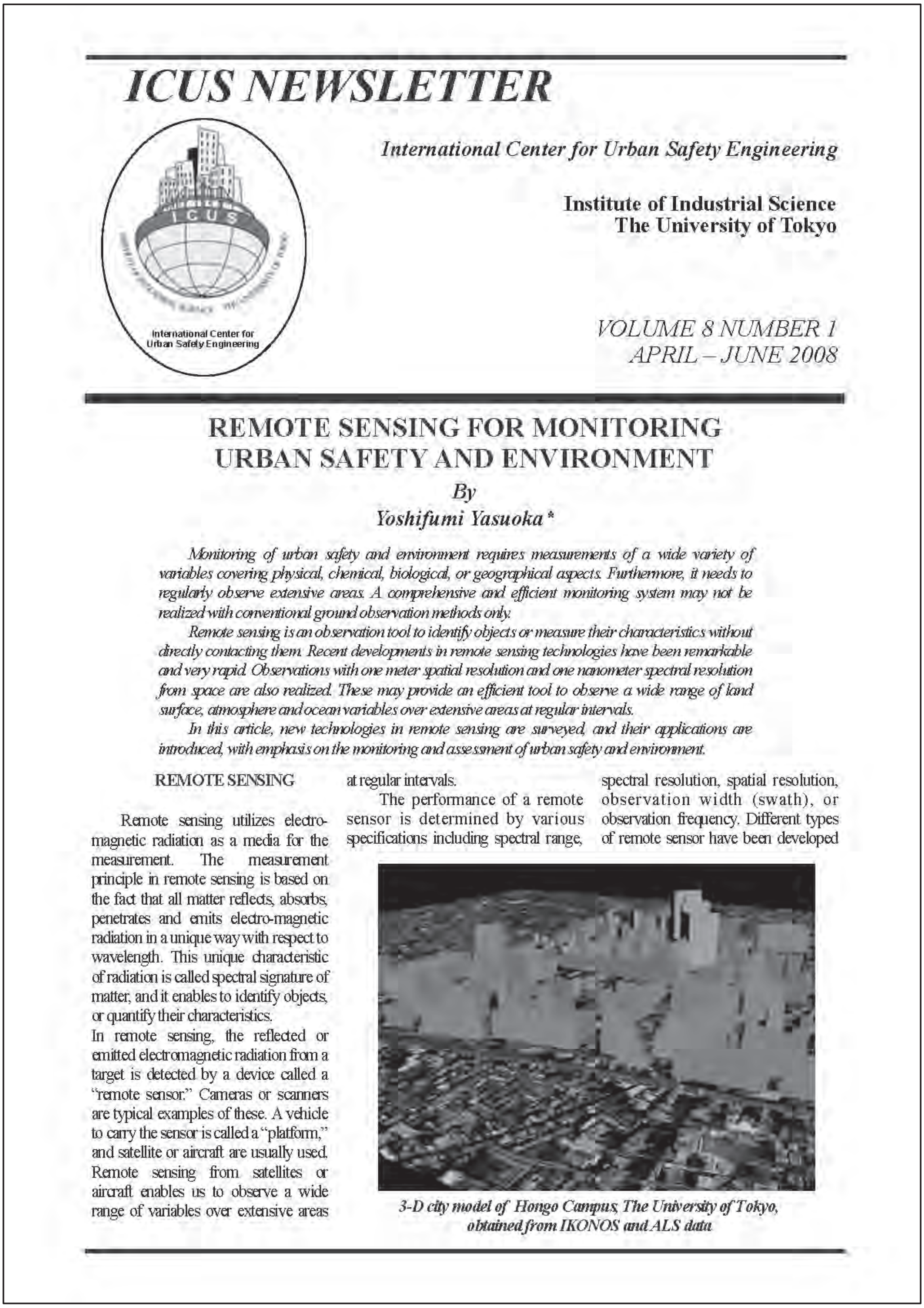
- Group 1: Mistakes by engineers and workers
- Group 2: False works due to insufficient knowledge
- Group 3: Intentional false works knowing that they are difficult to be detected

It is difficult to eliminate all problems belonging to Group 1. Any

Collapsed RC bridge due to the 1995 Kobe Earthquake

2007

VOLUME7 NUMBER 1, APRIL - JUNE 2007	
Importance of Technical and Social Problems to Prevent False Structures for Urban Safety	Taketo Uomoto, Professor, Shibaura Institute of Technology and Former ICUS Director
A Woman Died in Roller Coaster Accicent	Hisashi Kanada, Inspection and Measurement Division, Nippon Steel Techno Research Corporation
VOLUME 7 NUMBER 2, JULY - SEPTEMBER 2007	
Distress in the Tarmac	Worsak Kanok-Nukulchai, Ph.D., Professor Dean, School of Engineering & Technology Asian Institute of Technology and Vice President of the Engineering Institute of Thailand
A Method to Prioritize the Seismic Retrofitting of Disaster-prevention Bases	Reiko Amano, Former ICUS Visinting Professor
Earthquqke hits Niigata Prececture	Hiruma Meguro Labolatory IIS,The University of Tokyo
Niigata Chuetsu-Oki Earthquake Strong Ground Motion Recorded at IIS	Miho Yoshimura Ohara
The Mw. 8.0 Pisco Earthquake hits Peru	Paola Mayorca
2007 Flood in Bangladesh	Mehed Ansary, BUET, Bangladesh
VOLUME 7 NUMBER 3, OCTOBER - DECEMBER 2007	
Traffic Accicents –Another Disaster in Urban Safety-	Shinji Tanaka
Damage due to Cyclone SIDR in Bangladesh	Prfessor Mehedi Ansary, BUET, Bangladesh
VOLUME 7 NUMBER 4, JANUARY - MARCH 2008	
Flow Slides of Underwater Sand Deposits in Jamuna River Bed	Kenji Ishihara, Professor, Chuo Universitty
Numerical Simulation of Environmental Problems	Ryozo Ooka



ICUS NEWSLETTER

International Center for Urban Safety Engineering

Institute of Industrial Science
The University of Tokyo

VOLUME 8 NUMBER 1
APRIL – JUNE 2008

REMOTE SENSING FOR MONITORING URBAN SAFETY AND ENVIRONMENT

By

Yoshifumi Yasuoka *

Monitoring of urban safety and environment requires measurements of a wide variety of variables covering physical, chemical, biological, or geographical aspects. Furthermore, it needs to regularly observe extensive areas. A comprehensive and efficient monitoring system may not be realized with conventional ground observation methods only.

Remote sensing is an observation tool to identify objects or measure their characteristics without directly contacting them. Recent developments in remote sensing technologies have been remarkable and very rapid. Observations with one meter spatial resolution and one nanometer spectral resolution from space are also realized. These may provide an efficient tool to observe a wide range of land surface, atmosphere and ocean variables over extensive areas at regular intervals.

In this article, new technologies in remote sensing are surveyed, and their applications are introduced, with emphasis on the monitoring and assessment of urban safety and environment.

REMOTE SENSING

Remote sensing utilizes electro-magnetic radiation as a media for the measurement. The measurement principle in remote sensing is based on the fact that all matter reflects, absorbs, penetrates and emits electro-magnetic radiation in a unique way with respect to wavelength. This unique characteristic of radiation is called spectral signature of matter, and it enables to identify objects, or quantify their characteristics.

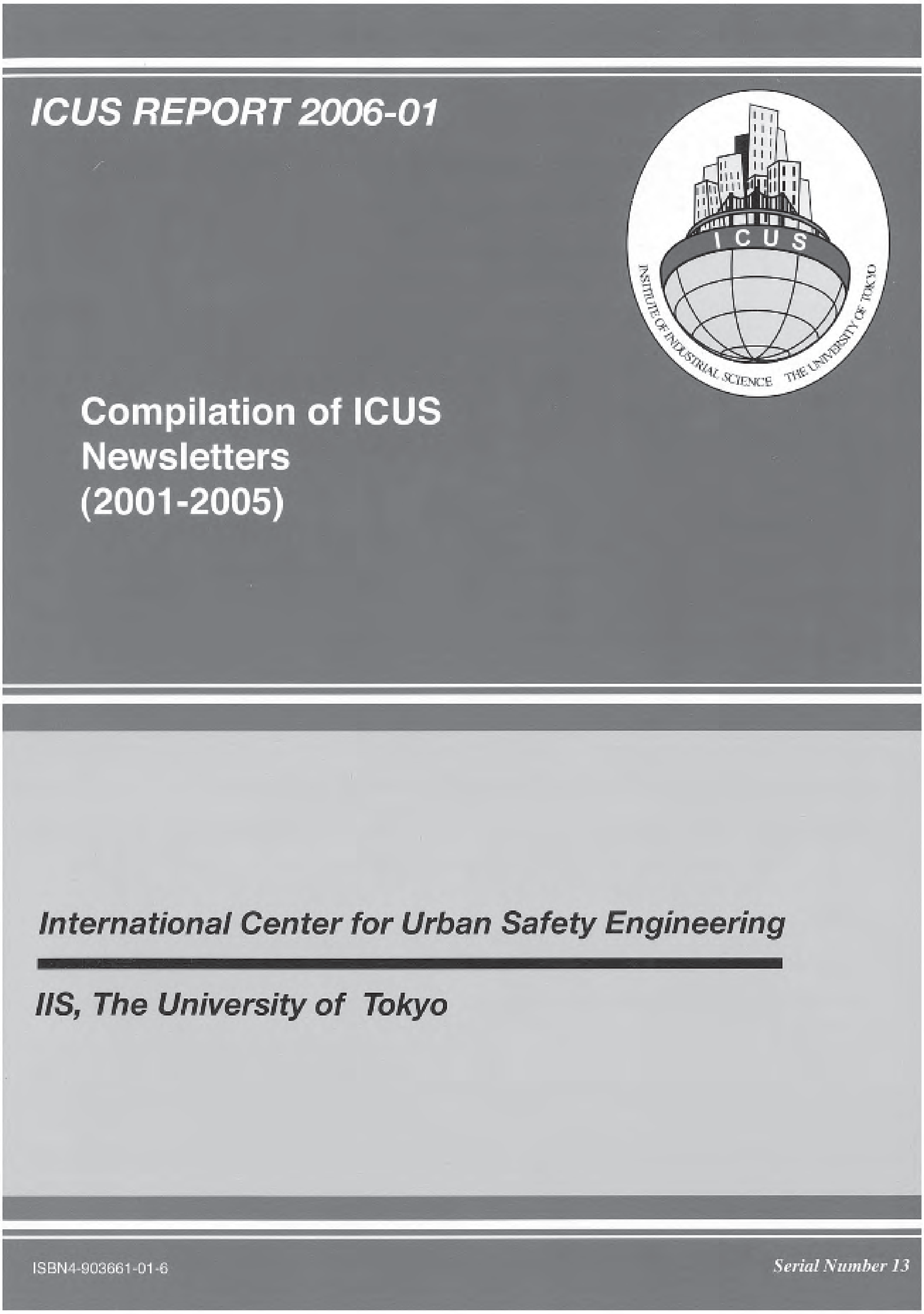
In remote sensing, the reflected or emitted electromagnetic radiation from a target is detected by a device called a "remote sensor." Cameras or scanners are typical examples of these. A vehicle to carry the sensor is called a "platform," and satellite or aircraft are usually used. Remote sensing from satellites or aircraft enables us to observe a wide range of variables over extensive areas at regular intervals.

The performance of a remote sensor is determined by various specifications including spectral range, spectral resolution, spatial resolution, observation width (swath), or observation frequency. Different types of remote sensor have been developed

3-D city model of Hongo Campus, The University of Tokyo, obtained from IKONOS and ALS data

2008

VOLUME 8 NUMBER 1, APRIL - JUNE 2008	
Remote Sensing for Monitoring Urban Safety and Environment	Yoshifumi Yasuoka,Executive Director, National Institute for Environmental Studies and former ICUS Professor
Upgrading the Seismic Performance of Wooden Buildings	Mikio Koshihara
VOLUME 8 NUMBER 2, JULY - SEPTEMBER 2008	
Contribution of Forests to Solving Global Warning Issues	Haruo Sawada
Towards a More Earthquake Resilient Built Environment in the Aftermath of the 2008 Sichuan Earthquake	Kimiro Meguro
VOLUME 8 NUMBER 3, OCTOBER - DECEMBER 2008	
Application fo Computational Fluid Dynamics on the Prediction of Urban Fire Safety and Urban Thermal Environment	Hong Huang
VOLUME 8 NUMBER 4, JANUARY - MARCH 2009	
Framework and Methodology of Public Safety	Weicheng Fan, Center for Public Safety Research, Tsinghua University, Beijing, PR China
Relationship between Surface O3 and Urban Heat Island effect in Tokyo	Ryuzo Ooka
Co-effect of Initial Curing Conditions and Exposure Environments on coastal Concrete Durability	X, Wen, Zhejiang University, PR China
Shaking Table Test of Timber Roof Masonry House Models Rtrofitted by PP-Band Meshes	N. Sathiparan IIS, The University of Tokyo
Making adobe and Brick Houses Stronger to Withstand Earthquakes	P.Mayorca, DNV Norway



ICUS REPORT 2006-01

Compilation of ICUS
Newsletters
(2001-2005)

International Center for Urban Safety Engineering

IIS, The University of Tokyo

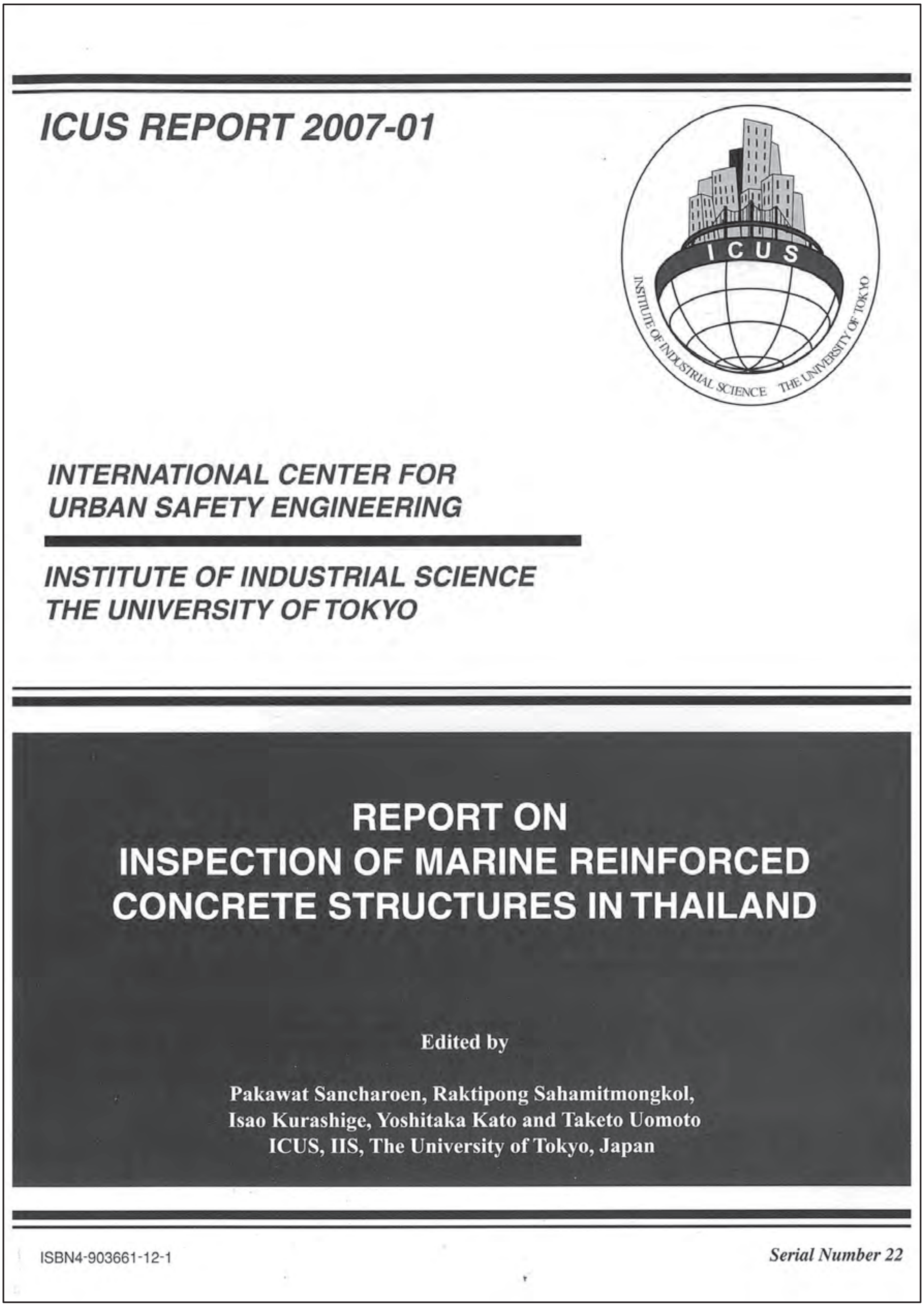
ISBN4-903661-01-6

Serial Number 13

- **ICUS Report**

2006

ICUS REPORT2006-01
 Complication of ICUS Newsletters (2001-2006)
ICUS REPORT2006-02
 ICUS ACTIVITY REPORT ICUS Summarizing the Activity of Quinquennium
ICUS REPORT2006-03
 第10回 IUCS オープンレクチャ講演記録
ICUS REPORT2006-04
 Proceedings of the Fifth International Symposium on New Technologies for Urban Safety of Mega Cities in Asia (USMCA2006)
ICUS REPROT2006-05
 Report on Application of Fly Ash as Concrete Ingredient in Thailand and Japan
ICUS REPORT2006-06
 Report on Mapping of Soil Moisture in Paddy Fields from Temporal Jers-1/Sar Images for Drought Assessment in Buriram Province, Thailand
ICUS REPORT2006-07
 Evaluation of the Seismic Vulnerability of Bangladeshi Buildings Using Non-Destructivie Testing
ICUS REPORT2006-08
 第11回 ICUS オープンレクチャ講演記録 2006年9月25日
ICUS REPORT2006-09
 マルチハザードマップを活用した巨大都市の防災都市空間の最適化瀬系方法の開発



ICUS REPORT 2007-01

INTERNATIONAL CENTER FOR
URBAN SAFETY ENGINEERING

INSTITUTE OF INDUSTRIAL SCIENCE
THE UNIVERSITY OF TOKYO

REPORT ON
INSPECTION OF MARINE REINFORCED
CONCRETE STRUCTURES IN THAILAND

Edited by

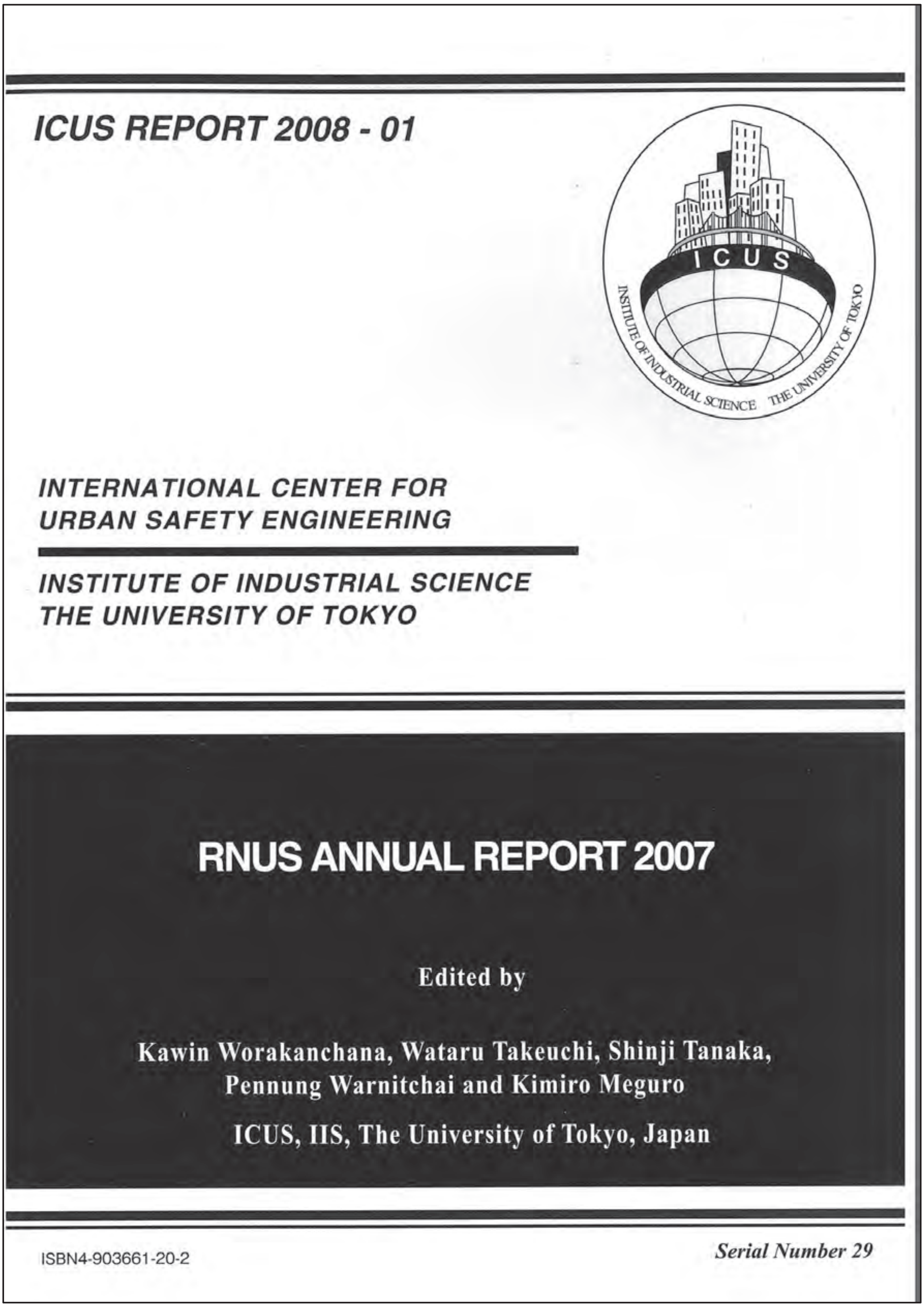
Pakawat Sancharoen, Raktipong Sahamitmongkol,
Isao Kurashige, Yoshitaka Kato and Taketo Uomoto
ICUS, IIS, The University of Tokyo, Japan

ISBN4-903661-12-1

Serial Number 22

2007

ICUS REPORT2007-01
  Report on Inspection of Marine Reinforced Concrete Structures in Thailand
ICUS REPORT2007-02
  Report on the Deterioration of Short-Span Traffice RC Bridges in Bangkok Metropolitan Area -A Preliminary Study-
ICUS REPORT2007-03
  BNUS Annual Reprot-2007
ICUS REPORT2007-04
  第12回ICUSオープンレクチャ
ICUS REPROT2007-05
  第13回ICUSオープンレクチャ
ICUS REPORT2007-06
  2007 New Technoologies for Urban Safety of Mega Cities in Asia
ICUS REPORT2007-07
  防災マニュアル及び地震時の東大病院の防災拠点としてのあり方に関するワーキング



ICUS REPORT 2008 - 01

INTERNATIONAL CENTER FOR
URBAN SAFETY ENGINEERING

INSTITUTE OF INDUSTRIAL SCIENCE
THE UNIVERSITY OF TOKYO

RNUS ANNUAL REPORT 2007

Edited by

Kawin Worakanchana, Wataru Takeuchi, Shinji Tanaka,
Pennung Warnitchai and Kimiro Meguro
ICUS, IIS, The University of Tokyo, Japan

ISBN4-903661-20-2

Serial Number 29

2008

ICUS REPORT2008-01
  RNUS ANNUAL REPORT 2007
ICUS REPORT2008-02
  Joint Student Seminar on Civil Infrastructures July 3-4, 2008
ICUS REPORT2008-03
  2008New Technoologies for Urban Safety of Mega Cities in Asia
ICUS REPORT2008-04
  第 14 回 ICUS オープンレクチャ
ICUS REPROT2008-05
  第 15 回 ICUS オープンレクチャ
ICUS REPORT2008-06
  R Workshop on Transportation Researches for Urban Safety
ICUS REPORT2008-07
  大規模災害におけるリモートセンシング技術活用例に関する調査報告書
ICUS REPORT2008-08
  BNUS Annural Report-2008

・**SEIKIEN SYMPOSIUM**

2006

SEIKIEN SYMPOSIUM 48
  “2006 NEW TECHNOLOGIES FOR URBAN SAFETY OF MEGA CITIES IN ASIA”

2008

SEIKIEN SYMPOSIUM 53
  “2008 NEW TECHNOLOGIES FOR URBAN SAFETY OF MEGA CITIES IN ASIA”

ICUS COMMITTEE REPORT 2006-01

都市基盤安全工学国際研究センター

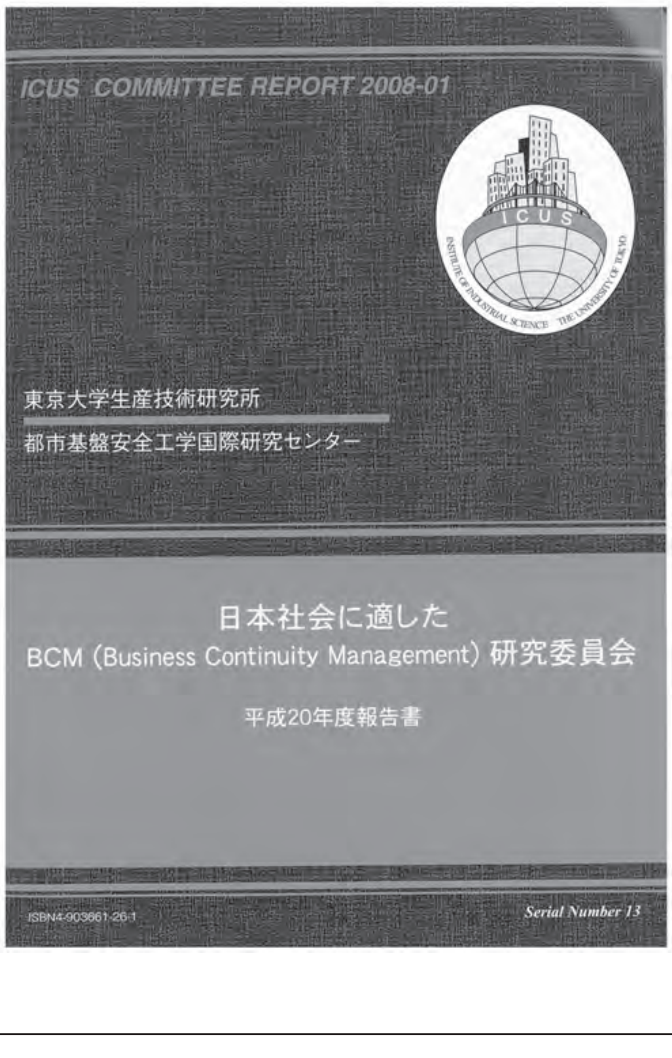
東京大学生産技術研究所

サステナブル都市システム研究委員会(RC39)

老朽化構造物WG

平成18年度報告書

ISBN 4-903661-08-3



ICUS COMMITTEE REPORT 2008-01

東京大学生産技術研究所

都市基盤安全工学国際研究センター

日本社会に適した
BCM (Business Continuity Management) 研究委員会

平成20年度報告書

ISBN4-903661-26-1

Serial Number 13

・**RC39,RC58**

2006

ICUS COMMITTEE REPORT2006-01
“サステナブル都市システム研究委員会(RC39)老朽化構造物 WG 報告書”
ICUS COMMITTEE REPORT2006-02
“サステナブル都市システム研究委員会(RC39)防災 WG 報告書”
ICUS COMMITTEE REPORT2006-03
“サステナブル都市システム研究委員会(RC39)環境 WG 報告書”

2007

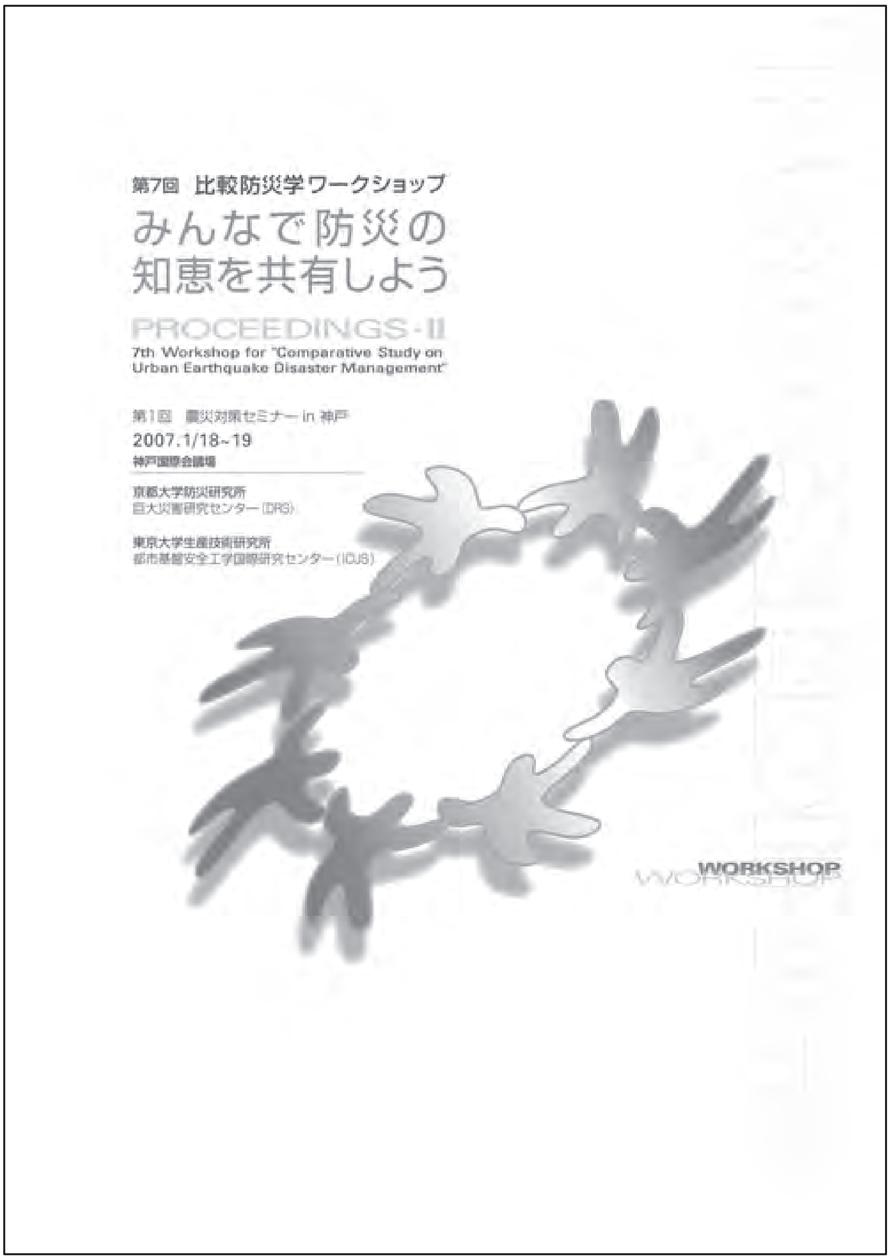
ICUS COMMITTEE REPORT2007-01
“日本社会に適した BCM(Business Contituity Management)研究委員会 19 年度報告書”

2008

ICUS COMMITTEE REPORT 2008-01
“日本社会に適した BCM(Business Contituity Management)研究委員会 20 年度報告書”

Annual Report

Annual Report 2005 年度 日本語版	Annual Report 2005 年度 英語版
Annual Report 2006 年度 日本語版	Annual Report 2006 年度 英語版
Annual Report 2007 年度 日本語版	Annual Report 2007 年度 英語版



第7回　比較防災学ワークショップ
みんなで防災の
知恵を共有しよう
PROCEEDINGS・II
7th Workshop for "Comparative Study on
Urban Earthquake Disaster Management"

第1回　震災対策セミナー in 神戸
2007.1/18~19
神戸国際会議場

京都大学防災研究所
巨大災害研究センター（DRS）

東京大学生産技術研究所
都市基盤安全工学国際研究センター（ICUS）

・その他

2006
第 6 回比較防災学ワークショップ　みんなで防災の知恵を共有しよう
(6th Workshop for “Comparative Study on Urban earthquake Disaster Management”)
2007
第 7 回比較防災学ワークショップ　みんなで防災の知恵を共有しよう
(7th Workshop for “Comparative Study on Urban earthquake Disaster Management”)

・**ICUS** パンフレット

21世紀の安全な都市をめざして

ICUS

ICUS / INCEDE
Institute of Industrial Science, The University of Tokyo

東京大学生産技術研究所
都市基盤安全工学国際研究センター
International Center for Urban Safety Engineering
Institute of Industrial Science
The University of Tokyo

都市基盤安全工学国際研究センターの概要

ー大学研究者が国際的な視野から実施する都市インフラの安全工学研究ー

東京大学生産技術研究所では、大学の研究機関として国際的な視野から都市基盤設備の整備と維持管理を含めた安全工学を研究する国際研究センターを設立しました。これまでに生産技術研究所で蓄積された研究成果を融合することによって、21世紀の安全な都市の実現に向けて活発な研究活動を展開しています。研究課題としては、「サステナブル・エンジニアリング部門」では、構造物の材料から構造全体までの基盤設備等の経年劣化による構造安全性の評価と維持管理技術を開発するための研究を、「都市防災・安全工学部門」では、地震や洪水等による基盤設備の構造安全性、ならびに災害時の使用安全性確保のための管理技術の開発を、「都市情報ダイナミクス部門」では、都市基盤に関する様々な情報を常にモニタリングし、常時及び非常時の都市基盤施設の安全な運用を確保するための動的制御技術の開発と評価を行っています。

都市基盤安全工学国際研究センター
都市基盤の安全に関する研究の中核と世界への情報発信

インフラと都市の安全にかかわる世界の人材ネットワーク

ICUS ネットワークの構築

ICUS はインフラと都市の安全にかかわる世界の人材ネットワーク（ICUS ネットワーク）を構築し、関連情報の活発な交換を行っています。現時点で世界 150 余カ国 2,000 余人／機関のメンバーを有しています。また海外の関係研究機関との研究協力協定（MOU）の締結や国際共同研究プロジェクトを実施しています。

◆研究協力協定の締結

現在ICUSは以下のような、米国、フィリピン、ロシア、ベネズエラ、タイの7つの研究機関と2つの国際機関とMOUを結び、情報交換と共同研究実施の環境を整備しています。(1)カリフォルニア大学地震工学研究協議会、(2)米国国立地震工学研究センター、(3)スタンフォード大学工学部土木工学科、(4)フィリピン気象庁、(5)フィリピン大学国立水理研究センター、(6)ロシア・カムチャツカ自然災害研究所、(7)ベネズエラ地震防災財団、(8)国連大学(9)アジア工科大学院アジアリモートセンシング研究センター。

NETWORKING FOR A SAFER AND SECURER WORLD

ICUSネットワークとMOU締結研究機関の分布

◆国際共同研究プロジェクトの実施

ICUSは現在、タイ・バンコク市にあるアジア工科大学院（AIT）にアジアの活動拠点を置き、アジアの巨大都市の安全性向上に関する研究を実施しています。具体的には「アジア諸国の都市化地域を対象とした構造物を含めた地域脆弱性の継続的定量評価手法の提案とそのためのデータベースの構築」に関する研究を進めています。

Network Building
ICUS Activities
Advanced Research
Information Dissemination

都市インフラの安全性向上に関する先端研究

超音波法によるコンクリート内部空隙の高精度探査法

物質
サステナブル・エンジニアリング部門
場
都市防災・安全工学部門
情報
都市基盤情報ダイナミクス部門
共同研究

人工衛星TERRA/MODISデータを利用したアジア地域の環境/災害観測

研究テーマ
サステナブル・エンジニアリング部門
都市防災・安全工学部門
都市基盤情報ダイナミクス部門

情報の発信基地として

◆ニュースレターとレポートの発刊

1年4回発行のICUS Newsletterと不定期の研究レポート（ICUS Report）を発刊しています。現在これらの刊行物は世界150余ヶ国、約3,000の研究者と研究機関に送付しています。

◆公開講演会の実施

ICUSは「安全で安心して生活できる都市環境の実現には、一般の人々が正確な知識を持つことが不可欠であり、また関係機関や関係者は、一般の人々の意識や認識を把握することが重要である」との認識に基づいて、内外の第一線で活躍する研究者や関係者を講演者として招き、専門家と一般の人々を対象とする公開講演会を年2回程度実施しています。

・ICUS カレンダー

ICUS Calendar 2007

Chulalongkorn University, Bangkok, Thailand

International Center for Urban Safety Engineering
IIS, The University of Tokyo

2007 ICUS Calendar

1

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

2007 ICUS Calendar

2

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28			

2007 ICUS Calendar

3

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
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2007 ICUS Calendar

4

S	M	T	W	T	F	S
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15	16	17	18	19	20	21
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29	30					

2007 ICUS Calendar

5

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13	14	15	16	17	18	19
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2007 ICUS Calendar

6

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2007 ICUS Calendar

7

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2007 ICUS Calendar

8

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12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

2007 ICUS Calendar

Newly developed non-destructive inspection method using near-infrared spectroscopy

9

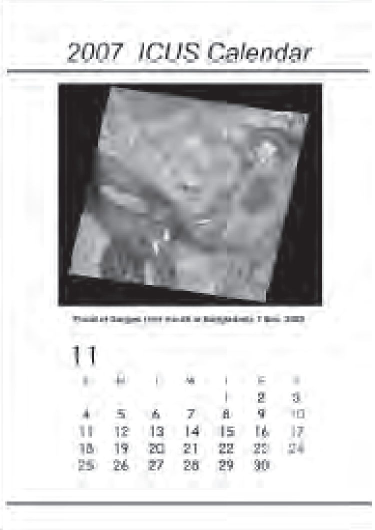
S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

2007 ICUS Calendar

Global hydrological cycles (Oki and Kanae, Science, 2006)

10

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			



2007 ICUS Calendar

Flood of Ganges river mouth in Bangladesh 7 Nov. 2003

11

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

2007 ICUS Calendar

Delegation of ICUS attending UNRCA 2006 on November 15-17, in Phuket, Thailand

12

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

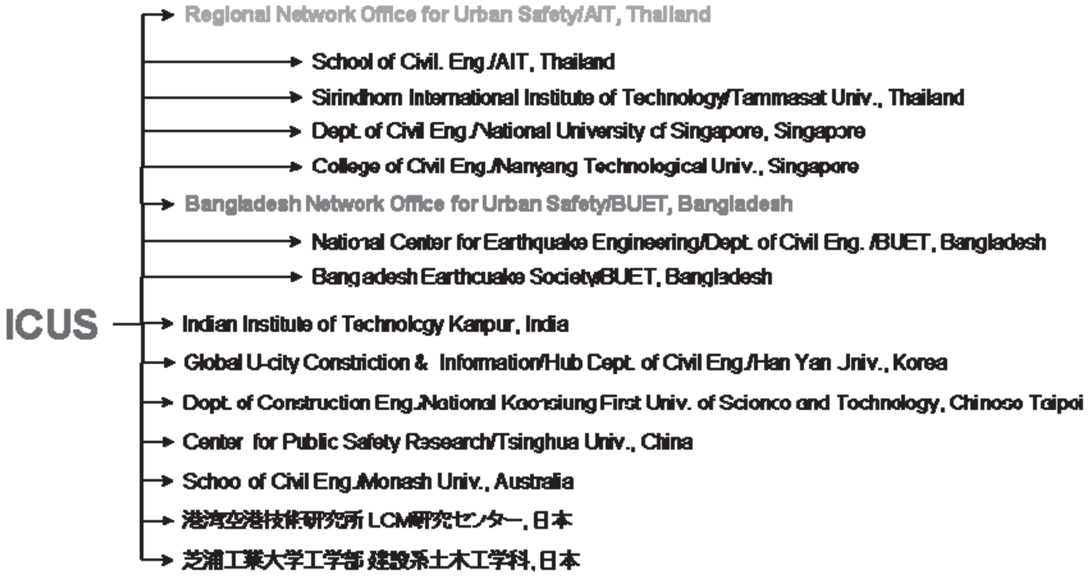
- ICUS 紹介ビデオ(日本語/英語)

ICUS 紹介ビデオ

3.4　グローバル連携活動

ICUS は，インフラと都市の安全性に関わる世界の人材ネットワーク(ICUS ネットワーク)を構築し，関連情報の活発な交換を行っている．また，国内外の関係研究機関との研究協力協定の締結や国際共同プロジェクトも実施している．

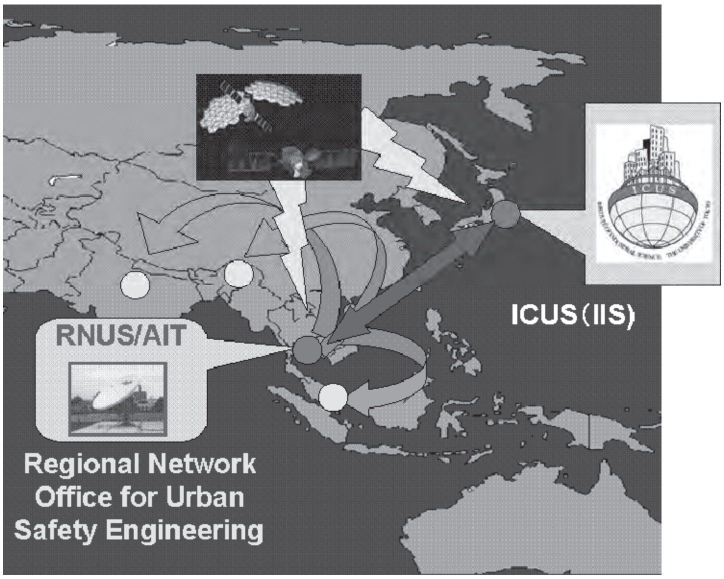
具体的には，2002 年にタイ・バンコク市にあるアジア工科大学院(AIT)にアジアでの活動拠点として Regional Network office for Urban Safety(RNUS)を開設した．RNUS を通じてアジアの巨大都市の安全性に関する研究を実施している．例えば，「アジア諸国の都市化地域を対象とした構造物を含めた地域脆弱性の恵贈的定量手法の提案とそのためのデータベースの構築」に関する研究を進めている．



ICUS のネットワーク

3.4.1 研究協力協定の締結

2008年3月末現在，ICUSは，AIT/RNUS(タイ)，シンガポール大学(シンガポール)，ナンヤン工科大学/PTRC(シンガポール)，インド工科大学・カンプール校(インド)，バングラディシュ工科大学/BNUS(バングラディシュ)，バングラディシュ工科大学/地震工学センター(バングラディシュ)，バングラディシュ地震協会(バングラディシュ)，モナシュ大学(オーストラリア)，Global U-City Construction & Information (GUCCI) Hub(韓国)，国立高雄第一科技大学/建設工学科(台湾)，清華大学/公共安全研究センター(中国)港湾技術研究所/LCMセンター(日本)，芝浦工業大学/工学部建設系土木工学科(日本)と研究協力協定を締結している.



ICUSの研究協力協定先

3.4.2 Regional Network Office for Urban Safety (RNUS)

3.4.2.1 RNUS設立の目的

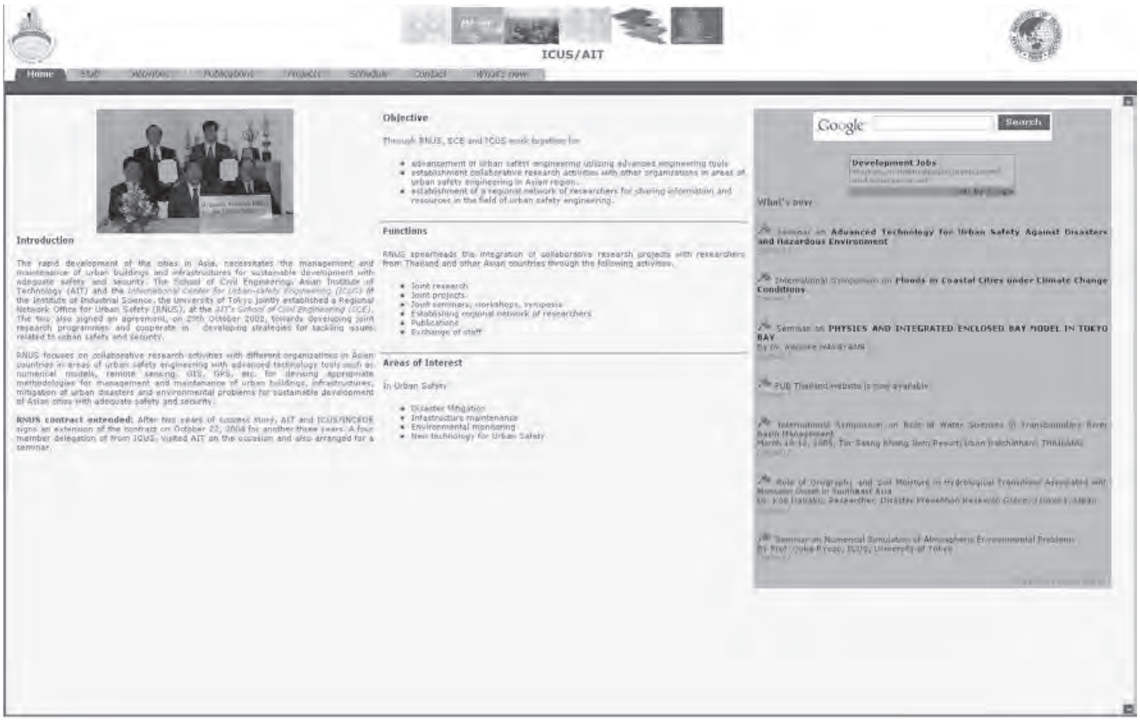
RNUSは，アジア諸国の都市化地域を対象とした構造物を含めた地域脆弱性の継続的定量評価手法の提案とそのためのデータベースの構築という研究を効果的に進めるため，2002年10月AIT内に設立された.本研究の対象エリアである東アジアや東南アジア地域では，設計基準の不備，不十分な施工管理や維持管理等を理由として，都市を構成する各種の構造物の脆弱性が大きな問題となっている．この問題の重要性は，地震などの特別な外力が作用しない状態でも構造物が崩壊してしまう事故が多発している事実からもはっきりしている．また，これらの地域では急激な地域開発が行われていることが多く，品質に問題のある構造物が建設ラッシュ期に集中的に造られていることから，近い将来に時期を同じくして問題が顕在化してくる可能性が高く．早急にこの問題に対する解決策を提示しない限り，今後，これがアジア諸国に対して社会的・財政的に大きな問題を与えることは自明である.

この問題に対処するには，構造物をはじめとする地域データ整備が不可欠であるが，アジア地域でこれが整備されているところは少なく，建物一棟ずつ調べてデータベース化するなどの手段は現実的ではない．そこで本研究では，これらの地域をカバーできる地球観測衛星データを活用して，地域における市街地化の時系列情報を収集するとともに，現地調査に基づいて市街地化の進行時期ごとの建築構造物をはじめとする地域のデータベース化を図る．さらに，このデータを活用して脆弱性評価モデルを構築する.

このモデルにより，アジア諸都市の，どの地区が，将来のどの時期に構造的な危険が生ずるかを予測することが可能となる．この調査研究は，アジア諸国の中でも問題の切迫性

の高いタイのバンコク市を対象として開始し，順次その対象を拡大する．

AIT に設置するオフィスを活動拠点として, 宇宙の視点と地上の視点からアジア諸都市の構造物をはじめとする地域特性の情報をベータベース化するとともに，これらを活用した地域の脆弱性評価モデルを構築する．



Introduction

The rapid development of the cities in Asia, necessitates the management and maintenance of urban buildings and infrastructures for sustainable development with adequate safety and security. The School of Civil Engineering, Asian Institute of Technology (AIT) and the *International Center for Urban-safety Engineering (ICUS)* of the Institute of Industrial Science, the University of Tokyo jointly established a Regional Network Office for Urban Safety (RNUS), at the *AIT's School of Civil Engineering (SCE)*. The two also signed an agreement, on 29th October 2002, towards developing joint research programmes and cooperate in developing strategies for tackling issues related to urban safety and security.

RNUS focuses on collaborative research activities with different organizations in Asian countries in areas of urban safety engineering with advanced technology tools such as numerical models, remote sensing, GIS, GPS, etc. for devising appropriate methodologies for management and maintenance of urban buildings, infrastructures, mitigation of urban disasters and environmental problems for sustainable development of Asian cities with adequate safety and security.

RNUS contract extended: After two years of success story, AIT and ICUS/INCEDE signs an extension of the contract on October 22, 2004 for another three years. A four member delegation of from ICUS, visited AIT on the occasion and also arranged for a seminar.

Objective

Through RNUS, SCE and ICUS work together for

- advancement of urban safety engineering utilizing advanced engineering tools
- establishment collaborative research activities with other organizations in areas of urban safety engineering in Asian region.
- establishment of a regional network of researchers for sharing information and resources in the field of urban safety engineering.

Functions

RNUS spearheads the integration of collaborative research projects with researchers from Thailand and other Asian countries through the following activities.

- Joint research
- Joint projects
- Joint seminars, workshops, symposia
- Establishing regional network of researchers
- Publications
- Exchange of staff

Areas of Interest

In Urban Safety

- Disaster Mitigation
- Infrastructure maintenance
- Environmental monitoring
- New technology for Urban Safety

What's new

Seminar on **Advanced Technology for Urban Safety Against Disasters and Hazardous Environment**

International Symposium on **Floods in Coastal Cities under Climate Change Conditions**

Seminar on **PHYSICS AND INTEGRATED ENCLOSED BAY MODEL IN TOKYO BAY**
By Dr. Keisuke NAKAYAMA

PUB Thailand website is now available

International Symposium on Role of Water Sciences in Transboundary River Basin Management
[illegible]

Role of Orography and Soil Moisture in Hydrological Transitions Associated with Monsoon Onset in Southeast Asia
[illegible]

Seminar on Numerical Simulation of Atmospheric Environmental Problems
[illegible], University of Tokyo

RNUS のホームページ　(http://www.sce.ait.ac.th/rnus/)

3.4.2.2　研究テーマ

- Earthquake disaster management using GIS, RS technology
- Advanced numerical simulation of concrete and masonry materials

3.4.2.3　設備

- Advanced computing facilities

3.4.2.4　プロジェクト

RNUS では，タイを中心にプロジェクトを通して，東南アジア諸国の研究機関，研究者と協力して研究を進めている．

下記に設立からのプロジェクトを示す．

- Inspection of Marine Reinforced Concrete Structures in Thailand
- Feasibility Study on the Application of Expansive Concrete to Alleviate the Cracking Problem of RC structure in Thailand
- Seismic Hazard and Vulnerability Mapping of Dhaka, Chittagong & Sylhet City Corporation Areas -- funded by European Commission (EC) and UNDP
- Master Plan for Earthquakes And Building Collapse Hazard Prevention and Mitigation In Thailand (Phase I) – funded by Department of Disaster Prevention and Mitigation (DPM)

3.4.2.5 ワークショップとセミナー

ワークショップリスト

- Seminar on “Advanced Technologies toward Sustainable Concrete Structure”, January 2006, Prof. Toyoharu Nawa, Dr.Pipat Termkhajornkit and Prof.Somnuk Tangtermsirikul
- Seminar on “Niigata-Tyuetsu Earthquake on October 23, 2004”, March 2006, Prof. Hiroshi Mutsuyoshi and Dr. Takeshi Maki
- Seminar on “Analysis and Treatments for Corrosion of RC Structure”, August 2006, Dr. Shinichi Miyazato and Dr. Mitsuharu Tokunaga
- Seminar on “Modeling of Concrete Properties and Non-linear Structural Analysis”, November 2006, Dr. Toshiharu Kishi and Dr. Yasushi Tanaka
- Seminar on “Ultrasonic and Its Application for Cement-Based Materials”, February 2007, Dr. Wonsiri Punurai
- ICUS and RNUS Participated in Thailand Science and Technology Fair 2007, August 2007
- Seminar on “Toward a Partnership on Disaster Management and Remote Sensing/GIS Technologies”, February 2008, Prof. Kimiro Meguro, Dr. Pennung Warnitchai, Mr. Siri Akaakara, Mrs. Praneet Disariyakul, Dr. Manzul K Hazarika, Dr. Masahiko Honzawa, Dr. Warakorn Mairaing, Dr. Sutat Weesakul, Prof. Tomonari Yashiro and Dr. Shinji Tanaka
- Short Seminar on Transportation at Chulalongkorn University, March 2008, Dr. Hironori Kato and Dr. Shinji Tanaka
- Seminar on “Joint Student Seminar on Civil Infrastructures”, July 2008, Dr. Pennung Warnitchai, Prof. Kimiro Meguro, Dr. Cho Gye-Chun, Dr. Shinji Tanaka, Dr. Pison Udomworarat, Kawasaki, Tomoya, Choi Sung-Woo, Owatsiriwong, Adisorn, Matsumura, Yusuke, Jo Seon-Ah, Hoang Phuong Tung, Henry Michael, Dung Tran Viet, Yooprasertchai Ekkachai, Ebizuka Hiroaki, Phongtinnaboot Weeraporn, Oh Tae-Min, Sorimachi Naoki, Eom Yong-Hun, Nishiuchi Hiroaki and Suweero Kittipong
- Seminar on "Remote Sensing And Urban Public Transport", September 2008, Prof. Haruo Sawada, Prof. Fumihiko Nakamura and by Dr. Toshiyuki Okamura
- Workshop on Transportation Researches for Urban Safety, December 2008, Prof. Fumihiko Nakamura, Prof. Yasuhiko Kumagai , Dr. Toshio Yoshii, Prof. Masao Kuwahara, Dr. Kazushi Sano, Dr. Pichai Taneerananon, Prof. Takashi Nakatsuji , Dr. Hidekatsu Hamaoka, Dr. Ryota Horiguchi, Dr. Sorawit Narupiti, Dr. Agachai Sumalee

3.4.3 BNUS

3.4.3.1 BNUS の設立の目的

BNUS は，南アジア諸国の都市化地域を対象とした構造物を含めた地域脆弱性の継続的定量評価手法の提案とそのためのデータベースの構築という研究を効果的に進めるため，2006 年 1 月にバングラディシュ工科大学内に設立された．本センター設立の目的は「地震や洪水の被害を受ける南アジア諸国の都市化地域を対象とした構造物を含めた地域脆弱性の継続的定量評価手法の提案とそのためのデータベースの構築」である．本センターの研究の対象エリアである南アジア地域では，設計基準の不備，不十分な施工管理や維持管理等を理由として，都市を構成する各種の構造物の脆弱性が大きな問題となっている．この問題の重要性は，地震やサイクロン(洪水)などの特別な外力が作用しない状態でも構造物が崩壊してしまう事故が多発している事実からもはっきりしている．またこれらの地域では急激な地域開発が行われていることが多く，品質に問題のある構造物が建設ラッシュ期に集中的に造られていることから，近い将来に時期を同じくして問題が顕在化してくる可能性が高い．早急にこの問題に対する解決策を提示しない限り，今後，南アジア諸国に対して社会的・財政的に大きな問題を与えることは自明である．

この問題に対処するには，構造物をはじめとする地域データ整備が不可欠であるが，南アジア地域でこれが整備されているところは少なく，建物一棟ずつ調べてデータベース化

するなどの手段は現実的ではない．そこで本センターを中心に，これらの地域をカバーできる地球観測衛星データを活用して，地域における市街地化の時系列情報を収集するとともに，現地調査に基づいて市街地化の進行時期ごとの建築構造物をはじめとする地域のデータベース化を図る．さらに、このデータを活用して脆弱性評価モデルを構築する．このモデルにより，地震や洪水の影響を直接的に受ける南アジア諸国の大都市の，どの地区が，将来のどの時期に構造的な危険が生ずるかを予測すること目的としてセンターを設立した．

3.4.3.2 研究テーマ

- Undertake collaborative research with different institutes
- Develop evacuation plans for different wards of Dhaka city
- Evaluation of building against cyclone and tsunami in the coastal areas
- Development of earthquake and tsunami preparedness program for coastal area
- Develop Training Manuals for Mason
- Conduct School Earthquake Safety Program
- Monitor Earthquakes through Strong Motion Accelerographs
-

3.4.3.3. 設備

- Expertise in application of GIS software
- Expertise on urban safety research
- Expertise on the application of 3D simulation
- Expertise in Architecture, Engineering, Planning

3.4.3.4 プロジェクト

- Seismic Microzonation for Cox’s Bazar Municipality
- Rain Induced Hill-Slope Erosion/ Landslide and Probable Control Measure in Chittagong Hilly Areas, 2008
- Natural Slope Stability Analysis of some Existing Livestock Shelters (*Killas*) for Cyclones in Bangladesh (current)
- Post Disaster Survey for Cyclone SIDR 2007
- Macroseismic Survey of Two Recent Earthquakes (Rajshahi and Mymensingh) in Bangladesh in 2008
- Strong Motion Monitoring System in Bangladesh, 2007, 2008, 2009
- Mason Training Regarding Earthquake Resistant Construction, 2009
- Evacuation plans for different wards in Dhaka city (current)
- Earthquake Vulnerability Assessment of buildings using RVS method and Turkish Level-I & II method, 2008
- School Earthquake Safety Awareness Program (SESAP), 2007-2009
- Rethinking the Public Buildings as Post Disaster Shelters – in the context of Old Dhaka
- Earthquake Vulnerability Reduction Strategies for Unplanned Urban Areas
- Evaluation of concrete structures of Bangladesh has been completed in two phases, 2006

3.4.3.5 ワークショップとセミナー

3.4.3.5.1 ワークショップ

- A Training Program for Masons on “How to Build Earthquake Resistant Buildings” was conducted on October 16-18 (theoretical) and October 23-26 (practical), 2008.
- Directorate of Continuing Education (DCE), BUET in association with Bangladesh Network Office for Urban Safety (BNUS), BUET has arranged a short course titled “DISASTER AND CONFLICT- WHAT SHALL WE DO ON IT?” at DCE Conference Room. The duration of this short course was two days long march 15-16, 2008.
- Workshop on ‘Sharing Knowledge on Disaster Warning: Community-based Last-Mile Warning System’ at ITN Center, BUET, Dhaka on 25 October, 2007 was organized by

BNUS together with LIRNEasia, Sri Lanka.

- BNUS together with DCE, BUET organized a two-day short course on “Evaluation of Concrete Structures” on 2006.
- An International Symposium on ‘New Technologies for Urban Safety of Mega Cities in Asia’ (USMCA-2007) was organized by BNUS in cooperation with ICUS was held on 9-10 December, 2008 at Dhaka.
- Workshop on ‘Earthquake Safety Awareness and First Aid’ was held at Armenitola Govt. High School, Old Dhaka on 30/11/2006, 1/12/2006 and 2/12/2006.
- Workshop on ‘Earthquake Safety Awareness and First Aid’ was organized at Narinda Government High School on November 18-19, 2006.
- ‘Search and Rescue Training Program’ for the students of Armenitola Government High School, Old Dhaka from 10th to 12th December, 2006.
- A ‘Mock Drill’ was organized by the students of Armenitola Government High School on 23rd February, 2007.
- A lab test on checking of performance of URM structure of resisting earthquake force

3.4.3.5.2　セミナー

- A seminar on Urban Safety and Disaster Management was organized on March 15, 2009. Prof. K. Meguro, Director, ICUS and Prof. H. Sawada, ICUS, IIS, University of Tokyo, delivered presentations on “The Most Important Issue for Disaster Mitigation and Integrated Information System for Total Disaster Management” and “Satellite Remote Sensing for Monitoring Natural Environment and Disasters” consecutively.
- A Seminar on “Raincut Erosion Control in Chittagong Hilly Areas” was jointly organized with Bangladesh Earthquake Society (BES) on November 15, 2008, chaired by Prof. Dr. Jamilur Reza Chowdhury, President, BES. Dr. Abdul Jabbar Khan, Professor, Dept. Of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), presented a lecture on the experience of visiting the landslide prone hilly areas of Chittagong, as an Expert Team Member of BNUS.
- A Roundtable Meeting on “Raincut Erosion Control in Chittagong Hilly Areas” was organized on August 28, 2008, chaired by Prof. Dr. A. M. M. Safiullah, Vice Chancellor, Bangladesh University of Engineering and Technology (BUET), Dr. Abdul Jabbar Khan, Professor, Dept. Of Civil Engineering, BUET, presented a lecture on Raincut Erosion Control in the hilly areas of Chittagong and Application of Geojute. Personnel from Education Engineering Department, Geological Survey of Bangladesh, Fire Service and Civil Defense, Institute of Water Modelling and several other oragnizaion as well as Professors from BUET participated in the meeting.
- Seminar on ‘Recent Development of Earthquake related activities in Japan’ Speaker: Prof. K. Meguro in 15 June, 2006 organized by BES and Engineering Staff College.
- Seminar on ‘Importance of Maintenance of Existing Concrete Structures’ was held on 5 December 2006 at Institution of Engineers, Bangladesh by Prof. T. Uomoto.
- Seminar on ‘Recent Development of Earthquake Related Activities in Japan’ was held at the seminar Room of Department of Civil Engineering, BUET on 6 December, 2006 by Professor K. Meguro, Professor, IIS, University of Tokyo and Director, International Center for Urban Safety (ICUS).

3.5　スタッフ海外出張記録

・2006 年度度

教官名	期間	場所	用務
魚本健人	8/2-8	Bangkok/Thailand	10th East Asia-Pacific Conferecne on Structural Engineering and Construction
	9/11-17	Vancouver/Canada	Shotocrete for Underground Support X
	10/15-18	Istanbul/Turkey	Field work
	10/24-27	Udon Thani/Thailand	Thai Annual Concrete Conference
	11/14-19	Phuket/Thailand	USMCA2006
	11/20-23	Bali/Indonesia	2nd Asian Concrete Federation International Institute of Technology
	11/26-12/2	Sydney,Melbourne/Australia	Seminar at Monash University
	12/4-7	Dhaka/Bangladesh	BUET
	2/10-14	Dusseldorf/Germany	Seminar at Bundesanstalt fur Materialforschung und-prufung(BAM)
	2/14-18	Istanbul/Turkey	Field work
	2/26-28	Bangkok/Thailand	Workshop at Chulalongkorn University
目黒公郎	4/13-20	Dhaka/Bangladesh	BUET
	4/16-23	San Franscisco	100th Anniversary Earthquake Conference
	9/3-7	Geneva/Switzerland	1st European Conference on Earthquake Engineering and Seismology
	9/10-18	Istanbul/Turkey	Workshop
	11/15-19	Phuket/Thailand	USMCA2006
	12/2-3	Singapore	Board of Directors of the World Seismic Safety Initiative
	12/4-7	Dhaka/Bangladesh	BUET
	3/5-9	Mongol	Seminar of the Research Center for Astronomy and Geophysics and the World Seismic Safety
	3/12-17	Teheran/ Iran	Workshop on Strengthening Earthquake Resistant Capacity of Masonry Houses in Iran
大岡龍三	5/30-6/4	Philadelphia/USA	10th International Conference on Thermal Energy Storage

	6/11-18	Denmark	6th International Conferece on Urban Climate
	6/24-29	Quebec/Canada	2006 ASHRAE Annual Metting
	10/15-19	Hong Kong/China	6th International Thermal Manikin and Modeling Meeting
	11/15-19	Phuket/Thailand	USMCA2006
	1/27-2/1	Dallas/USA	2007 ASHRAE Winter Meeting
	3/17-21	Barcerona/Spain	Annual Meeting of the Alliance for Global Sustainability(AGS)
加藤佳孝	4/17-5/17 6/21-7/7	Bankgkok/Thailand	RNUS
	6/26-7/1	St.Malo/France	2nd International Conference on Concrete Repair
	8/1-18 9/3-10/5 10/23-12/8	Bangkok/Thailand	RNUS
	11/14-19	Phuket/Thailand	USMCA2006
	11/20-23	Bali/Indonesia	2nd Asian Concrete Federation International Institute of Technology
	1/29-3/2	Bangkok/Thailand	RNUS
	2/10-14	Dusseldorf/Germany	Seminar at Bundesanstalt fur Materialforschung und-prufung(BAM)
	2/14-18	Istanbul/Turkey	Field work
大原美保	4/16-23	San Franscisco	100th Anniversary Earthquake Conference
	6/13-20	Dhaka/Bangladesh	BUET Workshop and Field work
	9/9-20	Istanbul/Turkey	Workshop
	11/14-19	Phuket/Thailand	USMCA2006
Paola Mayorca	4/16-23	San Franscisco	100th Anniversary Earthquake Conference
	9/3-7	Geneva/Switzerland	1st European Conference on Earthquake Engineering and Seismology
	10/14-22	Lima/Peru	Field Work
	11/14-19	Phuket/Thailand	USMCA2006
金田尚志	6/13-20	Dhaka/Bangladesh	BUET Workshop and Field work

	8/2-8	Bangkok/Thailand	10th East Asia-Pacific Conferecne on Structural Engineering and Construction
	8/13-20	St.Louis/USA	2006 NDE Conferecne on Civl Engineering
	11/3-5	Seoul/Korea	2006 Korea Concrete Federation Autum Meeting
	11/14-19	Phuket/Thailand	USMCA2006
	11/20-23	Bali/Indonesia	2nd Asian Concrete Federation International Institute of Technology
	3/11-16	Seoul/Korea	Seminar at Han Yang University
Sahamitmongkol Raktiporn	4/10-5/29	Bangkok/Thailand	RNUS
	4/20-23	Phuket/Thailand	NCCE11
	6/9-7/5 7/12-8/16 8/20-9/14 9/19-12/13	Bangkkok/Thailand	RNUS
	10/24-27	Udon Thani/ Thailand	Thai Annual Concrete Conference
	11/14-19	Phuket/Thailand	USMCA2006
	11/20-22	Bali/Indonesia	2nd Asian Concrete Federation International Institute of Technology
	12/29-3/24	Bangkok/Thailand	RNUS
天野玲子	7/11-13	Portprpz/Slovenia	12th International Symposium on Aerodynamics and Ventilation Vehicle Tunnels
	11/14-19	Phuket/Thailand	USMCA2006
須崎純一	11/14-19	Phuket/Thailand	USMCA2006
宮崎早苗	11/14-19	Phuket/Thailand	USMCA2006
遠藤貴宏	11/14-19	Phuket/Thailand	USMCA2006
吉本英子	11/14-19	Phuket/Thailand	USMCA2006

・2007 年度度

教官名	期間	場所	用務
目黒公郎	5/9-11	Bangkok/Thailand	RNUS
	6/20-23	Jakarata/Indonesia	3th Association of Pacific RimUniversities/Association of East Asian Research

			Universitities Research Symposium
	8/8-11	Bangkok/Thailand	Bangkok International Trade and Exhibition Center
	9/1-3	Taipei/Taiwan	The Taiwan-Japan Workshop on the Earthquake Early Warning System
	10/21-23	Stockholm/Sweden	Meeting of GFDRR
	11/26-30	Taipei/Taiwan	2nd International Conference on Urban Disaster Reduction
	12/1-6	Singapore	The Board of directores of the WSSI
	12/7-12	Dhaka/Bangladesh	USMCA2007
	2/7-11	Phuket/Thailand	RNUS seminar
	3/29-4/2	Riyadh/Saudi Arabia	Sympoium on Disaster Management and Safety of Buildings in Arab Courntries
大岡龍三	6/9-14	Helsinki/Finland	Clima 2007 and Roomvent2007
	6/23-28	Los Angeles/USA	2007 Annual Meeting of the American Society of Heating, Refrigerationg and Air-Conditioning Engineers
	6/30-7/5	Cairns/Australia	12th International Conference on Wind Engineering
	11/19-24	Beijing/China	Tsinghua University
	11/25-27	Seoul/Korea	Seminar
	12/7-12	Dhaka/Bangladesh	USMCA2007
	1/19-24	New York/USA	The 2008 American Society of Heating, Refrigerating and Air-Conditioning Engieerng Winter Meetng
	1/28-2/1	Boston/USA	Alliance for Global Sustainability(AGS)Annual Meeting 2008
	2/27-29	Seoul/Korea	Field work
加藤佳孝	4/17-5/15	Bangkok/Thailand	RNUS
	12/7-12	Dhaka/Bangladesh	USMCA2007
桑野玲子	11/3-10	Chongqing/China	3rd Sino-Japan Geotechnical Symposium
	12/7-12	Dhaka/Bangladesh	USMCA2007
大原美保	11/26-30	Taipei/Taiwan	2nd International Conference on Urban Disaster Reduction

	12/7-12	Dhaka/Bangladesh	USMCA2007
田中伸治	5/9-11	Bangkok/Thailand	RNUS
	6/24-30	Berkeley/USA	WCTR
	9/3-7	Bangkok/Thailand	RNUS
	10/10-15	Beijing/China	ITS World Congress
	12/7-12	Dhaka/Bangladesh	USMCA2007
	1/21-2/16 2/26-3/29	Bangkok/Thailand	RNUS
遠藤貴宏	12/7-12	Dhaka/Bangladesh	USMCA2007
Paola Mayorca	9/4-28	Pisco/Peru	Field Work
	12/7-12	Dhaka/Bangladesh	USMCA2007
Sahamitmongkol Raktipon	4/2-5/28 6/4-7/26	Bangkok/Thailand	RNUS
Warakanchana Kawin	8/6-10/26 12/1-2/28	Bangkok/Thailand	RNUS
	12/7-12	Dhaka/Bangladesh	USMCA2007
	3/11-26	Bangkok/Thailand	RNUS
横田弘	12/7-12	Dhaka/Bangladesh	USMCA2007
吉本英子	12/7-12	Dhaka/Bangladesh	USMCA2007

・2008 年度

教官名	期間	場所	用務
目黒公郎	8/26-28	Dhaka/Bangladesh	BNUS
	10/12-17	Beijing/China	14th WCEE
	10/18-23	Beijing/China	USMCA2008
	11/18-22	Bangkok/Thailand	UN-ESCAP
	1/2-5	Chengdu/China	Field Work
	3/8-9	Beijing/China	2nd Japan-China Forum
	3/14-16	Dhaka/Bangladesh	BNUS
沢田治雄	7/6-11	Beijing/China	presentation
	9/15-19	Bangkok/Thailand	Meeting ,RNUS

	10/18-23	Beijing/China	USMCA2008
	11/5-15	Colombo/Sri Lanka	ACRS
	11/15-22	Bangkok/Thailand	Fortrop II
	1/7-12	Khon Kaen/Thailand	Workshop
	3/14-20	Dhaka/Bangladesh	BNUS
横田弘	10/20-23	Beijing/China	USMCA2008
桑野玲子	9/21-26	Atlanta/USA	4th International Symposium on Deformation Characteristics of Geomaterials (IS-Atlanta 2008)
	10/18-23	Beijing/China	USMCA2008
加藤佳孝	6/9-16	Varenna/Italy	IALCCE08
	10/18-23	Beijing/China	USMCA2008
	11/25-30	Hangzhou/China	ICDCS2008
腰原幹雄	10/19-23	Beijing/China	USMCA2008
大原美保	10/12-17	Beijing/China	14th WCEE
	10/17-23	Beijing/China	USMCA2008
田中伸治	4/1-5/1 5/12-24	Bangkok/Thailand	RNUS
	5/18-19	HongKong	Meeting
	6/16-26 7/2-20	Bangkok/Thailand	RNUS
	7/14-18	Singapore	ITS Asia-Pacific Forum
	8/18-28 9/11-20 10/14-19	Bangkok/Thailand	RNUS
	10/20-23	Beijing/China	USMCA2008
	10/24-29	Bangkok/Thailand	RNUS
	11/16-22	New York/USA	ITS World Congress
	12/8-19	Bangkok/Thailand	RNUS
遠藤貴宏	10/18-23	Beijing/China	USMCA2008
Paola Mayorca	10/12-17	Beijing/China	14th WCEE
	10/17-23	Beijing/China	USMCA2008
Pranab J.Baruah	10/18-24	Beijing/China	USMCA2008
Warakanchana Kawin	5/12-28 6/28-7/25 9/14-10/11	Bangkok/Thailand	RNUS
	10/12-17	Beijing/China	14th WCEE
	10/18-23	Beijing/China	USMCA2008
	10/24-12/14 12/26-3/1	Bangkok/Thailand	RNUS
吉本英子	10/18-23	Beijing/China	USMCA2008

3.6　受賞記録

名前	研究室	年月	受賞名	授与機関名
目黒 公郎	目黒研究室	2006.5	年間優秀論文	地震工学会
加藤 佳孝	加藤研究室	2006.5	奨励賞	(社)日本コンクリート工学協会
金田 尚志	ICUS	2006.5	奨励賞	(社)日本コンクリート工学協会
金田 尚志	ICUS	2006. 7	年次論文奨励賞	(社)日本コンクリート工学協会
Pakawat Sancharoen	魚本研究室	2006. 7	年次論文奨励賞	(社)日本コンクリート工学協会
金田 尚志	ICUS	2006.11	Best Concrete Research	2nd Asian Concrete Federation
Raktipong Sahamitmongkol	ICUS	2006.11	Best Concrete Research	2nd Asian Concrete Federation
Kawin Warakanchana	目黒研究室	2006.11	Excellent Young Researcher	USMCA 2006
大岡龍三	大岡研究室	2007.6	Award of Excellency in Research	The Organizing Committee of SB07 SEOUL–the International Conference on Sustainable Building Asia
Micheal Henry Word	加藤研究室	2007.9	古市賞	東京大学大学院　社会基盤学専攻
Ruta Ireng Wicaksono	桑野研究室	2007.9	優秀講演者	土木学会
中島奈緒美	目黒研究室	2007.9	優秀講演者	土木学会
大原（吉村）美保	目黒研究室	2007.9	学術発表優秀賞	日本自然災害学会
Navaratnarajah Sathiparan	目黒研究室	2007.9	学術発表優秀賞	日本自然災害学会
Navaratnarajah Sathiparan	目黒研究室	2007.9	Mondialogo Engineering Award	UNESCO とダイムラー・クライスラー社
大岡龍三	大岡研究室	2007.11	最優秀論文賞	Taiwan Society of Sustainable Built Environment
大原（吉村）美保 宮崎早苗 目黒公郎	目黒研究室 宮崎研究室	2007.12	東京大学総長賞（業務改善）	東京大学
大岡龍三	大岡研究室	2008.1	Best Poster Award	The AGS (The Alliance for Global Sustainability)
藤田哲朗	加藤研究室	2008.3	田辺賞	東京大学　社会基盤学科
Micheal Henry Word	加藤研究室	2008.7	コンクリート工学後	(社)日本コンクリート工

			援会年次論文奨励賞	学協会
Navaratnarajah Sathiparan	目黒研究室	2008.10	Young Award USMCA2008	USMCA2008
Mayorca Arellano Paola	ICUS	2008.10	Outstanding Paper Award	14th World Conference on Earthquake Engineering
佐藤真理	桑野研究室	2009. 3	工学部長賞最優秀賞	東京大学工学部

付録　**ICUS**の活動を振り返る関連資料

A. 業績リスト
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報告　部分断面修復が補修後の再劣化に及ぼす影響

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要旨：本研究は，塩害で劣化したコンクリート構造物を補修した後に生ずる再劣化の原因とその対策を明らかにすることを目的として実施しているものである。今回報告する補修方法は，各種材料を使用した部分断面修復であり，内陸条件および海洋条件にて暴露し，内部に配置した鉄筋の腐食状況を調査した。暴露1年と3年における鉄筋腐食状況を定量的に測定した結果，使用する断面修復材の種類や暴露環境条件によって腐食形態が異なることが明らかになった。特に，断面修復材と母材コンクリートとの境界部の腐食速度が他の部位より速いことを定量的に示すことができた。

キーワード：塩害，断面修復，マクロセル腐食，劣化，暴露試験

1. はじめに

本報告は，塩害によって劣化したコンクリート構造物を補修した後に生ずる再劣化のメカニズムを明らかにし，合理的補修設計法を提案することを目的に実施している暴露試験結果の一部についてとりまとめたものである。

著者らのグループは，道路橋の鉄筋コンクリート床版を対象として，コンクリート中の塩化物イオン量，補修の広さ，補修材の種類，補修の深さおよび表面被覆材の有無等を要因とした鉄筋コンクリート試験体を作製して，海洋環境下と内陸環境下に長期間暴露し，外観観察，電気化学的測定，内在塩分の塩化物イオンの拡散性状および鉄筋腐食状況の観察等を実施している[1),2),3),4)]。

ここでは，これら暴露試験体のうち，断面修復材，表面被覆材が異なる10種類について暴露1年と3年の試験体から取り出した鉄筋の腐食状況について調査した結果について報告する。対象とした補修は，部分断面修復であるため，マクロセル腐食や補修境界部の腐食速度についての考察を行った。

2. 実験概要

2.1 試験体の形状・寸法

試験体の形状・寸法および補修条件は，**図－１**，**表－１**に示したとおりであり，寸法は15×15×53cm，かぶり3cmとして鉄筋を2本配置し，断面修復の範囲，深さおよび表面被覆材での補修範囲等を試験要因とした。

コンクリートの配合およびその使用材料は**表－２**に示すとおりとした。コンクリートには練混ぜ時に塩化物イオンを0，2.4，4.8kg/m^{3}それぞれ混入している。鉄筋は，SD345，D19であり，両端の折り曲げ部分はエポキシ樹脂で塗装を行った。

2.2 補修方法および補修材料

コンクリート試験体は，断面修復部に予め発泡スチロールを配置しておき，その状態でコンクリートを打ち込んで作製した。模擬したはつり部分は，ワイヤーブラシや圧搾空気を用いて表面のレイタンスや汚れを除去した。その後，プライマーの塗布，鉄筋の防錆処理を行い，次に，断面修復，表面被覆を行った。

補修材料は**表－３**に示すとおりであり，試験

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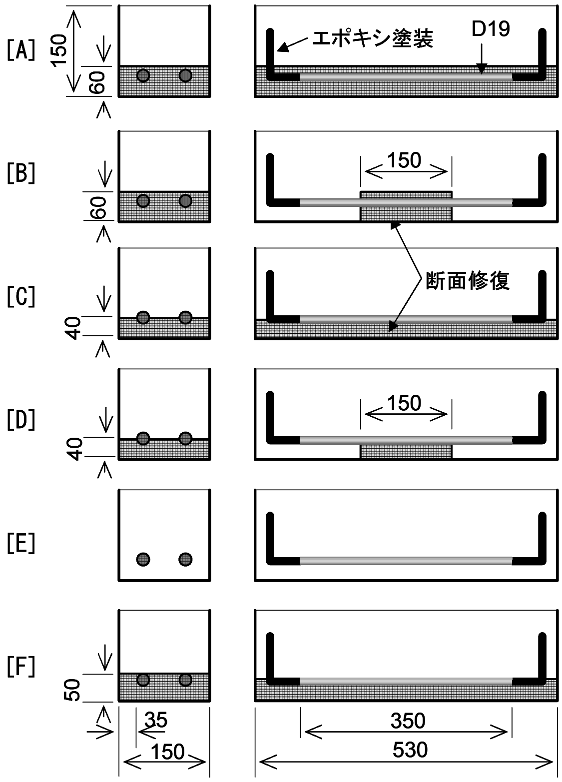
体A～Eについては補修材 No.0 とした。また，試験体Bについては，補修材 No.0～9 の 10 種類とし，補修作業はそれぞれのメーカに依頼して行った。



図－１　試験体の形状寸法と種類(単位:mm)

表－１　試験体の補修条件

記号	断面修復長さ(mm)	断面修復深さ(mm)	Cl-量 (kg/m^3)	表面被覆範囲
1-A-無	530	60	0	上面無し
1-B-無	150			
1-E-無	補修無し			
1-E-有	補修無し			全面被覆
2-A-無	530	60	2.4	上面無し
2-B-無	150			
2-C-無	530	40		
2-D-無	150			
2-A-有	530	60		全面被覆
2-B-有	150			
2-C-有	530	40		
2-D-有	150			
2-F-有	530	50		
3-A-有	530	60	4.8	
3-B-有	150			
3-C-有	530	40		
3-D-有	150			

表－２　コンクリートの配合，使用材料

粗骨材最大寸法	20mm
水セメント比	65%
スランプ	12±2.5cm
空気量	4.5±1.5%
圧縮強度	34.3N/mm^2
セメント	普通ポルトランドセメント　密度3.16g/cm^3
細骨材	大井川産陸砂　密度2.58g/cm^3
粗骨材	青梅産硬質砂岩系砕石　密度2.64g/cm^3
混和剤	AE減水剤、AE剤
塩化物イオン量	0 , 2.4 , 4.8 kg/m^3

表－３　補修材料の仕様

No.	プライマー	断面修復材	表面被覆材
0	PCP(Veo)	PCM(Veo)	柔軟型ｴﾎﾟｷｼ樹脂
1	ｴﾏﾙｼﾞｮﾝ(EVA)	PCM(SBR)	ｱｸﾘﾙ樹脂
2	ｱﾙｶﾘ付与剤、防錆剤	PCM(SBR、防錆剤)	柔軟型PCM
3	PCP(Veo)	PCM(Veo)	ウレタン樹脂
4	水性ｴﾎﾟｷｼ樹脂	PCM(SBR)	柔軟型ｴﾎﾟｷｼ樹脂
5	ｴﾎﾟｷｼ樹脂	ｴﾎﾟｷｼ樹脂ﾓﾙﾀﾙ	柔軟型ｴﾎﾟｷｼ樹脂
6	ｴﾏﾙｼﾞｮﾝ(Acr)	PCM(SBR、防錆剤)	柔軟型PCM
7	浸透性固化剤	PCM(Acr)	柔軟型PCM
8	PCP(SBR)	PCM(SBR)	ｸﾛﾛﾌﾟﾚﾝｺﾞﾑ
9	PCP(Acr、防錆剤)	PCM(Veo)	柔軟型ｱｸﾘﾙｳﾚﾀﾝ

PCP:ポリマーセメントペースト
PCM:ポリマーセメントモルタル
Acr:アクリル系，　SBR:スチレンブタジエンゴム系
Veo:ベオバ系，　EVA:エチレン酢酸ビニル系

2.3 試験体の暴露条件

コンクリート試験体は海洋環境下と内陸環境下に暴露した。海洋暴露場は，静岡県伊豆半島東海岸の波打ち際であり，常時海水飛沫を受ける厳しい腐食環境下である。内陸暴露場は，千葉県千葉市稲毛市の東京大学西千葉実験場内であり，海岸より 3km 内陸に位置し，飛来塩分の影響を受けない環境下である。

2.4 鉄筋の腐食度の測定方法

鉄筋の腐食面積率の測定は，暴露 1 年および 3 年経過した後に行った。試験体の外観観察後，試験体を割裂して鉄筋を取り出し，透明フィルムを巻きつけて発錆部分を写し取って 2 値化した。その画像を専用の処理ソフトを用いることで腐食面積率を計測した。

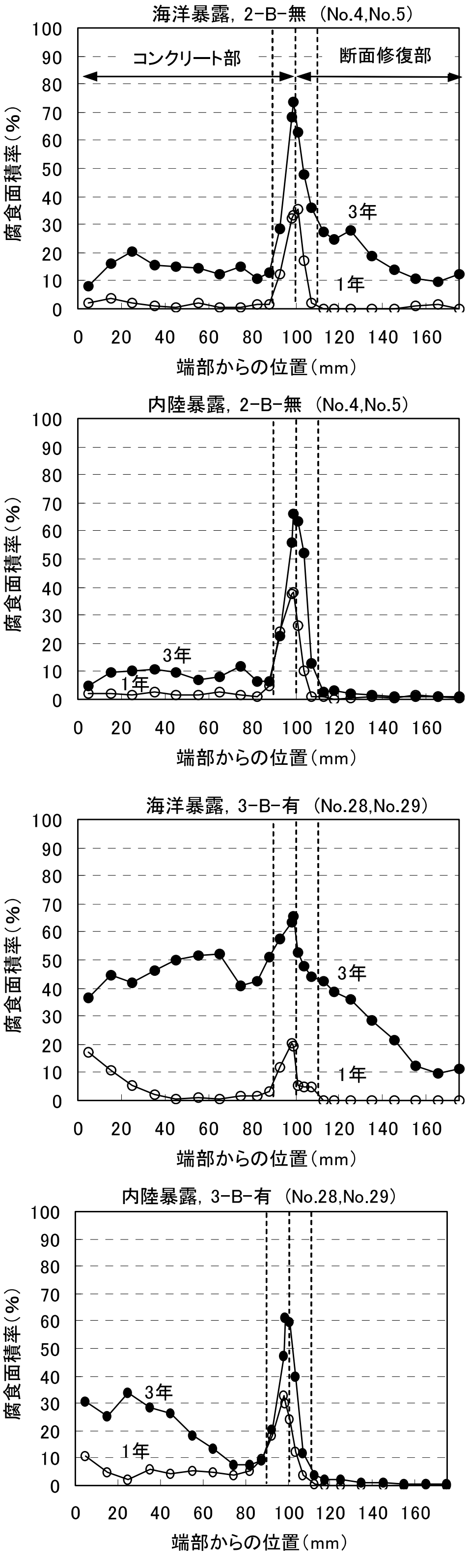
腐食減量の測定は，鉄筋をコンクリートに埋め込む前に予め質量を測定し，試験体を割裂して鉄筋を取り出した鉄筋の質量減少から求めた。鉄筋の錆の除去は，60℃のクエン酸アンモニウム 10%水溶液に 24 時間浸漬した後，ワイヤーブラシにて行った。このような測定は，試験体に埋め込まないで保管しておいた鉄筋についても同時に行い，黒皮分の補正量とした。

3. 鉄筋腐食面積率の分布

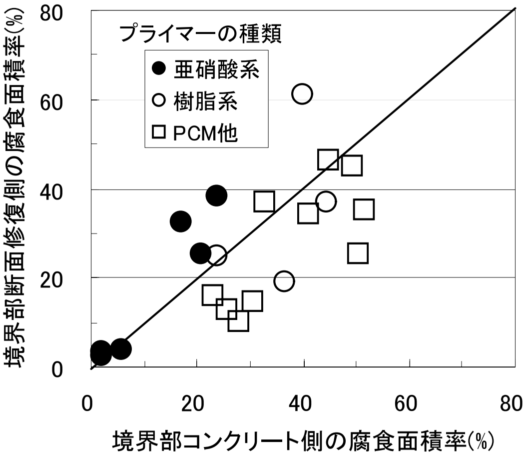
腐食面積率は，鉄筋の中央 350mm の区間で測定した。**図－２**は，部分断面修復を行った試験体Ｂ(補修材仕様 No.0)に埋め込んだ 2 本の鉄筋において，鉄筋の中央から左右対称としてそれぞれの部位の腐食面積率を平均して図示したものである。横軸の 0mm は鉄筋折り曲げ側のエポキシ塗装との境界, 0～100mm はコンクリート部, 100mm は断面修復材とコンクリートとの境界, 100～175mm は断面修復部，175mm は鉄筋中央を表している。

これらの図より，断面修復材とコンクリートとの境界部分における腐食が，他の部分より著しく大きいことが分かる。そして，腐食面積率が著しく大きくなる範囲は，境界面からそれぞれ 10mm 程度であり，部分補修を行った場合には境界部の±10mm 付近の鉄筋に着目する必要があることを示している。また，コンクリート部と断面修復部においては，コンクリート側が先行して腐食する試験体や，その逆に，断面修復部側が先行して腐食する試験体が認められた。

断面修復境界部の±10mm 付近を詳細に観察すると，境界面を挟んだコンクリート部分と断面修復材部分の両方で腐食が進行している。そこで，部分断面修復の試験体Ｂ(補修材仕様 No.0～9)において, 暴露 3 年における断面修復境界部のコンクリート側 10mm と断面修復側 10mm における腐食面積率の関係を**図－３**に示す。プライマーの種類として，亜硝酸系，樹脂系およびポリマーセメント系他の 3 種類に分類して表示した。一般的には，母材コンクリートに断面修復材を打ち継いで補修した場合には，母材コンクリート側が腐食するとされているが 5), 今回の試験では，樹脂系およびポリマーセメント系他のものがそのような傾向を示した。



図－２ 鉄筋腐食面積率の分布



図－３　断面修復境界部の腐食面積率

一方，亜硝酸系のプライマーを塗布したものは，コンクリート側と断面修復部側とがほぼ同程度の鉄筋腐食となっている傾向がある。これは，防錆剤の成分である亜硝酸塩が境界部のコンクリート側に浸透拡散したためと推測され，再劣化の原因となるマクロセル腐食の発生を抑制できる可能性があることを示唆している。

4. 腐食速度の推定

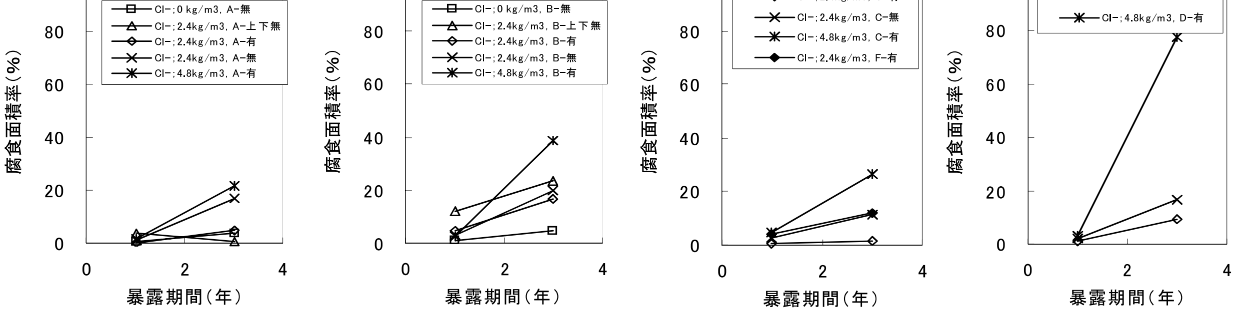
暴露試験体に埋め込まれた鉄筋の腐食速度は，腐食減量を測定すれば求められるが，3 年経過した段階においては，まだ孔食が認められず腐食減量が極めて小さいこと，および，断面修復材とコンクリートの境界面での腐食減量を直接測定するには範囲が極めて狭いため困難である。そこで，鉄筋全体の腐食面積率と腐食減少率の関係を詳細に測定した試験体（試験体Ａ～Ｅで補修材 No.0 を用いたもの）の結果より、腐食面積率から腐食速度を推定する方法を検討した。

図－４は，海洋暴露試験体における，暴露期間と腐食面積率の関係の代表例を示したものである。一部においては，腐食面積率が暴露期間に伴って直線的に増加していないものもあるが，大部分は概ね直線関係が認められる。このことより，腐食面積率は暴露期間で一次近似できるものと仮定し，その係数を腐食面積率による腐食速度（%/年）とする。また，同様に，鉄筋腐食減量は暴露期間で一次近似できるものと仮定してその係数を，腐食減量による腐食速度 (mg/cm^2/年)とする。

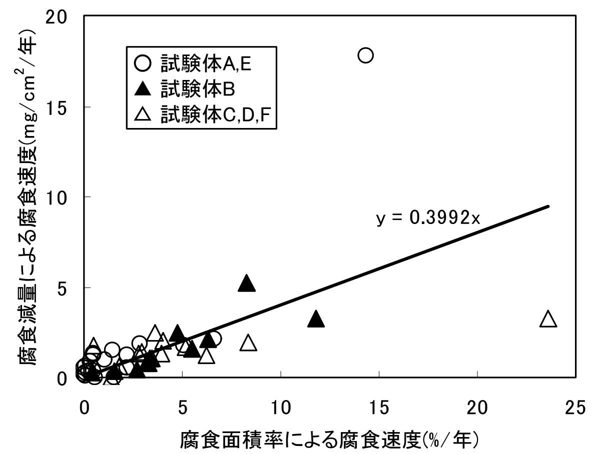
この腐食面積率による腐食速度(%/年)と腐食減量による腐食速度(mg/cm^2/年)の関係を図示すると**図－５**のようになる。このように，それら関係はほぼ直線関係として評価することができることを示している。よって，腐食減量が少ないような場合には，腐食面積率を測定することで腐食速度に換算して推定することが可能であると考えられる。

5. 部分断面修復試験体における鉄筋各部位の腐食速度

図－２で示したように，部分断面修復した試験体では，コンクリート部，断面修復部およびそれら境界部において腐食が進行する速さに違



図－４　鉄筋の腐食量の経時変化

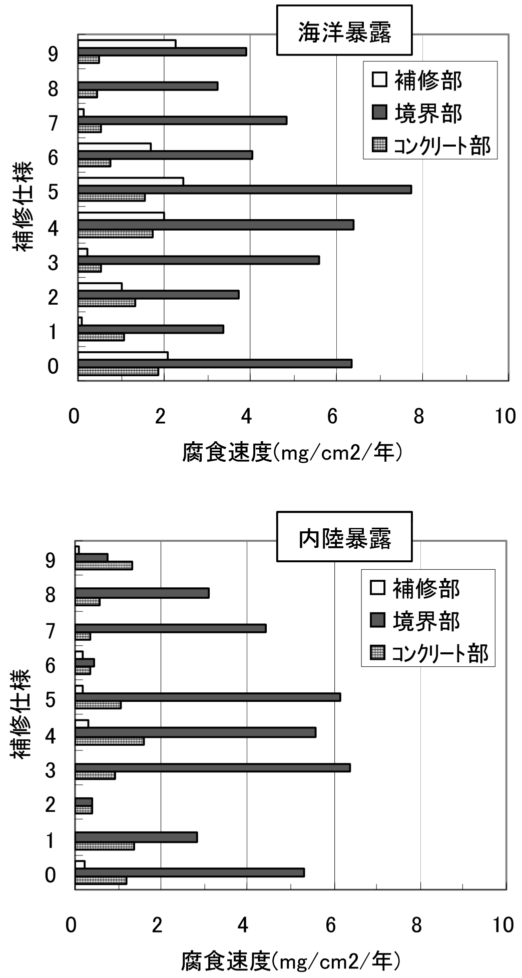


図－５　腐食面積による腐食速度と腐食減量による腐食速度との関係

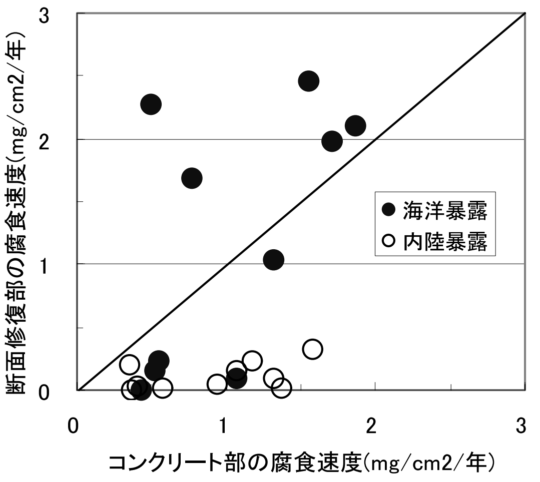
いがあることが認められた。そこで，部分断面修復した試験体Ｂ(補修材 No.0～9 の 10 種類)における各部位の腐食速度を推定することとした。

腐食速度の推定は，前章の暴露試験体より腐食量が少ないこと，樹脂を鉄筋防錆剤としているものがあるため腐食減量を正確に測定できなかったものがあること等より，**図－５**の関係を利用して，腐食面積による腐食速度から腐食減量による腐食速度を推定することとした。コンクリート部，断面修復部およびそれら境界部(境界面より±10mm の 20mm 区間)における腐食速度の推定結果を，海洋暴露試験体と内陸暴露試験体ごとに図示すると**図－６**のようになる。**図－６**より，内陸暴露試験体に比べて海洋暴露試験体の方が全体的に速いことが分かる。暴露 3 年の時点においては，コンクリートに内在する塩化物イオンが断面修復部分の鉄筋位置まで移動していないことが全ての試験体で確認されている。したがって，試験体が暴露される環境の温度や水分の供給状態の違いが腐食速度に大きく影響を及ぼしているものと考えられる。コンクリート部，断面修復部およびそれら境界部を比較すると，内陸暴露の一部試験体を除いて，境界部の腐食速度がコンクリート部，断面修復部より著しく大きい結果を示した。

また, 境界部±10mm の範囲を含まないコンク



図－６　鉄筋各部位の腐食速度(試験体Ｂ)



図－７　コンクリート部と断面修復部の腐食速度の関係(試験体Ｂ，補修仕様 No.0～9)

リート部と断面修復部とにおける腐食速度の関係は**図－７**のようになり，海洋暴露試験体においては，補修仕様の半数が断面修復部での腐食速度が速い結果を示した。このように，従来から言われているように，断面修復部がカソード，コンクリート部分がアノードとなるようなマクロセル腐食と逆の現象を示すものが多数存在することが分かった。これは，腐食速度が緩慢な場合にはコンクリート部が腐食するマクロセル腐食となり，腐食速度が速い，すなわち境界部での腐食が進行した場合には，その腐食の速さに依存してほぼ同程度の腐食速度になるとも読み取れるが，今後の詳細な検討が必要である。

6. まとめ

本報告は，塩害によって劣化したコンクリート構造物を補修した後に生ずる再劣化のメカニズムを明らかにする一環として，部分断面修復の試験体の 3 年までの暴露試験結果についてとりまとめたものである。その結果，以下のようなことが分かった。

(1)部分断面修復によって補修を行うと，母材コンクリート部や断面修復部に比べて，それら境界部分 20mm の範囲における鉄筋腐食が著しく大きくなる。境界部においては，コンクリート側 10mm と断面修復側 10mm とでは腐食面積率がほぼ同一であった。

(2)断面修復する前に塗布するプライマーとして亜硝酸系のものを用いると，境界部近傍におけるマクロセル腐食を抑制する傾向が認められた。

(3)鉄筋の腐食量がまだ少ないような場合には，腐食面積率による腐食速度(%/年)と腐食減量による腐食速度(mg/cm^2/年)とは一次比例関係にある。このことを利用して，鉄筋の部位ごとの腐食速度を推定することができた。

(4)部分断面修復を行った海洋暴露試験体では，10 種類の補修仕様のうちその半数が，コンクリート部より断面修復部での腐食速度が速い結果を示した。

以上，ここでは，暴露試験体の鉄筋腐食に着目してとりまとめたが，電気化学的測定や塩分の拡散状況等の各種調査も同時に実施しており，今後はそれらを総合的に評価して部分断面修復に関する課題を解決して行く予定である。

なお，本研究は，東京大学生産技術研究所と以下に示す産学17団体との共同研究として行っているものである。

芝浦工業大学，石川島播磨重工業(株)，(株)エヌエムビー, オリエンタル建設(株), (株)熊谷組，佐藤工業(株)，ショーボンド建設(株)，住友大阪セメント(株)，太平洋マテリアル(株)，大日本塗料(株)，電気化学工業(株)，東急建設(株)，飛島建設(株)，西松建設(株)，日本化成(株)，(株)ブリヂストン，前田建設工業(株)

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論文　実環境下におけるポリマーセメント系断面修復材の性能評価

伊藤　正憲[*1]・加藤　佳孝[*2]・魚本　健人[*3]

要旨：本研究は，劣化したコンクリート構造物の補修対策として実積の多いポリマーセメント系断面修復材を対象とし，現場での環境条件から受ける影響を定量的に評価し，今後計画的に構造物を維持管理していく上で有用な基礎データの提供を目的として行ったものである。本報は，実現場を想定した条件下に吹付け試験体を暴露し，ポリマーセメントモルタル中のポリマーの被膜形成過程およびセメントの水和の進行程度を定量化し，細孔構造分析結果とともに実環境レベルにおける硬化モデルの構築を行ったものである。さらに，中性化試験結果からこのモデルの妥当性の検証を行ったものである。

キーワード：ポリマーセメントモルタル，被膜化，水和反応，細孔構造，中性化

1. はじめに

1900 年初頭から市民生活を支える社会基盤の中核をなしてきた鉄筋コンクリートは，半永久的にメンテナンスフリーであると考えられていた。現に初期の構造物は非常に丁寧に材料を選び施工されているため現在でもその機能を十分に果たしているものが多い[1)]。しかし，100 年余り経過した 1980 年代から数十年経過しただけの新幹線のトンネルや高架橋からのコンクリート片のはく落事故が発生した。これらの構造物の多くは 1960 年代以降の高度経済成長期に建造されたものであり急速施工，大量打設の要求で導入されたコンクリートポンプ車によるところが大きいと言われている[2)]。このように奇しくもコンクリート構造物のはく離・はく落事故が多発した状況によってコンクリート構造物の維持管理，補修・補強が必要であり，ライフサイクルコストを最小限にするような各要素技術の開発が急務であると考えられるようになった。一方，劣化したコンクリート構造物，特に劣化した部分を除去したあとには断面修復工法が有効な対策法と考えられていた。しかし，これも早期に再劣化している事例が後を絶たない。これは適切な時期に適切な方法で補修されなかったと考えられ，主に適用されているポリマーセメントモルタル(以下，PMM)については材料の持つ特性を十分に理解し，理想的環境で獲得される補修材料の性能を現場でも再現できるとし，環境影響を想定した補修を行わなかったことも影響していると考えられる。

そこで，本研究は，劣化したコンクリート構造物の補修工法である湿式吹付け工法について，環境影響を把握するため実績の多い PMM を対象としてポリマーの被膜化とセメントの水和について詳細に検討し，細孔構造の分析結果とともにこれを加味した硬化モデルの構築を目指したものである。さらに，本研究では，構築した硬化モデルの妥当性について耐久性の面から検証を行った。

2. 実験概要

2.1 使用材料および配合

表－1に使用材料を，**表－2**に配合表を示す。使用したポリマーは再乳化形粉末樹脂であり，ポリマーセメント比(P/C)は 0%，5%，10%および 20%とした(NCM, P5, P10 および P20 と略記)。配合は，壁面に 20mm 厚で吹付け可能な配合を選定したものであり，それぞれ試験体の作製時

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表－１　ＰＭＭの材料諸元

種類	記号	諸元
セメント	C	普通ﾎﾟﾙﾄﾗﾝﾄﾞｾﾒﾝﾄ，密度$3.15g/cm^3$
ケイ砂	S	F.M=1.71，密度$2.60g/cm^3$
ポリマー	P	酢酸ﾋﾞﾆﾙ･ﾍﾞｵﾊﾞ･ｱｸﾘﾙ共重合樹脂
混和剤	SP	ﾎﾟﾘｶﾙﾎﾞﾝ酸系粉末高性能減水剤
消泡剤	DA	ﾎﾟﾘｴｰﾃﾙ系粉末型消泡剤

表－２　ＰＭＭの配合

No	W/C (%)	P/C (%)	単位量(kg/m^3)				(C*%)	
			W	C	P	S	SP	DA
NCM	38	0	233	614	0	1227	0.1	0.2
P5		5			31	1147		
P10		10			61	1069		
P20		20			123	907		

表－３　吹付け直後から材齢 28 日間の暴露条件

条件名	記号	詳細
封緘	S	ビニール袋に入れて水分蒸発を防ぐ
気乾	D	試験体周辺に囲いを立て、風を防ぐ
風環境	W	試験風洞内で2m/sの風に曝す
水中→気乾	SWD	封緘2日→標準水中5日→気乾21日
封緘→風	SE6	封緘 6 時間　→　風環境
	SE12	封緘 12 時間　→　風環境
	SE24	封緘 24 時間　→　風環境
	SE48	封緘 48 時間　→　風環境

＊20℃、65%RHの恒温恒湿室内で実施

に所要の材料を計量混合して使用した。なお，一般的な断面修復材には有機合成繊維や膨張材等の収縮補償材料が使用されているが，本研究ではこれらは添加せずに検討した。

2.2 試験体作製

練混ぜは，強制攪拌型のモルタルミキサを使用し 5 分間練り混ぜた。試験体の作製は，ポリマーを添加していない NCM は左官工法により，PMM は吹付け工法(吐出量約 $0.1m^3/h$，ノズル径 8mm)で行った。

2.3 暴露条件

表－３に設定した暴露条件を示す。風環境は，条件が特に厳しい地下鉄坑内での補修を想定し 2m/s とした(W)。また，PMM にとって理想的な養生条件として水中養生後，乾燥させる条件を設定し(SWD), さらに実現場を想定して初期のシート養生時間を変化させたものも設定した(SE)。

2.4 試験項目および方法

(1) 水分蒸発量試験

130×130×20mm のアクリル製型枠を使用し，吹付け直後からの質量変化を測定した。なお，この試験は，セメントの代わりに石粉を使用したものも対象とした。

(2) 細孔径分布測定

180×180×20mm のアクリル製型枠を使用し，吹付け後，材齢 28 日まで各条件に暴露し，表面から 10mm までの部分から試料を採取した。試料は 2.5～5mm に粗粉砕し, アセトンで水和を停止した後，D-乾燥してから水銀圧入ポロシメーターで細孔径分布を測定した。なお，測定結果は配合毎に細骨材量が異なることからポリマーセメントペースト当りの有効細孔量に変換した。また，評価は細孔の量を表す有効総細孔量(TPV)と質を表す空隙係数(Zp)で行った。なお，空隙係数とは 50nm よりも大きい細孔 Pb を 50nm よりも小さい細孔 Ps で除した値(Pb/Ps)である[3)]。

(3) Ｘ線回折・示差熱分析

細孔径分布測定用の試料と同じ小片を微粉砕したものを対象とした。X 線回折は Cu-Kα，40kV，40mA の条件で水酸化カルシウム(以下, CH)の反射ピークである $2\theta=18°$ の回折線強度で評価した。一方，熱分析は，同様の試料を対象として CH の脱水現象が起こる 400℃付近のピーク面積 PA_{DTA} により評価を行った[4)]。

(4) 促進中性化試験

中性化試験は，40×40×160mm の試験体を対象とした。試験体は，脱型後，直ちに打設面以外の 5 面をシールし，材齢 28 日まで各条件に暴露した。その後，20℃，60%RH，$CO_2$10%の中性化促進試験槽に移動し促進材齢 28 日(材齢 56 日)においてフェノールフタレイン法により中性化深さを測定した。

3. PMM の詳細分析に基づく硬化モデルの構築

3.1　PMM 中のポリマーの被膜化

図－１に PMM および石粉を使用した場合(Lm)の D および W 環境での経過時間と質量減少量の関係を示す。一般に乾燥を受ける水性塗料などは，時間当たりの蒸発量が一定となる恒率

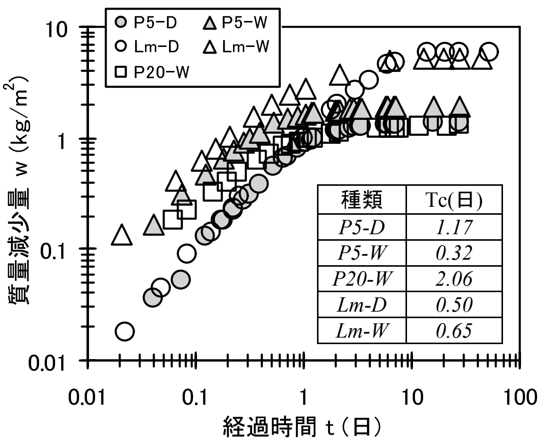
乾燥域と時間当たりの蒸発量が徐々に少なくなる減率乾燥域が存在すると言われている[5)]。これを参考とし本研究では，この恒率乾燥域の終点を表面部分でのポリマーの見掛けの被膜形成点であるとした(図中, 測定結果の変曲点=被膜形成時間 Tc)。

P5 の W 環境の Tc が 0.3 日程度であったのに対し，徐々に水分が逸散する D 環境では 1.2 日程度と長くなった。また，石粉を使用した場合とセメントを使用した PMM を比較すると D 環境では Tc に差があったが, W 環境ではその差は少なかった。つまり，初期に急激な乾燥を受ける環境では，被膜化に及ぼすセメントの水和の影響は少ないと言える。このことから水分の蒸発に伴って表面方向に移動するポリマー粒子は急激な乾燥を受ける W 環境の方が D 環境よりも自由に動き，より多くの粒子が移動して互いの距離を小さくし被膜は密実化するものと考えられた。しかし，W 環境においても Tc はセメントの凝結時間を越えており強度や耐久性に影響を及ぼしている可能性が高いと考えられた。

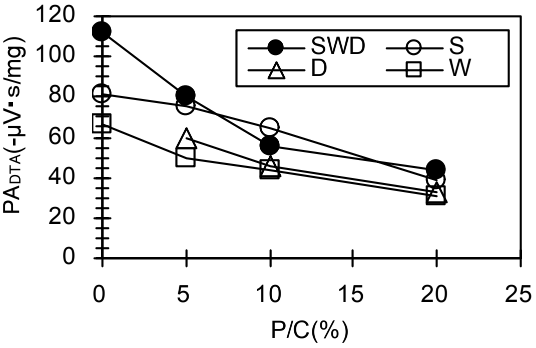
3.2　PMM 中のセメントの水和

図－２は各種環境条件における P/C とセメントの水和の指標となる PA_{DTA} の値を示したものである。PMM は乾燥条件が厳しくなるに従い水和に必要な水分が逸散することからセメントの水和の進行が抑制される傾向にあった。例えば, P10 の条件で S 環境を基準とすると D 環境では 71%, W 環境では 67%の水和率となった。一方, P/C の影響であるが，P/C が高くなるに従いセメントの水和は阻害される傾向にあり既往の研究とも一致した結果となった[6)7)]。これを定量的に評価してみる。

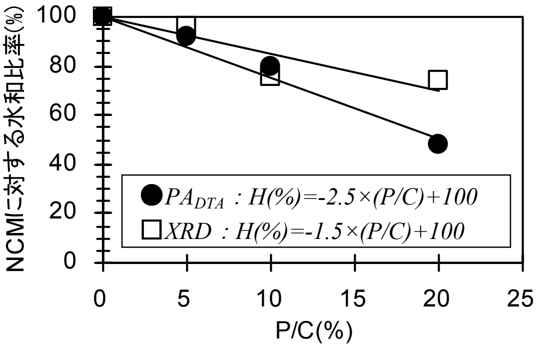
図－３は S 環境における P/C と NCM に対するセメントの水和比率を示したものである。この図に示すように P/C が 1%増加すると PA_{DTA}, XRD とで求めた結果の平均では，セメントの水和は 2%程度阻害されることがわかった。



図－１　経過時間と質量減少量の関係



図－２　Ｐ／ＣとＰＡＤＴＡの関係



図－３　Ｐ／Ｃとセメント水和率の関係

3.3　PMM の細孔構造

PMM の細孔構造はセメントの水和とポリマー被膜化が大きく影響していると考えられる。**図－４**に各種環境条件における TPV を，**図－５**に同じく Zp を示す。SWD および S 環境ではいずれの P/C でも細孔構造の大きな違いは認められなかった。一方，D 環境および W 環境ではいずれの配合でも細孔構造は粗大化する傾向にあり，特に，P5 は Zp が大きくなり細孔構造は粗大化していた。しかし，P/C が高い場合には乾燥

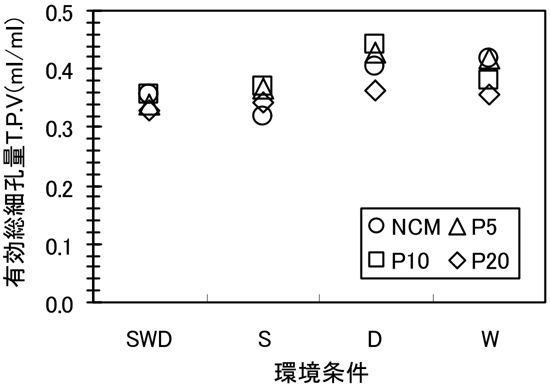
条件でTPVおよびZpともに低い値を示し，細孔構造は緻密化していた。前述のとおりPMM中のポリマーはセメントの水和を阻害する働きを持っている。しかし，高P/Cの条件で組織が緻密化したことから，これはセメントの水和によるものではなく，ポリマーの被膜充填効果によるものと考えられた。さらに**図－６**に既往の研究を参考としてPMM中のインクボトル細孔以外の部分を連続した状態にあるとして算出した連続空隙率を示す[8]。P/Cが高くなるに従い細孔の連続性は低下しており，ポリマーの添加は劣化因子の侵入抑制効果にも大きな影響を及ぼしているものと考えられた。

3.4 PMMの硬化モデルの構築

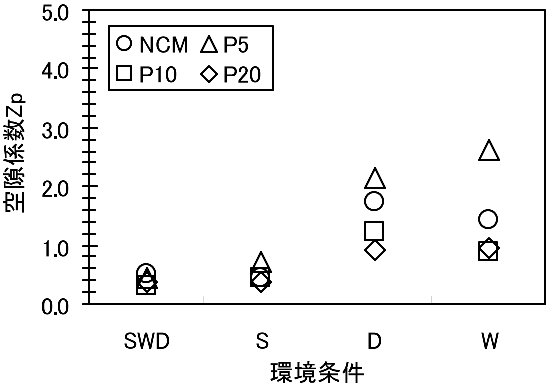
一般的にPMM中のポリマーとセメントには相互作用(インタラクション効果)があると言われている[5]。しかし, これは極僅かであると考え, 本研究ではこれを考慮せずに硬化モデルの構築を試みる。まず，既に定量化したポリマーの被膜化に及ぼす環境影響程度およびポリマー添加によるセメントの水和に及ぼす影響はモデル化に際して設定可能である。一方，不足した情報は練混ぜ直後からの水和の進行程度などであり，これは既往の研究を参考としC_3Sの水和率を指標として算定した[9]。その他，セメントを見掛け上，二次元配置された円形とし，ポリマー粒子の大きさはセメントの1/5，P/C=10%，W/C=38%とし，セメントが完全水和すると2倍の大きさになると仮定した[10)11]。

表－４にP10の各環境条件下における水和生成物層および未水和層の大きさを示す。これをを基に構築したD環境およびW環境下でのPMMの硬化モデルを**図－７**に示す。このモデルは乾燥を受ける表面部のポリマー粒子の移動と粒子相互の接着-融着-被膜化およびセメントの水和進行の状況をモデル化したものである[12]。

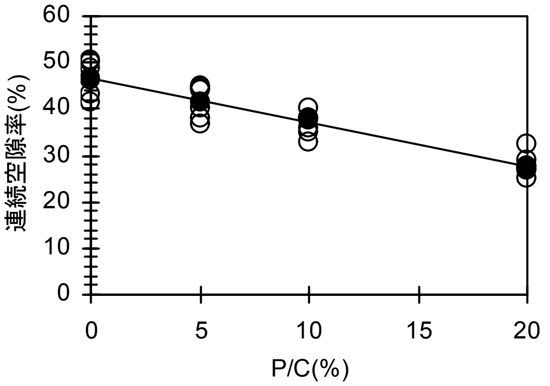
本モデルは実環境に暴露されたPMMの状態を示しており，以降でポリマーの被膜化を表現した本モデルの妥当性を評価するための検討として，中性化に着目した考察を行う。



図－４　環境条件別の有効総細孔量



図－５　環境条件別の空隙係数

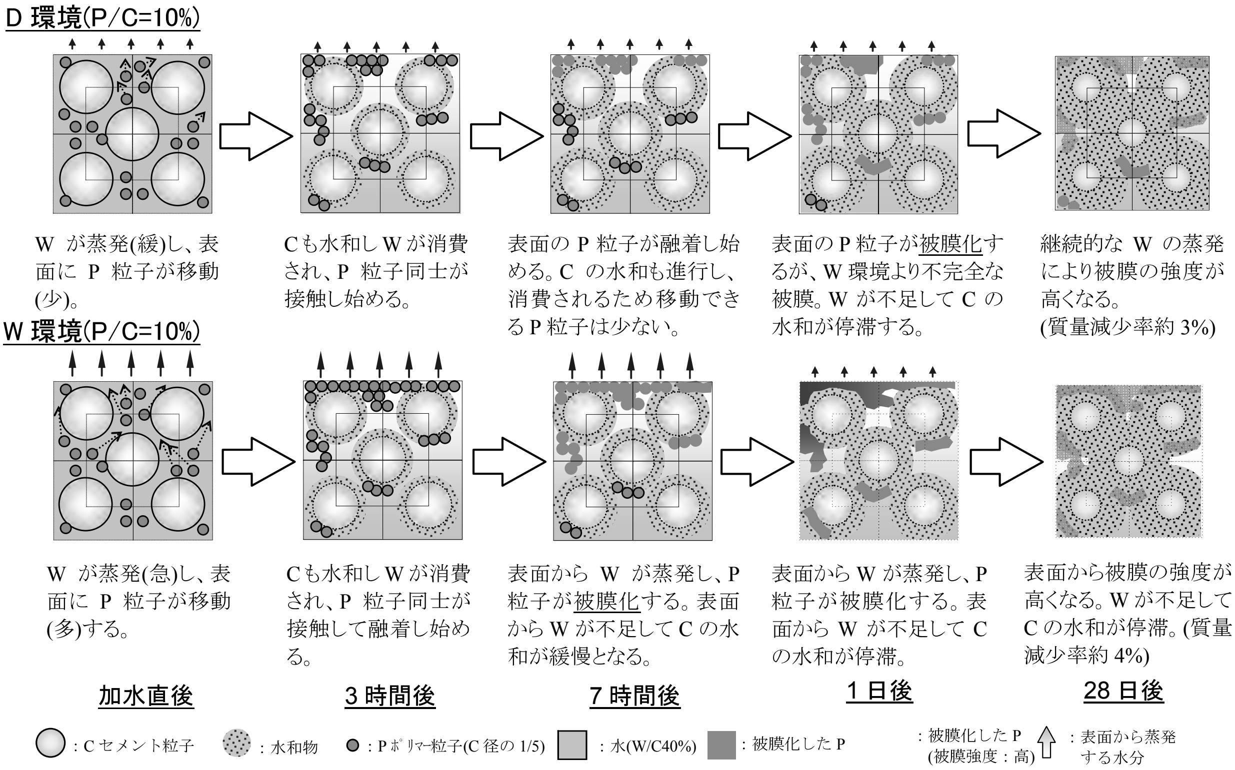


図－６　Ｐ／Ｃと連続空隙率の関係

表－４　ＰＭＭ中のセメントの水和進行状況

経過時間	C_3S水和率(%)	P10 水和生成物層			P10 未水和層		
		S	D	W	S	D	W
加水後	0	1.00	1.00	1.00	1.00	1.00	1.00
3時間	31	1.25	1.18	1.17	0.80	0.86	0.87
7時間	41	1.33	1.23	1.22	0.74	0.81	0.82
1日	58	1.46	1.33	1.31	0.63	0.74	0.75
28日	100	1.80	1.57	1.54	0.36	0.55	0.57

・加水直後のセメント粒子の大きさを1.00とした。
・材齢28日のC_3Sの水和率を100%とした。
・D環境の水和率71%, W環境67%とした。
・P/C10%で−20%の水和率とした。



W が蒸発(緩)し、表面に P 粒子が移動(少)。

C も水和し W が消費され、P 粒子同士が接触し始める。

表面の P 粒子が融着し始める。C の水和も進行し、消費されるため移動できる P 粒子は少ない。

表面の P 粒子が被膜化するが、W 環境より不完全な被膜。W が不足して C の水和が停滞する。

継続的な W の蒸発により被膜の強度が高くなる。(質量減少率約 3%)

W が蒸発(急)し、表面に P 粒子が移動(多)する。

C も水和し W が消費され、P 粒子同士が接触して融着し始める。

表面から W が蒸発し、P 粒子が被膜化する。表面から W が不足して C の水和が緩慢となる。

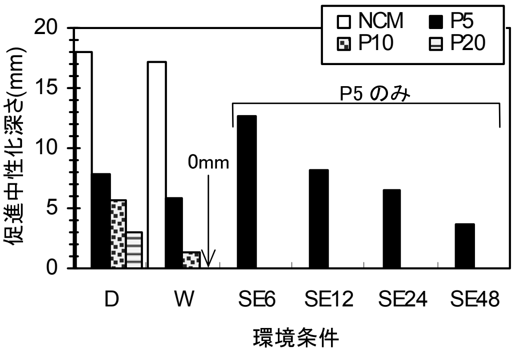
表面から W が蒸発し、P 粒子が被膜化する。表面から W が不足して C の水和が停滞。

表面から被膜の強度が高くなる。W が不足して C の水和が停滞。(質量減少率約 4%)

図－７　実環境からの影響を考慮したＰＭＭの硬化モデル

4. 中性化試験結果に基づく硬化モデルの検証

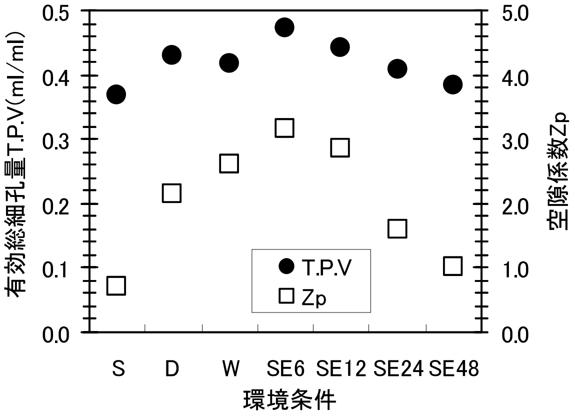
図－８に各環境条件別の促進中性化深さを示す。なお, S 環境ではいずれの条件でも中性化は進行しなかった。D および W 環境ではポリマーを添加していない NCM は中性化に対する抵抗が低くなった。PMM では P/C が高くなるに従い, 空隙の連続性を低下させることなどポリマー添加の効果により中性化の進行は抑制される傾向にあり, P5 でも相当の抑制効果が発揮されていた。一方, P5 のみであるが実現場を想定した条件(SE)では, 初期の数時間だけシート養生することにより中性化に対する抵抗性が低くなり, **図－９**に示す TPV および Zp の値からも細孔構造が粗大化していたことが伺える。この中性化に関する試験結果を前述の硬化モデルにより考察する。例えば, SE6 であるが, この初期の数時間はセメントの物性に大きく影響する凝結時間に相当する。この間, シート養生したことによりセメントの水和はある程度進行したと考えられる。前述**表－４**の C_3S の水和率では約 40%進行したことになる。その状況から風に曝され表面から水分が蒸発すると, 硬化体中の水分の移動(蒸発)は緩慢となり, 同様にポリマー粒子の表面への移動も少なくなると考えられる。結果として表面部の被膜は不完全なものとなり, さらに蒸発しやすく必要な水分が不足することからセメントの水和も阻害されると考えられる。



図－８　環境条件別の促進中性化深さ

つまり, 前述の硬化モデルで示した水分蒸発速度の速い W 環境よりも水分蒸発速度の遅い D 環境で表面部の被膜の密実性が低くなったとしたことと一致した結果を得ることができた。

一方, 実現場では, **図－９**より SE48 が S 環境とほぼ同等の細孔構造となったことから, 初期の 2 日間程度水分蒸発を抑制することが耐久性確保の面から重要であると考えられた。



図－９　環境条件別の有効総細孔量と空隙係数

5. まとめ

本研究では，限られた材料を対象としているが，PMM 系断面修復材の環境影響について検討した。本研究で得られた主な知見を以下に示す。

1)施工直後の PMM 表面からの水分蒸発速度が速いほどより多くのポリマー粒子が表面に移動して密実な被膜を形成すると考えられた。

2)乾燥条件が厳しくなるに従いセメントの水和は阻害され，また，ポリマー添加率が高くなるに従いセメントの水和は阻害される傾向にあった。定量的には P/C1%につき 2%程度の水和阻害であった。

3)乾燥が進む条件では PMM の細孔構造は粗大化する傾向にあった。一方，P/C が高い場合にはセメントの水和は阻害されるが，ポリマーの充填効果により細孔構造は緻密化し，空隙の連続性も低下する傾向にあった。

4)P/C が高くなるに従い中性化に対する抵抗性は高くなった。しかし，初期の数時間だけ封緘養生した場合や徐々に乾燥が進む条件では水分の移動が緩慢となり，移動できるポリマー量も少なく被膜は不完全なものとなる可能性が考えられた。現場においては 2 日間程度の封緘養生が必要であると考えられる。

5)実験により定量化したデータを基に実環境下における PMM の硬化モデルを提案した。さらに，耐久性試験結果からこのモデルの妥当性をある程度検証することができた。

以上の結果より，実環境下において断面修復後，セメントの水和を促すような養生ができない場合，高 P/C の膜養生剤を散布することは耐久性確保の観点などから必要な対策であると考えられた。

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論文　ポータブル型蛍光Ｘ線分析装置を用いたコンクリートの分析

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要旨：コンクリートの分析を行う場合，その用途や検出対象成分により様々な分析手法が用いられている。しかし，これらの分析手法のほとんどが，試験室据置型の分析装置により行われており，現場において短時間で分析を行ったり，コンクリート構造物を直接測定することは困難な場合が多い。近年，可搬型の高性能蛍光 X 線分析装置が開発され，オンサイト分析が可能となってきた。これにより，サンプルを試験室に持ち帰る必要が無くなり，測定部を直接，短時間で微破壊的に分析できるため，作業効率の改善やコストの削減が期待できる。ポータブル型蛍光 X 線分析装置のコンクリート分析への適用性を検証し，その有効性を確認した。

キーワード：ポータブル型蛍光 X 線分析装置，オンサイト分析，塩化物量，元素分析

1. はじめに

コンクリート構造物の劣化診断・調査の際，非破壊検査，化学分析・機器分析，モニタリング等が行われている。赤外線サーモグラフィ法，超音波法，レーダー法，打音法，X 線法等の従来の非破壊検査手法は，ひび割れ，はく離・浮き・空隙などの欠陥部の検出，鋼材の検出といったコンクリートの物理的な情報を得るのに有効な検査手法である。しかしながら，コンクリートの中性化や塩化物量等の化学的な情報を得ることはできない。著者らは，次世代型非接触・非破壊検査手法の構築を目指し，劣化因子を効率良く検出できる検査システムの開発を行っている。分光技術を応用した劣化調査手法の開発 1)もその一例で，劣化因子の検出，濃度推定，分布状況を非接触・非破壊的に短時間で測定することに成功している。今後，維持・管理が必要となる構造物が増えていく中，従来の検査手法では限界があり，オンサイト分析による作業性の向上が重要となってくる。

蛍光 X 線分析は新しい技術ではなく，元素分析の一手法として用いられている。軽元素よりも重元素の分析に適しており，検出される蛍光X線の波長から元素を特定でき，X 線の強度から元素を定量できる。コンクリート関連では，セメントの蛍光 X 線分析方法 2)が JIS 化されており，ig.loss，SiO_2，Al_2O_3，Fe_2O_3 等の定量分析について記述されている。実構造物の硬化コンクリートをサンプルとして採取し，劣化物質を定量分析することも可能であるが，試験室で測定することを考えると，他の分析手法と比較しても利点は少ない。従来の装置は試験室据置型で，装置内部に試料をセットする必要があり，大型・異形試料を測定することはできなかった。しかし，近年，小型で可搬型の高性能蛍光 X 線分析装置が開発され，オンサイト分析が可能となってきた。測定対象を直接，微破壊的に分析できるため，コンクリート構造物の調査に適用すれば，非常に有効な検査手法となる。

今回は，現場におけるコンクリート中の塩化物量測定の可否を検証することを主眼におき，実験を行った。その結果，蛍光 X 線分析法により，精度良く分析できることを確認した。

2. 蛍光 X 線分析

2.1 蛍光 X 線分析の原理

X 線を試料に照射したとき，試料から発生する蛍光 X 線を検出・分光して元素分析を行う方法を蛍光 X 線分析という。蛍光 X 線は，試料を構成する元素固有の波長(エネルギー)を持つので，簡単に定性

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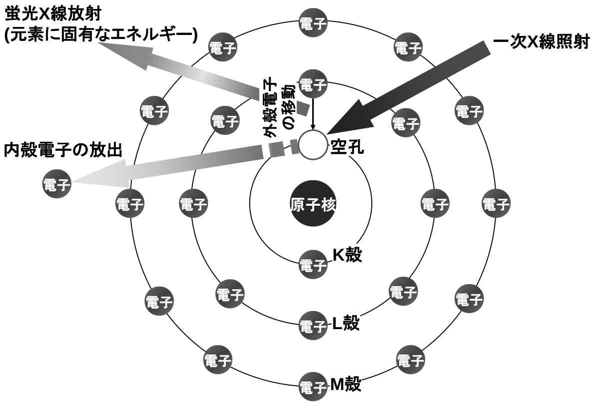
分析ができ，各スペクトルの強度から定量分析ができる 3)。



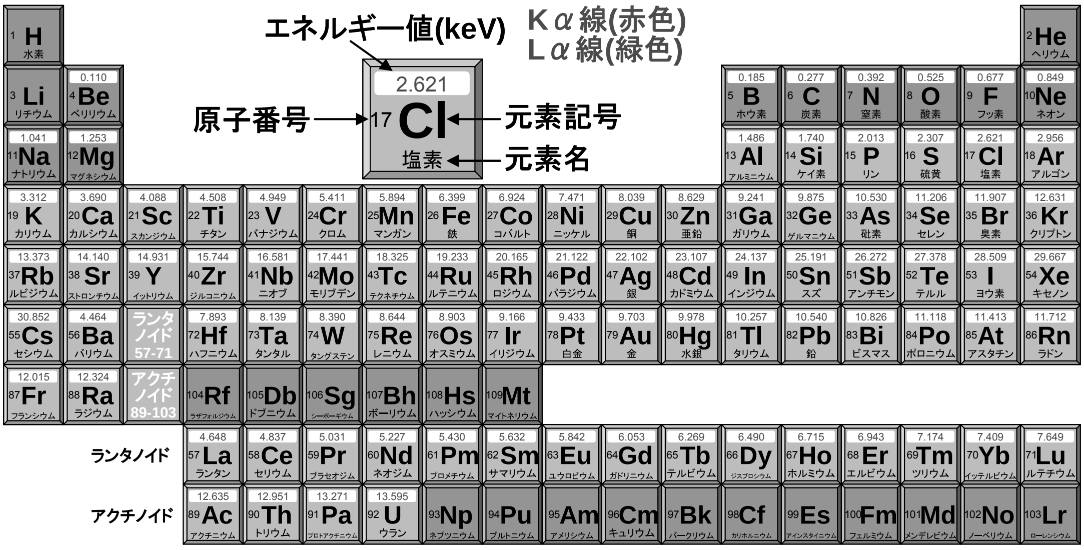
図−1 蛍光 X 線放射の原理

図−1 に蛍光 X 線放射の原理を示す。原子に X 線(一次 X 線)を照射すると，一部の内殻軌道の電子が励起されて外殻にはじき出される。内殻軌道に空間が生じると原子が不安定になるので，空いた空間(空孔)を埋めるために，外殻電子が落ち込んでくる。外殻電子はエネルギーが高い状態ではエネルギーが低い内殻軌道を回ることができないため，その差に当たるエネルギー差が蛍光Ｘ線（二次Ｘ線）として放射される。蛍光 X 線のスペクトルは各元素固有であり，その強度は試料中の元素濃度に比例する。

K 殻の電子が放出されて L 殻の電子が落ちてくるときの蛍光 X 線を Kα線，L 殻の電子が放出されて M 殻の電子が落ちてくるときの蛍光 X 線を Lα線と呼び，**図−2** に示すとおり，元素ごとに固有のエネルギー値を持っている。二(三)つ外側の殻からの電子が落ちてくるときの蛍光 X 線はβ(γ)線と定義されている。K 殻の電子をはじき出すのに一番大きな励起エネルギーを必要とし，また，原子番号が大きくなると，陽子が電子を引きつけている力が大きいため，より大きな励起エネルギーが必要となる。したがって X 線管球の特性にも依存するが，原子番号の大きい元素を測定するには，Kα線ではなく Lα線を用いる。励起エネルギーは，電子を外まではじき出すエネルギーであるから，外殻から落ち込んでくる際に放出される蛍光 X 線より高い必要がある。励起できる下限のエネルギーより低い X 線を強く放射しても励起は起こらない。励起に必要な最低のエネルギーを吸収端エネルギーという。

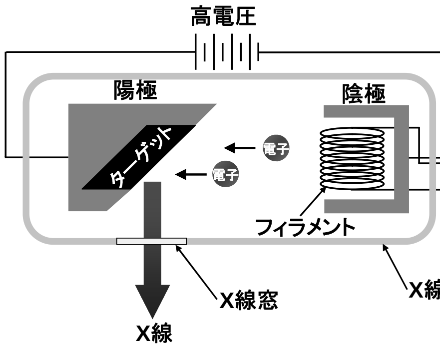
2.2 X 線管の原理

元素を励起するための一次Ｘ線はＸ線管で発生させる。X 線管は**図−3** のように陽極(ターゲット金属)と陰極を持っている。真空管内のフィラメントは，電流により加熱され，熱電子を放出する。陽極に高電圧を加えると熱電子はこの電圧により加速され，金属ターゲットに衝突する。そのとき失われる運動エネルギーのほとんど(99%超)は熱に変換され，一部は X 線の形で放射される(制動放射・連続 X 線)。また，その一部の電子はターゲット原子の電子を追い出すことにより X 線の形で放出しエネルギーを失う(特性 X 線)。この特性 X 線は原子に固有なエネルギーをもち，原子番号が高ければそのエネルギーも



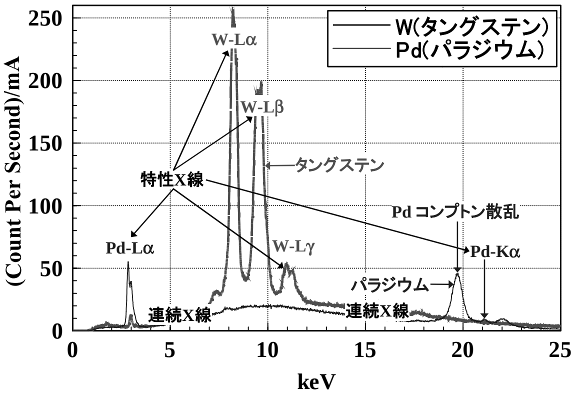
1 H 水素																	2 He ヘリウム
3 Li リチウム	0.110 4 Be ベリリウム											0.185 5 B ホウ素	0.277 6 C 炭素	0.392 7 N 窒素	0.525 8 O 酸素	0.677 9 F フッ素	0.849 10 Ne ネオン
1.041 11 Na ナトリウム	1.253 12 Mg マグネシウム											1.486 13 Al アルミニウム	1.740 14 Si ケイ素	2.013 15 P リン	2.307 16 S 硫黄	2.621 17 Cl 塩素	2.956 18 Ar アルゴン
3.312 19 K カリウム	3.690 20 Ca カルシウム	4.088 21 Sc スカンジウム	4.508 22 Ti チタン	4.949 23 V バナジウム	5.411 24 Cr クロム	5.894 25 Mn マンガン	6.399 26 Fe 鉄	6.924 27 Co コバルト	7.471 28 Ni ニッケル	8.039 29 Cu 銅	8.629 30 Zn 亜鉛	9.241 31 Ga ガリウム	9.875 32 Ge ゲルマニウム	10.530 33 As 砒素	11.206 34 Se セレン	11.907 35 Br 臭素	12.631 36 Kr クリプトン
13.373 37 Rb ルビジウム	14.140 38 Sr ストロンチウム	14.931 39 Y イットリウム	15.744 40 Zr ジルコニウム	16.581 41 Nb ニオブ	17.441 42 Mo モリブデン	18.325 43 Tc テクネチウム	19.233 44 Ru ルテニウム	20.165 45 Rh ロジウム	21.122 46 Pd パラジウム	22.102 47 Ag 銀	23.107 48 Cd カドミウム	24.137 49 In インジウム	25.191 50 Sn スズ	26.272 51 Sb アンチモン	27.378 52 Te テルル	28.509 53 I ヨウ素	29.667 54 Xe キセノン
30.852 55 Cs セシウム	4.464 56 Ba バリウム	ランタノイド 57-71	7.893 72 Hf ハフニウム	8.139 73 Ta タンタル	8.390 74 W タングステン	8.644 75 Re レニウム	8.903 76 Os オスミウム	9.166 77 Ir イリジウム	9.433 78 Pt 白金	9.703 79 Au 金	9.978 80 Hg 水銀	10.257 81 Tl タリウム	10.540 82 Pb 鉛	10.826 83 Bi ビスマス	11.118 84 Po ポロニウム	11.413 85 At アスタチン	11.712 86 Rn ラドン
12.015 87 Fr フランシウム	12.324 88 Ra ラジウム	アクチノイド 89-103	104 Rf ラザフォルジウム	105 Db ドブニウム	106 Sg シーボーギウム	107 Bh ボーリウム	108 Hs ハッシウム	109 Mt マイトネリウム									
		ランタノイド	4.648 57 La ランタン	4.837 58 Ce セリウム	5.031 59 Pr プラセオジム	5.227 60 Nd ネオジム	5.430 61 Pm プロメチウム	5.632 62 Sm サマリウム	5.842 63 Eu ユウロビウム	6.053 64 Gd ガドリニウム	6.269 65 Tb テルビウム	6.490 66 Dy ジスプロシウム	6.715 67 Ho ホルミウム	6.943 68 Er エルビウム	7.174 69 Tm ツリウム	7.409 70 Yb イッテルビウム	7.649 71 Lu ルテチウム
		アクチノイド	12.635 89 Ac アクチニウム	12.951 90 Th トリウム	13.271 91 Pa プロトアクチニウム	13.595 92 U ウラン	93 Np ネプツニウム	94 Pu プルトニウム	95 Am アメリシウム	96 Cm キュリウム	97 Bk バークリウム	98 Cf カリホルニウム	99 Es アインスタイニウム	100 Fm フェルミウム	101 Md メンデレビウム	102 No ノーベリウム	103 Lr ローレンシウム

図−2 各元素のエネルギー値(keV)4)

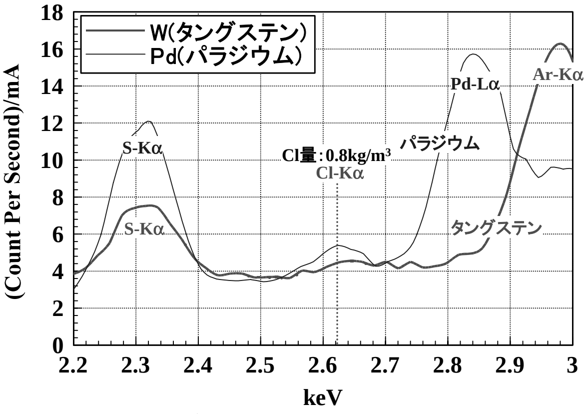


図–3 X線管の模式図

高くなる。ターゲット金属として，タングステン，パラジウム，ロジウム，モリブデン，クロムなどが用いられている。これらのターゲットは，分析する元素によって使い分ける。分析対象元素と同種のターゲットをもつX線管は，照射される一次X線と，試料から放射される蛍光 X 線が重なるため原則的に使用しない。また試料中に含まれる元素の種類により，特性 X 線のエネルギー位置が近接している場合は干渉し，試料の蛍光X線と重なる。元素の特性X線は，多くの場合一つだけではなくKα線、Kβ線…，Lα線，Lβ線…というように複数個存在するので注意が必要である。**図–4** は例としてパラジウムとタングステンをターゲットとした場合のX線特性を示したものである。



図–4 一次X線の特性（ターゲット：W，Pd）



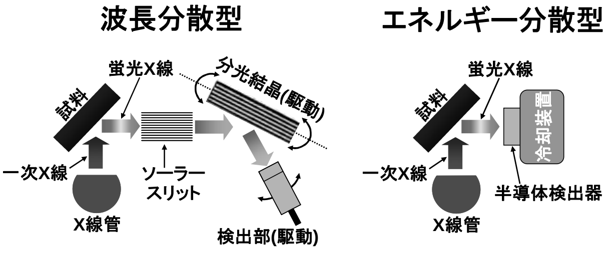
図–5 ターゲット種別 Cl の励起効率の比較

図–2に示すとおり，Clの検出にはCl-Kα線(2.621 keV：キロ電子ボルト)を用いる。パラジウムをターゲットとして用いた場合，Pd-Lα線(2.838 keV)と近接しているため，Cl の励起効率が高く，タングステンをターゲットとして用いた場合と比較して Cl 量が微量な場合でも Cl-Kα線が明確にあらわれる(**図–5**)。

タングステンをターゲットとして用いた場合，原子番号が大きいため他の材質の X 線管に比べ，連続 X 線の発生効率が高いという特徴があるが，タングステンの連続 X 線より Pd-Lα線で Cl を励起させた方が励起効率は高い。

2.3 蛍光X線分析装置の種類

蛍光X線分析法の方式には、分光結晶を用いた波長分散型(WDXRF)と半導体検出器(EDS)を用いたエネルギー分散型(EDXRF)がある(**図–6**)。



図–6 蛍光X線分析装置の種類

波長分散型は，試料から発生した蛍光 X 線を分光結晶によって分光し，これをゴニオメータで計測するものである。波長分解能に優れ，検出感度が高いという利点があるが，駆動系を組み込むため装置が大型で複雑になり，オンサイト分析には不向きである。エネルギー分散型は，試料から出る蛍光X線を直接，半導体検出器で検出した後に波高分析器で電気的に分光し，蛍光X線スペクトルの波長を求めて元素を特定する方法である。波長分散型と比較し，波長分解能や検出感度は劣るが，多数の元素を同時に分析することができ，短時間での分析が可能となる。波長分散型に比べ安価で装置が小型化できるため，オンサイト分析に適している。

2.4 X線フィルタの選択

バックグラウンドの低減，妨害 X 線の除去のために X 線フィルタを用いる。X 線フィルタの材質は，ターゲットと分析対象元素にあわせて選択し，注目す

る元素のピーク以外の干渉要因を取り除くのが目的である。**図-7** にフィルタの材質による蛍光 X 線スペクトルの変化を示す。

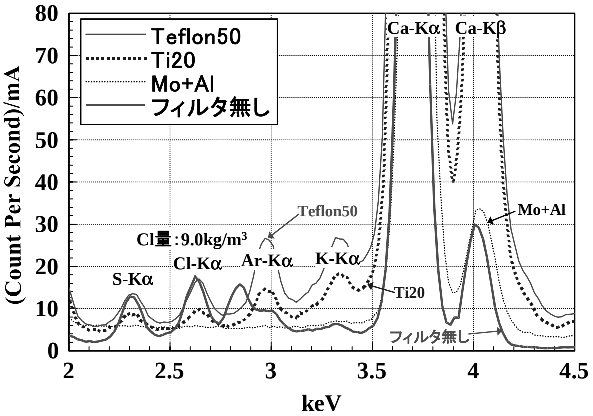


図-7 フィルタの材質によるスペクトルの変化

Teflon50 は S, Cl, Al 付近のバックグラウンドを落として S, Cl, Al の検出効率を高めるために使用し, Ti20 は Cr 付近のバックグラウンドを落として Cr の検出効率を高めるために使用し, Mo+Al は不要な軽元素部の連続 X 線をカットして Cd 付近のバックグラウンドを落として Cd の検出効率を高めるために使用する。しかし, 軽元素は, 低いエネルギーで励起するため, フィルタを使用しない方が Cl の励起効率が高いことがわかる。

3. 蛍光 X 線分析による塩化物量の測定

3.1 装置設定

前述のように, コンクリート中の塩化物量を蛍光 X 線分析で測定するには, Cl-Kα線を用いる。したがって, 試料から放射される 2.621 keV の光子数を高精度で検出できる装置設定が要求される。**図-6, 7** の結果から, ターゲットにパラジウム, X 線フィルタは使用せずに測定を行った。

表-1 配合表

W/C	セメントの種類		
40%	普通ポルトランドセメント		
塩化物混入量(kg/m^3) [重量比%]			
No.	塩化分量	No.	塩化分量
N40-0	無混入	N40-3.0	3.0 [0.154]
N40-0.4	0.4 [0.021]	N40-6.0	6.0 [0.308]
N40-0.6	0.6 [0.031]	N40-9.0	9.0 [0.462]
N40-0.8	0.8 [0.041]	N40-12.0	12.0 [0.615]
N40-1.0	1.0 [0.051]	N40-15.0	15.0 [0.769]
N40-1.2	1.2 [0.062]	N40-20.0	20.0 [1.025]
N40-1.5	1.5 [0.077]		

3.2 測定条件

測定サンプルは, **表-1** のようにセメントペースト供試体で, 練混ぜ水の中に塩化ナトリウムを混入した。供試体作製時には, 塩化物濃度が不均一にならぬよう材料分離に注意し, 封かん養生を行った。実験パラメータとして, X 線管の電圧, 焦点距離, 測定時間を変化させ, 測定結果にどのように変化するかを検証した(**表-2**)。

表-2 測定条件

ターゲット材質		X 線フィルタ
パラジウム		無し
X 線管電圧	焦点距離	測定時間(秒)
6〜9kV	0〜7mm	30, 60, 120, 180

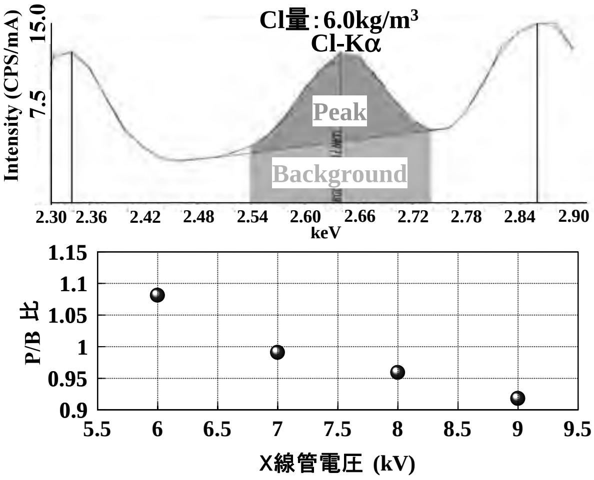


図-8 X 線管電圧と P/B 比

図-8 に X 線管電圧と P/B 比(ピークとバックグラウンドの面積比)の関係を示す。電圧を上げると P/B 比が低くなるため, 低い電圧で P/B 比の良い測定を行った。**図-9** は, X 線の焦点距離から, 測定面を離した場合, 蛍光 X 線の強度がどの程度低下するか

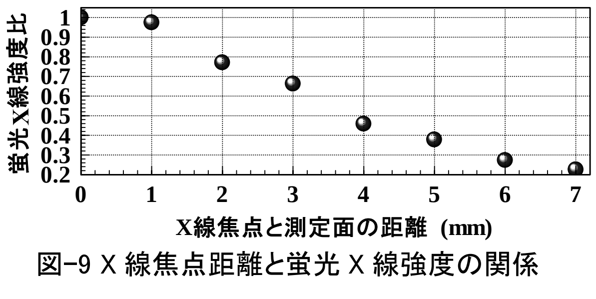
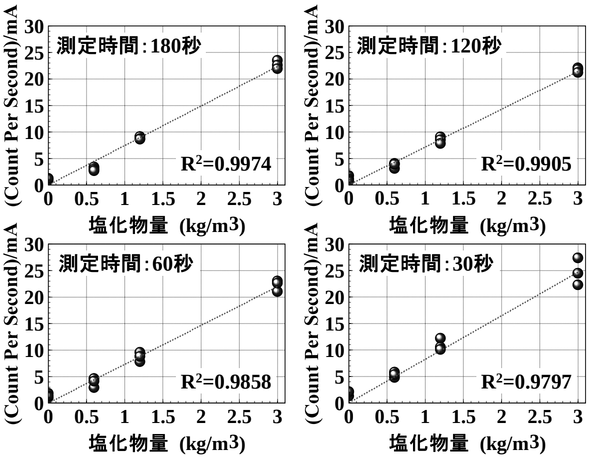


図-9 X 線焦点距離と蛍光 X 線強度の関係

を示したものである。X 線の焦点と測定面が離れると，空気層による減衰が大きくなり，4mm で半分以下になり，7mm 離れると 2 割に低減する。**図−10** は測定時間で Cl-Kα線(2.621 keV)のカウントがどの程度ばらつくかを示したものである。測定時間が 30 秒と短い場合は，測定結果の変動が大きく，120 秒以上では，安定した測定結果が得られた。

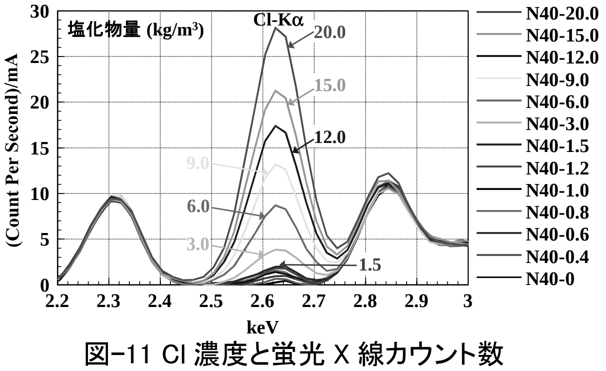


図−10 測定時間によるばらつき

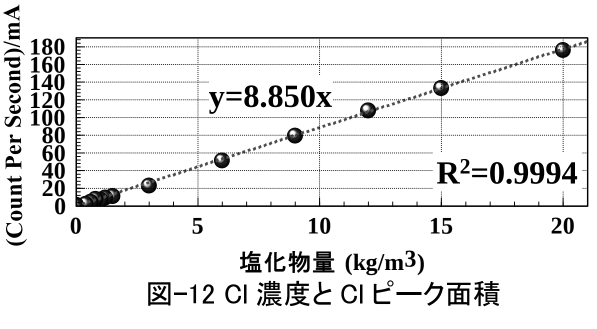
3.3 検量線の作成

図−11 のように試料の塩化物量が増えると，2.621 keV のカウント数が増えることが確認できる。ここで，定量分析を行うために，Cl の検量線を作成する。測定条件は，**図 7〜10** の結果から，X 線フィルタ無し，X 線管電圧 6kV，焦点距離 0mm，測定時間 180 秒に設定した。**図−12** に示すとおり，2.621 keV におけるカウント数(**図−8** 上図のようにピーク面積とする)と塩化物量に高い相関関係があることが確認できる。

よって，Cl ピーク面積を検量線に代入することにより，未知試料の塩化物量が推定できる。



図−11 Cl 濃度と蛍光 X 線カウント数



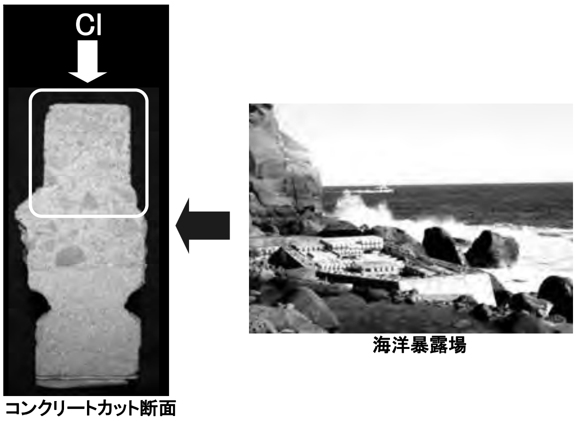
図−12 Cl 濃度と Cl ピーク面積

4. 現場計測への応用

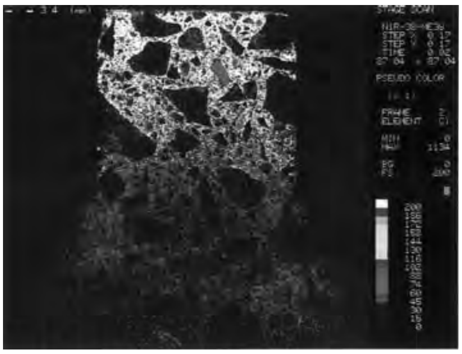
4.1 塩化物浸透深さの測定

実際のコンクリート構造物の塩化物量の測定は，ドリル粉やコアコンクリートを採取し，電位差滴定や EPMA による分析が行われている。ポータブル型蛍光 X 線分析装置により，ドリル粉(1g 程度で測定が可能)やコアコンクリートを直接測定すれば，現場で短時間に塩化物量の定量が可能となる。そこで，海洋暴露供試体の塩分浸透深さの測定を試みた。測定試料は，**写真−1** のように海洋暴露場で暴露されたコンクリート供試体をカットしたものを用いた。断面を EPMA で分析した結果が**図−13** である。

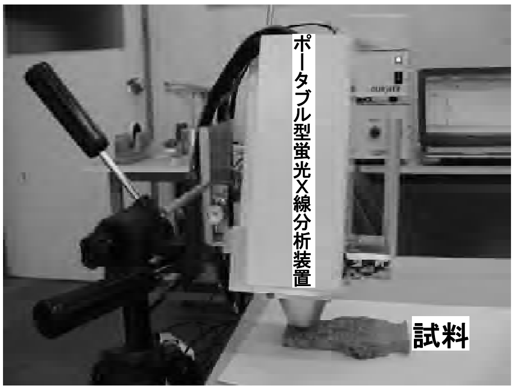
暴露面から Cl が浸透していることが確認できる。断面の蛍光 X 線分析は，**写真−2** のようにポータブル型蛍光 X 線分析装置の検出部を測定面に設定することで可能となる。



写真−1 海洋暴露状況と供試体断面

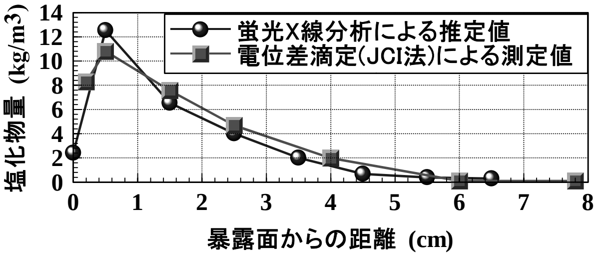


図−13 EPMA の結果（Cl の分布）



写真−2 ポータブル型蛍光 X 線分析による測定

任意の深さにおいて，骨材以外の部分の 3 点を測定部として選択し，平均値をその深さの値とした。**図−14** は，測定された蛍光 X 線スペクトルを検量線に代入し推定された塩化物量と，同じ供試体を電位差滴定(JCI 法)で測定したものをプロットした結果である。

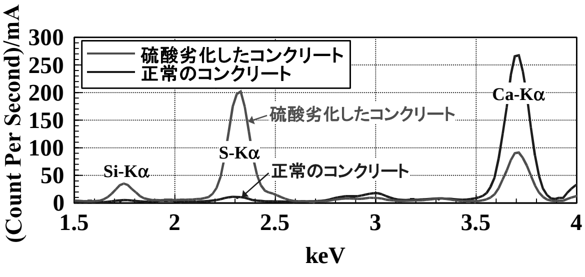


図−14 暴露面からの塩化物量分布

従来手法と比較し，同じ傾向を示していることが確認できる。電位差滴定法と比較し，試料の調整も必要無く，微破壊的に測定できるため，測定時間が大幅に短縮され，現場での計測も可能となる。しかし，現装置では X 線の照射径(3mm)が小さく，細骨材も避けて測定する必要があるため，実用化するためには，照射径の拡大の検討が必要である。

4.2 元素分析への応用

現在主流となっているエネルギー分散型蛍光 X 線分析装置の測定可能元素は $_{12}$Mg～$_{92}$U である。コンクリート中の Cl 以外の元素，例えば，Mg, Al, Si, S, K, Ca, Fe 等の分析も可能である。一例として**図−15** に硫酸による劣化を受けたコンクリートの蛍光 X 線スペクトルを示す。正常のコンクリートと比較し，S-Kα(2.307 keV)のカウント数が増加しているのが確認できる。同時に硫酸劣化により，骨材が露出したため，ケイ素のカウントが増え，カルシウムのカウントが減少している。



図−15 硫酸劣化による蛍光 X 線スペクトルの変化

5. 結論

蛍光 X 線分析装置により，コンクリート中の塩化物量が精度よく測定できることが確認された。従来の手法のように，サンプルを採取し，試験室に持ち帰って電位差滴定測定を行うより，測定時間が短縮され，現場で瞬時に結果を得ることができる。したがって，検査効率の向上ならびにコストダウンが可能となる。他の分析手法と比較し，蛍光 X 線分析法は化学薬品を使用せず，測定面の事前処理を必要としないため，微破壊，無公害，低エネルギー，環境負荷の少ない検査手法である。コンクリートの劣化検査への応用が期待される。

謝辞：蛍光 X 線分析の導入にあたりまして，山形大学工学部電気電子工学科の東山禎夫教授に助言をいただきました。また，EPMA の測定ならびに塩分分析は東京大学生産技術研究所の星野富夫氏に，蛍光 X 線分析はアワーズテック株式会社の永井宏樹氏，中嶋佳秀氏に多大なご協力を頂きました。ここに記して感謝の意を表します。

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人口減少社会における活断層対策の展望

目黒公郎* 大原(吉村)美保*

Prospect of active fault countermeasures in depopulating society

Kimiro Meguro* and Miho Yoshimura Ohara*

Abstract

Japan entered a longstanding depopulation process in 2006. The total population after 50 years is expected to decrease to about 70% of the current one. In this situation, it is important to avoid social impact due to disasters by guiding population from vulnerable area to safer area. This research focused the risk of active faults among various kinds of natural hazards and studied on the effect of land use control by active fault zoning in Japan.

First, the meaning of land use control along active faults in the society whose population started to decrease was discussed. If the residences in the seismic vulnerable area are relocated to the safer area by the land use control plan, these vacant lands could be effectively used for disaster-prevention facilities. So far, Japan has not adopted the earthquake fault zoning act due to several reasons, while it has been carried out for 30 years in U.S.. However, considering that more lands will become vacant due to depopulation in the future, the possibility of introducing fault zoning act will increase and the discussion on active fault zoning will become more meaningful.

Then, the distribution of population and buildings in the neighborhood of the active faults was analyzed based on GIS databases of the active faults, population and building stocks. The fault zones were hypothetically set along the active faults. In case of the fault zone whose width was decided to be 0.4km referring to the fault zoning act in U.S., the population inside the fault zone was 2.89 million and it corresponded to 2.3% of the total population in Japan. Half of the population living along the faults was located in Kinki area and the effect of land use control was different according to the region. The population inside the fault zone was increased in proportion to the width of the zone.

Finally, the possibility of active fault zoning in Japan was discussed. Based on the obtained results, we think that it is meaningful and possible to adopt active fault zoning in Japan for earthquake damage reduction. However, the appropriate width of fault zones should be discussed considering all the factors such as lessons learnt from past earthquake damage, uncertainty of the traces of both strike-slip and dip-slip fault, social impact of the zones.

1．はじめに

国立社会保障・人口問題研究所（2006）によれば，わが国は2005年をピークに長期の人口減少過程に入ると予想されている（第１図）．国勢調査による2005年の総人口は１億2,777万人であったが，出生中位推計に基づけば，2055年での総人口は8,993万人にまで減少すると推計され，これは2005年の総人口の約７割に相当する．65歳以上の老年人口の割合は2005年の20.2％から2055年には40.5％になる

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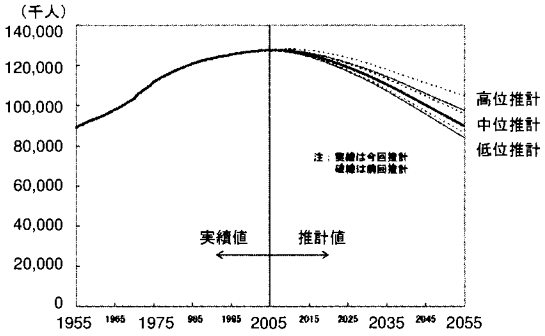


第１図　日本の総人口の推移
（国立社会保障・人口問題研究所，2006）

と予想され，著しい高齢化が懸念されている．人口減少が進むと，既存の住宅ストックが不要となり，空き家率や空地率が上昇すると考えられる．また，経済力が停滞し，災害後に社会を復興させる力も低下するため，いざ大規模災害が発生した場合には、その社会への影響はより大きくなると想定される．このような背景を考えると，今後は，洪水や地震，津波や土砂災害などの危険性の高い地域から安全な立地条件の地域へと長期的な人口誘導を図り，災害による社会的影響を回避することが重要だと考えられる．ここでは，このような人口減少社会における活断層対策についての展望を述べたいと思う．

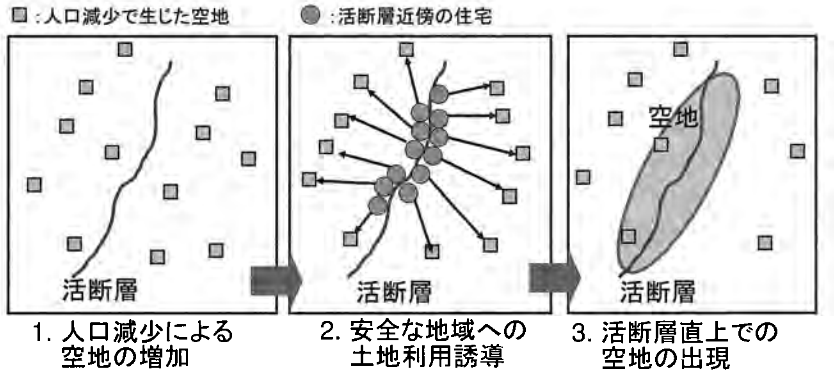
２．活断層近傍での土地利用誘導策の意義

人口減少社会においては，既存の住宅ストックの一部が不要となるため，空き家率や空地率が上昇すると考えられる．これらの空地を利用して，活断層近傍地域から安全な地域へと長期的な人口誘導を図ることにより，最終的には活断層近傍地域を空地化し，これらの土地を公園や備蓄倉庫を備えた防災拠点として利用することが可能になる（第２図）．このような活断層近傍での土地利用誘導策の前例としては，米国カリフォルニア州での断層ゾーニング法があり，断層ゾーン内での土地利用規制や不動産取引時の活断層情報の提供が行われている．この事例では対象となる活断層が主に横ずれ断層であるため，縦ずれ断層の多い我が国とは状況が異なる．しかし，新潟県中越地震や福岡県西方沖地震などの内陸活断層型の地震の多発，活断層調査結果の蓄積，将来的な人口減少などを背景として，我が国においても，活動度の高い既知の活断層周辺からの土地利用規制や市民への情報開示などの事前対策の可能性の議論は検討に値する（吉村・目黒，2004）と考えられる．

活断層近傍で土地利用誘導を行うにあたっては，第１表のような施策が考えられる．断層近傍域への人口流入を抑制するもの，断層近傍域からの人口流出を促進するもの，および規制・禁止などの直接的な方策，補助・税制・情報開示による間接的な方策という４つである．直接的方策より間接的方策の方が社会的影響は少なく，実現しやすい．活断層情報の周知方法には自治体によるマップの配布などの広報活動もあるが，漏れなく情報を周知するには不動産取引時における重要事項説明制度が有効である．宅地建物取引業法では，宅地建物取引主任者は売買，交換または貸借の契約成立前までに物件取得者に対して重要事項を口頭で説明する義務を負う．2000年に土砂災害防止法（土砂災害警戒区域等における土砂災害防止対策の推進に関する法律）が公布された後は，重要事項として「当該宅地建物が土砂災害警戒区域か否か」も説明するよう義務付けられている．現行制度では活断層に関する情報提示の義務はないが，土砂災害を対象とした制度が実現しているという

第１表　考えられる土地利用誘導策

	直接的方策	間接的方策
流入の抑制	・新築の規制＊ ・新築の禁止	・新築時の手続きに関する増税 ・既存建物の固定資産税・住民税等の増税 ・売買時の重要事項説明の義務付け＊ ・賃貸契約時の重要事項説明の義務付け ・活断層情報の広報＊
流出の促進	・既存建物の強制移転 ・増改築の規制＊ ・増改築の禁止 ・賃貸契約の規制 ・賃貸契約の禁止	・移転への補助 ・移転後の税制優遇措置 ・既存建物の固定資産税・住民税等の増税 ・売買時の重要事項説明の義務付け＊ ・賃貸契約時の重要事項説明の義務付け ・活断層情報の広報＊



1. 人口減少による空地の増加
2. 安全な地域への土地利用誘導
3. 活断層直上での空地の出現

第２図　活断層近傍での土地利用誘導の流れ

点で，活断層に関する重要事項説明の可能性もあると考える．

第1表中に＊印をつけたものは，米国カリフォルニア州で実践されている施策である．カリフォルニア州では，1971年のサンフェルナンド地震により地表面の断層変位で多くの住家が被害を受けたことを教訓として，断層ゾーン法（The Alquist-Priolo Earthquake Fault Zoning Act）を制定した．断層ゾーンは州の地質調査官により活断層の地表痕跡（Surface Trace）の両側に設定されており，ゾーン幅は1／4マイル（0.4km）程度である．自治体は，活断層地表痕跡の直上での新築および大規模増改築に対しては建築許可を与えてはならず，建築前の地質調査で活断層が発見されると、建物を50フィート（15m）セットバックして建設しなければならない．ただし，4戸未満で 2階建て以下の木造または鉄骨造の戸建て住宅は対象外とされる．また，断層ゾーン内に存在している既存の居住建物が売買される際には，売主から買主へと，物件が断層ゾーン内に立地している旨を告知する義務が課されている．1991年には地震ハザードマッピング法（Seismic Hazards Mapping Act）が制定され，地表痕跡が出ていない断層近傍や液状化・土砂崩れ危険地帯も含むハザードゾーンが設定され，これらについても不動産売買時の告知義務が課された．

米国では30年以上にわたり断層ゾーン法が施行されてきたのに対し，わが国で同様の法律が導入されることはなかった．その理由としては下記の点が挙げられる．

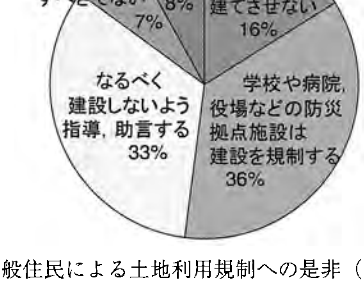
- カリフォルニア州の断層は主として横ずれ断層で地表にも痕跡が出現し，平常時からクリープ現象による建物への影響も生じている．
- 一方，わが国の活断層は縦ずれ断層が多く、断層パターンが複雑なだけでなく，地表面に痕跡が出現していないものも多く，断層の位置情報の不確実性が高い．
- わが国では人口密度が高く，既に活断層直上に居住している人口も多いため，社会的影響が大きい．

これらの経緯から，一般に，わが国において断層ゾーン法を検討することは非現実的であるとの指摘がされがちである．いくつかの自治体のハザードマップに活断層位置が明記され，市民が活断層の位置を知る環境が整備されつつある一方で，活断層情報の周知は現存する建物の不動産価値を低下させ、社会的混乱を招くため非現実的であると懸念する声も多い．しかし，国内における既存事例として，兵庫県西宮市では1995年の「震災に強いまちづくり条例」において，活断層周辺区域におけるマンションや宅地造成等の新規開発時には市から活断層情報を提供することとした．また神奈川県横須賀市では、野比4丁目地区において，地区計画制度をもとに活断層両側での建築を規制している（照本・中林，2007）．中田らは活断層法の必要性を指摘する（中田，1990）とともに，活断層直上に位置する多くの学校施設の危険性を指摘している（中田・隈元，2003）．住民を対象とした危機管理意識に関する調査（川西，2006）では，活断層近傍での何らかの規制や指導を望む声が85%に上り，規制や指導への反対意見はわずか7％であった（第3図）．住民レベルでの断層による規制に対しての反対は非常に低いことがわかる．

既に紹介したように，長期的な人口減少時代においては多くの地域において空地化が進む．一方活断層の近傍といえども，多くのエリアではすぐに地震が発生するわけではないので，今後30～50年という長期的な視点から，次のような断層ゾーンに基づく土地利用誘導策は可能である．すなわち空地化が進んだ地域の中で安全性が高い場所に断層付近の建物の移動を誘導し，断層付近の危険地域に空地を集約させる政策である．

活断層に起因した建物被害の要因としては，「地表に現れた断層運動による表層地盤の変状を原因とする被害」と「断層に近いことによる強震動による被害」の2種類がある．これまでの地震被害の経験から，最新の耐震基準に従って設計・施工されている建物は，将来の地震時の強い揺れに対しても十分耐えうることがわかっている．地震動によって大きな被害を受ける既存不適格建物も30～50年という時間の中では将来的には少なくなっていくと考えられる．しかし地表に現れた地盤変状による被害の抑止は土地利用対策以外に有効な対策が無い．よって，ここでの土地利用誘導策の主な目的は，断層運動による表層地盤の変状を原因とする被害の抑止である．

ところで，断層ゾーンを設定しただけでは，ゾーン内での地価の下落により，安い土地を求める市民の新たな流入などの逆選択問題が生じる可能性が高い．このような動きを避けるために，第1表に記すようなゾーン内での増税などのデメリット付与策との併用が望ましい．また，地価が下落した場合にはゾーン外への流出が困難になる可能性もあるため，移転への補助や移転後の優遇措置も効果的であ



第3図　一般住民による土地利用規制への是非（川西，2006）

る．なお，現時点で認識されていない活断層や十分に警戒されていない活断層による地震被害も発生しうるが，これも長期的な視点から見れば、今後の更なる活断層の調査研究によって改善されると考えられる．

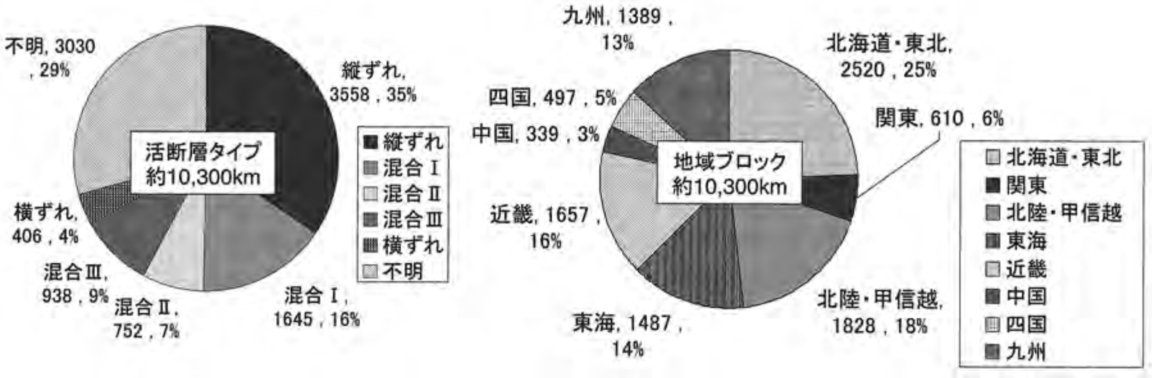
3．活断層近傍での土地利用誘導策による影響人口の検討

筆者らは，既存の研究（吉村ら，2007）において，活断層位置と人口・建物のGISデータベースを作成し，活断層近傍に存在する人口と建物の分布状況を把握した．この際，縦ずれ・横ずれ等の活断層タイプや活動度，確実度に着目した分析も行い，それぞれの活断層近傍の人口と建物の分布も把握した。これらの結果に基づき，活断層情報の周知や土地利用規制などの土地利用誘導策により影響を受ける人口の検討を行った．分析に用いたデータは，中田・今泉（2002）による活断層詳細デジタルマップ，平成12年国勢調査地域メッシュ統計（2000）によるメッシュごとの人口・建物データである．活断層帯ごとの活動度，確実度，縦ずれ断層での上盤・下盤側の位置データも活断層研究会（1991）に基づいて整理し，活断層データベースに補完した．

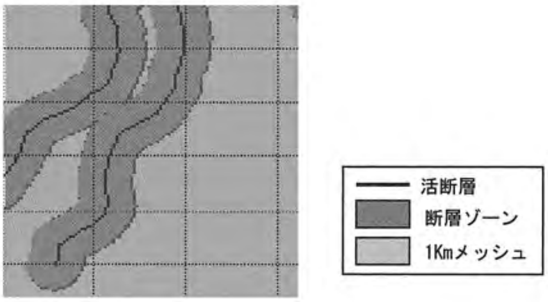
中田・今泉（2002）の活断層データを用いて断層帯ごとの活断層タイプを整理すると，第４図のように縦ずれのみが34%，横ずれのみが４％となり，縦ずれ断層の断層帯が多く存在していることがわかる．また，横ずれ断層の断層帯は，東海，近畿，中国地方に多い．第４図における「混合」とは同一断層帯内に，縦ずれ部と横ずれ部を有している活断層を示し，ここでは縦ずれが70%以上混在するものを「混合Ⅰ」，69～31%を「混合Ⅱ」，30%以下を「混合Ⅲ」とした．

また第５図に示すように，これらのＧＩＳデータベースを重ね合わせることで，活断層近傍の一定区域（断層ゾーン）に存在する人口と建物数を算出した．米国の断層ゾーン法を参考に，断層ゾーン幅を0.4Kmとすると（これを断層ゾーンⅠとする），ゾーン内にはわが国の総人口の2.3%に相当する約289.3万人が含まれ，木造建築物数は約62万棟であった．断層ゾーンの幅を0.8Km，２Km，４Kmと広げると，ゾーン内の人口はそれぞれ総人口の4.5%，10%，18%とほぼ比例して増加した．

断層ゾーンⅠを対象に少し詳しく解説する．横ずれ断層は存在する全断層長の４％を占めるのに対し，人口存在率では0.4%と非常に少ない（第６図）．多くの断層が存在する北海道・東北，中国，九州地方以上に，近畿地方で多くの人々が活断層近傍に居住していることがわかる（第７図）．都道府県別に見ると（第８図），人口の５％以上の人々が断層の近傍0.4Km以内に住んでいるのは，京都府が最高で9.6%，以下兵庫県，大阪府，奈良県，和歌山県と長野



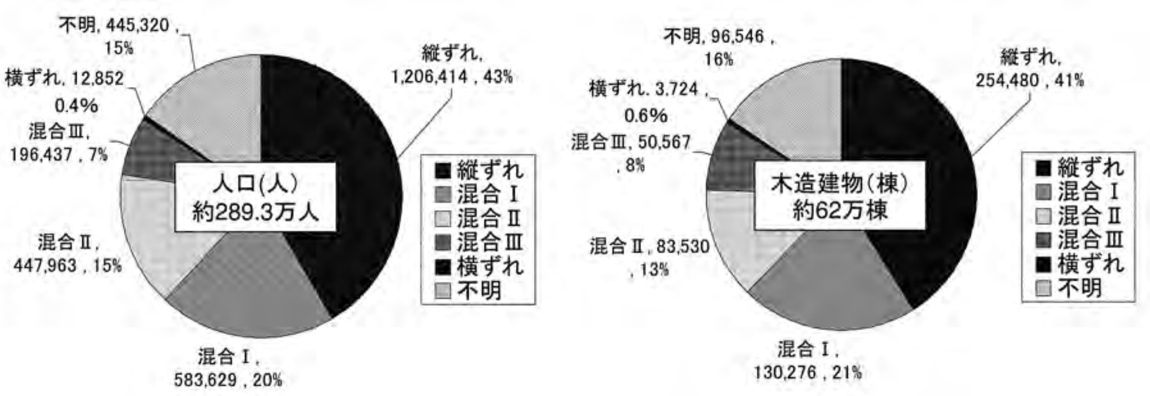
第４図　活断層タイプ，地域ブロック別の断層長



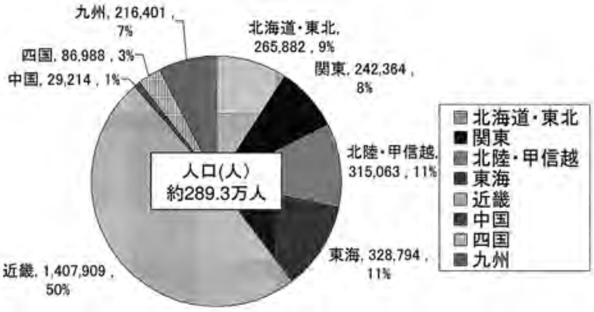
第５図　断層ゾーンの設定

県である．

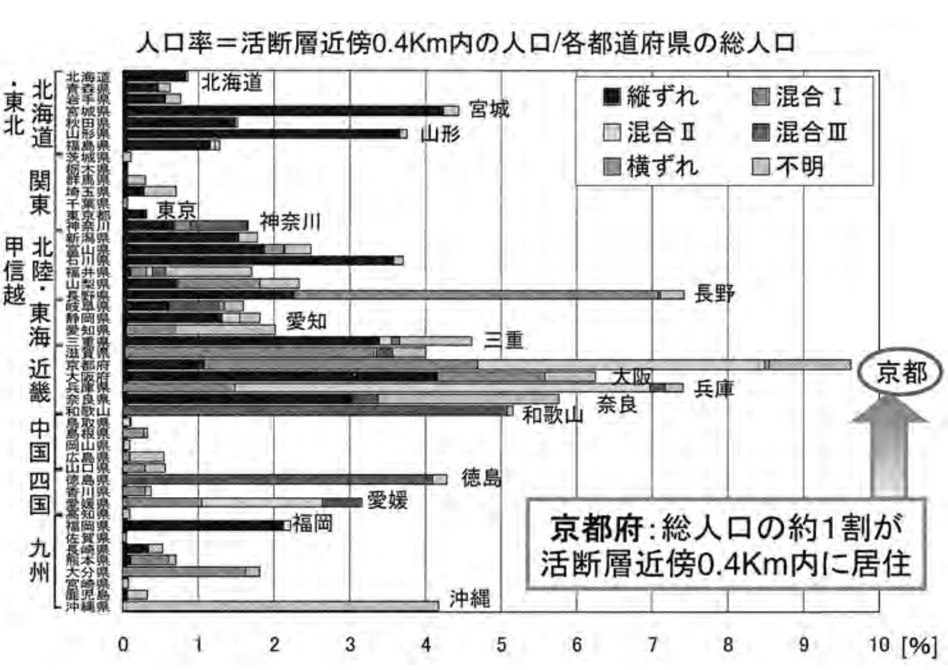
これらの結果より，断層幅0.4Kmの範囲内にすむ人口はわが国全体としては，現時点で全人口の2.3％，最も多い京都府でも10％未満であることがわかった．この結果は，今後50年で人口の３割が減少するわが国の人口減少社会を対象にすれば，活断層法の意義と可能性に関する議論を否定するものではない．むしろ容積率の若干の緩和を含めた適切な土地利用・都市計画的な政策によって，活断層近傍の危険性の高いエリアに住む人々に，長期的に安全なエリアに移り住んでもらうことで，将来の地震被害を大幅に軽



第６図　断層ゾーンⅠ内に居住する人口と木造建物数



第７図　断層ゾーンⅠ内に居住する人口の地域傾向



第８図　活断層近傍に住む人口の割合

減し，災害に強い国土づくりを実現する可能性を示すものである．このような分析を通して，望ましい土地利用誘導策とそれに対する影響人口を把握し，具体的に運用可能な施策を検討していくことが可能であると考える．

4．おわりに

本論文では，今後50年程度で人口が約３割減少することが予想される人口減少社会における安全な国土利用対策の一環として，活断層対策についての展望を述べた．

まず国内外での活断層近傍での対策をレビューし，人口減少社会において新たな意味を有すると考えられる活断層近傍での土地利用誘導策の意義について考察した．その上で，中田・今泉による「活断層詳細デジタルマップ」に記載されている全ての活断層を対象に，活断層近傍の人口と建物の分布状況を把握し，土地利用誘導策の影響を受ける人口の分析を行った著者らによる研究成果の一部を紹介した．分析結果によれば，断層幅0.4Kmの範囲内にすむ人口はわが国全体としては，現時点で全人口の2.3%，最も多い京都府でも10%未満であることがわかった．本結果は，今後50年で人口の３割もが減少するわが国の人口減少社会を考慮すれば，活断層近傍での土地利用誘導策の実現可能性を示すものと考えられる．もちろん具体的な断層ゾーンの導入に際しては，ゾーン幅や活断層のタイプ，断層の傾斜角や表層地盤の特性と厚さ，存在の確からしさや活動度などを踏まえた上で，望ましい情報周知法や規制の内容，これらの施策が住民や不動産価値に与える影響などに関する研究成果を重ね，総合的な検討を行っていく必要がある．

謝辞

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Key words : Active fault, Population, Land use control, Fault zoning act, Depopulation

耐震補強を推進するための イメージトレーニング

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1 はじめに

世界各地の地震被害を見てきた著者の考える防災力向上の基本は、発災からの時間経過の中で、自分の周辺で起こる災害状況を具体的にイメージできる人をいかに増やすかに尽きる。著者は、この能力、すなわち、発災時の様々な条件を踏まえた上で、災害状況の進展を適切にイメージできる能力を「災害イマジネーション」と呼んでいるが、効果的な防災対策は、この「災害イマジネーション」に基づいた「現状に対する理解力」と「各時点において適切なアクションをとるための判断と対応力」があってはじめて実現する[1]。

イメージできない状況に対する適切な心がけや準備などは絶対に無理である。現在の防災上の問題は、社会の様々な立場の人々、すなわち、政治家、行政、研究者、エンジニア、マスコミ、そして一般市民が、災害状況を適切にイメージできる能力を養っておらず、この能力の欠如が最適な事前・最中・事後の対策の具体化を阻んでいる点にある。

地震防災の最重要課題である既存不適格建物の耐震補強の推進においても、この「災害イマジネーション」が重要な役割を持っているが、この重要性に関しての理解が乏しい。

図１は、総合的な防災力を高めるために著者が提案している「危機管理／防災情報ステーションの概念図（地震防災版）」である。このシステムは、災害情報を創造する各種の数値解析モデルを融合したシミュレーションシステム（これをユニバーサル災害環境シミュレーションシステム[2]、[3]と呼ぶ）、災害情報を利用しやすい形で標準化した上で

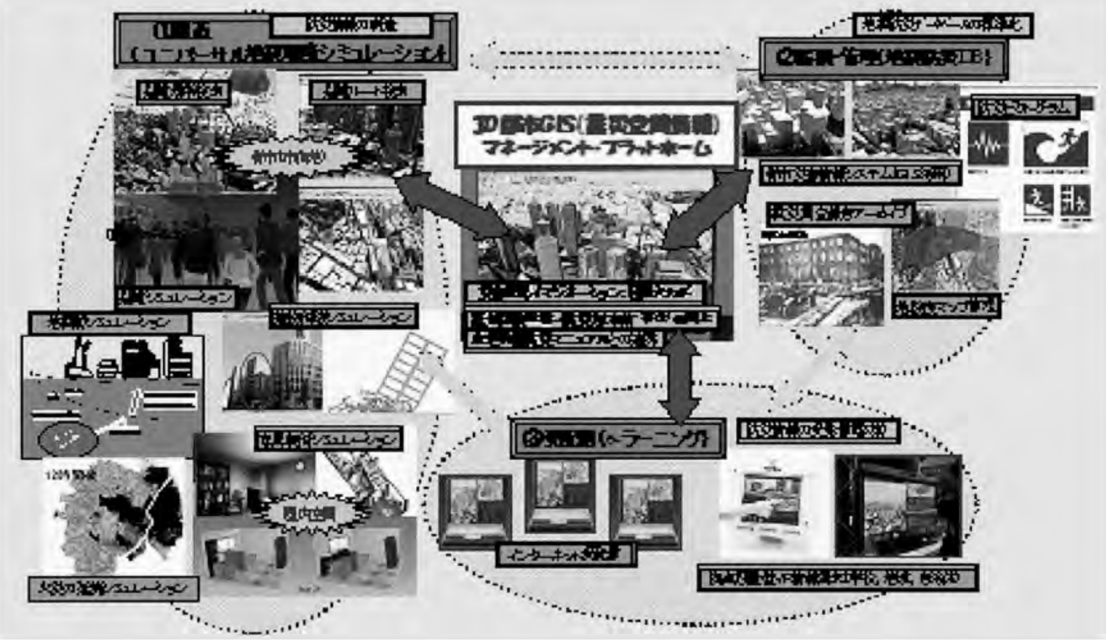

図１ 危機管理／防災情報ステーションの概念図（地震防災版）

災害現象と対策効果の高精度な可視化，過去の事実と教訓のわかりやすい整理，簡便で効果的な学習環境の整備により，多くの人の災害イマジネーション能力を高める．そして適切なイマジネーションに基づいた状況理解力と対応力を向上させることで，都市震災を軽減する環境を実現する．このシステムは，防災情報を①創造（シミュレーション）し、②蓄積・管理（地震防災DB）し、わかり易く③受発信（e－ラーニング）するシステムを④３次元都市GIS空間をプラットホームとして統合するものである．

これを蓄積・管理するシステム[4] [5]、多様なユーザとの災害情報の受配信システムの3つのシステムを、3次元都市GIS空間をプラットホームとして統合するものである。

このシステムを介して、利用者の災害イマジネーション能力、現状理解力、対応力が向上するとともに、事前・最中・事後の対策の効果が定量的に評価される。本稿では、このシステムの概要を説明するとともに、耐震補強を推進する上での「災害イマジネーション」の大切さと、耐震補強を推進するためのイメージトレーニングについて紹介する。

2　地震防災の最重要課題としての耐震補強とこれがうまく進展しないわけ

(1) 耐震補強の重要性

兵庫県南部地震をはじめ、最近内外で起こった多くの地震は私達に様々な教訓を与えたが、最も重要な教訓は、既存不適格構造物の問題である。総合的な地震防災力は、主として「被害抑止力」、「被害軽減／災害対応力」、「最適復旧／復興戦略」の3つによって達成されるが、3者の中で最も重要なのは「被害抑止力」だ。これがないと、いかに優れた事後対応システムや復旧・復興戦略を持とうが、地震直後に発生する構造物被害とそれに伴う人的被害を減らすことはできない。兵庫県南部地震で言えば、約25万棟の全半壊建物により、直後に約5,500人の犠牲者を出したこと[6]が、その後に発生した様々な問題（震後火災[7]と焼死者、仮設住宅、ゴミ処理、被災者の心理的な問題や孤独死、地域の経済活動の低下、復旧・復興期の諸問題、など）の根本的な原因であり、事前の対策で建物被害を少なくできれば、これらの問題は大幅に軽減したか、顕在化しなかった可能性が高い。

地震学的に活動度の高い時期を迎えているわが国では、今後30～50年くらいの間に、M8クラスの巨大地震が4、5回、首都圏直下地震などのM7クラスの地震の数はその10倍の40～50回発生すると予想される。一連の地震による被害は全壊・全焼建物棟数で200万棟の規模であり、これは350万～400万世帯が住家を失うことを意味する。政府は、既存不適格建物の耐震補強率を今後10年で90％まで上げる数値目標を打ち出したが、このままではこの目標の達成は難しい。どうすれば耐震補強が効果的に推進する環境を整備できるであろうか。

(2) 耐震補強が進展しないわけ

耐震補強が進展しない理由を、専門家を含め多くの人々は、家の所有者の金銭的な問題、あるいは行政による相談窓口や事前の支援制度の不十分さに求めている。しかし著者は、これらが進展を阻害している理由の一部であったとしても、全ての人々に当てはまるものではないし、より重要な理由があると考えている。

耐震補強費の目安は木造で1平米当たり1万5千円。100平米の木造住宅では150万円程度。最近ではもっと安い工法がいろいろと提案されている。この耐震改修費が高いという一方で、耐震補強と無関係なリフォームは、統計によってばらつきがあるものの、近年では年間40万～70万棟が平均400万円～700万円以上掛けて行われている。リフォームの機会に耐震補強を行えば、耐震補強に要する費用は大幅に安くなる。同様に自家用車を購入する際には、耐震補強費以上のお金を高いと思わず、強制保険はもちろん任意保険にも加入する。理由は、まちがって事故を起こした時の悲惨さがイメージできるからだ。高額所得者の多く住む高級住宅街であっても、耐震性に疑問のある建物は少なくない。ガレージには高級外車が何台もとまっている。これらの事実をどう説明するのか？

耐震補強を促進する上で著者が考える最も重要な課題は、「災害イマジネーション」の向上、そして適切な「技術」と「制度」の整備だ。

「災害イマジネーション」に関しては後述するとして、木造に限っても1,000万棟を超える既存不適格建物と、そこに住む人々の状況を考えると、「技術」に関しては性能は高いが高価な工法は問題解決の決定打にはならない。低価格なこと、ただし施工者に応分の利益が上がる価格であることが重要だ。安ければ安いほどいい、というのは依頼者側からのみの視点であり、これではまともな業者は参画しない。重要な課題を解決する上では、関係者の全てが得をする仕組みをつくることが重要だ。一部の人にしわ寄せが行くような仕組みは機能しない。そして実施した際の「効果」(これが著しく高くなくても) が信頼性の高い情報として、持ち主に理解してもらえる環境整備が重要だ。これは図面による評価だけではなく、現地の実際の建物に対して、補強前後での耐震性の変化を正確に評価する手法の確立を意味している。その際には、偏心荷重を与えやすい書斎や浴室などの位置など、利用形態の違いで同じ建物でも耐震性が異なることも考慮する必要がある。

「制度」としては、建物の持ち主に耐震補強に対する強いインセンティブを与えるものであり、かつ「技術」の価格や信頼度に関わる不確定性をカバーする機能を持つことが求められる。努力しな

いで弱い家に住み続け、地震で家が壊れた場合に手厚い支援を受けられる制度は本当に正しいのか。

現在の既存不適格建物の存在数と近い将来に予想される地震被害の規模を考えると、公助として一般的に考えられている「事前に行政がお金を用意して進める現在の耐震補強支援策」も、手続きの簡便化や支援額の増額などが盛んに議論されている「行政による事後の手厚い被災者支援策」も財政的に全く成り立たないし、副次的にも多くの問題を生む。前者では数を限って実施しても「やりっぱなし」の制度が、悪徳業者が入り込む環境を作っているし、後者は最も重要な事前の耐震補強対策へのインセンティブを削ぐ。いずれもオールジャパンを対象として、長期的な視点からわが国の防災に真に貢献する制度になっていないし、公的な資金の有効活用の点からも説明責任が果たせるものになっていない。これも政治家や行政の災害イマジネーションの低さによるものだ。

これらの課題に対する解決手段として、著者は「目黒の3点セット」と呼ばれる耐震補強活動を支援する新しい「公助」、「共助」、「自助」の制度を提案している。

事前の自力による耐震補強や建替え住宅が将来の地震時に被災した場合に手厚い公的支援を行うことで、地震時に市民と行政の両者の視点からの大幅な経緯費の節減を可能とする目黒の「公助」。この制度は、事前の自助努力が報われる、行政による事前の巨額の資金の準備が不要、住宅の継続的な品質管理に貢献する、悪徳業者の排除と責任あるビジネスの地元還元が実現、全壊建物の所有者に1000万円を優に超える支援をしても行政のトータルの出費は大幅に減る、などの特長を持っている。

現行の耐震基準を満足する住宅を対象としたオールジャパンの積立制度としての目黒の「共助」。この制度では、耐震改修時に数万円程度（消費税以下）の積立てをたったの1回だけ行えば、その積立金から、契約建物が被災した場合に、全壊で1,000万円、半壊で300万円以上の支援が可能となる。

目黒の「自助」は揺れ被害を免責とし、地震時の火災だけを保障する新しい地震保険である。初期出火率と全壊率の関係や消火活動と建物被害の関係の分析結果から、耐震性の高い物件の地震時の延焼確率は著しく低くなる。結果として、保険料は現在の地震保険の簡単に数％以下になる。耐震補強を促進する「目黒の3点セット」の詳細は、以前に本誌に執筆した文献7）を参照されたい。

これらの制度によって、将来の地震被害は大幅に減るとともに、市民と行政の両者の視点から地震時の出費の大幅な軽減が実現する。さらに市民は地震前に耐震改修か建て替えをしておけば、仮に地震の揺れで被災しても火事で焼けても、新築の家の再建に十分な支援金を受けられる環境が整う。また住宅メーカーでは、自社の住宅が将来の地震で被災した場合の無料再建を保証するビジネスモデルなどが実現する。著者の研究成果を踏まえ、現在さまざまなシステムや制度が具体化してきている。

著者は「弱者を切り捨てろ」と言っているのではない。大きな地震が頻発し、大規模な地震被害が発生することが確実視されている現在のわが国の状況を前提にすると、「目黒の3点セット」のような方法で自力で抑止力を向上できる人たちに事前に対策を講じてもらわない限り、財政的に弱く自力での対処が難しい人たちを救うことができないことをご理解いただきたい。

3　危機管理／防災情報ステーション

危機管理／防災情報ステーションは、①シミュレーションモジュール（以下ではS-モジュール）、②データ・アーカイビングモジュール（以下ではDA-モジュール）、③e-ラーニングモジュール（以下ではeL-モジュール）が、④Web3D-GISモジュールを共通のプラットホームとして相互に有機的に結合されることで、従来にない全く新しい機能と意味を持ったシステムである。

①のS-モジュールは災害情報を創造したり、過去の実際の災害記録を一般化して、より効果的に活用するためのシステムであり、各種の数値解析モデルを融合したユニバーサル災害環境シミュレーションシステムとなっている。地震動のシミュレーションから、構造物の挙動、対応行動、発災後の経済状況までをシミュレーションの対象としている。

②のDA-モジュールは災害情報を利用しやすい形で標準化した上でこれを蓄積・管理するシステムであり、過去の災害調査報告、新聞記事、教訓集などはもちろん、①によって作成された情報もこの中に入る。しかも①の精度向上と④の地域特性の変化に伴って、常に動的・かつインターラクティブにアップデートされる。

③のeL-モジュールは、学び手側からはラーニングシステムであるが、システム管理側からはデータ入手システムの機能も有している。一般ユーザの意識レベルを知るとともに、彼らが①のシステムに様々なデータを入力して得られる情報を②のデータとして整備するためのインターフェースと

しての機能である。

④のWeb3D-GISモジュールは、対象となる地域の時空間都市情報であり、Web3D-GIS環境を基本として、その中に時間パラメータを有した地域住民や地域特性データが常にアップデートされて格納されている。

①～④の主な構成要素を紹介すると、①としては、地震時木造建物崩壊および耐震化効果シミュレーション[8]、地震時家具転倒および転倒防止装置効果シミュレーション[9]、地震時ビル崩壊シミュレーション[10]、[11]、地震時高架橋崩壊シミュレーション[12]、地震時鉄道車両内乗客挙動シミュレーション[13]、津波災害時避難行動および避難誘導効果シミュレーション[14]、災害時地下空間避難行動および避難誘導効果シミュレーション[15]、災害時高層建築ビル内避難行動および避難誘導効果シミュレーション[16]、災害イマジネーションメソッド（目黒メソッド[17]、目黒巻[18]）、災害対応シミュレーション（次世代型防災マニュアル[19]、[20]）、事前・最中・事後の施策効果シミュレーション[21]、[22]、経済状況シミュレーション、などがある。

②は兵庫県南部地震教訓集や時刻歴対応活動記録、WTCテロ事件の新聞記事をはじめとして、過去の事故や災害の調査報告や新聞記事、さらに地域危険度分析や被害想定結果などを新しいスタイルでデータベース化したもの。関東大震災の被害写真と同じ場所・アングルから撮影した現況写真を比較できる「関東大震災フォトライブラリ」もこの一部である。

③としては、子供から老人までが簡単に操作できるユーザフレンドリーな入出力インターフェイスとして、多指認識型情報端末を用意した。またリアリティの高い「仮想被災体験」を可能にするため、VR時空間情報端末とHMDを用いた没入型３次元VR端末の特性を活かしたインターフェイスを作成した。

④としては、東京23区をはじめ、わが国の大都市圏を対象として整備した建物１棟１棟の３次元GIS情報を共通プラットホーム[23]とする。

提案システムによって実現する種々の物理・社会現象に関する最新のシミュレーションモデルとデータベースの組合せは、単なる過去の危機管理事例を収集・整理するだけでなく、異なる時刻、自然条件、地域の防災力、社会情勢のもとでの危機発生状況をシミュレートし、それを「擬似危機事例」として蓄積・更新していくことを可能とする。「擬似危機事例」を量産し、教材として用いることで、実際の危機事例の稀少性を補完し、危機に対するイマジネーション能力を高めることが可能となる。また災害発生時においては、実際の物理・社会環境条件を逐次入力することで、ごく近未来の災害状況を、高精度に予測・更新、危機対応時の意志決定を支援することが可能となる、などの特長を有している。本システムは、平時は危機管理／防災教育支援システムとして働き、緊急時には危機管理／防災対応支援システムとして機能することで、利用者の災害イメージ能力、現状理解力、対応力が向上するとともに、事前・最中・事後の対策の効果が定量的に評価され、総合的な防災力の向上に寄与する。

以下では、「危機管理／防災情報ステーション」の中から、耐震補強に深く関係するいくつかのサブシステムに関して簡単に紹介する。

４「目黒メソッド[17]」と「目黒巻[18]」

防災の基本である災害状況を正確にイメージできる能力の向上のために、後に「目黒メソッド」と呼ばれる災害イメージトレーニング法やこれを簡略化した「目黒巻」を考えた。

目黒メソッドでは、**図２**に示すような表を使う。縦軸の平均的な一日の行動を考える際には、自宅や職場周辺の環境、建物の耐震性や家具配置、時間帯別の家族各メンバーの居場所や行動などもまとめておく。さらに通勤手段が使えなくなった状況

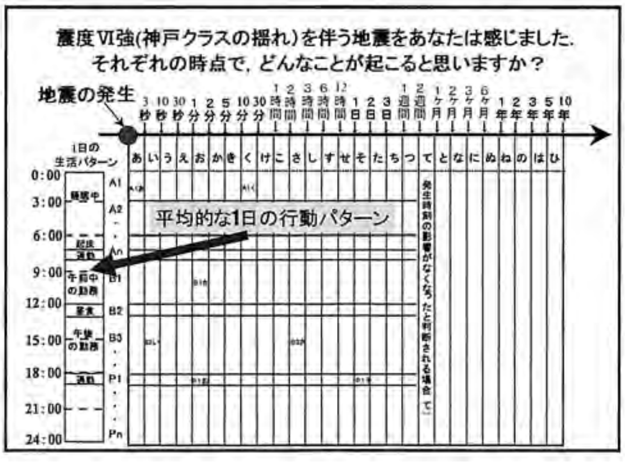

図２　目黒メソッドで用いる表
平均的な１日の行動パターンを縦軸に、発災後の経過時間を横軸とした表を用いて災害状況のイメージトレーニングを行うもの。縦軸の平均的な一日の行動を考える際には、自宅や職場周辺の環境、建物の耐震性や家具配置、時間帯別の家族各メンバーの居場所や行動などをまとめたり、通勤手段が使えなくなった状況を想定し、全て徒歩での所要時間も考えておく。その上で、季節や天候、曜日を決め、各時間帯に大きな地震が発生したと仮定し、発災からの経過時間に伴って、自分の周りで起こること、やるべきことを具体的にイメージし記載していく。季節や天候、曜日などの発災条件や、事前対策の有無で変化する災害状況を理解することで、具体的な防災対策の実施につなげていく環境整備を狙っている。

を想定し、全て徒歩での所要時間も考える。その上で、季節や天候、曜日を決め、各時間帯に大きな地震が発生したと仮定し、発災からの経過時間に伴って、自分の周りで起こること、やるべきことを具体的に記載してもらう。ほとんどの人は、状況がイメージできず何も書くことができない。つまり地震時に適切な行動が取れないということだ。

(1) 徹底した当事者意識と個人としての多面性の認識

目黒メソッドで特に大切な点は、自分の生活を強く意識して考える点だ。この点がしょせんは他人事と受け取られ、実際の対策に結びつきにくかった従来の各種のメディアが作成した災害教訓番組や教訓集との差だ。目黒メソッドを通して、自分の持つ「社会的な顔と私的な顔」、「つくってあげる側ともらう側」、「情報を出す側と受ける側」などの多面性に気づく。自分は「守ってもらう側」と考えている大多数の市民が、例えば家庭の若い主婦が、家に子供と自分しかいない時間帯に地震に襲われれば、自分が「守る立場」にならざるを得ないことを実感する。自治体の防災関係者が、職員として住民を「守る側」にいる時間が、1日8時間勤務、週休2日、その他の休暇・・・と考えていくと、自分の時間全体の2割程度であることに気づく。他の住民同様に被災する可能性と、防災職員として活動できない状況の多さも実感する。適切な災害対応には自分と家族の安全確保が不可欠である。

図3　目黒巻の例

「目黒メソッドを簡便化した「目黒巻」は、保育園や幼稚園、小学校や一般家庭等での活用を主目的としており、自分で条件を設定して、災害時の様子を、自分を主人公とした物語として書いていくもの。細長い紙の上に経過時間に沿って物語を書き込むので、巻物状になるため「目黒巻」と呼ばれている。目黒巻を書き進める中で、現状の問題点が認識されるとともに様々な疑問点が出てくる。さらにみんなの目黒巻を並べると、同じ時間帯での各人の内容が比較でき、認識のずれや相互連絡の難しさなどを発見できる。これらをみんなで話し合ったり、調べたりすることから、具体的な防災対策が始まる。どうすれば、自分の物語がハッピーエンドになるのかを考えることがポイント。事前に何をしておけば、物語がどう変わるのか。事前対策の重要性が認識され事後対応力もつく。関係者で条件を変えながらやってもらうことで、個人個人の、そして組織としての防災力を高めることが可能となる。学期や季節に合わせて、学年が変わった時、引っ越した時、それぞれのタイミングで実施すると効果的。

「目黒巻」は、保育園や幼稚園、小学校や一般家庭等での活用を主目的としており、自分で条件を設定して、災害時の様子を、自分を主人公とした物語として書いていくものだ。細長い紙の上に経過時間に沿って物語を書き込むので、巻物状になるため「目黒巻」と呼ばれている（**図3**）。

目黒巻を書き進めるなかで、現状の問題点が認識されるとともに様々な疑問点が出てくる。みんなの目黒巻を並べると、同じ時間帯での各人の内容が比較でき、認識の誤りやずれなどが発見できる。どうすれば、自分の物語がハッピーエンドになるのかをみんなで調べ、そして考える。事前と事後に何をすれば、物語がどう変わるのか。事前対策の重要性の認識と事後対応力がつく。関係者で条件を変えながら実施することで、個人と組織の防災力向上が可能となる。学期や季節の初め、引越時などに実施すると効果的だ。

(2) 健常者は潜在的災害弱者の意識と自分の死後の物語の想像

多くの人は緊急事態でも、自分が健常であることを疑わない。就寝中の地震、揺れの最中に、眼鏡やコンタクトレンズが紛失し、被災家屋の中でスペアも見つからない。落下物で腕や足を骨折した。そのような条件下で目黒メソッドの表をもう一度

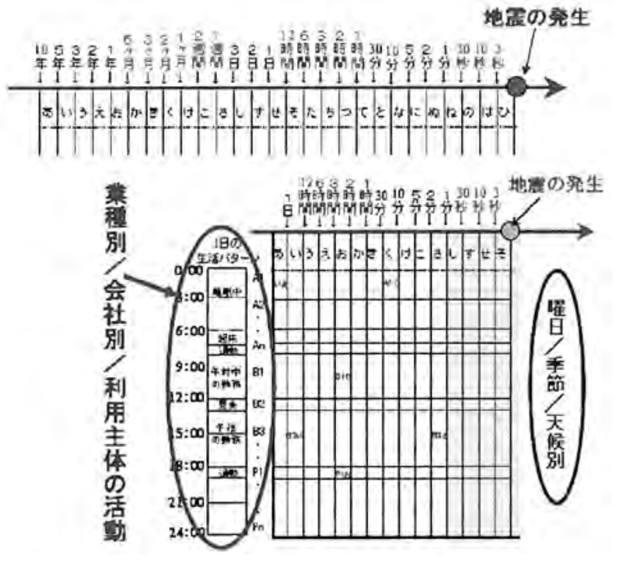

図4　地震までの時間が与えられた場合にその時間をどう有効活用するか

上段はある程度の長い時間が提供された場合、下段の数10秒以内は緊急地震速報の活用範囲

埋めてみる。自分が簡単に災害弱者になることに初めて気づく。防災では、「健常者＝潜在的災害弱者」と考えるべきだ。この意識を持つと見えてくる世界が変わる。健常者としての意識しかない人は、バリアフリーなどの問題は、自分と無関係なこととしか感じない。しかし「健常者＝潜在的災害弱者」の意識を持つと、福祉と防災は一緒に考えた方が合理的であることに気づく。

さらに不幸にして自分が亡くなってしまう状況ではどうか。目黒メソッドでは、自分が死亡する状況では、そこで物語を止めるのではなく、まわりの人々が自分の死をどう受けとめ、その後の人生を過ごされるのかを考える。すると否応なしにまわりへの感謝と自分が死んではいけない存在であることが強く意識される。この感覚が得られると、人は「防災対策しなさい」などと言われなくても、自分でできる対策をしっかり考え、これを実施する。

(3) 地震発生までの時間の有効利用

従来の「Aやれ、Bやれ、Cやるな」的防災教育の効果は低い。「グラッと来たら何をすべきか？」をあれこれ言う前に、今やるべきことは、災害イマジネーションを向上させることだ。

地震が起こるまでの時間と地震直後の時間、どちらに時間的な余裕があるか。もちろん前者だ。**図2**の地震発生からの時間軸を、**図4**のように地震発生までの時間軸に変えて考えると、災害イマジネーションのある人は、現在の自分の問題がわかるので、発災までの時間を有効活用して適切な事前対策をとる。ここで初めて減災が実現する。そしてもっと時間が短くなって数10秒以下になると、これが緊急地震速報の利用できる猶予時間だが、これも事前に、季節や天気、曜日や時刻、その時の自分の位置や活動を前提に、何秒あれば何ができるかを具体的に考え、それを実行できるように準備しておかないと、有効利用は難しい。

「グラッと来たときに、なるべく何もしなくていい状況」を事前にまず準備する。そして実際にそのときを迎えた際には、時間先取りで自分の直面する状況をイメージし、それがなるべく悪くならないように、そのつど適切な対応をする。これが被害全体を最小化できる術なのだ。

「目黒メソッド」や「目黒巻」を繰り返すほど確信することは、事前対策、特に被害抑止力の重要性


確認した住所を選ぶことができます
You can select your address below.

選択した地域から最寄の避難所までの経路と距離を地図上に示す。
Shortest path from user's selected area to evacuation space is shown on the map with its distance.

地域の地震危険度を火災延焼の危険性から評価したもの(真上に近い位置からの眺め)
Vulnerable rank in terms of fire spreading potential of the area.(View from just above the area)

図5 高精度3次元GISをプラットホームとした地域危険度評価
住所を選ぶと，その地域に飛んでいき，その地点からの最寄の避難場所までの経路や距離を示したり，各種の危険度を表示する．このようなシステムを利用することで，市民1人ひとりが地域の危険性や自分の問題を把握できる．

図6　あなたのまちの関東大震災時の様子

である。すなわち、既存不適格建物の建て替えと耐震改修、地震に強いまちづくりの実践である。

5　あなたの街の地域危険度3次元マップ[23)]

耐震補強を推進するには、住民が自分の住む地域についてよく知ることが重要である。地域全体の建物の倒壊危険度や火災危険度、避難場所はどこにあるのか、などの実態を理解しなくては適切な対策はとりようがない。そのための基礎情報を提示するのが地震危険度マップである。

東京を例として説明すると、東京都では、「建物倒壊危険度」、「火災危険度」、「避難危険度」の3つの危険度を、町丁名ごとに5つのランクに分けて相対的に評価するとともに、これら3つの危険度をもとに「総合危険度」を評価し、地図表示している。しかし、この地図が市民の視点からすると、必ずしもわかりやすいものにはなっていない。

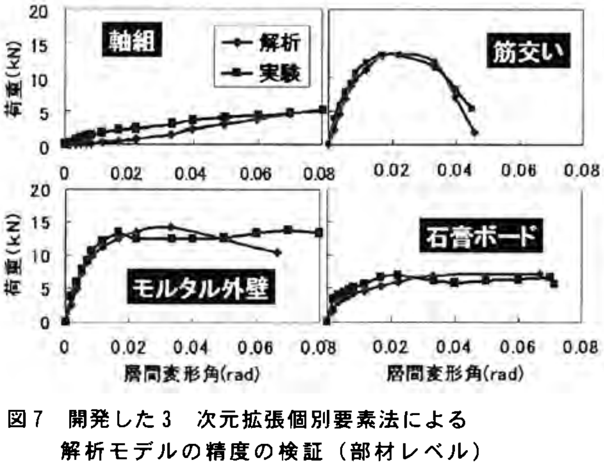

図7　開発した3　次元拡張個別要素法による解析モデルの精度の検証（部材レベル）

そこで著者らは、上記の評価値を活用した地域危険度マップを、市民が理解しやすい3次元都市空間を対象に、子供から老人までが簡単に操作できるユーザフレンドリーな入出力インターフェイスとして、指で触れるだけで簡単に操作できる多指認識型情報端末で見てもらえるシステムを開発した。**図5**はモニターに表示されるイメージの例である。

住所メニューから自分の住所を選択すると、3次元地図としてその地域の各危険度が色分けして表示されるとともに、自分の住まいから最も近い避難場所へのルートが距離つきで表示される。また自由自在の高さで街の上空を飛び回って、各地の危険度を見てもらうことができる。このような1軒1軒のレベルで建物が識別できるミクロな都市3次元空間を対象とした危険度評価ならびに表示を進めていくことで、一般市民の地域危険度に関する正確な知識の普及が進む。結果として、耐震補強をはじめとする発災前の適切な防災対策が推進し、地域の防災力の向上がはかられるものと期待される。

同様に、自分のまちの地震危険度を理解してもらうために、1923年の関東地震による様々な被害（これを関東大震災という）を、各被災場所の当時の写真と現在の様子を同じ視点から比較して見てもらうシステムを開発した（**図6**）。80年以上も経つと、

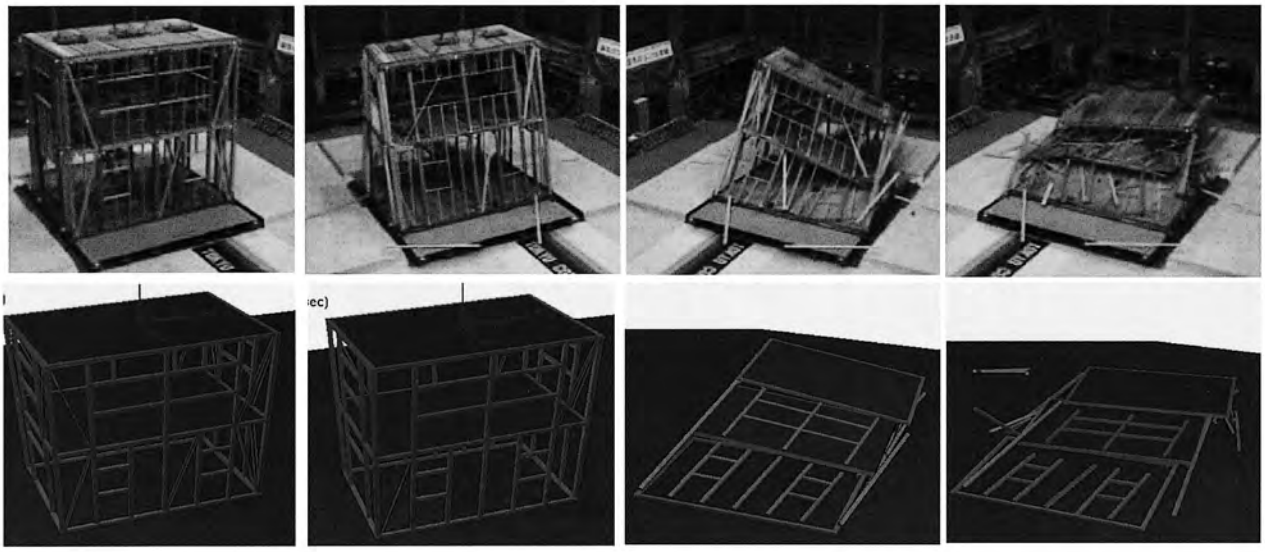

図 8　開発した 3 次元拡張個別要素法による解析モデルの精度の検証（構造物全体として）
上段は振動台による破壊実験、下段はその数値シミュレーション結果

一般の人々の意識の中ではもはや関東大震災は歴史的な出来事になってしまい、同じ場所に住む自分の生活と乖離している。これでは防災意識は向上しない。過去の災害を自分の問題として意識してもらう環境を整備することで、耐震補強をはじめとする対策の促進を狙ったものだ。

6　あなたの家の地震時の挙動と耐震補強効果のシミュレーション[8)]

著者らは、「危機管理/防災情報ステーション」の中に、倒壊実験を含め、過去に実施された建物の振動台実験の様子をデータアーカイブ化している。これは、口でいくら説明されても「ピン」とこない建物の倒壊挙動を実際に見てもらうことで、その恐ろしさと同時に耐震補強の効果を実感としてわかってもらうためである。

ただし、過去の実験は、自分の家を使って行われたものではないので、まだ当事者意識が低い場合がある。そこで自分の家を対象に地震時の様子を見てもらうシステムを開発した。解析手法としては、著者の研究室で開発した 3 次元拡張個別要素法(3D-Extended Distinct Element Method, 3D-EDEM)を用いている。3D-EDEM は連続体から非連続体までの挙動を解析できる数値解析法である。

事前の検討から、部材レベル（図 7）、さらに構造物全体（図 8）としての数値解析の精度を検証したうえで、「地震時にあなたの家がどうなるか」を確認してもらう。図 9 と図 10 に結果の一例を示すが、耐震補強前後の地震時の挙動の違いが一目瞭然でわかる。耐震補強の効果が、自分の家を対象としてわかることの意味は大きく、これを見た多くの人の意識は確実に変化した。

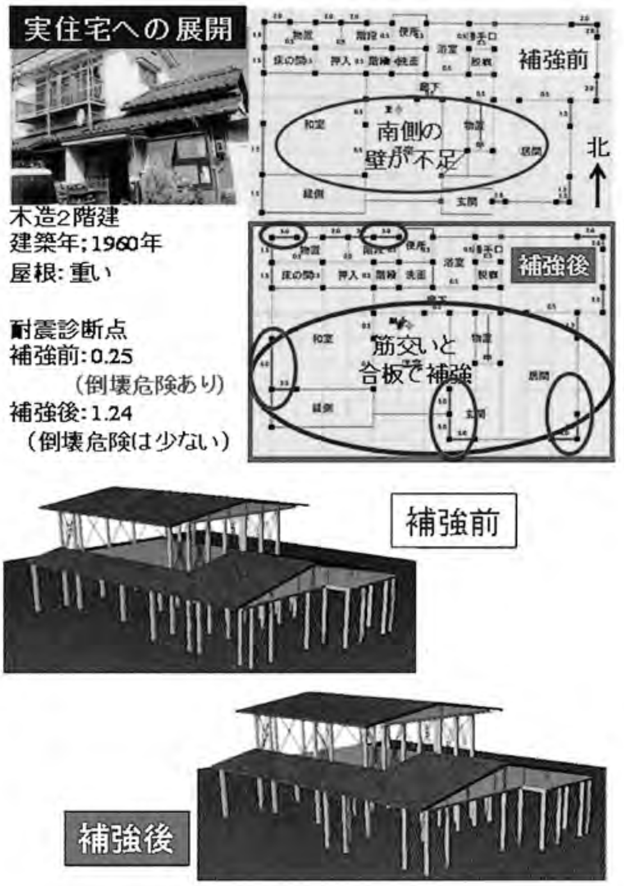

図 9　あなたの家の地震危険性（耐震補強前後）

7 あなたの部屋の地震時の家具の挙動シミュレーション[9)]

耐震補強を進める周辺環境を整えるという意味では、「地震時のあなたの部屋がどうなるか」を見てもらうことも重要である。ここで紹介するシミュレータは、先ほどと同じく三次元拡張個別要素法（3D-EDEM）により、配置の違いや転倒防止装置の有無などの影響も考慮した上で地震時の家具の動的挙動を表現するものである（図11）。

このシステムを利用することによって、特別な知識や経験のない一般市民でも、レイアウトの違いや転倒防止措置の有無などが地震時の家具の動的挙動に与える影響が比較できる。このようなシミュレータは、市民の防災意識を高め、家具を固定するなどの具体的な防災対策行動を促進し、室内被害の軽減につながるものと期待される。さらに意識の高まった市民が、耐震補強まで考えてくれることを期待しているものである。

8 耐震補強の経済的な効果シミュレーション[9)]

これまで紹介したシステムによって、自分のまちや建物、そして部屋が地震時にどうなるか、の理解が促進されるが、さらに耐震補強が経済的にも得な対策であることを市民に理解してもらえれば、対策がさらに進む可能性が高い。ここでは、長期地震予知情報を活用した耐震補強の費用対効果を評価するシステムについて紹介する。

地震予知とは、発生する地震の規模と位置と時間の3つの情報を、事前にある精度で評価するものであるが、3者の中で、規模と位置の情報は、発生時間に比べれば、すでに高い精度を有している。問題は時間だが、この発生時間に関しても、10年オーダーの予知期間を対象とする長期地震予知においては、かなり精度が高いことがわかっている。著者はこの長期地震予知情報が耐震補強のインセンティブやきっかけ作りに有効だと考えている。

発生時刻が不明でも、想定されている地震が発

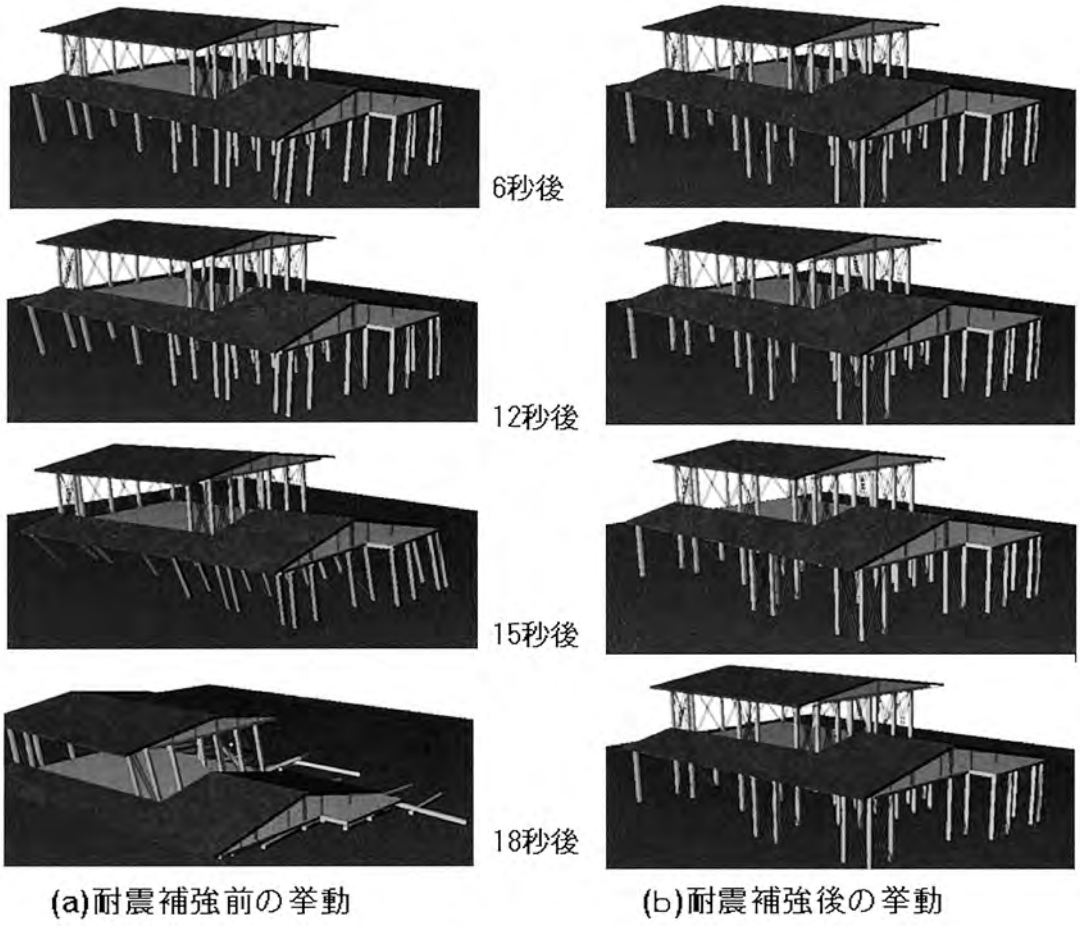

図10　あなたの家の地震時の挙動（耐震改修前(a)後(b)の動的挙動の比較）
入力地震動は兵庫県南部地震時の神戸海洋気象台記録

生した場合に、住所がわかれば、その場所と震源の位置関係と地盤条件から、**図12**に示すようにその地域を襲う地震動の強さは評価可能だ。そこに存在する建物の耐震性がわかれば、地震動との関係から地震発生時に受けるであろう被害の程度を評価することも統計的に可能となる。つまり、「住所○○に住む耐震性△△のあなたの家は、現在想定されている地震が発生すると□□円の被害を受ける。事前に耐震補強（費用◇◇円）をしておくと、被害（復旧・復興費を含んで）を◆◆円軽減できる」という評価ができるということだ。**図13**は評価の一例であるが、自分の家に対してこの評価値を示されると多くの人々の意識は変わる。ちなみに想定東海地震（発生確率30年で87%）を対象とすると、耐震補強による被害軽減の期待値が5～15倍という物件はざらに存在する。先に述べた自動車保険は保険ビジネスが成立していることから考えれば、支払っている保険料に対して受けるお金の期待値は確実に1以下である。しかし、自動車事故をイメージできる多くの人は任意保険にまで加入する。現在の地震学的な環境と、耐震補強の効果を広く市民に伝えることの重要性がここにある。

9　おわりに

地震学的に活動度の高い時期を迎えているわが国において、地震防災対策の最重要課題は弱い建物の耐震補強と建替えである。本稿ではこの推進のために、著者が重要と考えている「災害イマジネーションの向上」、「適切な技術」、「適切な社会制度」の中から、「災害イマジネーション」に関わる部分の話を紹介した。紙面の関係から、「適切な技術」や「適切な社会制度」に関しては、触れられなかったので、既刊の報告や今後の報告をご覧いただきたいが、「災害イマジネーション」は、「適切な技術」や「適切な社会制度」の実現においても最も重要なポイントである。すなわち、「災害イマジネーション」が乏しいと、良かれと思って、間違った技術や社会制度をつくってしまう。これは避けなくては

(a) シミュレーションシステムの流れ

(b) シミュレーションの例

図11　地震時の家具の動的挙動シミュレータ

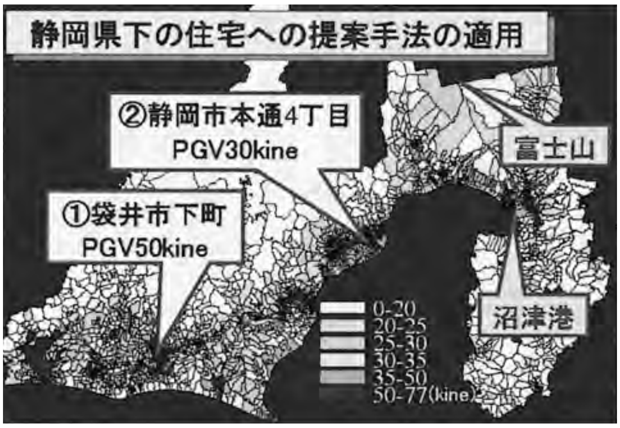

図12　想定東海地震が発生した場合の各地の揺れの強さ

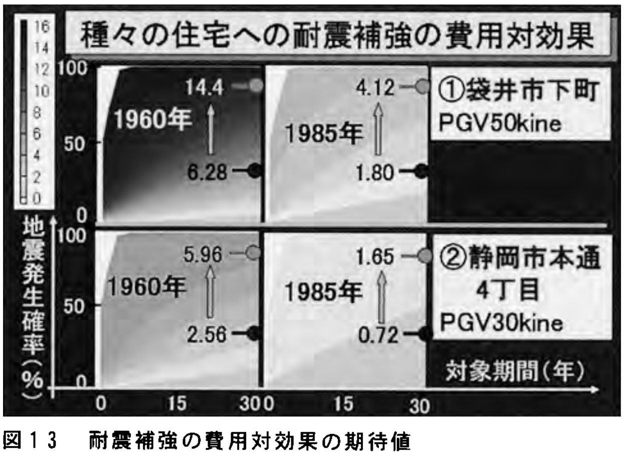

図13　耐震補強の費用対効果の期待値
（家の所有者が耐震補強の効果を理解できる）

いけない。

最近著者は専門書以外に、多くの一般向けの防災書籍、特に子供や女性向けの防災の絵本やコミックを多数出版している（**図14**）。これも将来を担う子供たちの災害イマジネーションを向上したいからであり、子供や住宅の購入などに大きな影響を持つ女性の意識を変えたいためである。

著者は切に願っている。防災に関わる人々はもちろん、多くの一般市民に、災害イマジネーションの重要性を認識していただくことを。そして本稿で紹介したような様々なシステムが広く普及することで、市民一人一人がの防災力が向上し、ひいては地域や社会、そしてわが国全体の総合的防災力の向上が実現することを。それ以外に、将来の地震災害を大幅に軽減できる術はないと著者は考えている。

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図１４　災害イマジネーションの向上のために著者が関係して最近出版した子供向け（上段）と一般向け（下段）の地震防災関係の書籍

上段の左端の本は英語と日本語のバイリンガルの絵本24)で、耐震補強の重要性について、地震で家族を失った男と構造物のつくり手のシンボルとしてのビーバーが語り合うものである。わかりやすい文章と美しくかわいい版画で綴られた内容を子供に語りかける中で、お母さんの意識改革を狙ったものだ。またバイリンガルとしたのは地震国日本に住む限りは外国人でも耐震補強の重要性を認識して欲しいからである。左から２冊目は、幼稚園や保育園、家庭を対象にした防災ハンドブック25)であり、この中に「目黒巻」の詳しい説明が入っている。左から３冊目は、小学校の低学年を対象にした絵本26)である。震度３から５－程度の揺れを伴う地震に遭遇した際に、そのタイミングを利用した防災教育を狙ったものである。震度３から５－程度の揺れは、「ひやっ」とする揺れではあるが、大きな被害は出ない。しかし意識は高まっているので、平時以上に高い教育効果が望める。今回以上に大きな震度でゆれた際には、自分や周辺はどうなってしまうのかを説明する。同時に事前に対策をしておくと被害は大幅に小さくできることを説明してあげる。右端の本は小学校の高学年向けに出版したコミック27)である。両親と妹のいる５年生の男の子を主人公に、地震の前から地震後の復旧・復興期まで、本人や家族、周辺でどのようなことが起こるのかをシミュレーションし疑似体験してもらうコンセプトだ。下段の左は、地震防災に関わる様々な「非常識な常識の打破」を狙ったものである28)。右側は、自分の生活の視点でまちを見ると防災上の様々な課題が見つかるので、それを家族でグループで改善していただきたいという本である29)。

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SEASONAL CHANGES OF FOREST ENVIRONMENTS IN THE MEKONG RIVER BASIN

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ABSTRACT:

Although the problem in tropical forest has been widely concerned, deforestation and forest degradation is still hot issue in the world. In some countries in the Mekong River Basin, scientific knowledge about forest ecosystem and forest law enforcement are not enough to maintain their forests in good condition from the natural environmental point of view. Remote sensing technology is considered one of the useful and important tools for monitoring various forest conditions. The phenological change of each forest is greatly related to the changes of natural environmental factors, such as water, temperature, soil and solar radiation. The authors proposed a monitoring system to get environmental information of forested area using remote sensing data. The pre-processing method named LMF and LMF-KF (Local Maximum and Fitting with the Kalman Filter) was introduced, which modelled the seasonal changes for time series data of frequent observation satellite data. This technology overcomes the influences of cloud cover and sensitivity fluctuations of the sensors. We applied these methods to SPOT-Vegetation and NOAA-AVHRR data of the Mekong River Basin. These dataset could show the environmental conditions, such as vegetation cover, temperature, snow cover area and leaf water condition in Mekong River Basin.

1. INTRODUCTION

1.1 Background

The forest meteorological tower with 60m high and wells for underground water measurement were constructed and many new instruments are monitoring environmental conditions at a evergreen forest in Cambodia since 2003. The activity is strengthen under the project “Establishment of the Integrated Forest Ecosystem Observation Sites and Network in the Lower Mekong (2008-2011)” funded by the Ministry of Environment of Japan. And a new observation site is going to be constructed in a deciduous forest.

Although the problem in tropical forest has been widely concerned, deforestation and forest degradation is still hot issue in the world. In most of the countries, scientific knowledge about forest ecosystem and forest law enforcement are not enough to maintain the forest are in good condition from the natural environmental point of view in South East Asia.

We have set up four subjects for the new joint project between Forestry Administration of Cambodia and Forestry and Forest Products Research Institute of Japan, such as:

1) Biodiversity and Forest Site Environment Study
2) Observation System for Water Cycle in Tropical Seasonal Forest
3) Near-real-time Observation System of Forest Environment by Satellite
4) Archiving System of Forest Observation Sites in the Lower Mekong

1.2 Remote sensing data for environmental issues

Remote sensing technology is considered one of the useful and important tools for monitoring various forest conditions in the world. However, appropriate monitoring system using remote sensing is not yet clear. Sader et al. (1990) suggested that higher resolution sensors (MSS, TM, SPOT, aircraft scanners and mapping cameras) are necessary tools to record the spectral and spatial details needed to link intensive ecological field studies to the forest community and biome levels. Even though these ideas on multi-stage observation are considered quite useful for studying environmental conditions, most of the activities could get limited results because of the remote sensing data which are obtained “by chance” depending on cloud cover and other problems.

While remote sensing data give us various data of the ecosystem related to the electro-magnetic reflectance and/or radiation, it is necessary to find the appropriate “remote sensing indices” for monitoring forest environment conditions. The phenological changes of ecosystem are greatly related to the changes of natural environment, such as water, temperature, soil and solar radiation. Therefore, “appropriate remote sensing indices” shall reflect the environmental conditions.

We studied to get information about seasonal changes of environmental conditions by remote sensing data. Various researches on global environment study utilize frequent observation satellite data. The NOAA-AVHRR and SPOT-Vegetation are commonly used for such purpose (Ricotta et al., 1999) and "the ten-day composite images", which are created by choosing the best data in ten days for every pixel, are often used to monitor seasonal changes of terrain conditions (Defries et al., 1994). However, the influences of cloud and haze still remain in those data and it makes difficult to monitor phenology with 10 days interval (Roerink et al., 2000). On the other hand, the “monthly” composite data to reduce the influence of noises are not appropriate for following phenological aspects because most of the dynamic seasonal changes of vegetation occur within a few weeks (Viovy et al., 1992).

Therefore, the authors developed the processing method named LMF (Local Maximum and Fitting) and LMF-KF (Local Maximum and Fitting with the Kalman Filter), which modelled the seasonal changes for time series data of frequent repeat observation satellite data. The LMF-KF introduces the form of the sum of cyclic functions with time-dependent coefficients (Sawada et al., 2005) and produces clear images with 10 days interval.

We applied these techniques to SPOT-Vegetation data to detect snow cover area and NOAA-AVHRR data to reveal the environmental conditions in the Mekong River Basin. These methodologies give us the opportunity to monitor environmental conditions of forest area in both global and national scale, which will help us monitoring with rather high spatial resolution satellite. We think that it will give us an ideal system for multi-stage monitoring as well.

2. DATASET FOR MONITORING IN GLOBAL SCALE

2.1 SPOT-Vegetation Data

The SPOT-Vegetation sensor was launched on the SPOT-4 in 1998. The sensor has four channels which have 1 km resolution at the nadir. The dataset called “S10” is the ten-day composite data which is created by the same concept with the NOAA 10-day composite data. These data are open to the public after a few month of observation. The SPOT-Vegetation has the same channel with SPOT-HRVIR which has 20 m resolution (10 m for panchromatic channel) and the combination of these two sensors are considered useful for monitoring in both global and local scale.

2.2 NOAA-AVHRR data

NOAA satellite data provide a valuable tool for vegetation mapping and monitoring at regional and global scales (Justice et al., 1985). The computer center of Ministry of Agriculture, Forestry and Fisheries, Japan, produces ten day composite images of NOAA AVHRR with 1 km resolution for South-East Asia region. The NOAA-AVHRR Pathfinder dataset (by NOAA) is one of the most popular one for global study.

2.3 LMF and LMF-KF Processing to the Dataset

The SPOT and NOAA datasets, however, have some difficulties in applying them to long-term change detection in regional scale. One of the main problems is the influences of cloud cover and other noises for observing terrain conditions even by the best composite images in 10 days. The changes of sensitivity of sensors on different satellites also make indispensable problem for data comparison in a long period of time (ex. the NOAA-Pathfinder data). Then, the LMF and LMF-KF processing were applied to minimize the effect of clouds and the sensitivity differences of sensors in these dataset.

2.4 NDVI and Temperature data

After the processing, we could get the same number of “clear (cloud-free)” images as the original dataset. The characteristics of each forest site on NDVI and temperature are evaluated from these data. For example, we created the summation data of NDVI in one year when the surface temperature is greater than 5 degree Celsius (this value is commonly used for the warm index). It seems that the summation values correspond to the vegetation production of one year, although further research is still needed.

2.5 Snow Index

The snow cover is one of the key environmental factors for forest ecosystem. Therefore many researchers have conducted to create snow cover maps. However, during the snow season, it is quite difficult to obtain clear sky remote sensing data. The LMF and LMF-KF processed images are effective even in this case. Saito et al(1999) reported the snow cover index for GLI data as the Eq. 1

S3={NIR1・(VIS-NIR2)}／{(NIR1+VIS)/(NIR1+NIR2)} (1)

where
NIR= near infrared data
NIR= middle infrared data
VIS= visible red

The results show that the snow index S3 has quite sensitive with snow cover. The LMF processed SPOT-Vegetation 10-day composite data made us possible to create snow cover maps every 10 days. The images showed the duration of snow cover for each pixel (1km). According to our pre-check, it was the first time that snow cover map with 1 km resolution was created for Mekong River Basin. However, where snow covers less than one month, the original SPOT S10 data itself does not useful to detect the duration of snow cover because of its characteristics of the data composition procedure.

2.6 Leaf Water Content Indices

2.6.1 LWCI (Leaf Water Content Index): The LWCI (Leaf Water Content Index) was reported effective to monitor leaf water condition or water availability (Anazawa et al., 2002). The LWCI is defined for the Landsat-TM as the Eq. (2).

$$LWCI = \frac{-\log[\alpha \times (TM4/A - \beta\, TM5/B)]}{-\log[\alpha \times (TM4\,ft/A - \beta\, TM5\,ft/B)]} \quad (2)$$

where
TM4= energy value of Landsat TM4
TM5= energy value of Landsat TM5
TM4ft=energy value of TM4 at full turgor (at the minimum water stress)

TM5ft=energy value of TM5 at full turgor (at the minimum water stress)
A=Maximum value of TM4 through a year
B=Maximum value of TM5 through a year
A=the correction coefficient (usually 1)
B=the coefficient for converting he energy value into the reflectance (the reflectance ratio at the season of the minimum water stress in a leaf = the ration of TM5 to TM4 in the theoretical solar radiation spectrum curve: the representative value=0.2)

2.6.2 NDII(Normalized Difference of Infrared Index): The NDII is defined as follows;

$$NDII = \frac{TM4 - TM5}{TM4 + TM5} \qquad (3)$$

The NDII is highly correlated to vegetation water content (Hunt, 2004). Both the LWCI and NDII are consisting from TM4 and TM5. The relationship between the two indices in vegetated area is quite high, although it somehow depends on ground cover.

2.6.3 Water Indices for NOAA data: Because the NOAA-AVHRR does not have middle infrared channel, we tried to develop an index that is suitable for monitoring water condition in forest area using NDVI, VTI (modified NDVI) and thermal data. The steps were as follows;

(1) Step 1 : to develop a suitable linear regression model related to NDII for Landsat TM (20 Feb. 2002).

The result showed that the best model was obtained as Eq. (4)

$$NDII = 390 + 1.20NDVI - 0.749VTI - 1.65CH6 \qquad (4)$$

where
NDVI= Normalized Difference of Vegetation Index
VTI= Modified NDVI
CH6=Channel 6 (Thermal channel)

(2) Step 2 : to apply the linear regression model to NOAA data (in middle Feb. 2002, LMF-KF processed)

Base on the idea in Step 1, the linear regression model related to TM-NDII was developed for NOAA-AVHRR. The obtained equation was Eq. (5)

$$NDII = 77.5 + 4.4NDVI - 2.04VTI - 0.014CH4 \qquad (5)$$

(3) Step 3 : to create NOAA water content images

The regression model was applied to each pixel to create the estimated NDII image (Fig.1).

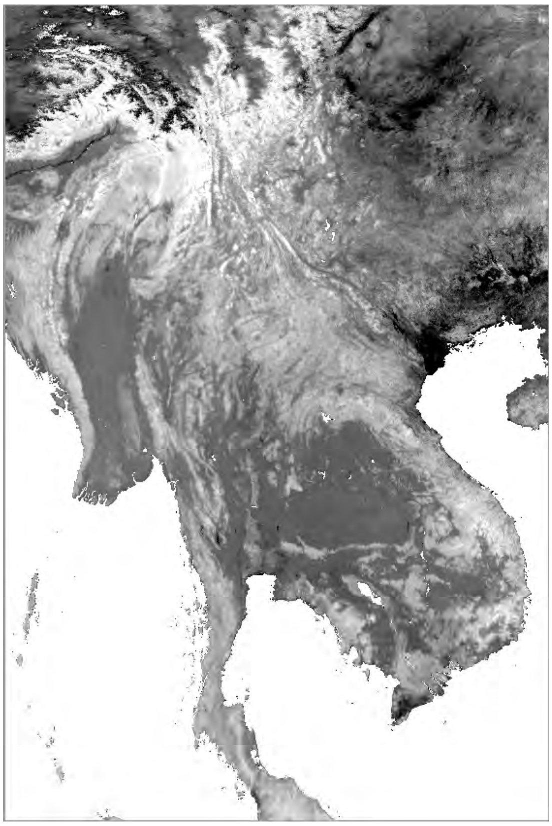

Figure 1. Water Index Image

3. DISCUSSION

The LMF and LMF-KF processing was found useful technique for deleting the effect of clouds and other noises for observing the ground condition in this region. Because the differences of sensitivity of the AVHRR sensors are also corrected by this method, it makes us possible to compare the phenological changes for a long period of time.

The LMF processed SPOT-Vegetation data were useful to create snow cover map every 10 days.

Water content indices were analyzed for Landsat TM and NOAA AVHRR data. A linear regression model was developed for estimating the water content of vegetation by the NOAA-NDVI and CH4 (thermal channel). The results show that the coarse resolution satellite data gives time sequential data by deleting the affect of clouds and other noises that interrupt the terrain observation. Therefore, these approaches are considered effective to reveal the most important environmental condition, such as water and temperature, in forest area.

Because the SPOT-Vegetation has middle infrared data, the water content index (NDII) is directly created by its own data. However, because the SPOT-Vegetation does not have thermal data and NOAA or other satellite data is needed to monitor surface temperature. Further study on water content index for NOAA data is still needed with sufficient data comparison with Landsat data and ground information (meteorological information).

Because high resolution satellite data are obtained “by chance” depending on the weather condition and system management, it is quite often difficult to get the “appropriate data” both in spatially and temporally. The multi-stage monitoring design with “cloud free” images shall be useful not only for broad-scale but also for local forest cover monitoring in various areas because of its usefulness of the monitoring efficiency of seasonal changes.

The combination of NDVI and the Surface Temperature derived from NOAA with 10 day interval show various information on ecological characteristics in regional scale (Fig. 2).

Figure 2. Summation of NDVI when temperature > 5 C

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Names of journals can be abbreviated according to the "International List of Periodical Title Word Abbreviations". In case of doubt, write names in full.

Scientific paper

Probability-Based Maintenance Planning for RC Structures Attacked by Chloride

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Abstract

There are many uncertainties relating to the deterioration of reinforced concrete (RC) structure, and as a result, the actual degree of deterioration of structures is not uniform. Currently, various safety factors are considered to cover those uncertainties. This paper proposes a new method for maintenance planning of RC structures degraded by chloride attack based on probability theory. Prediction models of deterioration caused by chloride attack both before and after repair are discussed. The effects of crack and macrocell corrosion were considered to accelerate the deterioration in the prediction model. Surface coating, patching repair, cathodic protection, and combinations thereof were considered as repairing options. Moreover, the effects of partial and full repair were also considered in the deterioration of the repair system. The actual variation of structural properties and the environmental conditions obtained from the inspection program were used directly as input for prediction. By using Monte Carlo simulation, variations of deterioration degree can be predicted. Based on the prediction result, repair and failure costs are determined and used to design the maintenance planning program. Finally, applications of maintenance planning of actual case studies are given as an example.

1. Introduction

Reinforced concrete (RC) structures deteriorate over time when they are subjected to an aggressive environment. To maintain structural safety and serviceability, almost all structures need an appropriate maintenance program to be applied during their service life. In 2002, Japan allocated approximately 13.5 trillion yen, which is 21.5% of the total construction budget, for the maintenance of the existing infrastructure. The ratio of maintenance budget to the overall construction budget is expected to continuously increase in the future because of the increasing number of aging structures.

Corrosion of reinforcing steel due to chloride attack is one of the main mechanisms degrading RC structures. The expansion of corrosion product causes cracking and spalling of covering concrete. Therefore, maintenance is required to prevent corrosion and to repair any damage that has been observed. In general, the mechanisms of chloride induced corrosion can be considered as consisting of 4 stages (JSCE 2005a). The initiation stage is dominated by the diffusion of chloride ions from the environment toward the surface of the reinforcing steel. The propagation stage starts when the chloride content at the steel surface exceeds the threshold level at which corrosion will initiate. Internal pressure is gradually generated by the corrosion product and finally corrosion cracks are generated after internal pressure exceeds the tensile strength of concrete. The third stage is the acceleration stage, during which the presence of corrosion cracks accelerates the deterioration rate. The final stage is the deterioration stage, during which the load bearing capacity of the structure is significantly affected. Various prediction models have been proposed for each stage of deterioration.

JSCE (2005b) regulates durability design to ensure the durability of structures during their design service life based on performance based design. In reality, there are many uncertainties, such as material properties, structural dimensions, environmental conditions, and the prediction model. As a result, the degree of deterioration of an actual RC structure is not uniform (Komure *et al.* 2002). Traditionally, safety factors are incorporated in design to cover these uncertainties, leading to high cost and overdesign of the structure.

During the service life of a structure, maintenance is required to ensure that acceptable structural performance is maintained. Various bridge management systems (BMS) have been developed in many countries (Hawk and Small 1998 and Thompson *et al.* 1998). BMS includes periodic assessment of structural conditions, updating deterioration prediction, and making maintenance decisions. Most of the current BMS are based on a deterministic prediction model that takes into consideration safety factors or a Markov process that uses a database of the deterioration progress. As a result, prediction of variation in the degree of deterioration of a structure as observed in the actual structure accurately based on fixed parameter values in a deterministic model is not

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possible. In this study, a method to predict variation in the degree of deterioration of an RC structure degraded by salt attack both before and after repair is proposed based on a deterministic model combined with consideration of actual variations in structural properties and environmental conditions based on actual inspection results. Monte Carlo simulation is used to consider the uncertainties. Finally, the predicted degree of deterioration is used to calculate repair and user costs for maintenance planning.

2. Deterioration prediction model

As explained, different deterioration prediction models have to be considered for different stages of deterioration, and re-deterioration of repairs that have been made. This section describes the deterioration prediction models used in this study.

2.1 Chloride diffusion prediction model

The penetration of chloride ions into concrete can be considered as a diffusion process and therefore can be described by Fick's second law of diffusion. The most famous solution used in the analysis of chloride diffusion in concrete is taking the surface chloride concentration as a boundary condition, as shown in Eq. 1.

$$C(x,t) = C_0\left[1 - erf\left(\frac{x}{2\sqrt{D_c \cdot t}}\right)\right] \qquad (1)$$

where C(x,t) is the chloride ion concentration at depth x (cm) after time t (years) (% by weight of concrete), C_0 is the surface chloride concentration (% by weight of concrete), D_c is the apparent diffusion coefficient of chloride ions (cm^2/year), and erf is the error function. JSCE (2005b) recommends values for the surface chloride concentration and chloride diffusion coefficient. In reality, the value of the apparent diffusion coefficient of chloride ions is time-dependent. Therefore, in this study, the variation in the surface chloride concentration and the apparent diffusion coefficient of chloride ions are obtained directly from the inspection result of the chloride concentration profile. As a result, the time-dependent property of the apparent diffusion coefficient of chloride ions is considered as a long-term average value from the inspection results as well as the effect of convection on the penetration of chloride ions.

After the chloride concentration at the surface of the reinforcing steel reaches the threshold value, corrosion is initiated. The threshold chloride concentration depends on various factors such as cement content, type of cement, and environmental conditions. (Glass and Buenfeld 1997, Taylor *et al.* 1999, and Whiting *et al.* 2002). In this study, the threshold chloride concentration is assumed to vary as a lognormal distribution with a mean of 0.05% by weight of concrete and coefficient of variation 10% (Enright and Frangopol 1999).

2.2 Corrosion induced cracking

After the initiation of corrosion, corrosion product is formed and the internal pressure gradually increases according to the rate of corrosion. As the internal pressure reaches the tensile strength of concrete, cracks are generated. Li *et al.* (2006) proposed a model to predict the width of corrosion cracks, as shown in Eq. 2, based on a mechanical model and the thick wall cylinder model proposed by Bazant (1979).

$$w_c = \frac{4\pi d_s(t)}{(1-\upsilon_c)\left(\frac{a}{b}\right)^{\sqrt{\alpha}} + (1+\upsilon_c)\left(\frac{b}{a}\right)^{\sqrt{\alpha}}} - \frac{2\pi b f_t}{E_{ef}} \qquad (2)$$

where w_c is the corrosion crack width (mm), υ_c is the Poisson's ratio of concrete, α is the stiffness reduction factor, which depends on the average tangential strain over the cracked concrete surface and can be determined from Li *et al.* (2006), f_t is the tensile strength of concrete (MPa), which can be estimated from the rebound hammer test result, E_{ef} is effective modulus of concrete, equals to $E_c/(1+\varphi_{cr})$ (MPa), E_c is the elastic modulus of concrete (MPa), φ_{cr} is the concrete creep coefficient, a is equal to $(D+2d_0)/2$, b is equal to $x + (D+2d_0)/2$, and D is the steel diameter (mm), d_0 is the thickness of the pore band of the steel and concrete interface (mm), which is the interfacial layer between the steel surface and the concrete. The pore band has to be completely filled before pressure can be generated from the rust. Its thickness is assumed as Liu and Weyers (1998), and $d_s(t)$ can be determined from Eq. 3.

$$d_s(t) = \frac{W_{rust}(t)}{\pi(D+2d_0)}\left(\frac{1}{\rho_{rust}} - \frac{\alpha_{rust}}{\rho_{st}}\right) \qquad (3)$$

where ρ_{rust} is the density of corrosion product (kg/m^3), ρ_{st} is the density of steel (kg/m^3), and α_{rust} is a coefficient related to the types of rust products and has a value in the range of 0.523 to 0.622, based on Liu and Weyers (1998). Also, Bhargava *et al.* (2005) reported values of α_{rust} of 0.777, 0.724, 0.699, 0.622, and 0.523 for FeO, Fe_3O_4, Fe_2O_3, $Fe(OH)_2$ and $Fe(OH)_3$, respectively. In this study, α_{rust} is set to be constant and equal to 0.57 as the average value of different corrosion products. $W_{rust}(t)$ is a mass of rust product (mg/mm) and can be determined from Eq. 4 (Liu and Weyers 1998).

$$W_{rust}(t) = \sqrt{2\int_{t_i}^{t}\left(\frac{0.105\pi D i_{corr}(t)}{\alpha_{rust}}\right)dt} \qquad (4)$$

where i_{corr} is the annual mean corrosion rate including microcell and macrocell corrosion (μA/cm^2). When corrosion is initiated, the corrosion rate should be measured in order to predict the corrosion cracking time during the deterioration stage or loss of cross section area of the reinforcing steel during the deterioration and acceleration stages by using linear polarization resistance. For more accurate prediction of structure deterioration, the corrosion rate should be obtained from a series of measurements or through continuous monitoring as the corrosion rate is affected by the conditions of the concrete structure at the time of measurement, such as moisture and temperature.

Actual variation in structural performance such as concrete compressive strength, steel covering depth, steel diameter, as well as the corrosion rate obtained from inspection, can be directly considered in the prediction.

The presence of corrosion cracks also accelerates the ingress of chloride ions as discussed by Maeda *et al.* (2002), Kato *et al.* (2005) and Islam (2006). By subtracting chloride diffusion in non-cracked concrete from cracked concrete, Maeda *et al.* (2002) determined the chloride diffusion coefficient along cracks. Eq. 5 is proposed based on this study. Therefore, chloride diffusion in cracked concrete can be predicted as shown in Eq. 6. The initial chloride content can also be considered if chloride is present. However, cracks can be also initiated by other means such as shrinkage, loading, or temperature changes. Therefore, the prediction of various deterioration mechanisms is very important and should be conducted and combined with the current study in the future.

$$D_{ccr} = \begin{cases} 72.4 \cdot w_c & ; w_c < 0.05\,mm \\ \left(3 \times 10^8\right) \cdot w_c^{6.086} & ; 0.05\,mm \le w_c \le 0.15\,mm \\ 3150 & ; w_c > 0.15\,mm \end{cases} \qquad (5)$$

where D_{ccr} is the chloride diffusion coefficient along the crack (cm^2/year). The effect of variation in predicted corrosion crack width can be seen in the variation of chloride diffusion along the crack.

$$C(x,t) = C_0 \left[1 - erf\left(\frac{x}{2\sqrt{(D_c + D_{ccr}) \cdot t}} \right) \right] \qquad (6)$$

2.3 Re-deterioration of repair system

A number of systems are available to repair an RC structure degraded by chloride induced corrosion. Based on the prediction of the deterioration of a concrete structure, different maintenance systems can be planned to ensure lifetime performance. Each repair system is associated with different costs and performance, and can be applied at different stages of the deterioration process with different effects.

Issues relating to the durability of concrete repair systems are discussed widely by Emberson and Mays (1990), Emmons *et al.* (1993), Morgan (1996), and Cusson and Mailvaganam (1996) as many repair systems show signs of re-deterioration or failure of the system in a short period after repair has been made. In the case of a structure degraded by chloride induced corrosion, surface coating, patching repair, and cathodic protection are the systems that are normally applied. Their deterioration prediction models are considered in this study.

2.3.1 Concrete surface coating

The main benefit of surface coating is that it suppresses the penetration of harmful ions. There are two major approaches to predict chloride diffusion of concrete with surface coating (JSCE 2005c). Surface coating can be considered as an artificial concrete covering depth. Due to the very low chloride diffusion coefficient of coating material, even 5mm of coating thickness is comparable to 20mm of normal concrete covering (JSCE 2005c). Another approach is to predict chloride diffusion through two layers of materials, i.e. coating material and concrete, as shown in Eq. 7 (JSCE 2005c). In this study, prediction of chloride diffusion of coated concrete leads to this equation.

$$C(x,t) = C_0 \left\{ 1 - erf\left[\frac{1}{2\sqrt{t}} \left(\frac{x}{\sqrt{D_c}} + \frac{C_s(t)}{\sqrt{D_s}} \right) \right] \right\} \qquad (7)$$

where C_s(t) is the thickness of coating material (cm) and D_s is the chloride diffusion coefficient of the coating material (cm^2/year).

A surface coating material is also gradually degraded by environmental attacks such as UV radiation. Uomoto *et al.* (2006) described the deterioration of many surface coating systems. Cracks, swelling and color changes in the surface coating material were observed following exposure of the specimens to a marine environment or urban outdoor environment. Due to the complex system and material of the surface coating, a satisfactory deterministic deterioration prediction model has not been determined yet. The review of a large body of literature by JSCE 2005c shows the effective protective period of surface coating to vary in the range of 8 to 26 years. This study evaluates the service life of surface coating based on the recommendation of JSCE 2005c that the effective thickness of surface coating decrease to 20% within 20 years after in-service and be ignored as insignificant after 20 years of service as shown in Eq. 8 (JSCE 2005c).

$$C_s(t) = \begin{cases} C_s \cdot \left(2 - e^{\lambda t}\right) & ; t \le 20 \\ 0 & ; t > 20 \end{cases} \qquad (8)$$

where C_s is the initial thickness of surface coating (cm) and λ is a constant equal to 0.029 according to the recommendation of JSCE (2005c).

The coating material can deteriorate owing to various reasons, both internal and external. Concrete cracks and ultraviolet are examples of internal and external causes of deterioration, respectively. Ultraviolet mainly decreases the thickness of the coating material. Cracks can be form due to cracking at the concrete surface, which may be caused by loading, corrosion, temperature changes, etc. Crack generation in the case of deterioration of the coating material is due to repeated loading such as cyclic temperature change or cyclic crack opening/closing due to service load. This differs from failure at ultimate strength and therefore is considered as fatigue failure. Kato *et al.* (2005) reported resistance of the surface coating material against cracking. Many surface coating materials with different thicknesses were tested by fatigue loading to determine the crack width at the concrete surface that will generate cracks in the surface coating. Kato *et al.* concluded that crack formation in surface coating does not depend on the type of coating material but on the thickness of the coating material. The relation between coating thickness and maximum resistible crack width of surface coating is shown in **Fig. 1** and Eq. 9.

$$W_{cs\lim} = 0.8683 \cdot C_s(t) + 1.7962 \qquad (9)$$

where W_{cslim} is the limit crack width at which the surface coating will be cracked (mm), as shown in **Fig. 1**, and $C_s(t)$ is the effective thickness of the coating material after t years (mm). The variation of W_{cslim} depends on the variation in the thickness of the coating material. In this study, the thickness of the coating material is assumed to be constant. Similarly, after a crack is formed in the surface coating, chloride diffusion along the crack also has to be considered, as shown in Eq. (6).

2.3.2 Patching repair

Patching repair is a method used to replace localized areas of concrete that shows signs of deterioration such as rust liquid, cracking, spalling, or delamination. The repair process removes loose concrete that has cracks, spalling, or delamination, cleans the surface of the steel reinforcement, and then replaces the defective concrete with patching materials. The patching materials normally used are Portland cement concrete, quick-set hydraulic mortar and concrete, and polymer mortar and concrete. Depending on the chloride diffusion coefficient of the patching material, chloride diffusion can be predicted with an equation similar to Eq. 1.

Many patch repairs and their surrounding areas exhibit new corrosion damage after a few months to a year (Qian *et al.*, 2006; Uomoto *et al.*, 2006). In patch repair systems, the patched area and the substrate areas provide the embedded steel bars with dissimilar electrochemical environments. Imbalance of electrochemical potential is caused by many factors including physical properties (density, porosity, and permeability), and chemical composition (chloride content and oxygen content). Nanayakkara and Kato (2007) also revealed that corrosion of reinforcing steel is mainly found in patch repaired area. This may be due to physical incompatibility such as permeability between the patching material and concrete substrate. Pruckner and Gjorv (2002) determined that the macrocell corrosion current can be simply determined by Ohm's law as shown in Eq. 10.

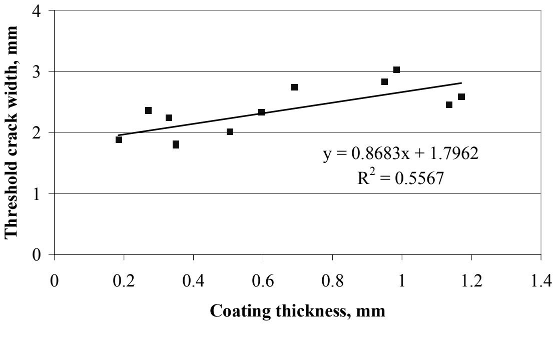

Fig. 1 Relation between surface coating thickness and threshold crack width.

$$I_{mac} = \frac{\Delta U}{R_E + R_{st} + R_A + R_C} \qquad (10)$$

where I_{mac} is the macrocell corrosion current (A/cm^2), ΔU is the corrosion cell voltage (V), R_E is the concrete resistance (Ω/cm^2), R_{st} is the reinforcing steel resistance (Ω/cm^2), R_A is the anodic reaction resistance (Ω/cm^2), and R_C is the cathodic reaction resistance (Ω/cm^2). Feliu and Gonzalez (1989) reported that the polarization resistance of steel in concrete without chloride (cathodic reaction) and with chloride (anodic reaction) is in the range of 10^5-10^6 Ω/cm^2 and 10^3-10^4 Ω/cm^2, respectively. Anodic reaction resistance and cathodic reaction resistance depend on the condition of the steel surface. For example, if the steel surface is no depassivated, the anodic resistance is infinite. If no oxygen is available, the cathodic resistance is infinite. In the deterioration stage, corrosion is ongoing. Therefore, the resistance of the anodic area (anodic resistance) is significantly lower than the resistance of the cathodic area (cathodic resistance) and concrete. Thus, anodic resistance can be neglected from Eq. 10 as well as the resistance of reinforcing steel, which is very low by nature. Concrete resistance can be measured directly as explained by Feliu and Gonzalez (1989). In this study, cathodic resistance is assumed to be 100,000 Ω/cm^2 and concrete resistance to be 600 Ω/cm^2 based on experimental results obtained by Feliu and Gonzalez (1989).

Corrosion cell voltage (ΔU) is caused by the electrochemical potential difference between the existing concrete and repair patch (Gu *et al.*, 1997) due to different chloride concentrations and permeability. The electrochemical potential at the reinforcing steel surface can be measured relatively by the half-cell potential method. Suzuki *et al.* (2007) measured the half-cell potential of similarly treated ordinary Portland cement concrete specimens cast with different chloride content. **Figure 2** shows the half-cell potential results. An empirical equation is proposed to estimate the half-cell potential at different chloride concentrations in concrete, as shown in Eq. 11.

$$U_c = -953.1 \cdot C(x,t) - 7.9921 \qquad (11)$$

where U_c is the half-cell potential of reinforcing steel in OPC concrete (mV) and C(x,t) is the chloride ion concentration in concrete at the steel surface at time t (% by weight of concrete).

The half-cell potential of reinforcing steel when using polymer modified mortar as the patching material is different from that in OPC concrete. Specimens made from patching material as described by Nanayakkara (2006) were measured for their half-cell potential, and the results are shown in **Fig. 3**. Similarly, the equation to estimate the half-cell potential at different chloride concentrations is shown in Eq. 12. The half-cell potential depends largely on the type of material. The specific equation of each material should be obtained before considering macrocell corrosion and the applied method proposed in this study.

$$U_p = -313.84 \cdot C(x,t) - 277.65 \qquad (12)$$

where U_p is the half-cell potential of reinforcing steel in patching material (mV), and C(x,t) is the chloride ion concentration in concrete at the steel surface at time t (% by weight of concrete). The comparison of the calculated macrocell corrosion current based on Eq. 10 and the measured corrosion current conducted by Nanayakkara (2006) is shown in **Fig. 4** at different chloride concentrations between the existing concrete and the repaired section. Although a trend of increase in the macrocell corrosion current with increasing chloride concentration can be seen in both the measured and calculated results, differences between the measured and calculated results can be observed. The corrosion current is affected by many factors such as temperature, the moisture condition of specimens, etc. For more accurate prediction of the macrocell corrosion, the corrosion rate should be obtained from a series of measurements or through continuous monitoring as the corrosion rate is affected by the conditions of the concrete structure at the time of measurement, such as moisture and temperature. The macrocell corrosion calculation principle is applicable but Eqs. 11 and 12 should be modified in the future when more data on the long-term monitoring of macrocell corrosion becomes available.

2.3.3 Cathodic protection

Cathodic protection is one of the most common and effective methods for corrosion control of steel reinforced concrete. Cathodic protection controls the corrosion of steel in concrete by applying an external source of direct current to the surfaces of the embedded steel. Depending on the type of anode system, the service life of the systems is between 5 and 35 years, as shown in **Table 1** (SHRP 1993a).

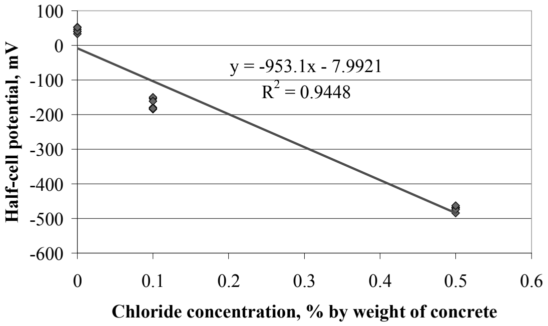

Fig. 2 Half-cell potential at different chloride concentrations in OPC concrete specimens.

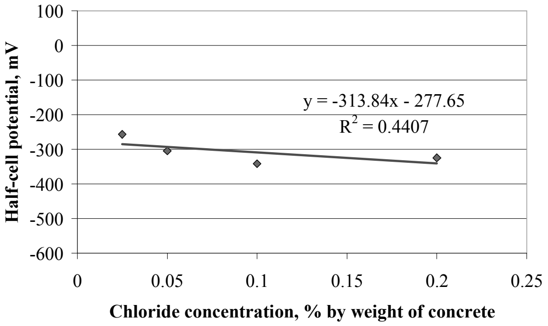

Fig. 3 Half-cell potential at different chloride concentrations in patching repair material.

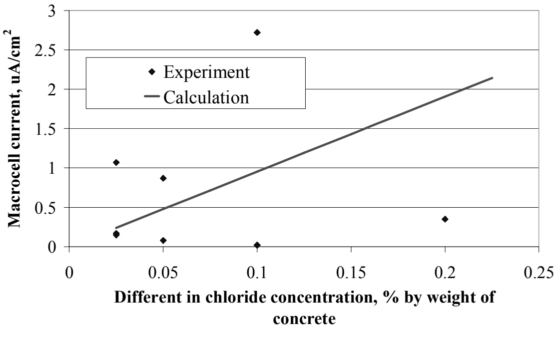

Fig. 4 Comparison between experimental measured macrocell corrosion current and calculation result.

Table 1 Estimated service life of cathodic protection system.

Anode system	Structure protected	Estimated service life, years
Coke-asphalt overlay	Decks	20
Slotted conductive polymer grout	Decks	15
Mounded conductive polymer with concrete overlay	Decks	20
Titanium mesh with concrete overlay	Decks	35
Titanium mesh with shotcrete	Substructures	35
Conductive paint	Substructures	5
Sprayed zinc	Substructures	15

During the effective period of the cathodic protection system, the corrosion current of the reinforcing steel is neglected even though the chloride concentration is higher than the threshold concentration. When the cathodic protection system is ineffective, the corrosion current is similar to no protection RC structure, as shown in Eq. (13).

$$i_{corr}(t) = \begin{cases} 0 & ; t \le t_{eff} \\ i_{corr} & ; t > t_{eff} \end{cases} \tag{13}$$

where $i_{corr}(t)$ is the corrosion current of reinforcing steel at time t ($\mu A/cm^2$) and t_{eff} is the effective service life of the cathodic protection system (year).

3. Probability-based deterioration prediction model

Due to the high level of uncertainty that exists in reality, it is difficult to predict the degree of deterioration of RC structures with certainty. Moreover, in practice, limited data and incomplete knowledge about the parameters used in the prediction model, and the varying nature of environmental conditions introduce a degree of uncertainty in prediction results. Instead of considering safety factors, a probability-based model is used in this study to directly consider uncertainties. Monte Carlo simulation is one of the methods used to deal with probability-based simulation and it is used in this study.

Monte Carlo simulation (Fishman 1995) uses generated random numbers and probability statistics sampling of uncertainty variables to provide approximate solutions to a variety of mathematical problems. The values of parameters are randomly generated based on the determined probability density function of each parameter and used in the prediction model. Therefore, variations in deterioration degree can be predicted. **Table 2** lists a sample of the various parameter values used in prediction from the literature (Nowak *et al*. 1994, Liu and Weyers 1998, Enright and Frangopol 1999, and JSCE 2005b). In reality, actual variation of parameters as shown in **Table 2** can be obtained directly by inspecting the target structure before conducting maintenance planning. Due to the variation of parameters used in prediction models, variation of prediction results can be seen in **Figs. 5** and **6** for the chloride content at the steel surface and the corrosion crack width at the concrete surface, respectively. Because the distribution function of input parameters differ(log-normal, normal, or constant) as shown in **Table 2**, and a random numbers is generated independently for each distribution function of input parameters, the prediction results shown in **Figs. 5** and **6** show unique distributions. The distribution of prediction results can be used to further estimate the amount of repair and the repair cost.

3.1 Probability of Damage

The probability of damage is defined as the probability that the limit state of a system will be violated after time period t. In order to determine the probability of damage, a limit state function has to be defined. Generally, a limit state function can be defined in terms of system resistance against applied load over time in different ways. In this study, the corrosion crack width is considered as a limit state. Therefore, the probability of damage is the probability that the corrosion crack width will be larger than the limit crack width. The crack width is limited as the deterioration of RC structure accelerates in the presence of cracks. JSCE (2005b) regulates the allowable crack width as shown in **Table 3**. The limit state function is shown in Eq. 14.

Table 2 Random variables of parameters.

Parameter	Type of distribution	Mean	Coefficient of variation	Reference
x	Log Normal	38.1 mm	0.05	Enright and Frangopol (1999)
D_{cl}	Log Normal	1.29 cm^2/year	0.1	
C_{lim}	Log Normal	0.05 % by weight of concrete	0.1	
C_s	Log Normal	0.20 % by weight of concrete	0.1	
D	Normal	1.6 cm	0.015	Nowak *et al*. (1994)
$f_c^{'}$	Normal	35.1 MPa	0.18	
i_{corr}	Constant	2 $\mu A/cm^2$	-	Liu and Weyers (1998)
d_0	Constant	12.5 μm	-	
α_{rust}	Constant	0.57	-	
ρ_{rust}	Constant	3600 kg/m^3	-	
ρ_{st}	Constant	7850 kg/m^3	-	
E_c	Constant	30.1 GPa	-	JSCE (2005b)
φ_{cr}	Constant	1.1	-	
υ_c	Constant	0.20	-	

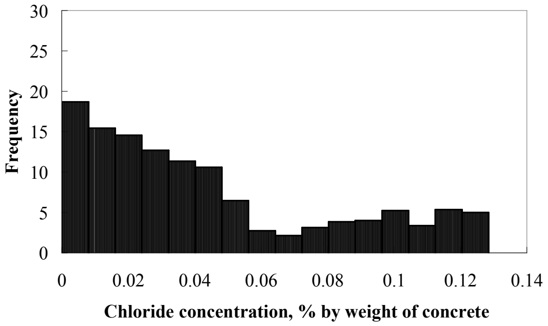

Fig. 5 Distribution of chloride concentration at steel surface after 10 years.

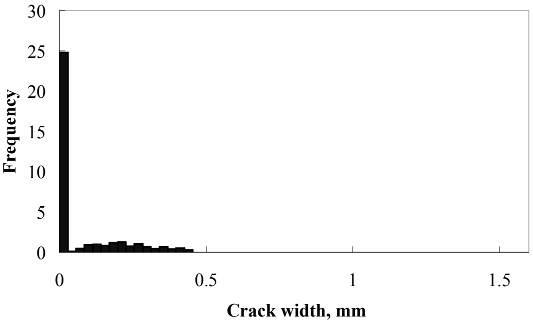

Fig. 6 Distribution of corrosion crack width after 10 years.

Table 3 Permissible crack width.

Type of steel	Environmental condition		
	Normal	Corrosive	Severely corrosive
Deformed and Plain bar	0.005C	0.004C	0.0035C
Prestressed steel	0.004C	-------	-------

C = covering depth (mm)

$$Z_x(t) = W_{c\lim} - W_c(t) \tag{14}$$

where w_{clim} is the allowable crack width (mm) as shown in **Table 3**, and $w_c(t)$ is the corrosion crack width at time t (years) (mm).

Individual random variables required in prediction by Monte Carlo simulation are generated. The value of the limit state function at time t, Z(t), is evaluated for N times. The whole life performance of a deteriorating structure can be characterized by finding its probability of damage over the lifetime interval (0, T] as shown in Eq. 15.

$$P_f(t) = \frac{N_f(t)}{N} \tag{15}$$

where $P_f(t)$ is the probability of damage at time t, $N_f(t)$ is the number of evaluations where $Z(t) < 0$, and N is the total number of evaluations.

The effect of cracking due to drying shrinkage, thermal cracking since the beginning of the service life of the structure, or corrosion cracking after the structure entered service can be considered in the prediction of the probability of damage. After cracking is initiated due to corrosion, the rate of chloride diffusion is accelerated. Therefore, the probability of damage increases faster after initiation of corrosion cracking after year 7 compared to when cracking is not considered, as shown in **Fig. 7**. Moreover, the effect of macrocell corrosion also increases the probability of damage. As shown in **Fig. 7**, considering initial crack does not significantly affect the result of probability of damage.

3.2 Effect of repair on probability of damage

After repair has been conducted, the performance of the repaired section normally recovers to the non-deteriorated condition, and the durability of the repaired section is normally improved, whereas non-repaired sections continue to deteriorate. There is also a difference in the deterioration rate of non-repaired and repaired sections. In this study, differences in the deterioration rates of repaired and non-repaired sections are also considered.

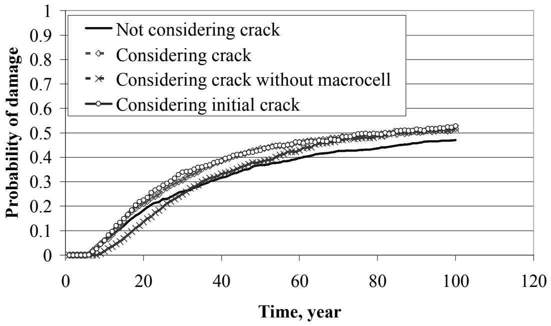

Fig. 7 Effect of crack on probability of damage due to corrosion crack width.

In this section, the parameters listed in **Table 2** are used for the calculation of structural performance, and the chloride diffusion coefficient of the patching material is 0.1 cm^2/year. **Figure 8** shows a comparison of the probability of damage between fully recovered and partially recovered repaired sections. The target structure was divided into 1000 sections and the degree of deterioration was determined for each divided section. The number of sections that fail at the limit state and need repair can be calculated based on the variation in inspection results as discussed in section 3.1. The macrocell corrosion current is affected by the number of repaired sections as the result of differences in chloride content between repaired and non-repaired sections. In the case of 100% recovery, this means all divided sections of a structure are assumed to have been recovered to the initial condition (0% chloride content) after repair at year 40 has been conducted. While in the case of partial recovery, this means that only the divided sections that need repair at year 40, which account for 40% of the structure as shown in **Fig. 8**, have recovered to the initial condition (0% chloride content). The chloride content of the remaining 60% of structures that have not been repaired remains undiminished and continues increasing. As shown, the probability of damage of partially recovered cases re-deteriorates faster than that of 100% recovered. The effect of each repairing method considered in this study on the probability of damage is discussed in the next section.

3.2.1 Concrete surface coating

Figure 9 shows the effect of the surface coating thickness on the probability of damage due to corrosion crack width. As shown, the probability of damage decreases as the thickness of the coating layer increases during the service life of the surface coating. In the case of a thin surface coating, the probability of damage increases before the end of the service life of the surface coating because the surface coating develops cracks before the end of the service life.

3.2.2 Patching repair

The probability of damage of a patching repair system depends on the performance of patching repair, which is mainly affected by the chloride diffusion coefficient and macrocell corrosion. **Figure 10** shows the effect of different diffusion coefficients of chloride ions of the patching material on the probability of damage. As the chloride diffusion coefficient of the patching material decreases, the probability of damage of the corrosion crack width also decreases following repair because the lower chloride diffusion of the repair material can decrease the rate of re-deterioration of the repaired section.

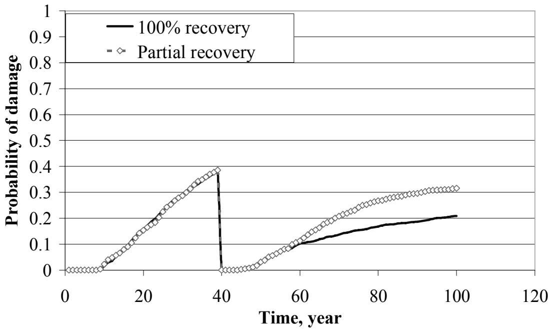

Fig. 8 Effect of recovery condition on probability of damage due to corrosion crack width.

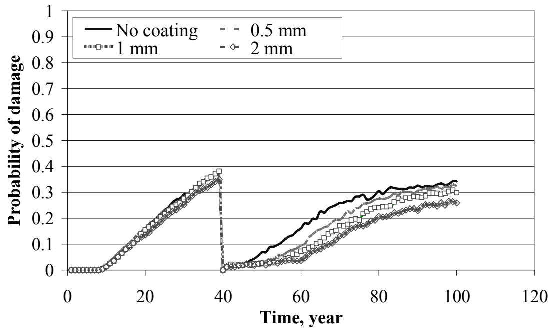

Fig. 9 Effect of coating thickness on probability of damage due to corrosion crack width.

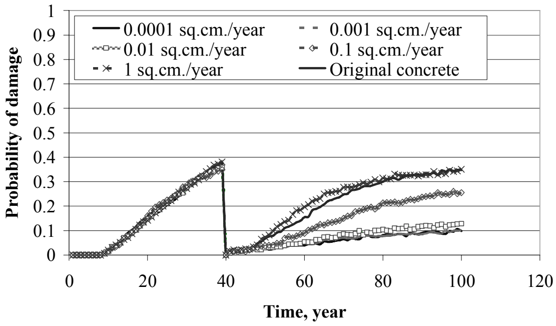

Fig. 10 Effect of chloride diffusion coefficient of patching material on probability of damage due to corrosion crack width.

3.2.3 Cathodic protection

As cathodic protection can prevent corrosion of reinforcing steel due to applied current, the system has an effective service life. In this section, the parameters listed in **Table 2** are used in calculation of structural performance and 20 years is used as the service life of a cathodic protection system. The chloride diffusion coefficient of the patching material is 0.1 cm^2/year and the thickness of the coating material is 2 mm. The structure is assumed to be repaired at year 40 by different repair methods. The effect of the cathodic protection system on the probability of damage due to corrosion crack width is shown in **Fig. 11**. This figure shows also a comparison between cathodic protection and other repair methods. As shown, following repair of the structure at year 40 using different repair methods, the probability of damage of repair by cathodic protection is the lowest among the various repair methods. After the effective period of cathodic protection, the probability of damage increases rapidly after cathodic protection system failure because there is no longer protection against chloride penetration. Application of cathodic protection with surface coating can minimize the probability of damage even after the failure of the cathodic protection system.

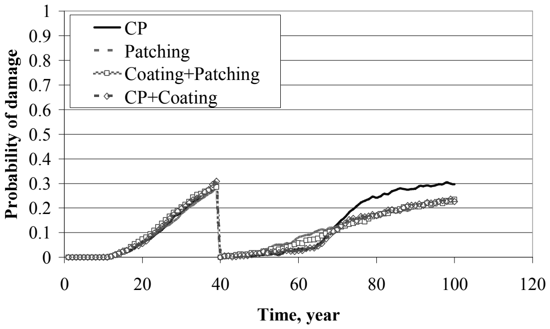

Fig. 11 Effect of cathodic protection on probability of damage due to corrosion crack width.

4. Maintenance planning

The general goals of engineering design are maximizing the utility of a structure while simultaneously minimizing its life-cycle costs, which actually include the costs for developing, manufacturing, and maintaining the structure. This task is complicated by the inherently non-deterministic nature of the structure itself and the environmental conditions to which it is exposed. Also, many maintenance methods presenting different costs and performance are available. Together with the probability-based deterioration prediction model, the maintenance program has to be economically planned. Life cycle cost evaluation is one of the economical tools that can help decision makers determine the most suitable plan. The repair method and its schedule can be planned based on the method proposed in this study.

4.1 Life cycle cost calculation

Life cycle cost can be classified mainly into agency direct cost and user cost. Agency direct cost includes all costs incurred directly by the agency over the life of the project such as construction cost, inspection cost, and repair cost. User cost consists mainly of cost of traffic delay or detour of users of that facility. Failure cost due to loss of life or property is also considered to be part of user cost. In this study, life cycle maintenance cost is considered to consist mainly of the repair cost, user cost, and failure cost.

4.1.1 Repair cost

In order to determine repair cost, information on the cost of repair and the expected quantity of repair have to be determined for each repair method as shown in Eq. 16.

$$E\left[C_{r_i,t}\right]=\sum_{i=1}^{n}\left[C_{rf,i}+\left(C_{rv,i}\cdot p_{i,t}\right)\right] \tag{16}$$

where $E[C_{ri,t}]$ is the expected cost of repair i^{th} at time t, $C_{rf,i}$ is the undiscounted fixed repair cost of repair i^{th}, $C_{rv,i}$ is the undiscounted variable repair cost of repair i^{th}, and $p_{i,t}$ is the quantity of repair i^{th} at time t.

In this study, surface coating, patching repair, and cathodic protection are considered as the available repair methods. Their costs of repair can be determined from historical cost data. Fixed cost, variable cost, and annual maintenance cost are defined, as follows. Fixed cost is repair cost that does not depend on the quantity of repair. It is the minimum amount of resources that have to be used in order to conduct one repair such as the cost of heavy equipment, office space, etc. Variable cost is repair cost that depends on the quantity of repair such as single-use items, material, and labor. In some repair methods such as cathodic protection, the annual maintenance fee includes electricity including power used for system monitoring is also a factor. Historical data of the Strategic Highway Research Program (SHRP) is used as the repair cost data in this study. SHRP (1993b) reported cost information of surface coating and patching repair. SHRP (1993c) reported cost information of various cathodic protection systems. A sample of the cost data is shown in **Table 8**. The quantity of repair is determined from the deterioration prediction result based on probability-based model explained in the previous section.

4.1.2 User cost

User cost is made up of added vehicle operating costs and delay costs to highway users resulting from the deteriorated condition of the structure. In this study, time loss due to increased travel time of users along the deteriorated target structure and loss of life and property of users due to structural failure are considered. Note that different user costs should be considered for different types of structures.

User loss time is the difference between the travel time of users along a healthy structure and deteriorated structure, as shown in Eq. 17.

$$t_{loss}(t)=\frac{Dist}{\alpha_v\cdot V_i}-\frac{Dist}{V_i} \tag{17}$$

where $t_{loss}(t)$ is the time loss of user (min), Dist is the travel distance of users along the target structure, V_i is the designed travel speed along the target structure, and α_v is the reduction ratio of travel speed of users along the deteriorated structure and can be determined from Eq. 18 obtained from the relation between the average speed and the ratio of current volume of users to capacity of the structure (New Jersey Department of Transportation 2001). Note that maintenance planning should use local information, if available, for appropriately determine the maintenance plan. In this study, results from the USA and Japan are used as examples as there is a shortage of user cost information in Thailand. However, this data from the USA and Japan is not actually appropriate for Thailand. Local information on the designed capacity of traffic volume and reduction of traffic volume at each level of structural deterioration should be collected and used in Eq. 18, as well as the local user cost, shown in **Table 4**, in the future.

$$\alpha_v = 0.7143\left[\frac{Vol(t)}{Vol_i}\right]^2 + 0.2381\left[\frac{Vol(t)}{Vol_i}\right] + 0.019 \qquad (18)$$

where Vol_i is the designed capacity of traffic volume of the target structure (vehicles/hour) (in this study 2200 vehicles/hour (New Jersey Department of Transportation 2001) is used), and Vol(t) is the maximum capacity of traffic volume of the deteriorated structure at time t (vehicles/hour), which can be determined from Eq. 19.

$$Vol(t) = Vol_i - \lfloor p_f(t) \cdot (Vol_i - Vol_{\min}) \rfloor \qquad (19)$$

where $p_f(t)$ is the probability of damage due to crack width at time t, and Vol_{min} is the minimum capacity of traffic volume along the fully deteriorated structure.

The Study Group on Road Investment Evaluation (2000) has determined the time value of road users, as listed in **Table 4**. Therefore, user cost can be calculated based on the expected volume of users and predicted time loss of users.

4.1.3 Net present value

In order to compare life cycle cost along the service life of the structure, it is important to convert the value of money at different times to a common point in time. Present value (PV) uses an appropriate discount rate to determine the value of future costs at present time, as shown in Eq. 20.

$$PV_{LCC} = \sum_{i=1}^{n} \frac{\lfloor E(C_{r,i}(t)) + C_f(t) \rfloor}{(1+r)^{t_i}} \qquad (20)$$

where PV_{LCC} is the present value of life cycle cost, $E(C_{r,i}(t))$ is the expected cost of repair i^{th} at time t, $C_f(t)$ is the failure cost at time t, and r is the discount rate.

5. Case studies

In order to demonstrate the application of the maintenance management program proposed in this study, actual RC structures attacked by chloride induced corrosion were selected for application of the methods proposed in the previous section. Two structures, one representative of a bad quality structure and the other of a good quality structure, were selected. In the case of a good quality structure, emphasis is placed on structural durability starting from the design phase, such as increasing covering depth, specifying a selective mineral admixture to improve the durability of the concrete material, and good quality control of construction. The background information of the selected structures is given in **Table 5**. **Figures 12** and **13** show the location and pictures of the structures. An inspection program was conducted to determine variations of structural properties such as covering depth, chloride diffusion coefficient, and compressive strength. Variation of deterioration degree was predicted and maintenance planning was proposed based on the expected life cycle cost. Note that the two structures have different ages in service. Thus, the older structure may show higher compressive strength due to full hydration and the younger structure may show a higher apparent chloride diffusion coefficient due to a lower degree of hydration. Inspection should be periodically conducted during the service life of each structure. Inspection results should be used to predict the structural performance during different periods.

Fig. 12 Area of inspection.

Table 4 Time value of user.

Vehicle class	Time value (yen/vehicle-minute), (US$/vehicle-minute)	
	Weekday	Holiday
Passenger car	56 (0.54)	84 (0.80)
Bus	496 (4.75)	744 (7.12)
Small truck	90 (0.86)	90 (0.86)
Ordinary truck	101 (0.97)	101 (0.97)

Table 5 Information of inspected structures.

Case	Location			Year of construction
	Province	Latitude	Longtitude	
Bad	Samutprakan	13°30′05.62″N	100°46′11.05″E	1963
Good	Chanthaburi	13°29′12.81″N	102°03′38.20″E	2005

(a) (b)

Fig. 13 Picture of actual inspected structure (a) Bad quality (b) Good quality.

5.1 Inspection program

Sancharoen *et al*. (2006a) revealed that parameter variables, including steel covering depth, chloride diffusion coefficient, surface chloride content, and concrete compressive strength, significantly affect the performance of RC structures against chloride attack as well as the prediction result of maintenance planning. Therefore, the inspection program conducted in this study was mainly focused on determining the random variable of these parameters, as explained below. The total numbers of samples of each inspected item are listed in **Table 6**.

The covering depth of reinforcing steel was measured by a rebar detector based on the principle of the electromagnetic method. Only concrete with a smooth surface was inspected. Then all of data were collected together for each structure to finalize their variations.

The chloride diffusion coefficient and surface chloride content were calculated from the profile of chloride content. Samples of concrete powder were collected on site using a drilling machine with a 14 mm diameter drilling bit based on the method of JSCE-G573. Sample powder was collected from three adjacent holes with depths of 0-2cm, 2-4cm, 4-6cm, 6-8cm, and 8-10cm from the surface to minimize the effect of aggregate size. Samples were collected not only at the same level from sea level but also at different heights in order to determine the effect of height from the sea level. The total chloride content of the powder was measured based on the method of JCI-SC4. Then the chloride diffusion coefficient and surface chloride content were calculated from the profile of chloride content. The number of samples for chloride analysis was limited owing to difficulty and high resource consumption. The average value was used from the inspection result but variation was assumed to be equal to variation of concrete properties measured by rebound hammer and normal distribution was used as the distribution type, as shown in **Table 7**.

Concrete compressive strength was measured by rebound hammer. Although there are other NDT methods such as the air permeability test, the rebound hammer is still one of the most convenient methods. Twenty points were tested for one sample set. Only smooth concrete surfaces were tested. As currently in Thailand there is no available formula to relate rebound number to compressive strength, concrete compressive strength can be calculated from the rebound number as shown in Eq. 21 (JSCE 2005d). The calculated compressive strength is in the range of the strength class normally used in Thailand.

$$f_c' = -18 + (1.27 \times RN) \tag{21}$$

where f_c' is the concrete compressive strength (MPa) and RN is the rebound number.

5.2 Inspection results

By the goodness-of-fit test, the most suitable distribution type and its parameters to inspected data were selected based on the chi-square goodness-of-fit test. The distribution type, its parameters, mean value, and coefficient of variation are reported in this section. **Table 7** lists the inspection results of covering depth, surface chloride content, chloride diffusion coefficient, and concrete compressive strength of both structures. As a result, actual variation of inspection results can be considered in the prediction model. Normally, higher variation of the inspection results at the same average value caused the structure to deteriorate faster. The effects of degree

Table 6 Number of collected samples.

Case	Covering depth	Chloride analysis	Rebound hammer
Bad	916	3	252
Good	334	6	1493

Table 7 Inspection result.

Parameters	Case	Specified value	Inspection result		
			Mean	COV, %	Distribution
Covering depth	Bad	50 mm	24.21 mm	38.69	Gamma (3.25, 5.08)
	Good	75 mm	88.34 mm	22.30	Weibull (6.69, 120.47)
Chloride diffusion coefficient	Bad	-	1.34 cm^2/year	18.35	Normal (1.34, 18.35)
	Good	-	0.92 cm^2/year	19.89	Normal (0.92, 19.89)
Surface chloride content	Bad	-	8.71 kg/m^3	-	Uniform (7.14, 11.17)
	Good	-	8.36 kg/m^3	-	Uniform (3.95, 14.39)
Compressive strength	Bad	24 MPa	34.30	18.35	Extreme value (38.10, 5.58)
	Good	30 MPa	34.97	19.89	Extreme value (39.35, 6.60)

Table 8 Conclusion of performance and cost of repair option.

No.	Method	Performance		Fixed cost, US$	Variable cost, US$/$m^2$	Annual cost, US$/$m^2$
		Mean	COV			
1	Patching	D_p = 0.175 cm^2/year	20%	1500	200	-
2	Patching	D_p = 0.175 cm^2/year	20%	1500	200	-
	Surface coating	C_s = 0.5 mm D_s = 1.0E-3 cm^2/year	C_s = 10% D_s = 10%	500	200	-
3	Patching	D_p = 0.175	20%	1500	200	-
	Cathodic protection	Titanium mesh (Service life 30 years)		6500	150	2.5

of variation of the inspection result are discussed by Sancharoen *et al.* (2006b). Other parameters used in prediction are from the literature (Nowak *et al.* 1994, Liu and Weyers 1998, Enright and Frangopol 1999, and JSCE 2005b), as shown in **Table 2**.

5.3 Maintenance planning

In this section, an example of a maintenance planning program for selected structures is given based on the actual inspection results of each structure. The service life of structures is considered to be 100 years. Therefore, there are 53 and 99 years of service life left for the bad and good structure, respectively. The life cycle costs of the remaining service life of different maintenance interventions are optimized and compared, using the 0% discount rate. The maintenance method with the lowest life cycle cost is considered as the most suitable option. The applicable interventions to maintain the structures considered in this study are shown below as examples. As patching repair and surface coating are the most frequently applied repairing methods in Thailand, they are considered in this study. Moreover, cathodic protection is also considered for comparison purposes. Combinations of different repairing methods are also considered, such as the combination of patching with surface coating or cathodic protection.

- Patching: Corrective maintenance through removal of chloride contaminated concrete and execution of patching repair as shown in **Table 8** after the limit corrosion crack width was reached.
- Patching and surface coating: Preventive and corrective maintenance by initial coating of overall surface of structure, and removal of chloride contaminated concrete, patching of repaired material and surface coating as shown in **Table 8** after limit corrosion crack width was reached.
- Patching and cathodic protection: Corrective maintenance by removal of chloride contaminated con-

crete, patching of repaired material and cathodic protection as shown in **Table 8** after limit corrosion crack width was reached. As there are various systems of cathodic protection, cathodic protection with a service life of 30 years is selected for application in this section.

Figures 14 and **15** show the probability of damage and life cycle cost in US$ of the bad quality structure following repair by different methods using the 0% discount rate. Only the schedule of repair that results in the lowest life cycle cost is shown in **Fig. 15**. As shown, the life cycle cost of the repaired case is significantly lower than the no repair case due to failure cost decreases. For the bad quality structure, 2 times patching with cathodic protection repair at year 49 and 79 shows the lowest life cycle cost even though the initial repair cost is higher than the other two options.

For the good quality structure, due to its designed covering depth having been increased to improve resistance against chloride attack, the probability of damage due to corrosion cracking is very low throughout the service life of the structure, as shown in **Fig. 16**. Therefore, repair is actually not necessary throughout the remaining service life of the structure. As shown in **Fig. 17**, the lowest life cycle cost of the good quality structure is the case without repair because failure is not significantly in this structure.

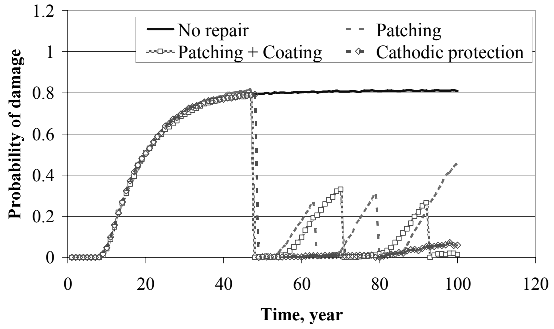

Fig. 14 Probability of damage of bad quality structure with different repair methods.

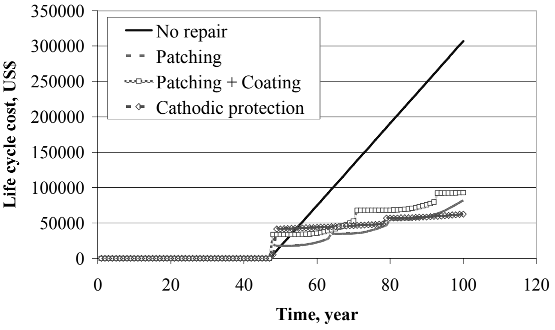

Fig. 15 Life cycle cost of bad quality structure with different repair methods.

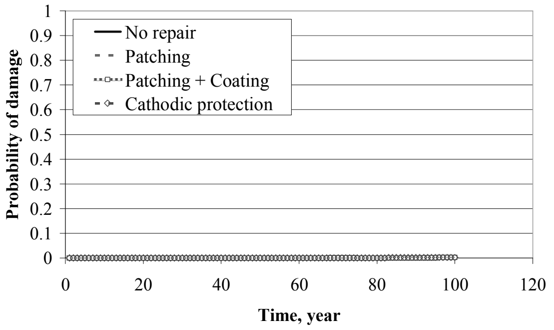

Fig. 16 Probability of damage of good quality structure with different repair methods.

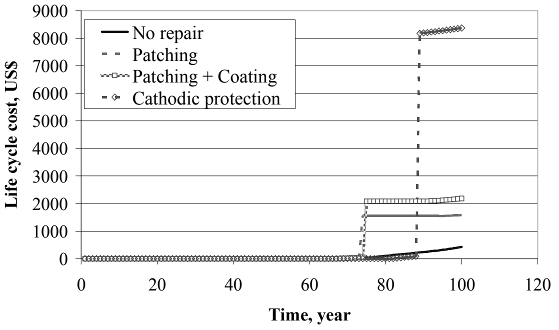

Fig. 17 Life cycle cost of good quality structure with different repair methods.

6. Conclusion

As an alternative to the current method of maintenance of RC structures based on safety factors, this study proposed a method of maintenance planning based on variations of actual inspection results and probability theory to predict variations of deterioration degree of RC structures and life cycle cost of maintenance. Therefore, not only the average value of inspection results is used in prediction but also their variations. The effects of cracks, macrocell corrosion, partial repair, and performance of different repair methods are considered in deterioration prediction. Therefore, time dependent variations of damage can be determined and repairing cost can be also estimated. The life cycle cost is calculated and maintenance planning can be decided based on optimization of the life cycle cost. The results show that the good quality structure requires lower maintenance cost during its service life compared to the bad quality structure.

In the future, besides salt attack, other deterioration mechanisms should also be considered for deterioration prediction. Moreover, prediction of damage location should also be considered in order to minimize the need for another inspection program for damage when repair has to be conducted. Further, more information on performance and repair cost is required for accurate determination of the repair method.

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Scientific paper

Flexural Behavior of Corroded RC Members with Patch Repair – Experiments & Simulation

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Abstract

Structural performance of RC repaired by patching method was experimentally investigated and compared with non-corroded as well as corroded RC. Two repair materials; namely, polymer-modified mortar and epoxy-based repair material was applied for the repair work. The mechanical properties as well as the bonding characteristics of these two repair materials are different. It was found that the polymer-modified mortar can partially restore the structural performance while the more ductile epoxy-based repair material strengthen corroded RC structure so that its ultimate load carrying capacity is beyond that of non-corroded RC.

The numerical analysis was conducted to reproduce the structural performance of repair RC observed by incorporating experimentally measured properties of repair materials. The bonding characteristic between repair materials and base concrete is represented by basic Coulomb friction model. The proposed concept of analysis shows satisfactorily accurate results which match well with experimental findings.

1. Introduction

Deterioration of concrete structure is a serious problem which may drastically degrade both load-carrying capacity as well as serviceability of the structure. Among different deteriorations, the corrosion of reinforcing bar is one of the most widely found deterioration. The corrosion reduces cross sectional area of reinforcing bar as well as induces corrosion cracking which destroys the bonding between concrete and reinforcing bar. It was reported that, when degree of corrosion increases, the ultimate strength of steel bars as well as the corresponding elongation of the bar before failures decreases (Almusallam 2001). The bonding between reinforcing bar and concrete is affected by the corrosion. With relatively low level of corrosion, reinforced concrete exhibited better bonding characteristics; however, the bonding capacity decreases when weight loss is greater than 4% and the loss of bonding capacity is substantial when the corrosion cracks forms (Almusallam *et al* 1996). The corrosion can also severely degrade ultimate load carrying capacity as well as ductility of RC (Uomoto and Misra 1984). Toongernthong and Maekawa (2005) studied structural performance of corroded RC under shear load and reported that the loss of bond caused by corrosion crack may change failure mode of RC and capacity of anchorage performance as well as the strength in shear span. The brittle failure by buckling of compression reinforcement may also be induced if the corrosion of compression reinforcement takes place (Uomoto and Misra 1984).

Remedial action is necessary not only to maintain safety and serviceability of the deteriorated structure but also to extend its service-life. The patching repair method is recommended as an appropriate method for the RC members which are in the corrosion acceleration period as well as the deterioration stage (JSCE 2001). There have been some researches on the performance of RC in both structural as well as durability aspects (Shash 2005; Nounu *et al* 1999). It is generally accepted that the response of the repair system to the changes exerted by the repair must be understood for design and construction of durable concrete repair (Emmons and Vaysburd 1995). Satisfactory compatibility of repairing materials to base concrete structure in both structural performance and durability aspect must be ensured.

There are several factors affecting the performance of RC structure repaired by patching method. Effect of rebar cleanliness, surface preparation of base concrete, and mechanical properties of repair materials and patching area have been experimentally investigated (Al-Dulaijan 2002; Nagataki *et al* 1987; Nagataki *et al* 1990). The structural performance of RC repaired by patching method is highly related to the mechanical properties of repair materials as well as their bonding characteristics with base concrete. In addition, it is expected that the structural behavior of RC repaired by patching method changes with the geometry of the repaired area. However, there is still no general methodology to analyze the structural behavior after repair precisely.

This study is therefore an attempt to investigate the

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structural performance of RC repaired by patching method as well as the mechanical properties of repair materials and conduct some numerical analysis to reproduce the observed performance by finite element method incorporating bond element. Corrosion of reinforced concrete specimen is induced by galvanic acceleration process. The repair procedure is controlled to be as similar to the practical operation as possible. Two different repair materials; namely, polymer-modified mortar and epoxy-based repair material was selected for the study since these two materials are commercially available and possess different mechanical properties.

2. Methodology

2.1 Experimental plan

Flexural behavior of corroded RC members and repaired members are investigated and compared with the flexural behaviors of control RC specimens. The tested specimens consisted of two undamaged RC members, three corroded RC members and six repaired RC members. Specimens were initially given a load until transverse cracking takes place. The corrosion was induced by accelerated galvanic corrosion until longitudinal corrosion cracks became observable. The corrosion acceleration process was stop when the degree of corrosion was approximately 2.5%. The corroded specimens were then repaired by patching repair method. There are three patching lengths studied in this experiment, namely, short patching (300 mm), long patching (1000 mm), and full span (1700 mm). Subsequently non-corroded, corroded, and repaired specimens were experimentally loaded to investigate their structural performance. The details of each process are given in following sections.

2.2 Specimen preparation and reinforcement arrangement

All specimens prepared for flexural test have same dimensions. The width, height, and length are 150 mm, 200 mm, and 1700 mm, respectively. The drawing of specimens is shown in **Fig. 1**. The deformed steel bars with 16-mm diameter and one with 12-mm diameter were used as tensile reinforcement and compression reinforcement, respectively. The shear reinforcement was 6-mm diameter round bar. The marks were written on the tensile rebar every 50 mm. These marks were used to indicate the initial length of reinforcement after loading which is a necessary parameter in the determination of weight loss. Cover thickness is 25 mm (from surface to shear reinforcement). The details of reinforcement are given in **Table 1**.

Both longitudinal reinforcement and shear reinforcement were prepared according to **Fig. 1**. 5-mm holes were drilled at the free end of hooks and electrical wires were connected to the tensile reinforcement by 5-mm nut. The electrical wires were used to supply direct current into the tensile reinforcement. Since the objective of this study is to investigate the degradation of structural performance caused by the corrosion of tensile reinforcement only, the electrical insulators (thin rubber sheets) were installed at the connection between tensile reinforcement and stirrups in order to limit the corrosion to be in tensile reinforcement only. All flexural RC specimens were cast at the same time and covered by plastic sheet. The formwork was removed at 24 hrs after casting. The specimens were cured under moist condition until the age of 7 days and subsequently kept in air dry condition. **Table 2** shows a list of flexural RC specimens. The specimens can be broadly categorized into 3 types; non-corroded, corroded, and repaired

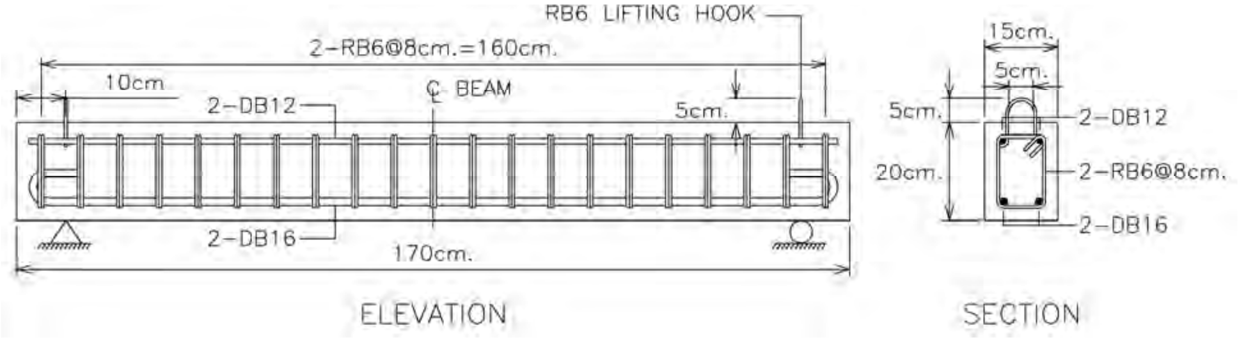


Fig. 1 Drawings of specimen & arrangement of reinforcement.

Table 1 Details of reinforcement.

Reinforcement Ratio (%)		Area of main steel (mm^2)		Area of Shear Reinforcement (mm^2/m)(A_v)
Actual	Balance	Tens. (A_s)	Comp. (A_s')	
1.67	3.95	402	226	707

specimens. Lengths of corrosion zone or repair area were varied as 300 mm, 1000 mm, and full length (1700 mm). Two types of repair materials; i.e., polymer modified mortar and epoxy based repair material, were applied in this study.

2.3 Materials

Ordinary Portland cement-only concrete with water to cement ratio of 0.49 was used. The mix proportion is given in **Table 3**. The longitudinal reinforcement and shear reinforcement are deformed bar (Grade SD40) and round bar (Grade SR24), respectively. The tensile mechanical properties of reinforcing bars were obtained experimentally. Two types of repair materials – polymer modified mortar and epoxy based repair material were used for patching repair. Polymer modified mortar (repair material type I) contains cement and silica powder as important ingredients. Its behavior is therefore similar to cement paste with high early strength. The mix proportion of polymer modified powder to water was 4:7 by weight. The epoxy based repair material (repair material type II) provides outstanding bonding capacity and lower modulus. It is therefore generally recommended as an adhesive to bond most surfaces in general structure. The epoxy based repair material has the ratio between epoxy and sand of 4:3 by weight.

Table 3 Mix proportion of concrete.

W/C ratio	Water (kg/m^3)	Cement (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)
0.49	210	428	880	835

2.4 Additional test for rate of corrosion

In order to accelerate the corrosion of RC specimen into the former acceleration state precisely, additional test for calculating the amount of electrical charges (coulombs) that will activate the corrosion as well as for determining relationship between electrical charges supplied with degree of corrosion. The specimen in this accelerated corrosion test is shown in **Fig. 2**. The specified portion of specimen is submerged in the 5.0% NaCl solution and supplied with 100 mA direct current where the positive side is connected to reinforcing bar and the negative voltage is connected to stainless steel plate beneath the NaCl solution. The submerge area is the 30-mm central part of the specimen The setting of this test is shown in **Fig. 3**.

During the testing on the rate of corrosion, the state of deterioration including crack pattern, rust exudation. After the corrosion acceleration process, the specimen was examined for distribution of corrosion cracks on the surface of specimen. The corrosion cracks width were also measured using crack measuring microscope. The specimen was split subsequently in order to take the corroded rebar. The corroded rebar was cut at the specified length and was cleaned with 10% di-ammonium hydrogen citrate solution along with 150 ppm of Thioglecolic acid solution. Exact length and weight of

Table 2 List of flexural RC specimens.

ID	Categories	Corroded/Repair Length	Repair Materials
NCB - 1	Non-corroded	-	-
NCB -2	Non-corroded	-	-
FCBNR-I	Corroded	300 mm	-
FCBNR-O	Corroded	1000 mm	-
FCBNR-F	Corroded	1700 mm	-
FCB1R-I	Repaired	300 mm	Polymer Modified Mortar
FCB1R-O	Repaired	1000 mm	Polymer Modified Mortar
FCB1R-F	Repaired	1700 mm	Polymer Modified Mortar
FCB2R-I	Repaired	300 mm	Epoxy Based Material
FCB2R-O	Repaired	1000 mm	Epoxy Based Material
FCB2R-F	Repaired	1700 mm	Epoxy Based Material

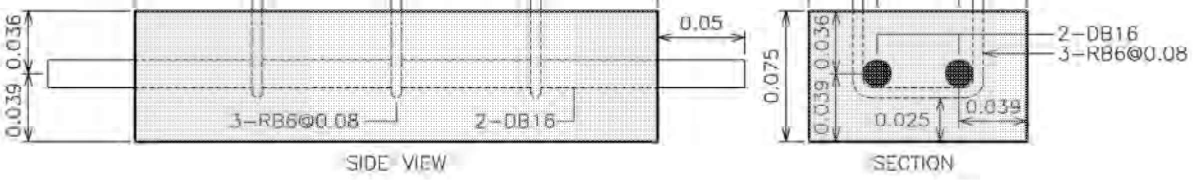


Fig. 2 Drawings of specimen & arrangement of reinforcement (Unit: meters).

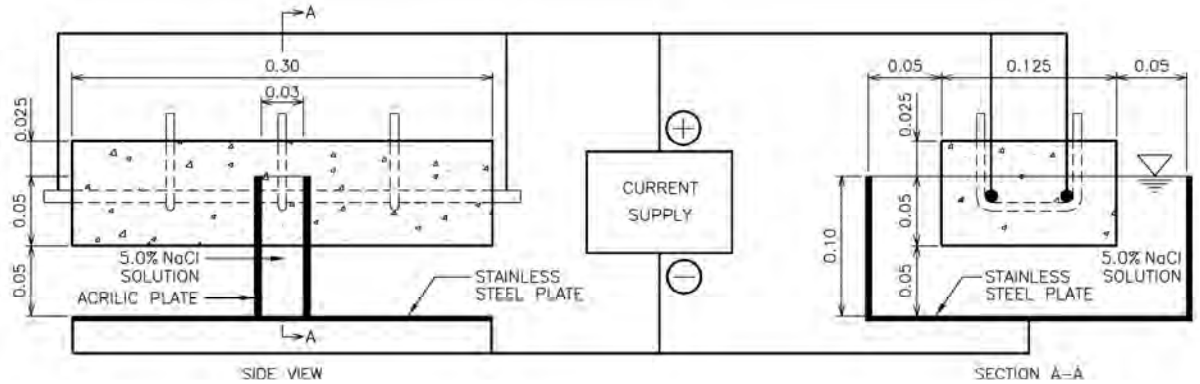


Fig. 3 Experimental setting for test of rate of corrosion (Unit: meters).

cleaned corroded rebar was measured. Finally, the weight loss was calculated based on the weight of rebar with the same length. The weight lost of reinforcement can be related with the corrosion current density applied to the specimen based on the Faraday's law as follows:

$$\delta = \frac{Ait}{\gamma ZF} \tag{1}$$

where;

δ : lost of metal (cm)

A : atomic weight of iron (56 g)

i : corrosion current density (Amp/cm^2)

t : time elapsed (seconds)

Z : valency of the reacting electrode (iron), commonly taken as 2

F : Faraday's constant (96,500 Amp-seconds)

γ : density of meterial (iron = 7.86 g/cm^3)

From the experimental investigation, it was found that the galvanic corrosion acceleration by direct currency of 100 mA for 192 hrs induces the actual weight loss of 0.30 gram/cm^2/cm) which is slightly lower than the predicted corrosion which is 0.4156 gram/cm^2/cm (2.63 %). It was also found that the total length of corroded portion is approximately 200 mm. In the other words, under this configuration, the corrosion can be induced as far as 85 mm from the submerged zone. This information was then used in the corrosion acceleration of flexural member.

2.5 Corrosion acceleration of flexural member

From the data obtained from the test, the time that each flexural RC specimen must be subjected to galvanic corrosion acceleration process. In order to induce the corrosion of the RC member, cracking was initially introduced into specimen by slow loading. The location of cracks was ensured to be in the predetermined location. Three points loading was applied to induce crack in the specimen to have shortest repair region (FCBNR-I, FCB1R-I, and FCB2R-I) and four-point loadings with constant moment span of 350 mm and 500 mm was applied to the specimen to have a repair region of 1000 mm (FCBNR-O, FCB1R-O, and FCB1R-O) and full length (FCBNR-F, FCB1R-F, FCB2R-F), respectively. All induced cracks had a specified depth of 50 to 60 mm from bottom surface. Examples of flexural cracks induced by pre-cracking process are shown in **Fig. 4**. The cracked specimens were connected to the direct current supply and the corrosion was accelerated. The setting of equipments is shown in **Fig. 5**. The direct current supplied for specimens and accelerated periods were set from the calculation for each case so that acceleration period was shorter than 7 days.

In order to confirm the level of corrosion, the actual corrosion level of corroded RC specimen was measured after the loading. The corroded tensile reinforcements were taken out by cutting out of corroded reinforcement with specific lengths (200 mm for shortest corrosion length and 300 mm for medium and full corrosion length). Actual weight losses of the taken corroded reinforcement samples were then calculated based on original weight of reinforcement with same length. The summarized detail of setting as well as actual measured degree of corrosion is shown in **Table 4**. The actual weight losses of reinforcement of all specimens were from 0.3 to 0.4 g/cm^2/cm. The patterns of induced corrosion cracks are also shown in **Fig. 6**. Corrosion cracks were observable on the sides as well as at the bottom of specimens.

It is noted that the accelerated corrosion induced to

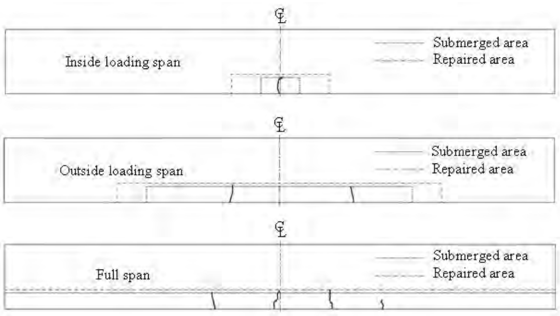


Fig. 4 Examples of pre-cracked specimens.

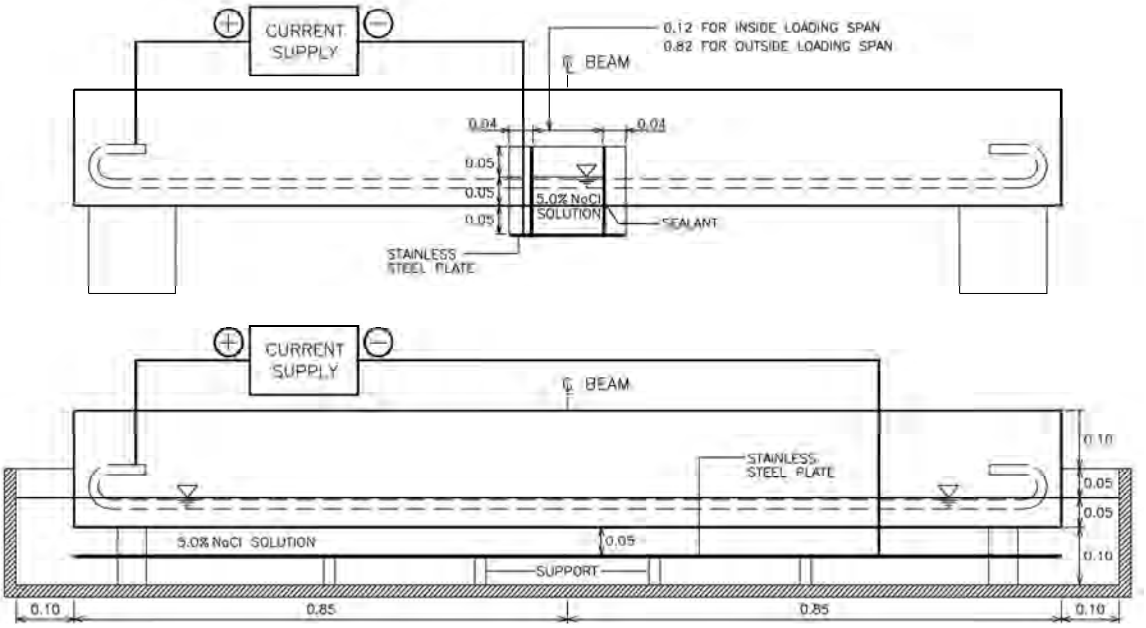


Fig. 5 Setting of galvanic corrosion acceleration of flexural RC specimen. (Unit: m)

Table 4 Details of galvanic corrosion acceleration process of flexural RC specimen.

Corroded Area	Degree of Corrosion				Time	
	Degree (%)	Current (Amp.)	Theoretical ($gm/cm^2/cm$)	Actual ($gm/cm^2/cm$)	Days	Min.
Inside loading span	2.50	0.15	0.3951	0.3450	5.08	7315
Outside loading span	2.50	0.80	0.3951	0.3927	6.50	9360
Full span	2.50	1.50	0.3951	0.3313	6.98	10051

the specimens is not exactly the same with the corrosion in actual circumstances. The difference is mainly the uniformity of the corrosion. In real situation, some portion of reinforcing bar acts as anode and the other acts as cathode. There is therefore high possibility of pitting corrosion especially in the case of chloride attack. On the other hands, the accelerated corrosion in this study is more uniform since all position on reinforcing bar is forced to be anode and cathode is located at the stainless steel plate. Previous study (Oyado *et al* 2006) showed that, at the same corrosion ratio, RC in real corrosive circumstances usually gives lower ultimate strength when compared with RC subjected to accelerated corrosion.

2.6 Patching repair procedure

Six corroded specimens (FCB1R-I, FCB1R-O, FCB1R-F, FCB2R-I, FCB2R-O, and FCB2R-F) were repaired by patching repair method. The patching regions were 300 mm, 1000 mm and 1700 mm (full span) for specimens with 120 mm, 820 mm, and full span corrosion acceleration, respectively. Initially, the damage portions of concrete were removed by a portable demolisher powered by high pressure pump. The reinforcements were then polished carefully by the electrical polishing tools equipped with steel brush. Chisel steel rods were then used to trim the area to be repaired into rectangular shape with uniformly rough surface. The patching areas were then cleaned by high pressured air activated by air pump. The specimens were flipped so that the patching area is on the top during patching in order to fill the repairing materials in to the patching area efficiently as well as to ensure a quality of compaction. After patching, the patched portions were wrapped by the plastic sheets in order to prevent the early lost of water from the repair materials. Special attention was given to the epoxy-based repair material which has a very short setting time. After the repair material set, the surface of the repaired region was then trimmed to have an exact dimension as original size of RC specimens.

2.7 Flexural loading test

The non-repaired RC flexural members (NCB-1 and NCB-2) were loaded at the age of 28 days. The corroded

RC members (FCBNR-I, FCBNR-O, FCBNR-F) were loaded at 7 days after galvanic corrosion acceleration was completed. And, the repaired RC members were loaded at 14 days after repair work. All specimens were loaded under 4-points loading with a total clear span (distance between supports) of 1500 mm. The distance between two loading points and shear span were 500 mm. Displacement transducers were installed at the middle of the specimens, at the location of loading points, and at the supports in order to measure the deflection of the specimen during the loading. Monotonic loading was slowly applied to specimen. The load cell was installed in order to measure the exact load applied on the specimen and cracking observations were performed every 5 kN of load. The loading continued until the specimens failed.

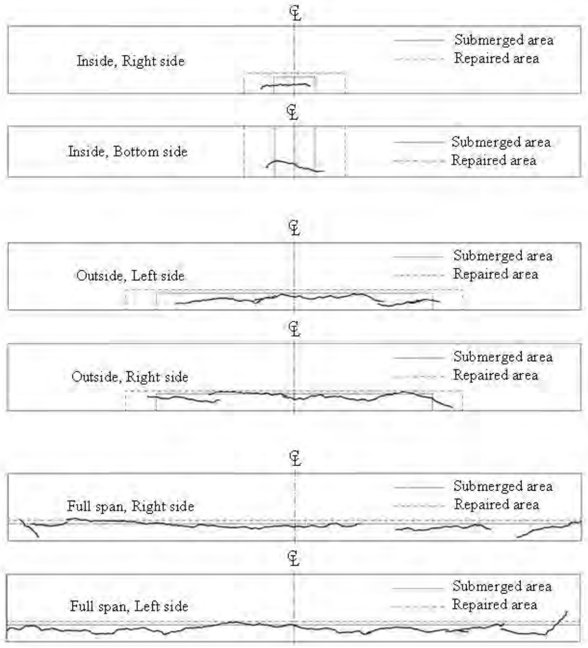


Fig. 6 Examples of corrosion cracking patterns induced by galvanic corrosion accelertion (FCBNR-I, FCBNR-O, and FCBNR-F).

2.8 Testing for mechanical properties of materials

Measurements of mechanical properties of concrete and repairing materials were conducted in accordance with the standard guidelines. **Table 5**, **6**, and **7** show lists of tests conducted in order to measure mechanical properties of concrete, repairing materials, and reinforcement, respectively. The tests on concrete were conducted at 28 days while the tests on repairing materials were conducted at 7 days and 14 days. Strains were measured on both sides of specimen and the average value is used to determine modulus of elasticity and Poisson ratio. Special note is given to the measurement of tensile strength of concrete. The pull-out test was conducted instead of other standard testing methods since the pull-out test can simulate the condition of concrete in tension more closely.

In addition to the tests for mechanical properties of

Table 7 Tests on mechanical properties of reinforcement.

Properties	Description	Specimen
Tensile stress-strain relationship	Tensile Test with strain gauges	16-mm and 12-mm deformed reinforcing bar and 6-mm round bar

Table 5 Tests on mechanical properties of concrete.

Properties	Description	Specimen
Compressive Strength	Compression Test on Cylinder Specimen with strain gauges (ASTM C-39, C-192, C-469)	150 mm diameter & 300 mm height
Elastic Modulus		
Poisson Ratio		
Tensile Strength	Tension pull-out test	100x100x100 mm^3 cube 50 mm diameter core drills cut through concrete surface, penetrating at least 55 mm

Table 6 Tests on mechanical properties of repairing materials.

Properties	Description	Specimen
Compressive Strength	Compression Test on Cylinder Specimen with strain gauges (ASTM C-39, C-192, C-469)	50 mm diameter & 100 mm height
Elastic Modulus		
Poisson Ratio		
Tensile Strength and Stress-Strain Relationship	Flexural test under loading at the center of specimen. Strain gauges were attached at top, bottom, and mid-depth of the specimens (ASTM C293)	75 mm depth, 50 mm width, and 400 mm length

materials, the testing on bonding between concrete and each type of repairing material (polymer-modified mortar and epoxy-based repairing material) was conducted. The objective of the bond testing is to determine the bonding capacity under tension and under combination of shear and axial load. The tension bond test was conducted to find the maximum stress that the contact interface can withstand before the separation takes place. In the case of shear bonding capacity, both direct shear test and combined compression-shear test were conducted in order to investigate the dependency of shear capacity of bonding surface on the perpendicular stress.

Table 8 describes details of direct tension test, direct shear test, and combined shear compression test on the contact interface between concrete and repairing material. Five different contact angles were applied in the combined shear compression test (**Table 9**). **Figure 7** illustrates the testing condition of each bond test.

3. Experimental results

3.1 Mechanical properties of materials

Table 10 shows the mechanical properties of concrete, polymer modified mortar, and epoxy-based repair materials. The mechanical properties of polymer-modified mortar are similar to those of concrete. The tensile strength is approximately double of concrete and the modulus of elasticity is lower by 40% when compared with concrete. The epoxy-based repair material shows an outstanding record in tensile strength (approximately 8 times of concrete's tensile strength). However, the modulus of elasticity is very low (0.1 of modulus of elasticity of concrete).

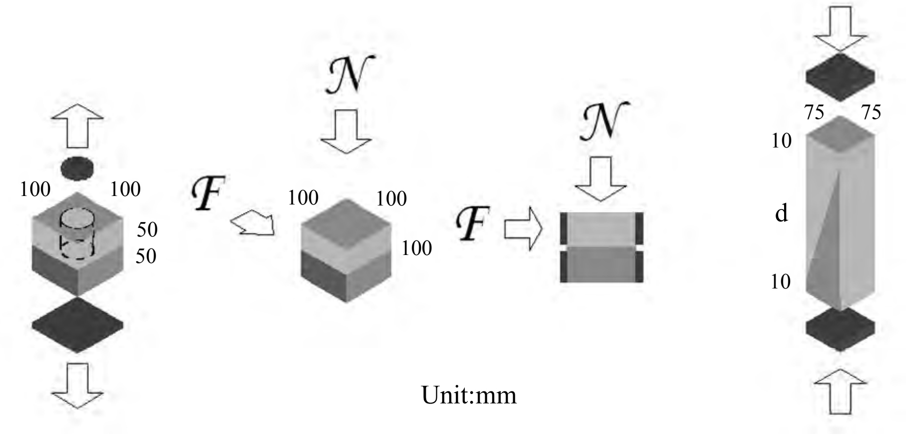
Yielding strengths of RB6, DB12, and DB16 were 280, 540 and 600 N/mm^2, respectively. The modulus of elasticity of all reinforcement is 206,000 N/mm^2.

Table 9 Dimensions (angle of contact interface and height) of specimens in combined shear-compression test.

Angle (degree)	Height of contact interface (mm)	Total Height of Specimen (mm)
30	130	150
45	75	95
50	63	83
55	53	73
60	45	65

Table 8 Tests on bonding properties between concrete and repairing materials.

Testing Method	Description	Specimen
Tension Bond Test	Tension pull-out test	100x100x100 mm^3 with 50-mm core drill cut through repair material penetrating at least 5 mm into concrete stratum
Combined shear compression test	Compressive test carried out on prism with one-half of concrete replaced with repair material	75x75 mm^2 with different heights according to the angle of contact. Concrete prism cut at an angle of 30,45,50, and 60 degree
Direct shear test	Test for shear capacity of the contact interface when the compressive forces is applied on the top	



(a) Direct Tension (b) Direct Shear (c) Combined Shear Compression Test

Fig. 7 Tests on bonding properties of interface between concrete and repair material.

Table 10 Mechanical properties of materials (28 days for concrete and 14 days for repair materials).

	Compressive Strength (N/mm^2)	Tensile Strength (N/mm^2)	Modulus of Elasticity (N/mm^2)	Poisson Ratio
Concrete (28 days)	43.00	3.70	35,000	0.22
Polymer-Modified Mortar (7 days)	35.26	6.13	16,500	0.16
Polymer-Modified Mortar (14 days)	42.43	8.14	20,250	0.22
Epoxy-Based Material (7 days)	34.08	29.25	3,421	0.35
Epoxy-Based Material (14 days)	36.32	30.13	3,131	0.34

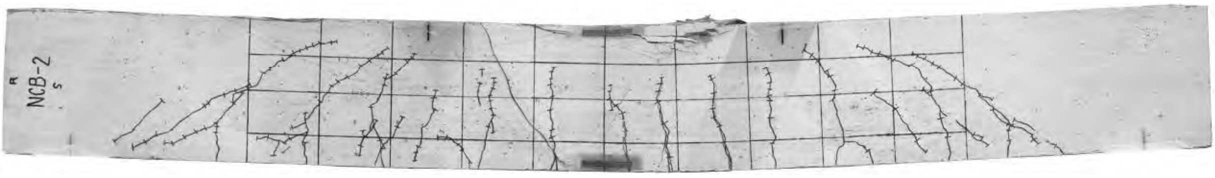


Fig. 8 Final crack pattern of non-corroded flexural RC member (NCB-2).

3.2 Structural behaviors & crack patterns

3.2.1 Non-corroded flexural RC specimens *(NCB-1 and NCB-2)*

Cracking loads were between 15-20 kN. Flexural cracks form initially in the constant moment span followed by the formation of shear cracks. Both NCB-1 and NCB-2 collapsed by flexural-compression failure. The loading capacity of NCB-1 and NCB-2 were 145.97 kN and 144.99 kN, respectively. The final crack pattern of NCB-2 is shown in **Fig. 8**.

3.2.2 Corroded flexural RC specimens

Three corroded RC specimens with different corrosion lengths were tested under flexure. Slight reductions of ultimate loading capacity were observed in all corroded RC specimens. The ultimate load of FCBNR-I, FCBNR-O, and FCBNR-F were 137.34 kN, 138.5172 kN, and 139.4 kN, respectively. The load-deflection relationship of NCB-1, FCBNR-I, FCBNR-O, and FCBNR-F is given in **Fig. 9**. The reduction in ultimate loading capacity is approximately 4.5% to 6% when compared with non-corroded RC specimens. The loss of cross sectional area of tensile reinforcement is a main reason of the lower ultimate loading capacity. It could be observed that the stiffness of all corroded specimen is significantly degraded mainly because bonding between tensile reinforcement and concrete was destroyed. However, final crack patterns of FCBNR-I (shortest corrosion length) was very similar to the final crack pattern of non-corroded specimen (see **Fig. 10**). In the case of FCBNR-O specimen, less flexural cracks was observed. The propagation of flexural cracks was also interrupted by the existing longitudinal corrosion cracks (**Fig. 10b**). The final crack pattern was drastically changed in the case of FCBNR-F. Propagation of shear cracks was disturbed by the corrosion crack. As the result, no traditional shear cracks was observable in this case. The shear crack which started from support was trapped by corrosion crack. (**Fig. 10c**); however, this mechanism did not have any significant effect on load carrying capacity of the beam. The absence of shear crack may be the reason why the deflection of FCBNR-F is smaller than that of FCBNR-O at the same load.

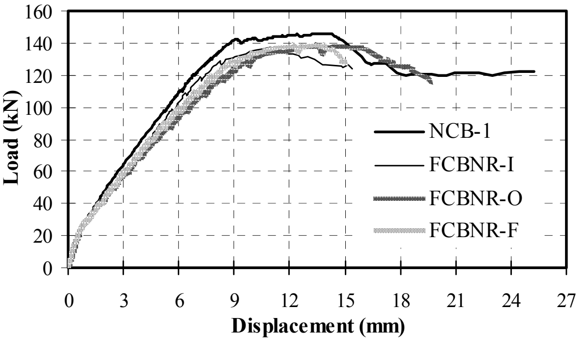


Fig. 9 Load – deflection relationship of corroded specimens compared with non-corroded specimen (NCB-1).

3.2.3 Specimens repaired with polymer-modified mortar

All corroded specimens repaired by polymer-modified mortar (FCB1R-I, FCB1R-O, and FCB1R-F) were cracked before the loads reached 10 kN which is lower than cracking load of non-corroded flexural RC specimens. This lower cracking load may be a result of shrinkage of the polymer-modified mortar itself. The shrinkage seems to affect the structural behaviors of RC specimens repaired with polymer-modified mortar.

Figure 12 shows the comparison between the load-deflection relationships of flexural RC specimens repaired with polymer-modified mortar and that of non-corroded RC specimen (NCB-1). The specimen with shortest patching area (FCB1R-I) shows very similar structural behavior to the control RC specimen regardless of lower cracking load. **Figure 11a** shows the final crack pattern of FCB1R-I. It was found that the first flexural crack was formed at the interface between polymer-modified mortar and base concrete. One additional crack was formed at the middle of repair material. These cracks propagated vertically toward neural axis of the section without any horizontal cracks observable at the interface between repair material and base concrete. The shear crack formation of FCB1R-I is similar to non-corroded RC specimen.

In the case of FCB1R-O of which the patching area is 1000 mm, the first flexural cracking took place at the vertical interface between polymer-modified mortar and base concrete although the flexural bending moment is smaller than the middle of the span (**Fig. 11b**). The sub-

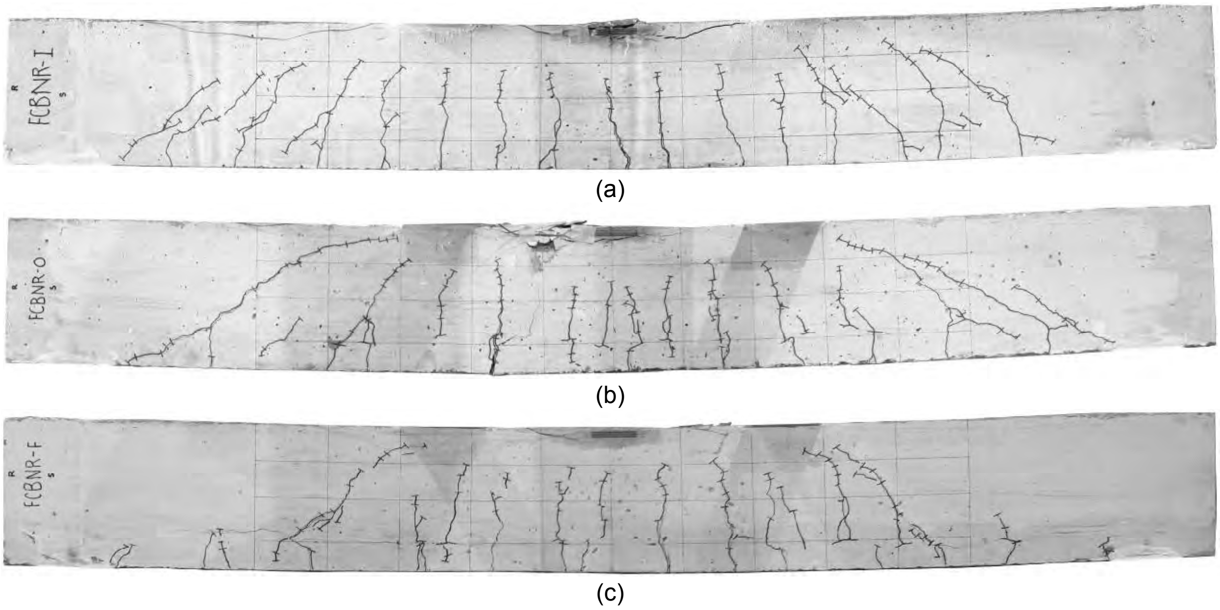


Fig. 10 Final crack patterns of corroded specimens; (a) FCBNR-I, (b) FCBNR-O, and (c) FCBNR-F.

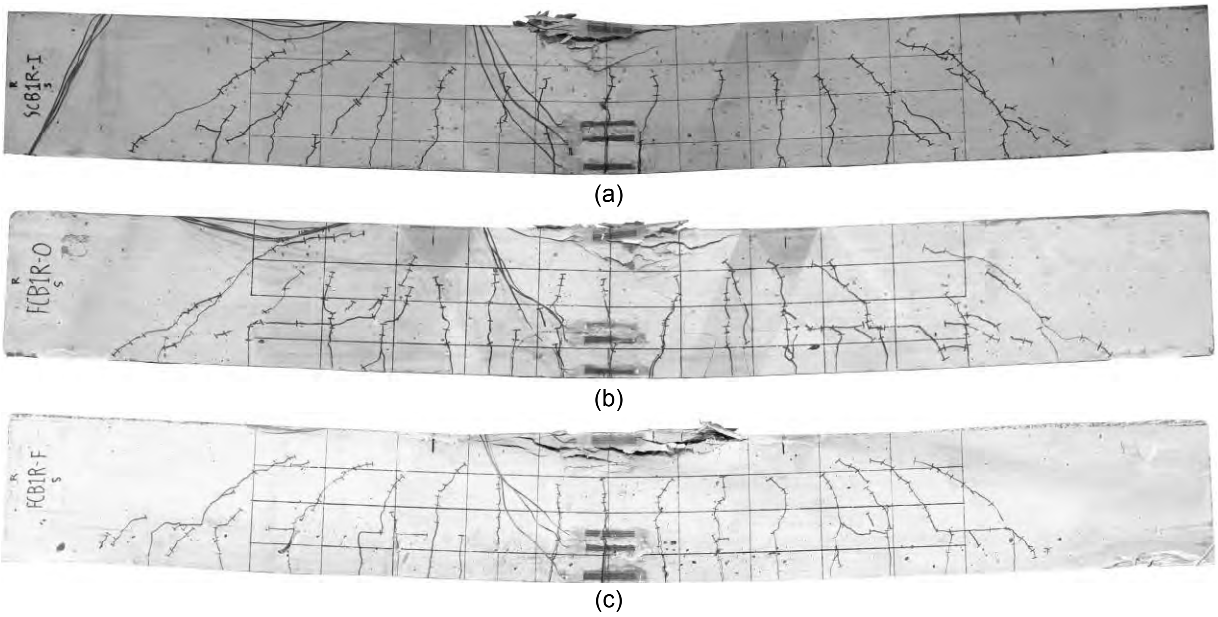


Fig. 11 Final cracks pattern of (a) FCB1R-I, (b) FCB1R-O, and (c) FCB1R-F.

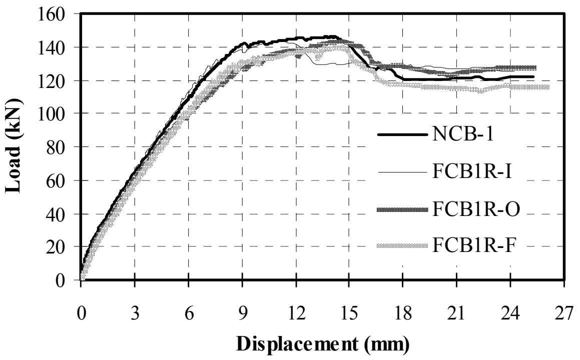


Fig. 12 Load – deflection relationship of specimen repaired with polymer-modified mortar in comparison with non-corroded specimen (NCB-1).

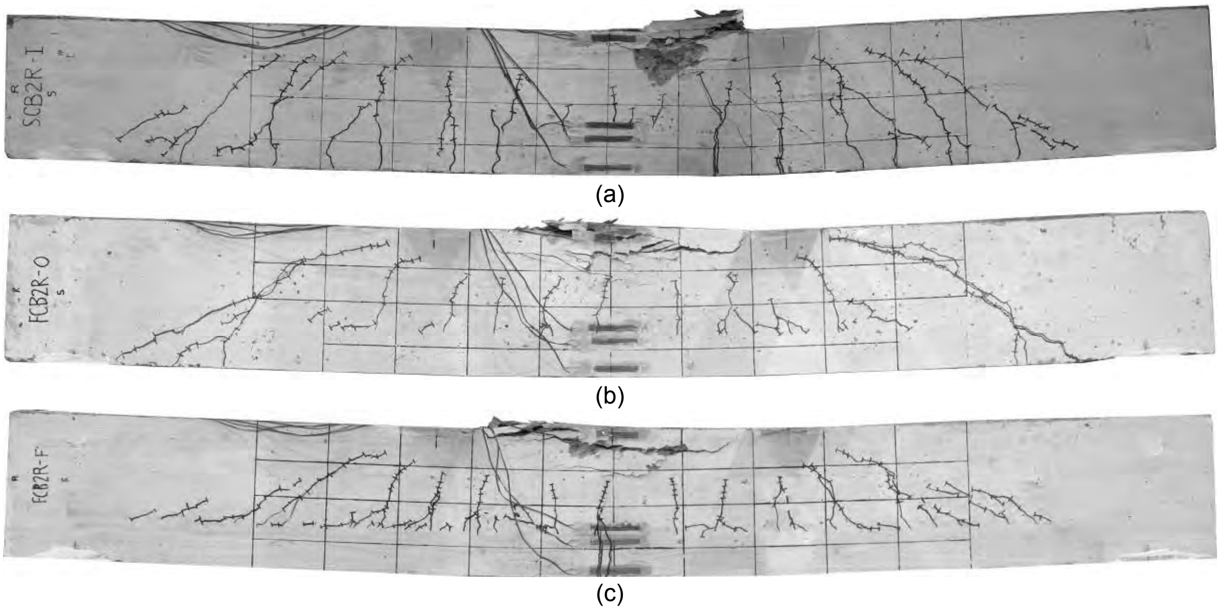
sequent crackings within the patching area were observed. When the loading continued, the cracks in the patching show larger crack growth. Discontinuity of the vertical bending cracks at the horizontal interface was observable. The shear crack was subsequently developed in the shear span and there was a clear interface failure caused by the excessive shear force in the interface (**Fig. 11b**). The interface cracks was connected with flexural cracks in repair material and propagated along the vertical interface at the end of patching area subsequently. Later on, additional shear crack (outermost) formed when the load increased and followed by the crushing of concrete in compression zone.

The similar interface failure was also observed in FCB1R-F (full span repair with polymer based material). It was found that the number of shear cracks in shear span increased in this case and there was no formation of larger shear crack at all. This is because the repair interface was extended to the end of the specimen. Final crack pattern of FCB1R-F is shown in **Fig. 11c**.

The ultimate loading capacity of FCB1R-I, FCB1R-O, and FCB1R-F were 143.42 kN, 143.23 kN, and 139.40 kN, respectively (**Fig. 12**). The stiffness of FCB1R-I is almost same with non-corroded RC specimen (NCB-1). This indicates that the loss of cross sectional area may not significantly affect the drop of stiffness if the bonding is restored by the repairing material. However, the stiffness of FCB1R-O and FCB1R-F was decreasing when load increased, especially beyond 100 kN. This loss of stiffness is caused by the shear cracks as well as the interface failure in shear span.

3.2.4 Specimens repaired with epoxy-based repair material

Figure 13 shows the final crack patterns of the specimens repaired with epoxy-based repair material (FCB2R-I, FCB2R-O, and FCB2R-F) and their load-deflection relationships are given in **Fig. 14**. It should be note that, before the first cracking, the deflections of NCB and FCB2R-I were smaller than those of FCB2R-O and FCB2R-F under the same load because the smaller modulus of elasticity of epoxy-based repairing material. The structural behavior of FCB2R-I is very similar with the control RC specimen because the patching area is shorter of the loading span (300 mm). The failure of FCB2R-I was governed by the compression failure of the concrete inside constant moment span but outside patching area. Since epoxy-based repairing material applied in this study is very ductile and strong in both tension and bonding. In FCB2R-O and FCB2R-F, the flexural cracks were formed in the base concrete without flexural cracks in the epoxy-based repair material (see **Fig. 13b** and **13c**). A good cracking resistance of epoxy-based repair materials contributed to the stiffness of the member. The deflections of NCB and FCB2R-I therefore became larger than the deflections of FCB2R-O and FCB2R-F after flexural cracking. When



(a)

(b)

(c)

Fig. 13 Final cracks pattern of (a) FCB2R-I, (b) FCB2R-O, and (c) FCB2R-F.

the load increased, distributed damage at the horizontal interface between epoxy-based repair material and base concrete could be observed in bothFCB2R-O and FCB2R-F; however, it was observable that there is still some stress transfer across the interface. The bonding was not completely vanished by these small distributed cracks. At approximately 90 kN, large shear cracks formed in FCB2R-O (**Fig. 13b**) and hence the deflection of FCB2R-O was consequently increased. On the other hand, the formation of shear crack in FCB2R-F was prevented by the interface between concrete and repair material. As the results, several shear cracks were formed instead of a single large shear crack (**Fig. 13c**). FCB2R-O was failed by crushing of concrete after shear crack fully propagated while the failure of FCB2R-F was caused by a sudden rupture of epoxy-based material. The maximum loading capacity of FCB2R-I, FCB2R-O, and FCB-2R-F were 154.12 kN, 171.77 kN, and 184.53 kN, respectively.

Figure 15 shows the comparison among different RC specimens in the study. All corroded beams (FCBNR-I, FCBNR-O, and FCBNR-F) show a lower load carrying capacity when compared with non-corroded RC (NCB-1 and NCB-2) of which the load carrying capacity was approximately 145 kN. Patching repair with polymer-modified mortar was able to slight improve load carrying capacity of corroded RC; however, the load carrying capacity after repair is still less than the original capacity of RC. The loss of load carrying capacity is caused mainly by the loss of cross sectional area of reinforcement. It should be also noted that the load carrying capacity of the RC repaired with polymer-modified mortar reduced when the patching length increased in this study. This may be due to a larger effect of debonding between repairing material and base concrete in specimen with longer patching area.

The most interesting experimental result in this study is that the patching repair with epoxy-based modified mortar can restore or even strengthen the flexural capacity of RC. The flexural capacity was increased up to 27% in the case of full-span patching although there is no replacement of reinforcement. In addition, the ultimate capacity increased when the patching length was longer. By comparing FCB2R-O and FCB2R-F which have same cross section in the loading span, it can be concluded that the ultimate load carrying capacity of RC repaired with epoxy-based repair material is not controlled by the cross section at the maximum moment. The structural behavior of RC is influenced by the stress transfer in the shear span especially in the case that repair material is very ductile.

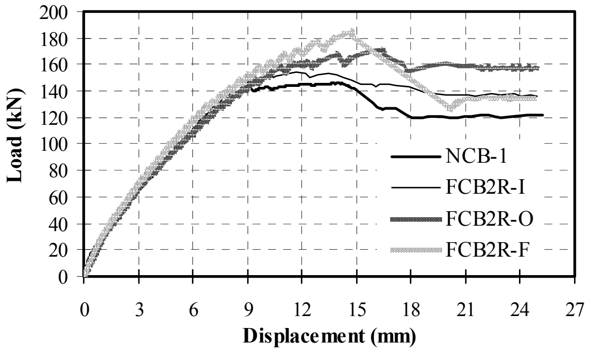


Fig. 14 Load – deflection relationship of specimen repaired with epoxy-based repair material in comparison with non-corroded specimen (NCB-1).

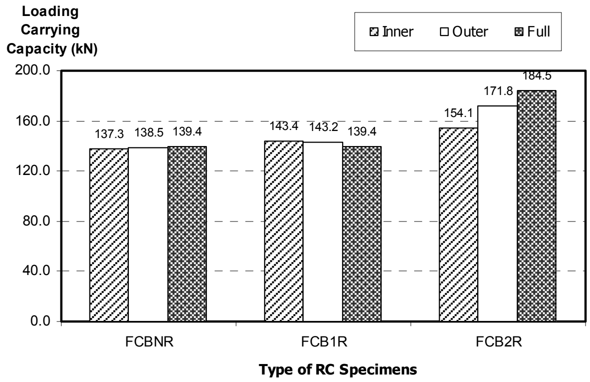


Fig. 15 Comparison of load carrying capacity of corroded RC (FCBNR), RC repaired with polymer-modified mortar (FCB1R), and RC repaired with epoxy-based repair material (FCB2R).

3.3 Bonding between based concrete and repair material

3.3.1 Direct tension bond test

Table 11 shows results of the direct tension bond test. Only the data from the specimens which failed by the interface failure was recorded. The bonding strength under direction of epoxy-based repair material is approximately 2 times to the polymer-modified mortar. In addition, there is not much difference between bonding strength at 7 days and 14 days of each material.

Table 11 Results of the direct tension bond test.

Repairing Material	Direct Tension Bonding Strength (N/mm^2)
Polymer-modified mortar (7 days)	1.13
Polymer-modified mortar (14 days)	1.27
Epoxy-based repair material (7 days)	2.38
Epoxy-based repair material (14 days)	2.38

3.3.2 Direct shear and combined shear compression test

The experimental results of direct shear test and combined shear compression test are shown in **Table 12** and **Table 13**, respectively. In the direct shear test, only data which was obtained from the interface failure was recorded while all data obtained from the combined shear compression test is used in this study although some specimens failed by the material failure. Both interface failure and material failure are taken as possible modes of failure in the actual structure and hence are considered in this study.

Table 12 Results of direct shear test.

Repairing Material	σ (N/mm^2)	τ (N/mm^2)
Polymer-modified mortar (7 days)	0.00	2.75
	4.00	6.31
Polymer-modified mortar (14 days)	0.00	2.20
	4.00	6.25
	5.00	6.70
Epoxy-based repair material (7 days)	0.00	3.62
	3.00	6.36
Epoxy-based repair material (14 days)	0.00	2.38
	1.50	4.62
	2.00	5.73
	3.00	7.24

Table 13 Results of combined shear compression test.

Repairing Material	Contact Angle (degree)	σ (N/mm^2)	τ (N/mm^2)
Polymer-modified mortar (7 days)	30	3.86	6.89
	45	12.76	13.15
	50	16.71	14.46
	55	26.53	19.31
	60	27.88	17.24
Polymer-modified mortar (14 days)	30	3.90	6.97
	45	12.66	13.04
	50	21.52	18.62
	55	25.87	18.83
	60	31.37	19.39
Epoxy-based repair material (7 days)	30	7.19	12.84
	45	19.33	19.91
	50	24.01	20.77
	55	29.69	21.61
	60	31.06	19.20
Epoxy-based repair material (14 days)	30	7.35	13.13
	45	18.78	19.35
	50	22.47	19.45
	55	27.10	19.73
	60	31.69	19.59

Table 14 Parameters of coulomb friction model.

Repairing Material	μ	τ_o (N/mm^2)	τ_{max} (N/mm^2)
Polymer-modified mortar	0.78	2.68	18.00
Epoxy-based repair material	1.35	2.98	19.00

A so-called Coulomb friction model is employed to simulate the bonding behavior of the repair interface. Three important parameters, namely, friction coefficient (μ), cohesion resistance (τ_o), and maximum shear stress (τ_{max}) can be obtained from the experimental results of the direct shear test together with the combined shear compression test. Cohesion resistance between concrete and repair material can be obtained from direct shear test with no axial stress. The friction coefficient can be determined from both direct shear test with an axial stress and combined shear compression test with relatively small angle. The maximum shear stress can be derived from the maximum shear stress when the normal stress is relatively high (combined shear compression test with larger angle). By applying Coulomb friction model, it is assumed that sliding occurs independent on normal pressure when shear stress reach maximum shear strength (Wrigger 2002)

Figure 16 and **Fig. 17** show the comparison between model and experimental result. Main parameters of Coulomb friction model for both repairing material are given in **Table 14**. Both repairing materials have approximately similar cohesion resistance (τ_o) but the fric-

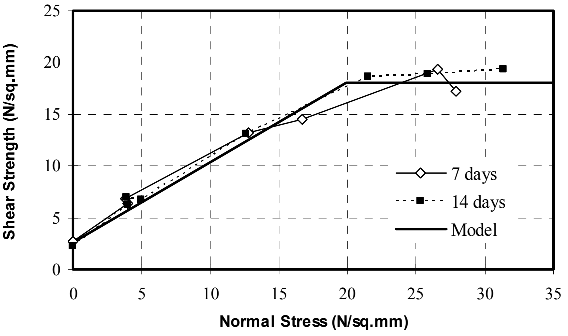


Fig. 16 Coulomb friction model for polymer-modified mortar.

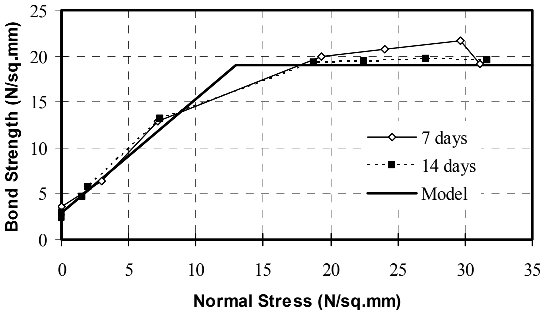


Fig. 17 Coulomb friction model for epoxy-based repair material.

tion coefficient (μ) of epoxy-based repair material is substantially larger.

4. Numerical simulation – FEM analysis

4.1 Finite element model

A 3-dimensional finite element model is created based on a so-called discrete model concept. The reinforcement is modeled using line elements connected to nodes of concrete or repair materials. The analysis was performed primarily using available models and element formulations available in the finite element software 'ANSYS'. **Figure 18** shows finite element model with the information of mesh and boundary condition applied for non-corroded RC beam and repaired reinforced concrete beam. Taking an advantage from symmetry of the member, one quarter of specimen with appropriate displacement boundary condition was analyzed in this study (**Fig. 19**). At the plane of symmetry, the displacement in the direction perpendicular to the plane was held to zero.

Concrete and repair material have been modeled as a three-dimensional eight node solid isoparametric element in order to model the non-linear response of brittle materials based on a constitutive model for the triaxial behavior of concrete (Williams and Warnke 1975). The element includes a smeared crack analogy for cracking in tension zones and a plasticity algorithm to account for the possibility of concrete crushing in compression zone. The longitudinal and transverse reinforcement have been modeled as discrete reinforcements using three dimensional spar elements embedded within the solid mesh. The stress-strain response of reinforcement based on experimental results was applied.

In this study, each FEM model contains two top longitudinal reinforcements and two bottom longitudinal reinforcements. The reinforcements with diameter of 12 mm and 16 mm were located at 37 mm and 161 mm from the top of the model, respectively. Transverse reinforcement with 6-mm diameter was also provided in the model. Note that only half of the transverse reinforcement was modeled at the center of the beam due to the symmetry. **Figure 20** illustrates the reinforcement model. Since the tensile reinforcement in corroded RC specimens is subjected to the loss of cross-section. The smaller area of the reinforcements was taken into account by reducing the cross sectional area of tensile reinforcement according to the experimentally measured weight loss. The perfect bonding is assumed for the interface between reinforcement and concrete or repair materials. Perfect bond can be reasonably assumed in this case because the bond model between rebar and concrete has only a minor effect on the tension stiffening which is already included with in fracture of concrete (in the case of discrete FEM) especially in the case of fine mesh element is applied (Jendele and Cervenka 2006).

The loading is applied by specifying a vertical dis-

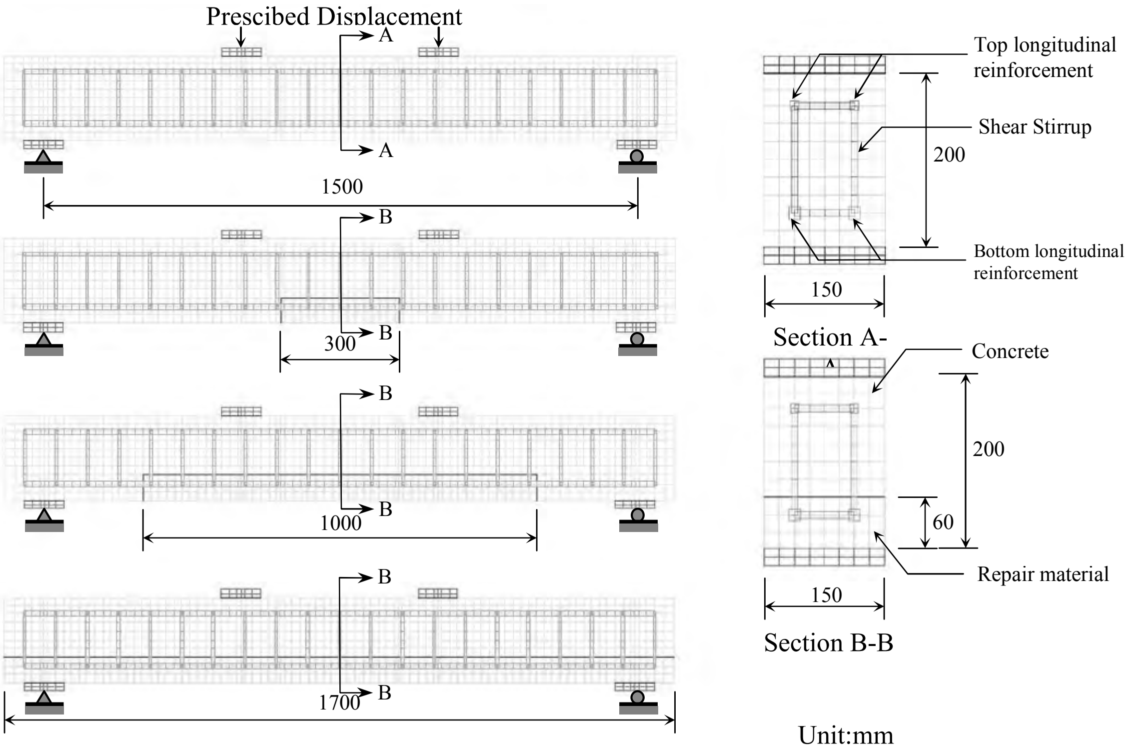


Fig. 18 Finite element model of non-corroded RC and repaired RC beams.

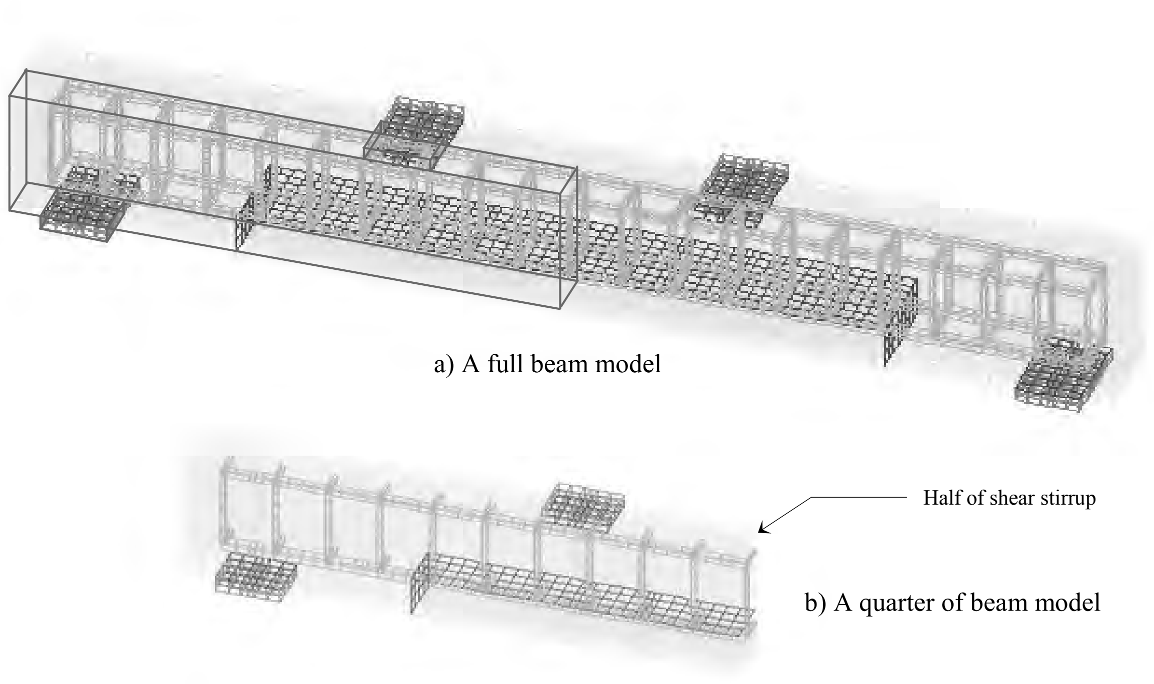


Fig. 19 A quarter of RC specimen model analyzed in this study.

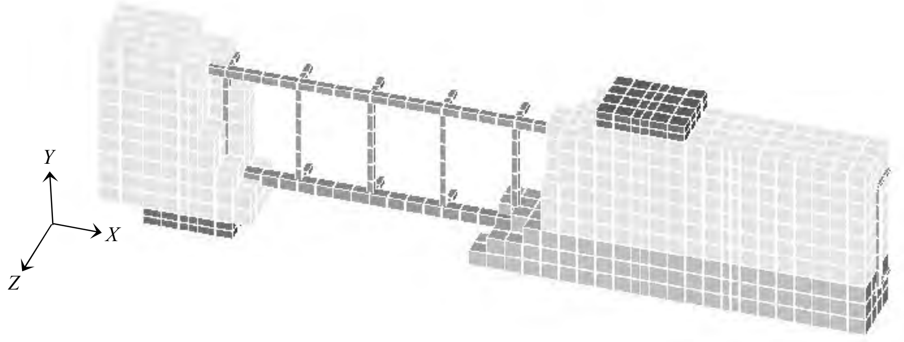


Fig. 20 Model of reinforcement in FEM analysis.

placement to the node of the loading plate located on top of the model (see **Fig. 20**). Similarly, the model was supported by support plates. Loading plate and support plates were modeled by solid element with elastic material model. This strategy was used instead of constraining vertical displacement of the beam nodes in order to avoid stress concentration problems. The summation of the reaction forces on these plates constitutes a load applied to the beam.

4.2 Material models

4.2.1 Concrete material model

Concrete is modeled by the solid element 'Solid 65' available in ANSYS. The element behaves in a linear elastic manner until either of the specified tensile or compressive strength is exceeded. After cracking, the element becomes orthotropic and has stiffness based on a bilinear softening stress-strain response. After crushing, the concrete is assumed to loss its stiffness in all directions. The failure surface of the element is computed based on the model proposed by William and Warnke (1975).

The tensile stress-strain relationship shown in **Fig. 21** is applied to plain concrete. The post-cracking tensile stiffness of concrete is accounted for when the strain is less than six times of the strain corresponding to the peak stress. R_t is the secant modulus which work with adaptive descent and diminishes as the solution con-

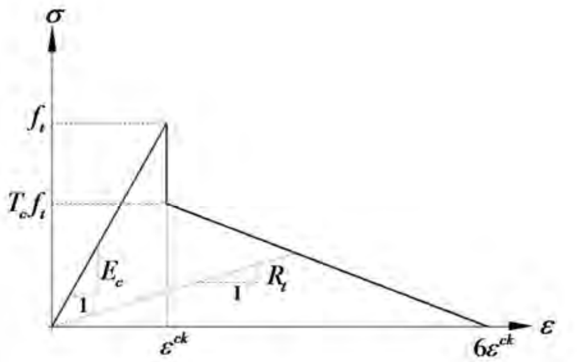


Fig. 21 Stress-strain response of concrete in tension-idealization used in ANSYS.

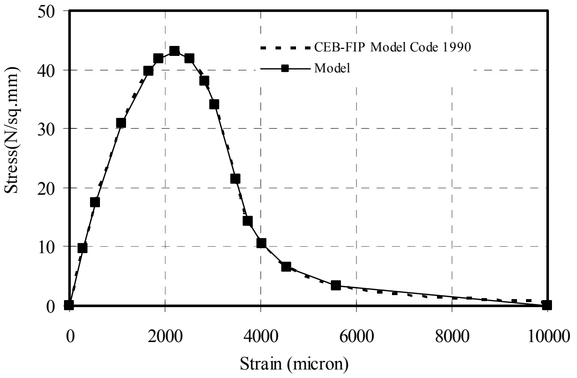


Fig. 22 Compressive stress-strain relationship of concrete employed in FEM analysis.

verges. And T_c is the multiplier for amount of tensile stress relaxation and was taken as 0.6 in this study. The tensile strength and strain corresponding to maximum stress were set as 3.5 N/mm^2 and 194 μ, respectively.

The compressive stress-strain relationship for concrete in this study follows the formula recommended by CEB-FIB model code (1990). Compressive strength, tensile strength, and modulus of elasticity were taken as 43 N/mm^2, 3.7 N/mm^2, and 35,000 N/mm^2 accordingly to the experimental results. In the FEM analysis, the CEB-FIB model was represented by multilinear stress-strain relationship as shown in **Fig. 22**. A shear transfer coefficient is also introduced in order to represent a shear strength reduction factor for those subsequent loads which induce sliding (shear) across the cracked plane. The coefficient for open cracks (β_t) should be in the rage of 0.05-0.5, rather than 0.0, in order to prevent numerical difficulties (Hemmaty Y. 1998). In this study the coefficient for open cracks (β_t) was set at 0.25 (Job T., and Anath R. 2006) while the coefficient for closed cracks was assumed to be 0.7.

4.2.2 Material model for repair material

Special attention was paid on the mechanical properties of repair materials. The stress-strain relationships were obtained experimentally and were slightly modified into multi-linear relationship (**Fig. 23** and **Fig. 24**). Note that the stress-strain relationship at 14 days was selected as an input for FEM analysis. The polymer modified mortar behaves very similarly with concrete and the tensile response was almost linear although the cracking strain capacity or crushing strain was much higher to those of normal concrete. The response of epoxy-based repair material was nonlinear under both tension and compression and shows remarkable ductility. Very large tensile cracking capacity (12,000 μ) is the reason why the RC specimen repaired with epoxy-based material has no flexural cracks formed in the patching area. The shear transfer coefficients for both repair materials were set at 0.55 for closed crack condition (β_c) and 0.15 for open crack condition (β_t). These coefficients are lower than coefficients of concrete since the maximum size of aggregate is lower (no coarse aggregate). Poisson ratio and modulus of elasticity applied in the numerical analysis were taken from experiments and is available in **Table 10**.

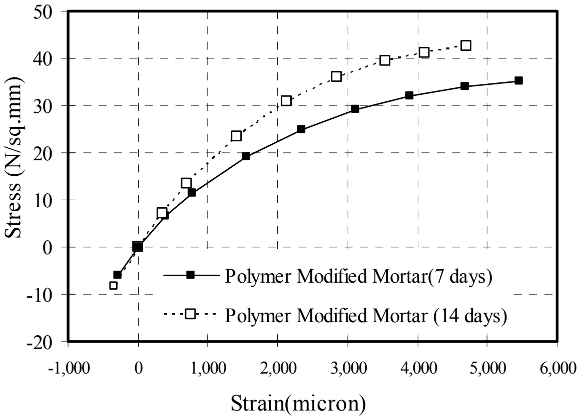


Fig. 23 Stress-strain relationship of polymer-modified mortar.

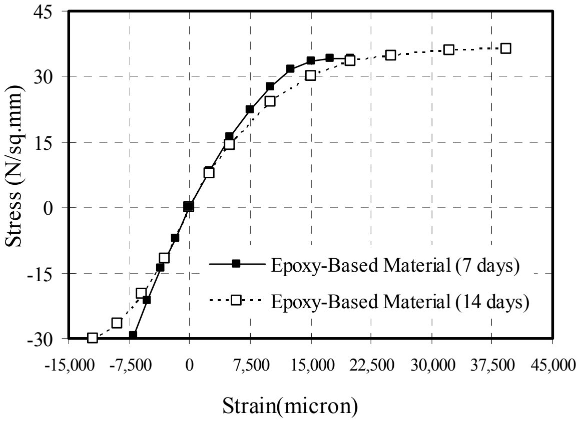


Fig. 24 Stress-strain relationship of epoxy-based repair material.

4.2.3 Stress-strain relationship of the reinforcement

Stress-strain relationship of reinforcement was modeled to be rate independent with multi-linear isotropic hardening with von-Mises yield criterion. By fitting the model with experimental data, the tensile stress-strain responses of all reinforcement were derived as shown in **Fig. 25**. Modulus of elasticity and Poisson's ratio were taken as 206,000 N/mm^2 and 0.3 for all reinforcing bars.

4.3 Contact interface between concrete and repair material

Two modes of local failure at the interface between concrete and repair material, namely, crack opening due to tensile stress (Mode I) and fracture due to shear stress (Mode II) were considered in the numerical analysis. To simulate crack opening due to tensile stress (Mode I), non-linear spring element was employed while the contact element was used to simulate interaction between shear and compressive stress at the interface (Mode II). The contact element contains a constitutive low which is expressed in terms of the contact tractions and relative displacements of two surfaces.

4.3.1 Modeling of mode I tension softening

Bilinear stress-crack opening diagram for concrete according to CEB-FIP model code 1990 was adopted in order to capture mechanical behavior of contact interface under tension. The model considers the softening of interface response after the formation of surface crack. The bilinear stress-crack opening diagrams can be obtained as shown below;

$$\sigma_{ct} = f_t\left(1-0.85\frac{w}{w_1}\right) \quad \text{for} \quad 0.15 f_t \le \sigma_{ct} \le f_t \tag{2}$$

$$\sigma_{ct} = \frac{0.15 f_t}{w_c - w_1}\left(w_c - w_1\right) \text{ for } \; 0 \le \sigma_{ct} \le 0.15 f_t \tag{3}$$

$$\text{With } w_1 = 2\frac{G_F}{f_t} - 0.15 w_c \tag{4}$$

$$w_c = \alpha_F \frac{G_F}{f_t} - 0.15 w_c \tag{5}$$

where,

σ_{ct} is the tensile stress (N/mm^2)

w is the crack opening (mm)

w_1 is the crack opening (mm) for $\sigma_{ct} = 0.15 f_t$

w_c is the crack opening (mm) for $\sigma_{ct} = 0$

G_F is the fracture energy (N-mm/mm^2)

f_t is the tensile strength (N/mm^2)

α_F is the coefficient which depends on the maximum aggregate size (taken as 8 for polymer-modified mortar and 7 for epoxy-based repair material)

The fracture energy (G$_F$) is the energy required for propagation of tension crack of a unit area and can be estimated as following;

$$G_F = G_{FO}\left(\frac{f_c^{'}}{f_{co}^{'}}\right)^{0.7} \tag{6}$$

where,

$f_c^{'}$ is the compressive strength of concrete (N/mm^2)

$f_{co}^{'}$ is 10 N/mm^2

G_{F0} is the base value of fracture energy which can be determined based on maximum aggregate size (taken as 0.025 for polymer-modified mortar and 0.030 for epoxy-based repair material) (N-mm/mm^2)

Table 15 shows parameters used to defined the force-deformation response of non-linear spring element. The values at 14 days were employed in FEM analysis. Tension softening model corresponding to these parameters are shown in **Fig. 26**.

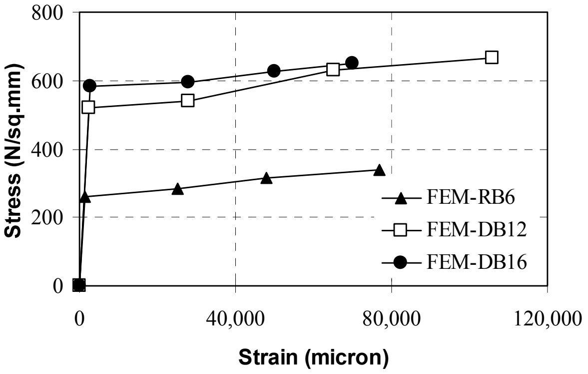


Fig. 25 Stress-strain response of reinforcements.

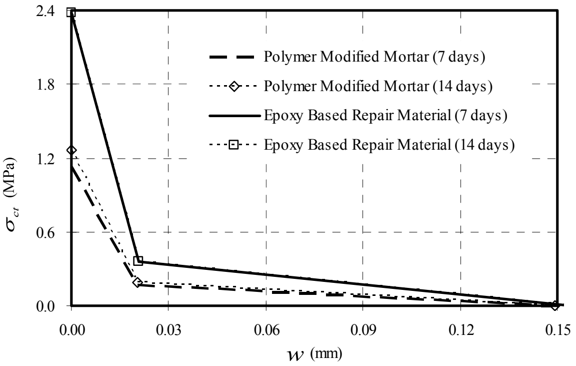


Fig. 26 Tension softening model for repair interfaces.

Table 15 Parameters used to define force-deformation of non-linear spring element.

Material	G_F (N-mm/mm^2)	f_t (N/mm^2)	w_1 (mm)	w_2 (mm)
Polymer-Modified Mortar (7 days)	0.019863	1.1247	0.014128	0.141284
Polymer-Modified Mortar (14 days)	0.022555	1.2694	0.014214	0.142141
Epoxy-based Repair Material (7 days)	0.052415	2.3822	0.020903	0.154020
Epoxy-based Repair Material (14 days)	0.052446	2.3835	0.020903	0.154025

4.3.2 Modeling of mode II relative displacement due to shear stress

Constitutive law of the repair interface under shear stress is expressed in terms of the contact tractions and relative displacement of two surfaces. The basic Coulomb friction model was adopted to simulate the response of interface in this mode. In the model, it is assumed that contact interface can carry shear stress up to a certain magnitude before sliding starts. The Coulomb friction model defined a shear stress (τ) at which sliding on the interface begins as a linear proportional function of the contact pressure (σ_n) with maximum limit (τ_{max}) which is provided so that calculated shear stress does not exceed the yield stress in the interface subjected to high contact pressure. Once shear stress limit is exceeded, slip takes place between the two surfaces. The model can be expressed in numerical formula as follow:

$$\tau = \tau_o + \mu\sigma_n \le \tau_{\max} \tag{7}$$

$$\tau_{y,z} = \begin{cases} k_s u & if \quad \tau < \sqrt{\tau_y^2 + \tau_z^2} - \mu\sigma_n \; (sticking) \\ \mu\sigma_n & if \quad \tau = \sqrt{\tau_y^2 + \tau_z^2} - \mu\sigma_n \; (sliding) \end{cases} \tag{8}$$

where,

τ_o : Cohesion sliding resistance (N/mm^2)

μ = Frictional coefficient

k_s = Tangential contact stiffness

u = Contact slip distance in y or z direction

The values for main parameters in this basic Coulomb friction model were obtained experimentally and available in **Table 14**. The integration of the friction mode is a nonassociated theory of plasticity. In each step that sliding friction takes places, and elastic predictor is computed in contact traction space. The predictor is modified with a radial return mapping function, providing small deformation along sliding response.

4.4 Results of FEM numerical simulation

The FEM numerical simulation incorporating loss of reinforcement as well as response of repair interface was conducted for all specimens. The numerical analysis of corroded RC repaired by patching method gives a peak load as shown in **Fig. 27**. The result shows that the FEM analysis can be used to predict the load carrying capacity of the repaired structure with acceptable accuracy when the model of interface response and precise model of repair material is incorporated.

5. Discussion

As shown by the experimental results, the structural behaviors of repaired reinforced concrete beams are dependent on mechanical properties as well as the size and location of repaired portion. In general, if the repaired portion is inside the constant moment span, the flexural capacity of the repaired member is similar to that of the control specimens because it is controlled by the crushing failure of concrete inside constant moment span. However, when very ductile repair material is applied, the flexural capacity of the repaired member is increased because of cracking in tensile area can be effectively prevented until the failure of member. When the maximum flexural capacity is increased, the possibility of shear failure is questionable. In fact, the structural performance of repaired reinforced concrete beams

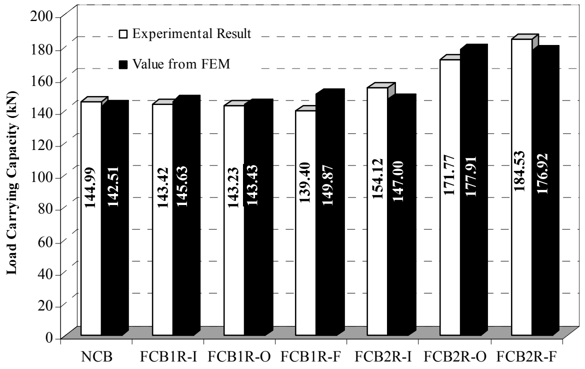


Fig. 27 Load carrying capacity obtained from experiments and by FEM analysis.

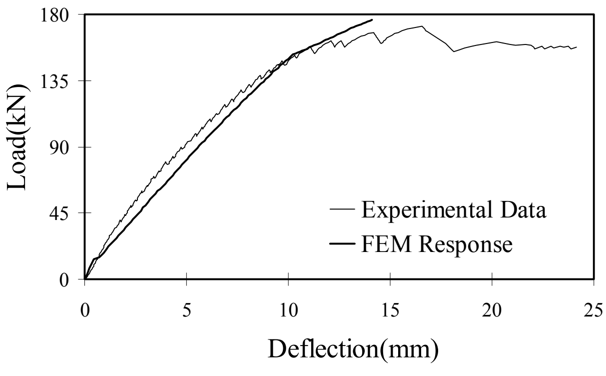
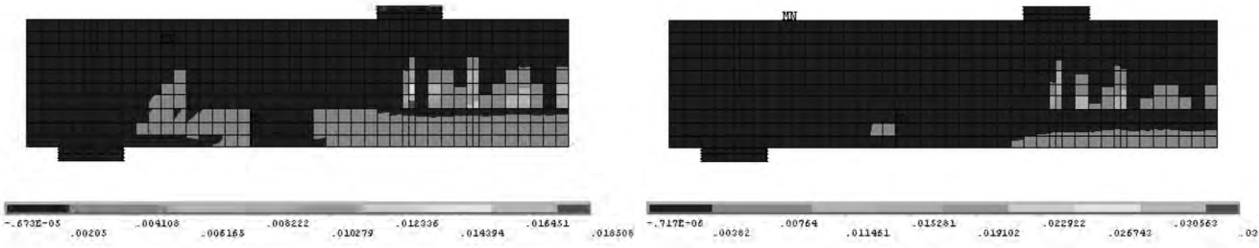


Fig. 28 Comparison between experimental data and numerical simulation of FCB2R-O.



(a) 150 kN

(b) At Failure

Fig. 29 Principal stress distribution in FCB2R-O (FEM analysis).

changed substantially when the section subjected to shear force is also repaired. Although the crack patterns give some clues how the mechanism of repaired beam changed, the information of stress field inside specimen could not be precisely measured in the experiment. Fortunately, the FEM analysis conducted in this study show the accuracy of applicable level for design work and some mechanisms of repaired beams can be captured by FEM analysis.

The explanation of how the stress field in shear span is changed by the length of repaired portion can be explained most clearly by the comparison between FCB2R-O and FCB2R-F. **Figure 28** shows the responses of FCB2R-O observed during and experiment and obtained by FEM analysis. Although FEM analysis could not precisely simulate non-linearity of FCB2R-O and gave a higher deflection at a specific load, it showed a good agreement with experimental finding on cracking pattern that no crack was formed in the patching area.

Attention should be paid to a sudden change of stiffness is observable at 150 kN (in FEM response) which is very close to the formation of diagonal shear crack observed in the experiment. Both the principle stress distribution (**Fig. 29**) and crack distribution (**Fig. 30**) show that considerable damage is located in shear span at 150 kN. It is therefore concluded that the loss of stiffness is caused by shear crack formation.

Figure 31 shows the load-deflection relationship of FCB2R-F obtained from experiment and FEM analysis. Unlike the case of FCB2R-O, the sudden change of stiffness was not observable because the existence of repairing interface prevents the formation of diagonal shear crack. Instead of large diagonal shear crack, damage is distributed throughout the shear span of FCB2R-F. **Figure 32** shows the crack distribution of FCB2R-F which agree very well with multiple shear cracks found in the experiment (see **Fig. 13**). The clear difference of damage localization can be observed (**Fig. 30** and **Fig. 32**).

In the case that repair material is not ductile and has comparatively low bonding strength, special attention should be paid to the interface failure. Additional consideration about volume change of repair material should also be taken into account. **Figure 33** shows the experimental data of FCB1R-F and the computational result. Very large discrepancy could be observed when the load was below 40 kN. This discrepancy is due to the fact that the shrinkage of the polymer-modified mortar was not considered in the numerical analysis and thus the cracking load could not be correctly calculated. However, both results show a good agreement when the load is beyond 40 kN. This indicates that FEM can predict flexural deflection of flexural RC repaired by polymer-modified mortar accurately. Nevertheless, unlike the case of ductile repair material, since the interface failure is likely in the case of polymer-modified mortar, special attention should therefore be paid to the controlled of deflection as well as other serviceability requirements.

Based on the experimental observation and numerical analysis, it is recommended that the influence of repair

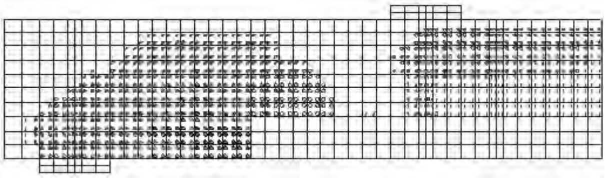


Fig. 30 Crack distribution in FCB2R-O at 150 kN (FEM analysis).

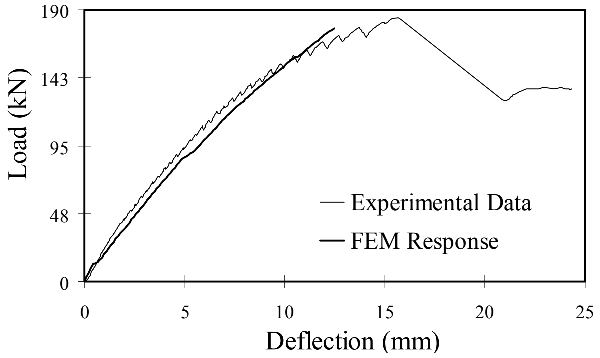


Fig. 31 Comparison between experimental data and numerical simulation of FCB2R-F.

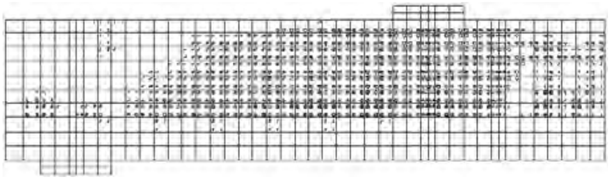


Fig. 32 Crack distribution in FCB2R-F at 150 kN (FEM analysis).

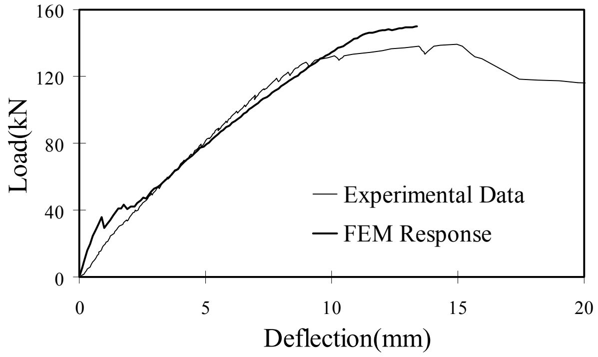


Fig. 33 Comparison between experimental data and numerical simulation of FCB1R-F.

material should be checked carefully in design stage. Since the mechanism of repaired beams varies based on properties of repaired material and location and size repaired portion, different type of failures is expectable for each repaired beam. This may be the reason why standard design guideline for patching repair cannot be easily proposed. However, this study shows that, with understanding on mechanical properties and application of FEM, the most likely failure mechanisms can be predicted with acceptable accuracy.

Although, as shown by the comparison between experimental data and numerical simulation in **Fig. 27**, the peak loads obtained from the numerical simulation were considerably close to the real loading capacity of the members, the applied numerical method was still unable to simulate the behavior after peak load. The authors expect that this limitation of the method may be caused by divergence problem when applying the proposed model with ANSYS. This limitation of the method should be solved in the future study.

6. Conclusion

Based on experimental observations and numerical simulation of repaired RC member, major findings can be concluded as follows:

(1) The structural behaviors of corroded RC specimens repaired by patching method are different based on both mechanical properties of repairing materials and patching area. However, in all cases, the repairing improves the structural behaviors when compared with corroded RC without repair.

(2) When polymer modified mortar is used as a repairing material, the failure of interface between repair materials is very likely to take place in the shear span. The interface failure disturbs the stress distribution in shear span as well as reduces overall stiffness of the repaired RC.

(3) Since the epoxy-based repair material is very ductile under tension, the flexural cracking was not observable in the patching area experimentally. The interface failure could also be successfully prevented by a better bonding characteristic which change brittle interface failure into distributed tiny cracks around the interface.

(4) The load carrying capacity of RC repaired by epoxy-based repair materials is higher than that of non-corroded RC. And the improvement of load carrying capacity is greater for the longer patching area.

(5) By incorporating the bonding between repairing material and based concrete using tension softening model and basic Coulomb friction model, the finite element analysis can give the sufficiently accurate prediction of ultimate load carrying capacity. However, the consideration of shrinkage of polymer modified mortar should improve the calculation.

(6) FEM analysis can successfully give information of stress distribution in repaired RC specimen and it is shown that the different patching area causes a specific stress distribution. For instance, in the case of epoxy-based repair materials, the patching length of 1000 mm caused a localization of stress in shear span and subsequently generated the large diagonal shear crack while the full-span patching helps in distributing stress over the shear span as well as preventing formation of diagonal shear crack.

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A triaxial investigation of kinematic yielding in sand

R. KUWANO* and R. J. JARDINE†

The elastic-plastic behaviour of a reconstituted sand is considered under triaxial conditions, covering a wide range of strains. Monotonic probing tests are used to identify two types of kinematic yield surface for samples with loose and dense initial states, under drained and undrained conditions and after different patterns of consolidation. Plastic strain development and global stiffness degradation are found to be closely interrelated, and the interpretation involves decoupling the elastic and plastic strain components. The sizes and the shapes of the loci are strongly affected by effective stress states and histories, including any periods allowed for creep and ageing. A tentative qualitative micromechanical explanation is offered for the phenomena observed.

KEYWORDS: anisotropy; laboratory tests; sands; stiffness

On observe ici le comportement élasto-plastique d'un sable reconstitué, dans des conditions triaxiales et sur une vaste plage de déformations. Des essais de sondage monotones sont utilisés pour identifier deux types de surfaces d'écoulement cinématique pour des échantillons aux états initiaux meubles et denses, dans des conditions drainées et non drainées et après différents modes de consolidation. On a observé que le développement de la déformation plastique et la dégradation globale de la rigidité sont étroitement liés, et l'interprétation implique de découpler les composantes de déformation plastique et élastique. La dimension et la forme des loci sont fortement affectées par les antécédents et états de contraintes effectives, y compris toute période de fluage et de vieillissement. L'article propose une explication micromécanique qualitative du phénomène observé.

INTRODUCTION

Classically, the term 'yielding' refers to the transition from elastic to plastic behaviour, and is associated with sharp curvature developing in a stress–strain relationship that had been linear up to that point. At the other end of the spectrum, it can be argued that the ultimate yielding of sands (under all-round compression) is delayed until the far later stage when particle breakage becomes dominant: see, for example, Coop & Lee (1993). Following Mroz (1967), schemes of multiple kinematic yield surfaces have been employed to model the progressive yielding of soil between such limits mathematically: see, for example, Simpson *et al.* (1979), Al-Tabbaa & Wood (1989), Stallebrass (1991) or Puzrin & Burland (1998).

High-resolution experiments are needed to investigate key questions: the possible shapes of such surfaces; whether the processes are smoothly continuous; or whether yielding involves any physically significant distinct phases. Laboratory observations with clays led Jardine (1985, 1992) to propose that at least two distinct kinematic surfaces (Y_1 and Y_2) exist within the classical large-scale yield surface (Y_3) that (*a*) mark significant changes in mechanical response and (*b*) surround the current effective stress point and can move and develop as the effective stress state changes. Some features of this scheme are illustrated in Fig. 1. The Y_1 surface corresponds to the linear quasi-elastic boundary. Once engaged, the Y_1 surface is dragged with the effective stress point, although its shape and size may change. In clays the plastic strains developed immediately after engaging the Y_1 surface are relatively small, and unload–reload cycles appear to follow closed hysteretic loops until the stress path engages the Y_2 surface. At this stage plastic straining develops more rapidly, with markedly more energy being dissipated in cycles, and the stress–strain behaviour becomes both rate dependent and subject to creep. The Y_2 surface is dragged with the effective stress point; plastic straining becomes progressively more important as the effective stress point moves towards the Y_3 surface. Y_3 yielding is associated with the onset of marked contraction, dilation or abrupt failure, and corresponds to the conventional geotechnical understanding of yielding. In cases where contraction is followed by dilation, the onset of phase transformation may be considered as a further phase, Y_4, of yielding. When plotted in normalised effective stress space the Y_3 yield points fall close to the local bounding surface (LBS) associated with the prior particular consolidation stress history; the LBSs generally fall within the soil's outer state boundary surface (e.g. Jardine *et al.*, 2004).

Smith *et al.* (1992), Smith (1992) and Jardine *et al.* (2002) found that the above scheme applied well to natural clays from Bothkennar and Queenborough in the UK. The Y_2 yielding surfaces were determined by noting:

(*a*) the limiting conditions at which hysteretic stress–strain loops fail to close and irrecoverable strains start to accumulate in slow undrained cyclic tests, and
(*b*) the points where abrupt changes in strain increment directions (or reduction in tangent stiffness) develop in drained probing tests.

The Y_2 surfaces applicable to undisturbed in situ conditions could be correlated with contours of either increments of strain, or an incremental measure of the work expended.[‡] The Y_3 surfaces were interpreted by logging

(*a*) effective stress path direction changes in undrained tests
(*b*) strain increment direction changes in drained tests or

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Discussion on this paper closes on 3 March 2008, for further details see p. ii.

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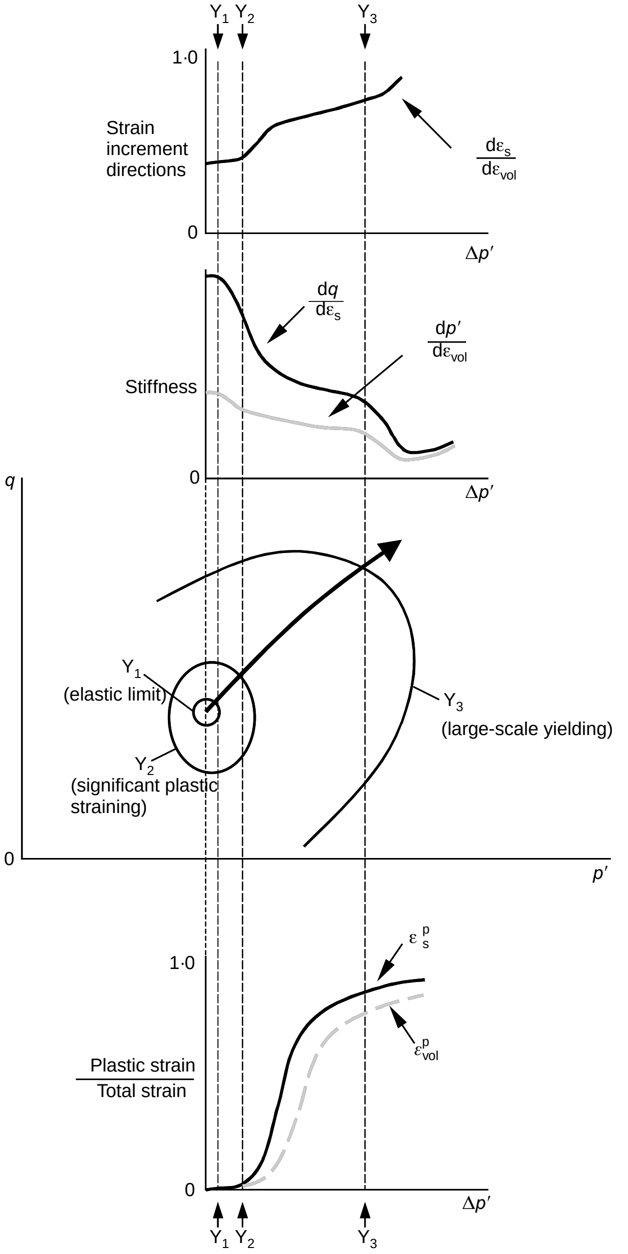
[‡] Burland & Georgiannou (1991) proposed that the incremental work ΔW $(= \int(\Delta p' \mathrm{d}\varepsilon_{\mathrm{vol}} + \Delta q \mathrm{d}\varepsilon_{\mathrm{s}}))$ was a useful measure for describing the kinematic small strain non-linear stiffness response of low OCR clayey sands; Hird & Pierpoint (1997) argued that the same applied to stiff Oxford clay.



ε_s: shear strain invariant = $2(\varepsilon_v - \varepsilon_h)/3$

ε_{vol}: volumetric strain = $(\varepsilon_v + 2\varepsilon_h)/3$ in triaxial tests

Fig. 1. Scheme of multiple yield surfaces (Jardine, 1992; Tatsuoka *et al.*, 1997)

(*c*) abrupt changes in tangent stiffness in either type of test.

The large-scale yielding characteristics of sands have been reported by Poorooshasb *et al.* (1966, 1967), Barden *et al.* (1969), Frydman (1974), Tatsuoka & Ishihara (1974), Nova & Wood (1979), Ishihara & Okada (1978), Vermeer (1978), Tatsuoka & Molemkamp (1983) and others. As is conventional in geotechnics, yield points were usually identified from marked changes in the stress–strain or stress–work relationships, with Graham *et al.* (1983) arguing that the two measures lead to similar results in clays. Yasufuku *et al.* (1991a, 1991b) reported that the work expended, $W(=\int(p'd\varepsilon_{vol} + qd\varepsilon_s))$, and a normalised measure of work $k(=\int(d\varepsilon_{vol} + \frac{q}{p'}d\varepsilon_s))$ were appropriate general parameters to define yielding in sand, finding approximately elliptical surfaces that were oriented parallel to (but not fully symmetrical about) the consolidation effective stress path.

Tanimoto & Tanaka (1986) reported yield loci interpreted from acoustic emission measurements that fell well inside the conventional (Y_3) surfaces, but were far more extensive than the elastic regions expected from high-resolution static testing on sands (see Tatsuoka *et al.*, 1997). They appear to have detected a sub-yielding process (possibly Y_2) that takes place between the elastic limit (Y_1) and the Y_3 surface. Relatively little other experimental evidence has been published concerning sub-yielding behaviour in granular media. Porovic (1995) described resonant column and torsional shear hollow cylinder tests on Ham River sand that indicated a Y_1 linear range that typically extended to a shear strain of $\gamma_{\theta z} \approx 0{\cdot}001\%$, while torsional shearing to beyond $\gamma_{\theta z} \approx 0{\cdot}02\%$ led to vertical strains ε_z developing in addition to $\gamma_{\theta z.}$ Porovic interpreted the onset of pronounced cross coupling as Y_2 yielding. Zdravkovic & Jardine (1997) interpreted similar features, and also changes in rates of pore water pressure development, as indicators of Y_2 yielding in hollow cylinder experiments on a non-plastic silt. Chaudhary & Kuwano (2003) reported the Y_1 to Y_4 yielding characteristics of Toyoura sand in a constant p' plane obtained by hollow cylinder experiments.

EXPERIMENTAL PROGRAMME

Kuwano (1999) undertook experiments to investigate the progressive yielding of Ham River sand (HRS) as part of a comprehensive study into granular media. HRS is a uniform clean sub-angular-shaped quartz sand, with a specific gravity of 2·66, a coefficient of uniformity of 1·67, a mean particle size of around 0·27 mm and maximum and minimum void ratios of 0·849 and 0·547 respectively.

Test series

We concentrate here on four of Kuwano's drained (A to D), and one of her undrained (U), triaxial test series. The Series A to D samples were air-pluviated and saturated by vacuum and water flushing prior to back-pressure application; those for Series U were water-pluviated.

Isotropic and anisotropic effective stress states were considered, with samples being taken slowly to 'consolidated' effective stress points prior to drained or undrained probing tests. All samples were aged for 12–24 h to allow creep to stabilise before applying a probing effective stress path. Each experiment involved a fresh sample that was subjected to a single style of probing, with only one nominated stress variable being changed. For example, in the tests termed '+v'', σ'_v was increased while keeping σ'_h constant. The abbreviations applied to the drained probing test types are defined in Table 1; undrained compression and extension tests were also performed.

The series involved samples with initial relative densities between 17% and 63% that had been taken to OCRs between 1 and 3·7 (under K_0 or isotropic conditions) and tested in the modes summarised in Tables 2 and 3. Most tests involved stress control, although the +v′, −v′ and undrained experiments employed strain control. The effective stress paths followed in Series A to D are shown in Figs 2(a)–(d). Where feasible, shearing was continued to failure.

As described by Kuwano (1999), Jardine *et al.* (2001) and Kuwano & Jardine (2002a), the sand's stress–strain behaviour is time dependent, a feature that has been emphasised by Tatsuoka *et al.* (2002a), Matsushita *et al.* (1999), Kuwano *et al.* (1999), Di Benedetto *et al.* (2001), Nawir *et al.* (2001) and others. The deformations accumulated during the HRS

Table 1. Loading type in probing tests

Type of probing test (abbreviations)	Loading conditions	Direction of effective stress path in p'–q space, θ (angle with respect to p'-axis)
+v′	$\Delta\sigma'_{\mathrm{v}} > 0$ with $\Delta\sigma'_{\mathrm{h}} = 0$	72°
−v′	$\Delta\sigma'_{\mathrm{v}} < 0$ with $\Delta\sigma'_{\mathrm{h}} = 0$	252°
+h′	$\Delta\sigma'_{\mathrm{h}} > 0$ with $\Delta\sigma'_{\mathrm{v}} = 0$	326°
−h′	$\Delta\sigma'_{\mathrm{h}} < 0$ with $\Delta\sigma'_{\mathrm{v}} = 0$	146°
+p′	$\Delta p' > 0$ with $\Delta q = 0$	0°
−p′	$\Delta p' < 0$ with $\Delta q = 0$	180°
+q	$\Delta q > 0$ with $\Delta p' = 0$	90°
−q	$\Delta q < 0$ with $\Delta p' = 0$	270°

Table 2. Probing test conditions

Test series	Sample	State of density (Initial void ratio) (Relative density)	Stress state at beginning of shearing	Type of probing test performed
A	A1–8	Loose (e_{i} = 0·76–0·77) (D_{r} = 25–30%)	Anisotropic Lightly overconsolidated (OCR = 1·3) (σ'_{h} = 127 kPa, σ'_{v} = 243 kPa)	+v′, −v′, +h′, −h′, +p′, −p′, +q, −q
B	B1∼4	Dense (e_{i} = 0·66–0·67) (D_{r} = 60–63%)	Anisotropic Lightly overconsolidated (OCR = 1·3) (σ'_{h} = 127 kPa, σ'_{v} = 243 kPa)	+v′, −v′, +h′, −h′
C	C1∼4	Loose (e_{i} = 0·74–0·76) (D_{r} = 30–36%)	Anisotropic Normally consolidated (σ'_{h} = 142 kPa, σ'_{v} = 316 kPa)	+v′, −v′, +h′, −h′
D	D1∼5	Loose (e_{i} = 0·74–0·76) (D_{r} = 30–36%)	Isotropic Overconsolidated (OCR = 2) (σ'_{h} = 197 kPa, σ'_{v} = 207 kPa)	+v′, −v′, +h′, −h′, +p′, −p′

Table 3. Undrained test conditions

Test series	Sample	State of density	Stress state at beginning of shearing	Type of shearing
U	U1	e_{i} = 0·77 D_{r} = 27%	Anisotropic Normally consolidated (σ'_{h} = 300 kPa, σ'_{v} = 600 kPa)	Compression (+v) Extension (−v)
	U2	e_{i} = 0·78 D_{r} = 24%		
	U3	e_{i} = 0·80 D_{r} = 17%	Anisotropic Overconsolidated (OCR = 2·0) (σ'_{h} = 216 kPa, σ'_{v} = 300 kPa)	Compression (+v) Extension (−v)
	U4	e_{i} = 0·76 D_{r} = 30%		
	U5	e_{i} = 0·80 D_{r} = 17%	Isotropic (after K_0 consolidation and swelling) Overconsolidated (OCR = 3·7) (σ'_{h} = 163 kPa, σ'_{v} = 163 kPa)	Compression (+v) Extension (−v)
	U6	e_{i} = 0·75 D_{r} = 33%		

tests’ consolidation ageing periods were considerable in comparison with those in the preceding ‘primary’ loading (Kuwano & Jardine, 2002b). The effects of varying the creep-ageing periods were not studied, but it is likely that slow consolidation and ageing allows the Y_3 surface to extend outwards in sands. Tatsuoka *et al.* (2002b) show that sand creep is related to (*a*) the rate at which time independent (inviscid) strains develop, and (*b*) any accelerations (or decelerations) of the inviscid strain rates. However, the data described are indicative of the response to moderately slow loading starting from an initial state where creep rates had fallen to below 0·002%/h.

Test apparatus

The drained tests were performed on specimens 100 mm in diameter and 200 mm high, in a computer-controlled stress path cell that employed lubricated ends (with enlarged platens) and had sufficiently precise local strain and bender element instrumentation to determine the cross-anisotropic elastic properties at very small strains: see Kuwano *et al.* (2000). The Series U experiments involved an automated Bishop and Wesley stress-path cell with specimens 38 mm in diameter and 76 mm high. Axial strains were monitored locally, but with insufficient resolution to identify the linear Y_1 ranges reliably.

KEY FEATURES OBSERVED

Shear failure parameters

The peak shear strength failure conditions for Series A to D are summarised in Figs 2(a)–(d). Samples reached failure by axial compression in the +v′, +q, −h′ and −p′ test modes. The mean peak value of ϕ' in compression for the loose samples was 35°, slightly higher than the typical HRS critical state angle of around 32°, and independent (as

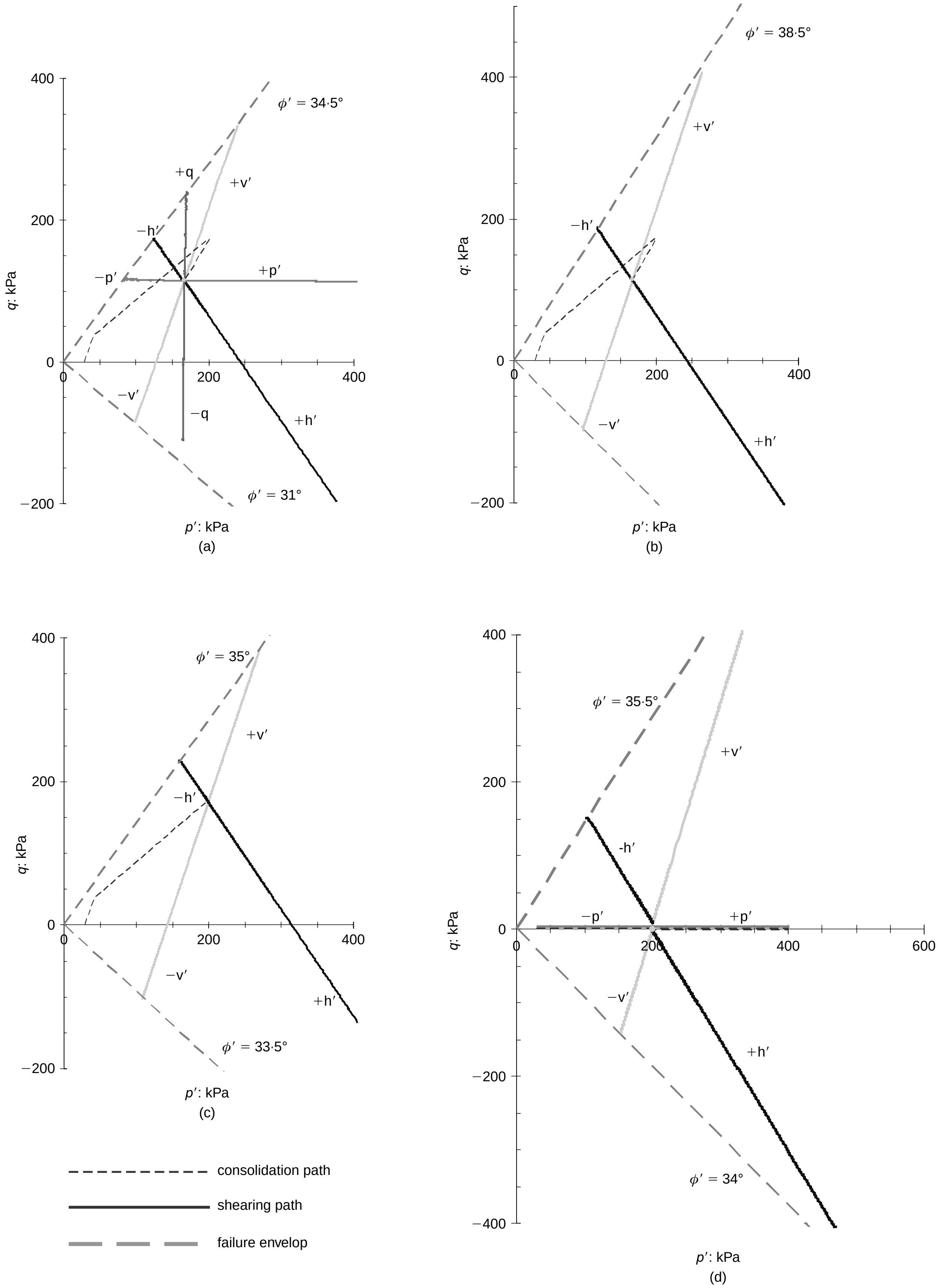


Fig. 2. Effective stress paths followed: (a) Series A (loose, K_0, OCR = 1·3); (b) Series B (dense, K_0, OCR = 1·3); (c) Series C (loose, K_0, OCR = 1·0); (d) Series D (loose, isotropic, OCR = 2·0)

expected) of the probing stress path direction. The −v′, −q and +h′ mode tests reached failure in extension, giving peak $\phi' = 31–34^{\circ}$ for the loose samples. Peak angles of 38·5° and 37° were developed in compression and extension respectively by the denser Series B samples.

The following sections describe the features identified in Series A, which involved K_0-consolidated specimens unloaded to OCR = 1·3 prior to probing. Lightly overconsolidated conditions are considered first, because the behaviour of normally consolidated samples is untypically constrained by the large-strain Y_3 yield surfaces (Jardine, 1992). Later sections concentrate on the features noted with denser samples (Series B), at lower OCR (Series C), after isotropic consolidation (Series D), and in undrained shearing (Series U).

IDENTIFICATION OF MULTIPLE YIELDING SURFACES IN SERIES A

Main features of pre-failure behaviour and Y_3 yielding

The stress–strain responses of the series A tests are presented in Figs 3(a)–(d) in terms of the axial ($\varepsilon_{\mathrm{v}} - \Delta\sigma'_{\mathrm{v}}$), radial ($\varepsilon_{\mathrm{h}} - \Delta\sigma'_{\mathrm{h}}$), volumetric ($\varepsilon_{\mathrm{vol}} - \Delta p'$) and deviatoric ($\varepsilon_{\mathrm{s}}$–$\Delta q$) incremental responses. As described later, the Y_3 points plotted as squares were interpreted by decoupling the elastic and plastic strain increments. The latter Y_3 points correspond reasonably well in most, but not all, of the tests to changes in the global tangent elastic-plastic stiffness. The +q, −h′ and −p′ tests showed unmistakable bends at their Y_3 points, while the +v′, −v′ and −q samples exhibited less abrupt changes, suggesting a more progressive form of Y_3 yielding. The +p′ and +h′ tests showed only moderate curvature, with no distinct Y_3 yielding.

Y_1 and Y_2 sub-yielding

The small-strain responses seen in Series A are presented in Figs 4(a)–(d), following the same scheme as Fig. 3. Each test had a linear start, the end of which defines a Y_1 point. The sign of the stress change did not affect the value of the initial stress–strain gradients (see, for example, tests +v′ and −v′), but it did affect the lengths of the linear segments. Kuwano & Jardine (2002b) describe companion small-amplitude cyclic tests, showing that, if the loading path reversed within the Y_1 region, the stress–strain relationship would retrace its initial path back to the origin without developing any plastic deformation. Shear wave velocity measurements were made with orthogonally oriented bender element transducers. Assuming rate-independent behaviour at very small strains and combining the above in a single interpretation indicated that behaviour within the Y_1 surfaces could be described by a cross-anisotropic elastic stiffness matrix whose terms varied as power functions of the relevant effective stress components, while also depending on current void ratio. Despite potential uncertainty in shear wave velocity determination, the best-fitting coefficients shown in Table 4 led to predictions that were compatible with measurements made in independent constant-p' and -q tests. The coefficients led to reliable predictions for the anisotropic stiffness measurements made over a wide range of effective stress states,. As shown by the Series C and U tests, the sizes and

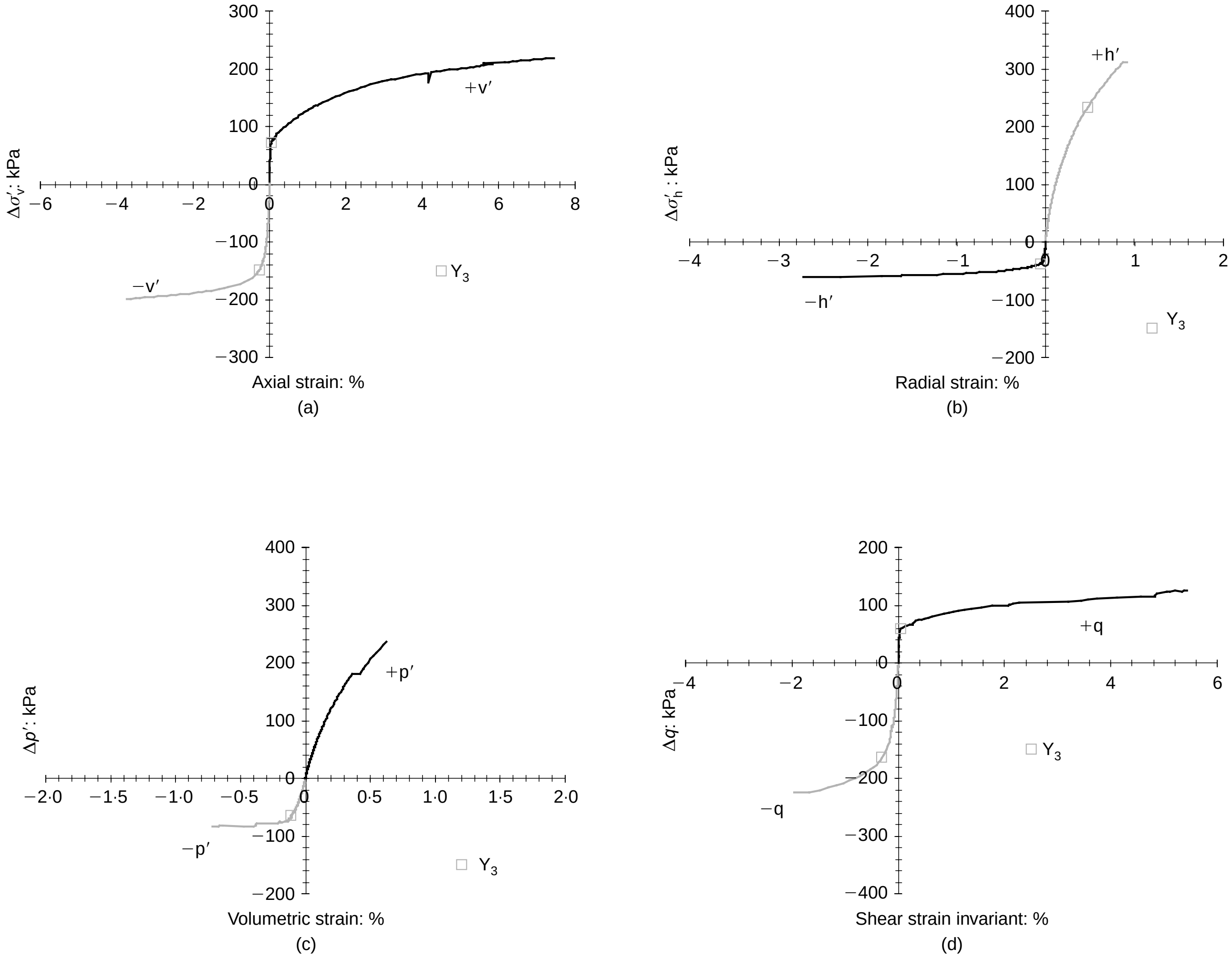


Fig. 3. Overall stress–strain relationship in drained probing tests (Series A): (a) ±v′ test; (b) ±h′ test; (c) ±p′ test; (d) ±q test

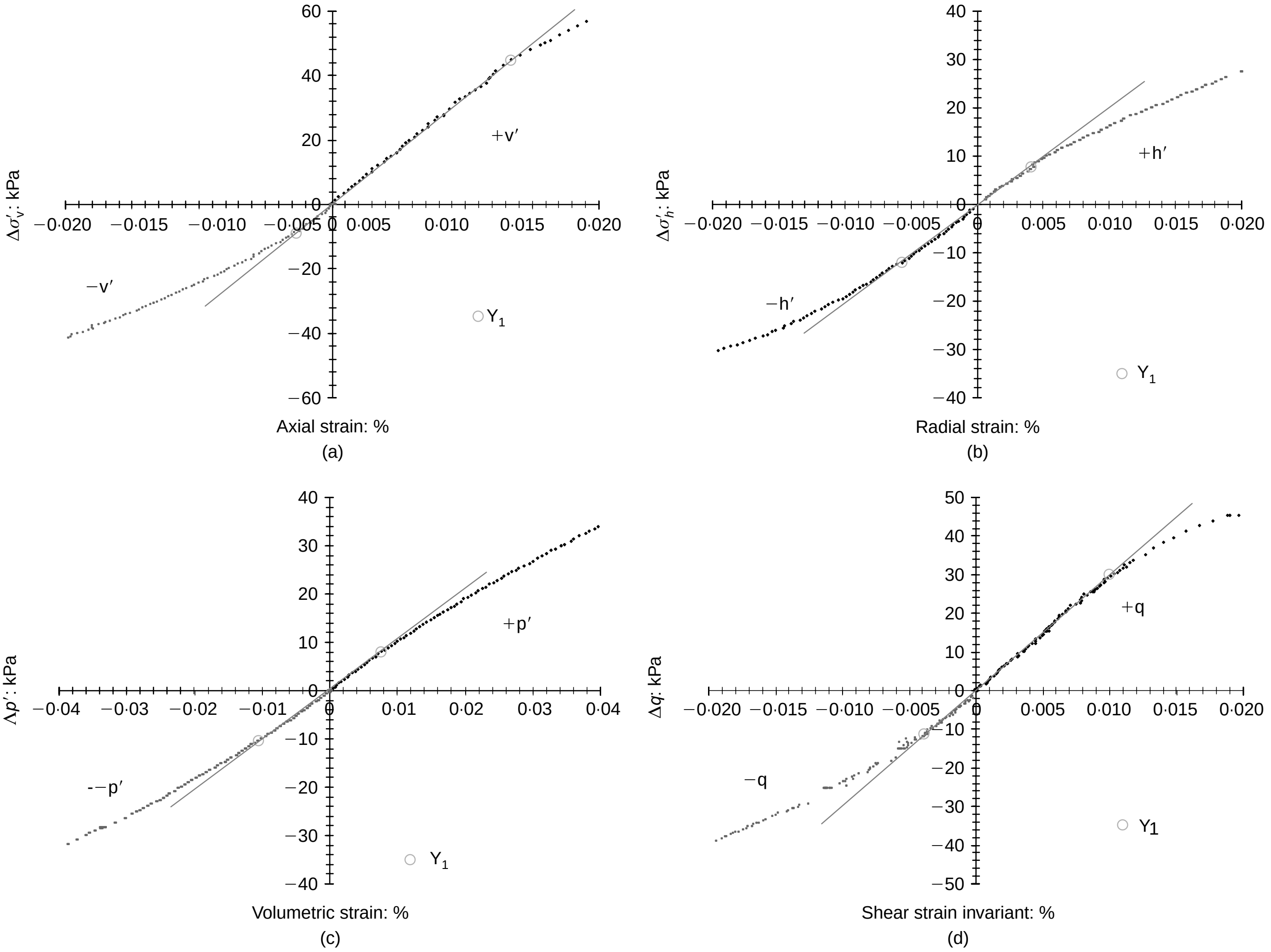


Fig. 4. Stress–strain relationship in drained probing tests at small strains (Series A): (a) ±v′ test; (b) ±h′ test; (c) ±p′ test; (d) ±q test

Table 4. Material constants for empirical expression of elastic stiffness

Stiffness		E'_v	E'_h	G_{vh}	G_{hh}
Material constants	C: MPa	204	174	72	81
	a	0·52	–	0·32	−0·04
	b	–	0·53	0·2	0·53

Empirical expression: $f(e)C(\frac{\sigma'_v}{p_r})^a(\frac{\sigma'_h}{p_r})^b$
where $f(e)$ is the void ratio function proposed by Hardine & Richart (1963) (= $(2{\cdot}17 - e)^2/(1 + e)$), and p_r is a reference pressure (= 101·3 kPa).

shapes of the kinematic Y$_1$ surface are highly dependent on both the current effective stress conditions and the recent stress history.

Figures 5(a)–(c) show the strain paths (ε_s–ε_{vol}) followed at three scales. The first diagram indicates that within Y$_1$ (at very small strains), the strain increment ratios, $d\varepsilon_s/d\varepsilon_{vol}$, were practically constant and showed a one-to-one correspondence with the applied stress increment directions. Quantitative checks show that the gradients match the values expected from cross-anisotropic theory, bearing in mind the effects of the current effective stresses on the cross-anisotropic stiffness matrix terms (Kuwano, 1999). The relationships between ε_s and ε_{vol} did not change immediately after passing the Y$_1$ points; the ‘elastic’ $d\varepsilon^e_s/d\varepsilon^e_{vol}$ ratios continued to apply until significantly larger strains had developed. The points where the strain path directions (defined in ε_s–ε_{vol} space) finally changed (in some cases only slightly) are indicated in Figs 5(a) and 5(b) as Y$_2$ yielding points.

Phase transformation and critical states

Kuwano’s research was concerned mainly with small-strain behaviour, and most of her tests were terminated before dilation ended and critical states had been achieved. However, clear Y$_4$ points, marking the onset of dilation, were seen in the Series A tests, with all four samples developing significant volumetric expansion as they were sheared towards failure: see Fig. 5(c). Similarly, her loose samples

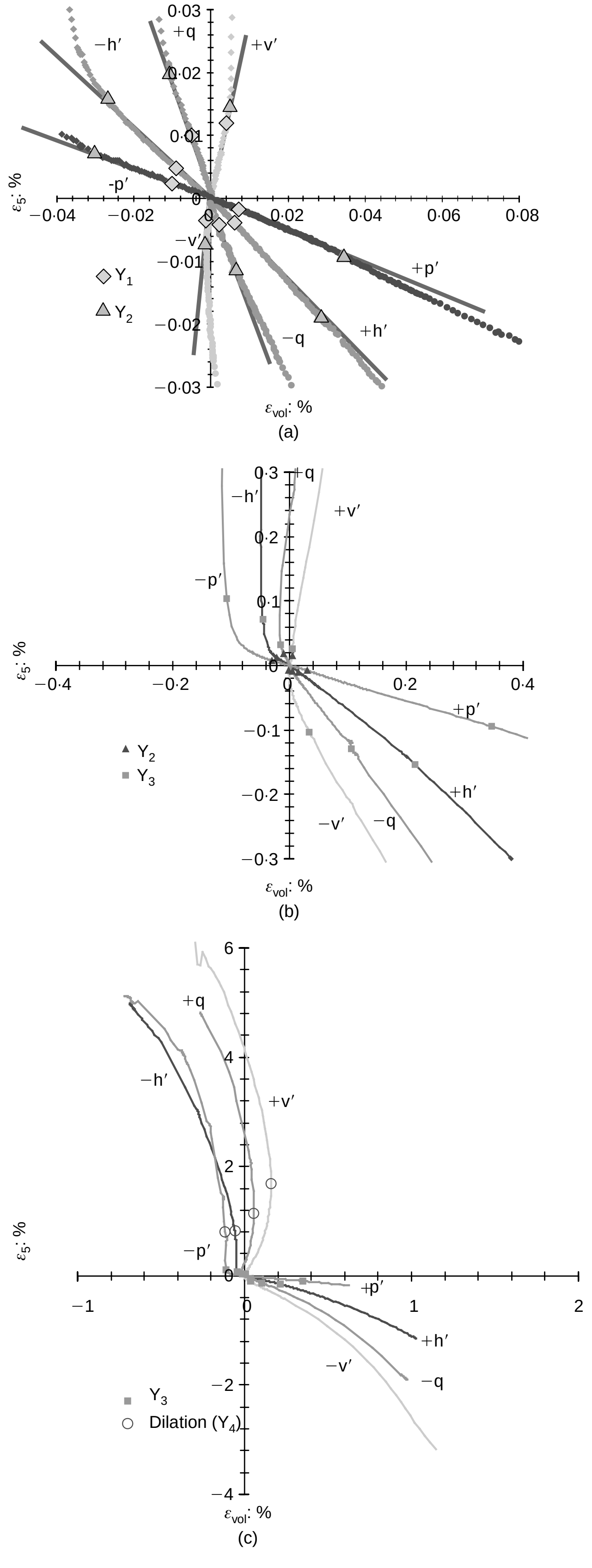


Fig. 5. Strain paths for test Series A: (a) at small strains; (b) at small to medium strains; (c) overall strain range

confirmed the sand's tendency to develop ultimate ϕ' values of ~32°. Undrained compression tests on her loosest samples (with $e \approx 0{\cdot}80$) tended towards critical states at $p' \approx 1$ MPa, with denser samples indicating higher p' values, broadly matching the critical state line shown in Fig. 6 from Coop & Lee (1993). Undrained extension tests experienced phase transformation at far lower p' values and developed strain localisation at earlier stages.

Y_3 yielding

It is difficult with sands to determine the intermediate large-scale yielding (Y_3) points consistently under the full range of triaxial conditions. The +v′, −v′, −h′, −p′ and +q tests showed reasonably clear stress–strain gradient breaks. But the other three Series A tests did not show any such breaks, or tell-tale changes in strain increment direction (see Fig. 5(c)). Coop & Lee (1993) argue that full yielding is delayed under isotropic (or K_0) compression conditions until particle breakage dominates and the e–logp' curves steepen to join the high-pressure virgin compression line (VCL). As shown in Fig. 6, Kuwano's normally consolidated HRS samples developed isotropic e–logp' curves at moderate stress levels that are relatively flat in comparison with Coop & Lee's VCL; we estimate that Kuwano's loosest samples might reach the VCL at $p' \approx 8$ MPa and the densest at perhaps 20 MPa. However, comparing the shapes of the loading and unloading stages of Kuwano's tests in Fig. 6; shows clear evidence of plastic straining at much lower pressure levels. Kuwano (1999) and Jardine *et al.* (2002) tracked the ratio of the plastic, $d\varepsilon^p$, to total strain, $d\varepsilon^t$, increments as

$$\frac{d\varepsilon^p}{d\varepsilon^t} = \frac{d\varepsilon^t - d\varepsilon^e}{d\varepsilon^t} = 1 - \frac{d\varepsilon^e}{d\varepsilon^t} \tag{1}$$

The elastic increments $d\varepsilon^e$ were evaluated by applying the cross-anisotropic hypoelastic stiffness expressions referred to earlier and described by Kuwano & Jardine (2002b). The first loading compression response of HRS was found to be predominantly plastic and rate dependent (and the unloading behaviour more nearly elastic) under typical engineering pressure ranges. Even initially dense samples gave $d\varepsilon^p/d\varepsilon^t \approx 0{\cdot}70$ while undergoing K_0 compression at $p' = 50$ kPa, rising to 0·85 at $p' = 200$ kPa. The $d\varepsilon^p/d\varepsilon^t$ ratios grew with test duration, with creep contributing 15–30% of the total strains

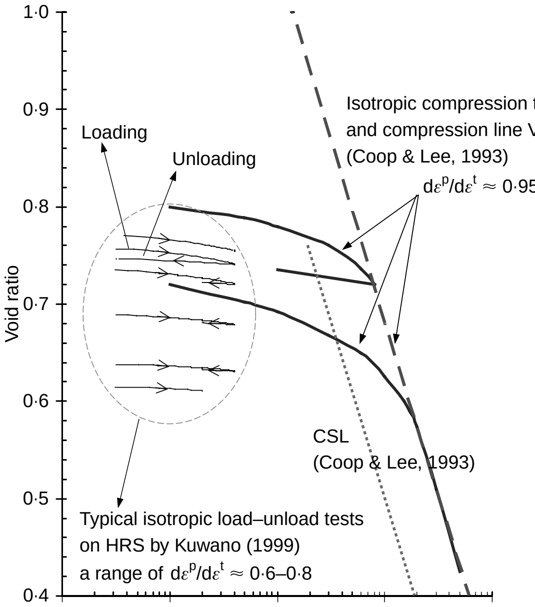


Fig. 6. Compression lines of HRS

developed by loose or dense HRS. The extreme values of $d\varepsilon^p/d\varepsilon^t$ applying under high-pressure compression conditions on the VCL can be estimated in a similar way. Comparing the elastic bulk stiffness expected at $p' \approx 8$ MPa with the equivalent global stiffness (vp'/λ) on the VCL indicates a $d\varepsilon^p/d\varepsilon^t$ ratio $\approx$ 0·95. Intermediate ratios apply between these limits, and a value of 0·85 is interpreted as being the most applicable single value to represent Y_3 in Series A to D, although it is noted that the ratio can climb nearer to unity for samples undergoing shear failure.

The development of $d\varepsilon^p/d\varepsilon^t$ with stress state has been computed for all of Kuwano's triaxial tests, taking account of effective stresses and void ratio, but not of any effects of 'shearing damage' that could change the cross-anisotropic hypo-elastic properties. Kohata *et al.* (1997) reported that such 'damage' was insignificant in reconstituted sand until near failure. Multiple vertical shear wave velocity measurements made in the Series A to D tests showed that 'damage' led to deviation from the predicted cross-anisotropic hypo-elastic pattern only after Y_4 and the onset of strong dilation (Kuwano, R. *et al.*, 1999).

Figures 7(a)–(d) show the plastic straining patterns developed in the Series A tests, which all started from 'aged' equilibrium initial stress states. The initially negligible plastic components gradually grew as strains increased (post-Y_1), with $d\varepsilon^p/d\varepsilon^t$ rising to a maximum of 0·98 in tests taken to shear failure. The steepest changes in $d\varepsilon^p/d\varepsilon^t$ occur over the 0·01–0·1% strain range, which has the greatest impact on practical engineering (Jardine, 1995).

Defining sub-yield surfaces in terms of a constant $d\varepsilon^p/d\varepsilon^t$ ratio offers an attractive approach when attempting to map a complete Y_3 surface in q–p' space. Kuwano (1999) adopted the $d\varepsilon^p/d\varepsilon^t = 0{\cdot}95$ contour tentatively, since this matched the clear yield points seen in the +q and −h′ tests. However, it was argued above that isotropic (or K_0 compression) tests would develop $d\varepsilon^p/d\varepsilon^t = 0{\cdot}95$ contours that extend out to very high pressures and approach the VCL at p' values 5 to 10 times greater than p'_c, where particle crushing dominates behaviour. None of Kuwano's normally consolidated samples approached such pressures, so the surface could not be closed on the right-hand side. As discussed later, the local bounding surfaces (LBS) indicated by the 'post-yield' sections of the undrained tests' effective stress paths also fell well inside the drained tests' $d\varepsilon^p/d\varepsilon^t = 0{\cdot}95$ contour, leading to a potentially severe incompatibility between Y_3 and the LBS. Recognising that $d\varepsilon^p/d\varepsilon^t$ is affected by rate processes and effective stress level, a lower ratio of 0·85 is proposed to cover Series A to D and U. This leads to a capped Y_3 shape that (*a*) hardens as 'consolidation' pressure increases, and (*b*) falls far closer to the normally consolidated effective stress points.

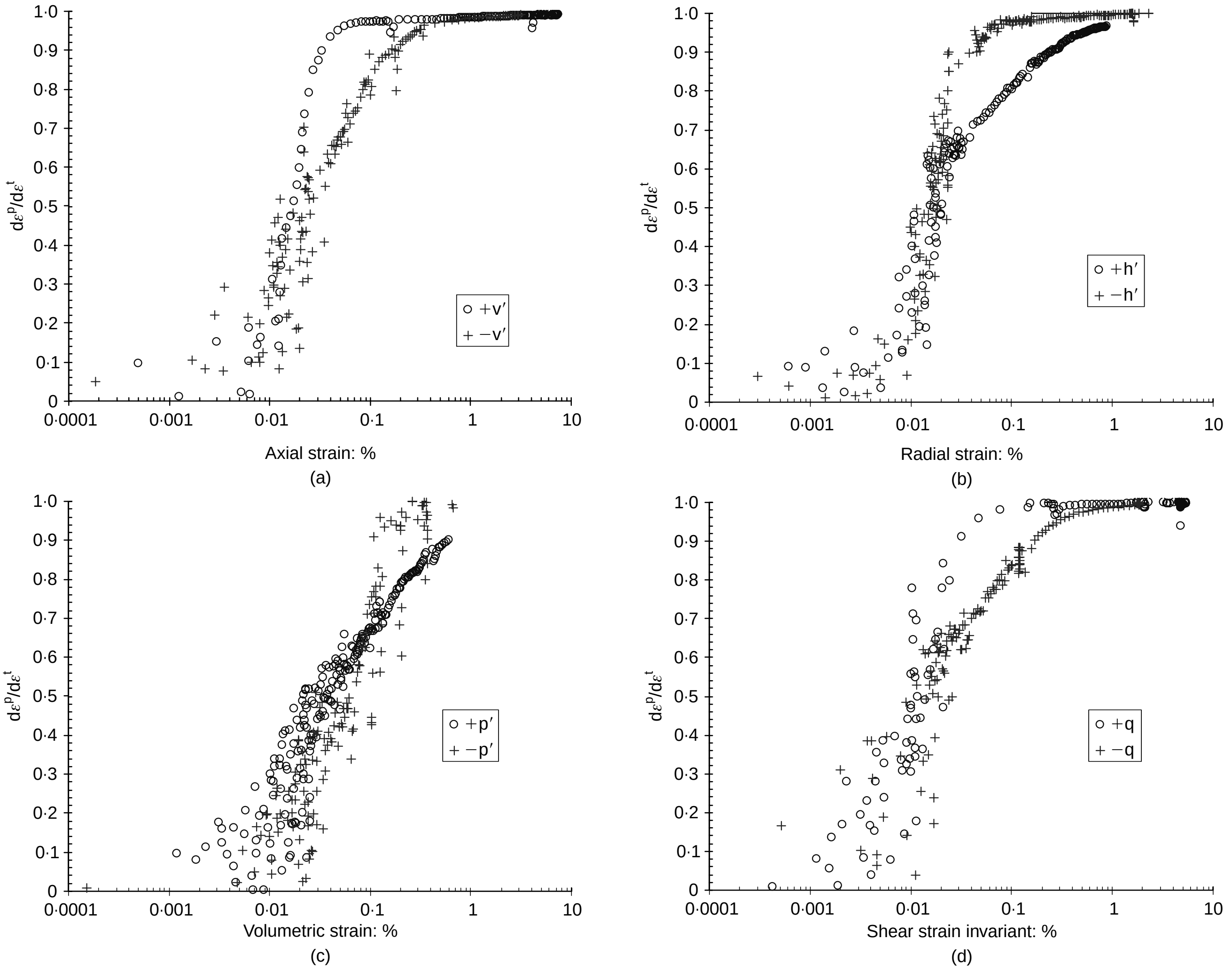


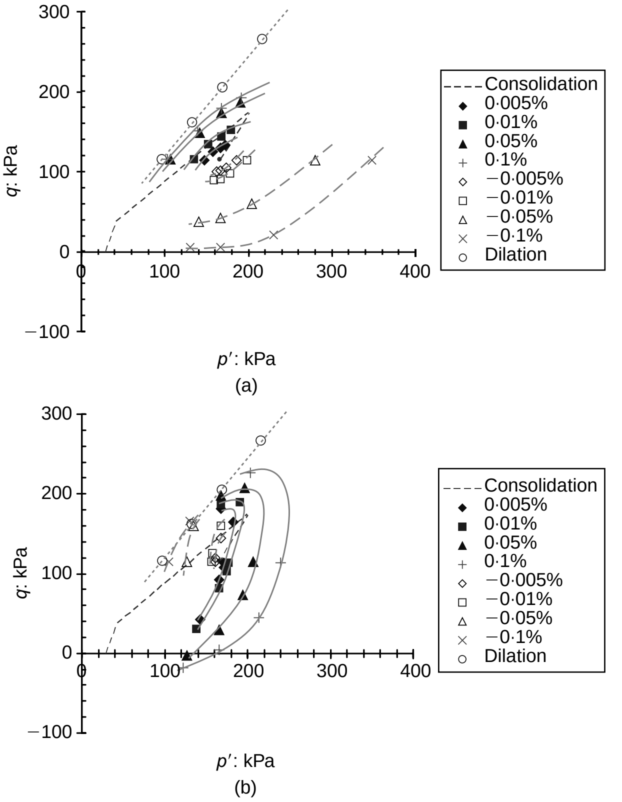
Fig. 7. Elastic and non-elastic components of strain increments for test Series A: : (a) ±v′ tests; (b) ±h′ tests; (c) ±p′ tests; (d) ±q tests

This ratio may appear to be marginally low when applied to the tests involving steeply inclined effective stress paths, but it is suggested that the original $d\varepsilon^p/d\varepsilon^t = 0{\cdot}95$ condition may be more consistent with states approaching the outer state boundary surface (SBS).

Contours of strain vector length

Kinematic yield surfaces have been related in earlier studies to strain criteria expressed in terms of invariant shear strain ε_s and volumetric strain ε_{vol}. Contours for these strain components are shown in Figs 8(a) and 8(b) from the Series A tests. The ε_s contours from the axial compression tests (+v′, +q, −h′ and −p′) are all aligned with the K_0 consolidation path, curving downwards at the higher p' levels. Those of the extension group (−v′, −q, +h′ and +p′) are similarly inclined, but show more curvature at lower p' values. The volumetric strain contours are more complicated, since both compressive and dilative volume strains develop. The compressive half of the diagram shows a progressive shift from steeply inclined, nearly linear, contours to a more cap-like curved shape at larger strains. The contours shown on the expansive side also tend to be steeply inclined.

In order to express the combined strains in a single measure, contours of the length $\bar{\varepsilon}$ of the strain vector (ε_s, ε_{vol}), $\bar{\varepsilon} = \sqrt{\varepsilon_{vol}^2 + \varepsilon_s^2}$, are plotted in Fig. 9. The patterns exhibited up to $\bar{\varepsilon} \approx 0{\cdot}05\%$ are approximately symmetrical about the recent effective stress path (unloading from OCR = 1 to 1·3). The $\bar{\varepsilon}$ contours become stretched to the right (p' increasing) at larger strains. Densely packed contours, which indicate rapidly reducing stiffness, were particularly noticeable in the upper left quadrant occupied by the −p′, −h′, +q and +v′ tests, where there is least space between the initial effective stress point and the Y_3 surface.



(a)

(b)

Fig. 8. Shear strain invariant and volumetric strain contours in Series A: (a) shear strain invariant; (b) volumetric strain

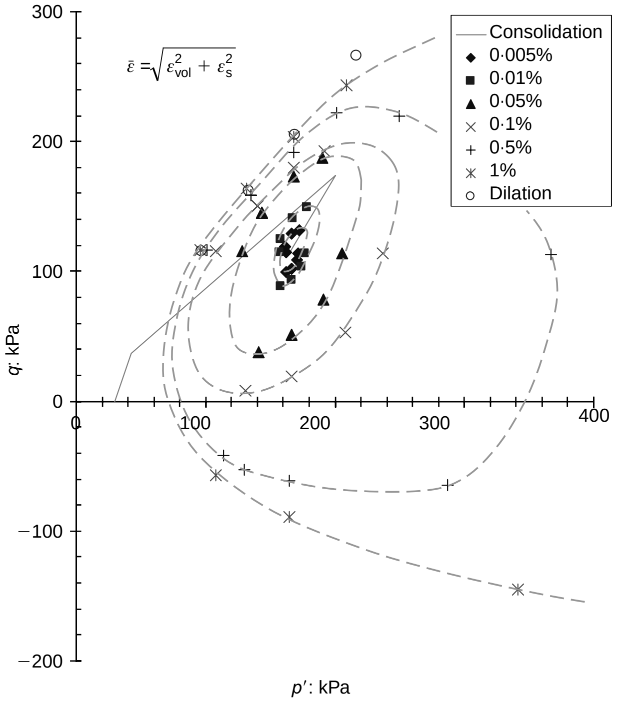


Fig. 9. Strain (length of strain vector) contours (Series A)

Contours of work expended

Incremental work has also been proposed as a criterion to define kinematic yield surfaces. The increment expended per unit volume in travelling along any given stress path is calculated as

$$\Delta W = \int (\Delta p' \delta \varepsilon_{vol} + \Delta q \delta \varepsilon_s) \qquad (2)$$

This measure does not represent the total amount of work expended (or recovered), which involves the full stresses and strains rather than their increments. However, the ΔW definition has the useful properties of (*a*) being related mainly to the incremental (kinematic) behaviour and (*b*) of being positive under most conditions (but not including shear-induced dilation). The two components of ΔW are illustrated in Fig. 10, which also shows how the signs of the components can vary with stress path direction. Contours of ΔW obtained from the Series A tests are presented in Fig. 11. Their shapes are broadly similar to those of the $\bar{\varepsilon}$ contours given in Fig. 9. Note that the contours plotted have absolute values. Dividing by a stress, such as p', makes the contours non-dimensional.

Observed yield surfaces, and contours of strain vector length and increments of work expended

The effective stress points at which the Series A samples reached $d\varepsilon^p/d\varepsilon^t$ values of 0·5, 0·7 and 0·85 are plotted in Fig. 12(a). The interpreted envelopes for Y_1 ($d\varepsilon^p/d\varepsilon^t = 0$), Y_2, Y_3 ($d\varepsilon^p/d\varepsilon^t = 0{\cdot}85$) and unit vectors of plastic strain increment[§] are also shown. Portions of the surfaces that must be considered as being tentative at this stage are shown as dashed curves. Cyclic tests, or creep holding experiments,

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[§] Unit vector of plastic strain increment:

$$\left(\frac{d\varepsilon_{vol}^p}{\sqrt{(d\varepsilon_{vol}^p)^2 + (d\varepsilon_s^p)^2}}, \frac{d\varepsilon_s^p}{\sqrt{(d\varepsilon_{vol}^p)^2 + (d\varepsilon_s^p)^2}} \right)$$

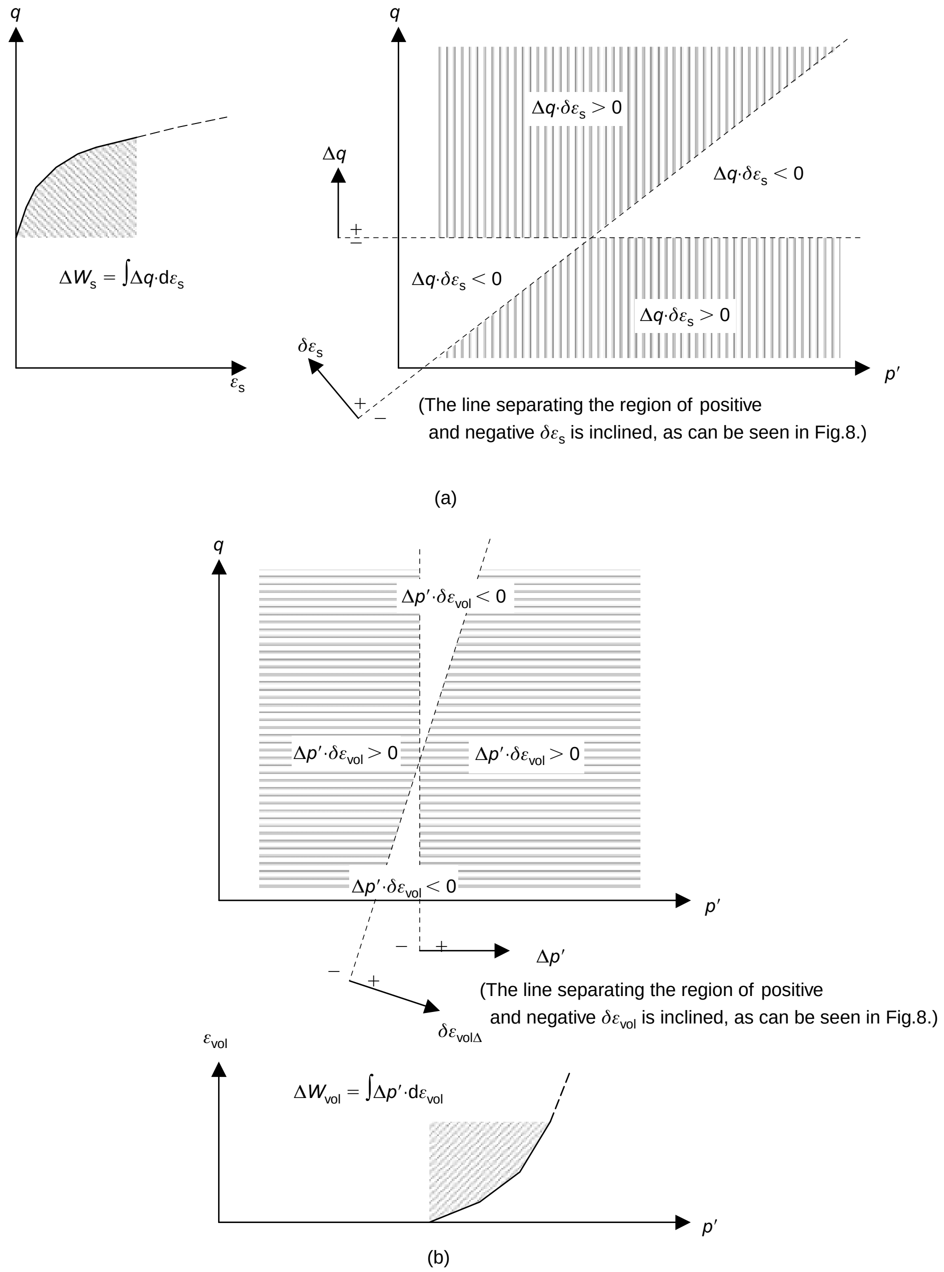

Fig. 10. Incremental energy expended by: (a) shear; (b) compression

might be able to identify Y_2 yielding more distinctly, particularly in the region of increasing p' and low q/p'. Points to note include the following.

(*a*) Unlike the contours of strain vector length and incremental expended work, the initial Y_1 locus is not symmetrical around the common initial (pre-probing) effective stress point. Instead it is significantly elongated in the σ'_v increasing direction.
(*b*) The contours of $d\varepsilon^p/d\varepsilon^t$ at 0·5, 0·7 and 0·85 have similar shapes to those of the strain or incremental expended work contours.
(*c*) Y_2 is located inside the $d\varepsilon^p/d\varepsilon^t = 0{\cdot}5$ contour.
(*d*) The directions of the unit vectors of plastic strain increment are practically constant within the Y_2 surface. In some cases, the unit strain vectors showed clear rotation on meeting the Y_2 surface.
(*e*) While the $d\varepsilon^p/d\varepsilon^t = 0{\cdot}5$ and 0·7 contours have similar shapes, the contours are stretched out in the p' increasing direction at larger values of $d\varepsilon^p/d\varepsilon^t$.

The Y_1 and Y_2 surfaces identified in Fig. 12(a) have closed shapes centred above and to the right of the initial effective stress point. The Y_3 surface has a capped shape, but is not symmetric about the isotropic axis.

Elastic-plastic stiffness–strain relationships from Series A

The degradation of tangent elastic-plastic stiffness with strain is illustrated in Fig. 13, considering the ±v′ and ±h′ tests from Series A. When calculating E'_h from the ±h tests, the initial Poisson's ratio ν'_{hh} measured at very small elastic strains was assumed to remain constant at 0·1 as strains grew. The interpreted Y_1 to Y_4 yielding points are also indicated. By definition, the overall elastic-plastic stiffness started to fall at the points of Y_1 yielding. However, the associated strain level depended on the recent stress history,

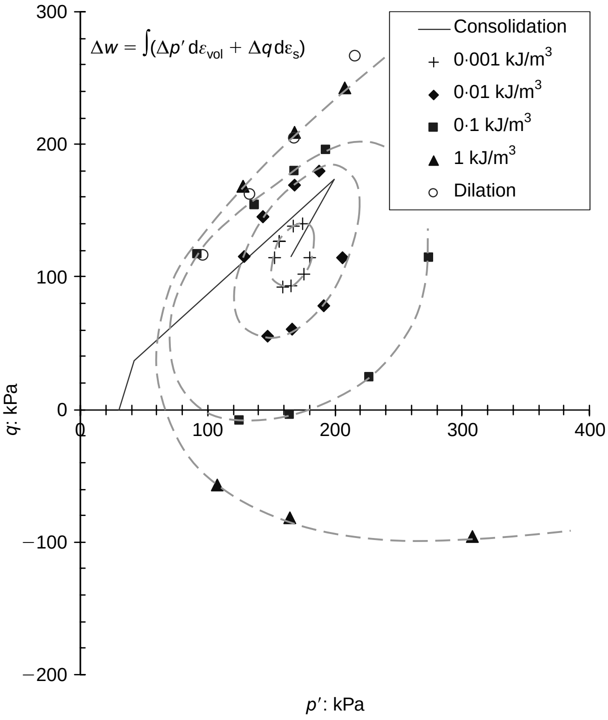

Fig. 11. Energy contours (Series A)

and the permitted ageing period. The degree of stiffness decay is clearly influenced by the distance between the initial effective stress point and the Y_3 surface. The +v′ and –h′ tests degraded rapidly post-Y_1 while the –v′ and +h′ test curves fell more gently, even though their elastic limits were reached at lower strains (around 0·001%). The stiffness–strain curves showed no clear break or change at the point of Y_2 yielding, with tangent stiffness falling 35–80% below their respective initial maxima. The tangent stiffnesses applying at the Y_3 yield points fall between 5% and 45% of the pre-Y_1 maxima: by definition, 85% of the incremental straining was plastic at this point.

PATTERNS SEEN IN TEST SERIES B, C, D AND U

Further drained experiments were conducted on denser samples (Series B), and at lower OCR (Series C) and after isotropic consolidation (Series D), as detailed in Table 2. The yield surfaces interpreted from these tests are presented in Fig. 12(b)–(d).

Series U, which involved undrained compression and extension tests on K_0-consolidated samples with OCRs 1 to 3·7 (see Table 3) gave the data presented in Figs 14 to 16. The first two figures present the stress–strain and excess pore water pressure plots, along with interpreted Y_2, Y_3 and phase transformation point (PTP, Y_4) yield points. The effective stress paths followed and the interpreted Y_2 surfaces are presented in Fig. 16. The early parts of the stress–strain (ε_v–Δq) curves exhibit an apparently initial linear portion, as did the pore water pressure–deviator stress change plots (Δu–Δq). Although the Y_1 points could not be identified precisely with the strain sensors employed for these tests, the undrained effective stress path directions dq/dp' appeared to remain constant well beyond the linear limits expected from Series A and B. The gradients dq/dp', which reflect the current directions of the plastic strain unit vectors, are subvertical, and the slight changes that are tentatively associated with Y_2 yielding are identified most easily by plotting the excess pore pressure ratios $\Delta u/\Delta q$. The onset of Y_3 yielding may be identified from the following three observations, which may lead to a spread of possible results in some tests:

(*a*) sharp curvature in the stress–strain relationship
(*b*) $d\varepsilon^p/d\varepsilon^t$ reaching the predefined limiting ratio, or
(*c*) any rotation of the effective stress path rotation to join the contractive (p' decreasing) post-Y_3 phase.

The latter eventually ended with phase transformation (Y_4 yielding) and the onset of suppressed dilation towards critical state conditions.

Tracking the Y_3 and Y_4 points shows that overconsolidation leads to inward shrinkage of the Y_3 surfaces. The latter feature was particularly pronounced in the compression tests; Porovic (1995) noted similar trends. As mentioned earlier, the Y_4 points were quite different under compression and extension conditions.

Figure 17 summarises the Y_1, Y_2 and Y_4 yield loci obtained from drained and undrained tests on loose HRS samples (Series A, C, D and U). Points to note from these and earlier figures include the following.

(*a*) The location, shape and alignment of the Y_1 loci depend critically on their recent stress history, with the kinematic loci developing elongated shapes that trail the effective stress path during both consolidation and overconsolidation.
(*b*) There is broad agreement between the shapes of the Y_2 surfaces interpreted from equivalent drained and undrained experiments; the same applies to the Y_3 surfaces based on the $d\varepsilon^p/d\varepsilon^t = 0{\cdot}85$ contour.
(*c*) The kinematic Y_2 loci are affected by the relative location of the current stress point in relation to the current Y_3 surface, as well as the recent stress history.
(*d*) The Y_3 surfaces grow in proportion to the consolidation p'_c values. Isotropic consolidation leads to more symmetrical Y_3 shapes than anisotropic, and (with all other factors held constant) the Y_3 surfaces of dense samples extend out to higher values of p' values than those of loose samples.
(*e*) Comparing Series A and C shows that overconsolidation (to OCR = 1·3) reduces the Y_3 surfaces' scale by perhaps 8%. The undrained Series U tests indicated shrinkage of up to 25% at OCR = 2 and 40% at OCR = 3·7. While significant, these changes are far less important than the corresponding relocations and changes in size of the Y_1 and Y_2 loci.
(*f*) Other features shared by all tests are: (i) constant directions of unit plastic strain vectors within the Y_2 surfaces; and (ii) the contours of $d\varepsilon^p/d\varepsilon^t$ at 0·5, 0·7 and 0·85 being similar to those of the incremental expended work, but not matching the interpreted Y_1 or Y_2 surfaces exactly.
(*g*) The areas inscribed by the Y_1 and Y_2 surfaces depend on the stress history and void ratio. The area A_1 within each Y_1 surface is evaluated in Table 5. The areas vary with p'^2, giving A_1/p'^2 ratios of $\sim 0{\cdot}035$ for loose samples and 0·042 for dense samples under similar effective stress conditions. Just as stiffness increases as void ratio reduces, so do the stress changes and work increments required to bring about Y_1 yielding.

The tangent stiffness obtained from the Series, B, C, D and U vertical compression and extension (±v′) tests are presented in Figs 18 and 19. The decay of stiffness is clearly linked to the span of stress (and hence strain) between the initial effective stress point and the Y_3 surface. The axial strains required for Y_1 yielding are of the order of 0·001%, while those for Y_3 ranged between 0·01% and 0·1%. Intermediate limits apply to Y_2 yielding (mostly around 0·01%),

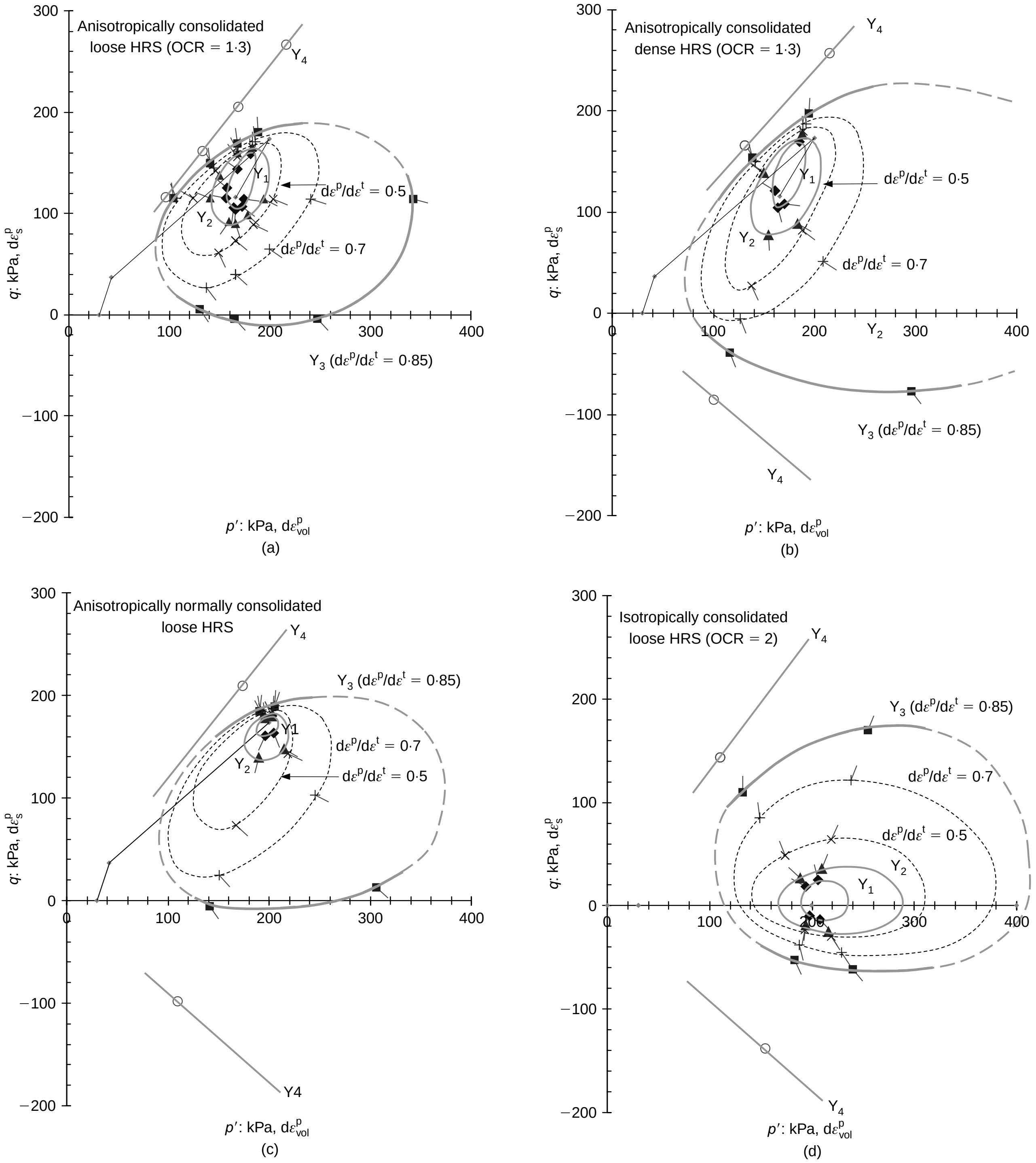

Fig. 12. Yield surfaces: (a) Series A; (b) Series B; (c) Series C; (d) Series D

while the tangent stiffnesses had typically lost 20–50% of their initial values by the onset of Y_2. As noted earlier, extended creep periods are likely to affect the sand's stiffness response, including the linear range and rate of stiffness decay post-Y_1.

SUMMARY OF THE FOUR STAGES OF YIELDING

The yielding of HRS takes place in four distinct stages. Insights gained from micromechanical analyses suggest a tentative correlation between the sand's micro- and macromechanical behaviour that is summarised in Table 6.

Pre-yielding: within the Y_1 surface

The sand's response within the initial Y_1 surface is practically linear elastic. Small load–unload loops indicate insignificant energy loss, and the stiffness response can be expressed in terms of a void ratio function and a hypoelastic cross-anisotropic compliance matrix. The matrix terms are affected by both void ratio and the current effective stresses.

As noted in Table 6, it is thought that stress changes that remain within the initial Y_1 surface do not alter the arrangements of, or contacts between, the sand particles. The particle assembly behaves as a highly redundant elastic structure, with most of the applied load being carried

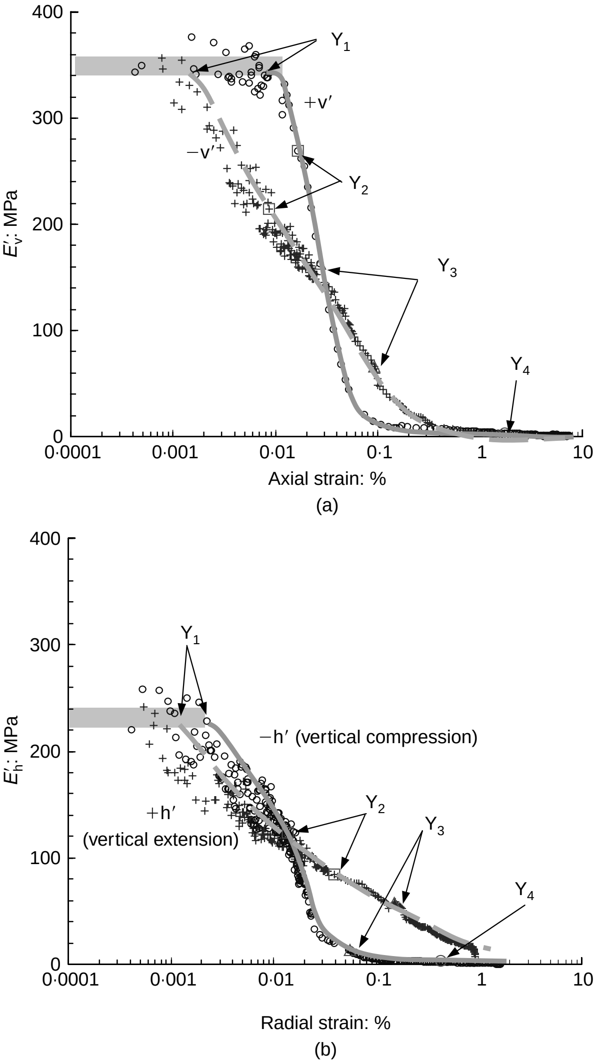

Fig. 13. Degradation of tangent elastic-plastic stiffness with shearing (Series A): (a) ±v′ test; (b) ±h′ test

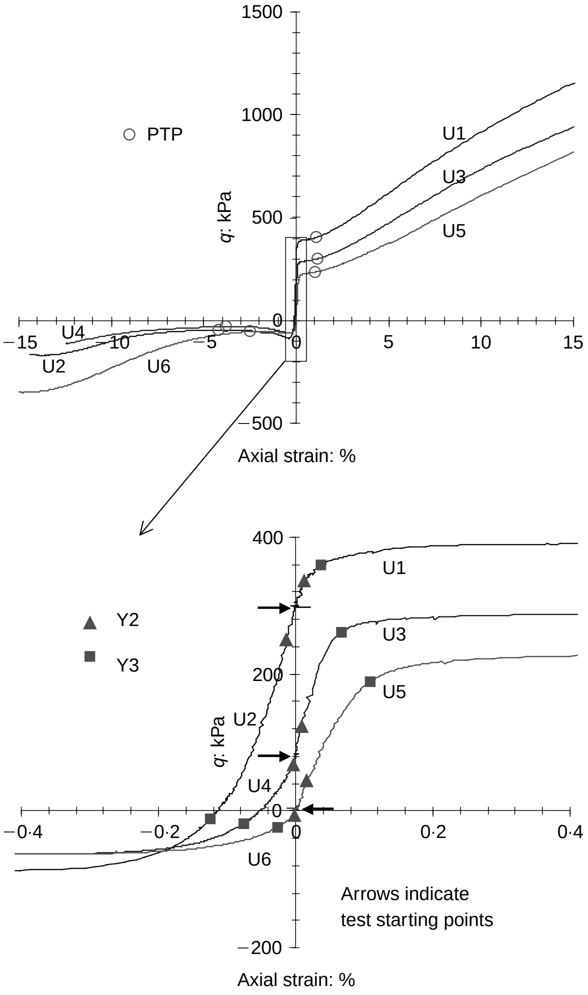

Fig. 14. Stress–strain relationships in undrained tests (Series U)

through concentrated force chains, very few of which undergo any yielding, even at their contact points. For the global (macro) response to be linear over even a very small strain range, the contacts need to have experienced some inelastic process such as creep, asperity flattening or bonding.

Y_1 yielding

Once the stress point engages the Y_1 surface, the stress–strain behaviour becomes inelastic. The sand develops plastic strains and a non-linear response. The strains do not recover if the stress path is reversed. Once engaged, the Y_1 yield surface is dragged with the current effective stress point, and the surface's orientation becomes significantly elongated in the trailing direction, creating a strong stress history dependence. The overall elastic-plastic stiffness degrades rapidly and significantly, with the tangent stiffnesses being affected by the direction and sign of the stress increment, the strain level, and the proximity of the Y_3 surface. Despite the onset of plastic straining, the directions of the strain increments, $d\varepsilon_s/d\varepsilon_{vol}$, remain related to the applied stress changes (as within Y_1) and unchanged in tests that follow constant stress path inclinations.

The global (anisotropic) stiffness response exhibited be-

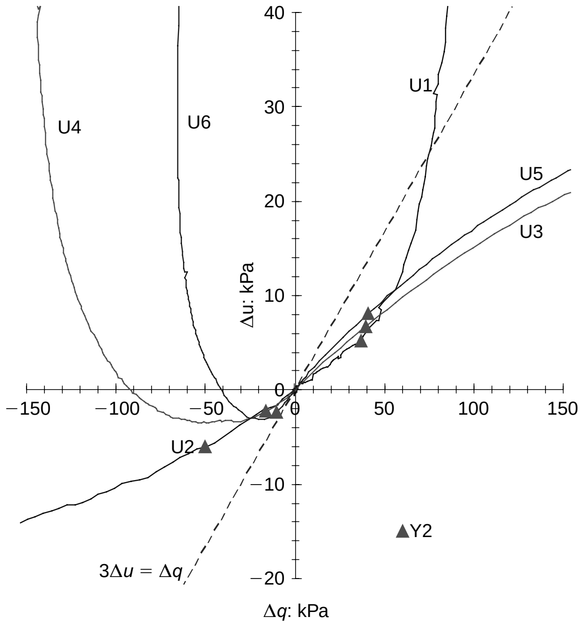

Fig. 15. Generation of pore water pressure in undrained tests

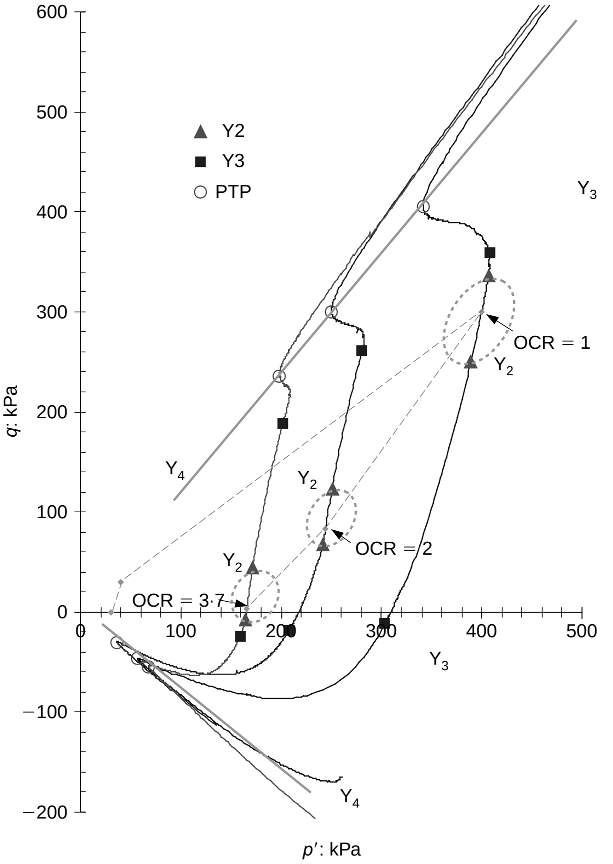

Fig. 16. Effective stress paths and yield points in undrained tests on loose HRS K_0-consolidated with various OCRs

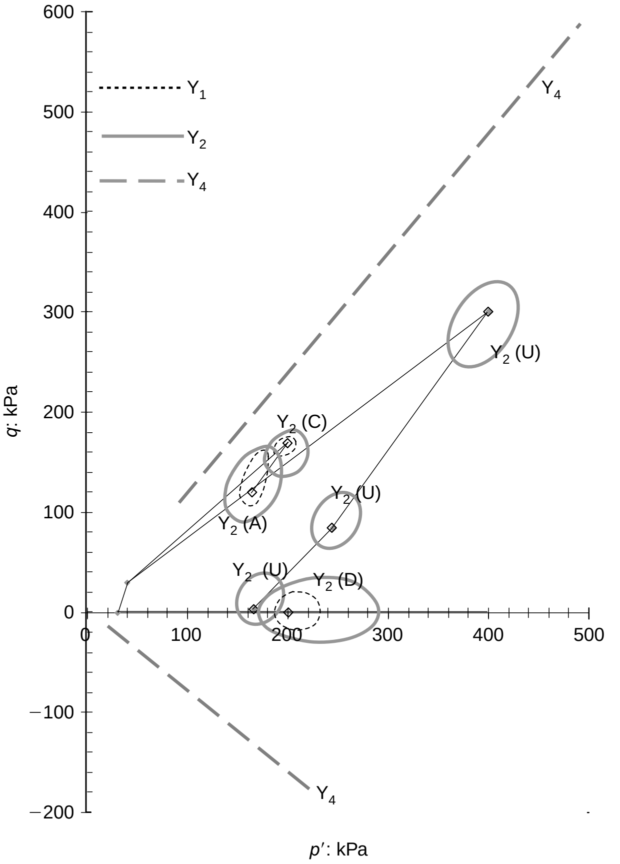

Fig. 17. Yield loci obtained from drained and undrained tests on loose HRS

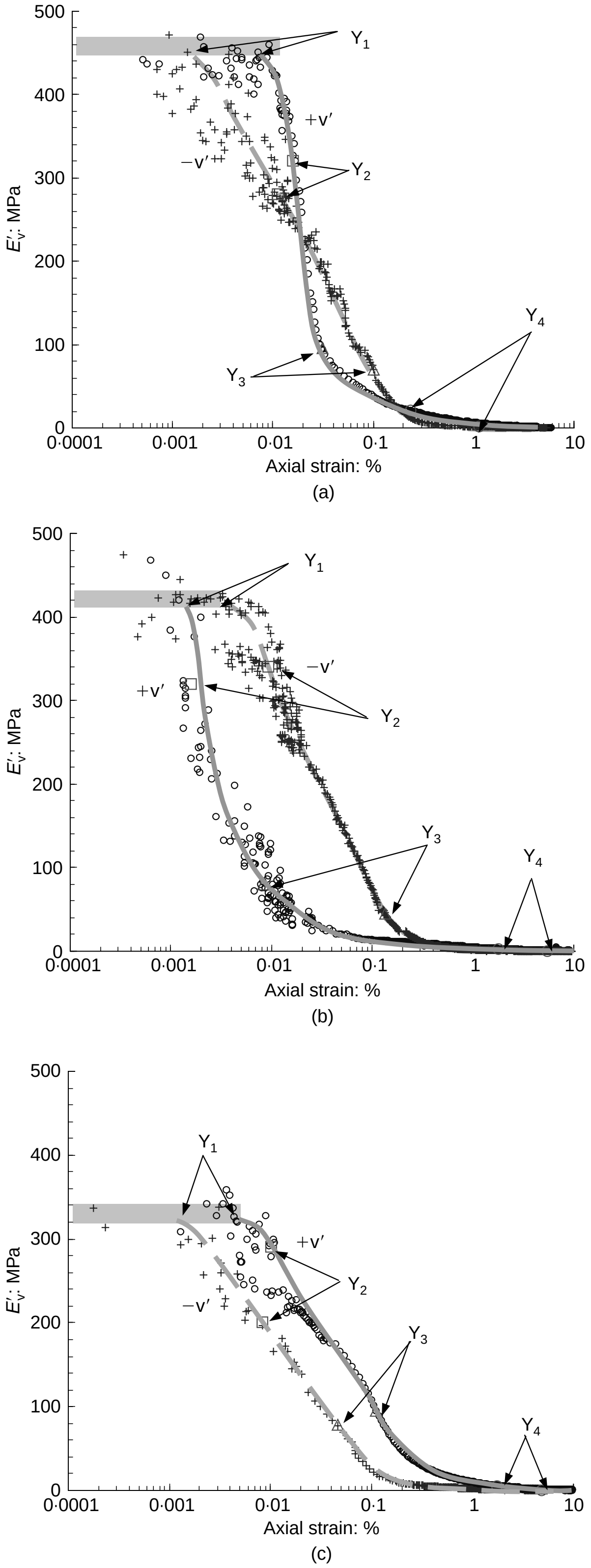

Fig. 18. Degradation of tangent elastic-plastic stiffness with strain (±v′ test): (a) Series B; (b) Series C; (c) Series D

tween Y_1 and Y_2 yielding cannot be expressed adequately in terms of a hypoelastic compliance matrix. The recent stress–strain history and the strain level affect the sand's stress–strain behaviour. It is postulated that local yielding can take place between the contacts of sand particles post-Y_1, leading to some energy dissipation and irrecoverable

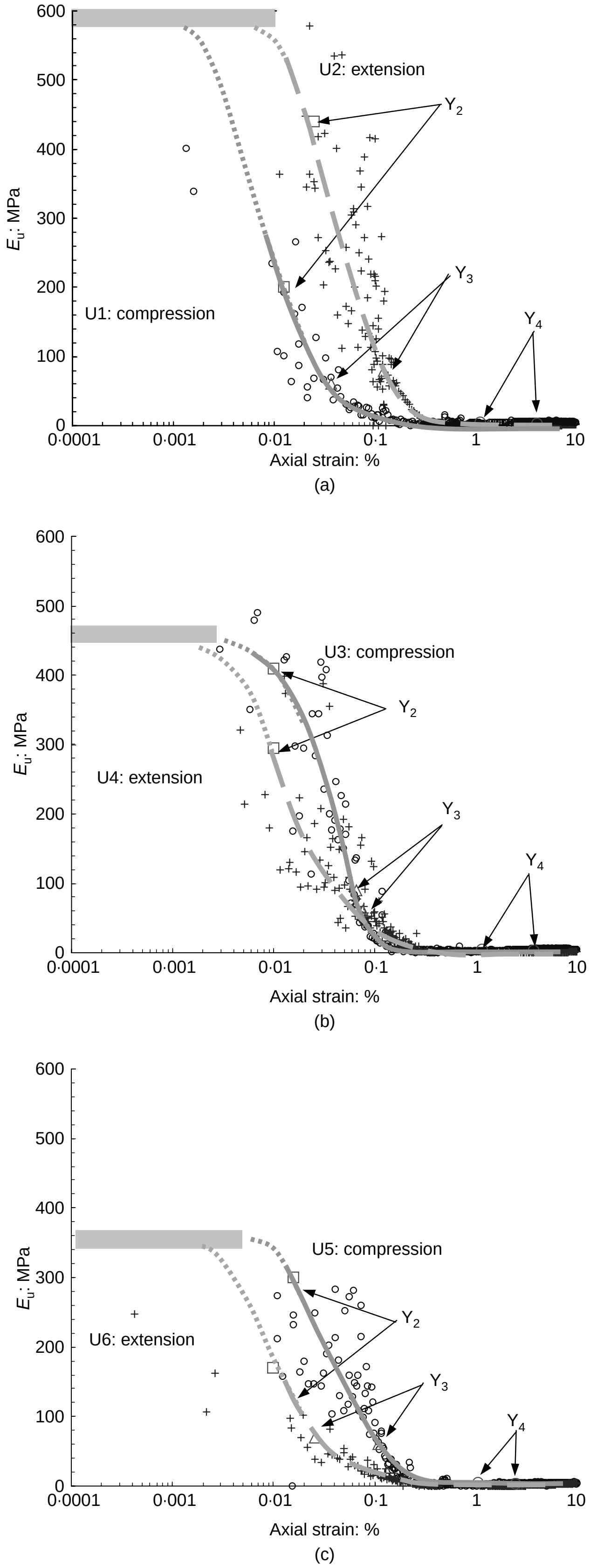

Fig. 19. Degradation of stiffness with strain (Series U): (a) U1 and U2 (OCR = 1); (b) U3 and U4 (OCR = 2); (c) U5 and U6 (OCR = 3·7)

straining. However, the particles experience only minor relative movements. The redundant structure formed by the strong force chains may be considered as being made of elastic bodies connected by elastic-plastic contacts.

Y_2 yielding

As straining continues, a second kind of yielding develops. In drained tests with constant stress path inclination a point is often reached where the strain increment directions $d\varepsilon_s/d\varepsilon_{vol}$ rotate towards the directions they will adopt later on meeting the Y_3 surface. In undrained tests, the effective stress path direction can change. These features are interpreted as Y_2 yielding, and Kuwano (1999) found them to be associated with a strongly increased tendency to creep at constant load, or to dissipate energy in load cycles. Sharp changes in strain increment direction were not evident in all tests; it is possible that Y_2 yielding might be clearer in small-strain load–unload, or creep-holding, experiments.

Relative movements (rotation and slip) between the sand particles are thought to become significant at Y_2, with some of the assembly's strong force chains buckling while others re-form within the granular 'structure'. The stress–strain behaviour is highly non-linear, and the overall stiffness reduces with strain as plastic straining becomes progressively more important.

Y_3 yielding

The above processes continue until the onset of Y_3 yielding, which may correspond to sharp changes in the stress–strain, effective stress path or stress–energy curves. Not all tests showed such points, and a continuous Y_3 yield surface could only be interpreted by assuming that it corresponded to the contour of plastic strain increment ratio, $d\varepsilon^p/d\varepsilon^t = 0{\cdot}85$, matching that seen during K_0 compression tests on normally consolidated samples. Ratios of 0·95 or greater can be seen during shear failure and high-pressure (K_0 or isotropic) compression tests where particle crushing brings the sand to join the appropriate virgin compression line.

Y_3 yielding may be associated with either a sudden increase in the rate at which the strong force columns buckle, or a less physically significant point at which a pre-specified (high) rate of buckling is reached through a more progressive yielding process.

Y_4 to critical state

All but the loosest sand samples eventually dilate when sheared, post-Y_3, to large strains under moderate effective stress conditions. Dilation continues (post-Y_4) until either the sample reaches a global critical state, or a concentrated shear band forms.

CONCLUSIONS

(*a*) High-resolution triaxial experiments on pluviated Ham River sand have shown four progressive phases of yielding, termed Y_1 to Y_4, developing in samples perturbed from previously stable stress states.

(*b*) The yield surfaces have been mapped in effective stress space, considering drained and undrained test conditions, normally and lightly overconsolidated states, K_0 and isotropic consolidation and loose and dense samples.

(*c*) The Y_1 loci show how the sand's small 'elastic' zone may be modified and moved by stress changes. Their areas grow in proportion to p'^2, and were around 20% larger with dense specimens than with loose specimens.

(*d*) The Y_2 surface, within which strain increment directions remain 'elastic' and behaviour remains relatively stiff and time independent, is also relocated and changed by significant stress perturbations. Like the Y_1 surface, it is strongly affected by recent stress history.

Table 5. Approximate area surrounded by the Y_1 surfaces

Test series	State of density	Stress state at beginning of probing tests	Y_1 locus (as approximation to an ellipse)			
			Short axis: kPa	Long axis: kPa	Area, A: kPa^2	A/p'^2
A	Loose	$p' = 166$ kPa, OCR = 1·3 ($\sigma'_h = 127$ kPa, $\sigma'_v = 243$ kPa)	21	57	940	0·034
B	Dense	$p' = 166$ kPa, OCR = 1·3 ($\sigma'_h = 127$ kPa, $\sigma'_v = 243$ kPa)	21	71	1170	0·042
C	Loose	$p' = 200$ kPa, OCR = 1 ($\sigma'_h = 142$ kPa, $\sigma'_v = 316$ kPa)	18	Not determined	NA	NA
D	Loose	$p' = 200$ kPa, OCR = 2 ($\sigma'_h = 197$ kPa, $\sigma'_v = 207$ kPa)	39	46	1410	0·035

Table 6. Micro- and macro-scale phenomena associated with multiple yielding, after Jardine *et al.* (2002)

Yield point	Micro-scale phenomena	Macro-scale phenomena	
		Drained condition	Undrained condition
Y_1	Particle contacts start to yield coaxially and under applied forces. Relative position of particles is unchanged	End of linear quasi elastic stress–strain range	
Y_2	Particle contacts start to yield under normal and tangential forces. Load columns start to collapse	Possible change of strain vector direction ($d\varepsilon_{vol}$, $d\varepsilon_s$). Marked increases in creep rates and effects of load cycling	Possible change in pore water pressure generation rate, $du/d\sigma_v$; dq/dp'. Marked increases in creep rates and effects of load cycling
Y_3	Change in pattern of load column collapses. Particles may rotate; large-scale relative movements may occur between particles	Plastic strain increment becomes greater than 85% of total strain increment (definition of Y_3 in this study)	Plastic strain increment becomes greater than 85% of total strain increment, associated with sharp curvature in stress–strain relationship and potential sharp rotation of effective stress path
		Changes in tangent stiffness relationships	
Y_4	Micro-scale patterns leading to dilation cannot be described simply	Onset of final strong dilation	Change in effective stress path direction leading to positive p' with q increasing in magnitude

(*e*) Behaviour between Y_2 and Y_3 is highly non-linear, and becomes progressively more plastic and time dependent as strains grow.

(*f*) The onset of Y_3 yielding is clear on paths that involve large shear strains, but can be difficult to identify on paths where volumetric strains dominate. Y_3 yielding may be associated with developing $d\varepsilon^p/d\varepsilon^t$ ratios of 0·85, or greater.

(*g*) The Y_3 yield surfaces grow with consolidation pressures, their alignment depends on the consolidation K_c ratio, and their leftward extent grows as the initial void ratio falls (or relative density grows). At moderate engineering stress levels, the Y_3 yield surfaces lie well inside the sand's outer state boundary surface. Particle crushing may lead to ratios $d\varepsilon^p/d\varepsilon^t = 0{\cdot}95$, or greater, in high-pressure compression tests that approach the outer SBS.

(*h*) Stress paths that move inside the current Y_3 yield surface cause the surface to change in scale. Overconsolidation to OCRs 1·3, 2 and 3·7 caused inward shrinkage of around 8%, 25% and 40% respectively; recompression may lead to comparable recoveries in surface size.

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THE DESIGN AND INSTALLATION OF A FIVE-STORY NEW TIMBER BUILDING IN JAPAN

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SUMMARY

Buildings in Japan have been constructed using timber since olden times. At the same time, Japan is a country beset by earthquake and timber buildings were weak against fire. So, from 1950 to 1987 wooden buildings over 13m height were prohibited by law. Revision of the Building Standards Law 2000 allowed the construction of buildings four-story or taller with fire-resistance performance. M-Bldg. built in 2005 is the first five-storied timber building after established Building Standard Law in Japan. This paper describes the structural framing and fire resistance system for this building and details. M-Bldg. was built in Kanazawa city, Ishikawa prefecture. In this building, first-story was built in reinforced concrete construction and from 2-5 stories was built in timber-based hybrid construction. In structural framing, the performance-based design method ("Calculation of Response and Limit Strength") was applied and some static structural experiments were conducted about the seismic performance of shearing wall and the buckling stress of timber-based hybrid column. In fire resistance system, fireproof construction was needed for this building. Three fireproof elements, column, girder and bracing, were tested for 1 hour fire resistive period. All elements could have enough properties for 1 hour fire resistance. The possibilities of middle-rise and high-rise timber buildings are extended by completion of this building.

1. INTRODUCTION

Buildings in Japan have been constructed using timber since olden times. Traditional timber temples and shrines, such as the Horyu-ji Temple, look the same as they did when constructed more than 1400 years ago. Many large-scale timber buildings were constructed during that time, and include the Hall of the Great Buddha in Todai-ji Temple (height: 46.8 m, area: 2878 m^2) and the five-story Pagoda in Toji Temple (height: 54.8 m). Even after the Meiji Era, four and five-story timber buildings were used as factories, warehouses, and inns, until the construction of large-scale timber buildings was restricted by the Urban Building Law of 1919, and the Building Standards Law of 1950 further restricted the construction of large-scale timber buildings. In 1959, the Architectural Institute of Japan carried a resolution against timber construction to prevent fire, storm, and flood damage, making it impossible to construct large-scale timber buildings. Timber building height restrictions were loosened in 1987, allowing the construction of three-story structures and buildings taller than 13 m. Eaves having a height of more 9 m were also permitted using large sections of laminated timber. Revision of the Building Standards Law in 2000 allowed the construction of buildings four stories or taller with fire-resistance performance. The present study reports the structural and fire resistance characteristics of the first timber-based hybrid structure in Japan, the five-story Kanazawa M building (Kanazawa M Bldg.), constructed in 2004.

2. OUTLINE OF THE BUILDING

The five-story Kanazawa M Bldg. (height: 14.237 m, area: 6.195 m x 12.100 m) was constructed in Kanazawa City, Ishikawa Prefecture.(Photo.1) The first story has a Reinforced Concrete structure and the second to fifth stories have a timber-based hybrid structure with built-in steel materials. Building data are listed in Table 1, and the floor plan and elevation are shown in Fig. 1 and Fig. 2.

Table 1 Building data

Architect	-architect office- Strayt Sheep
Structural Design	Kirino Structural Engineering Office
Area	$374m^2$(total floor) / $74.96m^2$(building)
Use	School
Height	14.237m
Structure	RC construction(first story) Timber-based hybrid construction(2-5 storied)

Photo.1 External view of Kanazawa M Bldg.

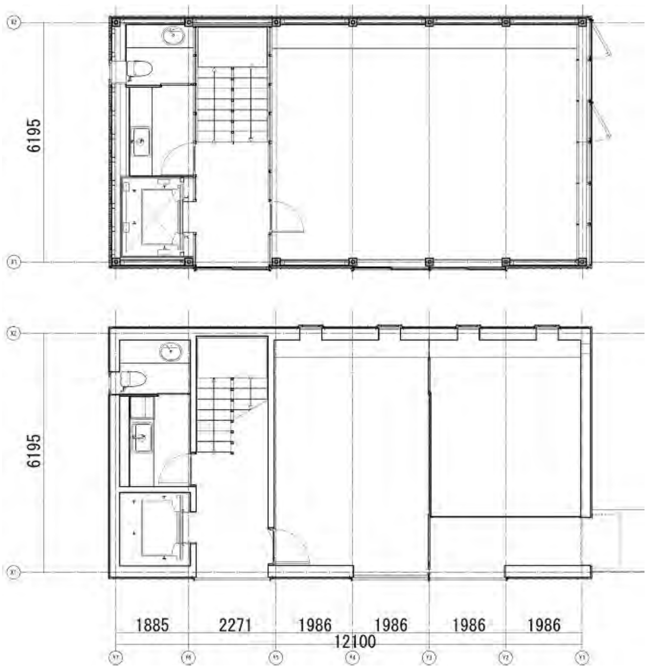


Fig. 1 Floor plan

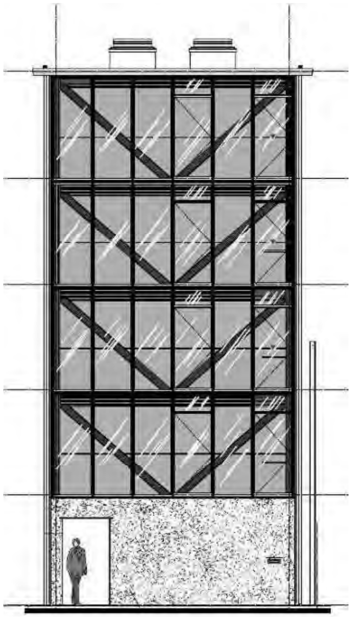


Fig.2 Elevation

Members

The building mainly uses the structural members listed below to satisfy the requirements for vertical load performance, seismic performance, and fire resistance. This building is required fire resistive construction, and structural elements are required 1 hour fire resistive period.

(1) Column, beam, and brace

The building uses laminated timber with built-in steel materials for columns, beams, and braces to satisfy the structural and fire resistance requirements of a five-story building. The cross section of each member is shown in Fig. 3.

The column is square laminated timber (larch E105-F300, 200 x 200 mm) with built-in square steel bars (SS400, 65 x 65 mm). The beam is laminated timber (200 x 330 mm) with steel plates (SS400, PL-22x300). The cross section of a brace looks identical to that of a column, which is necessary for fire resistance certification.

(2) Floor and roof

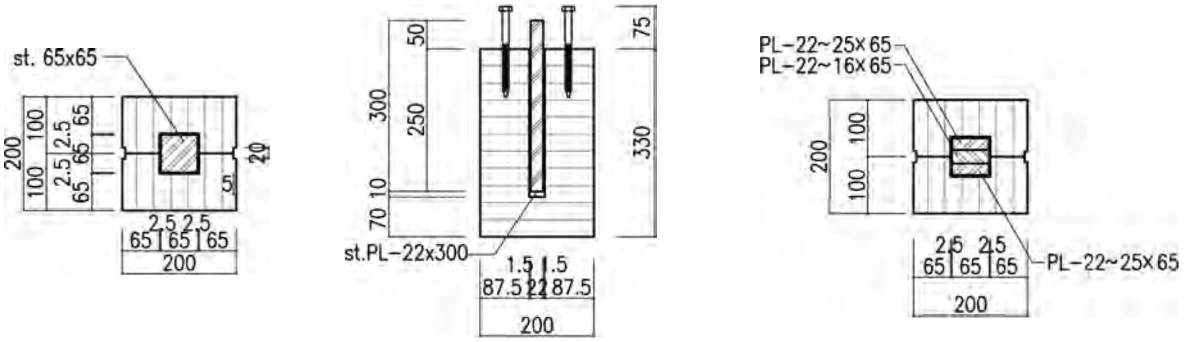
The floors and roofs are made of reinforced concrete slabs joined together with lag screws and steel plates built into the beams.

(3) Wall

The longitudinal walls are load-bearing and made of nailed plywood. The lateral walls are non-load-bearing, because of setting braces.

(4) Stairs

The stairs are made of steel frames.



column beam brace

Fig.3 Cross sections of column, beam, and brace

3. STRUCTURAL PLANNING

Similar to ordinary timber buildings, a five-story timber-based hybrid structure requires verification of its safety against self weight, live load, vertical load by snow coverage, and horizontal load under a horizontal force, such as an earthquake or wind. Fire resistive buildings are also required to maintain building integrity in the event of a fire. Based on these structural performance requirements, the following structural verification was conducted on the Kanazawa M Bldg.

Vertical Load

The timber and steel frame function together as a structural member in the second to fifth stories of a timber-based hybrid structure. To clarify the function of the timber and the steel frame about each member, the joint was designed as follows:

(1) Beam

Since the vertical deformation is equal between the timber and the steel frame, vertical load should be shared depending on their ratio of flexural rigidity, EI (E: Young's modulus, I: Geometric moment of inertia). The flexural rigidity ratio EI / ∑EI is shown in Table 2.

The timber and steel frame of the beam are joined at a beam edge using drift pins to transmit the load from the timber to the steel frame, so the steel frame bears all the shear force at the edge. The gusset plate from the steel frame of the column and the steel frame of the beam are joined with high

Table 2 Flexural rigidity ratio of timber and steel frame

	E (N/mm^2)	I (mm^4)	EI (Nmm^2)	EI/∑EI
Timber frame	1.05x10^4	5.55x10^8	0.583x10^{13}	0.366
Steel frame	2.05x10^5	4.95x10^7	1.01x10^{13}	0.634

tension bolts for the column-beam connection. The holes in the side of the timber frame are filled with timber after high tension bolts are clamped. (Fig. 4).

Snow load stress on both the timber and steel frame of the beam are designed not to exceed the short-term allowable limit, even in the very rare case of a snow load with a vertical depth of 1.2 m (multiplied by 1.4).

(2) Column

Vertical load is transmitted to the steel frame of a column through a gusset plate, and vertical loading of the timber is avoided using a 3 mm clearance, which is essential for combining the timber with the steel frame. The timber of the column functions as a buckling restraint for the steel frame, and, as the structural experimentation in Chapter 4 shows, alone, the steel frame of the column buckles at about 20% of the yield stress. However, the timber-based hybrid column did not buckle when the steel frame yielded to axial force compression because the timber functioned as a buckling restraint.

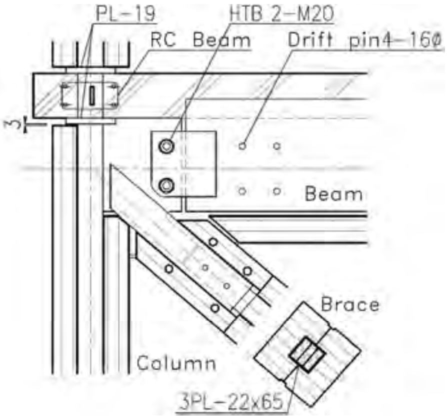


Fig.4 Joint (Lateral)

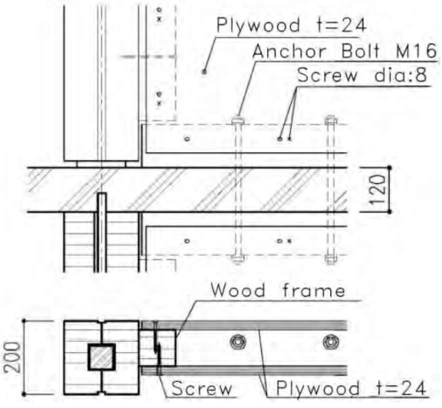


Fig.5 Joint (longitude)

Horizontal Load

The structural planning of the building is different from each direction. A timber-based hybrid beam is suspended laterally and supported by columns of identical material, and the longitudinal beam is built in a reinforced concrete slab. Damage limit seismic force produces greater horizontal force than the load exerted by very rare wind, as prescribed in the Building Standards Law, so horizontal resisting elements are braces the lateral roof face and the longitudinal plywood (load-bearing) walls.

(1) Beam

A lateral timber-based hybrid beam bears axial force and produces a reaction force of braces during an earthquake. The steel frame bears axial force, the timber frame functions as a buckling restraint, and calculations confirmed the absence of buckling within the safety limits of applied axial force.

(2) Column

During a lateral earthquake, a timber-based hybrid column produces a reaction force of braces. This column does not buckle when the steel frame yielded to axial force compression as mentioned above.

During a longitudinal earthquake, vertical shear force is transmitted from the plywood bearing wall to the timber of the column through the vertical frame (Fig. 5). The timber has a bearing plate of the steel frame (PL-19) at both ends of the timber of the column, and when the timber collides against the bearing plates, axial force is transmitted to the steel frame of the column. Therefore, during an earthquake, the timber functions as a buckling restraint.

(3) Brace

A brace bears axial force during a lateral earthquake. Only one steel frame (PL-22x65), at the center, contributes to the structure as the steel frames. Buckling of the brace was not observed under significant plastic deformation of the steel frame by compression axial force.

(4) Plywood bearing wall

A plywood bearing wall bears horizontal force during a longitudinal earthquake, and consists of structural plywood (thickness: 24 mm), screws (diameter: 8 mm) and both vertical and horizontal frames of laminated timber arranged around the plywood (Fig. 5). Vertical shear force of the plywood bearing wall is as mentioned in Section (2), and horizontal shear force is transmitted from the structural plywood to both the horizontal frame and the downstairs plywood bearing wall through anchor bolts (M16) embedded in the reinforced concrete slab.

After Fire

(1) Beam

Only the steel frame bears vertical load on the assumption that the timber had burnt completely. Although timber actually stops burning, the remaining timber cannot be used as a structural member under present law. The vertical load is assumed to be the same as before a fire, and for safety reasons, the steel frame stress should not exceed the long-term allowable limit.

(2) Column

The column also bears vertical load only using the steel frame and the stress applied should not exceed the long-term allowable limit for buckling.

(3) Brace

The timber of a brace is also assumed to have completely burned. The wind pressure, at the maximum momentary wind velocity of 15 m/s, is set as the constant wind load, and both brace tension and beam bending resist the lateral horizontal force. In this case, the steel frame stress is prevented from exceeding the short-term allowable limit.

(4) Plywood bearing wall

A plywood bearing wall is assumed to have completely burned.

(5) Longitudinal RC beam

An RC slab has a built-in longitudinal RC beam, as shown in Fig. 5. The rigid frame structure, consisting of the RC beam and the steel frame of the column, resists the longitudinal horizontal force produced by the constant wind.

4. STRUCTURAL EXPERIMENTATION

According to structural planning in Chapter 3, we clarified the structural performance of each member through experimentation. More specifically, we conducted a buckling performance test on a timber-based hybrid column and a shear performance test on a load-bearing wall.

Methods and Results of Experimentation

(1) Column

According to the structural design policy described in Chapter 3, the columns support vertical load only using the steel frames, but the surrounding timber supports axial force to resist buckling during an earthquake. Therefore, the timber requires a flexural rigidity (EI) that prevents buckling up to the yield load (Py) of steel.

We conducted a full-size buckling test to verify the buckling restraint of the timber a specimen of the full length (L = 2800 mm) was monotonously pressurized on both ends as shown in Photo 2, and the load-deformation relationship is shown in Fig. 6. Rigidity decreased at an axial deformation of 5 to 10 mm, resulting in strain hardening, because the partial loss of area at the end of the steel for jig yielded. Under a load of 1000 kN, the steel also yielded and suffered from a plastic deformation of approximately 30 mm. The yield axial force calculated from the result of a material test on a square steel bar (yield stress = 284 N/mm^2) is 912 kN. The square steel bar contracted and the timber of the column made contact with the jig, producing axial force, as axial deformation reached 30 to 40 mm. The timber cracked and buckled from a further increase in the load. The buckling strength (Nk) of the laminated timber is greater than the 672 kN calculated from the standard compressive strength. Results indicate that the timber-based hybrid column did not to buckle until the short-term allowable axial force (908 kN) of the square steel bar was reached.

Photo 2 Full view of experimentation

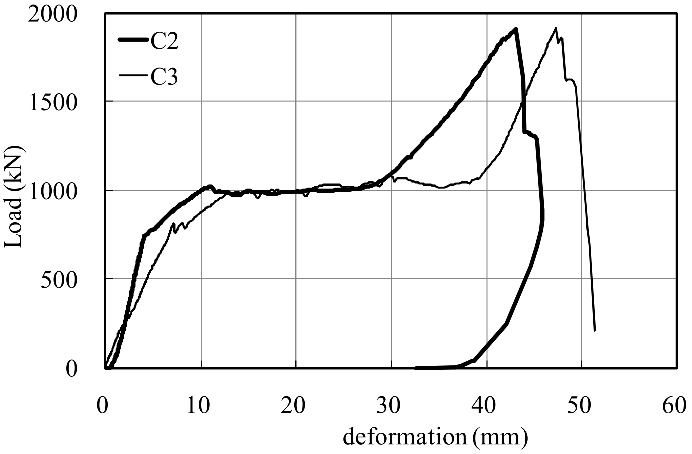
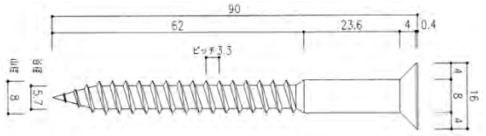


Fig.6 Column load-deformation relationship

(2) Wall

As a load-bearing wall, plywood (thickness: 24 mm) is secured on each side of a framework with screws (dia.: 8 mm) at intervals of 150 to 250 mm. The shear rigidity and shear strength of the screws securing the plywood were calculated experimentally, and are shown in Table 3.

Table 3 Performance per screw

Shear rigidity: K_1 (N/mm)	Shear strength (N)	
1300	7126	

An analytical model of the Plywood bearing wall and frame is shown in Fig. 7, and the detail of model is as follows:

1. The frame consists of square steel bar columns and RC beams, and the ends of the members form plastic hinges when yielded.
2. The load-bearing wall consists of plywood, timber column, sill, and both screws and bolts for joining the members.
3. The connectors between the plywood and the frame are modeled as a spring as screws (rigidity: K_1, Table 3).
4. The spring formed between the column timber and the square steel bar transmits shear force, received from screws colliding against the bearing plate, from the timber to the steel bar. To ensure elasticity, even during deformations

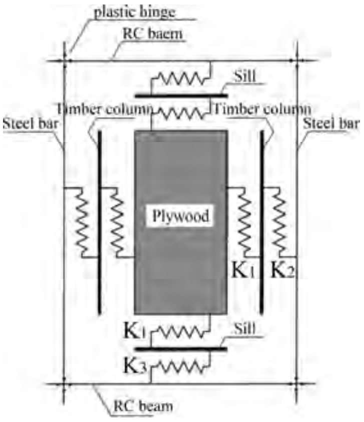


Fig.7 Plywood bearing wall model

within safety limits, K_2 is set at 11.5 N/mm. This also takes into consideration the axial rigidity of the column timber and the rigidity due to the clearance between the column timber and the bearing plate.

5. The spring formed between the sill and the RC beam transmits shear force, received from the screws through anchor bolts, from the sill to the RC beam. To ensure elasticity, even during deformations within safety limits, K_3 is set as 81.6 N/mm. this also takes into consideration the transmission of shear force between the bolt and the sill and the rigidity due to the clearance between the bolt and the sill.

If the rigidity K_1 of the plywood bearing wall is linked in series with the rigidity K_2 by the column timber or the rigidity K_3 by the sill, and K_2 and K_3 are linked in parallel, the equivalent rigidity can be calculated as follows:

$$K = 1/ \{1/K_1+1/ (K_2+K_3)\}$$

Using this equation, the yield strength and ultimate strength can be calculated as "analytical values" (Table 4).

Table 4 Performance of plywood bearing wall

	Analytical values	Experimental values
Rigidity (kN/mm)	2.85	2.56
Yield strength (kN)	97.5	92.3
Ultimate strength (kN)	178	182

We conducted a full-size static loading test to verify the performance of the plywood bearing wall. The specimen had a column span of 1710 mm and a height of 2740 mm as shown in Fig. 8. Reverse cycling loading was used for the static loading test, and the cyclic loading profile was controlled by apparent shear deformation angle. Loading of the same deformation profile was repeated three times, using a loading profile of ±1/600 - ±1/450 - ±1/300 - ±1/200 - ±1/100 - ±1/75 - ±1/50 - ±1/25 - ±1/15 rad. The load-deformation relationship of the plywood bearing wall is shown in Fig. 9. When the maximum strength (P_{max}) is 235 kN, the drift is 161.5 mm (1/17 rad.). A crack developed and grew along the RC part of the joint between the square steel bar column and the RC beam; resulting in the destruction of the screws by shear force and the collapse of the plywood. Performance of plywood bearing wall was investigated experimentally, and results are shown in Table 4. The experimental values are slightly greater than the analytical values.

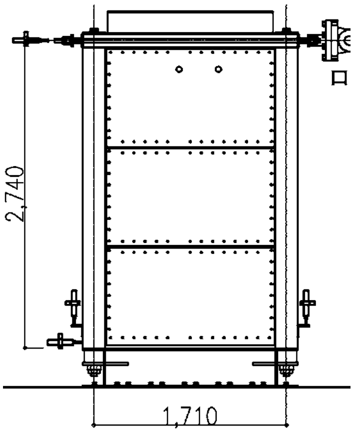


Fig. 8 Specimen of plywood bearing wall

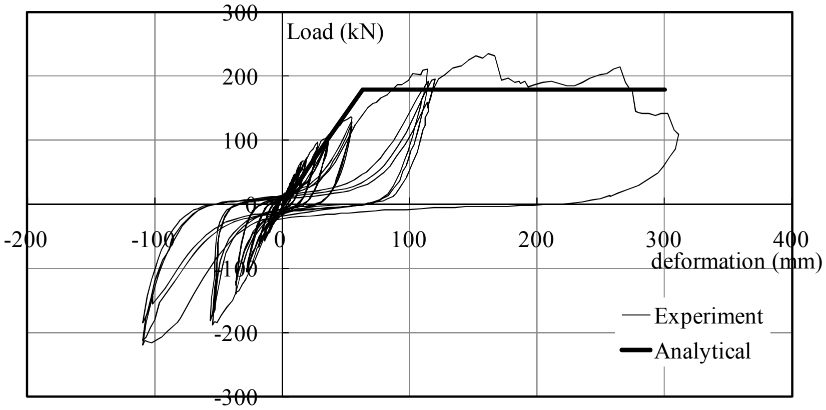


Fig.9 Wall load-deformation relationship

5. CALCURATION OF RESPONSE AND LIMIT STRENGTH

We created an analytical model of the building based on the experimental results, and verified the safety against seismic force by predicting response deformation using the performance-based design method ("Calculation of Response and Limit Strength").

Verification by Safe Limit Strength Calculation

(1) Safe limit drift angle

A safe limit drift angle of 1/50 was set for both the lateral and longitudinal directions. Since the strength of longitudinal plywood bearing wall rose to a drift angle of approximately 1/20, 1/50, as a safety margin, is more than adequate. This margin was set in accordance with the deformation tracking performance of a sash window used for an outside wall of an ordinary building.

(2) Calculation of response

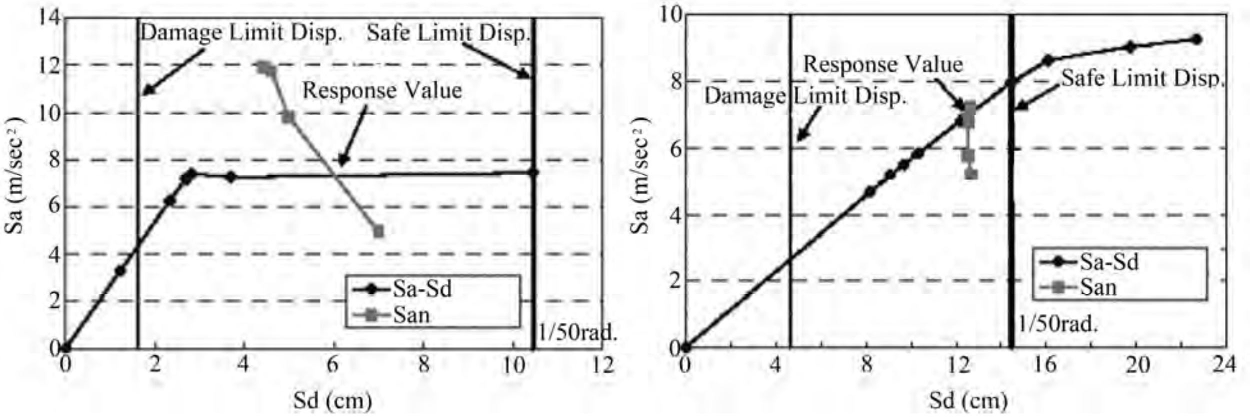
The experimental and analytical safety limit strength exceeded the required safety limit strength, and the true response value is calculated as follows:

a) Creating a relation diagram of the load-deformation curve (Sa-Sd) at the representative material point of the building

b) Calculating the acceleration (San) of input into the building at equivalent cycles by considering building attenuation at each step

c) Plotting San on a straight line connecting Sa-Sd (load deformation of the building) and the origin at the step

d) The true response value is the intersection of the San curve at each step (demand curve) and the Sa-Sd curve of the building.



lateral direction longitudinal direction

Fig.10 Prediction of responses at the time of an earthquake

Results of the calculation are shown in Fig.10. The safety against seismic force both direction was verified. In the lateral direction, strength hardly increases after the yielding of horizontal resisting elements. In the longitudinal direction, the plywood bearing wall is in an elastic area, up to 1/50 of the safe limit drift angle.

5. CONCLUSION

Besides verifying the safety against seismic force, to satisfy the fire resistance performance required for fireproof buildings, we verified fire resistance using a beam-loaded heating test, a column-loaded heating test, and a joint heating test. Based on the results of structure and fire resistance research, Japan's first building using a timber-based hybrid structure, having 1- hour fire resistance, was completed in Ishikawa Prefecture in 2005,

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CFD analysis on traffic-induced air pollutant dispersion under non-isothermal condition in a complex urban area in winter

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Abstract

There is a higher concentration of traffic-induced air pollution alongside roads in winter than in summer due to the relatively stable atmospheric conditions. In this study, a three-dimensional computational fluid dynamics (CFD) simulation coupled with radiation and conduction analysis was carried out to analyze the pollutant dispersion under non-isothermal conditions within an objective area in Kawasaki city, Japan, in winter. The temporal variations of wind speed and pollutant concentrations were analyzed at the pedestrian level (1.5 m above the ground level). The average wind velocity in the high-density building area is very low. The pollutant accumulates around the fencings on the road due to the weak winds and vortices around them. The surface and air temperature were also discussed. The results show a systematic variation of the differences from 9:00 to 17:00. Numerical predictions demonstrate reasonably good agreement with measurements. The concentration is a little lower under non-isothermal condition than under isothermal condition.

Keywords: Air pollutant dispersion; CFD; Non-isothermal condition; Complex urban area; Thermal effect

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1. Introduction

Traffic-induced air pollution alongside roads in large cities remains an environmental challenge despite significant improvements in fuel and engine technology. This is because vehicle emissions become trapped along roadways due to the high-density use of space, such as multi-layered roadways and high-rise buildings in urban areas. Wind flow patterns, which develop in cities around individual and/or groups of buildings, govern the local air pollutant dispersion about the building complex and its wake (Meroney et al., 1999). The complex urban structures lead to the complex dispersion of air pollutants. There are several studies on the effect of complex urban structures, including road structures, street canyons and building shapes, on air pollution dispersion (Brown and Dabberdt, 2003; Huang et al., 2000; Lee and Park, 1994; Meroney et al., 1999; Tokairin and Kitada, 2004; Tsai and Chen, 2004). Most of them treat the airflow as an isothermal turbulent flow. Some numerical simulations and observations have been conducted to analyze the thermal effect of surface temperature on the turbulent flow and air pollutant dispersion (Kim and Baik, 2001; Nakamura and Oke, 1988; Sini et al., 1996). Detailed analysis of the thermal environment, including convection, radiation and conduction phenomena, has not been discussed, and actual complex urban areas have not been considered in these works. Several works contribute to urban thermal environment numerical simulation coupling with computational fluid dynamics (CFD) analysis, radiation analysis, and conduction analysis in actual complex urban areas (Chen et al., 2004; Harayama et al., 2002; Huang et al., 2005; Mochida et al., 2005; Yoshida et al., 2000a, 2000b). Mochida et al., 2005 also coupled air pollution with non-isothermal condition in the central part of Sendai, Japan, in the summer. It is known that higher concentrations of air pollution exist in winter due to the relatively stable atmospheric conditions. However, there has been little study into the numerical analysis of air pollution dispersion coupled with detailed non-isothermal environment analysis in winter.

In this study, a three-dimensional CFD simulation coupled with radiation and conduction analysis was carried out to analyze pollutant dispersion under non-isothermal condition within an objective area in Kawasaki city, Japan, in winter. The temporal variations of wind speed, surface temperature, air temperature and pollutant concentration were discussed. The prediction accuracy was examined by comparing the numerical results with the field measurements, and the effect of non-isothermal condition on air pollution dispersion is examined.

2. Model description

The numerical simulation used consists of a three-dimensional CFD analysis, three-dimensional radiation analysis, and one-dimensional heat conduction analysis, which is suitable for the analysis of complex urban areas due to its application of the unstructured calculation grid system (Huang et al., 2005). Fig. 1 shows the flowchart for this numerical simulation. First, boundary conditions are set up from various input conditions. Second, a three-dimensional radiation calculation coupled with unsteady one-dimensional heat conduction is performed. Then, the surface temperatures of the ground and walls and the temperature distributions inside the ground and walls are calculated. Finally, three-dimensional coupled convection and pollutant dispersion simulations are performed continuously by adding new boundary conditions for the surface temperature distribution

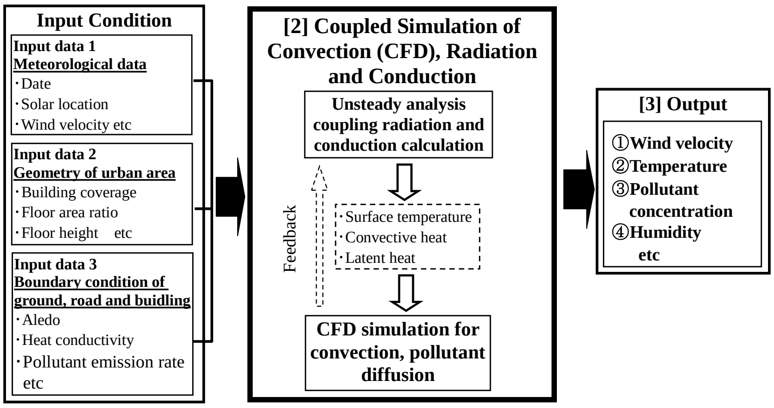

Fig. 1. Flowchart of the numerical simulation.

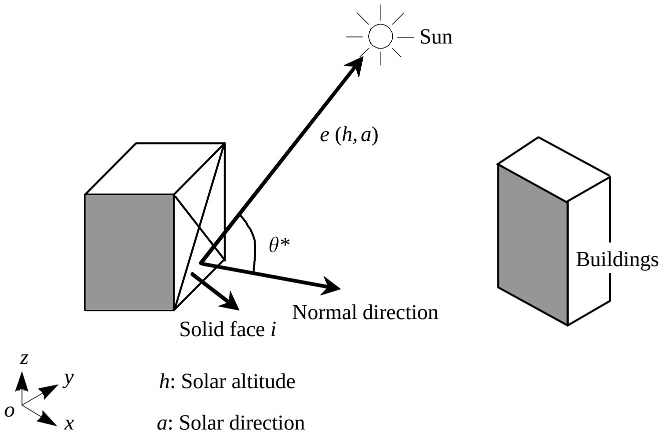

Fig. 2. Calculation of solar radiation.

of the ground and walls. The coupled simulations of convection, radiation, and conduction are then completed through serial repetition of these operations.

2.1. Calculation of temperature of a solid surface

In this study, the heat balance at the outdoor surfaces of the ground and building walls is calculated by the heat balance equation defined by Eq. (1) at each solid face i (Fig. 2), and the surface temperature T_i is obtained. On the left side of Eq. (1), a positive value shows an inflow of energy to solid face i, whereas a negative value shows an outflow (Fig. 3):

$$S_i + R_i + H_i + \mathrm{LE}_i + C_i = 0 \tag{1}$$

S_i and R_i are absorbed solar radiation and net long-wave radiation, respectively; H_i, LE_i, C_i are shown as follows:

(i) H_i, convective heat transfer at the solid surface:

$$H_i = A_i \alpha_c (T_{ao} - T_i) \tag{2}$$

where T_{ao} is the air temperature in the region adjacent to the solid face i and α_c is the convective heat transfer coefficient.

(ii) LE_i, amount of heat dissipation by evaporation from the surface:

$$\mathrm{LE}_i = A_i \alpha_w \beta^* L (f_a - f_s) \tag{3}$$

where α_w is the moisture transfer coefficient, β^* is the wetness, and L is the latent heat of evaporation. f_a and f_s are the vapor pressure and the saturated vapor pressure at the region adjacent to the solid face i, respectively.

(iii) C_i, amount of conduction heat to the building and ground.

The conduction in building walls and the ground is assumed to be unsteady one-dimension heat conduction. The equation is

$$\rho c_p \frac{\partial T_{\mathrm{wall}}}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T_{\mathrm{wall}}}{\partial x}\right) \tag{4}$$

where ρ, c_p and λ are the density, specific heat and thermal conductivity of the building material or ground, respectively. T_{wall} is the temperature inside the building wall or ground. C_i is the conduction heat conducted into the solid that forms the boundary condition of the outdoor surface:

$$C_i = -A_i \lambda \left.\frac{\partial T_{\mathrm{wall}}}{\partial x}\right|_{x=0} \tag{5}$$

2.2. CFD simulation

CFD simulation is based on the governing equations of continuity, momentum, temperature, species, turbulent energy and turbulent dissipation rate, which is shown in Table 1. Turbulence is modeled using the standard k–ε closure. Although the standard k–ε model shows some problems in the prediction of the wake phenomenon around buildings, such as overestimating turbulent kinetic energy around the windward corner (Murakami et al., 1988), it stills enjoys a good reputation for reliability in the field of wind engineering (Murakami, 1990) and air pollutant diffusion analysis (Huang et al., 2000). The effect of buoyancy is considered using the Boussinesq approximation, and the extra terms in the k and ε equations are introduced to allow for the production of turbulence due to buoyancy and the effect of thermal stratification on the turbulence dissipation rate (Huang et al., 2005).

The governing equations are solved by the finite-volume method using Star-CD software. A staggered grid system is employed for the vector (U_i) and scalar (P, C_i, k, ε) units. A hybrid second-order scheme named monotone advection and reconstruction scheme (MARS) (STAR-CD, 2001) is applied to the convective terms. Conservation of mass is obtained using the SIMPLE pressure correction algorithm (Patankar, 1980).

Table 1
Governing equations

Continuity equation
$\partial\langle u_i\rangle/\partial x_i=0$
Momentum equation
$\partial\langle u_i\rangle/\partial t+\partial\langle u_i\rangle\langle u_j\rangle/\partial x_j=-1/\rho\ \partial\langle p\rangle/\partial x_i+\partial/\partial x_j(v(\partial\langle u_i\rangle/\partial x_j+\partial\langle u_j\rangle/\partial x_i)-\langle u_i'u_j'\rangle)-g_i\beta(\langle\theta\rangle-\theta_0)$
Temperature transport equation
$\partial\langle\theta\rangle/\partial t+\partial\langle u_i\rangle\langle\theta\rangle/\partial x_i=\partial/\partial x_i(\alpha\partial\langle\theta\rangle/\partial x_i-\langle u_i'\theta'\rangle)$
Pollutant transport equation
$\partial\langle C_i\rangle/\partial t+\partial\langle u_i\rangle\langle C_i\rangle/\partial x_i=\partial/\partial x_i(D\partial\langle C_i\rangle/\partial x_i-\langle u_i'C_i'\rangle)$
Turbulent energy transport equation
$\partial k/\partial t+\partial\langle u_j\rangle k/\partial x_j=P_k+G_k+D_k-\varepsilon$
Turbulent dissipation rate equation
$\partial\varepsilon/\partial t+\partial\langle u_j\rangle\varepsilon/\partial x_j=D_\varepsilon+\varepsilon/k(C_{\varepsilon1}P_k+C_{\varepsilon3}G_k-C_{\varepsilon2}\varepsilon)$
$-\langle u_i'u_j'\rangle=v_t(\partial\langle u_i\rangle/\partial x_j+\partial\langle u_j\rangle/\partial x_i)-2/3k\delta_{ij},\ v_t=C_\mu k^2/\varepsilon$
$-\langle u_i'\theta'\rangle=v_t/\sigma_\theta\partial\langle\theta\rangle/\partial x_i,\ -\langle u_i'C_i'\rangle=v_t/\sigma_w\partial\langle C_i\rangle/\partial x_i$
$P_k=-\langle u_i'u_j'\rangle\partial\langle u_i\rangle/\partial x_j,\ G_k=-g_i\beta\langle u_i'\theta'\rangle$
$D_k=\partial/\partial x_j(v_t/\sigma_k\ \partial k/\partial x_j),\ D_\varepsilon=\partial/\partial x_j(v_t/\sigma_\varepsilon\partial\varepsilon/\partial x_j)$
$\sigma_k=1.0,\ \sigma_\varepsilon=1.3,\ \sigma_\theta=0.9,\ \sigma_w=0.9,\ C_{\varepsilon1}=1.44,\ C_{\varepsilon2}=1.92,\ C_{\varepsilon3}{:}1.44(G_k>0);0(G_k<0)$

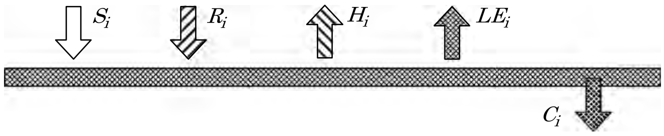

Fig. 3. Heat balance of solid surface.

3. Outline of field measurements

The target urban area in this study is a small part of Kawasaki city, which is shown in Fig. 4. High air pollution concentrations are reported here. It covers a large area, around $400\times400\,\mathrm{m}^2$. The Ikegami–Shinmachi crossing is the center of the studied area, through which a SW–NE direction trunk road and an elevated expressway—the capital expressway—run. The trunk road is at the ground level while the expressway passes overhead at a height of 8 m. There are also several sections of fencing installed under part of the expressway.

Field measurements of NO and CO concentrations were carried out from February 1 to 3, 2005, from 8:45 to 15:05 once per hour on the hour. A total of 13 measurement points were set up, as shown in Fig. 4. Measurement points 1–8 are on the sidewalks of the trunk road, points 9, 10, 13 are in a park, and points 11 and 12 are on a sidewalk of the SE–NW direction road. The measurement height was 1.5 m above the ground. The NO concentration of the sampled air was measured with a nitrogen oxide analyzer and the CO concentration with a carbon monoxide analyzer. To estimate the emission rates of automotive exhaust, automobiles passing the intersection were recorded via a video camera from a pedestrian bridge on the east side of the intersection. The observed automobiles were classified into (1) light and ordinary cars, (2) light and ordinary trucks, (3) large trucks and special vehicles, and (4) buses. The emission intensity of NO*x*, which is shown in Table 2, refers to a report of the Bureau of Environment of Tokyo (1997).

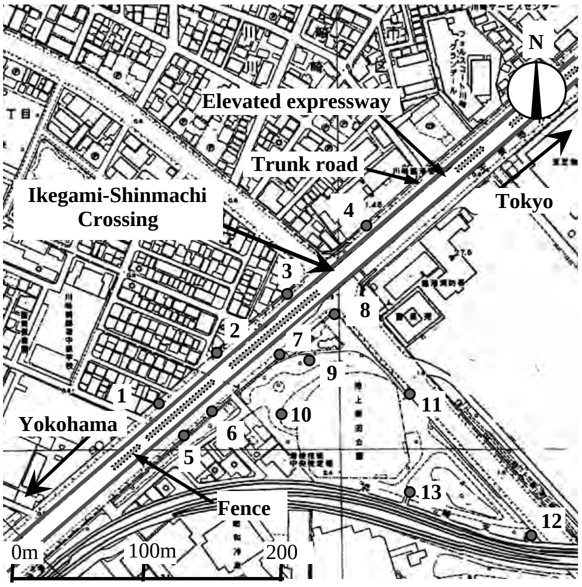

Fig. 4. Field measurements and analysis area.

Table 2
Emission intensity of NO_x (g/km)

Classification	Light and ordinary cars	Light and ordinary trucks	Large trucks and special vehicles	Buses
Emission intensity	0.179	2.0	3.8	5.98

4. Outline of numerical simulation

In such a complex urban area, the use of an unstructured grid system is most effective for CFD simulations (Huang et al., 2005). The official geographical data of the analysis objective provided by the Ministry of Land, Infrastructure and Transport in Japan were employed to set up the geometric frame for mesh discretization. February 2nd was targeted for the numerical analysis. The radiation and conduction analysis was performed for 24 h from 0:00 to 24:00 hours on February 2nd. The building wall is assumed to be concrete here. The thickness of the wall is set to be 22 cm. The CFD analysis was performed at 9:00, 11:00, 13:00, 15:00 and 17:00 hours using the surface temperature of the ground and building walls calculated by the radiation and conduction analysis. The dispersion of NO was analyzed here. Table 3 shows details of the analysis conditions. The inflow wind velocity is set at 1/4th power profile. The meteorological data provided by the Kawasaki city observation station (Daishi station), shown in Table 4, were used as the representative velocity of the wind (U_0 in Table 3). The estimated emission rates of NO are shown in Table 5. In order to investigate the thermal effect on air pollutant dispersion, an isothermal simulation was also conducted at 11:00 hours.

Table 3
Analysis conditions

Turbulent model	Standard k–ε model (Inclusion of buoyancy effect)
Difference scheme	Convection terms: MARS
Inlet	$U = U_0(Z/Z_0)^{1/4}$, $Z_0 = 16\,\text{m}$
	$k = 1.5(I \times U)^2$, $I = 0.1$
	$\varepsilon = C_\mu \times k^{3/2}/l$
	$l = 4(C_\mu \times k)^{1/2} Z_0^{1/4} Z^{3/4}/U_0$(Murakami et al., 1988)
Side, sky	Free slip
Wall	Generalized logarithmic law

Table 4
Wind velocities and directions observed at a height of 16 m at the Daishi measurement station

U_0	9:00	11:00	13:00	15:00	17:00
Velocity(m/s)	3.6	3.7	2.7	0.9	2.0
Direction	WNW	W	NW	SSE	W

Table 5
Emission rate of NO (g/m h)

	9:00	11:00	13:00	15:00
Emission rate(g/m h)	2.45	2.57	2.16	2.29

(NO generation is assumed to be 50% of NO_x).

5. Results and discussion

5.1. Wind velocity distribution

Fig. 5a–e presents the numerical simulation results of the wind velocity distribution in a horizontal section at a height of 1.5 m around the Ikegami–Shinmachi crossing for all cases. Different wind flows are evident for different cases. This indicates that the wind flow in this urban area is significantly affected by the approaching flow and the urban geometry. The average wind velocity in the area where few buildings exist (right-lower part in the Figures) is larger, while in the built-up area, it decreases significantly to a lower magnitude, because of the blocking effect of the buildings. When the direction of the approaching flow is west, it can be seen that the wind flows along the trunk road towards the NE. In the other cases, it can be seen that the wind is weaker behind the fencings if fencings exist, and circulatory flow occurs between the fencings and the buildings. When the approaching wind direction is WNW and NW, a strong wind flows alongside the SE–NW direction road. When the approaching wind direction is SSE, there is a large vortex after building A.

5.2. Surface and air temperature

Fig. 6a–e shows the surface temperature, and Fig. 8a–e shows the air temperature in a horizontal section at a height of 1.5 m for all cases. The results show the systematic

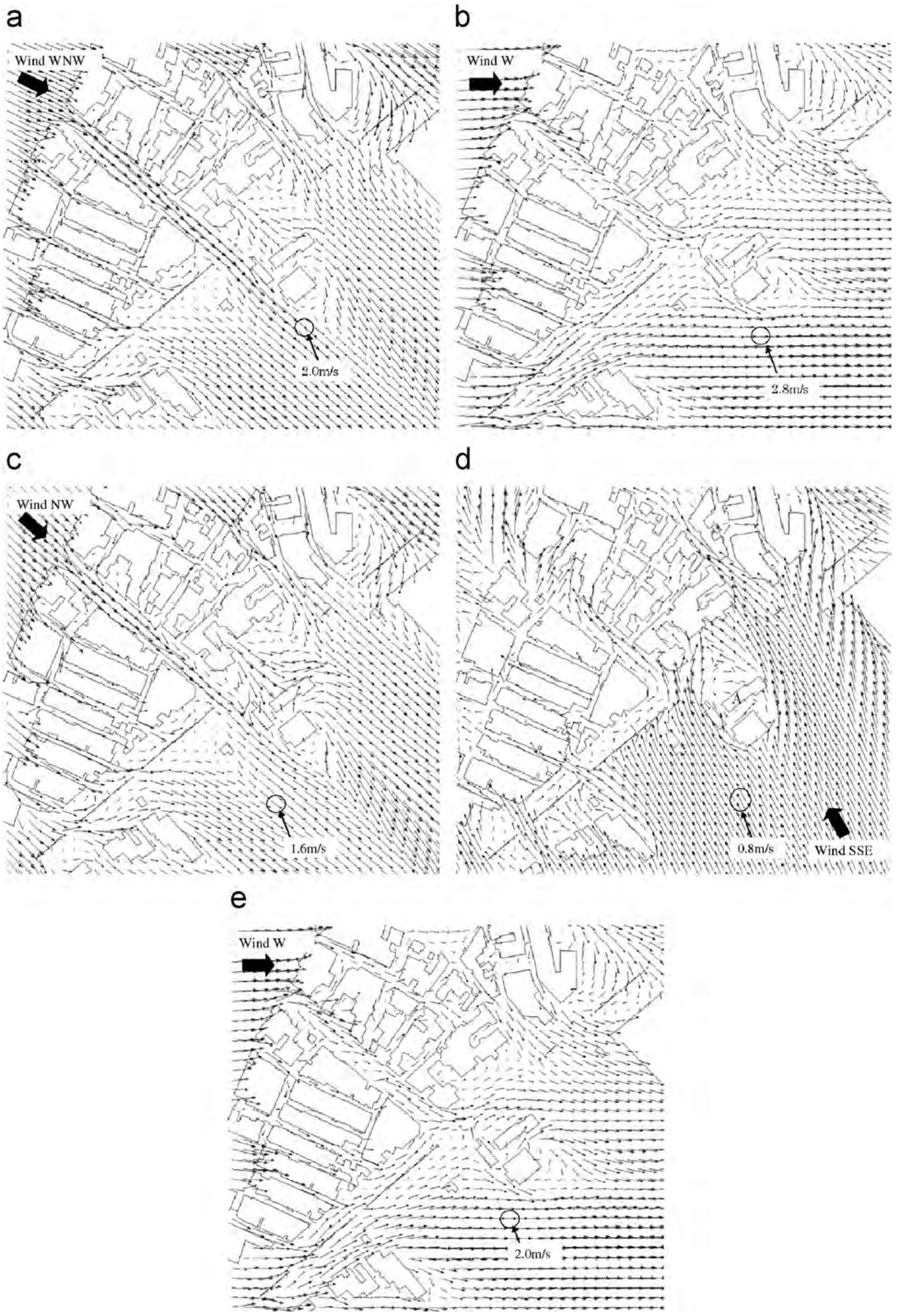

Fig. 5. (a) Wind velocity distribution at 9:00 hours. (b) Wind velocity distribution at 11:00 hours. (c) Wind velocity distribution at 13:00 hours. (d) Wind velocity distribution at 15:00 hours. (e) Wind velocity distribution at 17:00 hours.

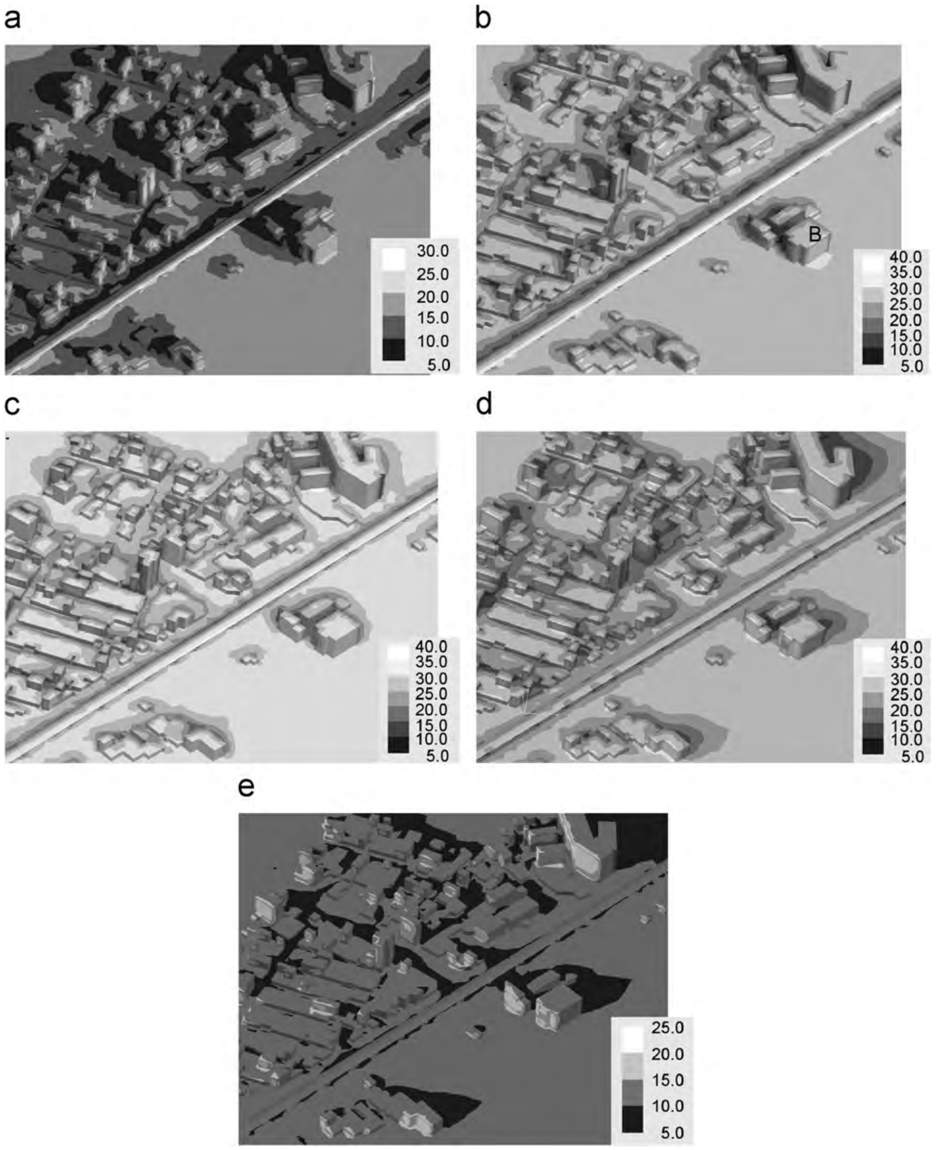

Fig. 6. (a) Surface temperature (°C) at 9:00 hours. (b) Surface temperature (°C) at 11:00 hours. (c) Surface temperature (°C) at 13:00 hours. (d) Surface temperature (°C) at 15:00 hours. (e) Surface temperature (°C) at 17:00 hours.

variation of the differences from 9:00 to 17:00 hours. The temperatures of the roofs, the walls and ground irradiated by sunshine are over 30 °C. Peak surface temperatures for the roof and ground are shown at 13:00 hours. Those walls and ground lying in shadow are at about 6 °C. The temporal variation of the wall temperatures of building B (refer to Fig. 6b) is shown in Fig. 7. The temperature variations for walls 2 and 3 are small compared to the other walls because they are in the shade almost all day. Wall 4 reaches its highest

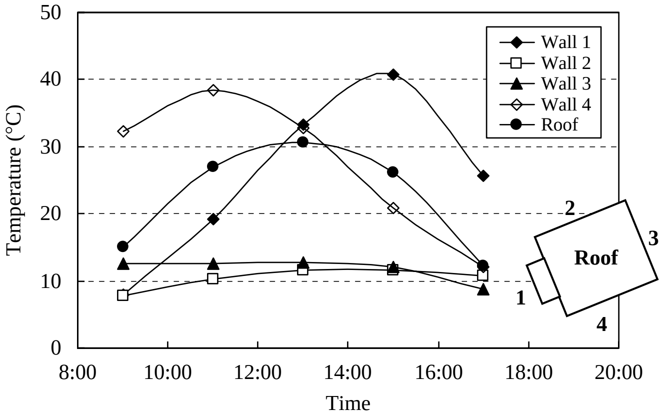

Fig. 7. Temporal variation of surface temperature of building B (°C).

temperature at 11:00 hours; wall 1 reaches its peak at 15:00 hours. This obviously reflects the relative movement of the sun. The air temperature over the trunk road, especially around the fencings, is higher than the inflow temperature. The inflow air is heated by the building walls. Weak wind velocity around the fencing also leads to the higher temperature (Fig. 8a–e), Fig. 9 shows the air temperature at 1 m above the ground at a horizontal distance of 1 m from the building walls. The air temperature is cooler than that of the surface. Near walls 2 and 3, the air temperatures reach their peak at 15:00 hours due to the higher surface temperature and the weak wind velocity and vortex at the time (refer to Fig. 5d).

5.3. Pollutant concentrations

Fig. 10a–d presents the NO dispersion concentrations in a horizontal section at a height of 1.5 m for all cases. NO is first emitted from the traffic road, then transported away by the wind and dispersed in the air. The dispersion is mainly determined by the approaching wind and the road structures. It is readily evident that pollutant accumulates around the fencings due to the weak wind and vortex around them. When the wind direction is west (11:00), it can be seen that pollution diffuses along the trunk road towards the northeast due to the wind along the road (refer to Fig. 5b). A higher concentration is found at 15:00 hours due to the weaker wind velocity than those of other cases.

5.4. Validation and the effect of non-isothermal condition

Since extensive validations have been conducted in previous studies on the wind field and temperature field during the development of this simulation system by the authors (Chen et al., 2004; Harayama et al., 2002; Huang et al., 2005; Yoshida et al., 2000a; Yoshida et al., 2000b), the focus of this study is on the validation of air pollutant concentration. The numerical simulation results for NO concentrations were compared with the field measurements. Fig. 11 shows the comparisons at 9:00, 11:00, 13:00 and 15:00 hours. There is agreement between the numerical simulation and the field measurement results. The disagreement at some points (8, 11) is thought to reflect the influence of the

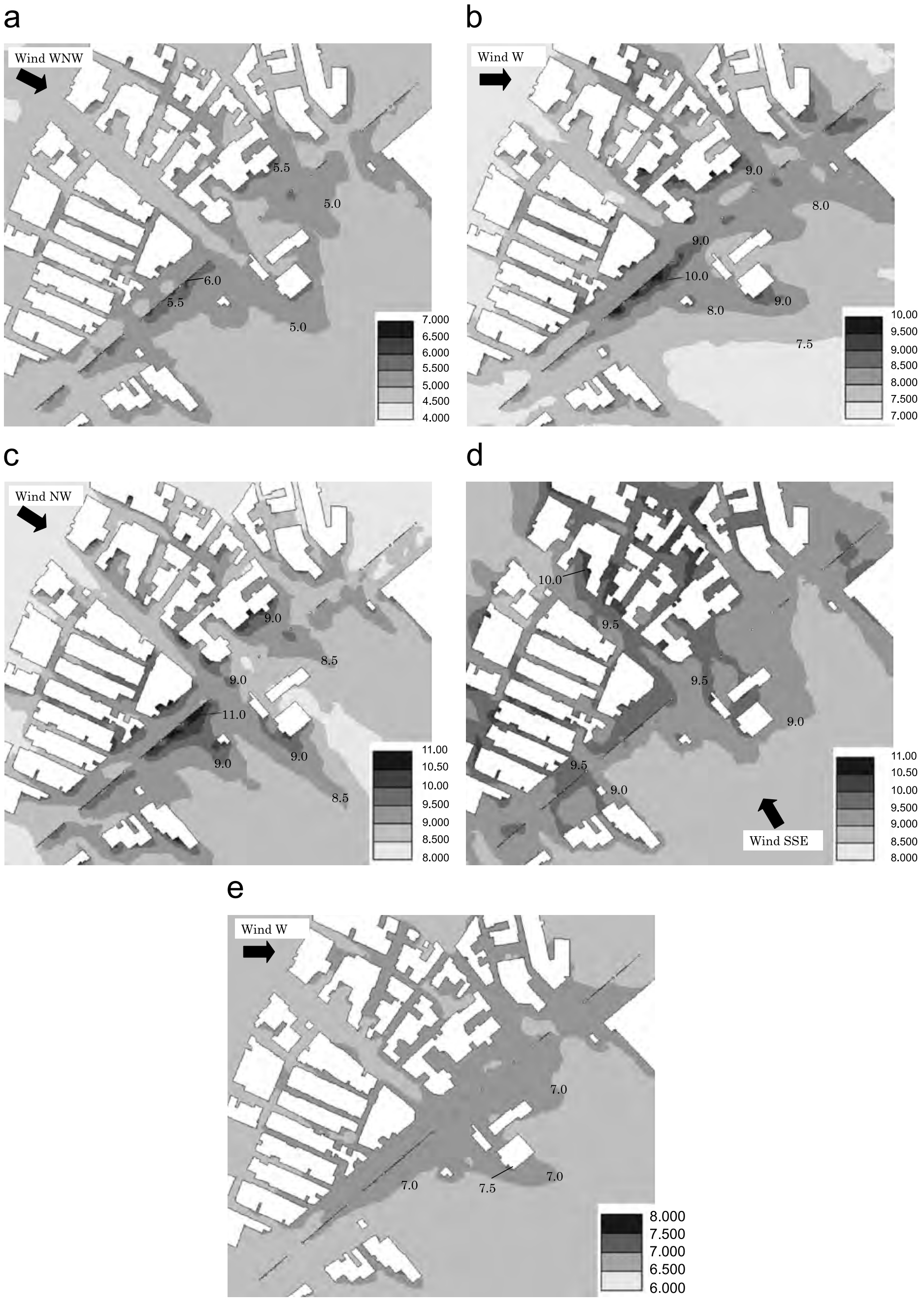

Fig. 8. (a) Air temperature (°C) at 9:00 hours. (b) Air temperature (°C) at 11:00 hours. (c) Air temperature (°C) at 13:00 hours. (d) Air temperature (°C) at 15:00 hours. (e) Air temperature (°C) at 17:00 hours.

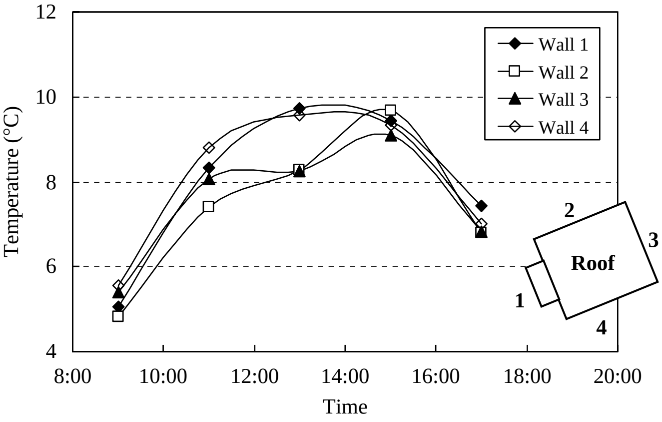

Fig. 9. Temporal variation of air temperature around building B (°C).

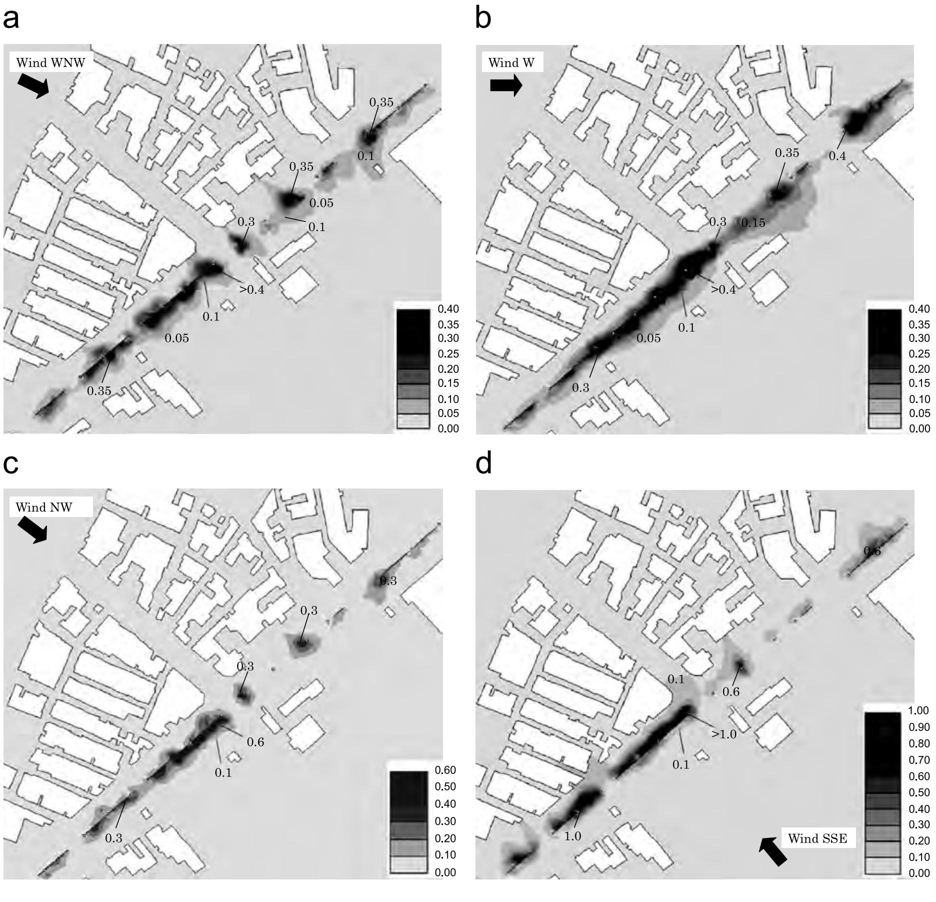

Fig. 10. (a) NO concentration (ppm) at 9:00 hours. (b) NO concentration (ppm) at 11:00 hours. (c) NO concentration (ppm) at 13:00 hours. (d) NO concentration (ppm) at 15:00 hours.

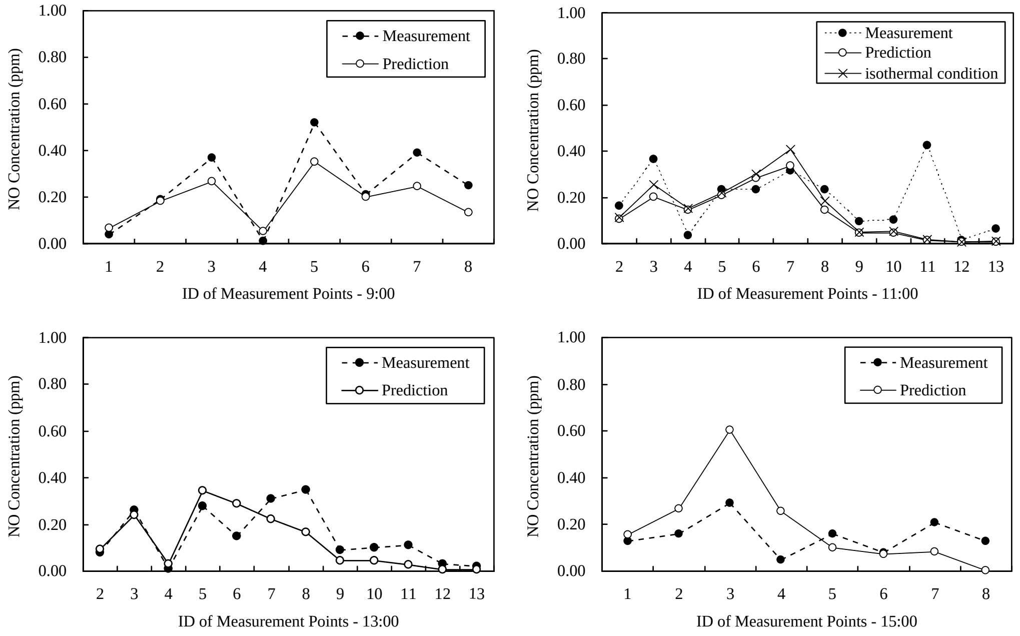

Fig. 11. Comparison of simulation and measurement for NO concentration.

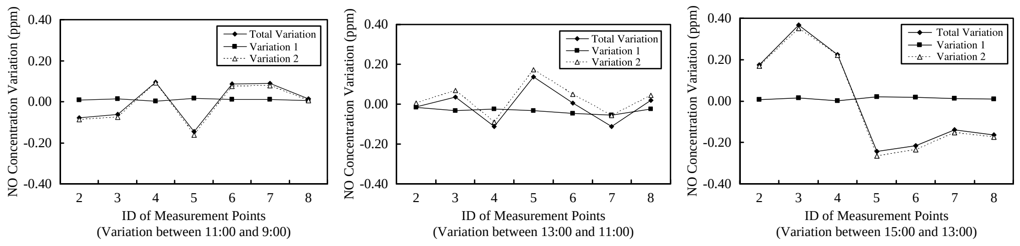

Fig. 12. Variation between current and last time.

other trunk road running in the SE–NW direction lying within the objective domain, which was not set as a pollutant source in the calculation. At 15:00 hours, overestimations are found at points 2, 3 and 4. Though the emission rate on the road bound for Yokohama (refer to Fig. 4) is rather lower than that for Tokyo (about 0.8 times), the emission rates were set to be the same in the simulation. This accounts for the overestimation. Meanwhile, at 15:00 hours, full development of the atmospheric boundary layer may lead to lower measurements. Therefore, the inclusion of a sub-model for evaluating the influence of the atmospheric stability on the turbulent diffusion may be helpful to provide a better comparison. It is also necessary to analyze how much of the variation presented in Fig. 11 is directly related to the variation of the source emission rate and how much is related to the transport due to the change in wind and temperature fields from this prediction. Therefore, the analysis results are shown in Fig. 12. 'Total Variation' means the total concentration change between the current and last time at every measurement point. 'Variation 1' means the variation related to the variation of the source emission rate;

'Variation 2' means the variation related to the transport due to the change in wind and temperature fields. It is found that the concentration changes linearly with the emission rate for each point in time. Though the source emission rate varied with time, the variation related to the transport due to the change in wind and temperature fields is more significant than the part related to the source in this case, especially between 15:00 and 13:00 hours, when there is a significant change in the wind field. In order to investigate the thermal effect of the surface on pollutant dispersion, an isothermal condition simulation was carried out at 11:00 hours. The result is shown in Fig. 11. The concentration is a little lower when considering the non-isothermal condition than in the case of not considering it. This is because the buoyancy effect increases due to the increasing surface temperature. However, this effect seems insignificant in winter.

6. Conclusions

In this research, a CFD simulation coupled with radiation and conduction analysis was carried out to study air pollutant dispersion during winter in a built-up area in Kawasaki city, Japan. The average wind velocity in the high-density building area is very low. The high fences alongside the road hinder diffusion of the pollutant. The surface and air temperature were also discussed. The results show a systematic variation of the differences from 9:00 to 17:00 hours. The temperatures of the roofs, the walls and ground irradiated by sunshine are over 30 °C. The air temperature over the trunk road, especially around the fencings, is higher than the inflow temperature due to heating by the wall and the weak wind velocity. The accuracy of the numerical simulation was studied by comparing its results with the field measurements. The results generally demonstrate good agreement, thus proving that the method is highly effective for handling complex urban air pollution issues. The effect of the non-isothermal condition was analyzed. The concentration is a little lower under non-isothermal condition than under isothermal condition.

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A STUDY ON THE EFFECT OF LAND USE CONTROL BY ACTIVE FAULT ZONING IN JAPAN

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ABSTRACT :

Japan entered an expected longstanding depopulation process in 2006. In this situation, it is important to avoid disaster social impacts due to the disaster by guiding population from vulnerable area to safer areas. This research focused on the risk of active faults among various kinds of natural hazards and studied on the effect of the land-use control along active faults in Japan. First, the meaning of land-use control by active fault zoning in the society whose population started to decrease was discussed. Japan has not adopted earthquake fault zoning act due to several reasons. However, considering the current depopulation process, introduction of the fault zoning act becomes meaningful. Then, the distribution of population and buildings in the neighborhood of active faults was analyzed based on GIS databases of active faults, population and building stocks. The effect of land-use control using fault zones was discussed based on the obtained results. If a fault zone with 0.4km width was decided, referring to the fault zoning act in U.S., it was estimated that the population living inside the fault zone was 2.3% of the total population in Japan. The effect of land-use control was different according to the region. The population living inside the fault zone increased in proportion to the width of the zone.

KEYWORDS: land-use control, active fault zoning, disaster mitigation planning

1.INTRODUCTION

Japan entered an expected longstanding depopulation process in 2006. According to the report by The National Institute of Population and Social Security Research, the total population after 50 years is expected to decrease to about 70% of the current one as shown in Figure 1. In this situation, it is important to avoid disaster social

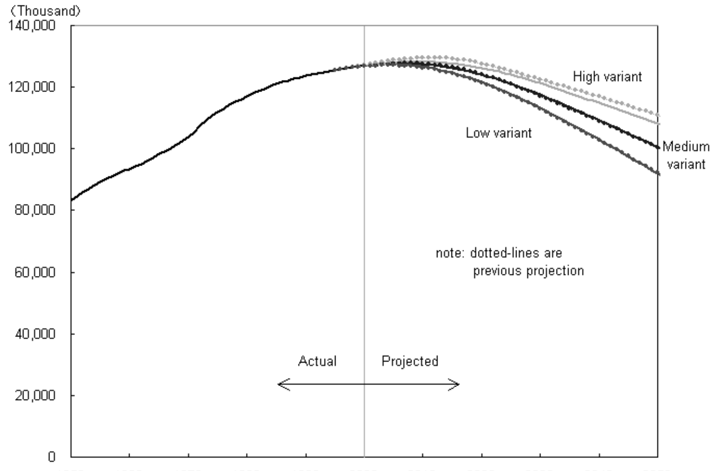
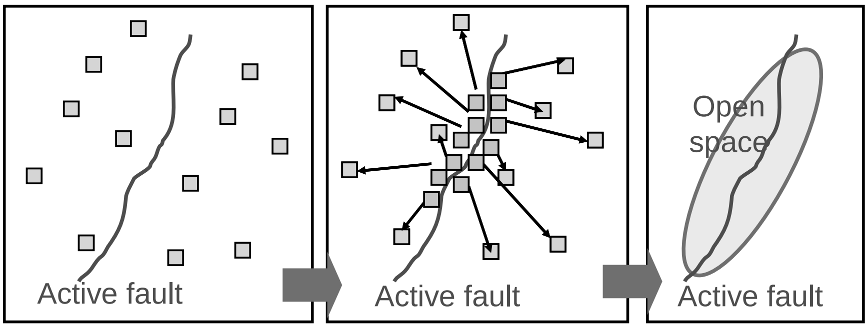


Figure 1 Population projections for Japan: 2001-2050

impacts by guiding population from vulnerable to safer areas.
Recently, Japan suffered the 2004 Niigataken Chuetsu Earthquake, the 2007 Noto Hanto Earthquake and the 2007 Niigataken Chuetsu-oki Earthquake. These earthquakes reminded the danger of active faults in Japan. This research focused on the risk of active faults among various kinds of natural hazards and studied on the effect of the land-use control along active faults in Japan. First, the meaning of land-use control plan along active faults in a society whose population started to decrease was discussed. Then, the distribution of population and buildings in the neighborhood of the active faults was analyzed based on GIS databases of active faults, population and building stocks. The effect of land-use control using fault zones was discussed based on the obtained results.

2. MEANING OF LAND-USE CONTROL PLAN ALONG ACTIVE FAULTS

When the total population decreases, part of the existing building stock becomes unnecessary, and the number of vacant houses and lands increases. If residents in the seismic vulnerable areas along active faults are relocated to safer areas by a land-use control plan, these vacant lands could be effectively used as disaster-prevention facilities having open spaces and warehouses for emergency supplies. These processes are illustrated in Figure 2.



1. Increase of vacant lands
2. Relocation to safer area
3. Open Space along the fault

Figure 2 Process of land-use control

Table 1 Conceivable policies for controlling land use

	Direct policy	Indirect Policy
Repression of population inflow	Regulation of ner construction*	Increase in tax for new construction
	Profibition of new construction	Increase in property tax for existing buildings
		Disclosure of seismic risk information on property sales
		Disclosure of seismic risk information on rental agreemet*
		Publicity of seismic risk information*
Promotion of population outflow	Relocation of existing buildings	Grant for relocation
	Regulation of extension or reconstruction of buildings*	Preferential tax treatment for relocation
	Prohibition of extension or reconstruction of buildings	Increase in property tax for existing buildings
	Regulation of rental agreement	Disclosure of seismic risk information on property sales
	Prohibition of rental agreement	Disclosure of seismic risk information on rental agreemet*
		Publicity of seismic risk information*

Table 1 shows the conceivable policies for controlling land use. The lands along active faults could be controlled by the repression of the population inflow and the promotion of the population outflow. These could be achieved by direct methods such as prohibition and regulation of land use or by indirect methods such as disclosure of seismic risk information and tax control. The policies marked with * in Table 1 are being enforced in California, U.S. by the Alquist-Priolo Earthquake Fault Zoning Act enacted in 1972.

While the earthquake fault zoning act has been carried out in U.S. for 30 years, Japan has not adopted it. There are several reasons why most of the Japanese specialists have opposed fault zoning. First, introduction of the fault zoning could have huge social impact because Japanese population density is high and a lot of people live on active faults. Next, most of active faults in Japan are dip-slip faults and there are many cases in which fault traces do not appear on the surface. Even if the traces on the surface are estimated, uncertainty of the position should be considered. On the other hand, active faults in California, U.S., are strike-slip faults and traces on the surface are easier to identify. However, considering that more lands will become vacant due to depopulation in the future, the possibility of introducing fault zoning act will increase and the discussion on the land-use control plan along active faults becomes more meaningful.

3. DISTRIBUTION OF ACTIVE FAULTS IN JAPAN

First, a GIS database of the active faults was developed by adding several data to the existing digital active fault map. The total length of active faults in Japan is about 10,300 km. When active faults are classified, it is found that 34% of them are dip-slip and 4% are strike-slip as shown in Figure 3. “Mixed ” in Figure 3 means a fault that has both strike-slip and dip-slip parts. In case of “Mixed I”, the length of dip-slip part is more than 70%. In case of “Mixed II”, the rate of dip-slip part is between 30% and 70%. Figure 3 shows the distribution of active faults in Japan.

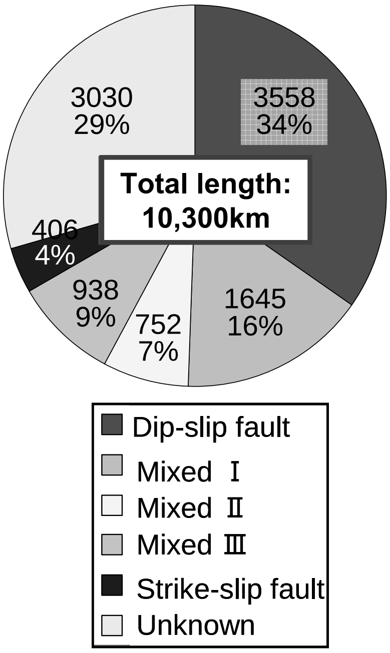


Figure 3 Composition of active fault types

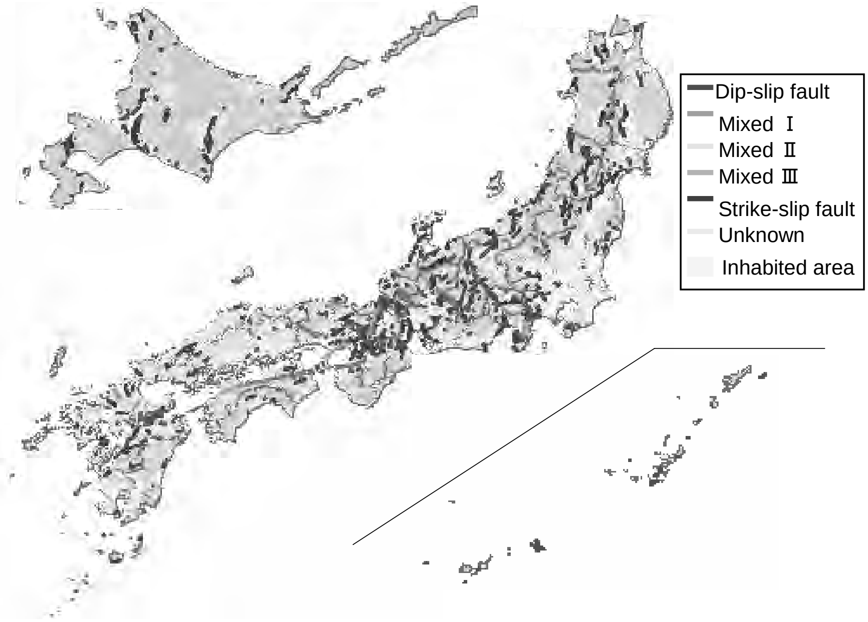


Figure 4 Distribution of active faults in Japan

4. ESTIMATION OF THE EFFECT OF LAND-USE CONTROL ALONG ACTIVE FAULTS

The distribution of population and buildings in the neighborhood of the active faults was analyzed based on GIS databases of the active faults, population and building stocks. Then, the effect of land-use control using fault zones was discussed.

The GIS databases of population and building stocks were developed based on a 1km mesh data from the Housing and Land Survey. The fault zones were hypothetically set along the active faults as shown in Figure 5. In California, the average width of fault zones is 0.4km. Referring to it, the width of the fault zone was first set to 0.4km. In this case, the population inside the fault zone was 2.89 million and it corresponded to 2.3% of the total population in Japan. 0.62 million timber residential houses were located inside the zone. Although 4% of the active faults were strike-slip as shown in Figure 3, the rate of the population living along the strike-slip faults were only 0.4% as shown in Figure 6. Figure 7 describes the regional tendency of population distribution along the active faults. Half of the population living along the faults was located in Kinki area while 40% of the faults were located in Hokkaido-Tohoku or Hokuriku-Koshinetsu Area. It was verified that the effect of land-use control was different according to the region.

If the width of the fault zone was increased to 0.8km, 2km, 4km, the population inside those zones was estimated as 4.5%, 10%, 18% of the total population, respectively. Population increase was almost in proportion to the width of the fault zones.

Considering the uncertainty of the traces of active faults, setting larger fault zones is safer. However, this causes a larger social impact on the population living along the active faults as confirmed in Figure 8. In order to implement land-use control along active faults in Japan, the appropriate width of fault zones should be discussed considering several factors such as lessons from past earthquake damage, uncertainty of the traces of both strike-slip and dip-slip faults, social impact of the fault zones, etc.

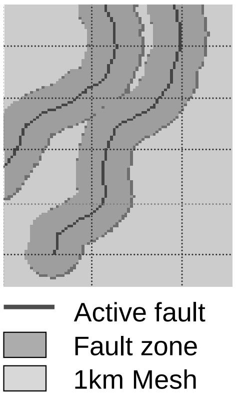


Figure 5 Example of fault zone

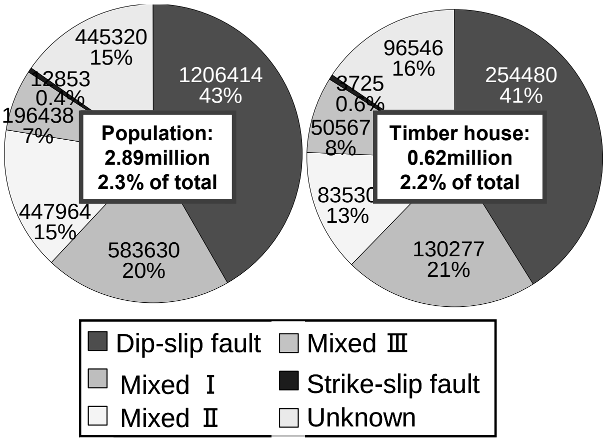


Figure 6 Population and buildings inside the fault zone

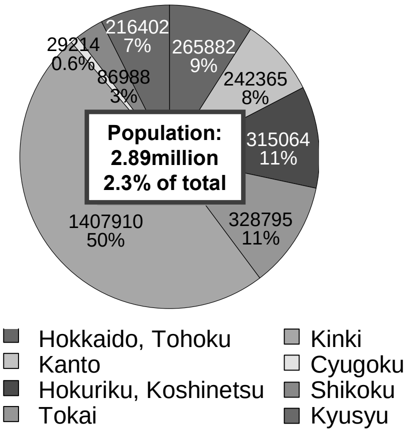


Figure 7 Regional tendency of population distribution

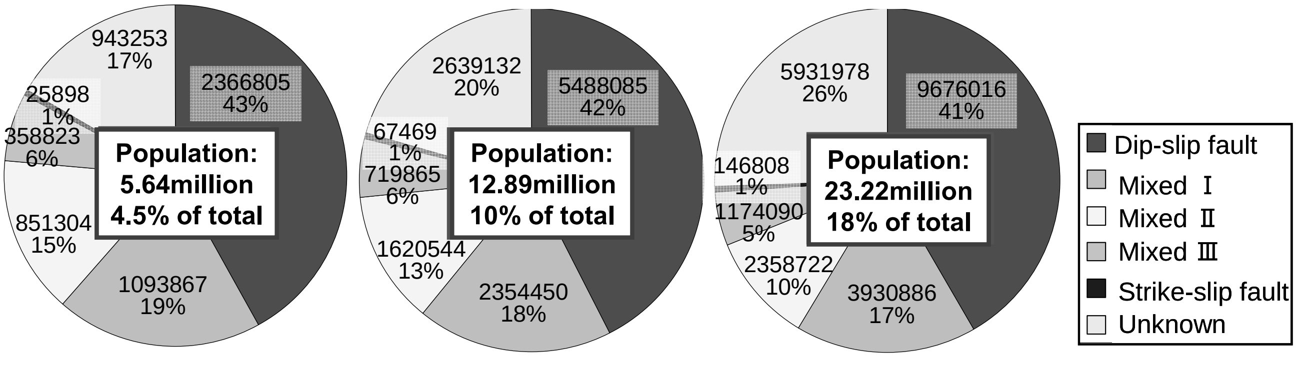


Figure 8 Population inside the fault zone when the zone width is changed

5. CONCLUSIONS

Japan entered an expected longstanding depopulation process in 2006. In this situation, it is important to avoid disaster social impacts by guiding population from vulnerable to safer areas. This research focused on the risk of active faults among various kinds of natural hazards and studied the effect of land-use control along active faults in Japan.

First, the meaning of land-use control plan along active faults in a society whose population started to decrease was discussed. While fault zoning has been carried out in U.S. for 30 years, Japan has not adopted it due to several reasons. Considering that land will become vacant due to depopulation in the future, the possibility of introducing a fault zoning act increases and the discussion on land-use control plans along active faults will become more meaningful.

Then, the distribution of population and buildings in the neighborhood of the active faults was analyzed based on GIS databases of active faults, population and building stock. In case of a 0.4km-width fault zone it was found that 2.89 million people or 2.3% of the total population in Japan live inside the fault zone. Half of the population living along faults is located in Kinki area and therefore, the effect of land-use control was different according to the region. The population inside the fault zone increases in proportion to the width of the zone.

The appropriate width of fault zones should be discussed considering several factors such as lessons from past earthquake damage, uncertainty of the traces of both strike-slip and dip-slip fault, social impact of the zones, among others. In the future, a study of the social impact of risk information of active faults is necessary.

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Evaluation of a road design considering on-street parking using the virtual reality traffic experiment system

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ABSTRUCT

A well-ordered on-street parking strategy in a city is highly desired to support urban social activities. This paper proposed a method to create on-street parking space on urban streets and evaluated its feasibility in the aspects of the efficiency and the safety by examining and modeling the driving behavior around on-street parking. For this evaluation, the virtual reality traffic experiment system, which is an integrated system of a traffic simulator and a driving simulator, is updated and used to conduct testee experiments. The results shows a possibility to make on-street parking spaces without deteriorating the efficiency and the safety.

KEYWORDS

On-street parking, Parking space design, Traffic simulation, Driving simulator

1. INTRODUCTION

Illegal on-street parking causes a lot of problems, such as traffic congestion, traffic accidents, inefficient use of road spaces, free ride of public spaces, inequality feelings among road users, and so on. Therefore in Japan, parking has been regarded to be done off street and on-street parking is generally prohibited in an urban area. However, there is not sufficient amount of parking space off street in a populated city and the enforcement is also not enough, so there are a lot of illegal parking vehicles almost everywhere on streets. Actually, urban businesses and commercial activities like loading and unloading depend on on-street parking widely, therefore, it is highly desired to prepare legitimate on-street parking spaces and to apply modulated parking regulation, which means, parking at harmful locations must be strictly prohibited but at the same time some parking space should be offered in other locations instead.

To achieve this idea, a methodology to create appropriately designed parking space on surface streets should be established. Here, it is quite important to ensure the traffic capacity as well as the safety between parking vehicles and passing vehicles in such on-street parking section. The purpose of this study is to propose a methodology to create on-street parking space in an urban street and to examine its feasibility in the aspects of the efficiency and the safety.

This study will contribute to realize a parking management which produces social merits of on-street parking for urban activities without deteriorating the traffic smoothness and the traffic safety. This concept can be shown in Figure 1. In the current situation, there are no parking vehicles in principle, therefore the level of the efficiency and the safety is much higher than the current actual situation, that is, there are illegal parking vehicles everywhere. However, from the social and economical points of view, as no-parking principle makes it difficult to conduct various business and commercial activities, the current illegal parking situation is better. The proposed scheme aims at enhancing the social and economical benefit by legitimate on-street parking space, while keeping almost the same level of the efficiency and the safety as the current principle.

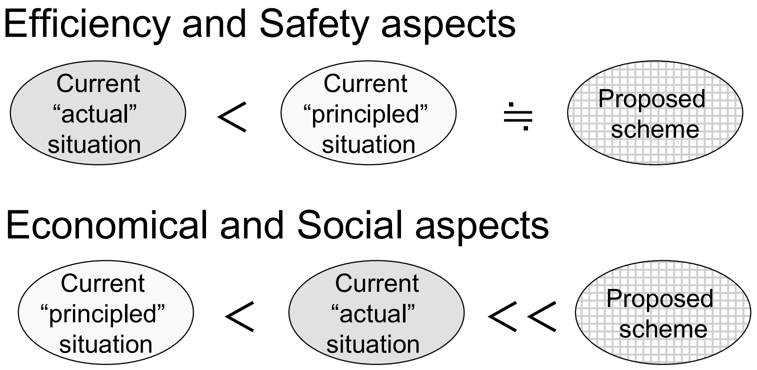

FIGURE 1 Conceptual image of proposed parking management scheme

For the evaluation of the proposed on-street parking space, the mixed reality traffic experiment system is used, which is an integrated system of a driving simulator and a microscopic traffic simulator with virtual reality image technologies. It can produce a highly realistic environment for driving experiments and makes it possible to analyze the driver's behavior in an unrealized traffic environment.

2. PROPOSED DESIGN OF ON-STREET PARKING SPACE

2.1 Outline of the proposed on-street parking space

As for traffic congestion in an urban area, the bottleneck is almost always at a signalized intersection, because the limited amount of signal green time has to be allocated among different directions of traffic. Therefore, on-street parking around an intersection which reduces the road capacity significantly should be strictly controlled. In other words, there is some room to allow on-street parking at a straight section between intersections.

According to this idea, the authors propose to create on-street parking space between intersections as shown in Figure 2, that is, to make a on-street parking bay at a straight pipe section between two intersections and to keep the maximum capacity at the intersection. This on-street parking space is designed inside road space, therefore before entering this section, the road width for passing vehicles has to be narrowed, which may sometimes cause capacity reduction or dangerous situations. However in the current situation in Japan, there are a lot of disordered illegal parking vehicles almost everywhere even near intersections, so this concentrated parking could be better solution. If appropriately designed, it does not reduce the capacity at the intersection even though the number of the lanes is reduced, which means, the congestion level of the network remains the same. It can be made only by lane marking, which is inexpensive and very advantageous to make it in every street. From a different point of view, we can say that the limited urban road space is used efficiently both for the traffic function and the access function of the street.

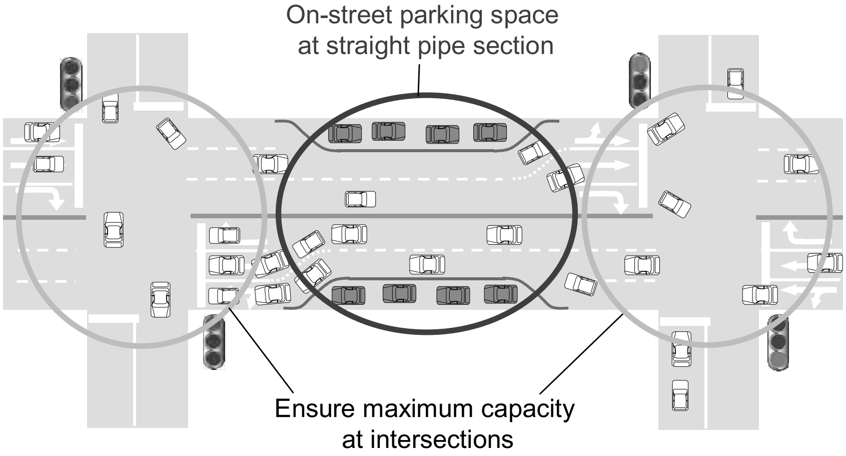

FIGURE 2 Proposed design of on-street parking space

2.2 Theoretical distance of the clearance from the intersection

The next question is how to design the proposed on-street parking space specifically. Let us call the distance from the intersections to the parking space “clearance distance”. Then, the problem is how to determine this clearance distance, that is, L_1 and L_2 in Figure 3. Here, we assume that this intersection is oversaturated with enough high demand from the upstream section. We also assume the volume of the turning out traffic from the target route and the turning in traffic to the target route is the same so that we only have to consider a condition that all the traffic goes straight and no traffic turns in from the crossing roads.

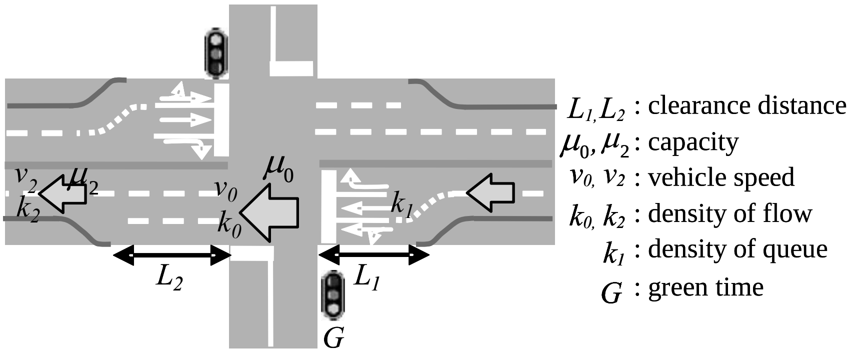

FIGURE 3 Clearance distance from the intersection

First, lets us consider the clearance distance L_1 at the upstream of the intersection. Because flow rate at the parking section is usually lower than that at the stop line, the saturation flow rate will decrease if the flow from the parking section reaches the stop line within the green time. In other words, to keep the maximum saturation flow rate at the stop line, green time flow from the upstream must be kept saturated. Therefore, the condition (1) is needed.

$$\mu_0 \cdot G \leq k_1 \cdot L_1 \qquad (1)$$

where μ_0 is the capacity of the intersection, G is effective green time of the signal, k_1 is the density in the queue from the stop line.

The left side of the inequality means the maximum flow during green time and the right side means the number of waiting vehicles in the clearance distance. By transforming it, L_1 is obtained as the condition (2).

$$L_1 \geq \frac{\mu_0 \cdot G \cdot}{k_1} \qquad (2)$$

Next, let us think clearance distance L_2 at the downstream of the intersection. In the case of on-street parking space in the downstream, traffic flow passing the intersection with relatively large rate arrives at the parking section with smaller capacity. After that, the excess demand forms a backward propagation and if it reaches the intersection, the saturation flow rate there will be decreased. This can be shown by time-space diagram in Figure 4.

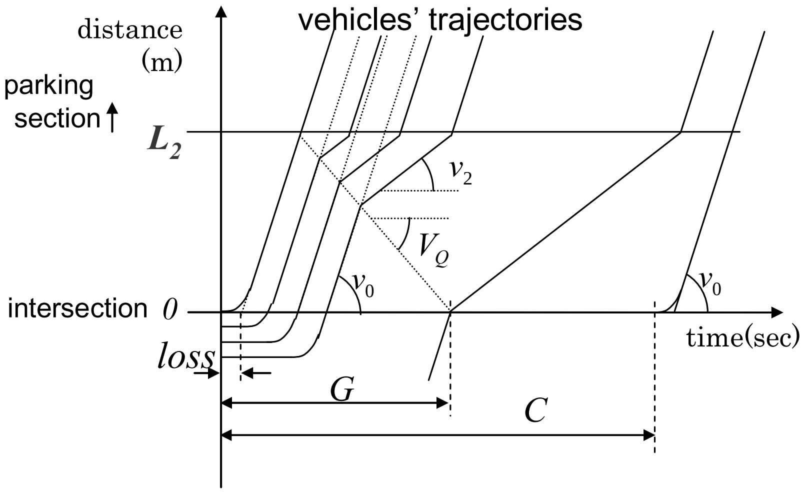

FIGURE 4 Time-space diagram at the downstream

The speed of backward propagation V_Q is derived using the difference of the capacity and the density as the equation (3).

$$V_Q = \frac{\mu_0 - \mu_2}{k_2 - k_0} \tag{3}$$

where μ_2 is the capacity of the parking section, k_2 is the density at the parking section, k_0 is the density at the intersection.

The condition for this propagation not to reach the intersection is, using the vehicles' speed at the intersection v_0,

$$\frac{L_2}{v_0} + \frac{L_2}{V_Q} \geq G \tag{4}$$

On the other hand, the queue from the parking section has to disappear before the vehicles of the next cycle reach the parking section, therefore the next condition is needed.

$$\frac{L_2}{v_2} < \frac{L_2}{v_0} + C - G \tag{5}$$

Transforming them using the relationship of $\mu = k \cdot v$, L_2 is obtained as the condition (6) and (7).

$$L_2 \geq G \cdot \left(\frac{\mu_0}{\mu_2} - 1 \right) \Big/ \left(\frac{1}{v_2} - \frac{1}{v_0} \right) \tag{6}$$

$$L_2 < (C - G) \Big/ \left(\frac{1}{v_2} - \frac{1}{v_0} \right) \tag{7}$$

From the above conditions (2), (6) and (7), as the capacity at the intersection is larger and the green time of the signal is longer, the necessary clearance distance becomes longer. And also, in the downstream section, the clearance distance has to be long in proportion to the capacity ratio between the intersection and the parking section. It means a multi-lane street which has a large capacity originally needs relatively less clearance distance even though the absolute value of the capacity reduction by parking section is the same. As for the signal parameters, the shorter green time allows the shorter clearance distance. It may sometimes become difficult to assure queue disappearance if the green time split of the target route is very large.

On-street parking space can be made theoretically as above mentioned. Although it may cause queue spill over at some local intersections from the downstream intersection due to transforming queue storage space into parking space, the total delay does not change as long as the limited bottleneck intersections are utilized in maximum capacity without influence of parking. However, it is still not clear whether it does not make negative influence on the efficiency and the safety. In the following sections, the feasibility of the proposed on-street parking space in these aspects is examined.

3. OUTLINE OF THE MIXED REALITY TRAFFIC EXPERIMENT SYSTEM

For the evaluation of the proposed parking space, we used the mixed reality traffic experiment system. It is an integrated system of a 6 axes motion driving simulator and a micro-and-macroscopic traffic simulator with virtual reality image technologies, which has been developed in the Sustainable ITS Project at CCR, The University of Tokyo. Figure 6 shows the current composition of the system. Explaining it by simple example, a person can drive the driving simulator as one of the cars running in the traffic simulation. The system can reproduce a realistic interaction between a driven vehicle by a testee and surrounding vehicles run by the traffic simulator, and can observe his/her driving behavior in several different scenarios under a fully controlled environment. The details of the system are explained in the references (Shiraishi et al. 2004, Suda et al. 2005)

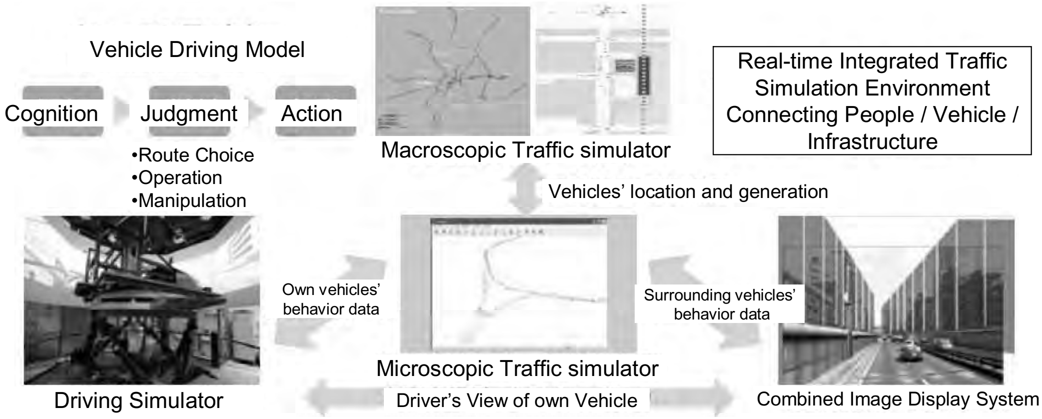

FIGURE 5 Composition of the mixed reality traffic experiment system

We used the microscopic traffic simulator function of this system for the efficiency evaluation and the driving simulator function for the safety evaluation. The former is described in Chapter 4 and 5, and the latter is in Chapter 6.

4. MODELING OF THE VEHICLE BEHAVIOR AROUND ON-STREET PARKING

In a conventional traffic simulator, vehicles run by a unit of the discrete lane. It means an actual lateral behavior like running over the boundary of lanes that is often observed around on-street parking cannot be described appropriately. Therefore, before using the microscopic simulator for the evaluation of on-street parking space, passing vehicle behavior model should be updated.

There are a lot of field surveys and observations about passing vehicle's behavior around on-street parking, for example, passing speed, amount of lateral shift, lateral clearance from the parking vehicles, and so on. Table 1 shows the items observed in the previous studies.

TABLE 1 Items observed in the previous studies

explanatory variable	explained variable
valid width	num. of parallel running
valid width	judgment of parallel running or lane change
valid width	rate of running over
valid width	passing speed
lateral clearance	passing speed
distance to parking vehicle	passing speed
distance to parking vehicle	lateral shift
1st order lateral shift	2nd order lateral shift
parking density	1st lane usage rate
section traffic volume	lane usage rate

Referring some of these results, the passing vehicle behavior around parking vehicles was modeled. The behavior of the passing vehicle consists of a series of actions, that is, finding a parking vehicle, judging how to pass, executing a determined action etc. Here, we introduced a continuous shift in the lateral direction in this passing behavior so that the simulator can describe a phenomenon like running over to the next lane. In this model, each vehicle has its own target point ahead which the vehicle moves aiming at, and this target point can have a continuous value of the lateral position. The flow of the passing vehicle's behavior model is shown in Figure 6.

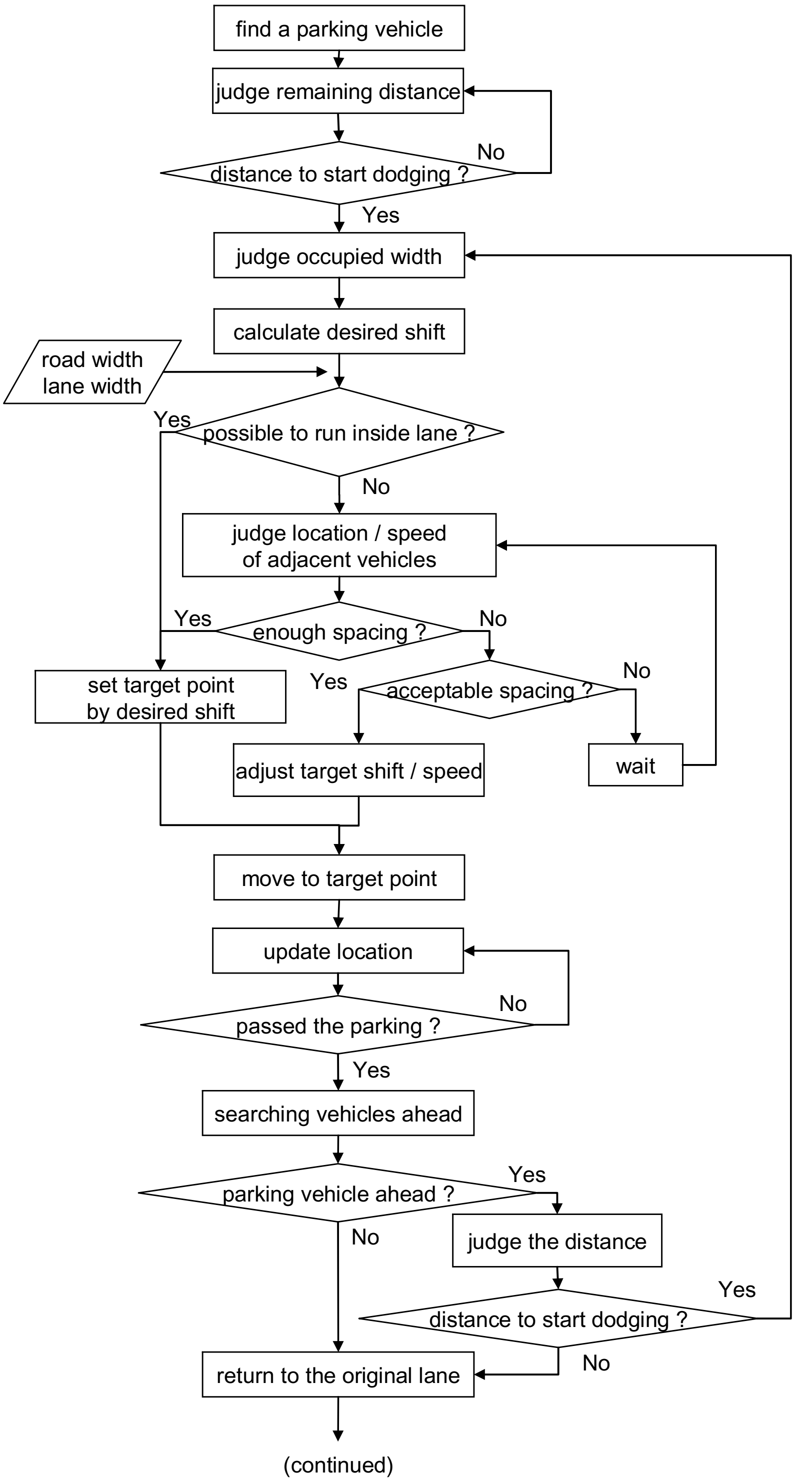

FIGURE 6 Flow of the passing vehicle's behavior model

The developed model is built into the existing microscopic traffic simulator as a module, and works to describe vehicles' behaviors around parking vehicles.

5. EFFICIENCY EVALUATION OF THE PROPOSED ON-STREET PARKING SPACE

5.1 Settings

Using the microscopic traffic simulation function which introduced the developed model explained in Chapter 4, the proposed on-street parking space was evaluated. We ran several settings of the simulations changing some variables shown in Figure 7 and Table 2.

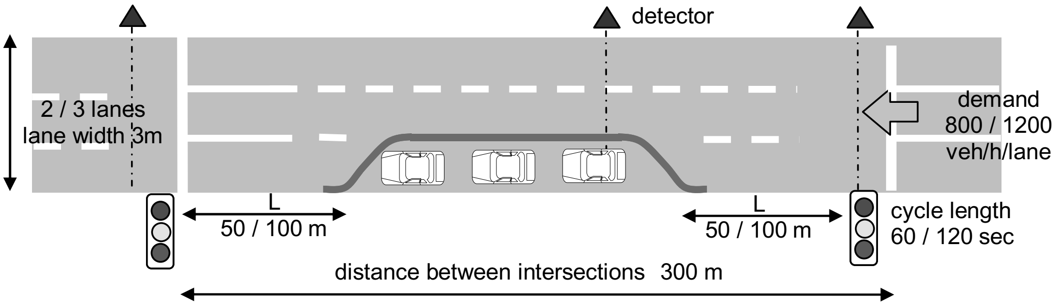

FIGURE 7 Representation of the on-street parking space

TABLE 2 Settings of the traffic simulation

item	setting
num. of lanes	2, 3 [lanes]
distance between intersections	300 [m]
distance from intersection to parking space (clearance distance) (L)	50, 100 [m]
cycle time (C)	60, 120 [sec]
green time	60% of cycle time
offset	simultaneous offset
Traffic demand (Q)	800, 1200 [veh/h/lane]

5.2 Results

First, let us show the result of 2 lanes simulation with the demand (Q) of 800 [veh/h/lane]. When the cycle time (C) is 120 [sec] and there is no parking space, the throughput of this section is 1447.6 [veh/h]. Here, if parking space is located with clearance distance (L) as 50 [m], the cumulative curve of the passing time of vehicles is shown in Figure 8.

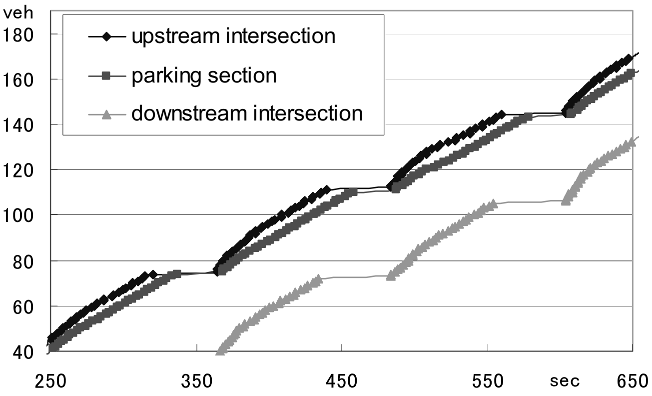

FIGURE 8 Cumulative curve (L = 50 [m], C = 120 [sec])

Next, if the clearance distance is set up as 100 [m] and the cycle time is set up as 60 [sec], the cumulative curve becomes as in Figure 9.

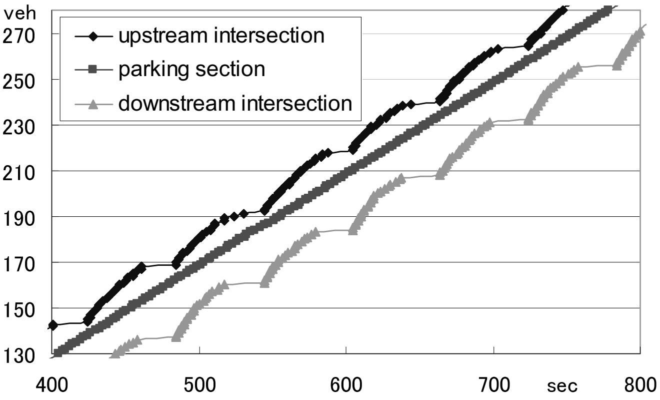

FIGURE 9 Cumulative curve (L = 100 [m], C = 60 [sec])

Comparing these two, the latter has a larger gradient, which means it has more ability to process traffic demand. (Note the displayed range of these two graphs is the same.) Actually, the throughput of the latter is 1425.2 [veh/], which is much larger than that of the former 1102.2 [veh/h] and almost the same as the situation of no parking space (1447.6 [veh/h]).

In the same way, different cases are simulated with the combination of the parameters mentioned above. The results are shown in Table 3.

TABLE 3 Throughput of 2 lanes road [veh/h]

throughput (veh/h)	no parking space (C=120sec)	L=50m C=120sec	C=60sec	L=100m	L=100m C=60sec
Q=800	1447.6	1102.0	1253.3	1247.4	1425.2

Q=1200	1856.9	1105.9	1238.1	1285.4	1431.0

TABLE 4 Throughput of 3 lanes road [veh/h]

throughput (veh/h)	no parking space (C=120sec)	L=50m C=120sec	C=60sec	L=100m	L=100m C=60sec
Q=800	2240.9	1930.0	2156.9	2045.2	2093.6
Q=1200	2758.6	1973.2	2180.5	2055.4	2445.1

In any cases, no parking space situations have the largest value of the throughput. When the parking space is located with L = 50 [m], the value of the throughput is reduced. However, as the cycle time is shortened and the clearance distance is extended, the value of the throughput is improved. Assuming the no parking situation 100%, the throughput rate is improved from 59.5% (L = 50 [m], C = 120 [sec]) to 77.1% (L = 100 [m], C = 60 [sec]) in the case of 2 lanes, and from 71.5% (L = 50 [m], C = 120 [sec]) to 88.6% (L = 100 [m], C = 60 [sec]) in the case of 3 lanes. From these results, it seems to be possible to keep the enough high throughputs depending on the clearance distance and the cycle time as indicated in Chapter 2.

6. SAFETY EVALUATION OF THE PROPOSED ON-STREET PARKING SPACE

6.1 Settings

Using the driving simulator function, safety aspect of the proposed on-street parking space was examined by conducting a driving experiment with test subjects. In the settings of the experiment, 3 patterns of the lane marking for on-street parking spaces were designed and the datasets to run the driving simulator were prepared as follows. The vehicles other than the testee’s vehicle are driven by the microscopic traffic simulator using the model developed in Chapter 4.

Figure 10 shows the first pattern A, a lane marking which does not consider that parking vehicles should be outside of the through traffic lanes. This marking actually imitates the current situation where illegal parking occurs.

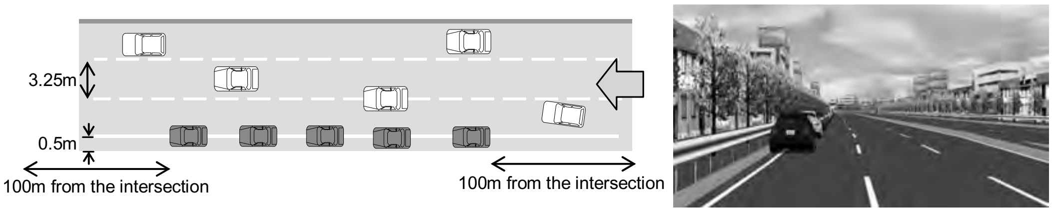

FIGURE 10 Current lane marking (pattern A)

The next lane marking pattern B creates a parking space by reducing each lane width for through traffic as shown in Figure 11. The number of lanes for through traffic remains the same.

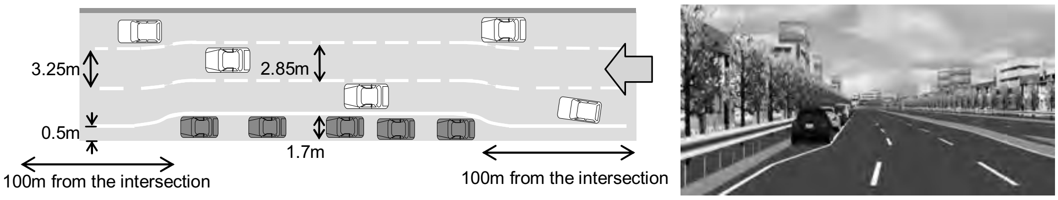

FIGURE 11 Lane width reduction (pattern B)

The third lane marking pattern C creates a parking space by reducing number of lanes for through traffic as shown in Figure 12. Each of the lane width for through traffic is maintained or widened.

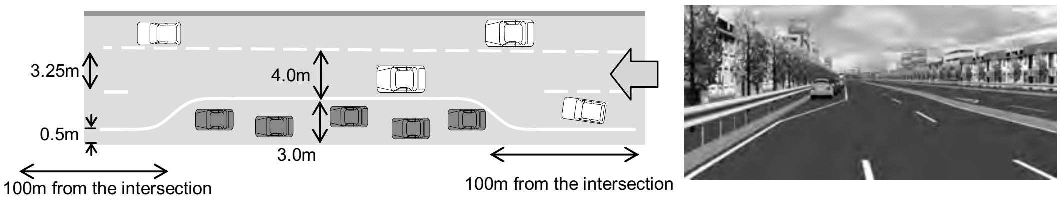

FIGURE 12 Lane number reduction (pattern C)

In the experiment, a testee is asked to drive at the leftmost (curbside) lane of this road stretch including these parking sections. The driving behavior data in every 0.1 second is recorded and questionnaire survey is also done after the driving. Here is an example of collected data.

Driving behavior data: vehicle's location, speed, acceleration/deceleration rate, steering angle etc.

Questionnaire survey: subjective evaluation on safety, uneasiness etc.

6.2 Results

A few dozens of testees has been invited to conduct the experiment. Table 1 shows the properties of the testees' at the experiment. From them, some of the results are shown in the followings.

TABLE 5 Properties of testees

Total	46							
Gender	**Male:**		32		**Female:**		14	
Age	**20s**	30	**30s**	12	**40s**	2	**50s**	2
Driving history	**< 1 year**	**< 3 years**	**< 10 years**	**< 20 years**	**20 and more**			
	4	15	26	17	4			
Driving frequency per week	**none**	**< 2 hours**	**< 5 hours**	**5 and more**				
	12	18	17	19				

Figure 13 shows the driving trajectories by several testees in the pattern A. In this pattern, most of the drivers change their lane to the right completely although parking vehicles occupy less than half of the first lane. We can see the trajectories vary especially at the entrance point of the parking section.

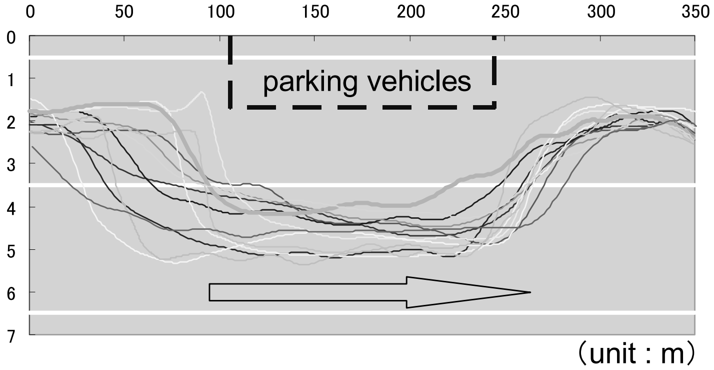

FIGURE 13 Driving trajectories

Picking up a certain testee, some kinds of personal the driving data such as brake pedal stroke, acceleration / deceleration rate, vehicle speed and steering angle corresponding to the vehicle trajectory can be shown in Figure 14. At the entrance point of the parking section, we can see the driver takes several actions, such as steering and accelerating / braking, in order to get into the adjacent lane.

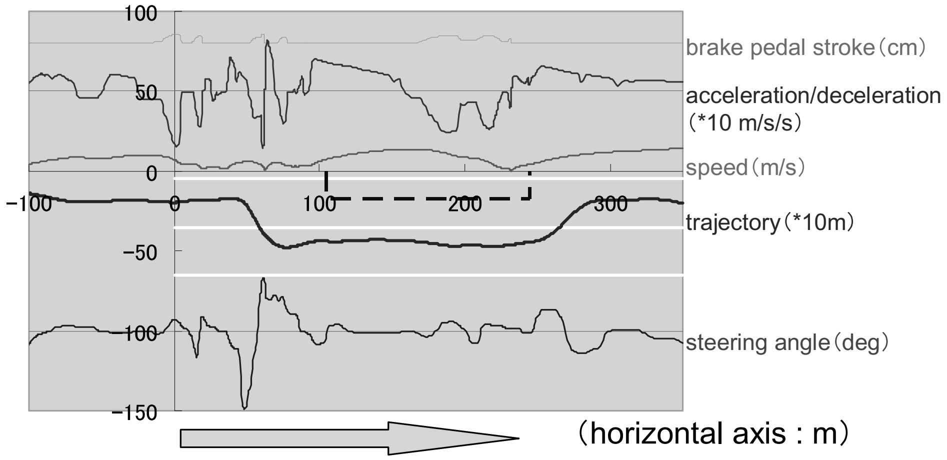

FIGURE 14 Example of personal driving data

If these values of the driving behavior exceed a certain thresholds, it may cause a dangerous situation. Therefore, from the recorded driving data, we selected the maximum values of deceleration and heading angular speed of each testee as simple indices of the safety. Figure 15 and 16 show the distribution of them including the maximum/minimum value and the standard deviation. From these results, the pattern B shows the lower value than others, which implies smoother and less dangerous driving could be realized.

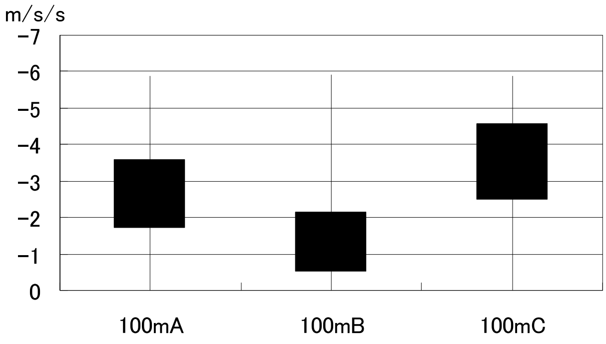

FIGURE 15 Distribution of maximum deceleration

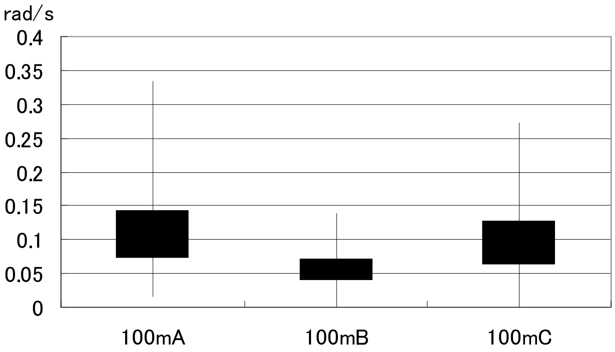

FIGURE 16 Distribution of maximum heading angular speed

A subjective evaluation by the testees is also done by conducting a questionnaire survey after driving. Figure 17 shows whether testees felt dangerous or not on each of the patterns of the lane marking. Compared with the pattern B and C, the testees feel more dangerous in the pattern A, a situation of the illegal parking.

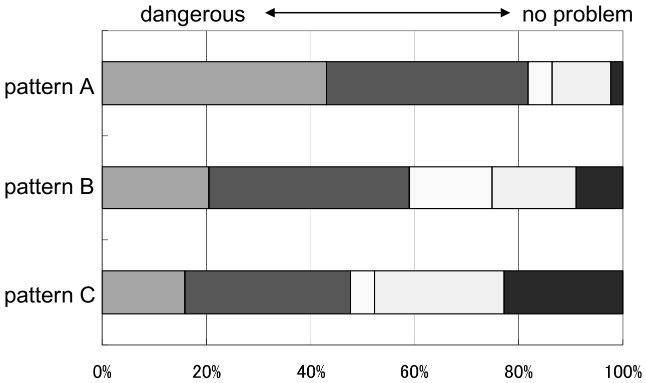

FIGURE 17 Subjective evaluation of lane markings

Figure 18 shows the result asking which was the most preferable pattern of the marking and why the pattern was preferred. The testees who preferred the pattern B raised no need of lane changes, while the testees for the pattern C find an advantage in wide lane configuration. The preference between the pattern B and C could depend on the traffic situation realized at the timing of their arriving at the parking section.

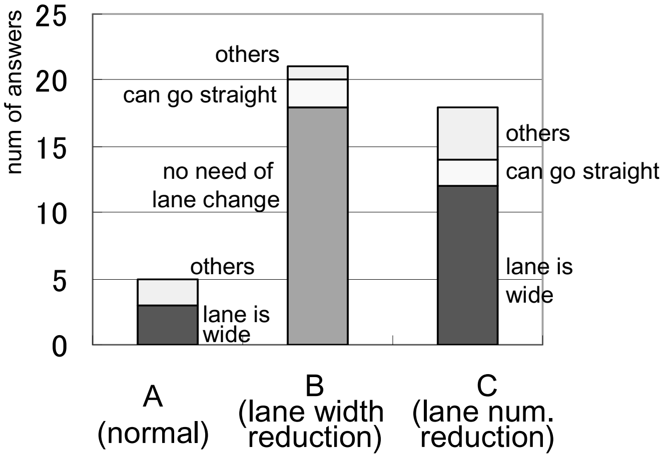

FIGURE 18 Reason of lane marking preference

From the analysis based on the experiment so far, testees feel uneasiness or danger in the pattern A, which is similar to actual illegal parking situation, and also, indices of recorded driving data show relatively high value of dangerous. Therefore, it would be justified to make some types of parking lane, such as pattern B and C, on street.

The data obtained at the driving simulator experiment can be utilized to improve the vehicle behavior model mentioned in Chapter 4. Then it will run the other vehicles in the driving simulator again. Therefore, it will work as a kind of feedback loop to improve the model, which would become a quite new approach to develop a model.

7. CONCLUSION

As one of the measures to solve the problem of illegal on-street parking vehicles, the authors proposed to create legitimate on-street parking space at a straight pipe section between intersections. And the way to calculate the appropriate clearance distance theoretically was presented not to make negative impact on the traffic capacity at the bottleneck intersection.

Based on this idea, the feasibility of this on-street parking space was examined in the aspects of the efficiency and the safety using a traffic simulator and a driving simulator. As for the traffic simulator analysis, the vehicle behavior model was updated to describe the passing vehicles' behavior around parking vehicles. Using this model, several different settings were simulated and the results showed a possibility to make on-street parking space not reducing the capacity. On the other hand, from the driving simulator analysis, the case like an illegal parking situation got the lowest evaluation, therefore to make intended on-street parking space may even improve safety from the current situation.

As this study only focused on the side of the infrastructure, it is also necessary to analyze parking demand, cost burden etc. as future works. Combining these analyses, the way of on-street parking treatment should be established and an orderly traffic environment without illegal parking vehicles will be realized.

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Classification of Airborne Hyperspectral Data Based on the Average Learning Subspace Method

Hasi Bagan, Yoshifumi Yasuoka, *Member, IEEE*, Takahiro Endo, Xiaohui Wang, and Zhaosheng Feng

***Abstract*—This letter introduces the averaged learning subspace method (ALSM) that can be applied directly to original hyperspectral data for the purpose of classifying land cover. The ALSM algorithm of classification consists of the following iterative steps: 1) generate the initial appropriate feature subspace for each class in training datasets using the class-featuring information compression method, and 2) update the subspaces according to the maximum projection principle. We compare ALSM with the support vector machine classifier. By conducting experiments on two hyperspectral datasets (48 bands and 191 bands, respectively), we demonstrate that the ALSM can make dimensional reduction and classification simultaneously. When compared with the SVM classifier, it appears that the ALSM can achieve a higher accuracy on classification in some cases.**

***Index Terms*—Averaged learning subspace method (ALSM), classifier, hyperspectral data, subspace method.**

I. INTRODUCTION

HYPERSPECTRAL data have potential applications in many scientific areas. However, the large-dimensional data introduce challenging methodological problems such as the curse of dimensionality [1]–[3].

To overcome this problem, many elegant classification approaches have been proposed in the literature, which include: 1) mathematical morphology-based classification methods [4], [5]; 2) feature selection and feature extraction methods [2]; 3) orthogonal subspace projection classification methods [6], [7]; 4) cluster and hierarchical classification methods [8], [9]; and 5) support vector machine (SVM) classifiers [10], [11].

As mentioned in [2] and [6], the dimensionality reduction method has been found to be an effective method for land cover classification purposes. However, sometimes the feature reduction algorithm is not related to the classifier. The subspace pattern recognition method is a dimensionality reduction method proposed originally by Watanabe [12]. The use of subspaces as class models is based on the assumption that the data within each class approximately lie in a lower dimensional subspace, which tends to be more easily interpretable. In this way, each class is represented by a subspace spanned by a group of basis vectors, and the classification criterion for the input pattern is its distance from the class subspace. The averaged learning subspace method (ALSM) is an iterative learning version of the subspace method which can generate an optimal subspace for each class trained by samples to get better recognition results. The ALSM has been successfully employed in numerous other applications such as optical character, speech, and character recognition [13]–[15]. In practice, these subspace methods are very useful and powerful in many cases and exhibit reasonably robust behavior with respect to convergence during training.

In this study, our goal is to modify the ALSM for the hyperspectral data classification scheme. ALSM was initially designed for pattern recognition problems. When a problem is involved with the hyperspectral data classification, an appropriate multiclass method is needed. For character recognition, the processing object is a binary image, but for the hyperspectral data, the object is a high-dimensional gray-scale image. To deal with this issue, we normalize the data and apply Jacobi's method [16] on training datasets to create the corresponding subspaces. The results of classification obtained on two real hyperspectral datasets are presented and discussed.

II. SUBSPACE METHODS

This section presents the class-featuring information compression (CLAFIC) [13] subspace method, the learning subspace method (LSM), and the ALSM subspace method for classification. Then we show the procedure of the ALSM for hyperspectral data classification.

The CLAFIC is as follows: let R^n denote the n-dimensional (bands) vector pattern space. Any set of p linearly independent vectors $\boldsymbol{u}_1, \boldsymbol{u}_2, \cdots, \boldsymbol{u}_p$ in R^n (with $p < n$) spans a subspace, say L, which is the set

$$\boldsymbol{L} = \boldsymbol{L}(\boldsymbol{u}_1, \boldsymbol{u}_2, \cdots, \boldsymbol{u}_p) = \left\{ \boldsymbol{x} | \boldsymbol{x} = \sum_{i=1}^{p} \boldsymbol{a}_i \boldsymbol{u}_i \right\} \tag{1}$$

where $\boldsymbol{a}_i, \boldsymbol{a}_2, \cdots, \boldsymbol{a}_p$ are coefficients. If basis vectors $\boldsymbol{u}_1, \boldsymbol{u}_2, \cdots, \boldsymbol{u}_p$ are a nonorthonormal set, they can be constructed as a set with the unit length of mutually orthogonal vectors using the Gram-Schmidt orthogonalization algorithm.

Consider c categories denoted by $\omega^{(1)}, \omega^{(2)}, \cdots, \omega^{(c)}$. Each category corresponds to a certain subspace in R^n given that $\boldsymbol{L}^{(i)}$ denotes the ith subspace with dimension $\boldsymbol{p}^{(i)}$. Let $\boldsymbol{u}_1^{(i)}, \boldsymbol{u}_2^{(i)}, \cdots, \boldsymbol{u}_{p^{(i)}}^{(i)}$ denote the unit-length orthogonal basis vectors of $\boldsymbol{L}^{(i)}$. According to the projection principle, any vector x can be represented as a sum of two vectors

$$\boldsymbol{x} = \hat{\boldsymbol{x}} + \tilde{\boldsymbol{x}} \tag{2}$$

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where $\hat{x}$ is the projection of vector x on the subspace $\boldsymbol{L}^{(i)}$, and $\tilde{x}$ is the orthogonal to the subspace $\boldsymbol{L}^{(i)}$, i.e., the projection is

$$\hat{\boldsymbol{x}} = \sum_{j=1}^{p^{(i)}} \left(\boldsymbol{x}^T \boldsymbol{u}_j^{(i)}\right) \boldsymbol{u}_j^{(i)} = \sum_{j=1}^{p^{(i)}} \left(\boldsymbol{u}_j^{(i)} \boldsymbol{u}_j^{(i)^T}\right) \boldsymbol{x} = \boldsymbol{P}^{(i)} \boldsymbol{x}. \quad (3)$$

Here $\boldsymbol{P}^{(i)} = \sum_{j=1}^{p^{(i)}} \boldsymbol{u}_j^{(i)} \boldsymbol{u}_j^{(i)^T}$ is the orthogonal projection matrix in the subspace $\boldsymbol{L}^{(i)}$. It is unique for subspace $\boldsymbol{L}^{(i)}$ and completely equivalent to the subspace $\boldsymbol{L}^{(i)}$. The squared length of $\hat{x}$ can be used as the discriminant function as follows:

$$g\left(\boldsymbol{x}, \boldsymbol{L}^{(i)}\right) = \left\|\boldsymbol{P}^{(i)} \boldsymbol{x}\right\|^2 = \boldsymbol{x}^T \boldsymbol{P}^{(i)} \boldsymbol{x} = \sum_{j=1}^{p^{(i)}} \left(\boldsymbol{x}^T \boldsymbol{u}_j^{(i)}\right)^2. \quad (4)$$

The decision rule for the label pattern x to class i is

$$g\left(\boldsymbol{x}, \boldsymbol{L}^{(i)}\right) = \max_{1 \leq j \leq c} \left\{ g\left(\boldsymbol{x}, \boldsymbol{L}^{(j)}\right) \right\}. \quad (5)$$

As the basis vectors $\boldsymbol{u}_1^{(i)}, \boldsymbol{u}_2^{(i)}, \cdots, \boldsymbol{u}_{p^{(i)}}^{(i)}$, the $\boldsymbol{p}^{(i)}$ first eigenvectors of the class $\omega^{(i)}$ correlation matrix are normally used corresponding to the largest eigenvalues $\lambda_1^{(i)}, \lambda_2^{(i)}, \cdots, \lambda_{p^{(i)}}^{(i)}$ in decreasing magnitude. The correlation matrix can be estimated from the training set of class $\omega^{(i)}$. The number of training samples must be greater than that of the corresponding subspace dimension to ensure that the basis eigenvectors are linearly independent.

One drawback with the CLAFIC is that subspaces obtained for one class are not dependent on subspaces of the other classes. To account for this problem, LSM and ALSM have been proposed. If CLAFIC is associated with classification errors, the classification results can be improved by rotating the subspaces. LSM is one of these rotating methods.

Given that a pattern vector x belongs to class $\omega^{(i)}$, which has been classified incorrectly into $\omega^{(j)}$, there are two subspaces to be rotated at each time of iteration. One is the correct subspace $\boldsymbol{L}^{(i)}$ and the other is the wrong subspace $\boldsymbol{L}^{(j)}$. To correct the error, the LSM uses following equations to rotate the subspace:

$$\begin{aligned} \boldsymbol{L}_{new}^{(i)} &= (\boldsymbol{I} + \rho_i \boldsymbol{x}\boldsymbol{x}^T)\boldsymbol{L}^{(i)} \\ \boldsymbol{L}_{new}^{(j)} &= (\boldsymbol{I} - \rho_j \boldsymbol{x}\boldsymbol{x}^T)\boldsymbol{L}^{(j)} \end{aligned} \quad (6)$$

where I is an identity matrix. Both ρ_i and ρ_j are positive parameters. The principle in applying the training sample vector is that the projection of x on the wrong class is always decreased and the one on the correct class is always increased.

LSM is very sensitive to the input order of samples. During one cycle, the sample that has been learned can be counteracted by the next arriving samples. They tend to cancel out each other's effects. To avoid this problem, ALSM was introduced [13]–[15]. When an error occurs in ALSM, the correct subspace is rotated toward the misclassified vector, and the wrong subspace is rotated away from it. This is achieved by modifying the class-conditional correlation matrices and then updating the basis vectors.

In the kth iteration, misclassified training samples are divided into two types; either a sample vector of class $\omega^{(i)}$ is misclassified into another class, say $\omega^{(j)}$, or a sample vector of another class, say $\omega^{(k)}$, is misclassified into class $\omega^{(i)}$. The estimate of an unnormalized conditional correlation matrix is

$$\boldsymbol{P}_k^{(i,j)} = \sum_x \left\{ \boldsymbol{x}\boldsymbol{x}^T | \boldsymbol{x} \in \omega^{(i)}, \boldsymbol{x} \mapsto \omega^{(j)} \right\} \quad (7)$$

where the symbol $\mapsto$ denotes "gets classified into." In the kth iteration, based on existing current subspaces, the entire training vector x is classified according to (5), and all matrices $\boldsymbol{P}_k^{(i,j)}, \boldsymbol{i}, \boldsymbol{j} = 1, 2, \cdots \boldsymbol{c}$ are computed. Thereafter, the correlation matrices for each class are computed and the basis vectors are updated as follows:

$$\boldsymbol{P}_k^{(i)} = \boldsymbol{P}_{k-1}^{(i)} + \sum_{j \neq i} \alpha^{(i,j)} \boldsymbol{P}_k^{(i,j)} - \sum_{j \neq i} \beta^{(i,j)} \boldsymbol{P}_k^{(j,i)} \quad (8)$$

where parameters $\alpha^{(i,j)}$ and $\beta^{(i,j)}$ are positive constants. The process stops when the predicted convergence condition is met. We find that ALSMs are completely independent to the order of input training samples. The main ALSM algorithm, which includes normalization of a pixel can be summarized as follows.

Step 1) Normalize each pixel to the unit-length vector by dividing each element according to the vector length (to avoid the overflow problem).

Step 2) Compute initial class correlation matrices, and then create subspaces by the CLAFIC and Jacobi's method.

Step 3) Label pixels by computing projection distance [(5)], and then update matrices [(7), $k = 0$].

Step 4) Create the new subspace using CLAFIC and Jacobi's method.

Step 5) Compute projection distance [(5)] and update matrices [(7)].

Step 6) Compute class correlation matrices [(8)]

Step 7) $k = k + 1$; go to step 5). Repeat until the desired condition is reached.

III. ALSM CLASSIFICATION STAGE

A. *CASI-2 Images*

The hyperspectral data of the Compact Airborne Spectrographic Imager-2 (CASI-2) with 48 spectral bands at 1.5-m resolution were acquired in the daytime of clear skies on October 17, 2003 for a site near Tokyo, Japan [139°35′51.09″ E. and 35°51′10.96″ N. Fig. 1(a)]. The data size was 4960 × 1113 pixels. The CASI-2 data were geometrically corrected by the data producers.

We conducted a field survey on October 17, 2003 at the same time as the CASI-2 data acquisition and again in November 2006. Based on field surveys, 11 ground cover types were selected in this experiment as shown in Table I. The training and test samples were selected from separate local patch data to ensure spatial disjointing and to reduce any potential correlation between the samples used to train the classifier and those used to test its performance.

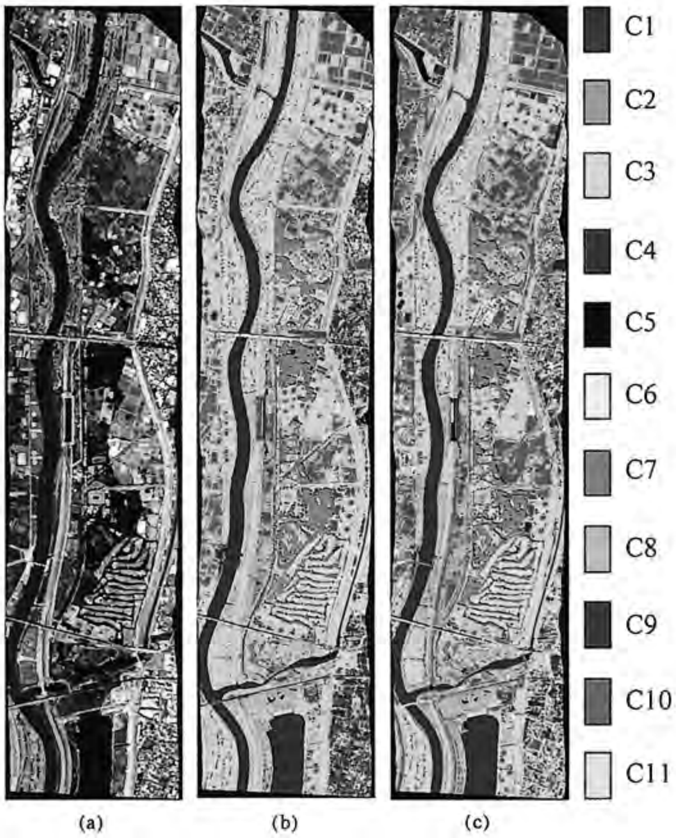

Fig. 1. (a) CASI-2 image (RGB = central wavelength: 663.79, 560.91, and 470.44 nm, respectively). (b) Classification maps of ALSM and (c) SVM.

TABLE I
LAND COVER CLASSES AND NUMBER OF TRAINING AND TEST SAMPLES IN THE EXPERIMENTS ON CASI-2

Class	Training samples	Test samples
C1. water	251	206
C2. woodland	300	186
C3. grassland	383	205
C4. roofs	410	206
C5. shadow	269	149
C6. asphalt (roads)	446	266
C7. farmland	306	188
C8. reeds	396	208
C9. parking lot	309	182
C10. bare soil	466	243
C11. concrete	307	142
Total	3843	2181

The proposed ALSM algorithm was developed by using the C program (Microsoft Visual Studio 2005.net). Training samples, test samples, and the whole of the CASI-2 data were normalized to the unit length.

To obtain the best parametric values in (8), different experiments were carried out by varying the values $\alpha^{(i,j)}$ and $\beta^{(i,j)}$ in (8) on training data. As a result, when the values are taken from the interval [0.15, 0.5], the classification accuracy is high, and the change of the classification accuracy is comparatively low. The best values are found to be 0.25 and 0.2, respectively. The terminating condition of learning process is set to occur when all training samples are recognized correctly and learning ceases. If no learning pattern is recognized after 1000 epochs, learning is abandoned. Jacobi's method was adopted to solve eigenvalue and eigenvector problems. By calculation, it is seen that the sum of the five largest eigenvalues is approximately equal to 99.9% of the sum of all total eigenvalues. Therefore, we select five vectors corresponding to the first five largest eigenvalues as the basis vectors. This means that subspace dimensions are kept to a constant of five during the learning and classification process for each subspace. The independently setting subspace dimensions for each class are given in [13].

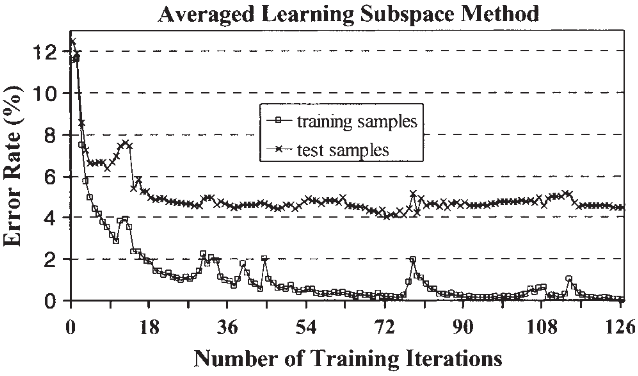

Fig. 2. Plots of the error rate (misclassified) versus the number of iterations for the training and test samples.

To check the time complexity and the classification error in the ALSM training iteration step, we compute the classification accuracy for the training and test dataset. The behavior of resulting accuracy as functions of iteration is shown in Fig. 2.

Fig. 2 also illustrates that the ALSM learning process converges after 126 iterations. The error rate of the training and testing dataset decreases steadily with the learning iteration. For the training dataset, the recognition error rate is decreased from 12.5% to 0%, and for the testing dataset, it drops from 11.6% to 4.5%. As one can see from Fig. 2, with the iteration increasing, the classification error rate does not increase for the test dataset. This implies that the ALSM overcomes the overfitting problem. These results demonstrate a success of the ALSM in generating a globally optimized subspace for each class.

After training, the constructed ALSM classifier is applied to the normalized hyperspectral data. The ALSM classification map is shown in Fig. 1(b), and the accuracy is given in Table II. As reported in Table II, the corresponding overall accuracy (OA) and average accuracy (AVE) achieved for the test dataset are 95.51% and 95.85%, respectively. Here, we use the SVM classifier to make a comparison. Recent research indicates that the SVM classifiers provide higher accuracy than other widely used techniques, and it can be directly applied to the original hyperspectral feature space without a feature-reduction procedure [10], [11].

We apply the SVM classifier directly to the hyperspectral data of the same training set (Table I). The SVM classifier with radial basis function (RBF) kernels in ITT ENVI™ software (version 4.3) was used in this study. To obtain the best parametric values, different experiments were carried out by varying the width and penalty values of the SVM parameters on training datasets. As a result, the best values of the width and penalty in SVM are found to be 0.21 and 90, respectively.

The corresponding classification map obtained by SVM is given in Fig. 1(c). The accuracy provided by SVM for the

TABLE II
OVERALL (OA), AVERAGE (AVE), AND CLASS ACCURACY BY THE ALSM AND SVM CLASSIFIERS ON CASI-2 DATA

Method	Classification accuracy (%)												
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	OA	AVE
ALSM	94.17	100	98.05	97.09	99.33	93.23	100	89.42	90.11	93.00	100	95.51	95.85
SVM	100	97.85	91.71	78.16	95.97	75.94	82.98	96.63	98.90	74.90	100	89.09	90.28

TABLE III
LAND COVER CLASSES AND NUMBER OF TRAINING AND TEST SAMPLES IN THE EXPERIMENTS ON AVIRIS

Class	Training samples	Test samples
C1. alfalfa	24	22
C2. corn-notill	755	585
C3. corn-min	467	326
C4. corn	117	87
C5. grass-pasture	228	226
C6. grass-trees	392	318
C7. grass-pasture	16	10
C8. hay-windrowed	250	231
C9. oats	10	10
C10. soybean-notill	473	451
C11. soybean-min	1235	1131
C12. soybean-cleantill	310	255
C13. wheat	102	105
C14. woods	670	581
C15. bidg-grass	199	162
C16. stone-steel	44	45
Total	5292	4545

test dataset is presented in Table II. As shown in Table II, the corresponding OA and AVE achieved with the test data are 89.09% and 90.28%, respectively.

As we can see from Table II, the ALSM obtains OA and AVE of 95.51% and 95.85%, respectively, corresponding to a strong gain of +6.42% and +5.57%, respectively, compared with that achieved by the SVM classifier. In terms of class-specific accuracy, it appears that the ALSM gives higher accuracy than the SVM classifier, except for C1, C8, and C9.

A comparison between the corresponding classification maps [Fig. 1(b) and (c)] also confirms this conclusion. The ALSM mainly improves the classification accuracy near fine structures and performs significantly better at the boundaries between larger regions than the SVM classifier does.

Several differences can be noticed visually in the two classification result maps. The water (C1), parking lot (C9), and concrete (C11) areas are obviously overrepresented in the SVM. For example, some shadow (C5) is misclassified into water (C1), the bare soil of playground (C10) areas is misclassified into parking lot (C9), and a playing field within C10 is misclassified into concrete (C11) in the SVM, whereas the ALSM labels these classes correctly.

B. AVIRIS Images

Comparison of the ALSM with SVM classification methods has also been carried out on the well-known "Indian Pine" datasets by Airborne Visible/Infrared Imaging Spectroradiometer (AVIRIS) sensors in 1992 [17]. From the 220 spectral bands acquired by the AVIRIS sensor, 29 bands were discarded because they were affected by atmospheric problems. The entire 16 land cover classes available in the original ground truth were used in our experiments to generate a set of 5292 training samples and a set of 4545 test samples (see Table III).

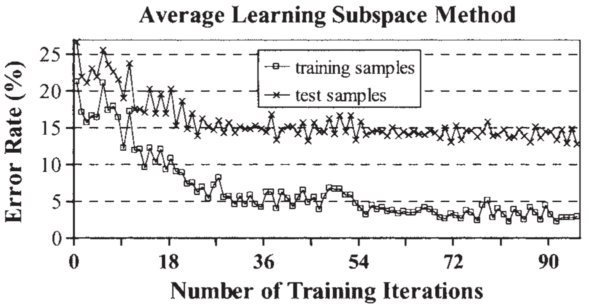

Fig. 3. Plots of the error rate (misclassified) versus the number of iterations for the training and test samples.

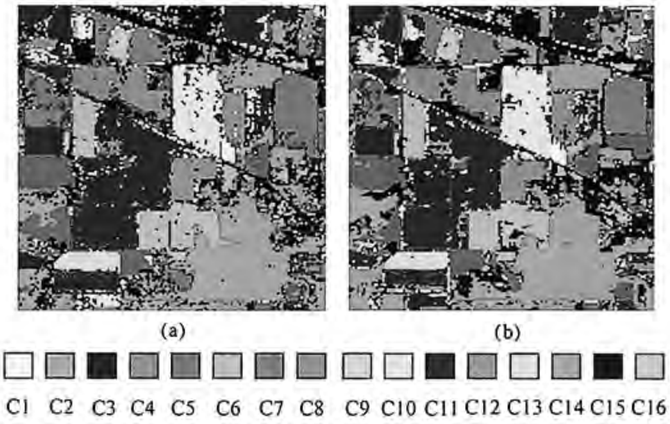

Fig. 4. Land cover classification maps of (a) ALSM and (b) SVM.

The subdivision of the ground truth into training and test data is spatially disjoint for each class to reduce the correlation between training and test datasets as much as possible.

For ALSM, based on the same experiments as those for CASI-2, the best parameters $\alpha^{(i,j)}$ and $\beta^{(i,j)}$ in (8) are fixed at 0.4 and 0.4, respectively. The subspace dimensions are fixed at 5, and the maximum iteration is set to 95. Training samples, test samples, and all of the AVIRIS data are also normalized to the unit length. Fig. 3 shows the behavior of the ALSM learning process. The error rate for training and testing datasets decreases steadily with the learning iteration. For the training dataset, the recognition error rate decreases from 21.3% to 2.9%, and for the testing dataset, it drops from 26.7% to 12.9%. The classification results are shown in Fig. 4(a), and the accuracy is presented in Table IV. The corresponding OA and AVE achieved by ALSM with the test data are 87.06% and 87.34%, respectively.

In SVM, we adopt the RBF as the kernel function for SVM. Based on testing, the best values of the width and penalty were fixed at 0.005 and 300, respectively. The corresponding classification map obtained by SVM is given in Fig. 4(b), and the accuracy provided by SVM for the test dataset is presented

TABLE IV
OVERALL (OA), AVERAGE (AVE), AND CLASS ACCURACY BY THE ALSM AND SVM CLASSIFIERS ON AVIRIS DATA

Method	Classification accuracy (%)																	
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	OA	AVE
ALSM	100	77.9	78.5	72.4	99.6	95.9	70	100	80	82.3	86.7	86.3	99.1	91.9	81.5	95.6	87.06	87.34
SVM	100	76.4	71.8	75.9	95.6	95.9	100	100	70	81.4	80.9	87.8	98.1	98.1	70.4	88.9	85.17	86.95

in Table IV. As illustrated in Table IV, the corresponding OA and AVE achieved with the test data are 85.17% and 86.95%, respectively.

As we can see from Table IV, the obtained results still confirm the strong superiority of ALSM over SVM even in very high dimensional feature spaces, with a gain in OA and AVE of +1.89% and +0.39%, respectively, compared with that achieved by the SVM classifier.

Some other experiments on the "Indian Pine" data were presented in [2], [10], and [11], which used the same ground truth datasets, but the way for selecting ground truth data into training datasets and test datasets may be different. Among these, the nonlinear SVM algorithm led to 93.42% of OA [10].

IV. CONCLUSION

In this letter, an ALSM subspace classification system for hyperspectral data has been presented. Compared with the SVM method on CASI-2 data with 48 bands and on AVIRIS data with 191 bands, the proposed method appears to yield better classification results than the SVM method. Experimental results also indicate that ALSM: 1) can achieve dimension reduction and classification concurrently; 2) possesses high-speed convergence. The algorithm can be extended to any hyperspectral data classification and seems to be a promising alternative to the SVM for hyperspectral data classifications in some cases.

It is worthy to mention that ALSM does not completely depend on the dimensionality of the input space and training dataset size. Therefore, the ALSM can provide a way to avoid the curse of dimensionality. To further improve the effectiveness of ALSM, this method should be conducted with extensive testing on hyperspectral datasets and with some existing ingenious techniques, and compared with more classifiers.

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The Business Case for Sustainability: With a Focus on LEED® Green Building Assessment System

Pranab J. BARUAH* and Kimiro MEGURO**

Abstract

Sustainability is about following the triple bottom line principles of environmental preservation, social responsibility and economic profitability. Traditional cost-benefit analysis with a short-term horizon fails to capture economic benefits of a product/solution satisfying the first two principles, leading to perceived economic infeasibility of sustainable products/solutions. This review article first discusses the sustainability concept and the need for a business case for sustainability before outlining the issues and components that should be considered to make a strong business case for sustainable products/solutions. Based on presently available knowledge, an integrated, holistic, life-cycle based and longer-term approach to costs and benefits with due inclusion of intangibles is proposed to make a proper business case for such product/solutions in order to make them commercialized and absorbed in the society effectively and faster. It is also shown how elements of green building movement, such as LEED® green building assessment system, are making tremendous market transformation by presenting a good business case for green buildings.

Sustainability Revisited

In recent years, sustainability has become the buzzword in political, business and academic arena. Public awareness about climate change from anthropogenic green house gas (GHG) emissions is probably the biggest factor for the heightened awareness about sustainability. Additionally, increasing energy prices, rising commodity prices from depleting natural resources, concerns about food and water security with ballooning population and rising instability in society from increasing inequity (probably) from globalization are some other major factors contributing to wide-spread sustainability awareness. While sustainability and sustainable development have the same goal, academicians and businesses tend to use the former phrase, while NGOs and international organizations often use the later one. Based on the UN Brundtland Commission Report in 1987, which popularized and defined the concept of sustainable development, it is defined as *"the development which meets the need of the present without compromising the ability of the future generations to meet their own needs"*.

Despite the widespread awareness, myths about sustainability persist that eventually hinder its achievement (Lemonick, 2009). One myth is that, sustainability is a synonym for *"green"*. *"Green"* is often preference for the natural over the artificial or being better in use of energy and/or resources (producing no or lesser GHG emissions) than the average. Thus, *"Greening"* is essentially a step towards sustainability. For example, a sustainable building has no net impact on environment and co-exists with world's ecological balance indefinitely, a green building is the *"..one that uses energy and material more effectively both in production and operation while polluting and damaging natural systems as little as possible"* (Straube, 2006). Also, contrary to a myth, sustainability is not all about environment or achieving a low-carbon economy by pursuing cleaner technologies and production, though these are integral factors to it. Social issues, personal issues, political issues and other economic issues (such as employment) are important as well for its achievement (Sterman, 2009). Climate change (GHG emissions issue) has attained its centrality and due prominence in sustainability discussions primarily after the publication of IPCC 3rd Assessment Report in 2001. For sustainable solutions, including equity and ethical issues are as important as climate change since *"climate change may destroy the society in few hundred years, ethical issues can destroy it in few years"* (IR3S Report, 2009). Reaching the UN Millennium Development Goals is therefore must to achieve true sustainability in global scale. In this review article, however, we use sustainability and green alternatively for easy understanding.

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Why Need a Business Case for Sustainability ?

A sustainable product/solution should satisfy the triple bottom line principles of environmental preservation, social responsibility and economic profitability. Until recently, businesses, the backbone of a consumer society, focused only on maximizing the economic profitability for their immediate stakeholders or shareholders, setting aside issues of environmental preservation and social responsibility as externals in their profit equation. Now, in order to get the *"social license to operate"* from increasing public concerns on sustainability issues, they have to prove their credibility on the first two principles. However, in a modern human society, a non-profitable or costly product/solution with traditional economic assessment would hardly be attractive to its stakeholders/customers even it is one that does all good to the society and environment. This is particularly important in light of another myth that sustainable products/solutions are expensive, because in order to satisfy the first two bottom line principles, they take a holistic approach to problems taking into account complex interconnections among relevant issues. With this myth, businesses and policy makers are in a dilemma and pressure to perform, which may lead to unwanted greenwashing activities to prove their green credentials. This argument in the myth may seem true when assessing the profitability/benefits of a product/solution with a short-term perspective using traditional economic assessments that fail to quantify and/or include the benefits (in hard numbers) from satisfying first two bottom line principles. A robust business case, that quantifies and includes all the costs and benefits involved in pursuing sustainability with different scenarios, therefore is key to widespread acceptance of a product/solution by all stakeholders in society.

For those in academia and scientific field, it is also important to present their proposed research, inventions, solutions and recommendations with a holistic viewpoint and with a business case in order to become attractive to businesses and policymakers thereby ensuring rapid value addition to society. In interdisciplinary directed researches, where absorption of a scientific product/solution in the society is high on the agenda, a sound business case and its effective presentation are must-have pre-requisites. In fact, in an increasingly interconnected world threatened with serious and rapidly deteriorating sustainability issues needing urgent attention, probably it would not be an overreaction to envision an academic and research environment where every proposed research project aims to produce a direct solution to a major sustainability issue or a well-defined part of it, and is accompanied with a business case that allows fast and efficient commercialization and/or implementation.

Requisites in Business Case for Sustainability

In a consumer society, business case is performed for a product or service taking into account the costs involved in producing/developing it and revenues gained by selling it. In not too distant past, corporations did not have to worry about paying for their GHG emissions that contributed to the warming of our planet, nor about using water and resources efficiently, and in many cases about paying for the air and water pollution caused by their operation. Also, they did not have to care about what happened at the upstream (supply-chain) or downstream (customer/client) of their businesses. However, when calculating the return on investment (ROI) for a sustainable product/solution, traditional models with narrow short-term focus and not putting appropriate price on intangibles may make it look like expensive. However, only after expanding the analysis to entire life cycle (cradle to grave) of a product/solution which takes a long-term view and ideally includes intangibles quantitatively into the cost and benefit (=increased revenue, when compared with average) analysis, ROI of a sustainable product/solution becomes complete. Figure 1 shows the major components that constitute the business case for a sustainable product/solution. Items on the right are generally quantifiable by traditional economic analysis and therefore a product/solution focused on these initiatives gets easiest sell in many organizations. Left side shows mostly intangibles, benefits from which are perceived but difficult to be expressed in hard numbers. For example, there are not enough studies quantifying benefits of pursuing corporate social responsibility efforts directed on these items. In figure 1, often an individual item has positive (or sometimes negative) feedback on another (feedback loops not shown in figure). For example, efficiency improvements listed on the right side will generally increase brand image of an organization listed on the left side. Likewise enhanced understanding of entire supply chain can help improve efficiencies further. Efficiencies on the right include improvements from better management & production practices and/or reduced consumption from improved employee awareness. The list in the figure is not exhaustive.

Green Building amd LEED® Assessment System

Greener buildings are key to sustainable development since we spend 90% of our time inside built environment and because the energy, water and other resources consumed during construction and utilization of the buildings in their entire lifespan is responsible for about 40% of CO_2 emission, 30% of solid waste generation and about 20% of water effluents, with use of about 40 % of energy, 20% of water and 10% of land-area (UNEP-SBCI, 2006).

Despite the potential huge gains in various efficiency improve-

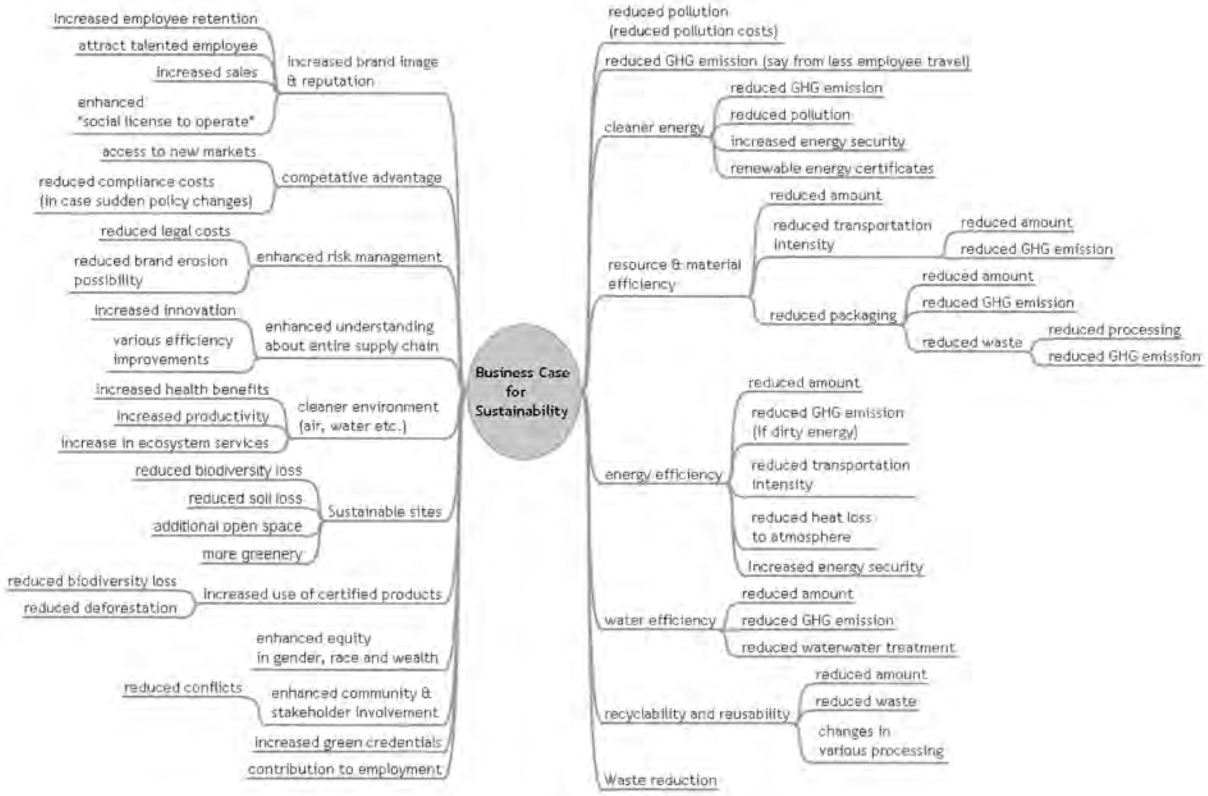

Figure 1. Benefits to be quantified and included in making business case for a sustainable product/solution. Items in the left are mostly intangibles while on the right are mostly quantifiable using traditional economic analysis.

ments with numerous *"low hanging fruit"* solutions and a green building movement in the west since 1970s from the oil shock, cost-effective green buildings based on a integrated whole building design approach were not able to generate widespread interest among stakeholders. However, unveiling of UK's Building Research Establishment Environmental Assessment Method (BREEAM®) building sustainability assessment system in 1990 and US Green Building Council (USGBC)'s Leadership in Energy and Environmental Design (LEED®) building sustainability assessment system in 1993 ushered in a new era by presenting the movement with a strong business case. USGBC's third party voluntary LEED® assessment system is briefly discussed here since despite starting later than and based on the BREEAM® (with a purpose to serve the US building sector), it has grown tremendously worldwide in past years setting example on how a good business case makes a sustainable product/solution attractive.

Sustainability with a Business Case by LEED®

The LEED® rating system promotes the whole-building approach to sustainability by measuring performance in key areas of (1) sustainable sites, (2) water efficiency, (3) energy & atmosphere, (4) material & resources, (5) indoor environmental quality, (6) design innovation, (7) location & linkages, and (8) regional priority. Last two aspects are incorporated in various forms in first 6 ones. Figure 2 shows how LEED® gives weight to the sustainability aspects.

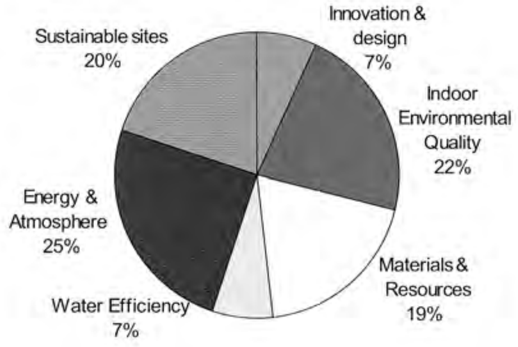

Figure 2. Break-up of points for different sustainability aspects in LEED® green buiding assessment system.

LEED® is probably not the best assessment system to assess sustainability features in a building and has many known discrepancies (Baruah *et al.*, 2008). However, its note-worthiness comes from the way it is generating action-oriented interests among stakeholders to make buildings greener, especially praise-worthy in a sector known for its significant inertia to change. Following factors has been instrumental in developing a strong business case for green buildings by LEED®.

1. The focus of greening in buildings till now has been mainly on energy efficiency in buildings. However, LEED® is

incorporating all major sustainability elements, not just energy efficiency, including intangibles like community development or biodiversity protection into the system (as subcategories).
2. An easy to follow point based system with graded certification levels. Simplifying assessment of complex sustainability issues may not be adequate for its purpose, but for wider adoption at a faster scale it definitely helps.
3. Third party assessment by certified assessors. This makes the assessment more legitimate than self-assessments by the developers. Also an organized assessor examination system with worldwide and year-round examination facility is providing required number of expert personnel. Anybody passing the exams can be technically an assessor and certification point can be earned by having a certified assessor in development/design team.
4. Customized and flexible individual assessment systems for different types of buildings, i.e. commercial buildings, residential buildings, commercial interiors etc. This helps to identify additional hidden benefits.
5. Extensive promotion about ROI and various benefits of green buildings by working with stakeholders by publishing relevant information and independent studies. Providing or facilitating research grants to carry out studies on technology innovation and cost benefits.
6. Flexible points for innovation that can be applied and gained for multiple projects.
7. Networking and promotion by opening local and country chapters.
8. Accurate, up-to-date and informative webpage with prompt support. Fully online and systematic registration and certification system.

Overall cost premiums for green buildings were found to be 2 %, ranging from 0.7% to 11.5% for various levels of certification. The payback period for existing buildings was found to be between 3–6 years (Nelson *et al.*, 2007). To prove the impact of its business case, Watson *et al.* (2008) reported that, LEED® registrations and certifications doubled in 2008 than previous 7 years with few individual systems growing upto 20 fold in last 2 years. LEED® buildings are found to save 25–30% energy than average commercial buildings. Overall, LEED® buildings reduced 7 million tones of CO_2 by 2008 reaching 700 million tones by 2020. It is spurring a $10 billion green material market in 2008 and increasing employee productivity valued at $120 million (high estimate) in 2008. LEED® certified buildings are also found to have higher occupancy levels and rents per square feet even during this economic downturn.

Other Issues of Interest to Business Case for Sustainability

Several other issues and factors need to be considered and may be helpful when making the business case for sustainability. These are as follows:

1. Though sustainability is high on everyone's agenda, functionality and design (aesthetic) of a product/solution must be at par while it satisfies the triple bottom line principles. People think about sustainability issues only after functionality, price and design expectations are satisfied; exception may be LOHAS customers.
2. To build a business case for sustainability effectively, an organization may approach sustainability in four steps outlined by McNamus (2009). The incremental steps are, awareness though symbolic actions, greening facilities, greening operations (in corporations, across the entire supply-chain) and finally greener products/solutions (in entire life-cycle).
3. Sustainable products or solutions which are unattractive financially in short term should target key sectors with strong sustainability and profitability image (e.g. clean energy sector) and *"low hanging fruits"* solutions to maximize benefit in short-term and generate stakeholder interests.
4. Policies and new technologies may change prices and incentives overnight. Scenarios including positive trends in policy change (such as higher prices of carbon, pollution and/or water) and new innovative technologies (e.g. a new competitive solar PV technology) will benefit the business case and drive interests from stakeholders.
5. Cultural, regional and country-specific considerations and information are essential for a suitable business case.

Concluding Remarks

Making a good business case showing relevant benefits and costs is crucial for success of every product/solution, particularly so in sustainable ones, since that would add tremendous value to society by getting the product/solution commercialized, implemented and absorbed faster and effectively. An integrated, holistic, life-cycle based and longer-term approach, including the benefits of intangibles in hard numbers or by showing their direct relationships with well-being elements, is the basis of making a business case for a sustainable solution/product. Green building assessment systems, such as LEED®, are creating greater awareness and market involvement by putting forward a strong business case based on these approaches. In a business case for sustainability, putting emphasis on items that need society's increased attention, such as prices of carbon, pollution and water would help add value to society and help us move faster towards achieving a sustainable society.

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GREEN BUILDINGS:
CURRENT STATUS AND PROSPECTS

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ABSTRACT

With global warming becoming mainstream policy issue for governments and businesses alike due to increasing public awareness about environment, buildings are coming under focus for their large carbon emission and use of humongous amount of energy, water and material both during construction and utilization phase. "Greening" of real-estate, which started a decade earlier in several developed countries, is gaining momentum and moving into new frontiers as developed countries are acting towards low-carbon economy and emerging economies are urbanizing rapidly amid sustainability concerns. In this paper, we review current trends in embracing green buildings and how different factors, such as, green-building rating-systems worldwide are shaping the movement in various countries. Based on findings from other studies, we discuss how higher energy costs, greater environmental concern and innovations in technologies (such as in IT) will give positive dynamics to green building market for achieving lesser environmental impact.

1. INTRODUCTION

According to 4th Assessment Report of IPCC (IPCC, 2007), it is 'very likely'(>90% likelihood) that global warming of about 0.6^0C over the past century is due to anthropogenic increase of green house gases (GHG), mainly CO_2. Since 1970 to 2004, commercial and residential buildings constitute about 8% of the total anthropogenic GHG emissions in CO_2 equivalent (IPCC, 2007). Considering the energy, water and other resources consumed during construction and utilization of the buildings in their entire lifespan, built environment is responsible for about 40% of CO_2 emission, 30% of solid waste generation and about 20% of water effluents. In terms of resources used, about 40% of energy, 20% of water and 10% of land-area are used by the building and construction sector (UNEP-SBCI, 2006). This makes it a key sector and a "key factor for sustainable development" with its immense benefits to the society and at the same time associated negative impacts without appropriate attention (UNEP-SBCI, 2006). Additionally, as numerous studies have found, indoor air quality and energy efficiency in buildings are key factors of health of the inhabitants. Now, with increasing public awareness about environment as a result of globalization and internet, governments and businesses alike are putting increasing focus on the real-estate sector to reduce CO2 emission for mitigation of climate change. The sector is becoming important from another dimension in context of successful mitigation of climate change and sustainability - the future of the world is urban, with about 60% of human population (~5 billion) projected to live in cities by 2030 from 50% (~3.2 billion) in 2005 (Deutche Bank Research, 2008), and mostly in developing countries. Also, "greening" of building sector is gaining momentum particularly from the fact that, it presents it with several "long hanging fruit" solutions to reduce GHG emissions and increase energy efficiency with minimal or sometimes negative costs.

This review paper discusses the essentials of a green building, green building rating systems around the world, key factors effecting its development along with current and future trends of green building market. Based on currently available studies, a qualitative outlook of the future of green buildings in emerging economies is also presented.

2. WHAT IS GREEN BUILDING

Although the terms "sustainable building" and "green building" are often used interchangeably in activities such as advertisements and speeches, they are fundamentally different. This shows the poor understanding of the concept of sustainability among different stakeholders and highlights the fact how some entities in society are using these terms for "green-washing" to profit from increased public interest in environmental issues.

Based on the UN Brundtland Commission Report, which popularized and defined the concept of sustainable development as "*..the development which meets the need of the present without compromising the ability of the future generations to meet their own needs*", a sustainable building can be defined as the"*…one that can be produced and continue to be produced over the long term without adversely affecting the natural environment necessary to support human activities in the future*". On the other hand, green building can be stated as the "*..one that uses energy and material more effectively both in production and operation while polluting and damaging natural systems as little as possible*". (Straube, 2006). Therefore, while a sustainable building has no net impact in environment and co-exists with world's ecological balance indefinitely, a green building "*focuses on incremental steps to solve known and measurable problems with our current practice*"(Building Science, 2008).

Based on present environmental & sustainability concerns, available technology and knowledge of linkages between different systems on earth (i.e. social, economical, environmental), green building is a step towards a sustainable society by being significantly better than similar, or average, building of same size and type in the same location by reducing the overall impact of the built environment on human health and the natural environment in following areas:

- ♦ Landuse
- ♦ Material and Resources Efficiency
- ♦ Design and Delivery Process
- ♦ Energy Efficiency
- ♦ Global Ecological Impact
- ♦ Durability

- Social Transformation
- Water Resources Management
- Community Development
- Indoor environmental Quality
- Affordability
- Transport

3. GREEN BUILDING MOVEMENT

Brief History

Several ancient societies practiced principles of geomacy which has similar attributes to present green buildings. The Chinese used *Fengshui*, which comprises of broad spectrum of theories regarding selection of a location, layout of buildings etc. Indian geomacy principles in *Vastu Shastra* laid out criteria for layout and planning of buildings to influence the peace and prosperity of its inhabitants. Both of these guidelines use principles of astronomy, and incorporate energy and environment in their practices. Ancient Greeks used passive solar heating techniques to build entire cities to receive solar heat in winter (US-EPA, 2008).

Although green building features described above has been incorporated collectively or in isolation through centuries in various parts of the world, modern green building movement started in western developed economies in around 1970s out of interests in improving energy efficiency due to oil crisis and environmental movements. In 1990s, the movement gained momentum with the UN Earth Summit, Rio de Jeneiro in 1992 passing Agenda 21 for sustainable development, release of UK’s and world’s first building environment assessment system BREEAM in 1990, US Department of Energy’s Energy Star Program in 1992 and formation of US Green Building Council (USGBC) in 1993. Recent years have seen sudden upsurge in interest among buyers, developers, builders and governments across the world (including emerging economies) to build green buildings voluntarily or through mandated programs.

Present status

With global warming becoming a central issue for businesses and governments in recent years, green building movement is gaining momentum in developed economies, notably in USA, EU, and Japan.

According to Martin et al. (2007), green building movement in USA is nearing a tipping point with tremendous growth seen in non-residential market. In 2004, non-residential market accounted for about 2% of the US market (about $ 3.3 billion), which is growing and forecasted to be about $10-20 billion in 2010. McGraw-Hill Construction suggests residential green building market to grow to $19 to $38 billion by 2010 from $7.2 billion in 2005. Without any market measure on green building development, growth in certified buildings by building certification systems are quoted often in reports. The report said that, value of newly constructed registered buildings by USGBC’s LEED certification system has grown from $792 million to $10 billion in 2006. Another summary from USGBC (Green Buildings, 2008), states the annual market for green building in products and services to be $12 billion. Number of certified homes by US-EPA Energy Star are increasing at rapid rate and value of such homes stands at $26 billion in 2005. In early 2008, National Association of Home Builders (NAHB) has launched the voluntary NAHB National Green Building Program, which is seen to compete aggressively with LEED rating system.

Though USA does not have national green building policies with mandates, several states are adopting mandates for greener buildings. Notable among them are state of California and Washington D.C. From beginning of 2009, California non-residential buildings would require energy-use reporting, and from beginning of 2010 commercial buildings would have to report on their energy-use and Energy-Star certification status to potential buyers and leasers (Building Green, Sep.16, 2008). Washington D.C. will require the city buildings to benchmarked annually starting in 2009 with annual benchmarking for private buildings to be done between 2010 and 2013 (Building Green, Sep.1, 2008).

In EU, the Energy Performance of Buildings Directive (EPBD), based on 1993 ‘SAVE’ Directive on energy efficiency, came into effect in January 2006. EPBD provides a common methodology for calculating energy performance and setting energy performance standards of buildings (in both new and existing) in individual member states. It is estimated that, with proper implementation of EPBD, 11% reduction in oil consumption can be achieved in 2020 (EurActive, Sep 15, 2008). However, progress is reported to be slow with only Denmark, Germany and Austria fully complying with the EPBD and other states lagging behind (EurActive, Apr 26, 2008). In EU-wide effort for greener buildings, Germany proposed mandatory energy efficiency labeling for buildings and apartments in April, 2007 (Reuter, Apr 20, 2007). At present, UK does not have a single plan of action on green building. However, variety of policies, regulations, performance standards, guidance documents and voluntary initiatives by numerous organizations are available. UK Building Research Establishment (BRE)’s voluntary rating system BREEAM and USGBC’s LEED are increasingly being embraced by businesses.

In Japan, energy efficiency has been a core national policy due to its lack of natural resources and as a strategy for energy security since the oil shock of 1970s. Surprisingly, there is no government policy to promote efficiency exclusively in the building sector where about 25% of total energy is used for space heating and cooling of buildings. Energy consumption in commercial buildings in Japan is about 8% of world energy consumption in such places (European Business Council Japan, Jul 2008). However, under Energy Conservation Law, 1979 (amended 1999), voluntary energy saving labeling programs for home appliances exist and mandatory reporting of energy conservation measures in buildings over 2000 m^2 floor space were introduced in 2003 and tightened in April 2006. Statistics shows that compliance rate is increasing, from 34 % in 1999 to 74% in commercial buildings, and is likely to increase in future (Hong et al., 2007). In 2004, Japan Sustainable Building Consortium (JSBC) introduced the voluntary CASBEE green building rating system to assess the environmental efficiency of buildings, popularity of which is increasing among government and industry as well as in other Asian countries.

Elsewhere in developing economies, China and India, two emerging giants are slowly but seriously adopting green buildings as their population rapidly urbanize and real-estate sector is growing at a blazing speed. Currently, China's buildings consume about 18% of total energy and projected to reach 40% by 2030 when the urban population reaches 1 billion (Howard et al., 2007). China's Ministry of Construction (MOC) has unveiled "Evaluation Standard for Green Building", which took effect on June 1, 2006 and is similar to USGBC's LEED rating system. Rating systems such as LEED and CASBEE are being increasingly adopted for upcoming projects. For a greener Summer Olympics 2008, China used Tsinghua University's Green Olympic Building Assessment System (GOBAS), which is based on CASBEE.

In India, building energy consumes about 33% of total energy in 2005. Integrate Energy Policy unveiled in 2006 identifies 10 key areas for efficiency improvement, half of which relate to building sector. For Investments above $11.6 million, developers need clearances from government before construction in terms of environmental impact assessment. There is no national mandatory green building related program. Recently, there is growing interest in USGBC-LEED rating system promoted by Indian Green Building Council (IGBC). Bureau of Energy Efficiency (BEE) is working on to mandate energy audit of buildings and Ministry of New and Renewable Energy Sources (MNRE) is planning to develop a voluntary green building rating system with an incentive mechanism (Hong et al., 2007).

Factors driving green building movement

Nelson (2007) and Martin et al (2007) cite several factors driving investments in and demand of green buildings in US. However, most of these factors are also working in other parts of the world in varying mix and degrees. According to Martin et al. (2007), several studies have found that, a particular class of tenants are interested and creating demand of green buildings at present. They are referred as *LOHAS customers, Creatives* or *True Blue Greens* who are well-educated & wealthier than average, and well-aware of key environmental issues such as climate change.

Next, governments are playing increasingly active role due to realization of the benefits of pursuing green building programs in context of rising energy prices and tackling mitigation of climate change through minimal costs. They are moving forward by formalizing new regulations, raising awareness and through tenancy by setting standards for building it sets for its own occupancy. In countries like China, where government has a strong influencing power on businesses by virtue of the political system will possibly be the biggest driver in setting the movement in the right and faster path.

Third, due to increasing environmental awareness among general public, companies are responding by taking environmental action and being "green". Moving to green facilities is providing them with greater credibility on their greening commitment to stay ahead of the pack. At the same time, builders and developers are realizing this necessity to green-up to prove their socially responsible character and at the same time retain competitive advantage by moving before being pushed by governments through new regulations. Investors are realizing that "future of building is green" and finding a new socially responsible investing (SRI) opportunity in a lucrative sector. With recent worldwide downturn in conventional real-estate market, green buildings are also getting new investors due to their positive returns and increasing market.

Last but not the least, professional and international organizations like USBGC and UNEP-SBCI are playing an active role by creating awareness of the opportunities, serving necessary professional information, creating quantitative assessment systems and presenting the movement with a business case. Especially, the green building assessment systems are paving ways for both public and corporate policymaking. Also, they are motivating innovation across builders as well as suppliers of materials and by providing summaries of building performance which are helping to create demand through awareness (Cole et al., 2005)

4. GREEN BUILDING ASSESSMENT SYSTEMS

Green building assessment systems provide effective framework for assessment of building environmental performance quantitatively to be presented in terms of indicators which are easy to understand. It can integrate the complex concept of sustainable development effectively into building and construction process. Conventionally, buildings are designed to meet building code requirements. Green building assessment systems go beyond the code to incorporate various elements concerning sustainability to improve overall building performance and minimize life-cycle environmental impact and cost (Gowri, 2004).

Assessment tools developed till date may be classified into two categories. First category is based on a purely criteria based system assigning point values to a selected number of parameters on a scale. BREEAM (UK), LEED (USA) and Green Stars (Australia) are some examples of this category. Second group of tools are based on life cycle assessment (LCA) methodology employing "cradle to grave" assessment approach to the inputs in order to evaluate (mainly) environmental impacts from key outputs. Example of such tools are BEES (USA), Beat (Denmark), ECO QUANTUM (Netherlands), ECO-PRO (Germany), EQUER(France) etc. (Larsson et al., 2001; Hikmat, 2008). Table 1 lists the major green building assessment systems from different countries/organizations.

Most assessment system's primary focus is on energy efficiency, resource efficiency, indoor air environment, water resources management and sustainable site selection. Among the rating systems in Table 1, those getting wider recognition worldwide are BREEAM, LEED, CASBEE, GreenStar, and GBTool. We discuss in brief the first three rating systems below.

Table 1: Major green building assessment systems.

Country	Assessment tool
UK	♦BRE Environmental Assessment Method (BREEAM) ♦Environmental Estimator (ENVEST)
USA	♦USGBC Leadership in Energy and Environmental Design (LEED) ♦NAHB National Green Building Standard ♦US-EPA Energy Star for New Homes ♦DOE Building America ♦Building Environment and Economical Sustainability (BEES)
Canada	♦Green Building Tool (GB Tool) ♦Green Globes CEE & EEC ♦LEED-Canada ♦BREEAM-Canada
Australia	♦Green Star AGBC ♦National Building Environment Rating Scheme (NABERS)
Germany	♦German Ministry of Transport, Construction, and Urban Development (DGNB) Sustainable Building Certificate
Netherlands	♦BREEAM-Netherlands ♦Eco Quantum
Japan	♦JSBC Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)
Korea	♦Korea Green Building Label
Singapore	♦Building and Construction Authority (BCA) Green Mark
Hong Kong	♦Hong Kong Building Environment Assessment Method (HK-BEAM)
China	♦China Green Building Standard ♦Green Olympic Building Assessment System (GOBAS)
India	♦LEED-India, 2007 ♦The Energy and Resources Institute GRIHA (TERI-GRIHA)
Brazil	♦LEED-Brazil ♦AQUA

BREEAM is the first green building rating tool in the world, developed by Building Research Establishment (BRE) and private sector researchers of UK in 1990. It is a voluntary assessment system. Recently, a tougher version of the system has been released in 2008, emphasizing more on energy efficiency and requiring mandatory credits. The system is recognized by UK building industry and is being adopted in Canada, Australia, India and EU countries.

USSBGC developed the voluntary LEED rating system in 1998 with a market-driven strategy to accelerate adoption of green building practices (Bowri, 2004). It was inspired by BREEAM to serve the building community in US. Originally developed for new commercial buildings (LEED-NC), LEED has gone through major update in 2003 and now several versions, such as, LEED for Homes, LEED for Existing Buildings (EB), LEED for Core and Shell (CS), LEED for Commercial Interiors, LEED for School, Healthcare & Retail and LEED for Neighborhood development. According to USGBC, the system will have a major overhaul in early 2009. In the new version, points will be allocated differently and reweighed, and the entire process will be flexible to adapt to changing technology, account for regional differences and encourage innovation. Over the years, LEED has gained immense popularity around the world with the system being adopted in countries like Canada, UK, Brazil, China, India and Middle-East. Green Building (2008) reported that, nearly 4 billion commercial building space is being registered or certified by LEED rating system with projects in 69 countries and 57,400+ accreditated professionals. Figure 1 below gives a comparison between LEED-NC and BREEAM 2008 in credit weightage given to different green building features (Greenworkplace, Aug 11, 2008).

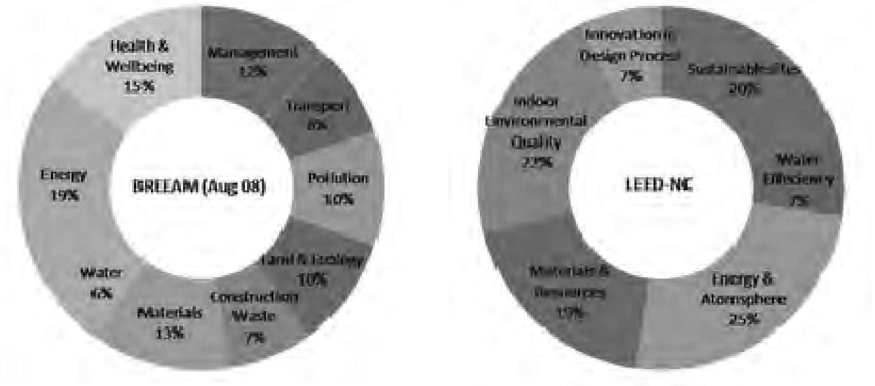

Figure 1: Comparison of LEED-NC and BREEAM 2008 weights
(*source & copyright: Greenworkplace, Aug 11, 2008*)

Japan Green Building Council (JGBC) unveiled the CASBEE rating system for new construction in 2004. It has four integrated tools on building life-cycle: pre-design tool for owners and planners, design tool for architects and engineers, environmental labeling tool for labeling body and sustainable operation and renovation tool for owners and caretakers. Noteworthy difference with LEED and BREEAM is that it re-categorizes the positive building attributes to a Quality (Q) category and negative attributes as loading (L) category to estimate a Building Environmental Efficiency (BEE) index as Q/L. The concept has gained popularity because it can provide trade-off between environmental loadings and quality of space provided. Based on Q/L value ranking is given to a building's sustainability. Table 2 lists the rating categories available in BREEAM, LEED and CASBEE.

Table 2 : Rating categories in BREEAM, LEED and CASBEE

BREEAM	LEED	CASBEE
Excellent	Platinum	S
Very Good	Gold	A
Good	Silver	B+
Pass	Certified	B-
		C

Despite their positive influence on different stakeholders in the movement, green building assessment tools such as LEED or BREEAM are criticized for their lack of assessment scope post-construction. Critics argue that, these systems award points based on design features pre-construction which may not be constructed properly as designed (such as sealing tightness in windows). Additionally, simulated usage pattern of resources, such as energy or water, during design phase may be drastically different during utilization. Certification not before but after construction, and based on few years of energy & resources utilization data, is often recommended. Others point out the necessity of integrating LCA-based analysis into the systems. Also, caution is advised before using a foreign system in local conditions, as a system developed for a certain country may not produce expected performance when applied in another country due to differences in climatic, economic and cultural conditions. Both LEED and BREEAM are addressing these issues in their latest and coming versions.

5. COSTS AND BENEFITS OF GREEN BUILDINGS

Green buildings are often cited to incur higher cost, which is proved as a misconception by several recent studies. According to Nelson (2007), examination of 33 LEED office and school buildings in 2003 by a consultant firm Capita E Analysis found that, overall cost premium for green buildings to be about 2%, averaging 0.7% for the LEED-certified buildings, 2.1% for the LEED-Silver, 1.8% for the LEED-Gold, and 6.5% for the LEED-Platinum building. The study also found that, cost premiums declined as regional experience in green building increased. Another comprehensive 2005 study by engineering firm Morrison Hersh field-reviewed four U.S. studies and estimated construction cost premium required to meet different levels of LEED certification. Their result showed cost premiums averaged only 0.8% for the LEED certified buildings, 3.5% for the LEED-Silver, and 4.5% for the LEED-Gold and jumped to 11.5% for LEED-Platinum buildings. There is increasing consensus among green building developers that, with careful planning and integrated design of the sustainable concepts, the cost premium can indeed be minimal to non-existent (Nelson, 2007).

The benefits of green building can come from energy and water savings, reduced waste, improved indoor environmental quality, increased comfort/productivity, reduced employee health costs and lower operation and maintenance costs (Kats, 2003). According to USGBC, LEED-certified buildings are 25-30% more energy efficient and more likely to generate renewable energy. Another study by Co Star group in 2008, found that, Energy-star and LEED-certified buildings has higher occupancy rate, higher rental rate and higher sale price per square feet when compared with conventional buildings. For existing buildings, studies have found that payback period for various green retro-fitting should be between 3 to 6 years (Nelson, 2007).

6. FUTURE DIRECTIONS

All trends clearly show that, green building movement worldwide is picking up momentum. Start of various green building programs in key future growth countries such as China, planning of mandated green building program in India, release of newer version of BREEAM system and the coming version of LEED in 2009 are fewer examples to indicate tremendous growth ahead for green buildings as an industry. Many have said year 2007 to be the tipping point for green building construction. By aggressive estimates, annual LEED-NC and CS combined is expected to reach about 200 million square foot from about 30 million square foot in 2006 (Nelson, 2007). Launching of UNEP-SBCI in 2006 and United Nation Framework Convention on Climate Change (UNFCCC)'s decision to prioritize building sector in coming Conference of Parties (COP)-14 in December 2008 in Poland will also accelerate awareness about greener buildings among different stakeholders. Additionally, increasing emphasis on localized renewable energy generation and current rapid growth of other clean-tech sectors are likely to give boost to the sector. Deployment of innovative, cheap and energy efficient technologies such as Light Emitting Diode (LED) providing clean bright light will likely give great impetus to the movement and will be key to bring the movement successfully to lower income countries. Last but not the least, with proper planning and active participation of relevant stakeholders, the potential-laden Information and Communication Technology (ICT) sector can provide added efficiency by its "enabling effect". The recent SMART2020 (2008) report has shown that, through deployment of proper ICT, buildings can significantly save energy consumption and reduce GHG emission to an extent of 15% in 2020. To achieve this potential, the report outlined measures such as, intelligent lighting and HVAC (Heating, Ventilation, Air-conditioning), voltage optimization, installation of ICT-based BMS (Building Management System) and smart grids.

7. CONCLUSION

With importance in immediate action for climate change mitigation, depleting natural resources and increasing energy cost, green buildings are poised to be the future of building and construction industry. Green buildings are right step towards sustainable low carbon society providing added benefits of health and comfort achieved at minimal or negative costs to the users. Assessment systems for green building are proving to be useful framework to achieve the intended goals while presenting it with a business case. Coming years are likely to see explosive growth in green building investment across the world with more government mandates and increasing public interest. In coming years, innovative and cost-effective technologies as well as incorporation of existing technologies in smart ways will be the key to increase the energy efficiency and GHG reduction potential of green buildings.

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Effects of Water Screen system in compartments

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The importance of fire safety with regard to the use of underground spaces has been increasing since the “Special Measures Act for Public Use of Deep Underground” was enforced. Fire experiments were conducted by using 1/2 scale models to study a compartment system using Water Screens (WS) and to understand the performance of this system.

In WS experiments carried out using the 1/2 scale model with a compartment length of 50m, the ceiling temperature and the radiation receiving calorie showed about an 80% decrease regardless of the heat release rate and the wind velocity. Under a condition, the generated gas concentration showed about a 40% decrease and the heat release rate showed about a 30% decrease owing to the presence of WS. It can be thought that thermal properties outside the compartment are attenuated and combustion is controlled by the WS.

1. INTRODUCTION

With the adoption of utilization methods for deep underground spaces and the development of urban renewal, underground spaces have created new potential with regard to areas that can be utilized by society. Therefore, technical know-how to ensure the safety of occupants in the case of the occurrence of accidents, as well as that dealing with the controlling of accidents is required.

It is also very important under the assumption of the occurrence of underground disasters to maintain “the structural fire safety” by restraining the spread and expansion of a fire or by cooling the structures and to ensure “the safety for evacuation” by isolating occupants from heat, smoke and poisonous gas and guiding them to safe places.

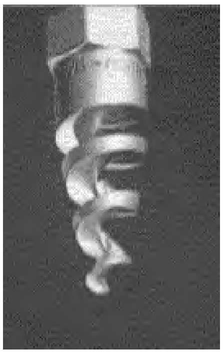

Photo. 1
Spiral Head

With regard to the safety design methodology for fires in underground spaces, a number of data were accumulated through investigations and experiments in the “Studies on fire safety design methodology for underground tunnels” carried out (Oct., 1994~Mar., 1999) in partnership with the National Research Institute of Fire and Disaster.

In 2000, technological investigations into the “Compartment technology for fire zones using water screens” started and in 2001 this WS technology was authorized by the Minister of Land, Infrastructure and Transport first in Japan on the basis of its performance evaluation as specific fire prevention equipment in the architectural field.

This technology creates water screens by spraying water from spiral heads (**Photo.1**) arranged in lines at positions which form compartments.

This system for preventing fire disasters can not only ensure the safety of occupants by restraining the diffusion of heat and smoke using water screens to compartment a fire zone as well as by seizing and washing out poisonous particles but it can also minimize the thermal damage to structures.

The compartmenting is a concept for preventing the diffusion of fire induced heat and smoke in an entire space by confining them in certain fixed regions. It has been applied to fireproof steel shutters, fireproof sheets and air curtains. However, there are cases where the compartments for the fireproof shutters and sheets can not be satisfactorily completed due to the damage caused by falling objects. Furthermore, there are problems impeding safe evacuation. Namely, with an increase in the temperature in the compartment, the equipment is distorted by intense heat and the handles of the shutters are heated. With regard to air curtains, it is pointed out that there is a problem where ventilation equipment is large and accordingly, it is difficult to control them. These problems are difficult to solve for the large sections and complicated shapes of underground tunnel spaces containing railways and roads.

With this as a background, studies on the applicability of a new fire disaster prevention system “Water Screen Fire Disaster Prevention System” to railways and road tunnels constructed in deep underground spaces were carried out. .

In November 2002, the 1st fire experiment using a model of a road tunnel was carried and the validity of this system was confirmed (1)~(3). In order to quantitatively understand the compartmenting effects of water screens (hereafter referred to as WS) based on the results of the 1st experiment, the 2nd tunnel model fire experiment was conducted in 2003 in partnership with the National Research Institute of Fire and Disaster. This paper describes the details and the results of the 2nd tunnel model fire experiment.

2. DESCRIPTION OF AN EXPERIMENTAL METHOD FOR MEASURING PHYSICAL EFFECT OF WATER SCREENS IN A SMALL SCALE MODEL

Under the condition that it is difficult to apply past compartment technology to transport spaces, preparatory experiments for the efficiency of the WS as a new compartment technology for practical fire prevention was carried out. The validity of the experiment method for maintaining and understanding the efficiency of this compartment technology was confirmed. In the previous paper (1)~(5), the effects of WS obtained from the experiments for the 1/2 scale model with a longitudinal length of 18.2m using n-heptane as fire source fuel were reported on. Due to the fact that the separation between fire source and WS was too short to realize the effects of the WS on an actual tunnel accurately, the experiment results showed that the WS and the fire source were highly influenced by each other. Therefore, in the experiments for the new system carried out in order to quantitatively understand the following items ①,②,③.

① Understanding of the WS behavior with ventilation
② Understanding of the effects of the WS with regard to seizing CO,CO_2
③ Understanding of the conditions inside of the compartment

The length of the model was extended with consideration to 50m being the compartment length for an actual tunnel corresponding to the road standard 1st type AA class. Tunnels for the exclusive use of cars in Japan are classified into five categories from AA to D depending on the length of the tunnel and the traffic volume as shown in **Fig.1**. The official specifications for the installation of emergency equipment have been established for each category.

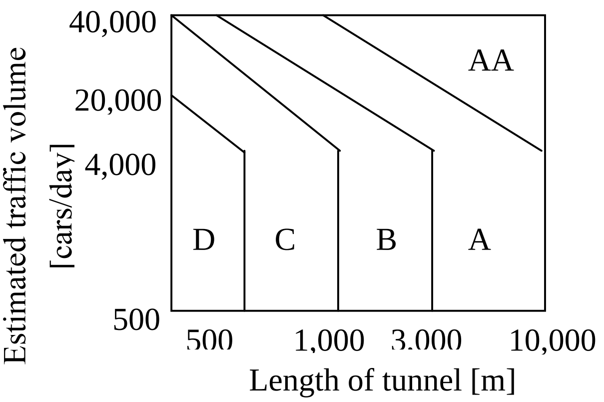

Fig.1 Road Tunnel Standard

3. DESCRIPTION OF THE EXPERIMENT ITSELF

3.1 Period

From June 30, 2003 through July 11, 2003

3.2 Place

The fire test center of the Hochiki Corporation in Kakuda City, Miyagi Prefecture

3.3 Model

A tunnel space with a rectangular-shaped section having a height of 2.7m(=H), a wide of 5.4m(=W) and a length of 43.7m was used as a model. It was made by connecting movable units composed of steel frames and calcium silicate plates. Parts surrounding the fire source were equipped with fireproof panels in order to protect them from unfavorable conditions such as high temperature and water spray. Furthermore, fireproof glass observation windows were installed at four locations in the wall side near the fire source and the WS. **Photo.2** shows the general view of the model. The air was pumped from the right side of the model shown in this photo toward the left side during a period of forced ventilation.

Photo.2 General view of model

3.4 Attachments

Fig.2 shows the locations where attachments and main measuring instruments were installed. The outlines of these attachments are described below.

●WS: The specifications of each head are as follows:

Water pressure: 1.0MPa, Mean particle diameter: 200 μ m, discharge rate of sprayed water: 10liter/min, Spraying angle: 150° ~170°

As shown in **Fig.2**, two lines of 1.6m separations were arranged for installing heads 12.5m away from the fire source. 5~6 heads were installed on each line in a zigzag pattern at intervals of 1.0m. The total discharge rate of water sprayed from the 11 heads on one side was 110liter/min. The WS at both ends of the 1/2 scale model created a fire prevention compartment with a longitudinal length of about 25m(=2L) (with consideration to 50m being the compartment in an actual tunnel space). **Photo.3** shows the interior conditions of the model before the WS were activated and **Photo.4** shows those after the WS were activated.

Photo.3 Interior conditions
(Before WS are activated)

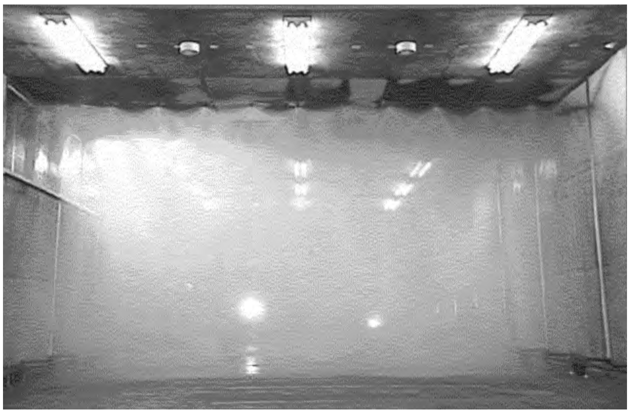

Photo.4 Interior conditions
(After WS are activated)

●Water sprayer: The specifications of each head are as follows:

Water pressure: 0.34MPa, Mean particle diameter: 500 μ m, discharge rate of sprayed water: 140liter/min, Spraying angle: 100° ~110°

In the experiments, water sprayers were installed at a different angle for each at two places from which water was not sprayed directly on the fire source from the viewpoint of comparing the effect of the WS with that of the water sprayer. The water-supply piping for the water sprayer was set up as a separate system from that for the WS so as to work independently without any connection to the WS.

●Smoke exhaust duct: In order to understand the behavior of high temperature smoke generated, hoods for exhausting smoke were installed at the upper parts of both ends of the model and rectangular ducts (1m×1m) with a plate thickness of about 1mm were used.

●Smoke exhaust fan: Exhaust fans (rated quantity of flow: 30,000CMH) were installed at the ends of the ducts.

●Equipment generating wind velocity: 20 fans for industrial use were distributed at a position 2m away from the model end on the air-supply side. Preparatory measurements for equalizing the sectional wind velocity at the position where the fire source was placed were carried out in order to adjust the number of activated fans and the locations for arranging them.

●Washing out of soot and smoke:

① Soot recovery measurement using a collection pan for sprayed water

The recovered soot particles contained in the water sprayed from the WS was analyzed using a drying method for five liter samples collected in two polyethylene vessels after collecting the water in the pan.

② Soot collection using a cylindrical filter paper

The collection soot contained in the high temperature smoke layer induced by a fire was measured using a cylindrical filter paper based on the method for measuring the dust density in exhaust gas.

③ Measurement of optical density of smoke using a dimming smoke density meter

The optical density of flowing smoke was measured using a dimming smoke density meter fitted to the duct used for sampling.

3.5 Other measurements and observations

Table.1 shows the outline of measurements (items, subjects, apparatuses, places and the number of points for measurements).

The heat release rate which is the fundamental quantity in the case of a fire was obtained using the oxygen consumption method and the weight conversion method in the experiments. For the purpose of understanding the effect of the WS on the removal of soot produced during a fire, a duct was installed at the end of the opening of the model and the behavior of the soot in the high temperature smoke was studied. Furthermore, in order to understand the combustion conditions of the fire source, the water sprayed from the WS and the flow of smoke as well as to observe the behavior of the fire source and to plan a direction for evacuation in cases of taking refuge or fighting a fire, observations were carried out using video cameras and thermo-cameras.

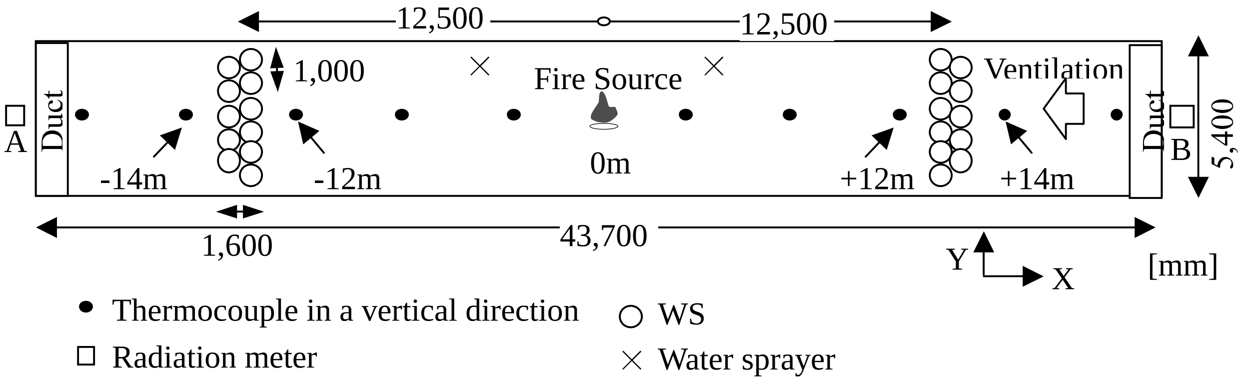

Fig.2 Model outline

Table.1 Measurement outline

Measurement	Subjects	Apparatuses	Measurements (the number of measurement points)
Temperature	Temperature profile near the ceiling	Sheath type thermocouple	18 places (Y=0.0,Z=2.65) @2m from X=0.0 (18 points)
	Vertical temperature profile	K-type thermocouple	8 points at intervals of @0.3m at one place from Z=0.6m 10 points at 10 places @3.5~4.0m from ×X=0.0 (80 points)
	Temperature profile near the fire source	K-type thermocouple	0.1m mesh above the fire source in Y 0.9m×Z 1.7m (97 points)
	External temperature	K-type thermocouple	An unaffected position 5m away from the model (1 point)
	Internal temperature of a hood	K-type thermocouple	Center of the entrance section of the hood on the exhaust side (1 point)
	Internal temperature of a duct	K-type thermocouple	Center of the section of the horizontal part of the duct (1 point)
Wind velocity	Establishment of sectional wind velocity	Hot-wire anemometer	Measurements were taken before the burning test to establish sectional wind velocity (6 points)
Wind pressure	Wind velocity for experiments	2-direction tube	At X=-10.0m @0.2~0.7 from Z=0.7m (6 points)
Heat flux	Heat flux	Medtherm	Near the fire source (5 points)
Radiation	Radiation	RE-4type (by Tokyo Seiko)	X=±25.0m, Y=00m, Z=1.2m (2 points)
Fuel Weight	Variation in fuel weight	Load cell for 1kN	Under the fire source plate (1 point representing a total of 3 points)
Gas concentration	O2 concentration	BMG-110 (by Best Sokki)	Center of the section of the horizontal part of the duct (1 point)
	CO,CO_2 concentration	CGT-7000 (by Shimadzu)	Center of the section of the horizontal part of the duct (1 point)

Table.1 Measurement outline

Measurement	Subjects	Apparatuses	Measurements (the number of measurement points)
Humidity	Humidity of gas	Vaisala	Center of the section of the horizontal part of the duct (1 point), A point in the WS compartment (1 point)
Smoke density	Variation in smoke density in test site, compartment, duct	Dimming smoke densitometer	X=-5.8,-8.8, Y=0.0, Z=0.79 in the compartment, Center of the section of the horizontal part of the duct (3 points in all), Ends of the test site
Quantity of soot washed out by water	Collection of soot near WS and in duct	Dust sampler, Water sprinkling measure	-2m~6m with the WS compartment as a center, Center of the section of the horizontal part of the duct (1 point)
・Directions X, Y and Z: The center of the fire source was set as X=0.0. The air supply side was set as + and the air exhaust side was set as -. ・Direction Y: The center of the fire source was set as Y=0.0. The left direction toward the air supply side of X (longitudinal direction) was set as + and the right direction was set as -. ・Direction Z: The floor center where the fire source was installed was set as Z=0.0. The vertical upper direction was set as +.			

3.6 Experiment conditions

Table.2 Coefficient of Reduced Scale

	Full-Scale	Model-Scale
Typical Length	50m	25m
Wind velocity	2.0m/sec	1.4m/sec
Heat Release Rate	8.5MW	1.5MW
Time	14.1min	10min

Five items were taken up as the factors for experiments: (1) wind velocity (0.0,1.4,1.8,2.2 [m/sec]), (2) kinds of fuel (density of smoke), (3) fire source size (1.5,5.0 [MW]), (4) with/without water sprayers and (5) with/without WS. With consideration to the reduced scale ratio of the model using the Froude law (**Table.2**), the value for the heat release rate was set to be 1.5MW. This value corresponds to that for one ordinary passenger car which has been completely burnt. The standard value for the ventilation velocity for preventing the heat flux from flowing backward on the windward side under the operation of a natural ventilation or longitudinal ventilation method in the case of a fire was set to be 1.4m/sec. **Table.3** shows the experiment conditions and the experiment cases.

Table.3 Experiment conditions and the experiment cases

Conditions for investigation	Wind Velocity [m/s]	Fuel	Heat Release Rate [MW]	Water Spray	**Case No.**	
					Without WS	With WS
① Basic condition	0.0	G	1.5	N	**1**	**2**
② Fuel	0.0	H	1.5	N	**3**	**4**
③ Water spray	0.0	G	1.5	Y	**5**	**6**
④ Heat release rate	0.0	G	5.0	N	**7**	**8**
⑤ Low wind velocity	1.4	G	1.5	N	**9**	**10**
⑥ Low wind velocity, Heat release rate	1.4	G	5.0	N	**11**	**12**
⑦ Middle wind velocity	1.8	G	1.5	N	**13**	**14**
⑧ High wind velocity	2.2	G	1.5	N	**15**	**16**

*Fuel: G=Gasoline, H=n-Heptane

3.7 Combustion time and measurement time

The amount of fuel was set with a period of 10 min as the target burning time. Measurements were carried out at intervals of 2 sec over a period from 1 min before ignition through 2 min after extinguishment. The value used for the investigation of the results in Chapter 4 was a mean value for a period of 60~30 sec before ignition and the value used for the investigation in Chapter 5 was a mean value obtained during a period of 120~240 sec after ignition. The value for the rise in temperature was obtained by subtracting the initial value from the experiment value.

3.8 Procedure for operating experiment equipment

The WS equipment was activated 30 sec after ignition and the water sprayers were activated 3 min after ignition. The ventilation equipment began to work before igniting the fire source.

4. EXPERIMENT RESULTS

In this section, outlines of the experiments carried out under the investigation condition ① (no ventilation air flow, gasoline, HRR 1.5MW) (Case 1, Case 2) are described as an example.

4.1 Effects on temperature profile in the vicinity of ceiling surface

Fig.3 illustrates the temperature profile obtained using sheath type thermocouples installed at points 5cm under the ceiling surface. In the case of the without WS, the temperature rose at a place just above the fire source, but it gently fell toward the exits. On the other hand, in the case of the with WS, although the temperature increased slightly in the compartment, it showed almost the same behavior as that seen in the case of the without WS and it rapidly fell on the outside of the compartment.

4.2 Effects on radiation receiving calorie

Fig.4 illustrates the time history obtained using radiometers installed on the exterior of the opening of the model. The peak value for the radiation receiving calorie after ignition in Case 1 (without WS) reached about 120~140W/m^2 and that in Case 2 (with WS) was about 5W/m^2. The compartmenting effects resulted in reducing the quantity of radiation emitted to the outside of the compartment.

4.3 Effects on heat release rate

Fig.5 illustrates the time history of heat release rate. The heat release rate in Case 1 attained a maximum value of 1.5MW. The maximum value in Case 2 was 1.0MW. It can be estimated that this was caused by the effects of the compartment by the WS and waterdrop particles restraining combustion.

4.4 Effects on gas concentration

Fig.6-a and **Fig.6-b** show the time history of CO concentration and that of CO$_2$ concentration respectively. The figures show not only the effects of the decrease in the heat release rate on the amount of gas generated but the gentle reduction of the gas after extinguishment. It can be thought that this was so because the gas confined due to the compartmenting effects gradually flows out.

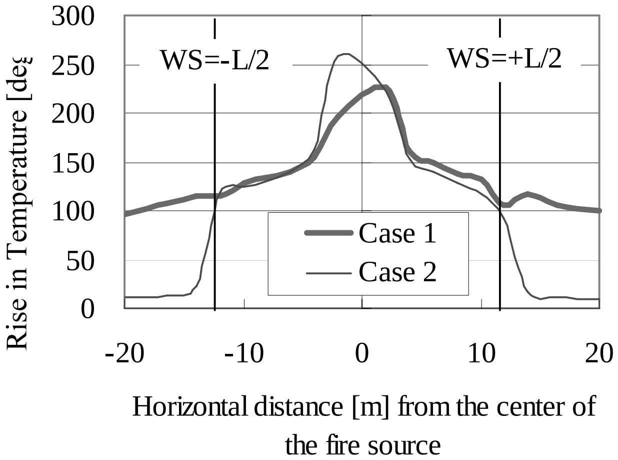

Fig.3 Ceiling Temperature
Condition ①

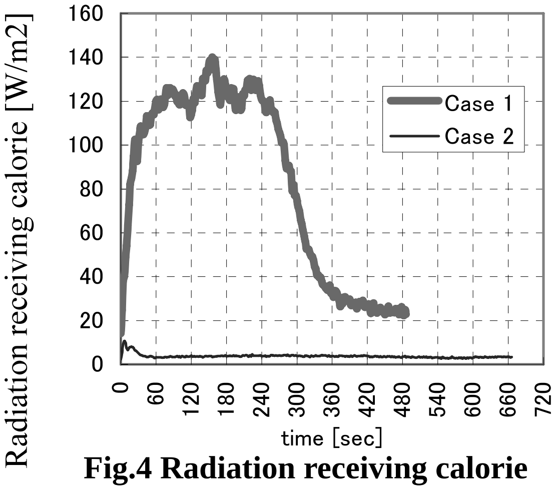

Fig.4 Radiation receiving calorie
Condition ①

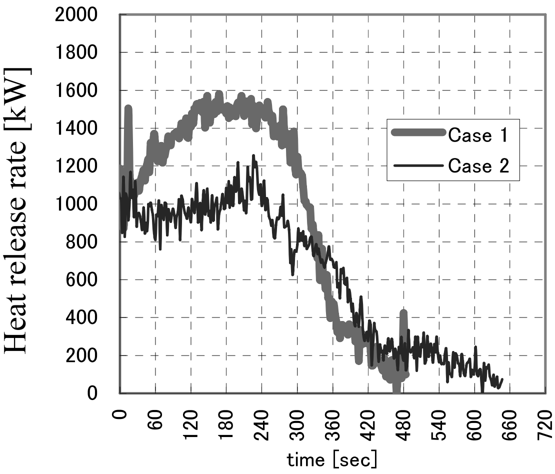

Fig.5 Heat release rate
Condition ①

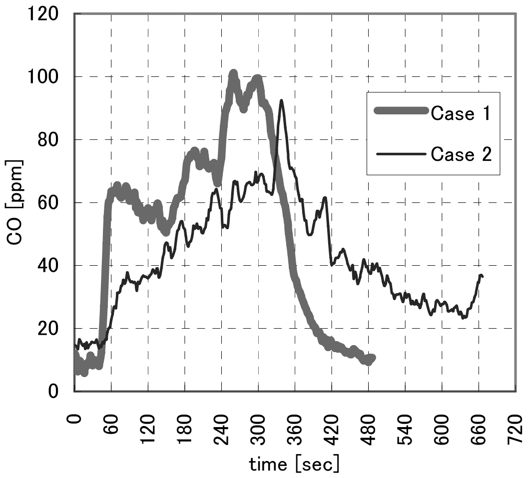

Fig.6-a CO gas concentration
Condition ①

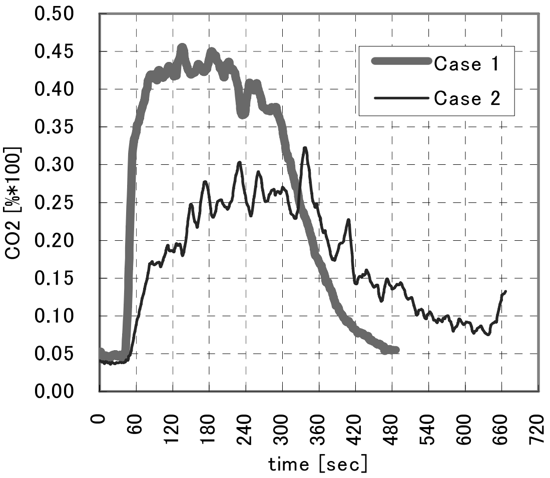

Fig.6-b CO_2 gas concentration
Condition ①

5. DISCUSSION ON TEMPERATURE AND GAS CONCENTRATION REDUCTION

The effects of the WS on evacuees and structures were investigated. With consideration to the effects of the heat isolation caused by the compartment (thermal environment on the outside of the compartment, thermal environment difference between inside and outside of the compartment, radiation both on the inside and outside of the compartment) and the effects of the gas isolation (gas concentration in the tunnel space) which are exerted on evacuees as well as with consideration to the heat release rate in the compartment which is exerted on structures, the reduction ratios were confirmed using the following five methods. (Each reduction effect is indicated with %.)

5.1 Definition of reduction ratio

5.1.1 Reduction effects based on temperature measurements on the outside of the compartment

As for the heat isolation effects of the compartment (reduction effects for the thermal environment on the outside of the compartment), the reduction ratio obtained by comparing the rising temperatures measured at the same positions on the outside of the compartment in both cases where the WS being activated and not being activated is indicated as equation (1).

Equation $$\eta_1 = 1 - \frac{\Delta T_{with-WS}}{\Delta T_{without-WS}} \qquad (1)$$

Where △T: Value for the rise in temperature

5.1.2.Reduction effects based on temperature measurements on the inside and outside of the WS compartment

As one of the heat isolation effects of the compartment, the reduction ratio obtained by comparing rises in temperature both on the inside and outside of the WS compartment at the same time is indicated as equation (2). The effects obtained under Equation (1), (2) were not seen in the other fire prevention compartments. The effects under these conditions were the same as the temperature reduction effects in a compartmented fire source space in the case of a fire in an underground space.

Equation $$\eta_2 = 1 - \frac{\Delta T_{outside-WS}}{\Delta T_{inside-WS}} \qquad (2)$$

5.1.3.Reduction effects based on measurements using radiometers

In order to confirm the radiation environment for evacuees and the prevention of a fire from spreading to combustibles in neighboring compartments, the reduction ratio shown in equation (3) was obtained by comparing the values for the radiation receiving calorie measured using radiometers installed on the exterior of the openings of the model.

Equation $$\eta_3 = 1 - \frac{\Delta E_{with-WS}}{\Delta E_{without-WS}} \qquad (3)$$

Where △E: Value for the rise in radiation receiving calorie [kW/m^2]

5.1.4.Reduction effects based on measurements of gas concentration

The concentration of CO and that of CO_2 can both have a serious effect on evacuees. It can be thought that the reduction of gas concentration results in the decrease in the exposure of evacuees to gas produced by combustion. The reduction ratio obtained by comparing the gas concentration measured by sampling in the duct is explained using equation (4).

Equation $$\eta_4 = 1 - \frac{\Delta D_{with-WS}}{\Delta D_{without-WS}} \qquad (4)$$

Where △D: Value for the rise in gas concentration of CO and CO_2

5.1.5.Reduction effects based on heat release rate

The restraint of combustion speed caused by the compartmenting effects of WS is closely related to the restraint of the maximum temperature at the ceiling and the entire thermal environment both of which have influences on a structure. The reduction ratio obtained by comparing the values for the heat release rate measured in a weight measurement carried out using load cells is indicated as equation (5).

Equation $$\eta_5 = 1 - \frac{Q_{with-WS}}{Q_{without-WS}} \qquad (5)$$

Where Q: Heat release rate [MW]

5.2 Reduction ratio of temperature at the same positions outside the WS

Fig.7 shows the reduction ratio obtained by applying the results from temperature measurements to equation (1). The temperature measurement point was located 1.5m away from the WS where there was no direct effect from the WS. The reason why the value under condition ③ was low was that the sprayed water was uniformly mixed with the air in the compartment and the temperature fell. Under conditions ⑦ and ⑧, a value for the reduction ratio in a +direction from which the wind velocity was supplied became small, but it showed about 80% as a whole.

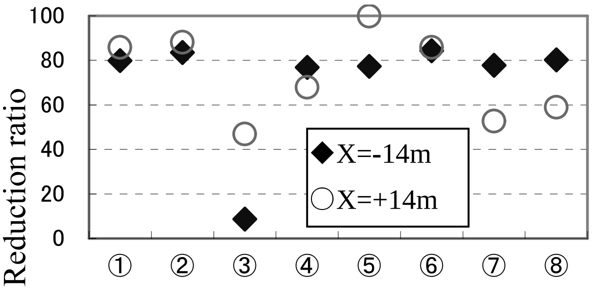

Fig.7 Temperature reduction ratio on the outside of the compartment
Eq.(1)

5.3 Reduction ratio of temperature on the inside and outside of the WS

Fig.8 shows the reduction ratio obtained from the results of temperature measurements carried out on the inside and outside of the WS using equation (2). In the same manner as that described above, a low value was shown under condition ③. The conditions of ⑦ and ⑧ on the air supply side were eliminated from the analyses. The values under other conditions were about 80%.

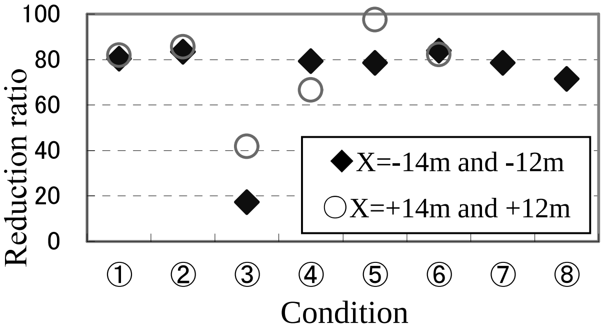

Fig.8 Temperature reduction ratio on the inside and outside of the compartment
Eq.(2)

5.4 Reduction ratio of radiation receiving calorie

Fig.9 shows the radiation ratio obtained from the results of measurements using radiometers installed at positions other than the WS. Equation (3) was used in this case. The reduction ratio under the conditions except ③ was 80~90% and it was shown that the WS was very effective for the radiation isolation.

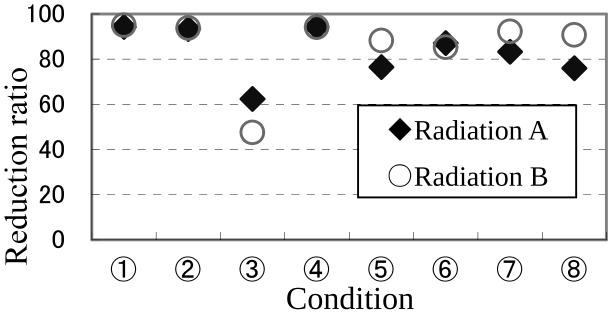

Fig.9 Reduction ratio from radiation Radiometer A,B
Eq.(3)

5.5 Reduction of gas concentration

Fig.10 shows the reduction ratio obtained from

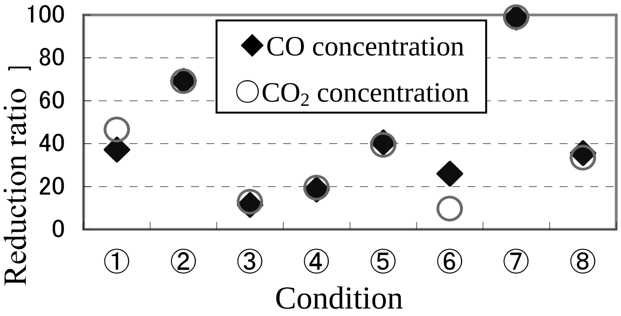

Fig.10 Reduction ratio of CO, CO_2 concentration
Eq.(4)

the results of gas concentration measurements through gas sampling in the duct. Equation (4) was used in this case. The gas concentration showed a reduction ratio of 10~95% as a whole. The reduction ratio under the standard condition of ① was about 40~50%.

5.6 Reduction ratio of heat release rate

Table.4 shows the reduction ratio of the heat release rate obtained from the mass loss method using equation (5). It is clear that the heat release rate in the case of the water sprayers being activated was small and that the reduction effect of the WS was great. With regard to the reduction effect of fuel, gasoline is more effective than n-heptanes. In a range for the heat release rate from 1.5MW through to 5MW, a combustion restraint effect of about 30% was confirmed. Moreover, a tendency was shown in which the burning time was extended due to a decrease in the heat release rate caused by the compartmenting effect of the WS.

Table.4 Reduction ratio of heat release rate Eq.(5)

Conduction	Case No.	Heat Release Rate [MW]	Reduction Ratio [%]
① Basic	Case 1	1,519	31.3
	Case 2	1,043	
② Fuel	Case 3	1,294	11.9
	Case 4	1,140	
③ Water spray	Case 5	1,118	8.6
	Case 6	1,022	
④ Heat release	Case 7	4,655	28.6
	Case 8	3,325	

5.7 Washing out of soot and smoke

Table.5 and **Fig.11** show the recovered soot weight and the smoke density in the test site. It is deduced that there is an overall tendency that in the case of the WS being activated the soot can be washed out effectively and that the smoke density in the tunnel can be restricted. Furthermore, it can be thought from the gradual increase in the smoke density that the WS has the effect of confining the smoke in compartments.

Table.5 Washing out of soot and smoke

Condition	Case No.	WS	Wind Velocity	Estimated total soot volume	Figures for washing out using a duct	Figures for the collecting of WS sprayed water in a pan	Maximum value for the smoke density in the Test Site
			[m/sec]	g	g	g	1/m
①	1	Without	0.0	666	661		0.075
	2	With			554	164	0.028
⑤	9	Without	1.4		398		0.043
	10	With			141	23	0.030

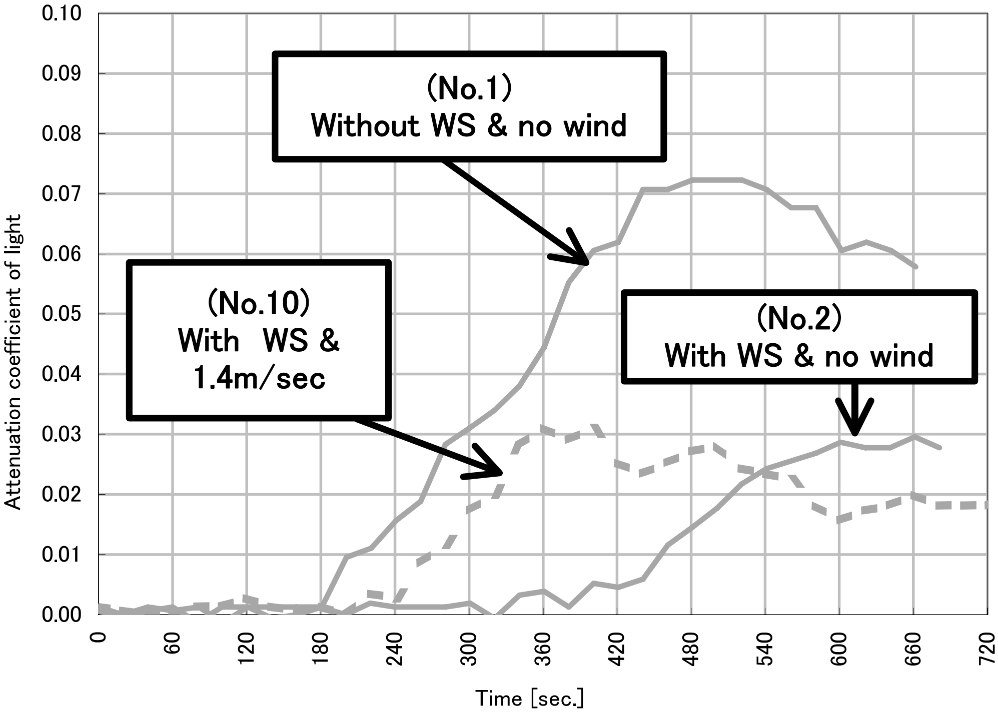

Fig.11 Smoke Density in the Test Site

6. CONCLUSIONS

As the result of WS experiments using a 1/2 scale tunnel model with 43.7m for the longitudinal length, the reduction ratio with regard to both the temperature in the vicinity of the ceiling and the radiation receiving calorie was shown to be about 80% regardless of any value for the heat release rate and wind velocity. Under the experiment condition of ①, the reduction effect of the WS on the gas concentration was about 40% and that on the heat release rate for the behavior of the fire source was about 30%. It can be thought that this was so because the thermal behavior at the outside of the compartment was attenuated and the combustion was restrained.

Fig.12 shows the reduction ratio of Eq. (1)-Eq. (3) obtained from non-dimensional heat release rate. Reduction effect of the WS was about 80%. We installed a dimming smoke densitometer in the model, but the meaningful knowledge was not got.

Compartmenting is valuable technique for protection method that a power line, a signal line, a emergency facilities, etc, necessary for function maintenance at the tunnel fire. When injured people stay for a short term, it becomes a necessary condition of life support to confine a area of a high temperature part by compartmenting. It is useful to start

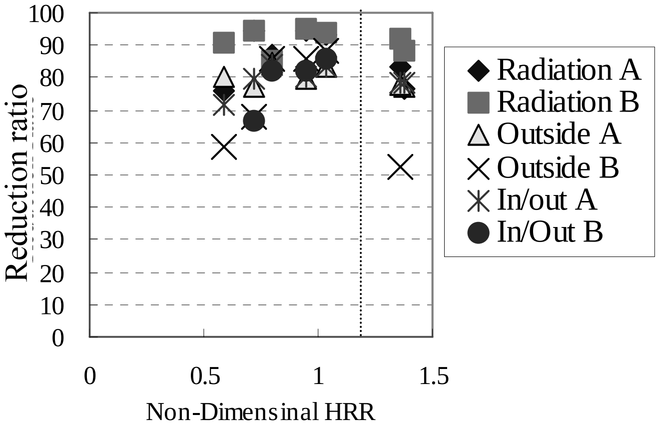

Fig.12 Non-Dimensional HRR-Reduction Ratio

plural WS to raise safety of an evacuee.

It can be judged from the points mentioned above that the compartment system using WS can not only secure the efficiency of a fire prevention compartment but also reduce the thermal effects exerted on structures. It can also be thought that as for the safety of evacuees as well as for the safety of those engaged in fire fighting activities, a favorable evacuation environment can be created on the outside of the WS compartment.

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APPLICABILITY OF WATER SCREEN FIRE DISASTER PREVENTION SYSTEM TO ROAD TUNNELS IN JAPAN

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ABSTRACT

With the enforcement of the Special Measures Act for Public Use of Deep Underground as well as with ongoing urban renewal, there is a need for fire disaster prevention technology to secure the occupants' safety in case of fire breaking-out in any underground space.

In this respect, a fire disaster prevention system using a water screen was developed for potential fires in underground spaces. This system is aimed at securing the occupants' integrity from the fire by partitioning the fire zone using a water screen and also at the safety of a structure by reducing damage due to the fire. It would correspond to the performance-based-design for providing refuge for the occupants.

In the paper to be prepared, results obtained from experiments on the characteristics of the water screen when used as partitioning technology will be described first. Next, the applicability of this water screen fire disaster prevention system to road tunnels will be examined.

Keywords: water screen, fire disaster prevention system, tunnel

1. INTRODUCTION

Although Japan has entered days of population decline, the demand for space in urban areas has greatly increased under the recognition of the importance of improved urban infrastructures. In order to cope with the decrease in population while maintaining the urban functions within limited areas, it is necessary to further improve the infrastructures of big cities. For that purpose, the Special Measures Act for Public Use of Deep Underground was enforced with the view of making full use of underground spaces and urban reproduction projects for effectively utilizing underground spaces with a depth of 40m or more have been carried forward.

However, it is difficult to take appropriate and prompt measures to meet with a fire breaking out in underground spaces where routes through which heat, smoke and particles can pass to the outside are limited.

Large-scale fires which broke out in tunnels such as the Euro Tunnel and the Mont Blanc Tunnel and at a subway station in Taegu city in Korea inflicted severe damage. Due to the fact that these spaces were enclosed and the supply of air from outside was limited, the occupants took refuge in a direction to which high temperature smoke spread and eventually big disasters occurred.

In cases where fires break out in tunnels or in underground spaces, it is very important to secure the "safety of structures" by restraining the spread and extension of flames while also cooling structures to ensure the "safety for evacuation" in order to isolate occupants from heat, smoke and any poisonous gases generated by a fire and to guide them to safe places.

In cases where fires break out in tunnels or in underground spaces, it is very important to secure the "safety of structures" by restraining the spread and extension of flames while also cooling structures to ensure the "safety for evacuation" in order to isolate occupants from heat, smoke and any poisonous gases generated by a fire and to guide them to safe places. Namely, for the purpose of protecting lives, it is necessary to keep the temperature and air quality in a range where survival is possible as well as to secure passageways of refuge for leading occupants from underground spaces through to the outside spaces. Furthermore, rescue teams must move in close to fire zones in safety. In the case of a fire breaking out in a tunnel, two different methods are taken into account; one for protecting lives throughout the tunnel and the other for protecting them in partially compartmented spaces. In Japan, a method for compartmenting a fire zone using water spraying equipment installed in road tunnels has been standardized. With regard to deep underground tunnels in big cities, highly developed monitoring and safety measures for protecting lives from earthquakes, flood damage and terrorist attacks must always be maintained. In this respect, a method for creating compartments while always maintaining the function for monitoring and safety is required.

A water screen fire disaster prevention system for improving the safety of occupants escaping from a fire in order to protect their lives by compartmenting a fire zone using water screens (hereafter referred to as WS), was developed.

The characteristics of this water screen fire disaster prevention system as well as emergency facilities of road tunnels in Japan are described below for the purpose of indicating the applicability of this new fire disaster prevention system to the existing systems in the future.

2. EMERGENCY FACILITIES OF ROAD TUNNELS IN JAPAN

2.1. Procession

On the night of July 11,1979, the worst fire accident in Japanese history happened in the Nihonzaka Tunnel. 170 cars were caught in a fire that broke out in a tunnel with a length of 2045m on the Tomei [Tokyo-Nagoya] Expressway. 7 people were killed in this accident. Furthermore, the interruption of the Tomei Expressway, which is indispensable for the Japanese economy, inflicted a great economic loss.

Accordingly, the existing conception of the installation of emergency facilities for road tunnels in Japan was put in order to create the road tunnel emergency facilities installation standards in 1981 based on the lessons obtained from this accident. Later on, the standards were partially revised as a result of investigations carried out through fire tests in actual tunnels. Details of the road tunnel emergency facilities installation standard and explanations issued by the Japan Road Association in 2001 are described below.

2.2. Road tunnel emergency facilities

Road tunnels in Japan are classified into 5 ranks extending from class AA to class D depending upon the length of tunnels and traffic volume (Figure.1). Standards for the installation of emergency facilities are determined according to each classification rank. Namely, a scale for the extent of emergency facilities is decided upon due to the fire occurrence ratio for each tunnel. As for very long tunnels on national high ways classed AA, complete facilities must be installed.

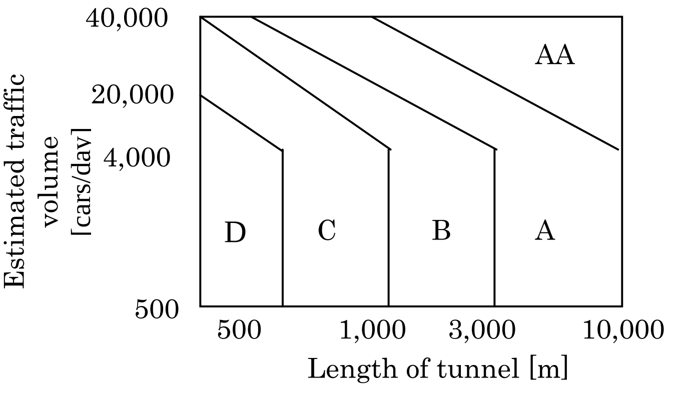
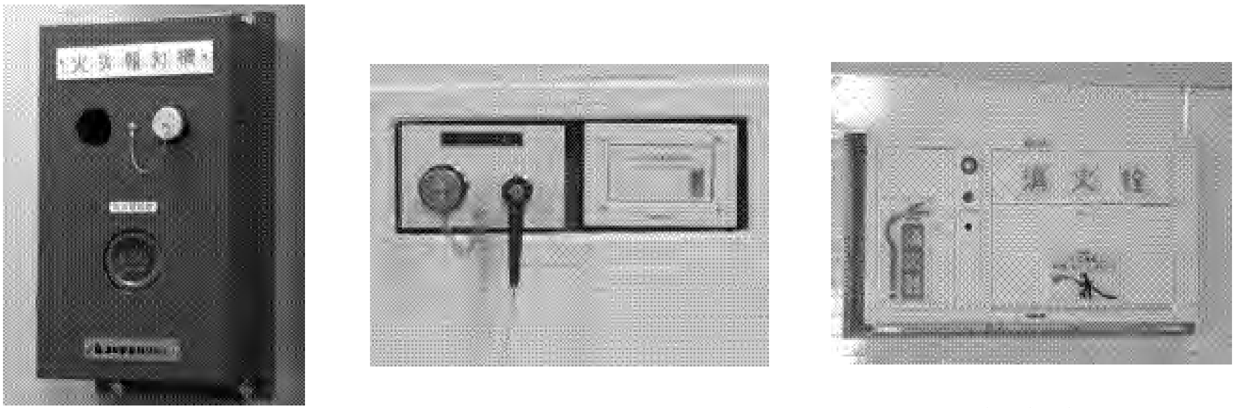


Figure 1: Road Tunnel Standard

Equipment for notification and alarm, extinguishment equipment, refuge instruction equipment and other pieces of equipment are installed as emergency facilities.

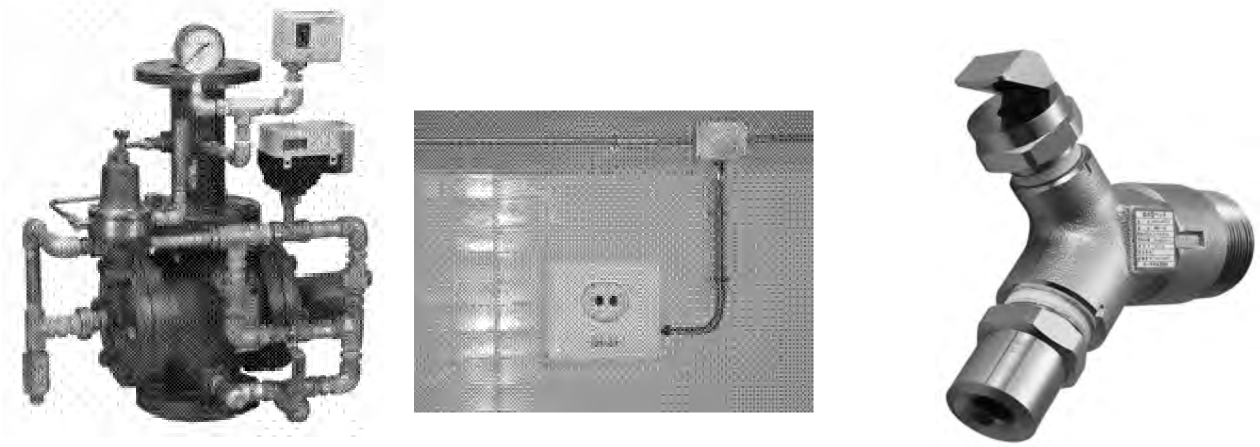
① Equipment for notification and alarm

This equipment is used for notifying road management personnel, fire stations or police stations of the occurrence of a fire and other accidents in tunnels as well as for informing road users inside and outside the tunnels. Emergency telephones, push-bottom notification devices and fire detectors are all part of the notification equipment. Alarm equipment has emergency alarm devices (photo 1).



Fire alarm Faucet Fire hydrant

Pump unit External faucet Emergency exit



Deluge valve Emergency telephone Water Spray Head

Photo 1: Emergency Facilities

② Extinguishment equipment

Fire fighting implies initial fire fighting carried out by occupants in tunnels and full-scale fire fighting by fire-brigades. Extinguishment equipment including fire extinguishers and fire hydrants is installed assuming initial fire fighting.

③ Refuge instruction equipment

This equipment is used for guiding occupants who have met with a fire or accidents in tunnels for evacuation to the outside in safety.

There are guide sign plates, smoke exhaustion equipment and exit passageways included in the refuge instruction equipment. The guide sign plate indicates information with regard to distances to exits, the distances or directions to exit passageways and their locations.

The smoke exhaustion equipment restrains the spread of smoke in order to improve the environment for evacuation in the case of a fire breaking out in tunnels. It also compulsorily exhausts smoke permeating the whole tunnel to the outside in order to facilitate fire fighting and rescue・first aid activities easily. In general, ordinary ventilators are used for smoke exhaustion.

In the case of a longitudinal ventilation system being applied, a wind speed in a one-way traffic tunnel is set at 2m/s in order to restrain the spreading of smoke toward the windward side when a fire breaks out. Moreover, in a two-way traffic tunnel at the initial evacuation stage just after a fire has broken out, operation of ventilators is stopped in order to control the spreading of smoke. When fire fighting or rescue and first aid activities are carried out, ventilators are activated in order to exhaust smoke.

Exit passageways are used for guiding occupants in a tunnel to other safe spaces for evacuation.

④ Other pieces of equipment

Other pieces of equipment supplement equipment for notification and alarm, extinguishment equipment and refuge instruction equipment in order to carry out effective fire fighting.

There are water taps, radiocommunication auxiliary equipment, radio rebroadcast equipment, loud speaker broadcast equipment, water spraying equipment and monitors as other pieces of equipment.

Water spraying equipment restrains the force of flames by cooling a fire source and its vicinity and supports fire fighting as well. Specifications of water spraying equipment were determined in 1968 based on the results of fire tests conducted in actual tunnels in 1960s. Since then, the specifications of water spraying equipment have been investigated through carrying out several model tests and fire tests in actual tunnels.

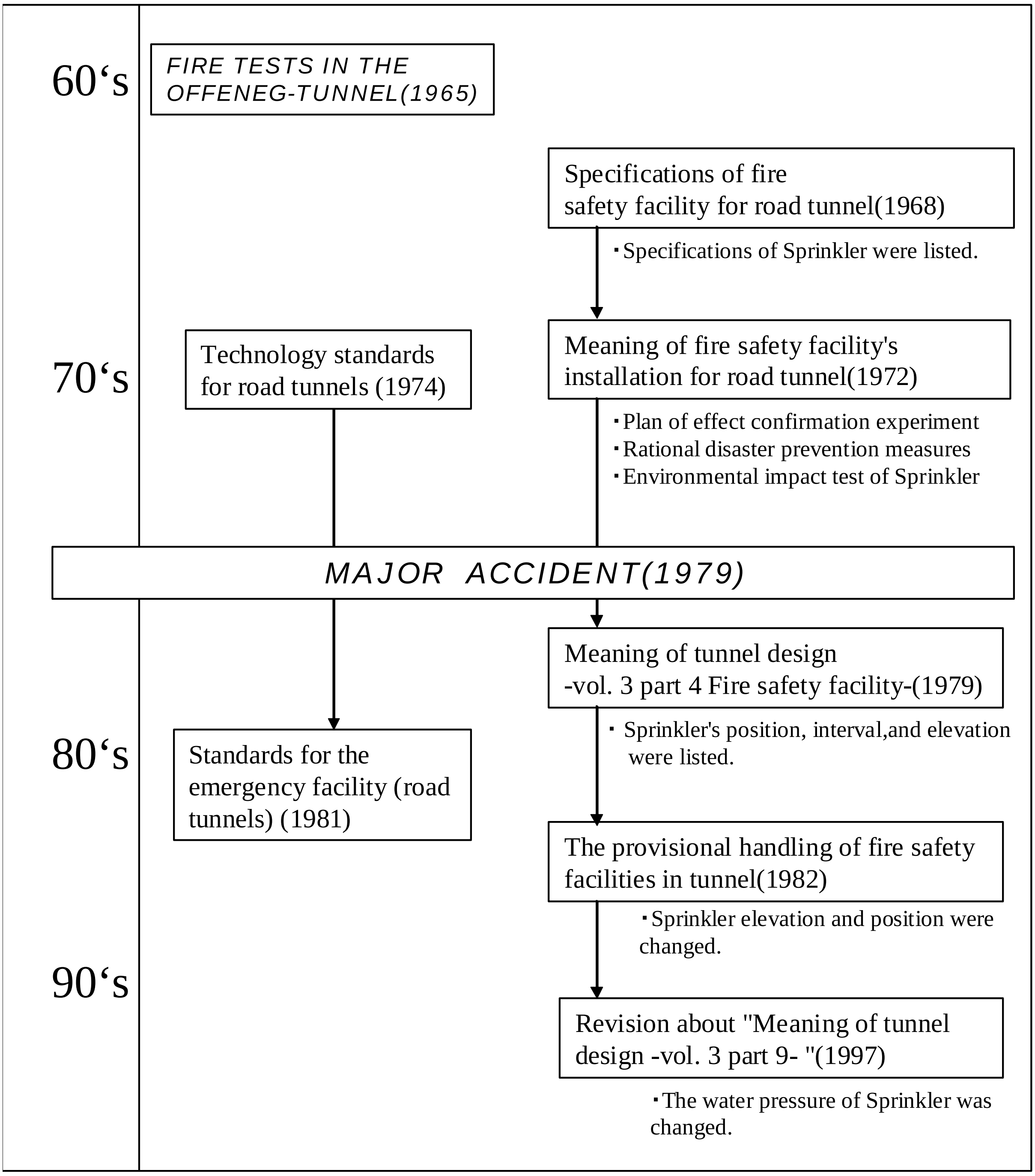


Figure 2: Progress

Emergency facilities for road tunnels in Japan have been installed on the basis of the aforementioned concept since the fire accidents happened in the Nihonzaka Tunnel. However, with regard to water spraying equipment, it has been pointed out that it may well be that the environment for evacuation will be deteriorated due to the spreading of smoke in the case of the water spraying equipment being activated at an early stage of a fire. It can be thought that when deep underground spaces are utilized in big cities in the future, technology to secure the safety of occupants there is necessary without fail.

3. WATER SCREEN FIRE DISASTER PREVENTION SYSTEM

The water screen fire disaster prevention system was developed as technology for improving the safety of occupants taking refuge in the case of fires breaking out in tunnels or underground spaces. This system aims at securing the safety of occupants by compartmenting a fire zone using WS, restraining the spread of heat and smoke and seizing and washing out poisonous floating particles. It also can minimize the degree of damage to structures. This system is a technology for creating water screens by spraying water under high pressure in a hanging bell shape from spiral type water screen heads (photo 2) arranged in lines in patterns which form compartments.

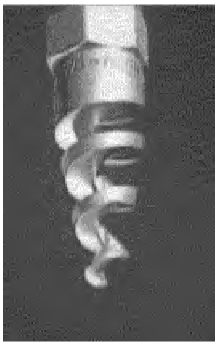


Photo 2:Spiral Head

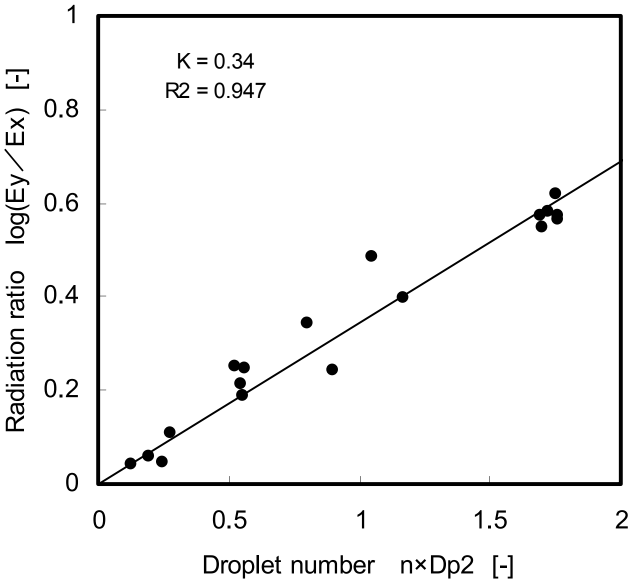


Figure 3: Relationship between mean particle diameter and heat radiation

3.1. Compartmenting using WS

Past studies have resulted in confirming the fact that the smaller a mean particle diameter and the slower a dropping speed for sprayed water under the condition of the same amount of water, the higher the heat radiation isolation effect (Figure 3). Furthermore, investigations were carried out under the condition of the mean particle diameter being 100 μ m or more in order that the water particles may not be swept away by fire plumes or be vaporized.

As a result, WS with a mean water particle diameter of about 200 μ m was developed as a new method for compartmenting a fire zone which has functions other than just the fire extinguishing performance of water sprinkling equipment, namely functions for fire prevention compartments and escape equipment. The water particle diameter of the WS is about 1/5 of about 1000 μ m for the diameter of a rain particle and the diameter of a water particle from a sprinkler. In this case, the volume of a water particle sprayed from the WS is about 1/125 of rain or sprinkled water particles and the number of water particles corresponding to the same volume of water is about 125 times. The surface area of a water particle from the WS becomes about 1/2, so the total surface area for the same volume of water reaches 5 times. This new compartmenting method with WS was developed utilizing the fact that the dropping speed for water particles from the WS decreases and the heat radiation isolation effect is heightened. Moreover, the water screen can be created by using the effect of water particles with a diameter of about 200 μ m (Figure 4).

This water screen can be formed by the water sprayed at 10L/min from each of the special spiral type heads in a hanging bell shape with a radius of about 800mm. Moreover, since the water is sprayed from each head in an almost horizontal direction under drainage pressure of about 1.0MP, there is no vacant space between the ceiling surface and the sprayed water surface.

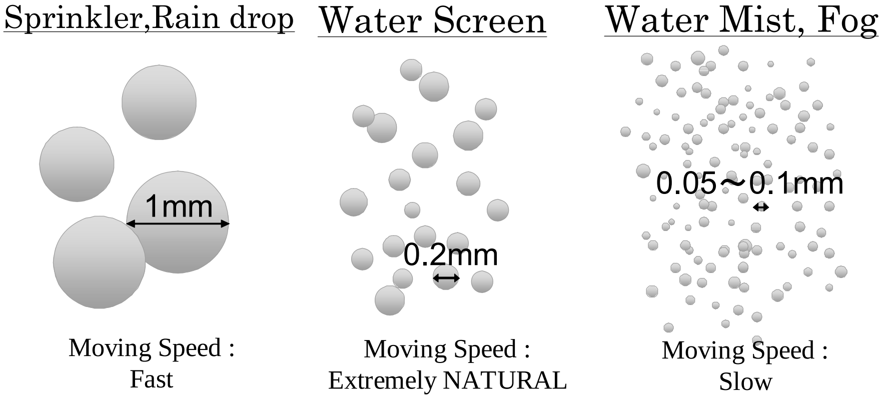


Figure 4: Comparison

In cases where a fire breaks out in a tunnel under natural ventilation conditions, with regard to the flow in an axial direction, the flow of high temperature smoke floating toward an exit at the upper part of the tunnel becomes a function of a heat release rate from the fire source and it agrees with the flow of air moving in the reverse direction at the lower part of the tunnel in the mass flow flux. When actuating the WS installed at right angles to the longitudinal direction of a tunnel at fixed intervals, the density difference at the upper end of the flow becomes small due to a cooling effect of the WS upon the high temperature smoke layer. Accordingly, the flow stops and the effects of the compartment such as the decrease in heat radiation are exerted. Compartmenting is based upon the conception that heat and smoke generated by a fire should be confined within a limited area to prevent them from spreading in the whole space. Furthermore, it can be estimated that the water screen fire disaster prevention system has an effect to restrain the heat release rate due to the decrease in the air flowing in from the outside of the tunnel.

3.2. Characteristics of WS

In order to confirm the compartmenting effect of the WS in a road tunnel, a fire test was carried out (Photo 3) using a ventilation control wind speed (0~3.2m/s) and a gasoline fire source (corresponding to 8.5MW, 28.5MW) as main variables assuming tunnels of class AA for the Road Standards Type 1.

Radiant heat absorption characteristics as well as heat generation characteristics in the case of a compartmenting length being set at 50m were obtained. This fire test was carried out using a 1/2 scale model of a tunnel (Photo 4). Each variable used in the test was reduced based on the Froude law (Table 1). As a result of the test, the following compartment characteristics of the WS were obtained.

Table 1 Coefficient of Reduced Scale

	Full-Scale	Model-Scale
Typical Length	50m	25m
Wind velocity	2.0m/sec	1.4m/sec
Heat Release Rate	8.5MW 28.5MW	1.5MW 5.0MW
Time	14.1min	10min
Quantity of WS	10Liter/min	56Liter/min

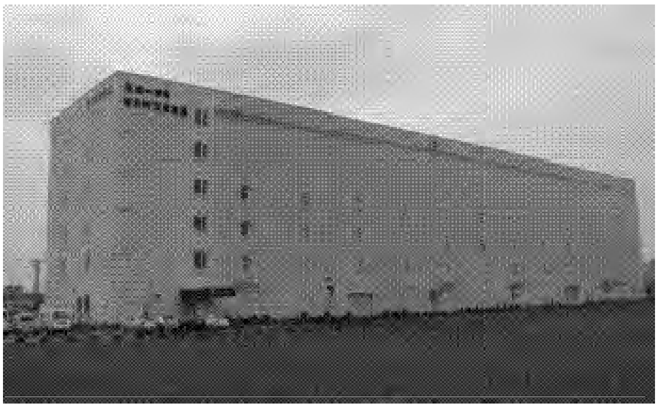


Photo 3: Emergency Facilities

Photo 4: 1/2 Scale Model

Photo 5: Interior conditions (Before WS are activated)

Photo 6: Interior conditions (After WS are activated)

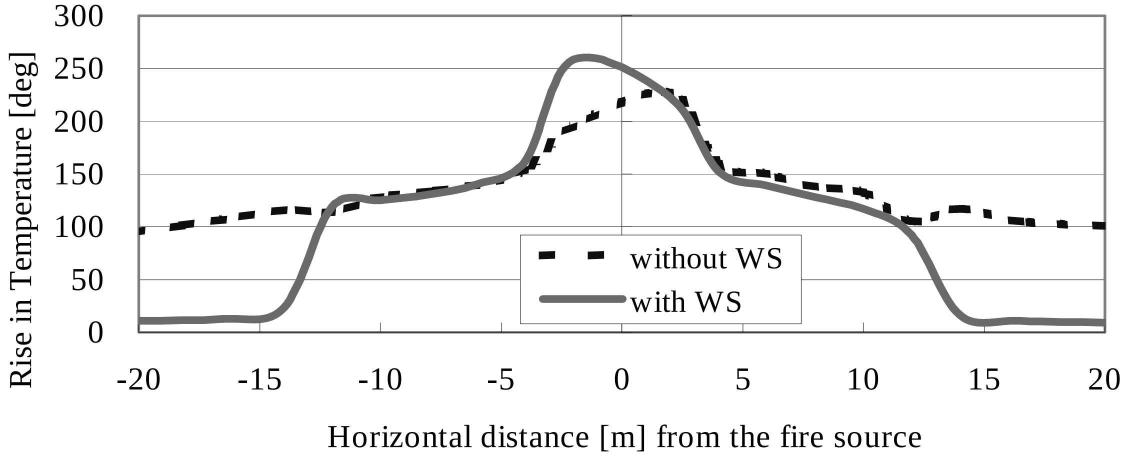


Figure 5: Ceiling Temperature

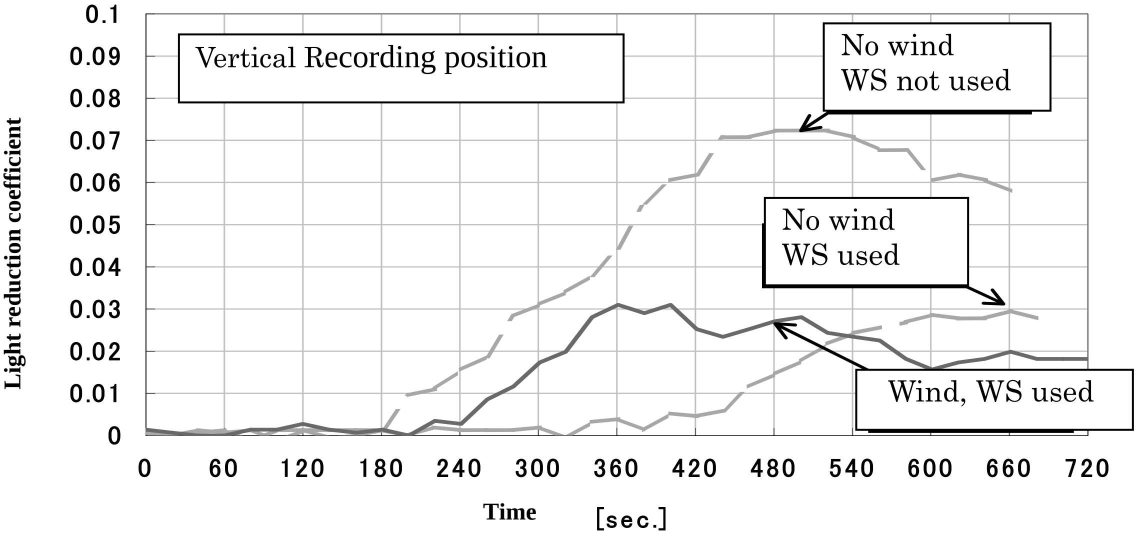


Figure 6: Smoke Density in the Test Site

① 70~80% for the reduction of heat, 60~80% for smoke and about 15% for poisonous gas (CO) were confirmed respectively.

② The water screen was formed at an inclination of 33° in the case of an actual scale conversion wind speed being 20m/s (test wind speed: 1.4m/s) and the same compartmenting effect as that mentioned above was confirmed.

③ A fire zone compartmented by WS can protect the lives of any occupants.

④ Evacuees can easily pass through water screens.

As mentioned above, it was verified that the WS is very effective as a technology for compartmenting a fire zone when a fire breaks out in tunnels.

3.3. Main Equipment of WS

The main equipment is relatively simple and consists of water supply units such as tanks, high pressure pumps and piping, and water screen spray nozzle heads connected to this as well as dedicated fire detectors and a control panel. It can easily in existing structures.

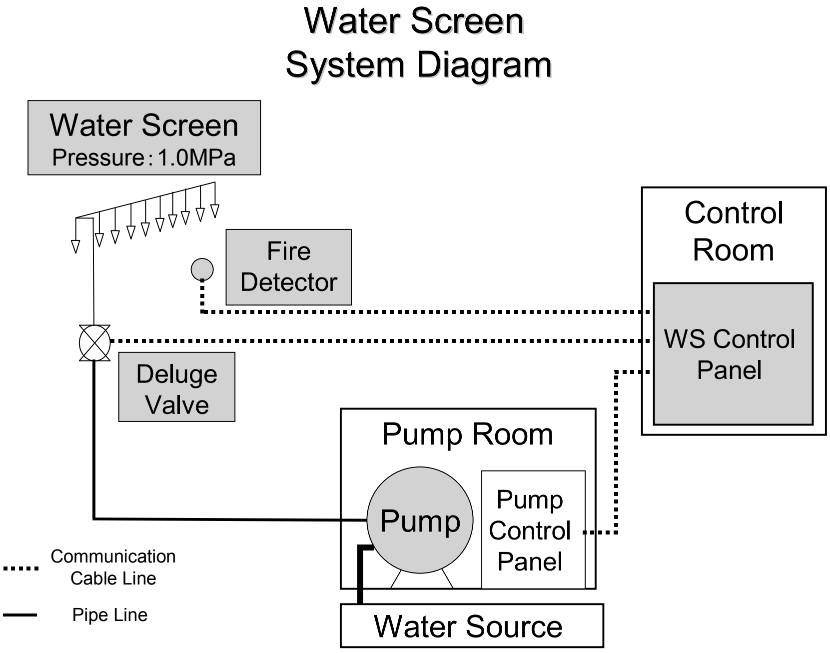


Figure 7: Main Equipment

4. APPLICABILITY OF THE WS TO ROAD TUNNELS

Up to now, road tunnels have yet to be compartmented in order to avoid traffic conjestion. However, the applicability of the WS to road tunnels as a compartment technology has been investigated in order that occupants may take refuge in safety and that fire-fighting・rescue operations may easily be carried out. This is so because the WS does not obstruct traffic and it also reduces heat and smoke in road tunnels.

A deep underground tunnel in urban districts is subjected to the investigation this time. A shield tunnel such as Tokyo wan aqua-line which is a representative underground tunnel structure in Japan was assumed.

Places of safety are located under floor decks. Air pressure is applied to these places for the purpose of preventing the inflow of heat and smoke from driveways. The basic safety of occupants can be secured if they take refuge in these places. Therefore, it is important to guide them to places of refuge in safety from the viewpoint of security of safety for evacuation.

A longitudinal ventilation system was applied to vertical shafts for air ventilation. A tunnel section area was set at 100m2 or more. Water spraying equipment and WS were arranged at intervals of 5m and 50m respectively. Owing to the fact that in a tunnel the air flows toward a fixed direction due to effects of ventilation and the movement of vehicles, heat and smoke easily spread on the leeward. In particular, it is an important subject in tunnels in urban districts which are apt to be crowded with a great number of vehicles to check the spread of a fire for vehicles as well as to prevent the extension

of damage caused by heat and smoke flowing on the leeward side.
The steps of procedure for the water screen fire disaster prevention system subjected to the investigations this time are as follows:

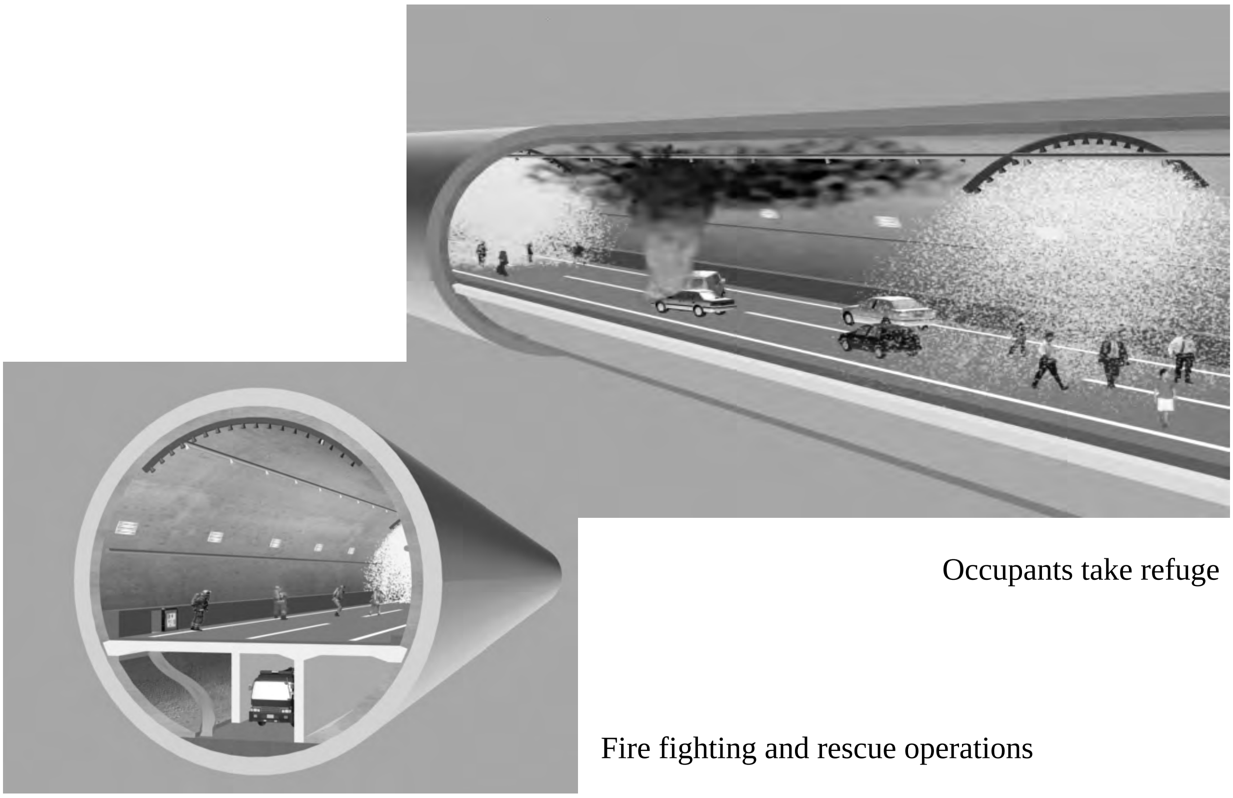


Figure 8: View of the system when applied to a road tunnel

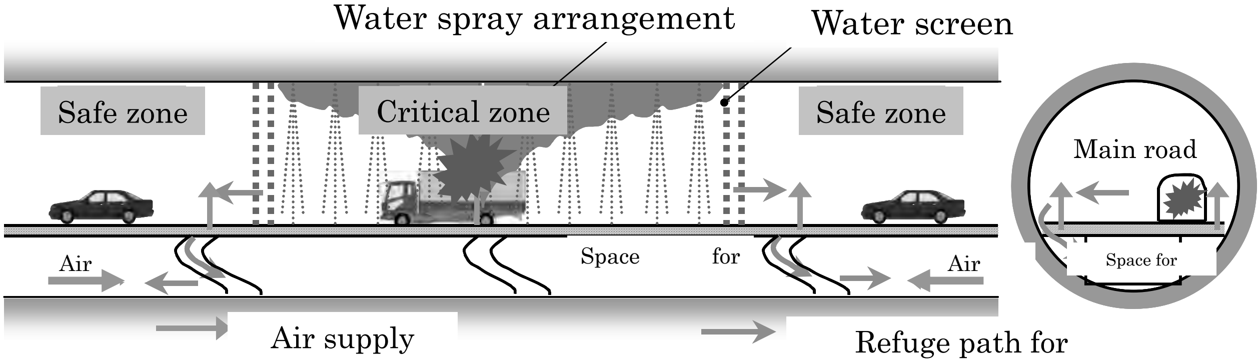


Figure 9: Water screen fire prevention system for road tunnels

[Steps of procedure for the water screen fire disaster prevention system]
① A fire zone is to be specified after detecting the occurrence of a fire.
② A fire compartment is to be formed by actuating WS so that it can surround the location of the fire in order to reduce heat and smoke spreading to other zones.
In the case of a one-way traffic tunnel, the wind speed is controlled at 2m/s. In the case of a two-way traffic tunnel, the operation of the ventilators is stopped.
③ Occupants move to safe zones (safety zones) on the road surfaces where the effects of heat and smoke are small after passing through WS from a fire zone. Then, they move to places of safety located under the road surface going down slopes from fire exits and they take refuge on the outside of the tunnel.
④ After the occupants have moved to the outside of the fire zone through WS, water spraying equipment in the fire zone is to be activated for initial fire-fighting in order to cool tunnel structures.
⑤ Fire brigades enter onto road surfaces outside the fire zone going up slopes from places of safety under the floor decks and move in close to the fire zone. Fire–fighting and rescue operations are carried out after confirming actual conditions in the fire zone from various sources located on the

outside of it. It can be taken into account whether to activate ventilators for smoke exhaustion without using WS depending upon conditions in the fire zone.

The safety of occupants moving to refuge can be improved in accordance with these steps of procedure.

5. CONCLUSION

In this paper, application examples of the water screen fire disaster prevention system as a technology for the compartmenting of road tunnels are described. However, the applicability of this system to railways tunnels, places for doors leading to places of refuge in the case of mountain tunnels and junctions of two tunnels.

Furthermore, in view of the fact that the time, in which occupants can take refuge in safety, can be quantified as the time for actuating WS, a rational design of a fire disaster prevention system including specifications of ventilation equipment and fire prevention equipment for the arrangement of places of safety can be made by combining the simulation of occupants' actions for refuge and both a 3rd mode heat behavior analysis and a smoke flow analysis.

In the future, development for further improving this system will be carried out.

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MAINTENANCE STRATEGY OF HARBOR STRUCTURES IN JAPAN BASED ON LIFE-CYCLE MANAGEMENT

Hiroshi Yokota[1], Mitsuyasu Iwanami[2], Toru Yamaji[3] and Ema Kato[1]

ABSTRACT : Port and harbor structures have to keep structural performance over required levels in extremely severe marine environments for constituent materials. This can be achieved both with sufficient durability design and maintenance work based on the concept of life-cycle management. Focusing on a reinforced concrete superstructure of open-type wharf, at first, this paper discusses the maintenance strategy for generally, then put forward some questions about Fick's diffusion law for prediction of deterioration progress, at last presents the concepts of life-cycle cost (LCC) and methodologies of rational and efficient maintenance work based on maintenance strategies formulated in relation to durability design.

KEYWORDS: Life-cycle management, maintenance strategy, harbor structure, prediction.

1. INTRODUCTION

Japan is an island country with long coastlines of about 30000 km. Thus, it is very easy to understand the importance of harbor and coastal structures there. The life of port and harbor structure is rather long and a structure designed today must be expected to meet demands during its lifetime that cannot be foreseen. While many port and harbor structures are newly built every year, a great numbers of existing structures require remedial actions including repair, strengthening, upgrading, or renovation.

Marine areas are very severe for structures from the viewpoints, not only of mechanical actions but also of environmental actions. Materials tend to deteriorate relatively rapidly in marine environments and loss of structural performance or even structural collapse may be consequences. The most common and costly deterioration mechanism suffered by concrete structures in marine areas is chloride-induced corrosion of reinforcement embedded in concrete. At the initial design of a concrete structure, designers must have several assumptions, in which probably worst conditions are considered, so that the structure can keep its structural performance over required levels. Serious deterioration of concrete members may be caused by insufficient durability design with optimistic assumptions against materials deterioration and by lack of proper maintenance work after construction of the structure.

To meet these facts, strategic maintenance is the only way to be taken in relation to the result of initial durability design. To realize the strategic maintenance, the comprehensive life-cycle management is one of the key technologies. The life-cycle management is a series of actions to evaluate the grade of deterioration and structural performance degradation by inspection, to predict the future progress of performance degradation, and to propose the alternatives of appropriate remedial action based on life-cycle cost minimization or performance maximization under budget capping. The authors have tried to establish the life-cycle management system for a reinforced concrete superstructure of open-type wharf that is one of the most vulnerable structures in ports and harbors. This paper introduces the methodologies of rational and efficient maintenance work based on maintenance strategies formulated in relation to durability design.

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Figure 1. Examples of deterioration on reinforced concrete beams of open-type wharf

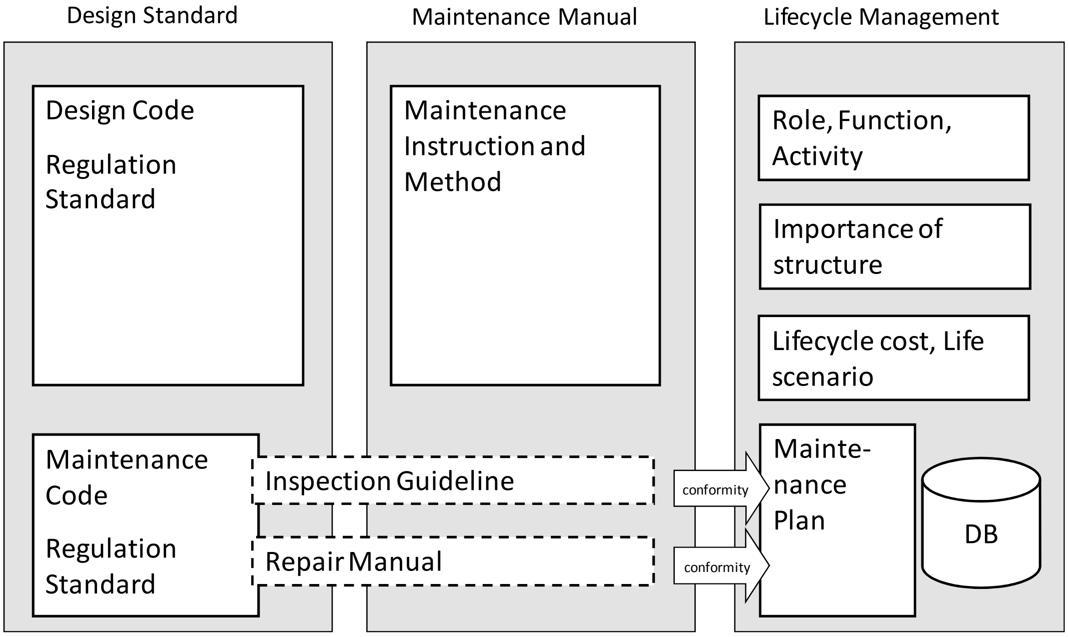
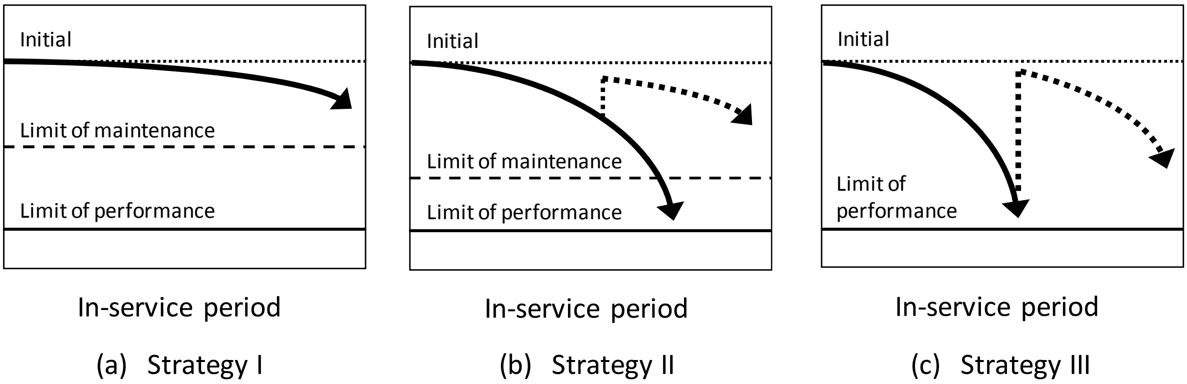


Figure 2. Collaboration between durability design and maintenance work

2. MAINTENANCE STRATEGY

It is usually very hard to keep structural performance of a port and harbor concrete structure over required levels for the whole service life because it is exposed to marine environments with rich chloride ion supply. As shown in Figure 1, chloride-induced corrosion and consequent damage can be often seen in concrete beams and slabs of open-type wharf. Therefore, sufficient durability design has to be employed at the initial design stage, in which some kinds of mitigating measures are needed. One simple measure that anyone can realize is to increase concrete cover, but it seems distant because a concrete cover of about 200 mm or even larger is required. Instead of taking actions only by means of durability design, maintenance work during service period should be collaborated to ensure the structural performance. Figure 2 shows the collaboration system between durability design and maintenance work before and after construction of structure, respectively. With durability verification at the design stage and performance assessment at the maintenance work, the structure can keep its structural performance over the requirements.



(a) Strategy I (b) Strategy II (c) Strategy III

Figure 3. Definition of three maintenance strategies

For realizing rational and effective maintenance work, a maintenance strategy should be properly formulated during the durability design of structure before construction or after regular inspection for already existing structure. Importance and substitutability of structure and difficulty of maintenance work should be well taken into account for the strategy-making. Figure 3 shows three maintenance strategies indicating basic concepts of how structural performance will be guaranteed beyond the performance limit or the maintenance limit. Strategy I is defined that the structural performance is always kept above the maintenance limit during the design working life. This strategy is realized by use of highly durable materials and/or preventive measures. Examples of durable materials and measures are epoxy-coated reinforcement, highly durable permanent formwork, extremely high quality concrete such as UFC, etc. Maintenance work in this strategy is not ignorable even serious deterioration is not expected to occur. Instead, the maintenance is required on the regular-basis including careful monitoring to avoid unexpected deterioration. Strategy II is defined that even performance degradation is expected in the design stage, minor remedial actions are repeatedly applied before the maintenance limit is reached. In Strategy II, it is necessary to predict the progress of deterioration and draw up a maintenance plan based on the result of prediction. Maintenance in this category allows performance degradation due to deterioration at the design stage, but minor remedial action should be taken as early as possible when deterioration exposes. Strategy III is a kind of corrective maintenance, in which performance degradation is allowed to occur but major remedial actions may be applied once or twice for performance recovery.

Since an open-type wharf is expected to be highly safe and serviceable during performing cargo-handling work, its main performance requirements are safety and serviceability. It is, therefore, preferable to adopt Strategy I or II for the maintenance of a superstructure of open-type wharf.

3. LIFE-CYCLE MANAGEMENT

3.1 Overall concept

The maintenance work is carried out to assess the present conditions of structure and to quantify the level of structural performance. In addition, by predicting future progress of performance degradation, the most appropriate method of remedial action is chosen for minimizing the life-cycle cost or maximizing structural performance recovery under budget capping. A general procedure of maintenance work is shown in Figure 4, which is based on the life-cycle management (LCM) concept. The life-cycle management system is composed of the following five main components:

- Inspection of the present conditions of structural members
- Assessment of structural performance
- Prediction of future progress of performance degradation

- Proposal of method and timing of remedial action
- Decision of action among proposed alternatives

3.2 Judgment of deterioration

Judgment of deterioration is made by a two-step inspection system as shown in Figure 5; namely, primary inspection and detailed inspection. The state of deterioration is visually evaluated and judged using the deterioration grade: Grade *d* to *a* according to the general grading criteria in the maintenance manual for port and harbor structures [1]. Grade *d* refers to a sound condition without any signs of deterioration, while Grade *a* is the most severe deterioration state. For example, the criteria of judgment for a reinforced concrete superstructure of open-type wharf are summarized in Table 1. For proper judgment, inspection should be carried at with regular intervals. At the moment, the standard time interval is set at 2 years.

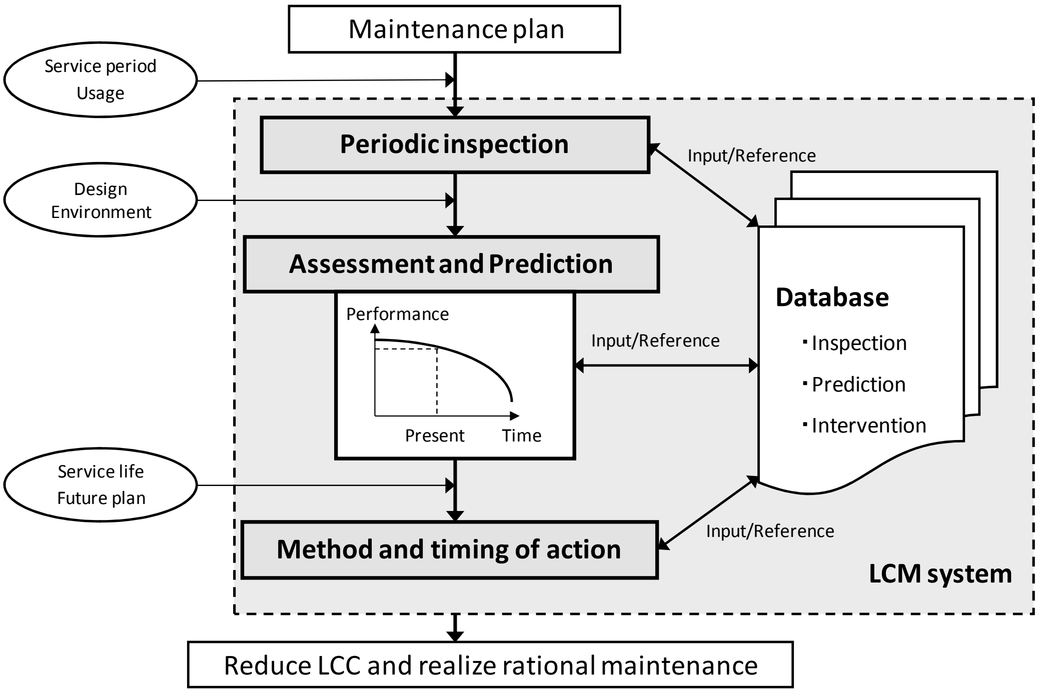


Figure 4. Procedure of life-cycle management

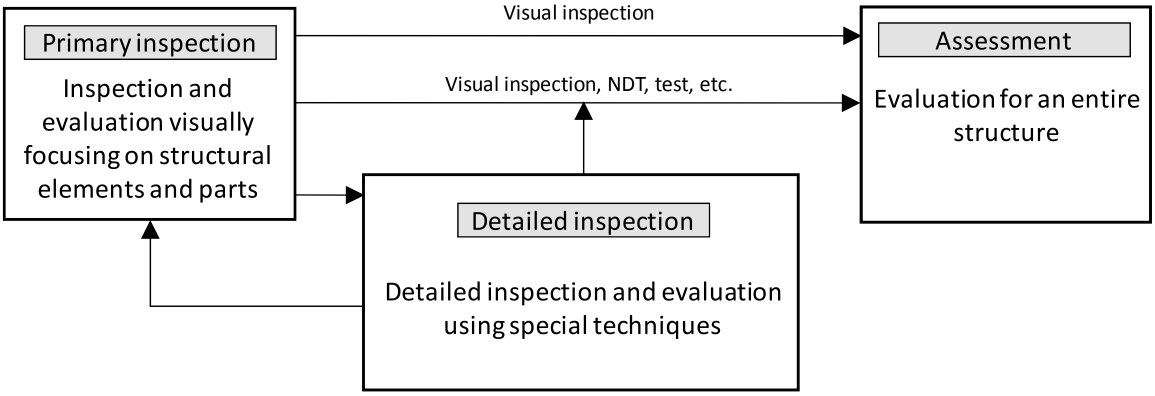


Figure 5. Process of assessment

Table 1. Grade of deterioration of wharf superstructure

Item	Method		Judgment criteria
Cracking, delamination, and spalling	Visual inspection on cracks, surface appearance etc.	a	Widely extended spalling off of concrete cover or cracks of 3 mm or wider
		b	Partially spalling off of concrete cover or many corrosion cracks
		c	Some corrosion cracks or partial delamination
		d	Nothing observed
Corrosion of reinforcement	Visual inspection on corrosion and rust stain	a	Broken reinforcement, directly exposed reinforcement, or heavy rust stain
		b	Much rust stain
		c	Partially extended rust stain
		d	Nothing observed

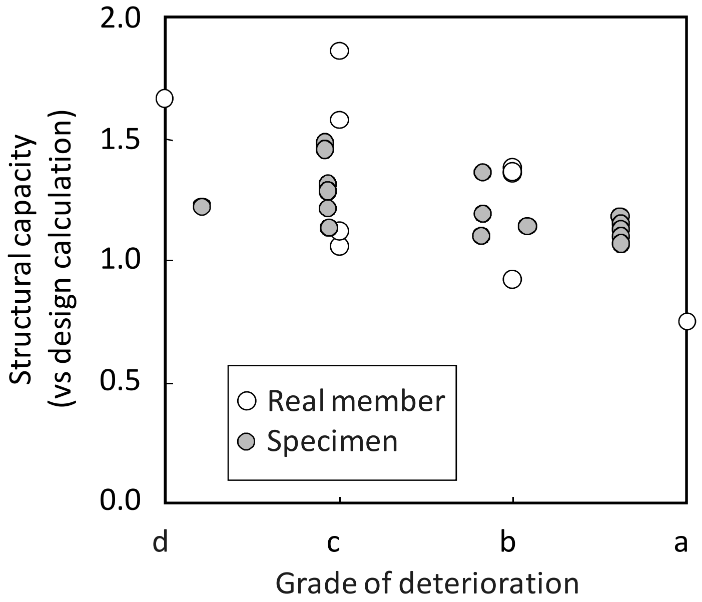


Figure 6. Structural capacity vs. grade of deterioration

When the primary inspection is insufficient to provide proper data for assessment, the detailed inspection is carried out. The detailed inspection includes visual inspection by well-trained divers for submerged parts, measurement with non-destructive or destructive techniques, etc. After the onset of corrosion of reinforcement, structural performance will be degraded very rapidly. Therefore, material deterioration should be captured before its appearance on the surface of member. For this purpose, non-destructive techniques are of use. However, before their application, the effectiveness and accuracy should be well examined under real environmental conditions.

3.3 Assessment

It is required to quantitatively make overall assessment of a structure from the viewpoint of structural performance. The visual inspection is only able to provide the change in appearance of structural member, but structural performance has to be evaluated as precisely as possible.

The relationship between structural performance (structural capacity) and the grade of deterioration is shown in Figure 6. This figure was obtained by loading tests on reinforced concrete beams prepared for exposure tests for more than 20 years and extracted slabs from real structures which had been in service for more than 30 years [2]. When the deterioration grade reaches Grade *b*, structural performance tends to become lower than the design requirement level. These facts are well considered for the overall assessment from the viewpoint of structural performance.

3.4 Prediction

Since deterioration of a reinforced concrete member is induced and accelerated by chloride ion provided by sea water, the chloride ion profile inside concrete and the volume loss of reinforcement are predicted as main indices for durability performance. The calculation theory based on Fick's second law of diffusion of chloride ion in concrete has been widely used for the prediction of deterioration progress. For simulating the diffusion of chloride ion in concrete with this theory, it is necessary to quantify four fundamental parameters: threshold value for onset of reinforcement corrosion; chloride ion content on the surface of concrete, C_0; an apparent diffusion coefficient of chloride ion in concrete, D_{ap}; and the concrete cover depth. C_0 represents the environmental condition around structural members and D_{ap} represents the diffusivity of chloride ion in concrete depending on the quality of concrete particularly on the type of cement and the water-to-cement ratio.

When the chloride ion content reaches a threshold value at the position of reinforcement, corrosion of reinforcement will start and progress rapidly. The threshold value for onset of reinforcement corrosion is specified to be 2.0 kg/m^3 for a superstructure of open-type wharf. This is based on experimental test results as shown in Figure 7 [3].

As the progress of deterioration of a structure differs widely by its location because of inhomogeneous characteristics of materials and diversity of environmental conditions, the proper determination of C_0 and D_{ap} is not so easy. An example of wide variations of values C_0 and D_{ap} in three reinforced concrete slabs of about 1.5 m square each of open-type wharf as shown in Figures 8 and 9, respectively [4]. Though the concrete core specimens were taken out from non-deteriorated parts of the slabs, the surface chloride ion concentration and diffusion coefficients widely vary with location. The maximum differences of measured results between the adjacent points were about 70 % in the surface chloride ion concentration and more than double in the diffusion coefficient. Therefore, even in one structural member, variability in chloride ion profiles may appear significantly.

In the practical investigation of existing structures subjected to marine environments, chloride ion profile of concrete has generally been estimated according to one or a few sampled concrete. However, it seems that such a few numbers of concrete cores may not be representative.

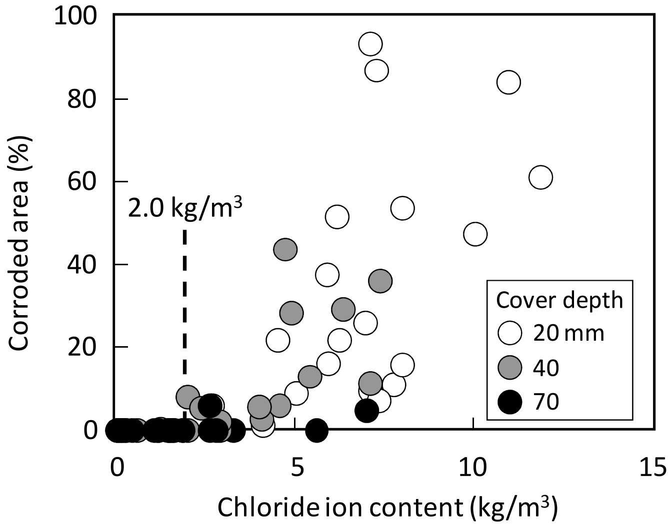
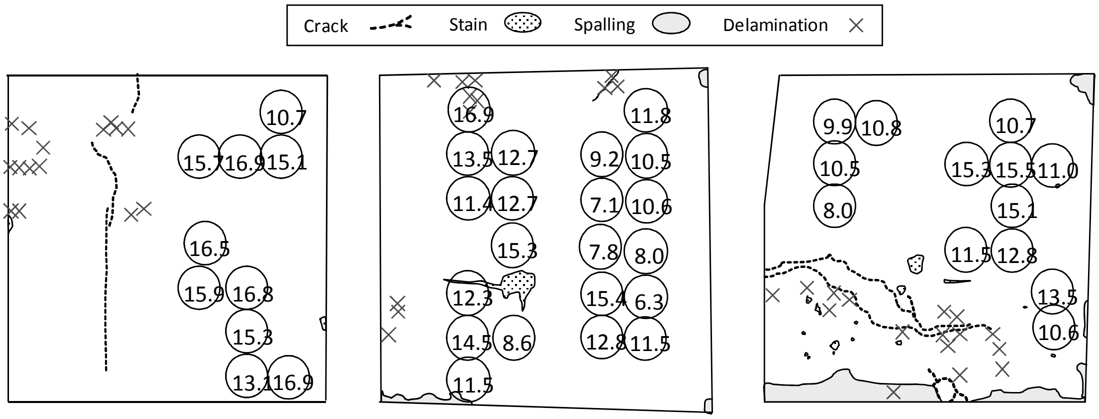
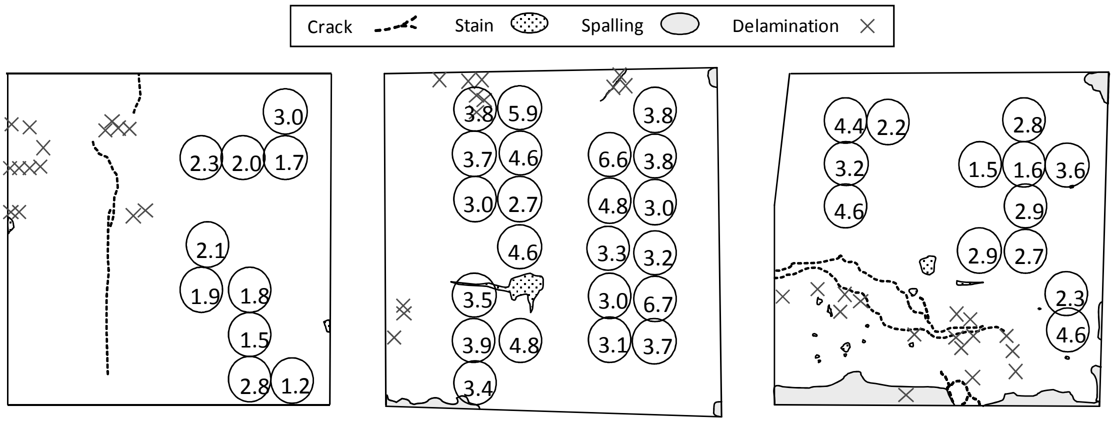


Figure 7. Threshold chloride ion content to initiate rebar corrosion



(unit: kg/m^3)

Figure 8. Distribution of surface chloride ion concentration, C_0



(unit: cm^2/year)

Figure 9. Distribution of diffusion coefficient of chloride ion in concrete, D_{ap}

These facts indicate that it is practically rather difficult to accurately predict the progress of deterioration and remaining structural capacities by using the diffusion theory. Instead of this, the authors have tried to investigate the applicability of a calculation model to predicting the progress of deterioration by analyzing the variation of visually observed deterioration grades with the Markovian chain model [5]. This approach is of use to understand the overall tendency of deterioration in consideration of its variation by the experienced progress of deterioration.

In the model, the state and the transition are main components, and a probability of shifting from a certain state to the next state is expressed by a transition probability, p_x. The process of application of the model is shown in Figure 10. The assumptions of the prediction are as follows:

- A structural member belongs to a certain grade of deterioration; that is, Grade *d*, *b*, *c*, or *a*.
- The grade of deterioration shifts to the next grade in a time step with a certain transition probability, while the other structures remain in the present deterioration grade with the remaining probability.
- These calculations continue step by step during the life span of structure.
- At the commencement of calculation, the deterioration grades of all structural members are set at Grade *d*.
- Grade *a* is the worst condition; that is, the final stage of deterioration.

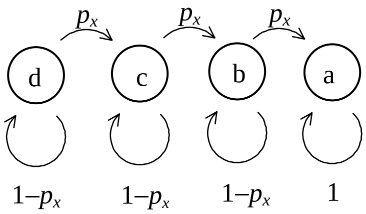


Figure 10. Markovian model for predicting the deterioration progress

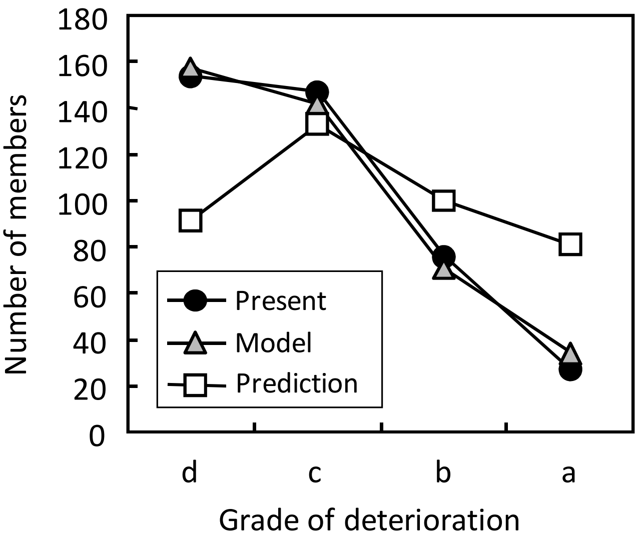


Figure 11. Prediction by Markovian chain model

When a transition probability is determined with good accuracy, the overall trend of future deterioration can be predicted. The transition probability is one of the indices to express the behavior of deterioration progress affected by environments, materials, and so on. When the years in service of each structure were substituted to the number of calculation steps, the most suitable transition probability was found for members so that the calculated result by the model agreed well with the result of actual distribution of deterioration Grades.

The example of application is shown in Figure 11. This figure shows collected data from all the structural members in a specific port, in which the transition probability is obtained through fitting the actual distribution and simulated distribution. Based on the prediction result after 15 years, the number of members probably judged as Grade *a* may increase up to about 3 times. For the application of the Markovian chain model to prediction, many data should be collected and accumulated for members under almost the same environmental and material/structural conditions.

4. LIFE-CYCLE COST ESTIMATION

To determine the maintenance strategy or to consider the appropriate timing and method of remedial action, estimation of life-cycle cost (LCC) is one of the best indices. LCC is calculated for several maintenance scenarios among maintenance strategies as mentioned earlier. In the calculation, the initial cost, maintenance cost including inspection cost, and the cost of planned remedial action are totaled.

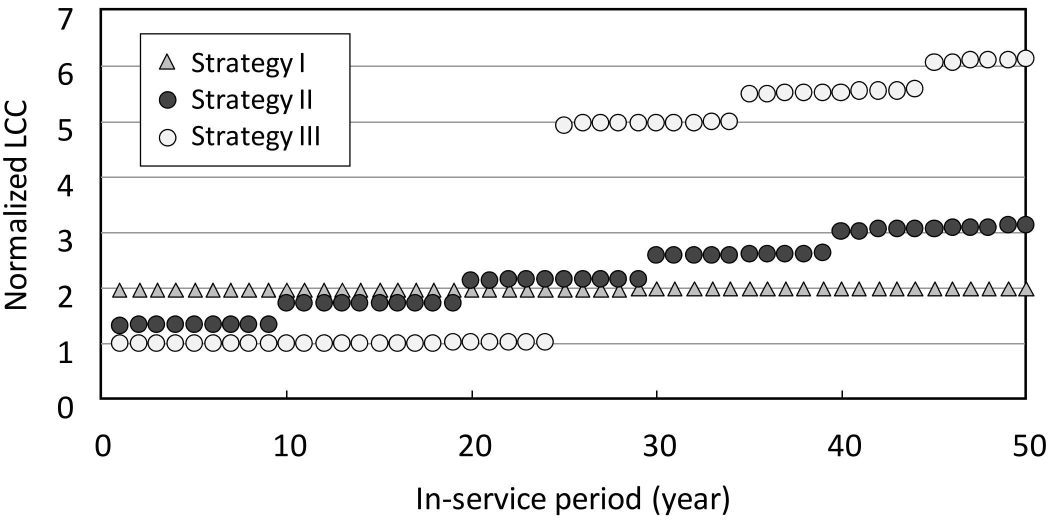


Figure 12. Example of LCC estimation for 50 years

An example of estimated LCC is shown in Figure 12 [6]. In Strategy II, all concrete surfaces of slabs and beams are coated, and they are re-coated at the end of the life of the coating material (assumed to be 10 years in this figure). In Strategy III, the timing of repair is deferred as much as possible. When the second half of the acceleration period begins 25 years after the completion of the structure, section repair and surface coating are carried out extensively for the relatively deteriorated parts of the structure. It is assumed that the cross sections of 95% of all members are section-repaired. LCC, thus, calculated is expressed in terms of the ratio to the initial construction cost in the case that a general reinforced concrete superstructure within Strategy III is constructed. The social discount rate is not taken into account in the calculation.

At the end of design working life (50 years in this calculation), Strategy I has the smallest LCC even its initial cost is largest. It should be confirmed here that the more durable structure in construction, the lower LCC achieved. Since Strategy I is not likely to cause deterioration resulting in performance degradation and only primary inspection is needed, LCC at 50 years after construction is not significantly higher than the original construction cost. For the scenario considered in Strategy II, one option is to carry out coating at the beginning of construction because deterioration of structures exposed to severe environmental conditions is very fast. It should be noted that this scenario based on Strategy III shows the largest LCC and the amount of incremental increase in cost is so large that single-year costs are far larger than those for the other two scenarios.

LCC is calculated based on various assumptions, but it provides important information needed for making decisions about the future direction of maintenance. An advantage of Strategy II is that the accuracy of the initial deterioration estimation can be checked during the maintenance process so that they can be modified to more realistic predictions. Another advantage is that maintenance cost can be equalized more or less because necessary funds can be prepared in advance. Strategy III should be avoided from the viewpoint of LCC. If neither Strategy I nor Strategy II can be used for some reason, it is necessary to draw up funding and technical plans in advance. In Strategy III particularly, various problems may arise with the progress of deterioration, affecting the conditions under which the structure is to be used. It is, therefore, necessary to determine the best timing for taking measures through regular inspections.

LCC calculated here can be a useful indicator by which an appropriate scenario can be selected according to the determined maintenance strategy. Durability verification results obtainable at the design stage, however, have large safety margins because of considerable variability at the design stage. A deterioration investigation of open-type wharf, for example, showed that in many cases the corrosion of reinforcement did not occur even when chloride ions accumulate far exceeding the threshold chloride ion concentration. It is necessary, therefore, to draw up maintenance plans with full understanding of this variability and assumption of deterioration predictions. It is essential to take proper maintenance measures during the service life of the structure instead of unquestionably believing the estimates.

5. CONCLUDING REMARKS

The life-cycle management system including prediction of the progress of deterioration was developed and being implemented for maintenance of port and harbor structures in Japan. After modification of the original system, the authors expect that rational and effective maintenance is realized so that LCC reduction and performance maximization can be attained.

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研究速報

災害における情報基盤システムの在り方

Concept of Disaster Intelligence Infrastructure

宮崎早苗*
Sanae MIYAZAKI

1. はじめに

近年，多くの新しい情報技術が進展しており，災害分野でも様々な情報システムが提案あるいは導入されているが，現在この分野で情報基盤システムが有効に活用されている例はまだ少ない．本稿では，災害分野における現状の情報基盤システムの問題点を明確化するとともに，数々の新しい情報基盤システムを災害分野で役立てるための対策について提案する．

2. 災害関連の既存の情報基盤システムとその問題点

2.1 既存の情報基盤システム

最近の情報通信技術，情報システム技術は日々急速に進展しており，災害分野においても Fig. 1 に示すように，これらの新しい技術に基づく情報基盤システムが数多く提案あるいは実用化されている．

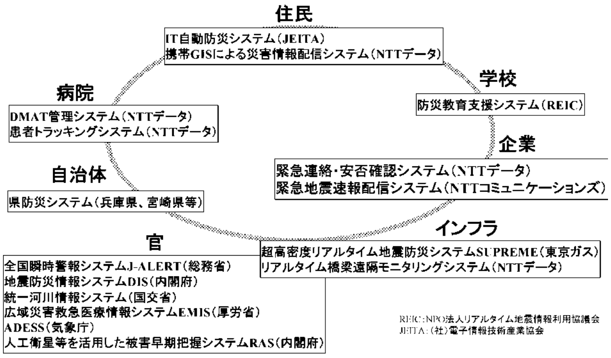

Fig. 1　The example of the information infrastructures.

例えば，住民向けには情報家電を活用したIT自動防災システム1)や携帯GISを活用した災害情報配信システム，学校向けには緊急地震速報を利用した防災教育支援システム2)，企業向けにはWebやモバイル端末を利用した緊急連絡・安否確認システム3)，IPv6マルチキャストを利用した緊急地震速報配信システム4)，病院向けにはWebやモバイル端末を利用したDMAT管理システム5)やRFIDを活用した患者トラッキングシステム5)，インフラにおいては最新のセンシング技術を活用した超高密度リアルタイム地震防災システム6)やリアルタイム橋梁遠隔モニタリングシステム，官においては全国瞬時警報システム7)や地震防災情報システム8)等，様々な情報基盤システムが整備されつつある．また将来的には，これら情報基盤システムを結合した防災情報共有プラットフォーム構想9)も内閣府を中心に検討が進められている．

2.2 既存の情報基盤システムの問題点

ところで，災害における情報基盤システムの役割とは一体なんであろうか．筆者は，災害における情報基盤システムの役割とは，災害によって引き起こされる人的･経済的･社会的被害を最小限に抑えるために，平常時・災害時の双方において，効率的・効果的に必要な情報を迅速に収集・分析・加工し，次のアクションにつなげる，またそのアクションの実行をサポートするものであると考えている．

一方，現在世の中に数多く構築された災害関連の情報基盤システムのすべてが有効に活用されているかというと，YESとはいえない状況にある．筆者が目にしたいくつかのシステムの中には，稼働中のはずであるにもかかわらず，電源さえ入っていない状態のものや，システムのオペレーション部が災害発生時には人がいない場所に設置してあるもの，稼動はしているが全く災害業務に活用されていないシステム等が少なからずみられた．

このような災害関連の情報基盤システムが有効活用されない原因はいくつか考えられるが，1つの大きな理由として，他の災害関連の基盤システム，例えば社会基盤システム，医療基盤システムなど，とうまく連携して機能していない，すなわちこの情報基盤システムが災害関連業務プロセスに適合していないことが考えられる．

3. 活用される情報基盤システムの構築に向けて

3.1 米国の危機管理分野における情報活用の考え方
ー Intelligence Cycle ー

筆者は，災害関連の情報基盤システムの在り方を考えるにあたって，米国のインテリジェンス分野（諜報分野）で

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用いられている『Intelligence Cycle』[10]の考え方が非常に有効であると考えている．このIntelligence Cycleは，危機管理分野における情報収集活動を効率的・効果的に進めるためのもので，Fig. 2に示すように，下記5つのプロセスで構成されている．

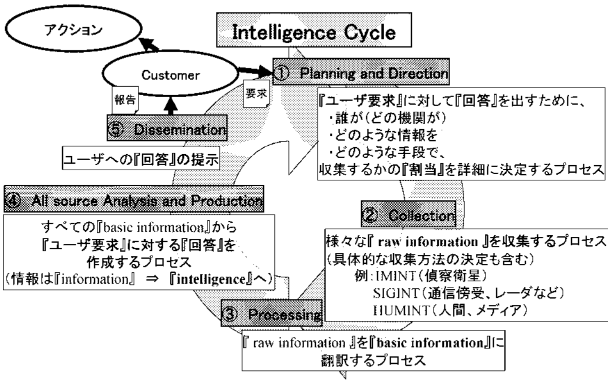

Fig. 2　The example of the intelligence cycle.

① Planning and Direction
ユーザ要求に対して，誰が，何を行うかを計画し割り当てるプロセス．

② Collection
様々なraw informationを収集するプロセス．手段としては，画像（IMINT：IMage INTelligence），傍受（SIGINT：SIGnal INTelligence），諜報（HUMINT：HUMan IMTelligence）などがある．

③ Processing
集めた様々なraw informationが示していることを明確化しbasic informationとして作成するプロセス．（例：衛星画像（raw information）　⇒　飛行場が新しく建設された（basic information））

④ All source Analysis and Production
様々な手段で集められた様々なbasic informationを組み合わせ，評価・分析を行うプロセス．このプロセスでinformationはintelligenceになる．

⑤ Dissemination
Customer（政策決定者）へのIntelligenceの伝達プロセス．

まず，政策決定者からのオーダ（ユーザ要求）を①が受け取る．①では『ユーザ要求』に対して『回答』を出すために，誰が（どの機関が），そのような情報を，どのような手段で収集するかの詳細な『割り当て』を決定し，それを各機関へ伝達する．②では各機関が①から受け取った要求に対して，具体的にどのように情報を収集するかを計画し実行する．その後，③において収集した生の情報（raw information）から状況把握のための情報（basic information）に変換する．さらに各機関で作成された③の情報（basic information）は，④を実施する機関に集約され，ここですべての情報を組み合わせて『ユーザ要求』に対する『回答』を作成する．このプロセスで『information』は『intelligence』になる．最後に⑤において，④で作成した『回答』を政策決定者へ伝達する．

この『回答』をベースに政策決定者は具体的なアクションを起こしたり，さらに新たな情報収集を指示したりする．CIA等の欧米の機関では，このIntelligence Cycleに基づき，迅速な情報収集，意思決定，行動を可能としている．

3.2　Intelligence Cycleに基づく情報基盤システムの提案

災害関連業務プロセスにおける情報収集や意思決定プロセスも全くインテリジェンス活動と同様であると考えられる．しかしながら，現状のわが国の状況をみると，②，③のプロセスで行われる個別の情報収集・加工はある程度機能しているものの，①，④のプロセスが効率的・効果的に機能しておらず，結果として災害関連業務プロセスがうまく回っていないようにみえる．そのため，結果的に災害における情報基盤システムが有効活用されていないと考えている．そこでわが国の災害関連の活動をこのIntelligence Cycleに当てはめて，そこで必要となる情報基盤システムを構築することを提案する．

そのためには，まず災害関連の業務プロセスの洗い出しを行い，社会基盤システムや医療基盤システム等も含めた情報基盤システムの運用シナリオを構築する必要がある．具体的には，平常時や災害発生時に起こりうる様々な状況を洗い出し，それに応じた複数のシナリオに対する災害対応マニュアルを整備し，その上で，そのマニュアルに沿った活動を円滑に進めるために必要な情報基盤システムはどう在るべきかを分析･検討していく必要があると考えている．

4. ま　と　め

本稿では，数々の新しい情報基盤システムを災害分野で役立てるために，米国のインテリジェンス分野で用いられている『Intelligence Cycle』[10]の考え方を導入したアプローチについて提案した．

今後は，さらにハードおよびソフトの両面から災害における情報基盤システムの在り方に関する検討を進めていく予定である．

（2007年3月13日受理）

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4)　http://www.ntt.com/release/2006NEWS/0010/1018.html
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10)　https://www.cia.gov/cia/ciakids/who_we_are/cycle.shtml

AUTOMATIC AND REAL-TIME BRIDGE HEALTH MONITORING FOR HEAVY TRAFFIC ROUTES

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ABSTRACT

A real-time bridge remote monitoring system for a quick detection of the damage caused by earthquakes and for a reliable measurement of the damage caused by its aging was developed. The system is consisted of various sensors, high-speed data transmission networks, and an information center that produces high-level information associated with the bridges-health. A demonstration system was developed on a Metropolitan expressway in Tokyo, Japan, where many heavy vehicles over regulation weight passes on. By this system, the reliability and the durability of our system was confirmed.

1. INTRODUCTION

Around 40% of Japanese bridges were constructed about 40 years ago, and they have various kinds of damage known or unknown, serious or non-serious in recent years. Even these old bridges have to be remained in service with effective maintenance because of a recent review of public investments. Both strong earthquakes and the daily use can trigger serious disasters similar to a Minneapolis bridge collapse on Japanese bridges in a few years, and also its damage might be very huge especially in mega city areas. A quick and time-serial reporting of quantitative diagnoses to road administrators associated with bridges-health measured using scientific systems would be extremely important to establish a sustainable city. In this paper, a concept of our real-time bridge remote monitoring system using various sensors, such as video cameras and various kinds of fiber-optic sensors for a quick detection of the damage caused by earthquakes and for a reliable measurement of the damage caused by its aging was described. A demonstration system developed on Metropolitan expressway in Tokyo, Japan was also introduced.

2. SYSTEM ARCHITECTURE

The advantage of our system is on its ability to monitor the time-serial condition of bridges automatically from remote locations in real-time without electric power supply at the field. Ensuring this, as shown in Figure 1, our bridge monitoring system is consisted of five subsystems; sensor subsystem, data transmission subsystem, data analyzing subsystem, diagnosing subsystem and administration support subsystem. The detail is as follows.

2.1 Sensor Subsystem

In our monitoring system, various sensors, namely video camera and fiber-optic sensors such as strain gauges, displacement meters, inclinometers and accelerometers are attached to each bridge as a sensor subsystem. Figure 2 shows the example of these sensors.

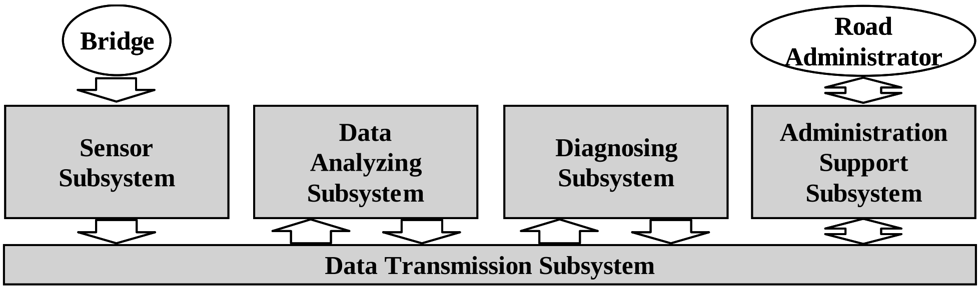


Figure 1: System architecture

FBG displacement meter **FBG inclinometer** **FBG accelerometer**

BOTDR displacement meter **FBG strain gauge** **Video camera**

Figure 2: Example of sensors

2.2 Data Transmission Subsystem

The data measured by the sensor subsystem is automatically transmitted to the data analyzing subsystem using the data transmission subsystem. We can choose the data transmission technology, e.g. the Internet, fiber-optic communication, wireless communication, etc., appropriately to the needs of a road administrator according to its reliability, capacity, cost, etc.

2.3 Data Analyzing Subsystem

The data transmitted from the sensor subsystem using the data transmission subsystem is stored in the database, and then various calculations and analyses are automatically done using the data analyzing subsystem.

2.4 Diagnosing Subsystem

As a next step, the diagnosing subsystem generates the gap information between the measurement data and the pre-known normal data using the output of the data analyzing subsystem. The gap information is represented in three ranks, namely “large”, “small” and “non”.

2.5 Administration Support Subsystem

The administration support subsystem visually provides the information generated by the data analyzing subsystem and the diagnosing subsystem to support road administrators for the decision of their next actions, etc.

3. FEASIBILITY STUDY ON HEAVY TRAFIC ROUTES

As a feasibility study, a demonstration system was developed on Metropolitan expressway, which consists mostly of bridges, in Tokyo, Japan. The reliability and the durability of the system was also examined.

3.1 Overview of our demonstration system

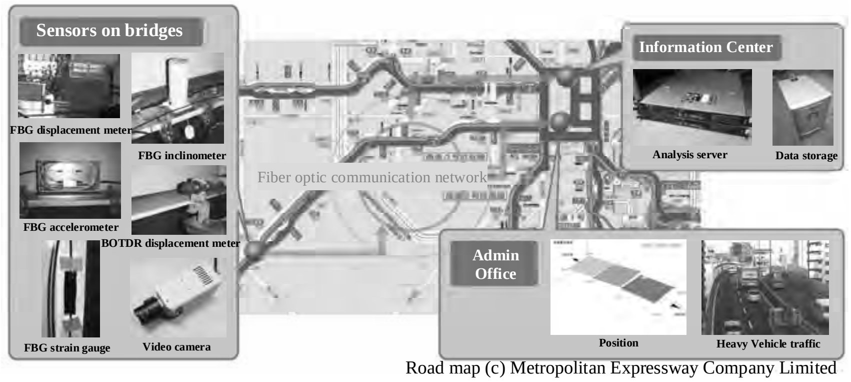
Figure 3 shows a geographical location of our demonstration system. The detail of our test site and our system are as follows.

3.1.1 Test site characteristics

Our test site is Komazawa and Sangen-jaya on the route No.3 of Metropolitan expressway that is one of the heaviest traffic routes in Tokyo Metropolitan City, where many heavy vehicles over regulation weight passes on. The route No.3 of Metropolitan expressway, which wholly consists of bridges, was constructed in the middle of 1960’s, and about 110,000 vehicles, including 30% heavy vehicles, pass through this route per day; namely 50,000 vehicles go toward the metropolitan core, and 60,000 vehicles go away from the metropolitan core. Therefore, both aging damage and daily damage caused by the traffic are extremely serious in our test site, and practically various maintenance is enforced on the route perpetually.

3.1.2 System configuration

Our demonstration system is consisted by five parts in accordance with our system architecture described in Section 2. As shown in Figure 3 and 4, the sensor subsystem is set between Komazawa and Ikejiri on the route No.3 of Metropolitan expressway. We use twenty-four FBG displacement meters, eight BOTDR displacement meters, eight FBG inclinometers, twelve FBG strain gauges, four FBG accelerometers and two FBG heat gauges for our measurement. The data measured using these sensors is collected at Ikejiri local station located 1.8 km away from Komazawa (and 5 km dummy fiber is added for our experiment), and is transmitted to the data analyzing subsystem in our information center located at Otemachi IDC by using the data transmission subsystem; here we use a fiber optic communication network provided by NTT, and then the data is calculated and analyzed for generating measurement data and diagnosis information using the data analyzing subsystem and the diagnosing subsystem, respectively. After that, measurement data and diagnosis information are transmitted to the administration support subsystem located at the road administrator’s office, Toranomon by using a similar data transmission subsystem, and then they are visually provided to the road administrators for supporting their decision making.



Road map (c) Metropolitan Expressway Company Limited

Figure 3: Geographical location of our demonstration system

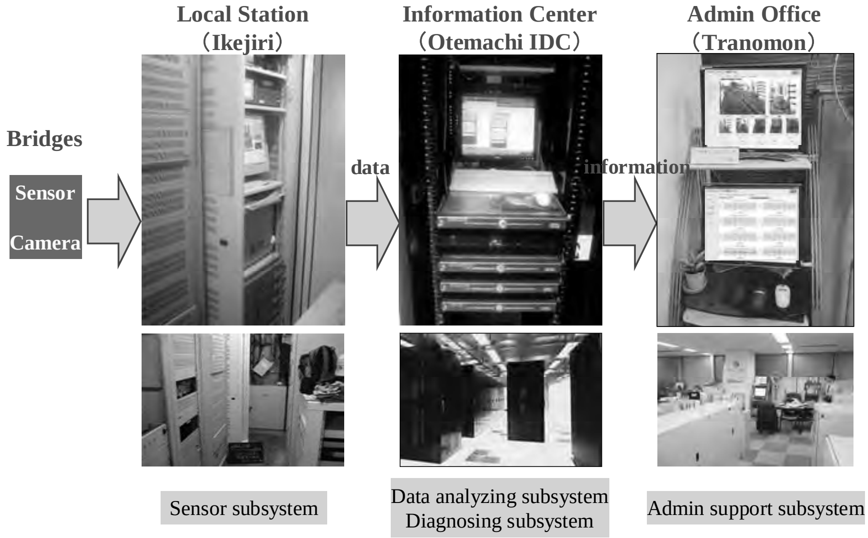


Figure 4: Data and information flow

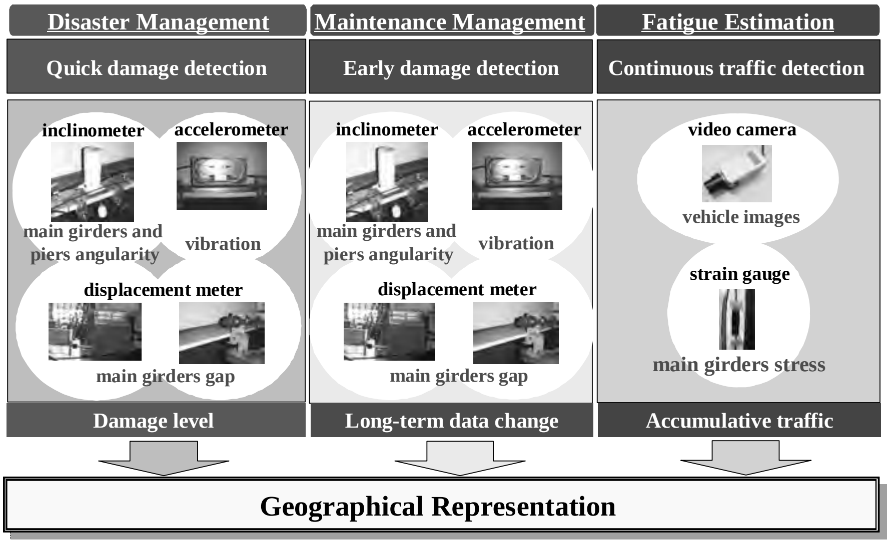


Figure 5: Output information

3.1.3 Measurement items

Figure 5 shows the data and information provided by our demonstration system corresponding to each sensor. As shown in figure 5, we provide them for three purposes, namely the disaster management, the maintenance management and the fatigue estimation, that are indispensable to the bridge management. Only one sensor system is required both for the disaster management and the maintenance management.

3.2 Data and information provision

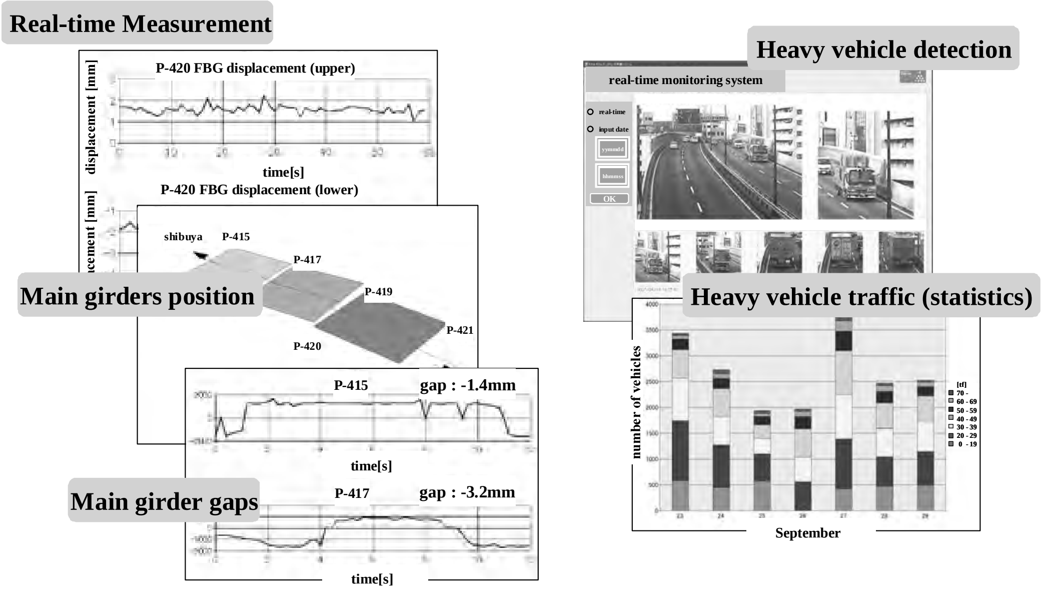
In this section, some examples of measurement data and diagnosis information provided to the road administrators in our demonstration system are introduced.

3.2.1 Measurement data provision

Figure 6(a) shows the display representation of measurement data. It is updated corresponding to data collecting cycle, namely 1Hz for FBG displacement meters, every thirty minutes for BOTDR displacement meters and 125Hz for the other sensors. Figure 6(b) shows a result of a real-time detection of heavy vehicles passing thorough our test site, and a histogram of its passing-vehicle number corresponding to its weight levels. These data can be redrawn if only they specify the date and time that they are interested in.

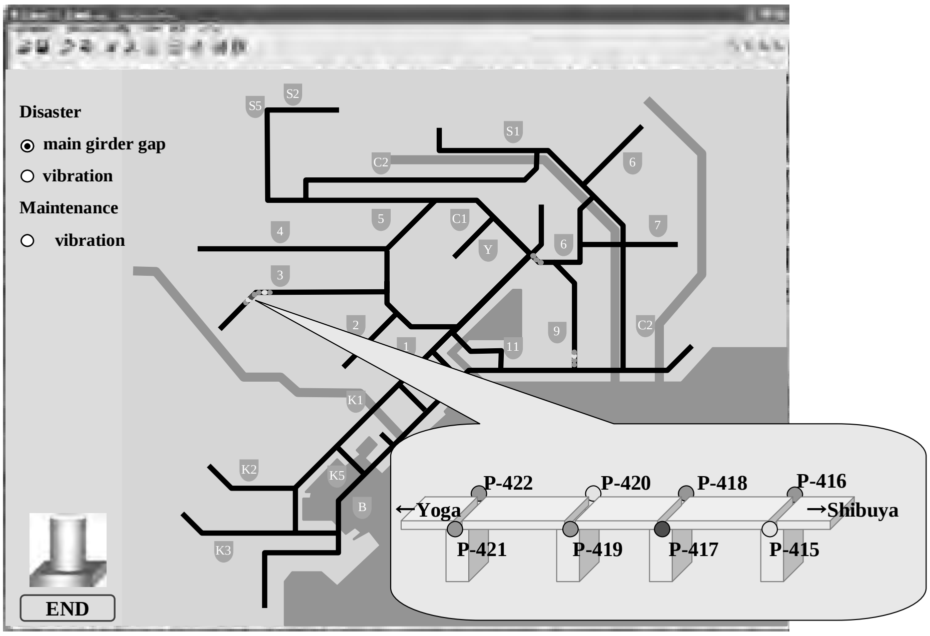
3.2.2 Diagnosis information provision

Figure 6(c) shows the display representation of diagnosis information. It is shown on a 2D geographical map using different colors corresponding to each gap level, namely "large", "small" or "non".



(a) Measurement data

(b) Heavy vehicle detection



(c) Example of the diagnoses information

Figure 6: Display representation of the administration support system

4. CONCLUSIONS

We introduce a concept of our real-time bridge remote monitoring system using various sensors for a quick detection of the damage caused by earthquakes and for a reliable measurement of the damage caused by its aging, and also introduce a demonstration system developed on Metropolitan expressway in Tokyo, Japan, for our feasibility study. The system has been in operation since March 2007 without any trouble and failure. In the next step of our research, we will try to establish the reliability and the durability of our system, and to estimate a cost effectiveness for the road administration.

ACKNOWLEDGEMENT

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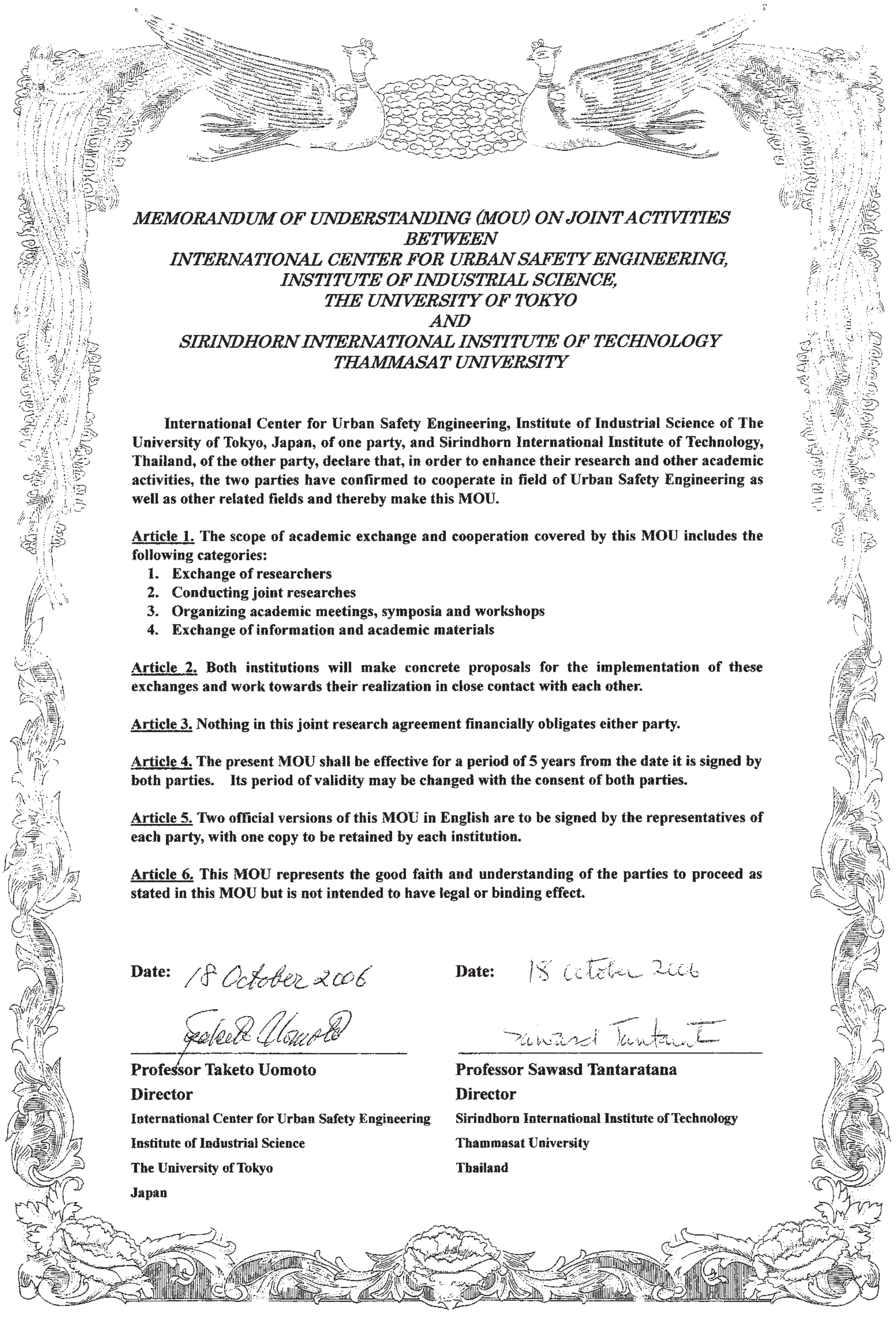
C. MOU

調印日	協定側	代表者	国名	期間
2006.6.14	Bangladesh Network Office For Urban Safety (BNUS) At Department of Civil Engineering, Bangladesh University of Engineering & Technology (BUET)	Head Md. Mazharul Hoque	Bangladesh	2007.8
2006.10.18	Sirindhorn International Institute of Technology Thammasat University	Director Sawasd Tantaratana	Thailand	5 年
2007.2.5	芝浦工業大学工学部 建設系土木工学科	学科主任 岩倉 成志	日本	5 年
2007.2.22	Global U-City Construction & Informaiton (Gucci) Hub Department of Civil Engineering (BK21) Han Yang University	Director Byung-Wan Jo	Korea	5 年
2007. 3.6	Department of Construction Engineering, National Kaohsiung First University of Science and Technology	Chairman Tai-Ping Chang	Chinese Taipei	5 年
2007.6.29	Center for Public Safety Research, Tsinghua University	Director Weicheng Fan	People's Republic of China	
2007.7.10 (継続)	Bangladesh Network Office For Urban Safety (BNUS) At Department of Civil Engineering, Bangladesh University of Engineering & Technology (BUET)	Head Md. Mazharul Hoque	Bangladesh	2009.3
2007.12.9 (継続)	School of Civil Engineering, Asian Insititute of Technology	Dean Worsak Kanok-Nukulchai	Thailand	2009.3
2008. 3.18	School of Applied Sciences and Engineering Monash University, Gippsland Campus	Head Samuel B. Adeloju	Australia	



MEMORANDUM OF UNDERSTANDING (MOU) ON JOINT ACTIVITIES
BETWEEN
INTERNATIONAL CENTER FOR URBAN SAFETY ENGINEERING,
INSTITUTE OF INDUSTRIAL SCIENCE,
THE UNIVERSITY OF TOKYO
AND
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY

International Center for Urban Safety Engineering, Institute of Industrial Science of The University of Tokyo, Japan, of one party, and Sirindhorn International Institute of Technology, Thailand, of the other party, declare that, in order to enhance their research and other academic activities, the two parties have confirmed to cooperate in field of Urban Safety Engineering as well as other related fields and thereby make this MOU.

Article 1. The scope of academic exchange and cooperation covered by this MOU includes the following categories:

1. **Exchange of researchers**
2. **Conducting joint researches**
3. **Organizing academic meetings, symposia and workshops**
4. **Exchange of information and academic materials**

Article 2. Both institutions will make concrete proposals for the implementation of these exchanges and work towards their realization in close contact with each other.

Article 3. Nothing in this joint research agreement financially obligates either party.

Article 4. The present MOU shall be effective for a period of 5 years from the date it is signed by both parties. Its period of validity may be changed with the consent of both parties.

Article 5. Two official versions of this MOU in English are to be signed by the representatives of each party, with one copy to be retained by each institution.

Article 6. This MOU represents the good faith and understanding of the parties to proceed as stated in this MOU but is not intended to have legal or binding effect.

Date: 18 October 2006

Professor Taketo Uomoto
Director
International Center for Urban Safety Engineering
Institute of Industrial Science
The University of Tokyo
Japan

Date: 18 October 2006

Sawasd Tantaratana

Professor Sawasd Tantaratana
Director
Sirindhorn International Institute of Technology
Thammasat University
Thailand

東京大学生産技術研究所都市基盤安全工学国際研究センターと
芝浦工業大学工学部建設系土木工学科との間における
教育研究連携に関する覚書

東京大学生産技術研究所都市基盤安全工学国際研究センターと芝浦工業大学工学部建設系土木工学科は，教育研究の協力と交流を推進させるため，ここに次のとおり覚書を締結する。

1．両機関は，両者の間で共通な学問分野において，次のような諸活動を推進するものとする。

（1）教員及び研究者の交流
（2）学生の交流
（3）共同研究の実施
（4）セミナー，シンポジウム，講義等の実施
（5）学術情報及び資料の交換

2．前条に基づく活動の実施細目については，両機関が協議の上決定するものとする。

3．この覚書は，両機関の代表者による下記の署名日の遅い方の日より５年間有効とする。有効期間は両機関の合意で延長することができる。有効期間内といえども，各機関は６ヶ月前の書面による通知により本覚書を解除することができる。

4．この覚書は２通作成し，両機関で各１通を保有する。

東京大学生産技術研究所
都市基盤安全工学国際研究センター

魚本健人

魚 本 健 人 センター長

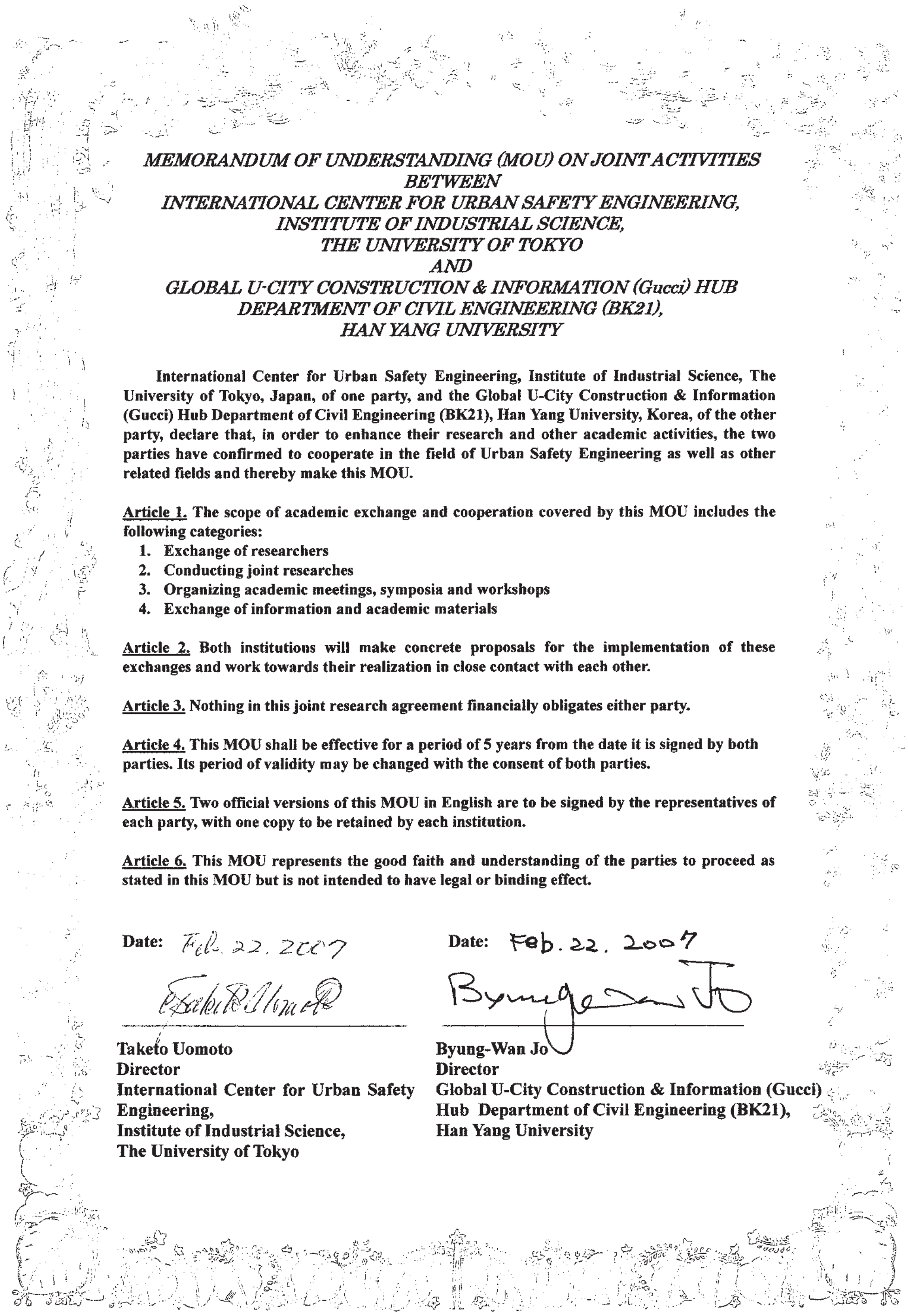
2007年＿2＿月＿5＿日

芝浦工業大学工学部
建設系土木工学科

岩倉成志

岩 倉 成 志 学科主任

2007年＿2＿月＿1＿日



MEMORANDUM OF UNDERSTANDING (MOU) ON JOINT ACTIVITIES
BETWEEN
INTERNATIONAL CENTER FOR URBAN SAFETY ENGINEERING, INSTITUTE OF INDUSTRIAL SCIENCE, THE UNIVERSITY OF TOKYO
AND
GLOBAL U-CITY CONSTRUCTION & INFORMATION (Gucci) HUB DEPARTMENT OF CIVIL ENGINEERING (BK21), HAN YANG UNIVERSITY

International Center for Urban Safety Engineering, Institute of Industrial Science, The University of Tokyo, Japan, of one party, and the Global U-City Construction & Information (Gucci) Hub Department of Civil Engineering (BK21), Han Yang University, Korea, of the other party, declare that, in order to enhance their research and other academic activities, the two parties have confirmed to cooperate in the field of Urban Safety Engineering as well as other related fields and thereby make this MOU.

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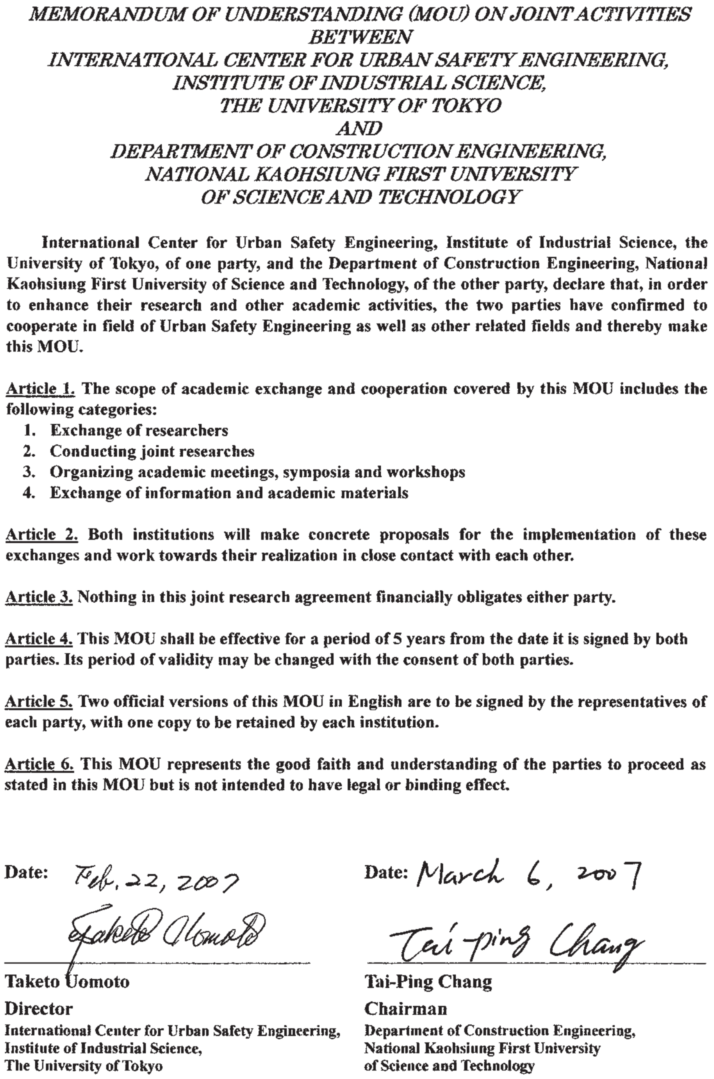
Article 6. This MOU represents the good faith and understanding of the parties to proceed as stated in this MOU but is not intended to have legal or binding effect.

Date: Feb. 22. 2007

Taketo Uomoto
Director
International Center for Urban Safety Engineering,
Institute of Industrial Science,
The University of Tokyo

Date: Feb. 22. 2007

Byung-Wan Jo
Director
Global U-City Construction & Information (Gucci) Hub Department of Civil Engineering (BK21),
Han Yang University



MEMORANDUM OF UNDERSTANDING (MOU) ON JOINT ACTIVITIES
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INTERNATIONAL CENTER FOR URBAN SAFETY ENGINEERING,
INSTITUTE OF INDUSTRIAL SCIENCE,
THE UNIVERSITY OF TOKYO
AND
DEPARTMENT OF CONSTRUCTION ENGINEERING,
NATIONAL KAOHSIUNG FIRST UNIVERSITY
OF SCIENCE AND TECHNOLOGY

International Center for Urban Safety Engineering, Institute of Industrial Science, the University of Tokyo, of one party, and the Department of Construction Engineering, National Kaohsiung First University of Science and Technology, of the other party, declare that, in order to enhance their research and other academic activities, the two parties have confirmed to cooperate in field of Urban Safety Engineering as well as other related fields and thereby make this MOU.

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Date: Feb. 22, 2007

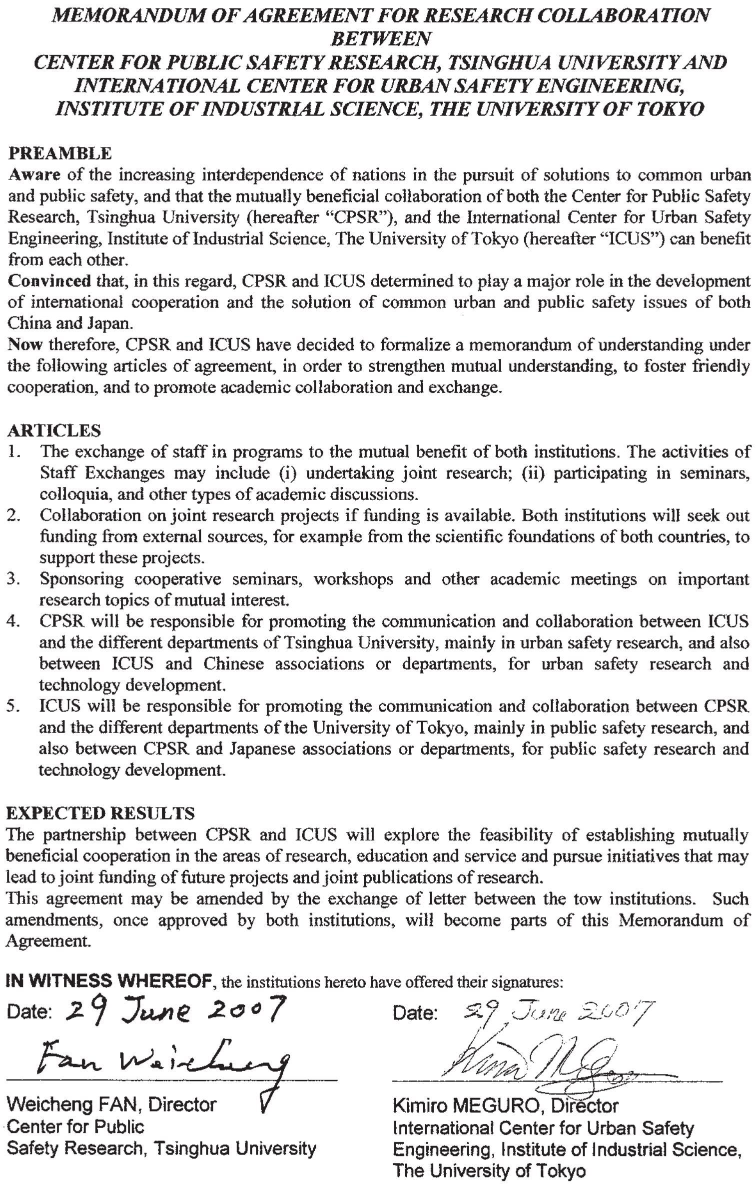
Taketo Uomoto

Taketo Uomoto
Director
International Center for Urban Safety Engineering,
Institute of Industrial Science,
The University of Tokyo

Date: March 6, 2007

Tai-ping Chang

Tai-Ping Chang
Chairman
Department of Construction Engineering,
National Kaohsiung First University
of Science and Technology



MEMORANDUM OF AGREEMENT FOR RESEARCH COLLABORATION BETWEEN CENTER FOR PUBLIC SAFETY RESEARCH, TSINGHUA UNIVERSITY AND INTERNATIONAL CENTER FOR URBAN SAFETY ENGINEERING, INSTITUTE OF INDUSTRIAL SCIENCE, THE UNIVERSITY OF TOKYO

PREAMBLE

Aware of the increasing interdependence of nations in the pursuit of solutions to common urban and public safety, and that the mutually beneficial collaboration of both the Center for Public Safety Research, Tsinghua University (hereafter "CPSR"), and the International Center for Urban Safety Engineering, Institute of Industrial Science, The University of Tokyo (hereafter "ICUS") can benefit from each other.

Convinced that, in this regard, CPSR and ICUS determined to play a major role in the development of international cooperation and the solution of common urban and public safety issues of both China and Japan.

Now therefore, CPSR and ICUS have decided to formalize a memorandum of understanding under the following articles of agreement, in order to strengthen mutual understanding, to foster friendly cooperation, and to promote academic collaboration and exchange.

ARTICLES

1. The exchange of staff in programs to the mutual benefit of both institutions. The activities of Staff Exchanges may include (i) undertaking joint research; (ii) participating in seminars, colloquia, and other types of academic discussions.
2. Collaboration on joint research projects if funding is available. Both institutions will seek out funding from external sources, for example from the scientific foundations of both countries, to support these projects.
3. Sponsoring cooperative seminars, workshops and other academic meetings on important research topics of mutual interest.
4. CPSR will be responsible for promoting the communication and collaboration between ICUS and the different departments of Tsinghua University, mainly in urban safety research, and also between ICUS and Chinese associations or departments, for urban safety research and technology development.
5. ICUS will be responsible for promoting the communication and collaboration between CPSR and the different departments of the University of Tokyo, mainly in public safety research, and also between CPSR and Japanese associations or departments, for public safety research and technology development.

EXPECTED RESULTS

The partnership between CPSR and ICUS will explore the feasibility of establishing mutually beneficial cooperation in the areas of research, education and service and pursue initiatives that may lead to joint funding of future projects and joint publications of research.

This agreement may be amended by the exchange of letter between the tow institutions. Such amendments, once approved by both institutions, will become parts of this Memorandum of Agreement.

IN WITNESS WHEREOF, the institutions hereto have offered their signatures:

Date: 29 June 2007

Fan Weicheng

Weicheng FAN, Director
Center for Public
Safety Research, Tsinghua University

Date: 29 June 2007

Kimiro MEGURO, Director
International Center for Urban Safety
Engineering, Institute of Industrial Science,
The University of Tokyo

D. 新聞への掲載記事および記者会見

年月日	形式	掲載紙	タイトル	被掲載者
2008年10月号	雑誌掲載	NHK 出版　住まい自分流 DIY「我が家を守る！」防犯･防災徹底ガイド	災害イマジネーションを高めることが一番の防災	目黒公郎 教授
2008年10月号	雑誌掲載	日経サイエンス	地震から命を守るには	目黒公郎 教授
2008年9月号	雑誌掲載	新都市　Vol.62 No.9 2008	地震防災上の最重要課題である既存不適格建物の耐震補強を推進するための環境整備	目黒公郎 教授
平成21年度版	雑誌掲載	ｱｰｽ工房（新建新聞社）　緊急地震速報ｽｰﾊﾟｰｶﾞｲﾄﾞ	緊急地震速報の「真の高度利用」	目黒公郎 教授
2008.09.01	新聞報道	日刊工業新聞	まずは転倒･落下防止から	目黒公郎 教授
2008.09.01	新聞報道	日刊工業新聞	途上国普及へ制度づくりも	目黒公郎 教授
2008.08.30	雑誌掲載	「医学のあゆみ」Vol.226 No.9	大地震時に効果的な救急医療を実施するために	目黒公郎 教授
2008.07.25	雑誌掲載	新宿区議会だより	間違いだらけの地震対策	目黒公郎 教授
2008.07.20	新聞報道	静岡新聞	災害想像力が不可欠	目黒公郎 教授
2008.10.14	雑誌掲載	芝浦工業大学　BULLETIN	目黒巻	目黒公郎 教授
2008.07.01	新聞報道	熊本日日新聞	公助、共助、自助で補強を	目黒公郎 教授
2008.06.28	新聞報道	河北新聞	自助、共助、公助	目黒公郎 教授
2008.06.26	新聞報道	高知新聞	耐震化推進の仕組み必要	目黒公郎 教授
2008.06.19	新聞報道	福井新聞	耐震化＋補償　新たな減災ｼｽﾃﾑを	目黒公郎 教授
2008.06.18	新聞報道	神戸新聞	自助、共助、公助	目黒公郎 教授

2008.06.16	新聞報道	徳島新聞	公助、共助、自助で補強を	目黒公郎 教授
2008.06.10	新聞報道	山陽新聞	公助、共助、自助で補強を	目黒公郎 教授
2008.05.16	TV	NHK	中国四川地震、二つの活断層　連動か◇「日本も耐震補強が急務」 東大生産技術研究所教授の目黒公郎さんの話	目黒公郎 教授
2008.05.16	新聞報道	朝日新聞	中国四川地震、二つの活断層　連動か◇「日本も耐震補強が急務」 東大生産技術研究所教授の目黒公郎さんの話	目黒公郎 教授
2008.02.21	新聞報道	読売新聞	期待の緊急地震速報	目黒公郎 教授
2007.10.22	新聞報道	毎日新聞	闘論　被災者の住宅支援　耐震改修促す施策を	目黒公郎 教授
2007.10.20	新聞報道	神奈川新聞	間違いだらけの地震対策	目黒公郎 教授
2007.10.02	新聞報道	東京大学新聞	緊急地震速報１日から開始　有益な情報、使い方次第	目黒公郎 教授
2007.10.01	TV	フジテレビ	特ダネ：緊急地震速報について、目黒巻	目黒公郎 教授
2007.09.15	新聞報道	中日新聞	【暮らし】幼児を災害から守る　緊急地震速報を有効に	目黒公郎 教授
2007.09.01	新聞報道	読売新聞	減災　暮らしをつなぐ　（５）　緊急速報　認知度は33％　本格導入控え　怖い過剰反応	目黒公郎 教授
2007.08.30	TV	中京テレビ	特番：緊急地震速報について	目黒公郎 教授
2007.08.28	ラジオ	ドイツ国営ラジオ	緊急地震速報について	目黒公郎 教授
2007.07.21	TV	NHK	ゲストコメンテータ：新潟県中越沖地震の被害と教訓	目黒公郎 教授
2007.07.18	新聞報道	毎日新聞	進まない耐震補強	目黒公郎 教授

2007.07.17	TV	フジテレビ	新潟県中越沖地震ニュース	目黒公郎 教授
2007.07.11	新聞報道	生活産業新聞	防災を語る:欠かせない当事者意識	目黒公郎 教授
2007.03.24	TV	NHK	サイエンスゼロ　研究紹介	目黒公郎 教授
2007.02.17	新聞報道	防災情報新聞	基調講演――目黒　公郎（東京大学生産技術研究所・教授）「緊急地震速報の一般利用への課題」より	目黒公郎 教授
2007.02.09	新聞報道	高知新聞	耐震補強推進のために　東京大学目黒教授講演	目黒公郎 教授
2007.01.24	新聞報道	和歌山新報	命救うには何より耐震補強　意識改め改修推進を　目黒東大教授が必要性を訴える	目黒公郎 教授
2007.01.24	TV	NHK	災害情報一見附市の実証実験	目黒公郎 教授
2007.01.19	新聞報道	朝日新聞	人脈記:震度 7 からの伝言⑪人々に物を、街に光を	目黒公郎 教授
2007.01.18	新聞報道	朝日新聞	人脈記:震度 7 からの伝言⑩建物崩壊、特撮に衝撃	目黒公郎 教授
2007.01.17	新聞報道	神奈川新聞	川崎市が新システム　地震直前消防署に警報	目黒公郎 教授
2007.01.17	新聞報道	毎日新聞	緊急地震速報　消防車両にも配信	目黒公郎 教授
2007.01.17	新聞報道	朝日新聞	「地震！」緊急速報で備え	目黒公郎 教授
2007.01.17	新聞報道	日経新聞	緊急地震速報　川崎市、消防に活用　全署・車両に自動伝達	目黒公郎 教授
2007.01.15	新聞報道	中日新聞株式会社	東海地震に備える「静岡特集」 室内の危険度　シミュレーション　吹っ飛ぶテレビ　倒れる家具	目黒公郎 教授
2006.10.11	TV	NHK	首都圏ネットワーク「首都圏・災害に備える～マンガで学ぶ防災」	目黒公郎 教授
2006.09.26	TV	NHK	プライスの謎	目黒公郎 教授

2006.08.27	TV	フジテレビ	報道 2001」:大地震発生への備えを徹底検証。「緊急地震速報」とは何なのか？	目黒公郎 教授
2006.06.02	新聞報道	朝日新聞	ジャワ地震　下敷き死　農村に集中　れんが積み構造原因か	目黒公郎 教授
2006.05.30	新聞報道	東京新聞	高価木材買えない。知恵や経験支援を　貧困層直撃　政府施策も不十分　荷造りひもで補強可能	目黒公郎 教授
2006.05.29	新聞報道	朝日新聞	社説:ジャワ地震　津波の傷も癒えぬのに	目黒公郎 教授
2006.05.11	新聞報道	The Daily Yomiuri	Packing tape offers quake protection	目黒公郎 教授
2006.05.09	新聞報道	読売新聞	荷造りテープで耐震補強東大教授開発　JICA 海外普及目指す　パキスタンなどで実施	目黒公郎 教授
2006.04.17	新聞報道	朝日新聞	新防災力、生き残るために	目黒公郎 教授
2006.04.08	新聞報道	パキスタン地元新聞	「PP-バンド耐震補強法、ムザファラバードでデモンストレーション」	目黒公郎 教授
2006.04.08	TV	NHK	おはようにっぽん 「PP-バンド耐震補強法、パキスタン地震被災地でデモンストレーション」	目黒公郎 教授
2006.04.06	新聞報道	朝日新聞	日本の智慧、復興に一役に感服	目黒公郎 教授
2006.03.21	新聞報道	東京新聞	防災教育　幼稚園も	目黒公郎 教授
2006.03.21	新聞報道	日本経済新聞・朝刊	大地震　死んではいけない！	目黒公郎 教授
2006.01.27	新聞報道	The Asahi Shinmbun	I'll be fine: Eleven years after the 'Imiya memo' showed most of the Kobe quake victims killed by badly constructed house， apathy remains the biggest obstacle to quakeproofing the nation's 11.5 million unsafe homes.	目黒公郎 教授

2006.01.17	新聞報道	東京新聞	危ない！　２００６ニッポン、地震被害軽減へ進む研究	目黒公郎
2006.01.16	TV	日本テレビ	地震防災のあり方	教授 目黒公郎
2006.01.16	TV	NHK	クローズアップ現代「大丈夫ですか？あなたの家　～木造住宅･進まぬ耐震化～」	教授 目黒公郎
2006.01.15	新聞報道	朝日新聞	「災害と社会　なぜ備えないのか」進まぬ耐震化　想像欠き「私は安全」	教授 目黒公郎
2006.01.13	新聞報道	朝日新聞	レンガの家に荷造りヒモ　震度 5 強に耐えた	教授 目黒公郎
2006.01.13	TV	NHK 神戸	関西クローズアップ「耐震化　あなたの家は安全？」	教授 目黒公郎
2006.01.09	TV	テレビ東京	迫り来る巨大地震！？	教授 目黒公郎
2006.01.06	新聞報道	ロイター通信	世界の防災への日本の貢献	教授 目黒公郎

地震災害イメージを

東大目黒教授 対策の実践書発行

「そのとき」をイメージできますか—。生活者の視点に立った「間違いだらけの地震対策」が出版された。筆者は目黒公郎東大教授。「家族にけがは？」「あなた自身は？」…と迫り、読者に地震被害の当事者の立場に立った対策の必要を訴える〝実践書〟。

「まず火の始末」「水に食料、毛布」は大間違い—。こうした地震対策の「常識」を筆者は否定、過去に国内外で発生した大規模地震のデータを分析して、最大のポイントは「建物の耐震性」と断言する。

さらに、「本棚の本が落ちてくるかもしれない」「激しい揺れの中で眼鏡やコンタクトレンズを紛失した」「家族に犠牲者が出たら…」と、徹底した当事者の立場で災害をイメージすることの意味、重要性を問いかける。

その上で、日々の生活サイクルを見つめて被災状況をシミュレーションし、自分だけの危機管理マニュアルをつくることを奨励する。防災グッズをそろえることに満足することなく、災害をイマジネーションできる頭（思考）こそが最大の防災対策に通じる、というわけだ。

飛散アスベストの問題などに触れたコラム、マグニチュードの解説や「地震が起きるまでにやっておくべきこと」を列挙した八項目の「基礎知識」コーナーもあって、入門書的な役割も担っている。

目黒教授は東大生産技術研究所都市基盤安全工学国際研究センター長。中央防災会議専門委員、地域安全学会理事など歴任。大規模地震発生時の横浜など東京湾臨海部の物流機能の確保を検討している国交省関東地方整備局「港湾ＢＣＰによる協働体制構築に関する委員会」委員。

税別千四百円。県内の主要書店で発売中。問い合わせは、旬報社☎０３（３９４３）９９１１。

（三好　秀人）

出版された「間違いだらけの地震対策」

2007年11月7日（水）神奈川新聞

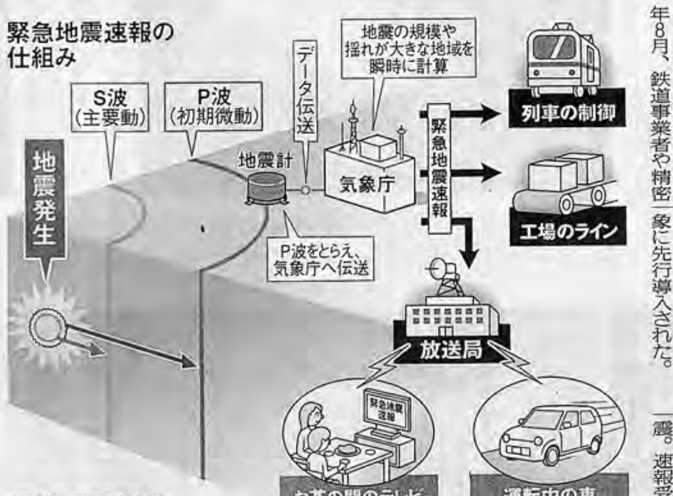
期待の緊急地震速報

ぴっくあっぷ

緊急地震速報の提供が昨年10月に始まって4か月余り。世界でも類を見ないという画期的なシステムだが、今年1月に能登半島で起きた地震では予測を誤って速報が流れないなど、技術的な限界も露呈している。2度の震災に見舞われた本県ではどの程度、導入が進んでいるのか。速報に接した時にどう対処すべきか。課題を探った。（大藪剛史）

「死者8割減」試算も

震央近くは間に合わず



（気象庁のHPなどから）

緊急地震速報は2006年8月、鉄道事業者や精密工場などを持つ業者らを対象に先行導入された。07年3月の能登半島地震。速報受信機などの販売会社「パルコミュニケーションズ」（新潟市東区）の五十嵐修社長は、携帯電話のメールで速報を受信。主要動が来る前に、家族に「家具から離れろ」と指示した。五十嵐社長は「工場で危険な製造ラインから少し離れるだけで、被害を減らせる」と話す。同年7月の中越沖地震では、関東の私鉄3社が大きな揺れの前に電車を緊急停止させた。

同年10月から一般向けにも供用を開始。最大震度が震度5弱以上と予測される場合に、震源の位置や震度4以上と推定される地域名など、簡略な情報が伝えられる。東京大学の目黒公郎教授（都市震災軽減工学）は、今後想定される東海地震が正午の地震で、市民全員が退避行動をとれたという理想的な条件下では「速報が整備されていた場合、死者を8割ほど減らせるだろう」と試算する。

一方で、震央の近くでは速報が間に合わないケースも予想される。同年7月の中越沖地震発生時、速報はまだ一般には提供されていなかったが、気象庁によると、仮に速報が柏崎市内に流れていたとしても、主要動到達から約3秒後になっていたという。新潟市内にいた五十嵐社長が速報を受信したのも、主要動を感じてから数秒後だった。

能登半島地震の余震と見られる今年1月の地震では、別の技術上の問題も露呈。最終的な最大計測震度は4・5だったが、気象庁は当初計測震度を4・3（震度4）と予測し、誤差が出た。一般向けの速報は最大計測震度4・5（同5弱）以上の場合に発令されるため、速報は流れなかった。

大きな地震では、震源断層がずれるのに一定程度の時間がかかり、ずれ始めの予測だけでは、最終的な震度の大きさと誤差が生じる場合がある。同庁地震火山部管理課は「地震計を増やしても、ある程度の誤差は埋められない」とする。

実際の緊急地震速報受信機の画面を見せる五十嵐社長（昨年10月、新潟市東区のパルコミュニケーションズで）

緊急地震速報　気象庁と防災科学技術研究所（茨城県つくば市）が全国に設置した約1000個の地震計で、地震発生直後の初期微動（P波、秒速約7㌔）をとらえ、次に来る主要動（S波、秒速約4㌔）の規模や揺れる地域を推定する。NHKと民放テレビが字幕による放送を開始しており、テレビをつけていれば、誰でも速報に接することができる。

2008年2月21日（木）読売新聞

2008年（平成20年）6月18日　水曜日　神戸新聞（夕刊）　（第3種郵便物認可）

建物耐震化促進へ3つのカギ

東大・目黒教授

自助　共助　公助

地震保険　共済制度　行政支援

五月の中国・四川大地震では、耐震性が不十分だった多くの学校や家屋が倒壊し、下敷きとなった人々の命を奪った。東京大生産技術研究所の目黒公郎教授（都市震災軽減工学）は「自助、共助、公助」で建物の補強を進め、地震による被害を食い止める仕組みを提案している。

都市での大地震というと、火災による被害を連想しがちだが、目黒教授は「家屋の倒壊が火災被害を拡大させている」と指摘する。阪神・淡路大震災の直後二週間に行った監察医らの調査では、建物や家具の下敷きになって窒息死、圧死、焼死した人が、犠牲者全体の約95％を占めていた。

家屋の倒壊は、さまざまな悪影響を生じる。道路がふさがれ消防車などが通行しにくくなる、下敷きになった人の救助を優先させるため消火が後回しになる、倒壊した家屋で発生した火災を素人が消火するのは難しい―などだ。

四川大地震による被害について目黒教授は「浅い場所で大規模な地震が起きた。震源域付近では、手抜きなしで基準通りに造った建築物でも、大きな被害を防げなかっただろう」と話す。

巨大地震でも

耐震基準を引き上げても、住宅などの耐震性向上には必ずしも直結しないという。目黒教授は「地域や国の経済力、技術力に見合った基準と、それを守らせる仕組みが必要だ」と訴える。

中国・四川大地震で倒壊した自宅跡で食事をする被災者家族＝5月24日、四川省什邡市（共同）

四川大地震で惨状あらわ

「東南海」視野に備えを

日本では「自然災害は自力復興」が原則だが、目黒教授は、耐震補強を進めた人や耐震診断で「問題ない」とされた人の家が地震で壊れた場合、行政が優遇して支援する方法（公助）を提案する。耐震化が進み被害が大きく減るため、がれきの撤去や仮設住宅の建設費用などの公的負担も減少。全壊世帯に一千万―一千五百万円を支援しても、公的負担の総額はむしろ少なくなるという。

さらに、補強済みの住宅のみを対象とする共済制度（共助）を新設。補強した建物で被害が出るのは震度6以上の地域で、全壊率は数％。想定される東海地震などの巨大地震でも、震度6以上の地域に入るのは全国の建物の数％にとどまる。

このため、加入時に数万円を払い込めば、東海地震や東南海・南海地震でも全壊で一千万円、半壊で三百万円の支援が可能だ。

81年が分岐点

その上で、補強済み住宅を対象に、揺れによる被害を免責して地震火災の被害を補償する地震保険（自助）を設ける。耐震性が高ければ初期出火や延焼を減らすことができるため、保険料を大幅に低く抑えることが可能という。

三つの制度が整えば、建て替えや補強をした家が大地震で壊れたり焼けたりしても、新築するのに十分な支援を受けられる。ただ、残念ながらまだ提案の段階だ。

では、今すぐできることは何か。目黒教授は「一戸建てなら、二〇〇〇年以降のものの多くは大丈夫。一九八一年の建築基準法改正前の物件は、耐震診断と補強を考えた方がいい」としている。

あなたの科学

ナノテクノロジーで扱う一―百ナノメートル（ナノは十億分の一）という原子レベルの微小な世界。このサイズで人工的な制御が可能になれば、あらゆる産業で革新的な進歩が期待できる。

医療では、細胞の一つ

を探る

ナノテク

クをベースにした製品を世界で最も多く世に出している」と話す。特に素材は圧倒的に強いという。

良い例が、電子の磁気的な性質を利用して高性能のメモリーを作るスピントロニクス。日本の産業技術総合研究所が開発した高密度記録技術は、

）素材開発

近年のハードディスク大容量化を支えている。電源を切っても情報が消えない、次世代メモリー「MRAM」の開発も東芝などがIBMと競っている。

ただし、将来は楽観できない。技術を支える工

2008年6月18日（水）　神戸新聞（夕刊）

二つの活断層　連動か

四川大地震　専門家が分析

活断層（内陸）型の地震としては世界最大級の中国・四川大地震。原因となった断層の長さは250～300キロに達し、地震のエネルギーは阪神大震災の30倍に達するとみられることがわかってきた。専門家は、中国大陸特有の地下構造が大きな地震を起こし、耐震性のない建物の倒壊で、人的な被害が拡大したと指摘する。

（黒沢大陸、鈴木彩子）

断層の長さ300キロ　エネルギー「阪神」の30倍

地震を起こしたのは竜門山（ロンメンシャン）断層帯の一部とみられる。竜門山断層帯はヒマラヤをつくったプレート（岩板）の動きで西から押され、ひずみがたまって割れてできた。

筑波大の八木勇治准教授らの解析によると、四川大地震でずれ動いた断層の長さは2段階で計約300キロに達する。地震発生から約50秒で南側にある長さ100キロ、幅40キロの部分が最大7メートル動いた。その後10秒ほどかけて北側の領域に破壊が広まり、さらに1分間ほどかけて北側の長さ150キロ、幅30キロの部分が最大4メートル動いたという。

八木准教授は「前半は（一方の地盤がもう一方の地盤の上に覆いかぶさる）逆断層の、後半は（両側の地盤が水平にずれる）横ずれ断層の成分が多く、二つの活断層が連動し、大地震になったと考えられる」と話している。

東京大地震研究所の引間和人研究員は、長さ250キロ、幅40キロの活断層が100～120秒程度かけて最大13メートル動いたとみている。

当初、活断層の長さを100キロとしていた名古屋大の山中佳子准教授も、その後の余震分布を反映し長さ260キロ、幅50キロの断層が110秒かけて最大6・7メートル動いたとする解析を公表した。

米地質調査所は、活断層は長さ250キロ、幅20キロで、最大で9メートル程度動いたと解析しており、地震の規模を断層の大きさやずれから算出するモーメントマグニチュード（Mw）で7・9としている。八木准教授、引間研究員も7・9、山中准教授は7・8と算出した。地震のエネルギーはMw6・9だった阪神大震災の約30倍になる。

政府の地震調査委員会は、静岡の富士川河口断層帯などでマグニチュード8程度の地震が起きる可能性を指摘しており、国内でも同規模の活断層型地震の恐れがある。

プレートの力回り込む

加藤照之
東大地震研究所教授

中国はちょっと特殊な場所だ。通常、地震はプレート境界に集中して発生するが、中国ではチベット高原の一帯で起こっている。インドのプレートが中国大陸を押した結果、チベット高原付近の全体が変形している。インドのプレートは、広大な大陸が広がる西や北にはなかなか進めない。東に進もうとすると、南中国ブロックという固い地盤がじゃまになるため、南に向かって回り込む形に力が働いている。こうした力が集中している地域で、今回の地震が起こった。

この付近は、四川―雲南地震活動帯とも呼ばれている。とくに鮮水河（シェンシュイへ）断層帯は活動が活発で、同じ所で繰り返し地震が起きている。それに比べると竜門山断層帯は活動度が低いが、少しずつエネルギーが蓄積されていたと考えられる。中国はプレートの動きが活発な日本周辺に比べてひずみがたまる速度は小さいが、国土が広く活断層も多いのであちこちで地震が起こり、全体として地震の数が多くなっているのではないか。

日本も耐震補強が急務

目黒公郎
東大生産技術研究所教授

倒壊の状況を見ると、断層の直上では、日本の震度で6強や7の揺れが起きた可能性が高い。地震動が広範囲に影響を与え、7千人余の死者を出した1891年の濃尾地震（M8・0）に匹敵する。山崩れも多発しており、雨が降ると大泥流が起こる可能性もある。

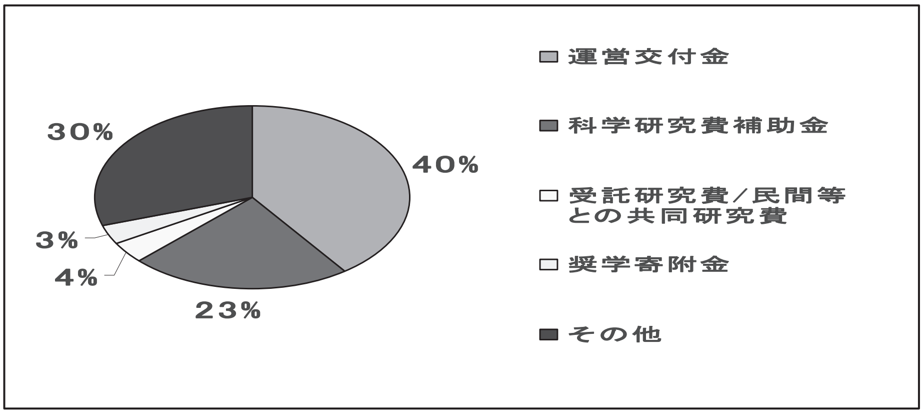
鉄筋コンクリートの柱の間にブロックやれんがを積んだ構造の公的施設や学校が多く崩れた。日本の建築物と違って枠と梁（はり）のつなぎ目の鉄筋がきちんと組まれておらず、揺れでれんがなどが崩れたために鉄筋の枠がゆがんで倒れ、床板がそのまま重なり合っている様子が見てとれる。田舎の地域ではれんがづくりや木造の家が多く崩れていた。

今回の地震を、ひとごとと思ってはいけない。大阪の上町断層帯の地震では56万戸が全壊するとの想定を政府も出した。犠牲者を減らすには建物の耐震化が何より重要だ。耐震補強をした建物が壊れたら、復旧のために公的資金が投入される仕組みをつくるなど耐震化を促す政策が必要だ。

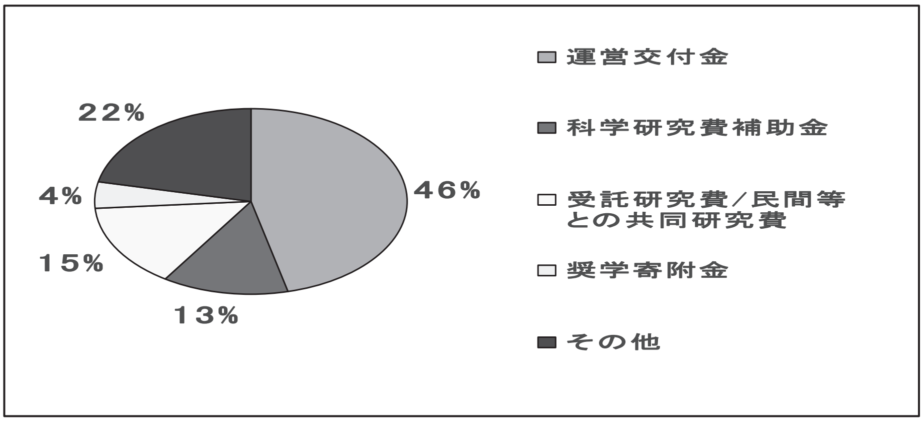
2008年5月16日（金）　朝日新聞　朝刊

E. ICUSの予算内訳(2006-2008)

2006年度



2007年度



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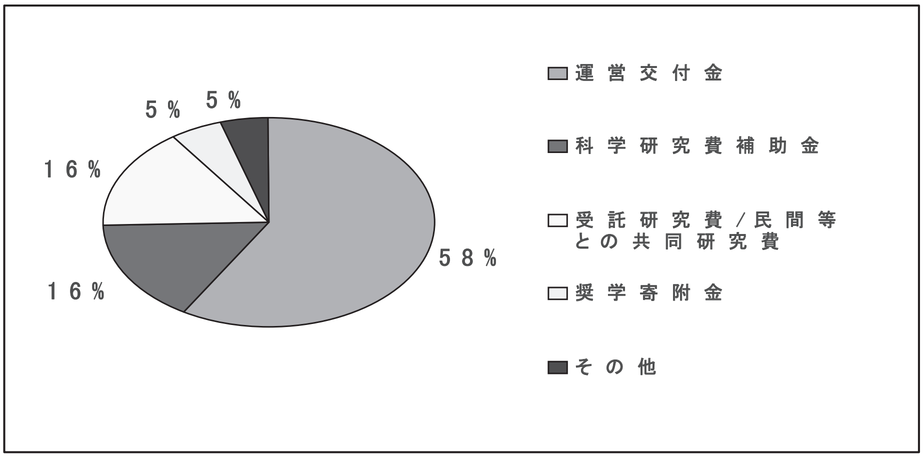

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The University of Tokyo

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COMMUNICATING RISKS TO THE PUBLIC

By

*Toshiko KIKKAWA**

WHAT IS RISK COMMUNICATION?

Definitions of risk and risk communication

Although there are some variants of the definition of risk and risk communication, the most accepted one was given by the National Research Council in the United States which is a part of the National Academies providing science, technology and health policy advice under a congressional charter. In its epoch-making report on risk communication, it is stated that "an act or phenomenon is said to pose a hazard when it has the potential to produce harm or other undesirable consequences to some person or thing" and that "the concept of risk further quantifies hazards by attaching the probability of being realized to each level of potential harm." In short, risk can be defined as a probability of hazard occurrence.

The report defined risk communication as: "an interactive process of exchange of information and opinion among individuals, groups, and institutions. It involves multiple messages about the nature of risk and other messages, not strictly about risk, that express concerns, opinions, reactions to risk messages or to legal and institutional arrangements to risk management."

The emphasis of the definition is on the interactive process of communication among interested parties. Risk communication is not a one-way message that delivers the results of scientific risk assessments and the political decisions based on the assessments from risk experts to the general public. The risk experts, e.g. scientists, governmental officials, or business persons, are those who have more and detailed information about risks.

Risk communication failure: Warnings about tobacco related health problems are hidden behind price tags

The figure on this page gives a graphical representation of risk communication. Risk messages are delivered from risk experts to interested people and concerns, opinions, or reactions to risk messages or to risk management are delivered from interested people to risk experts.

In the past, only risk experts could have access to the information and were assumed to make appropriate decisions based on reasonable evidence. This meant, on the contrary, that the general public had little access to information and was excluded from decision-making.

Risk Communication

Historical background of risk communication

The word "risk communication" is a relatively new concept in the field of risk management. It has emerged and drawn attention since late 70's or early 80's. The reasons for this might be three: the increase in risk problems, changes in nature of risks, and rises in concerns for people's rights to know and participate in democratic societies. The former two deal with risks themselves and the last one deals with a social aspect.

Firstly, risk problems have increased. Fair examples of this are environmental pollution and infectious diseases. Environmental pollution has been increasing presumably because of the urbanization and population growth. The spreading of infectious diseases such as AIDS has also become a serious problem partly because of the development of transportation systems that enable a world-wide interaction of people. The increase of risk problems would imply that risks are ubiquitous in our society. Therefore, for people who want to avoid these increasing risks as much as possible, information concerning them has become more important than ever before.

Secondly, the nature of risks has changed, thus the importance of risk communication has increased. Even experts may sometimes find difficulties in assessing risks because either the hazard or the risk probability is uncertain or both of them are uncertain. The word "uncertain" implies that certain substances may have adverse effects in the long run, but currently, tools for measuring risks are not well developed or there is little or no available data. Risks can also be said to be uncertain in case that there are disputes among experts about how to interpret the data or estimate the probability.

Let me take some examples. Natural hazards such as earthquakes or volcanic eruptions will cause catastrophic consequences but the probabilities of such natural hazards can not be exactly estimated. They may occur once in every fifty years, or perhaps more or less frequently. Bovine Spongiform Encephalopathy (BSE), commonly known as mad cow disease, is another example whose consequence is cruel but its pathogenic probability is still unclear.

The vague nature of these risks makes risk communication more difficult and thus sometimes leads to inappropriate political decisions of risk experts. For example, in case of the Minamata disease in Japan, where serious mercury poisoning was caused by eating contaminated fish, victims were left unattended during the dispute on the cause of the symptom among medical professionals and governmental officials. The situation became more serious during the dispute and the resulting inaction cost dearly in the long run.

The BSE crisis in the United Kingdom is another example of failure in risk communication, which led to mismanagement. The first discovery of the disease in British cattle was in 1986. However, it was not until 1996 that the British Government officially recognized the link between a new variant of Creutzfeld-Jakob disease and the consumption of beef from cattle with BSE. During this inaction period, from the perspective of risk communication, the Government took a position that seemed to support the beef industry rather than admitting to, and informing about, the risk, however small it might be. This bureaucratic mismanagement finally led to the overnight collapse of the British beef market after the official recognition. Beef consumption across the European Union dropped 11% in 1996, and the EU spent 2.8 billion US dollars in subsidies alone for the beef industry. The U.K. cost is estimated over 4 billion pounds.

In addition, there are social costs which are slower and more difficult to account for than economic ones. The examples of them are management distrust, collapse of farmers' lives, and so on. Although risk experts, especially business persons and governmental officials, often focus only on short term economic cost, it might be wiser to approach these risk situations from a wider perspective, including social aspects. Risk communication is one of the promising approaches for dealing with such situations as it requires a long-range perspective of scientific, economic, and social risk management.

Lastly, there has been increasing concern on the peoples' rights to know and participate in political decision-making in democratic societies. As the former has been widely recognized, people are more carefully scrutinizing the political process as to whether information is censored or not. Furthermore, they ask to participate in the decision-making process from the very beginning stage of the planning, something they had never been involved in before. If risk experts such as governmental officials and business persons ignore this desire, serious and persistent resistance that can not be resolved in the short term is likely. To avoid such hopeless confusion in advance, it might be better to build a system for public participation.

Examples of them are 'public involvement' or 'public counseling' plans which are realized and, in some cases, institutionalized in the US, Europe, Japan, and so on.

Misconceptions about risk communication

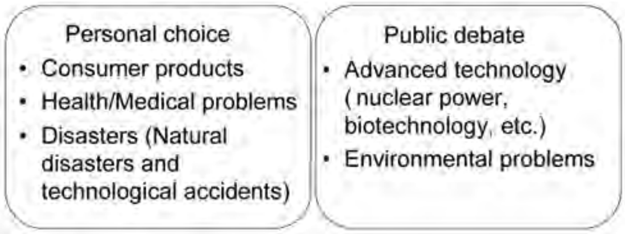
At the very beginning when the concept of risk communication was proposed, it might have been thought of as a tool for communicating the results of scientific risk assessments to lay persons. It was sometimes used as a tool to persuade laypersons to accept risks.

However, there can be an inherent flaw in this assumption. Risk experts are sometimes wrong in the sense that they underestimate risks. Unfortunately, some risks are found to be higher than their estimation as in the above mentioned BSE case. The problem is that they often wish to persuade lay persons to accept these risks as being so low as to be negligible. This situation may prove to be not only wrong, but also disastrous. The tragic consequence of the negligence ended with huge loss of lives, as in the cases of HIV-contaminated blood, September 11 terrorism, and so on. Governmental officials might have received some underestimated forewarnings and the number of victims increased as a result of the underestimation.

Furthermore, there is conflict between risk experts and the public when the officials are slow to react to the increasing public concerns and interpret these as public overreaction. The possible result of the conflict may be that the risk experts are undermined.

Let me again take the case of BSE. For nearly 10 years, the British government insisted there was no risk, or the risk was so small that it could be neglected. The persuasion might have been effective at first, but slowly lost its effectiveness as contradictory data prevailed. At the end of this story, it achieved adverse effects on the attitudes of people and the society. Once trust in management is destroyed, it becomes difficult to inform people even if the information is true the subsequent time. Destroying trust is easy, but rebuilding it needs a ceaseless and tremendous effort. It might be easier to disclose information and properly inform people from the very beginning rather than to make a, long, huge communication effort afterwards.

Risk communication is a trust-building process in the ideal and practical sense. It requires disclosure of communication among interested parties in democratic societies and it really works as a kind of 'insurance' for the future as well.



Personal choice
- Consumer products
- Health/Medical problems
- Disasters (Natural disasters and technological accidents)

Public debate
- Advanced technology (nuclear power, biotechnology, etc.)
- Environmental problems

Settings of Risk Communication

SETTINGS OF RISK COMMUNICATION

Risk communication of personal choice

The National Research Council distinguished two types of risk communication settings: personal choice and public debate.

The figure on this page gives the typology of risk communication settings. Examples of personal choice setting are risk communication of consumer products, health problems, and disasters. Examples of the public debate setting are risk communication of nuclear energy, genetically modified food, environmental problems, etc.

In the personal choice setting, a person is informed of risks and, whether he/she will accept the risks is determined by his/her own choice. It is known that one of the biggest problems of personal choice setting is that people underestimate risks and are reluctant to avoid risks, although being fully informed of them. This psychological tendency is called 'unrealistic optimism.' Because of this tendency, more continuous and truthful communication efforts are necessary to let people know and avoid risks.

One solution to this problem is to plan educational programs to properly inform about risks using some persuasive techniques. An example of them is fear-arousing appeal, which causes a strong emotional state of fear by showing, for example, a dramatic film of victims, and then recommending taking protective measures.

Risk communication of the public debate

In the public debate setting, many interested parties will try to reach a consensus through many paths of communication. In this setting, risk communication requires all the interested parties to participate in the decision-making from the very beginning of the process.

It is unfortunate but possible, that, even if being properly informed of risks and having thoroughly discussed them, people involved may not reach a consensus. This is partially because people have their own values and cultures to which they adhere.

Toward a successful risk communication

To make risk communication successful, two crucial factors, that is, disclosure of information and transparency should be guaranteed in the decision-making process.

Firstly, disclosing all information regarding risks to the public increases the probability that additional risks or flaws in management approaches are found. As the number of people who are involved increases, there might be more chances to find previously unidentified risks. It can be an efficient way of detecting risks.

Secondly, the whole process of decision-making is recorded and opened to the public. It can be reviewed and alternative decisions be taken when it becomes clear that the first decision proved to be wrong. This situation is possible merely because of time constraints in the first decision-making process or because new scientific evidence is found and added.

***Associate Professor, Keio University**

Elementary school students discover the value of their town

From April to May of this year, sixth grade students from Uehara Elementary School, located close to ICUS, have been exploring Uehara town under the guidance of university students mainly from Muramatsu laboratory, IIS. The title of this special project is "We are the town explorers" and has been carried out from the last year under the initiative of Muramatsu Laboratory based on the premise that it is necessary to start teaching early the importance of preserving our urban cultural heritage, resources, etc.

The participants were divided in seven groups of five to six students each of them with one university student leader. Each group chose one topic suggested by the leader, and explored the neighborhood looking for it. I was the leader of Team Red and decided to search for the “town guardians” or elements that take care of several town aspects such as safety, beauty, convenience, etc. I wanted the children to think about various town elements and their interaction. During our explorations we identified several guardians based on many discussions. Finally, we prepared our images and presented them on June 2 at the IIS Open House.

Uehara town “guardians”

Because I have not been in contact with young children for a long time, it was a tough but exciting experience for me. I discovered Uehara town and also different aspects of children.

(By Mariko Abe, Graduate student, Meguro Laboratory)

ICUS joined IIS Open House

ICUS joined the Institute of Industrial Science Open House which was held from June 1 to 3. In this event, our institute is open to the public to share with the visitors its research outcomes. This year ICUS topic was “Towards the Establishment of a Sustainable Urban System.” As every year, all laboratory members participated and displayed their panels. Topics varied in a wide range from diagnosis, repair, and strengthening of concrete structures to diffusion of contaminants in urban areas. The problem of formation of cavities and loose ground above old underground pipes, the need of disaster resilient water cycle systems for sustainable societies, and the challenge to integrate countermeasures to achieve earthquake disaster resilient urban systems were also addressed. The open house was also an opportunity to introduce the 2005 Annual Report as well as RNUS activities. Reports and newsletters were given away to visitors.

An ICUS Quiz was prepared following the success of last year issue. Twenty one questions were proposed and based on the number of correct answers, ICUS calendars and pen cases were offered as prizes. Almost 60 persons participated in the quiz and 25 calendars were distributed. This year it was the first time that the open house was held on a Saturday giving the opportunity to whole families to visit our campus. Many children were enthusiastic about the ICUS Quiz and put their parents under pressure to help them get the correct answers.

(By P. Mayorca)

ICUS quiz drew attention of the open house participants. In the photo, three calendar awardees.

RNUS Activities

Inspection on Short Span Traffic Bridges in Bangkok Metropolitan Administration Area

The Regional Network Office for Urban Safety (RNUS), in cooperation with the Sirindhorn International Institute of Technology (SIIT), launched the infrastructure inspection program for the Bangkok Metropolitan Administration Area (BMA).

Students measuring concrete strength using Smidth’s hammer

The program started with the inspection of short-span concrete bridges across canals in western Bangkok. The inspection aimed at evaluating the condition of these bridges regarding to its serviceability and durability. Smidth’s hammer was used to measure the structure strength while the carbonation depth and reinforcing bar corrosion were closely observed.

The inspection results will be used to determine the required maintenance and how to efficiently allocate the available budget. In addition, a group of students from AIT and the SIIT joined this activity as a part of their training.

(By R. Sahamitmongkol)

Structure deterioration was investigated from a boat

Prof. Meguro promotes safer communities in Algeria and Pakistan

As a part of ICUS international activities, Prof. Meguro visited Algeria and Pakistan from March 17 to 26. The Japan International Cooperation Agency (JICA) is carrying out a microzonation study for the capital city Algiers and Prof. Meguro is the chairperson of the advisory committee. The project objective is to prepare the basic data needed for the establishment of a comprehensive disaster management plan for Great Algiers. On this occasion, Prof. Meguro reported on the project progress and helped outlining its next stage.

Shaking table demonstration carried out in Muzaffarabad, Pakistan

In Pakistan, Prof. Meguro visited Muzaffarabad, the most affected region during the 2005 Kashimir Earthquake. During his first trip to the area last year, he introduced the PP-band method to retrofit masonry structures. Due to the great interest that the technique generated on the local people, JICA decided to carry out a demonstration project at the site. A typical house was constructed and then retrofitted with PP-band meshes. The cost of the material needed to retrofit one ordinary house was US$30 and the total retrofitting cost, including installation, was approximately 5% of the total construction cost. This value is expected to reduce as workers' skill improves.

In order to effectively explain the benefits of retrofitting, demonstrations for the public and decision makers are powerful tools. The Nepalese NGO National Society for Earthquake Technology (NSET) has been carrying out shaking table demonstrations in many countries for this purpose and joined this project. Two 1/6 model replicating the full size house, one retrofitted and the other non-retrofitted, were prepared and shaken. The non-retrofitted specimen collapsed whereas the other stood. The demonstration was carried out in front on governmental authorities, NGO representatives, mass media people, and the general public and had a strong impact on them. Before the demonstration, Prof. Meguro explained the background and principles of PP-band retrofitting and Mr. Amod M. Dixit, Executive Director of NSET, translated the presentation to the local language.

(By K. Meguro)

Pilot model constructed to show PP-band retrofitting method

ICUS members visited BUET, Dhaka, Bangladesh

Prof. K. Meguro, Dr. M. Yoshimura, Dr. H. Kanada, and Mr. K. Tsukimoto, graduate student of Meguro laboratory, visited Bangladesh University of Engineering & Technology (BUET) from June 14 to 19, 2006.

On 14, ICUS signed the contract for the establishment of the Bangladesh Network Office for Urban Safety (BNUS) with the Department of Civil Engineering, BUET. The new office will open in September 2006.

Ceremony participants

A short course on Evaluation of Concrete Structures was held on 14-15, Prof. Meguro, Dr. Yoshimura, and Dr. Kanada delivered presentations on the importance of earthquake disaster prevention, seismic vulnerability assessment using microtremor measurements and introduction of non-destructive inspection (NDT) methods for concrete structures, respectively. On the afternoon of the second day, a demonstration using actual equipments was performed for the participants.

Dr. Yoshimura explains how to operate equipment

On 15, Prof. Meguro was invited as a guest speaker to the seminar organized by the Engineer Staff College Bangladesh and the Bangladesh Earthquake Society. He introduced recent developments of earthquake related activities in Japan. After his presentation, Bangladeshi engineers asked many questions on how to adopt these technologies to their country.

Seminar organized by Bangladesh Earthquake Society

Investigation of bar arrangement of RC slab using NDT equipment

From 16 to 19, many structures (BUET facilities, fire stations and buildings under construction) were surveyed with BUET members. Dr. Yoshimura and Mr. Tsukimoto measured their dynamic properties using microtremor measurement equipment and Dr. Kanada investigated rebar arrangement using NDT equipments.

(By H. Kanada)

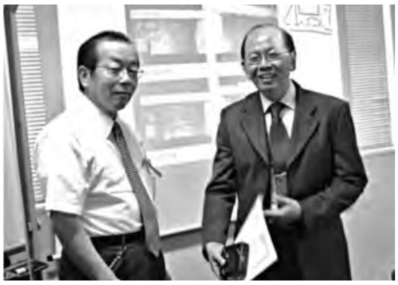
Dr. Tan visited ICUS under JSPS Scientific Exchange Program 2006

Dr. Kiang Hwee Tan, Associate Professor in the Department of Civil Engineering at the National University of Singapore (NUS), visited ICUS from 10 to 24 June 2006, under the JSPS Scientific Exchange Program. The visit is a significant step towards further academic exchange and cooperation between the two institutions, which signed a memorandum of understanding on joint research in March 2005.

Dr. Tan obtained his doctorate degree from the University of Tokyo in 1985. He has carried out research on beams with openings, fiber-reinforced concrete and ferrocement, external post-tensioning, and fiber-reinforced polymer reinforcement. He has published more than 150 refereed papers and a book on "Beams with Openings: Analysis & Design." Dr. Tan is a member of the editorial/advisory board for six international journals, including ASCE Journal of Composites for Construction (USA), JCI Journal of Advanced Concrete Technology (Japan), and ICE Structures & Buildings Journal (UK). He is also the Vice-Chairman (Technical) for the International Committee for Concrete Model Code for Asia. He was the organizing chair for the Sixth International Symposium on FRP Reinforcement for Concrete Structures (FRPRCS-6), held in Singapore in July 2003.

During his visit, Dr. Tan gave a lecture on "Rational Approaches to Structural Strengthening." In the lecture, he explained the use of strut-and-tie models and strip method for beam and slab strengthening using fiber-reinforced polymer (FRP) systems, and illustrated them with tests on dapped beams, beams with recess or opening, and slabs with an opening. Dr. Tan discussed the use of the load-balancing method in structural strengthening using external tendons for both simple-span and continuous RC beams. It was evident that these approaches that are based on principle of statics are versatile and safe for application, especially for complex structures.

Dr. Tan shared his other research interests with researchers at ICUS. He is currently doing research on blast resistance of masonry and reinforced concrete walls, sprayed polymer and sprayed FRP, and fire-resistance of FRP systems and FRP-strengthened beams. He was impressed with the test facilities at ICUS, especially the wind tunnel and the tri-axial shake table, and with the work carried out at ICUS, in particular on the use of polypropylene bands as a cheap strengthening material. He hopes to initiate joint research in these areas with ICUS, and looks forward to ICUS researchers visiting his department at NUS in the near future.



Dr. Tan receives certificate from Prof. Uomoto after delivering a lecture at ICUS

Dr. Tan also visited three construction sites dealing with FRP strengthening and tunnel boring, and had discussion with researchers from the research institutes of Kajima Corporation and Obayashi Corporation. He also met members of the Association for Advanced Composite Technology on Construction Field (ACC) and Information Technology Building System (ITBS) Group. He is grateful to his host, Prof. T. Uomoto, and his staff for the arrangement and for making his visit a memorable and fruitful one.

(By K. H. Tan, ICUS Network member)

Prof. Hayashi left ICUS after two-year appointment

After holding the position of Visiting Professor at ICUS, Prof. Shogo Hayashi, former Commissioner of the Fire Disaster Prevention Agency, retired from our center this June. Recently, he was appointed Vice-Minister of the Ministry of Internal Affairs and Communications, Japanese Government. During his stay, he lectured at the course entitled Fire Defense and Disaster Prevention Administration and Techniques of Disaster Prevention given during the Summer Semester at the Graduate School of Civil Engineering, the University of Tokyo. He focused on fire disaster management, particularly on the importance of efficient personnel management. He also led visits to the "Fire Research Institute" and the "Fire Defense College".

Prof. Hayashi participated in the preparation of a website to promote seismic retrofitting of public buildings. The site compiles and presents information related to seismic activity in Japan, importance of structure retrofitting, available vulnerability evaluation methods, and recommended retrofitting alternatives. It also includes a database of past retrofitting examples, company names, construction costs and duration of the required works. The website is hosted at the Fire Disaster Management Agency webpage.

Prof. Hayashi gave speeches at the 8th Open Lecture and the 31st Seiken Evening Seminar. We would like to thank very much Prof. Hayashi for his fruitful stay and great contributions to our center.

(By K. Meguro)

Prof. Hayashi delivered several lectures during his stay at ICUS

Two new members joined ICUS

We would like to welcome warmly Drs. Reiko Kuwano and Paola Mayorca who joined ICUS on April 1st, 2006 as Associate Professor and Project Research Associate, respectively.

Dr. Kuwano, formerly a senior researcher in the Public Works Research Institute, received her Master degree from the Department of Civil Engineering at the University of Tokyo in 1988. After she gained practical work experience in a construction company for some years, she obtained her PhD from the Imperial College, London University in 1999. Her research interest is geotechnical engineering, including characterization of mechanical behaviour of geomaterials, long-term behaviour of underground structures, remediation of contaminated ground, etc.

Dr. Mayorca got her undergraduate degree from the Pontifical Catholic University of Peru in 1994 and worked as a structural engineer in Peru for three years. In 2000, she got her Master Degree and in 2003 she got her PhD both from the Department of Civil Engineering at the University of Tokyo. She has been working on the development of retrofitting techniques to improve the seismic performance of unreinforced masonry structures with particular focus on housing in developing countries. In her PhD dissertation, she investigated experimentally and numerically the use of PP-bands, which are commonly used for packing, as a feasible method to prevent collapse of masonry houses during earthquakes and reduce fatalities in future seismic events.

(By T. Uomoto)

Dr. Reiko Kuwano

Dr. Paola Mayorca

ICUS Activities

- *Prof. Meguro attended the 100th Anniversary Earthquake Conference commemorating the 1906 San Francisco Earthquake, which was held at San Francisco, US, together with Drs. Yoshimura and Mayorca (April 16-23).*
- *Prof. Meguro, Dr. Yoshimura, and Dr. Kanada visited BUET, Dhaka, Bangladesh (April 13 - 20).*
- *Dr. Oki attended the Hydrology 2020 Conference in Delft, Holland (June 27-July 1).*
- *Dr. Ooka participated in the 10th International Conference on Thermal Energy Storage at the Richard Stockton College of New Jersey, in Philadelphia, US (May 30-June 4), the 6th International Conference on Urban Climate at the Technical University of Denmark in Sweden and Denmark (June 11-18), and the 2006 ASHRAE Annual Meeting in Quebec, Canada (June 24-29).*
- *Dr. Kato stayed at AIT for his research work and teaching duties at RNUS (April 17-May 17, June 21-July 7). He participated in Concrete Solutions 2006, 2nd International Conference on Concrete Repair at St. Malo, France (June 26-July 1).*
- *Dr. Sahamitmongkol stayed at AIT for his research work and teaching duties at RNUS (April 10-May 29, June 9-July 5). He joined the 11th National Convention on Civil Engineering at Phuket, Tailand (April 20-23).*
- *The RC-39 Committee met on May 23. After each working group reported on their activities, Prof. Tachibana, Prof. Emeritus of the University of Tokyo, gave the presentation entitled "Estimation of current traffic noise conditions"*
- *ICUS Student seminar was held on May 30. Students from all ICUS related laboratories participated and gave presentations.*
- *ICUS Open House was held together with IIS Open House during June 1-3.*
- *Metropolitan Highway Watching was held on June 9.*
- *Prof. Tan visited ICUS (June 10-24) supported by the Japan Society for Promotion of Science Scientific Exchange Program 2006.*
- *ICUS seminar, in which Prof. Tan delivered the lecture: "Rational approaches to Structural Strengthening," was held on June 19.*

Awards

- *Dr. Kato received the "Incentive Award" from the "Japan Concrete Society" for his paper "Study of a Method for Deciding the Inspection Program to Assess the Risk of Material Heterogeneity and Uncertainties."*
- *Dr. Kanada received the "Incentive Award" from the "Japan Concrete Society" for his paper "Application of Near-infrared Spectroscopy for Inspection of Concrete."*
- *Drs. Ema Kato, Kato, and Prof. Uomoto received the "Best Paper Award" from the "Japan Concrete Society" for their paper "Development of Simulation Model of Chloride Ion Transportation in Cracked Concrete."*
- *Prof. Meguro received the "Excellent Paper Award" from the "Japanese Geotechnical Society" for his paper "What I have been thinking for the last 10 years since the 1995 Kobe Earthquake."*

Editor's Note

A devastating earthquake hit Java, Indonesia on April 27 2006 showing again the urgent need to strengthen the existing low earthquake resistant housing stock (Photo by Masasuke Takashima, ICUS network member)

On April 27, 2006 a magnitude 6.3 earthquake hit Java, Indonesia killing nearly 5,800 people and injuring almost 38,000. We would like to convey our deepest condolences to the affected population. What makes this event even sadder is that most of the casualties and destruction could have been prevented.

Reportedly, the seismic strength of the houses in the stricken area was very low which translated into more than 350,000 dwellings damaged beyond usability. If these structures would have been sufficiently strong, most of the fatalities could have been prevented. Furthermore, the resources needed for reconstruction could have been smaller. This tragic event reminded us of similar situations faced at Gujurat (India, 2001), Bam (Iran, 2003), and Kashmir (Pakistan-India, 2005).

The Java Earthquake put on the spotlight again the issue of existing low earthquake resistant masonry houses. Because 60% of the world's population lives in this type of structures, even in earthquake prone regions, future earthquakes will have similar devastating consequences. It also exposed our failure, as earthquake experts, to communicate risk to the general public as discussed by Dr. Kikkawa in this Newsletter edition. These problems should be tackled with two approaches: technical and social. The first one means that any proposed retrofitting method should consider local availability, applicability, and acceptability. At my research group we are recommending the use of Polypropylene band (PP-band) meshes for retrofitting because the material is locally available at a very low price and the installation process is very simple and can be carried out by the house owners. We have performed several shaking table tests and confirmed the excellent behavior of structures retrofitted by PP-band meshes.

A viable technical solution alone is not enough to solve the problem of existing weak structures. It should come together with a social program which encourages its implementation. This program should focus on raising seismic risk awareness among the population with adequate risk communication tools coupled with policies to promote reinforcement through incentives. We are also working on this type of schemes at my laboratory. If you would like more information on PP-band retrofitting method or our proposed social system to foster retrofitting, please do not hesitate to contact us at ppmethod@iis.u-tokyo.ac.jp.

(By K. Meguro)

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp.

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Institute of Industrial Science
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HIDDEN CAVITIES UNDER THE GROUND - THEIR CAUSES AND CONSEQUENCES -

By

Reiko KUWANO

HIDDEN CAVITIES UNDER THE GROUND

You may think that the ground is firm and solid, unless some natural disasters like earthquake or landslide occur. But this is not always the case. Sometimes, you may be standing on an underground pitfall covered with solely a layer of pavement, which may collapse without a clear sign of warning. The photos below show a sinkhole that appeared on a road, caused by failure of a sewer pipe lying underneath, on the left, and a much larger cave-in, about 30 m wide and 3 m deep, which occurred in Tsu-city, Mie Prefecture in July 2006, on the right. The cause of this huge hole has not yet been clarified, although it is suspected that numerous old small pits and tunnels for mining sands in this area, an activity that stopped more than 20 years ago, are the most likely responsible.

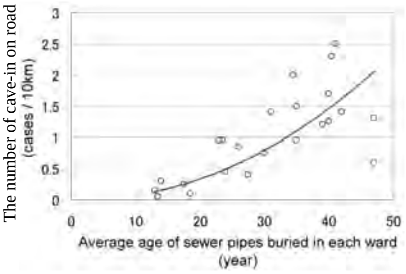
In most cases, a cavity in soil precedes such a sudden collapse of ground surface. The origin of the cavity could be natural or artificial. When the stability of the cavity is lost for any reason, soil above the cavity falls causing loosening of surrounding soil. The loosened area spreads up until the surface collapse eventually occurs.

A cave-in due to failure of a corroded sewer pipe

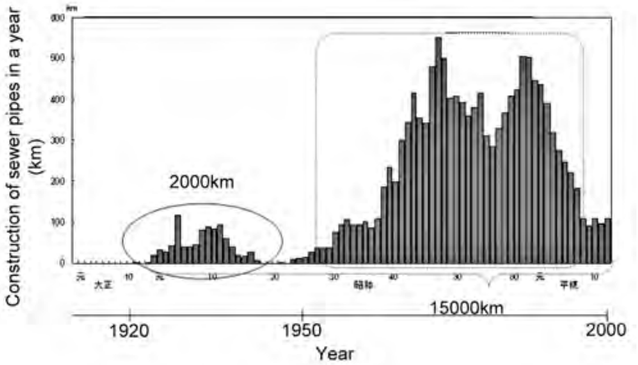
POTENTIAL SOURCES OF UNDERGROUND CAVITY

We have laid various infrastructures, such as tunnels, trenches, water pipes, sewer pipes, gas pipes and others, deeply underground. In order to catch up with the growth of urban population and functions, construction of those lifelines has rapidly progressed in the recent decades. The current underground situation is congested and complicated. All the underground lifelines are potential sources of cavities when they are too deteriorated to support the surrounding soil. Old abandoned mines and tunnels and air-

A cave-in of 30 m wide and 3 m deep affected road and residents. (Photo courtesy of the Tsu Municipal Government)



Relationship between the average age of sewer pipes in 23 wards in Tokyo and the number of cave-in incidents (after "Prospects of Sewerage 2001" Tokyo Metropolitan)



History of sewer pipe construction in 23 wards of Tokyo (after the website of the Ministry of Land and Infrastructure)

raid shelters are the most dangerous sources of underground cavities as they are likely to be poorly supported and their locations are not well recorded.

CAVE-IN DUE TO FAILURE OF SEWER PIPES

Recently, approximately 1000 cave-ins on roads occur every year due to the failure of sewer pipes in the urban area of Tokyo, within the 23 wards. Especially areas, where the urbanization started early and the existing sewer pipes are old, are suffering from frequent cave-ins, as shown in the figure on the upper left corner of this page.

Damage to old deteriorated sewer pipes appears to be the major source of soil cavities leading to cave-ins in earlier developed cities. Looking at the history of sewer pipe construction in Tokyo depicted on top right corner of this page, we note that the situation will soon become more serious.

Tokyo metropolitan government as well as other local governments are well aware of this problem and carrying out various actions for the efficient maintenance of existing sewer pipes. Their efforts include systematic reconstruction of old pipes and early detection of damage to pipes or cavities in soil, both of which apparently contribute to prevent further increase in the number of cave-in.

In fact, the reasons for the damage to sewer pipes are not only age. It was reported that around 15% of sewer pipe failures in Tokyo were caused by "other" construction works. The photos on the right show sewer pipes broken by water pipes. Such sewer pipe failures are not always noticed immediately, and could be discovered even years later. Developing underground mapping information seems to be necessary to fundamentally sort this out.

RESEARCH ON THE MECHANISM OF GROWTH OF CAVITY AND SOIL LOOSENING

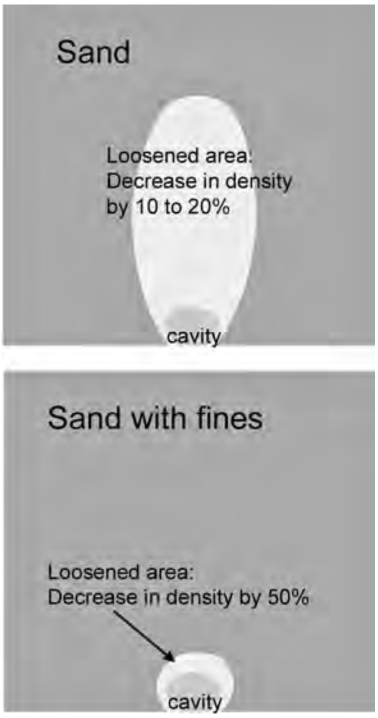
Whatever the reason is, once a buried pipe is broken, surrounding soil will be disturbed. This will loosen the ground and when the disturbance reaches the ground surface, local settlements will appear. Rainfalls seem to accelerate the process, judging from the fact that larger number of cave-ins occur in rainy seasons, from spring to autumn. The difficulty is to answer more specific questions. How fast does the initial disturbance reach the surface? How can we identify the dangerous void/cavity which will grow bigger? If we find a small defect in a pipe like a thin crack, do we need to worry?

Unfortunately, the basic mechanism of the formation of initial voids in soil and the growth of cavity resulting in the eventual ground surface cave-in has not been well understood yet. The author and her colleagues investigated this phenomenon by small scale model experiments, results of which are shown in the figure on the top left corner of the next page. The main findings from the study were:

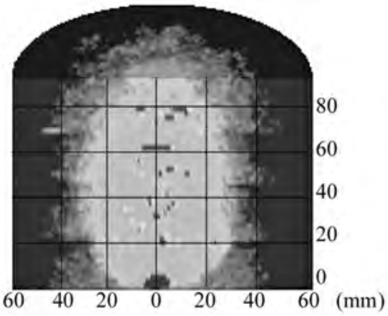
- Even a small crack or gap (5 mm wide) is sufficient to cause a cave-in.
- In sandy soils, an initial small void can quickly grow, especially when the ground is saturated. Above a cavity in sand, a loosened part largely develops where the dry density decreases by approximately 10 to 20 %.
- For sands with fines, which are commonly used for backfilling sewer pipes in practice, the rate of cavity growth seems to be slower. A loosened part, where almost half of the soil is lost, develops above a cavity, but it is not considerably large. A schematic diagram is displayed in the next page.
- In order to prevent soils from being washed away and form a cavity even in case a sewer pipe is broken, it is ultimately necessary for soil particles to be bonded to each other. Even, weak bond is enough for the purpose.

A water pipe passing through an existing sewer pipe, found under a cave-in

A water pipe broke an existing sewer pipe, found under a cave-in



Typical patterns of cavity and loosened area developed in sandy ground



X-ray CT image of cavity and loosened area in sand obtained from a small scale model test

Sand is the least resistible material. The content of fine fraction improves the situation although not for a long time. Soil around a cavity loses confinement and when it is saturated, soil particles would yield to water. Thus, a heavy rainfall significantly affects the process of cavity growing. The figure on the top-center of this page is an X-ray CT scanning image, showing a cavity and loosened area formed in a small model sand chamber. Above a cavity of only 5mm in size, the loosened area vertically spreads and reaches the surface. When this happens in the actual ground, the loosened area masks the small cavity underneath and its detection by radar exploration may become difficult.

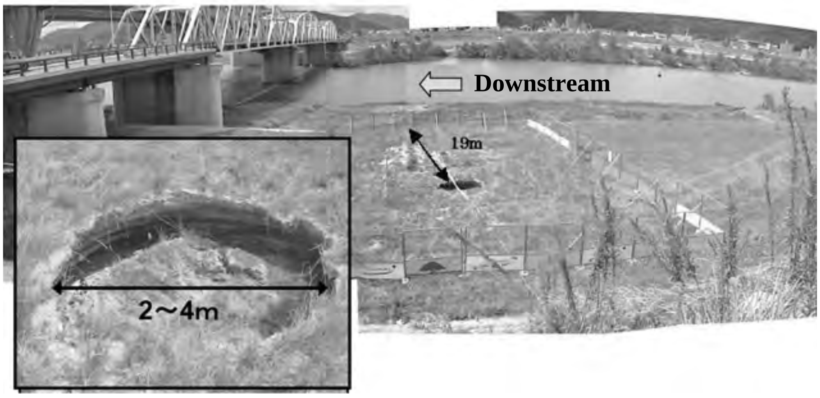
CAVE-IN WITHOUT AN APPARENT CAVITY

A cave-in sometimes occurs without a preceding cavity formation. The photo on the right shows a hole that appeared in a flood plain along a river. Due to heavy rain brought by a typhoon, the level of river water rose and inundated the plain for a day. After the water level lowered, local people found the hole approximately 2 to 4m wide and 1m deep.

Under the hole, at a depth of 15m, a water pipe of 2m diameter had been constructed by shield tunneling method. The front of the tunnel had passed the location of the cave-in more than 6 months before. Yet, there was no indication that the tunneling work excavated too much soil, equivalent to the hole size. Because the profile of the ground was sand/gravel with cobbles, conventional sounding techniques, like standard penetration test (SPT) or cone penetration test (CPT) could not be successfully applied. In fact, the SPT, that had been carried out before the tunnel construction, recorded an N-value over 50 by simply hitting large cobbles. A radar exploration was performed to search for cavities and loosened parts in relatively shallow ground, up to a depth of 3m. A new sounding technique measuring the resistance with drilling was also carried out to explore deeper sectors up to a depth of 15m. Although there was no apparent cavity, the ground above the tunnel was found to be noticeably loosened all along. The loosened area was constrained to only above the tunnel, which is not usually expected in tunneling works. All the holes, cavities, and loosened areas were filled/grouted securely, not to affect the safety of the river bank which was adjacent.

TOWARDS FUNDAMENTAL SOLUTIONS

Thus, a cave-in is mostly a man-made disaster. Once we open a space in the ground, it should be properly maintained. When we decide to abandon the man-made space, it should not be left unfilled. A cavity in the ground grows and creeps upward in silence, then with some trigger, which in many cases is a rainfall, it suddenly appears on the surface. Currently, the problem of cave-ins is not prevented but mainly addressed once it occurs by temporarily filling up the holes. Several aspects should be considered to fundamentally sort this out, including developing techniques for early detection of dangerous underground cavity/looseness, proper and efficient maintenance of underground pipes, and developing filling materials and burying techniques which are not washed away in case a pipe is deteriorated.



A hole appeared in a flood plain along a river (after the website of the Ministry of Land and Infrastructure)

UTITU Workshop was held in Istanbul

UTITU Ordinary / Emergency Workshop 2006 was held in Istanbul Technical University (ITU), Istanbul, Turkey during the week of September 10-16. Both Istanbul and Tokyo are seismic prone areas. This workshop was one of the activities among the joint study project together with ITU and the University of Tokyo (UT). The objectives of the workshop were enhancing the strategic approach for the regeneration of Galata region, the historical site in the central business district of Istanbul. It was organized to be an educational seminar for 17 students from ITU and 12 students from UT. The students were divided into three groups. After having a field excursion, they discussed new image of public space in their target area during both ordinary and post-earthquake emergency situations. They surveyed current problems and future possibility in the area during the field excursion. Finally, regeneration plans were proposed integrating four research interests: urban design, urban history, water engineering and earthquake disaster mitigation engineering. This workshop was a valuable opportunity not only for the integration of different researches but also for exploring new educational strategies for urban regeneration.

(By M. Yoshimura)

Evacuation plan proposed using 3D-GIS data

Japanese and Turkish students discussing plans

Final presentation

Field excursion in Galata area by students

Disaster-preparedness drill held at the University of Tokyo Hospital

As informed in Newsletter Vol.5, No.4, 2006, a project team was formed to consider the role of The University of Tokyo Hospital at a time of a disaster. ICUS members are now investigating the social demands of a disaster base hospital such as the number of patients after large-scale disaster.

The University of Tokyo Hospital conducted a comprehensive disaster-preparedness drill on September 8, 2006. ICUS members and students of Meguro laboratory joined and supported the drill.

The disaster scenario was conceived by Dr. Yoshimura to simulate an actual large earthquake disaster; the drill was planed in order to adapt the scenario. Dr. Kanada designed a central administration tool for disaster headquarter. This enabled to display important information such as damage to facilities or triage results on a large screen.

Confirmation of the safety of hospital inpatients and facilities was carried out just after earthquake. Nurses permanently reported the situation to the disaster command center. The hospital headquarter director decided to accept outside disaster victims after judging the facility capability from the collected information.

Simulated patients were transported in ambulances and triage training was carried out in front of the hospital main entrance.

A simulated press interview meeting was held after the drill and the director commented on the exercise outcome. All processes were filmed with video cameras and a documentary DVD will be completed in the near future.

(By H. Kanada)

Disaster command center

Simulated patient

Triage training

11th Open Lecture was held

The 11th ICUS Open Lecture was held at IIS in the afternoon of September 25, 2006. The title of the lecture was "Risk Management of Building Sanitation" and reported the achievements of the research project under the same name which is supported by the Japanese Ministry of Health, Labour and Welfare. About 80 people attended the lecture.

Four speakers delivered the following presentations:

- Dr. Koichi Ikeda, Director of the Department of Architectural Hygiene and Housing, National Institute of Public Health of Japan, and Project Leader, explained the project outline and "Risk management of hygiene for architectural equipments".
- Prof. Shinsuke Kato, Director of the Center for Development of Instrumentation Technology, IIS, the University of Tokyo, delivered the talk: "Diffusion of hazardous agents in buildings".
- Dr. Masaki Itoh, Chief of the Water Supply Planning Section, Department of Water Supply Engineering, National Institute of Public Health of Japan, gave the speech: "Ensuring drinking water safety in buildings".
- Dr. U Yanagi, Chief of the Health Housing Section, Department of Architectural Hygiene and Housing, National Institute of Public Health of Japan delivered the lecture: "Countermeasures for bio and chemical terrorism in buildings".

Finally Professor Kimiro Meguro of ICUS made concluding remarks and expressed gratitude to the participants.

(By R. Ooka)

Lecture by Dr. K. Ikeda

Lecture by Dr. M. Itoh

Lecture by Prof. S. Kato

Lecture by Dr. U Yanagi

RNUS Activities

RNUS Seminar

On August 9, 2006, RNUS organized a seminar on "Analysis and Treatment for Corrosion of Reinforced Concrete Structures."

A group of researchers from Kanazawa Institute of Technology led by Associate Professor Shinichi Miyazato and Associate Professor Mitsuharu Tokunaga kindly delivered lectures to AIT students and staffs.

The seminar was composed of four presentations, three were about the corrosion of reinforcement in concrete structures and one was about a three-dimensional measurement method using remote sensing technology.

After the seminar, guests from Kanazawa Institute of Technology visited the RNUS office as well as the laboratory of the Structural Engineering Department and discussed RNUS activities.

Dr. Kato gives a memorial gift to Dr. Shinichi Miyazato for his kind presentation

Special Presentation on the Utilization of Expansive Concrete for Higher Cracking Resistance of Structure

On September 26, 2006, Dr. Sahamitmongkol held a seminar on "The Utilization of Expansive Concrete to Prevent Cracking in Concrete Structures." The audience included undergraduate and graduate students of the Department of Civil Engineering and Technology, Sirindhorn International Institute of Technology.

Group photo of presenters, students and staffs of Structural Engineering after RNUS Seminar

RNUS Staff Served as Local Organizing Committee of EASEC-10

Dr. Kato and Dr. Sahamitmongkol were assigned by Prof. Worsak Kanok-Nukulchai as part of the local organizing committee of the 10th East Asia-Pacific Conference of Structural Engineering & Construction (EASEC-10).

Initiated 30 years ago, EASEC-10 is the biggest conference related to structural engineering and construction in the Asia-Pacific region. There were more than 700 presentations and more than 850 participants.

(By R. Sahamitmongkol)

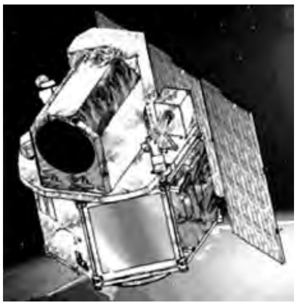
THEOS: An eye in the sky for development of Thailand

Since the introduction of remote sensing technology to Thailand in the early years of 1970's, the world has witnessed tremendous advance in both the technology itself and also the applications. As a developing country, Thailand has been following such development with great interest and has committed resources to tap on the benefit of this technology. In November 2000, a new public organization was set up by the Royal Thai Government (RTG) to engage in remote sensing and geographic information system. Geoinformatics and Space Technology Development Agency (GISTDA) is thus a specialized organization with the objectives of maximizing the benefit of 3S, namely, remote sensing, GIS and GPS for national development.

In July 2004, GISTDA signed the contract agreement with EADS Astrium of France in Bangkok to build and launch Thailand's first earth observation satellite: Thai Earth Observation System (THEOS). The project will take 30 months to complete at a cost of 128 million euros to the Thai Government. It is scheduled to be launched in the second half of 2007. Although this is a commercial undertaking, nevertheless, THEOS was initiated under the umbrella of the Thai-French Government Agreement on Space Technology Development. As such, several projects are being implemented to support the long term exploitation of space technology. For example, the training and hands-on experience of 20 Thai engineers at the company factory in Toulouse, France and a series of joint cooperative application are being implemented with satisfactory results.

THEOS is a sun synchronous, polar orbiting satellite with a designed life time of 5 years. The main characteristics are as follows.

Altitude	832 kilometers
Sensors	Panchromatic with 2.0 m resolution. Multispectral with 4 bands from blue to near IR and 15.0 m resolution
Swath	22 km for panchromatic 90 km for multispectral
Viewing	±35 degree with 3-5 day revisit
On board memory	50 GB
Weight	750 kg



THEOS spacecraft
(image credit: EADS Astrium)

Several countries have expressed their interest to access to THEOS within their footprints. Therefore, THEOS will not only contribute to the development of Thailand, but also to other regions of the world. The Thai government has also expressed its intention to offer THEOS data to the disaster mitigation efforts under the International Charter. It has always been the RTG's policy to abide by the Principles of the Exploitation of Outer Space for the benefit of mankind. Since admitted as a full member of the Committee on the Peaceful Users of Outer Space (COPUOS) in 2005, Thailand has been participating actively in two subcommittees (Scientific and Technical Subcom and Legal Subcom) as well as in the main COPUOS.

Besides applications in agriculture, land use planning, forestry and environmental assessment, etc. THEOS will be used in the integrated urban river basin management, urban flood disaster prevention and mitigation and urban sprawl planning.

(By Dr. Suvit Vibulsresth
Executive Board Member and
Former Director, GISTDA)

Establishment of BNUS at BUET and it's Activities

A contract has been signed to establish the Bangladesh Network Office for Urban Safety (BNUS) at BUET, Bangladesh between Prof. Dr. Md. Mazharul Hoque, The Head, Department of Civil Engineering, BUET and Prof. Dr. Taketo Uemoto, The Director, International Center for Urban Safety Engineering, Institute of Industrial Science, the University of Tokyo in June 14, 2006. The main objective of this office will be to promote and enhance high quality cooperative research in areas related to urban safety.

BNUS office comprise of four rooms at the fifth floor of Civil Building, BUET. The current BNUS members are Prof. Dr. Mehedi Ahmed Ansary, Dr. Munaz Ahmed Noor, Ms. Israt Jahan, Mr. Md. Yasin, Mr. Qumruzzaman and Mr. Qurban Ali. BUET has already provided a space for BNUS in its webpage.

The current and future activities will be as follows:

- *Evaluation of concrete structures of Bangladesh (already done for BUET buildings in June 2006)*
- *School earthquake safety program (Launched in September 2006)*
- *Seismic evaluation of lifeline infrastructures*
- *Evacuation plans for different wards of Dhaka city*
- *Evaluation of concrete bridges and flyovers of Dhaka*
- *Development of indigenous instruments for reinforcement detection*

Please visit BNUS website at http://www.buet.ac.bd/BNUS/

(By M. A. Ansary
Professor, BUET)

BNUS office at the 5th floor, Civil Building, BUET

Dr. Sanae Miyazaki joined ICUS


Dr. Sanae Miyazaki

Dr. Miyazaki got her undergraduate degree from the Tokyo Institute of Technology (TIT) in 1988 and has worked for NTT DATA Corporation since then. She also got her Ph.D. degree from the TIT in 2000.

Dr. Miyazaki research interest is in remote sensing technologies, especially satellite remote sensing and sensor network systems. Her recent research target is the data fusion analysis using various sensor data for disaster management.

(By T. Uomoto)

ICUS Director is the first visitor at Chula Unisearch IIS Branch Office

As agreed in the Memorandum of Understanding signed between Chulalongkorn University and the Institute of Industrial Science (IIS), the University of Tokyo, on March 21, 2006, the Chula Unisearch IIS Branch Office was officially opened at the beginning of July 2006.

On August 7, 2006, Prof. Taketo Uomoto, Director of ICUS became the first visitor of this IIS Branch office. On this occasion, Prof. Uomoto discussed with Associate Professor Boonchai Stitmannaithum, Associate Dean of the School of Engineering, the possibility of collaborative research activities between ICUS and the Faculty of Engineering, Chulalongkorn University.

Located in the central Bangkok, this branch office of IIS will serve as an easy-to-access business center for IIS professors who visit Bangkok for their research activities. The communication facilities (internet and local telephone) as well as other office supplies are well prepared for the visiting IIS professors.

(By R. Sahamitmongkol)


ICUS visitors and Dr. Stitmannaithum at Chula Unisearch IIS Branch Office

ICUS Activities

- *Prof. Uomoto attended the 10th East Asia-Pacific Conference on Structural Engineering and Construction held in Bangkok, Thailand, during Aug. 2-8 together with Dr. Kanada. Prof. Uomoto also joined Shotcrete for Underground Support X held in Vancouver, Canada, from Sept. 11 to 17.*
- *Prof. Meguro attended the 1st European Conference on Earthquake Engineering and Seismology in Geneva, Switzerland from Sept. 3 to 7. Dr. Mayorca joined the same conference from Sept. 3 to 8. Prof. Meguro took part in a Center Of Excellence action study workshop carried out at Istanbul, Turkey during Sept. 10-18. Dr. Yoshimura also participated in this workshop from Sept. 9 to 20.*
- *Dr. Oki participated in the observation at Beijing Site in Beijing, China from Jul. 30 to Aug. 3. He joined The United Nations-Sigma Xi Scientific Expert Group on Climate and Sustainable Development/World Water Week held at Washington DC, USA and Stockholm, Sweden. He attended the IPCC WGILL Meeting held at Cape Town, South Africa from Sept. 8 to 16.*
- *Visiting Professor Reiko Amano attended the 12th International Symposium on Aerodynamics and Ventilation Vehicle Tunnels in Portoroz, Slovenia from July 11 to13.*
- *Dr. Kato stayed at AIT for his research work and teaching duties at RNUS during Aug. 1-18 and Sept. 3-Oct. 5.*
- *Dr. Kanada attended the 6th International Symposium on Nondestructive Testing in Civil Engineering held at St. Louis, US from Aug. 13 to 20.*
- *Dr. Sahamitmongkol stayed at AIT for his research work and teaching duties at RNUS during July 12-Aug.16, Aug.20-Sept.14, and Sept.19-Dec.13.*
- *ICUS Seminar was held at Kawaguchi-ko during July 14-15.*
- *The RC-39 Committee met on July 25. After the meeting Prof. Ura delivered a speech on “Autonomous Underwater Robot for Observation-From Kamaishi Bay breakwater offshore to Myojin reef caldera.”*
- *Prof. H. Wiggenhauser, Director of the Federal Institute for Materials Research and Testing, Germany, visited ICUS on July 30*
- *A delegation of 18 professors from the National Kaohsiung First University of Science and Technology of Taiwan led by Prof. Tai-Ping Chang, visited ICUS on Aug. 15.*
- *Former Visiting Prof. S. Hayashi was appointed President of the Japan Foundation for Regional Art-Activities on Sept. 1.*
- *ICUS Open Lecture was held on Sept. 25.*

Awards

- *Mr. Ramesh Guragain from Meguro Laboratory obtained the Furuichi Award on September 29 for his excellent Master Degree Thesis entitled “Numerical Simulation of Masonry Structures under Cyclic Loading using Applied Element Method.”*
- *Dr. Kanada and Mr. Pakawat Sancharoen from Uomoto Laboratory got the Incentive Award for Excellent Paper at the 2006 Annual Meeting of the Japan Concrete Institute for their papers “Componential Analysis by Portable Fluorescence X-ray Analyzer” and “Life Cycle Repairing Cost Considering Uncertainties of Deterioration Prediction Model,” respectively.*

Editor's Note

The existence of the global warming problem has been confirmed by recent research results, even though some researchers still doubt about it. It is expected that natural disasters such as flood and typhoon will become more and more frequent and hazardous in the future. The reduction of CO_2 emission is urgent for prevention of global warming. However, it is not readily progressing. Energy and drug consumption are similar in the sense that human beings become addicted to them and cannot easily get rid of a living style based on them once they get accustom to it. Currently, some holy human lives are taken by the struggle for energy.

The necessity of paradigm shift from a life of quantity to a life of quality has been recognized for more than 20 years. Unfortunately, this shift is not moving ahead because people do not have a concrete image of their future quality of life and thus no consensus has been reached among them. As a result, the global warming problem is not been addressed .

Incidentally, ICUS women staffs further increased with the arrival of Dr. Miyazaki. Currently six ladies belong to ICUS: one Professor, two Associate Professors, two Research Associates, and one Secretary. They are very active in their fields as evidenced in the main article of this newsletter which was written by one of them: Dr. Reiko Kuwano. Men have been the main contributors to material civilization up to the present. However, they have not paid much attention to the quality of life. I believe that women ideas and senses will be greatly useful to shift from a life of quantity to a life of quality in the future. Therefore, I am looking forward to the continuation of the active participation of ICUS women staffs.

(By R. Ooka)

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp.

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ICUS
INSTITUTE OF INDUSTRIAL SCIENCE THE UNIVERSITY OF TOKYO
International Center for
Urban Safety Engineering

ICUS NEWSLETTER

International Center for Urban Safety Engineering

Institute of Industrial Science
The University of Tokyo

VOLUME 6 NUMBER 3
OCTOBER-DECEMBER 2006

HEALTH RISK MANAGEMENT IN THE FIELD OF BUILDING HYGIENE

By

*Koichi IKEDA**

Recent years have seen the frequent appearance of health hazards related to the architectural environment. Events such as the outbreak of the Severe Acute Respiratory Syndrome (SARS) mainly in China in 2003, the mass outbreak of legionnaires' disease at a spa in Miyazaki Prefecture in 2002, and the terrorist attack with sarin gas in the Tokyo subway system in 1995 are still fresh in the minds of the public. These events nevertheless have not been thoroughly examined with respect to factors such as the routes involved in the mechanism of mass infection, characteristics of diffusion in building interiors, and human exposure; many issues about them still remain uncertain.

Taking into account these circumstances, our research group was organized under the support of the Ministry of Health, Labour and Welfare with the ultimately aim to define measures to be taken in the event of emergency situations, such as the outbreak of unforeseen health hazards in buildings with high concentration of people. The first task of this research group is to collect reports from related researches conducted to date and summarize their findings. This is to be followed by experimental studies and numerical fluid analyses to predict, for instance, the characteristics of the dispersion of contaminants inside buildings and exposure to them among residents, in order to establish countermeasures applying available technology. These studies and analyses would be premised on the outbreak (release) of pathogenic microorganisms or hazardous chemical substances in the building environment, particularly air-conditioning facilities, water supply and drainage facilities, and building interiors. The final step is to compile the results of these activities for preparation of an effective manual to be used in the event of actual health hazards.

Terrorism: Sarin gas spraying in the underground in Tokyo (March, 1995)

MEASURES AGAINST BIOCHEMICAL TERRORISM IN BUILDING ENVIRONMENT

Four areas should be focused at the present situation: 1) background factors, 2) current status of health hazard management in Japan, 3) trends in research in other countries, and 4) measures against biochemical terrorism in a building environment.

According to Dr. Yanagi, Chief of the National Institute of Public Health's Department of Architecture, Hygiene and Housing, over the period 1900 - 2003, there were a total of 1,154 acts of terrorism of a certain scale using chemical, biological, radiological, or nuclear (CBRN) material throughout the world. Of this total, about 90 percent of the acts involved biochemical substances. Mr. Yanagi pointed out that the 9/11 terrorist attack in the United States served to heighten wariness about biochemical terrorism around the world.This was followed by a description of the current status of health hazard management in Japan. In response to the 9/11 attacks and the incidents of anthrax poisoning by mail shortly thereafter, the Japanese government made an urgent study of preparedness and had setups for health hazard management constructed by the government as a whole, the prefectural administrative authorities, and health centers. In addition, it took steps for smooth provision of information to citizens on a timely basis.

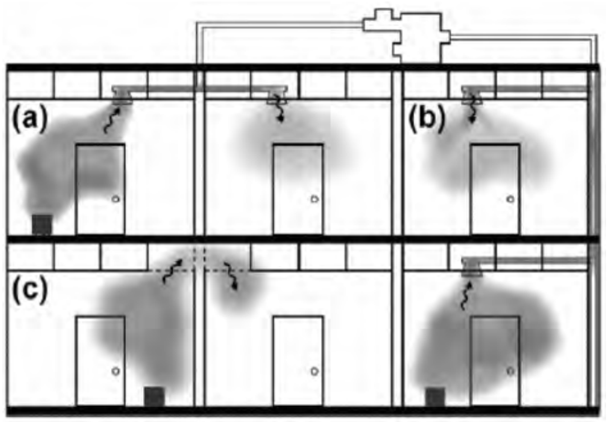
Disaster: Smoke dispersion at fire

An FBI agent opens letter addressed to US Senator Patrick Leahy. (Courtesy of the Monterey Institute of International Studies, Center for Nonproliferation Studies)

DISPERSION OF HAZARDOUS SUBSTANCES WITH AN ADVERSE INFLUENCE ON HEALTH WITHIN BUILDINGS

Let us consider ways of dealing with the diffusion, whether deliberate or accidental, of acute toxins within buildings as viewed from the aspect of architectural environmental engineering. It could first be noted that prevention of the dispersion of such toxins within buildings (i.e. the release of hazardous substances by acts of terrorism) is of primary importance. Measures to curtail any damage to the absolute minimum are, naturally, of a second-best nature. The discussion presented hereinafter concerns the latter. In this context, the first prerequisite is to detect the diffusion of the hazardous substance within the building. This demands development of systems to sense the substance. Canaries were once carried into mine shafts to test the quality of the air. Hinted from this practice, Professor Kato at the Institute of Industrial Science, the University of Tokyo, is now currently developing a bioassay sensor that detects the presence of toxins in the air by blowing it into a tank of killifish ("medaka"), whose behavior changes if the concentration of toxins is significantly high. The next step is to accurately forecast the difussion of the hazardous substance within the building and effectively prevent it. The urgent task to this end is development of a simulation system enabling analysis of the complex circulation of air in the building interior. Dispersion within buildings can be estimated by three-dimensional simulation of non-regular air flow and of the dispersion, but this takes a very long time. In response, Professor Kato is now developing a system which makes it possible to analyze the detailed distribution of contaminant concentrations in interior spaces and their changes over time, without heavy calculation loads. The system consists of investigation of the flow through a three-dimensional air flow simulation, followed by analysis of only contaminant diffusion using a simple method. It derives from the fact that formulas for flow and diffusion related to the dispersion of contaminants are linear. This makes it possible to calculate the non-regular concentration response through a convolution computation using a response coefficient for a limited time width pulse. The work has already moved out of the stage of theoretical studies into that of developing a concentration-response simulation system for use in the event of the introduction of contaminants into interior spaces due to terrorism or other.

SAFETY OF DRINKING WATER IN BUILDINGS



Ventilation ducts provide pathways for contamination to flow among rooms (Courtesy of the Lawrence Berkeley National Laboratory)

Positioning of water supply equipment

Water supply equipment consists of the pipes leading from the distribution pipes for supply of water to customers and the fittings attached directly to them. At present, the management of hygiene varies with the supply arrangement. In buildings such as condominiums, for example, the water may be either put into a receiving tank before being supplied to customers or supplied by direct connection to each unit. This difference in supply arrangements conveys a differentiation on where the responsibility for water quality at the tap in homes lays. While there are ministerial ordinances concerning the standards for the structure and material quality of water supply equipment, they have not completely eliminated accidents occurring through such equipment.

Cases of occurrence of water quality accidents within buildings

In 1994, there was a mass infection of 461 people with cryptosporidium in a multiuse building in the city of Hiratsuka, Kanagawa Prefecture. Authorities suspected contamination of tap water because the people who were infected had drunk the water from the water tank. The investigation determined that the underground water tank, sump tank, and other facilities had an outdated design and inappropriate structure, and that the trouble was caused by an overflow of sanitary sewage from the sanitary sewage tank into the water tank due to failure of the sump pump at the time of occurrence.

In 2001, there was an incident in which tap water in a certain condominium turned yellow after a power outage. It was thought that the power outage resulted in a negative pressure in the condominium standpipe, and subsequent backflow of the hot water remaining in bathtubs. As there was a high incidence of defects among the backflow prevention devices on the storage-type water heaters in the building, modifications were made in the structure and material of the check valves to prevent backflow. It is not clear, however, whether the backflow prevention equipment on the line from the condominium units to the outside functioned abnormally.

There were also complaints about service water quality from people living near a hotel. An investigation revealed installation of illegal cross connections. It was concluded that drinking water for the hotel (supply to the third and higher floors based on chlorination of groundwater) had flowed backward into the utility water distribution pipes.

Experimental apparatus for detecting malfunctions of backflow preventers

Research concerning water supply in buildings

In Japan, research in this area funded by expenditures for scientific studies under the Ministry of Health, Labour and Welfare may be exemplified by two studies: one concerning abnormality monitoring and management for water supply equipment, and another consisting of a fact-finding survey of water storage facilities (particularly unregulated small-scale ones), and preparation of a manual for their operation and maintenance for their installers. The former proposed a methodology for detection of water quality concentrations and quantities beyond a certain level as well as the development of techniques for sensing abnormalities affecting backflow prevention devices. The World Health Organization, too, has prepared a document entitled "Water Safety in Public Buildings." As these activities suggest, there is a widespread recognition of the importance of maintaining high levels of water quality in order to assure the safety of drinking water.

**** Director,***
Department of Architecture,
Hygiene and Housing, National
Institute of Public Health

ICUS & AIT Organized the 5th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia

The Asian Institute of Technology (AIT), Thailand, and the International Center for Urban Safety Engineering (ICUS), Institute of Industrial Science (IIS), the University of Tokyo, Japan, co-organized the Fifth International Symposium on New Technologies for Urban Safety of Mega cities in Asia (USMCA-2006) at Phuket on November 16 – 17, 2006. The symposium was sponsored by the Japan Aerospace Exploration Agency (JAXA), Japan; the Center for Sustainable Urban Regeneration, the University of Tokyo, 21st Century Center of Excellence Program (COE), Japan; the Geo-Informatics and Space Technology development Agency (GISTDA), Thailand; Siam City Cement, Thailand; and Index International Group Co., Ltd., Thailand.

The two-day long program of the symposium was arranged in two plenary and ten technical sessions, in which four keynote speeches and twelve special lectures were delivered by invited distinguished academicians and researchers from several Asian countries. The symposium was inaugurated by Dr. Pennung Warnitchai, School of Engineering and Technology (SET), AIT and it was followed by the welcome address of Prof. Worsak Kanok-Nukulchai, Dean of SET, AIT and the opening speeches of Dr. Takashi Moriyama, JAXA, Dr. Surachai Ratanasermpong, GISTDA and Prof. Taketo Uomoto, ICUS. The keynote speakers for the plenary sessions were Prof. Tsuneo Katayama (Department of Architecture, Tokyo Denki University, Japan), Dr. Suvit Vibulsresth (GISTDA), Dr. Absornsuda Siripong (Marine Science Department, Chulalongkorn University, Thailand) and Prof. Mehedi Ahamed Ansary (Department of Civil Engineering, Bangladesh University of Engineering and Technology, Bangladesh).

A total of 64 papers were presented in technical sessions covering a wide range of issues in the areas of urban safety including flood risk management, sustainable infrastructure management, earthquake, fire, tsunami, disaster mitigation and environmental impacts. Several presentations were made on newly developed advanced tools and methodologies for addressing these issues.

For the first time, ICUS prepared the Excellent Young Researcher Award to encourage activities of young researchers in the field of urban safety engineering. The winners of this award were Dr. Hong Huang (IIS, the University of Tokyo), Ms. Kulapramote Prathumchai, Geoinformatics Center (AIT), and Dr. Kawin Worakanchana (IIS, the University of Tokyo.)

The next symposium will be held at Dhaka, Bangladesh on December, 2007. Further information will be announced in ICUS web site soon.

(By Y. Kato)

Number of participants per country

Country	Number of participants	Country	Number of participants
Australia	1	Pakistan	1
Bangladesh	2	PR China	2
India	1	Singapore	5
Japan	31	Thailand	45
Malaysia	1	Uganda	1
Nepal	1	Vietnam	1
		Total	92

Symposium participants in a group photo

JAXA representative shares his view of USMCA 2006

I would like to extend my sincere appreciations and congratulations to all people belonging to the organizing agencies who worked very hard to make the 5th International Symposium on New Technologies for Urban Safety of Megacities in Asia (USMCA 2006) a success, specially to the Asian Institute of Technology (AIT) and the Institute of Industrial Science, the University of Tokyo. It was my great pleasure to deliver the Opening Speech in this event during which views and experiences on new technologies for natural disaster mitigation and urbanization technologies were shared and exchanged.

One of the Japan Aerospace Exploration Agency (JAXA) main emphases is the use of space technology to cope with environmental problems, prevent and mitigate risks of disasters, improve quality of life, and bring about better future for the next generation. This initiative is being taken together with its partners in the Asia-Pacific Regional Space Agency Forum. JAXA feels a strong commitment to achieving sustainable urban spaces and hopes to actively continue contributing to events such as USMCA.

(By T. Moriyama, JAXA)

Dr. Moriyama Delivers Opening Speech at USMCA 2006

ICUS joined Chiba Experiment Station Open House

On November 10, the Institute of Industrial Science, the University of Tokyo organized the 'Open House' of Chiba Experiment Station. Under the splendid weather, there were 650 visitors altogether.

ICUS joined the event by presenting its research progress on "Towards the Establishment of a Sustainable Urban System". Panels were prepared to make an easy-to-understand explanation to visitors, including pupils from local primary and secondary school.

(By R. Kuwano)

ICUS Exhibition

1st Transdisciplinary Federation of Science and Technology Symposium

The first Transdisciplinary Federation of Science and Technology Symposium was held on December 1-2, 2006 at the Campus Innovation Center in Tamachi, Tokyo. The nonprofit organization was established to merge essential technologies from various fields. Forty-three academic societies join the organization whose total number of individual members reach 60,000.

On the morning of the second day, a session on disaster risk was convened by Prof. Y. Yasuoka, IIS. ICUS members were invited as speakers:

- Prof. Meguro explained the importance of structuring researches on disaster and its countermeasures and infrastructure system for proper disaster management.
- Dr. Yoichi Kitsuta, a emergency physician of the Univ. of Tokyo Hospital (a member of project team with ICUS) presented the implementation of an advanced technology into a major medical incident management and support.
- Dr. Miyazaki introduced a future infrastructure information database for disaster management.

Prof. Yasuoka, Prof. Meguro, Dr. Kitsuta and Dr. Miyazaki delivered speeches

After their presentations, the necessity of information exchange with other organizations at a time of a disaster and proper data preparation, i.e. collection, processing, analysis and command systems, were discussed.

(By H. Kanada)

RNUS Activities

Training Program on Infrastructure Maintenance and Non Destructive Testing

Jointly organized with the Sirindhorn International Institute of Technology, RNUS staffs led by Dr. Raktipong Sahamitmongkol made a demonstration of non-destructive testing machine for the inspection of reinforced concrete structure on November 8, 2006 at Bang Pakong Power Plant.

This activity was a part of the training program for technical staffs of the Electricity Generating Authority of Thailand in order to explain the importance of good maintenance practices as well as the deterioration processes and inspection procedures of concrete structures.

Demonstration of corrosion detection at a damaged structure

Located in Bang Pakong district, Chachoengsao Province, the Bang Pakong Power Plant is presently Thailand's biggest and most modern thermal power plant employing state-of-the-art technologies for power generation and environmental management. With an aggregate capacity of 3,600 Megawatts, Bang Pakong plays a vital role in securing well over 25 percent of Thailand's electricity needs.

RNUS Seminar

On November 13, 2006, RNUS organized the seminar on "Modeling of Concrete Properties and Nonlinear Structural Analysis".

Associate Professor Toshiharu Kishi, IIS, the University of Tokyo gave the presentation 'Microscopic Approach to the Governing Mechanism of Concrete Properties – Fluidity, Heat Generation, Strength, Water Movement, and Microstructure'. He discussed the different mechanisms of concrete as well as the relationship among them and subsequently the modeling of concrete behavior was explained.

Dr. Yasushi Tanaka, Research Associate from Nagaoka University of Technology presented 'Constitutive Model for Non-linear Analysis of Reinforced Concrete Structures.' In the presentation, fundamentals and techniques for simulation of structural response of RC structure were discussed.

(By R. Sahamitmongkol)

Dr. Y. Kato gave a memorial gift to Dr. Toshiharu Kishi.

IIS seminar was arranged by ICUS

The IIS seminar was held on October 3, 2006 organized by the Foundation for the Promotion of Industrial Science. This seminar was arranged by ICUS, the theme was “Towards safer and more comfortable urban space.”

Dr. Kuwano delivered a presentation on the causes and mechanisms of ground depression. Dr. Ooka presented the prediction and control of heat-island effect. Dr. Miyazaki introduced the detection of landslides by satellite remote sensing and real time 4D system for disaster information. Prof. Meguro outlined a new proposal on how to change low earthquake-resistant houses to strong ones and how to educate people and organizations to prepare against earthquakes.

About 40 people attended the seminar. Certifications were given during the closing session.

(By H. Kanada)

ICUS members instructed their topics

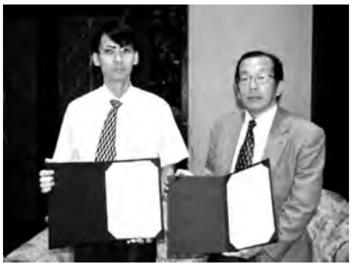
Certification was given

MOU between ICUS and SIIT was signed

On October 25, 2006, the Memorandum of Understanding (MOU) between the International Center for Urban Safety Engineering (ICUS) and the Sirindhorn International Institute of Technology (SIIT), Thammasat University was signed.

SIIT has been one of the regional partners of ICUS in promoting the importance of urban safety especially in central areas of Thailand. Several joint activities and collaborative research projects have been carried out by ICUS and SIIT in the last few years. The signature of this MOU will strengthen the relationship between these two parties and bolster collaborative activities in the region

(By R. Sahamitmongkol)



Prof. S. Tangtermsirikul, Deputy Director of SIIT and Prof. T. Uomoto, Director of ICUS

Delegation of Thai scholars visited ICUS

A delegation of 24 members of the Council of Deans of Engineering of Thailand visited the Institute of Industrial Science (IIS) on October 23, 2006. Their fields of expertise covered a broad spectrum including Civil, Mechanical, Industrial, Electrical and Computer Engineering, among others. At IIS, they were received by a group of professors led by the institute President, Prof. Maeda. Research activities, on-going projects and collaborative schemes of the institute were introduced to the guests.

In the afternoon, the delegation split in four groups and alternately visited the Collaborative Research Center for Computational Science and Technology with Prof. C. Kato, the Collaborative Research Center for Advanced Mobility (ITS Center) with Prof. Suda, the Nanoelectronics Collaborative Research Center with Lecturer Iwamoto, and ICUS with Prof. Uomoto.

Dr. Miyazaki explained about real time monitoring of bridges

At ICUS, a brief introduction of the center activities was given by Prof. Uomoto and then the following talks were delivered:

- *“Sustainable Tsunami Disaster Mitigation System for the Indian Ocean Rim Region and others” by Prof. Kimiro Meguro*
- *“Real Time Bridge Remote Health Monitoring System” by Dr. Sanae Miyazaki*
- *“Integrated Information System for Total Disaster Mitigation” by Dr. Miho Yoshimura*

At the end of the visit, group pictures were taken.

(By P. Mayorca)

Inauguration Ceremony of BNUS and Seminars

The Bangladesh Network Office for Urban Safety (BNUS) was inaugurated by the honorable Vice Chancellor, Prof. Dr. A. M. M. Safiullah of Bangladesh University of Engineering and Technology (BUET) on December 6, 2006, at the 4th floor of the Civil Engineering Building, BUET, Dhaka. Prof. T. Uomoto and Prof. K. Meguro of ICUS attended the ceremony with Prof. Md Hossain Ali, Dean of Civil Engineering Faculty, Prof. Md. Mazharul Haque, Head of the Civil Engineering Department and Dr. Munaz Ahmed Noor, project manager of BNUS.

Attendants of the ceremony with Vice Chancellor

BNUS staff members

Prof. Uomoto presented a talk on 'Importance of Maintenance of Existing Concrete Structures' at the Institution of Engineers, Bangladesh, organized by Engineering Staff College, Bangladesh (ESCB) and BUET on December 5, 2006. Prof. Meguro also delivered a talk on ‘Recent Developments of Earthquake Related Activities in Japan' on December 6, 2006 at the seminar room of the Department of Civil Engineering, BUET.

VISIT TO JAPANESE EMBASSY IN DHAKA

Prof. Uomoto, Prof. Meguro and Dr. Munaz Ahmed Noor (BNUS, BUET) visited the Japanese Embassy in Dhaka on December 6, 2006. The professors explained ICUS activities and the plan to cooperate with BUET to Ambassador Masayuki Inoue and other embassy staff members. They also asked for support to the activities of ICUS, especially the international symposium which will be held in Dhaka in 2007.

(By T. Uomoto)

Meeting at the Embassy of Japan in Bangladesh

ICUS Activities

- *All ICUS members attended the USMCA 2006 held at Phuket, Thailand on Nov. 16-17.*
- *Prof. Uomoto visited Istanbul, Turkey from Oct. 15 to 18 to join the field inspection of an undersea tunnel across the Bosphorus strait. He traveled to Udon Thani, Thailand from Oct. 24 to 27 together with Dr. Sahamitmongkol in order to join the Thai Annual Concrete Conference and sign a Memorandum of Understanding with the Sirindhorn International Institute of Technology, Thammasat University. He attended the 2nd Asian Concrete Federation International Conference from Nov. 19 to 23 at Bali, Indonesia together with Drs. Kato, Kanada and Sahamitmongkol. Prof. Uomoto visited Sydney, Melbourne, and Gold Coast, Australia from Nov. 26 to Dec.2 to give a seminar on concrete deterioration and hold meetings with teaching staff at Monash University.*
- *Professors Uomoto and Meguro visited Dhaka, Bangladesh from Dec. 4 to 7 to hold a seminar at the Bangladesh University of Engineering and Technology and meet the Japanese Ambassador to Bangladesh.*
- *Prof. Meguro visited Singapore from Dec. 2 to 3 to attend the meeting of the Board of Directors of the World Seismic Safety Initiative.*
- *Dr. Oki was promoted to Professor on Nov.1st. He retired from ICUS and returned to the 5th Department of the Institute of Industrial Science, the University of Tokyo.*
- *Dr. Oki visited Bangkok/Phitsanulok, Thailand from Oct. 15-22 to carry out observations there.*
- *Dr. Ooka attended the 6th International Thermal Manikin and Modeling Meeting held at Hong Kong, China, from Oct. 15 to 19.*
- *Dr. Kato stayed at AIT for his research work and teaching duties at RNUS from Oct. 23 to Dec. 8.*
- *Dr. Yoshimura held a series of four lectures for introducing earthquake engineering at Hayashi-cho elementary school in Tokyo in December. About seventy students learned the meaning of seismic vulnerability and importance of countermeasures through small-scale experiments.*
- *Dr. Kanada visited Seoul, Korea from Nov. 3 to 5 to join the 2006 Korea Concrete Federation Autumn meeting.*
- *Dr. Mayorca traveled to Lima, Peru from Oct. 14 to 22 to introduce PP-band retrofitting technique for masonry structures to several governmental agency representatives.*
- *Dr. Sahamitmongkol stayed at AIT for his research work and teaching duties at RNUS during Sept. 9-Dec. 18 and Dec.29-Mar.24.*
- *The RC-39 Committee met on October 10. After the meeting Drs. Kuwano and Miyazaki gave talks on their respective research activities.*

Awards

- *Drs. Kanada and Sahamitmongkol received the “Best Concrete Research Award” at the 2nd Asian Concrete Federation International Conference for their papers: “Radiography of Reinforced Concrete Structures Using Compton Backscattered Laser Photons Beam” and “Effect of Mix Proportion and Cover Thickness on Electromagnetic Properties of Concrete Measured by Radar Method”, respectively.*
- *Dr. Worakanchana (Meguro laboratory) received the “Excellent Young Researcher Award” at USMCA 2006 for his paper: “Voronoi Applied Element Method: Theory and Application for Linear and Non-linear Materials.”*

Editor's Note

The word that showed social conditions in 2006 was "Life (Inochi: 命)". This word was chosen by a public advertisement company based on an interview survey carried out in all Japan. The reasons why people chose "Life" may be classified into the following four categories: 1. Imperial prince "Hisahito" birth; 2. frequent occurrence of suicide (child suicide cuased by bullying, suicide of senior citizen because of hard living conditions, etc.); 3. frequent occurrence of painful accidents and events (deaths in traffic accidents caused by drunken drivers, cruel murders, sudden deaths by natural disasters such as tornadoes, etc.); 4. frequent occurrence of events that make life feel uneasy (execution of nuclear test in North Korea, increase of medical treatment expense load for senior citizens due to medical care reforms, doctor shortage, etc.). (Reference: http://www.kanken.or.jp/event/index.html)

The year 2006 ended with two unhappy news that symbolized the above issues: the suicide of adolescents who worried about being bullied and a murder by the victim's relative. It is very difficult to find the actual reasons behind these events and to take countermeasures against them. However, I think that "Communication" and "Consideration" are important key words to solve these problems. It is very difficult or impossible to guess what other party thinks. However, it is most important to make our best effort to guess it in order to make an excellent interpersonal relationship. Then, do not forget to try to guess others' thinking as mentioned above. You cannot communicate with the other party when thinking that you completely understood other party's thinking. Modesty is always important. This is also important for ICUS. We tackle several problems in the field of urban safety such as aging of structures, natural disasters, environmental destruction, etc. At this time, we should not only pay attention to the object in the concrete problem but also to the thinking of the users in the city. I am wishing that our activity is useful for the improvement of our "Life".

(By Y. Kato)

Priest writing the kanji character for 'Inochi' or Life (Photo courtesy of the Sankei Shinbun)

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp.

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International Center for Urban Safety Engineering

Institute of Industrial Science
The University of Tokyo

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TSUNAMI RISK IN THAILAND

By

*Absornsuda SIRIPONG**

Tsunami disasters, such as the one that occurred on December 26, 2004 can cause tremendous lost of livelihood, properties and ecosystems in many countries around the Indian Ocean. Thailand was the fourth affected country with a death toll of 8,396. A tsunami disaster mitigation procedure is proposed for Thailand. Tsunamis, with return periods of 475 and 975 years, may reach more than 20 m-height along the entire subduction zone. Away from the subduction zone, the amplitudes are significantly lower, but there is strong variability along the coastline of Thailand. In particular, the highest recorded tsunami amplitudes are at Kao Lak, Cape Pakarang (15.7 meter), which were hardest hit during the 2004 event. The high waves along this stretch of shoreline are evidently caused by local bathymetry and topography. This illustrates the usefulness of a method to identify stretches of coastline that are particularly vulnerable to tsunami impact. The recent researches on real-time tsunami prediction are important to enable safe evacuation and coastal zone management. Without sophisticated system of instruments or tsunami modeling, local people should be given adequate information on actual tsunami disasters, characteristics of tsunami wave, evacuation route and refuge places. Knowing that a coastal area may be subjected to certain coastal hazards is important to create awareness. Risk knowledge will help to manage it and to mitigate damage as a result.

Resort villa buildings at Kao Lak damaged by the tsunami which occurred on December 26, 2004 (Photo courtesy of Prof. K. Meguro)

Three fundamental areas of effort to cope with tsunami disaster were proposed by Dr. Eddie N. Bernard, the Director of NOAA/PMEL (Pacific Marine Environmental Laboratory): 1. Tsunami Hazard Assessment, i.e. preparation of inundation maps; 2. Tsunami Warning, i.e. installation of sea level gauge and seismometer networks and deployment of tsunami detection buoys; 3. Mitigation Program, i.e., preparation and analysis of tsunami hazard and risk maps for emergency management.

Before planning any method to prevent tsunami disaster, we should first know where the tsunami risk areas are. The seismologist, geophysicist and geologist can map the risk and tsunami hazard zone from small scale (local area) to large scale (whole country coastline) for further planning. This can be done from historical data and paleotsunami and past earthquake records in the area of interest. During the Workshop on Seismic Hazard in Thailand, January 16-19, 2007 at Chulalongkorn University, the Thai scientists with assistance from the experts from the US Geological Survey (USGS), worked on an earthquake hazard map of Thailand.

Not all submarine earthquakes generate tsunami. For the Indian Ocean, two potential sources have been identified, namely Mekran near Pakistan coast and the Andaman to Sumatra subduction zone. The frequency of historical tsunamis can be found in many old documents, paintings, and proxy data in geological time. The earthquake source and geophysical characteristics of the two tsunamigenic-earthquakes should be investigated by seismologists. These data can be used to infer the tsunami recurrent interval. Based on the plate tectonics theory and the history of past events in the area, Professors Kerry Sieh (California Institute of Technology) and Emile Okal (Northwestern University) roughly estimated that the recurrence interval for an ocean-wide tsunami generated by a magnitude 9.3 submarine earthquake, similar to the December 26, 2004 event, occurring at the same spot, is about 500-1000 years. The recurrence interval at any one spot for a local earthquake of magnitude 8 is roughly estimated at 120-400 years. The recurrence interval for a local tsunami of magnitude 8, that may occur anywhere along the 5,000 km long Indian-Burma trench is estimated to be about 30-100 years.

Given the range of numbers provided above, a conservative recurrence range for hazard mitigation planning purposes can be provided. Due to additional uncertainties inherent in attempting to predict future natural hazard events, 500 years is used as a conservative estimate for the magnitude 9 event and 100 to 120 years, for a local earthquake of magnitude 8. Over time, it is likely that these numbers will be refined as further studies in specific areas are conducted.

Consideration should be given to conducting studies that model the tsunami impact for each country, as different portions of the active subduction zones around the Indian Ocean rupture to relieve built up stress. Both Sieh and Okal recognize that the December 2004 event did not relieve all stresses along the southern portions of the Indian-Burma plates. This may be the cause of Java tsunami on July 17, 2006.

Norwegian experts such as F. Løvholt and C.B. Harbitz (Norwegian Geotechnical Institute) proposed a model for future tsunami risk for Thailand in both short and long term. The earthquake source is developed based on available seismological and geodetic inversions, and the simulation using the submarine earthquake source as initial condition agree well with sea level records and run-up observations. They concluded that another megathrust earthquake generating a tsunami affecting the coastline of Thailand is not likely to occur again for several hundred years. This is in part based on the assumption that the Southern Andaman Microplate Boundary near the Simeulue Islands constitutes a geologic barrier that will inhibit significant rupture across it, and in part on the decreasing subduction rates north of the Banda Ache region. It was also concluded that the largest credible earthquake along the part of the Sunda-Andaman arc that could affect Thailand, is within the next 50-100 years an earthquake of magnitude 8.5, which is expected to occur with more spatial and temporal irregularity than megathrust events.

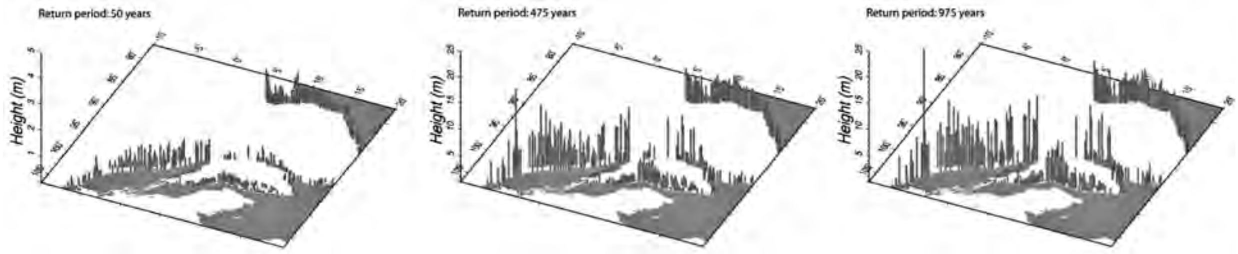
Numerical simulations have shown such earthquakes to cause tsunamis with maximum water levels up to 1.5-2.0 m along the west coast of Thailand, possibly 2.5-3.0 m on a high tide. However, in a longer time perspective (say more than 50-100 years), the potentials for earthquakes of similar magnitude and consequences as the 2004 event will become gradually larger and eventually pose an unacceptable societal risk. These conclusions apply only to Thailand, since the effects of an M 8.5 earthquake in the same region could be worse for north-western Sumatra, the Andaman and Nicobar Islands, maybe even for Sri Lanka and parts of the Indian coastline. Moreover, further south along the Sunda arc, the potentials for large ruptures are now much higher than for the region that ruptured on December 26, 2004.

Paul Somerville, Hong Kie Thio and Gene Ichinose from URS Corporation, Pasadena Office assessed the tsunami hazard over a long time scale using Probabilistic Tsunami Hazard Analysis (PTHA). Probabilistic Seismic Hazard Analysis (PSHA) has become a standard practice in the evaluation and mitigation of seismic hazards on structures, infrastructure, and lifelines. Its ability to condense the complexities and variability of seismic activity into a manageable set of parameters greatly facilitates the design of effective seismic resistant buildings and infrastructures.

Although PSHA usually considers the ground shaking hazard from earthquakes, the same approach can be used to estimate other seismic hazards, such as fault displacement, surface folding due to subsurface faulting, soil liquefaction, lateral spreading of soil, and landslides. They have extended the capability of PSHA to include tsunami wave height at the shoreline.

PTHA can be used to identify whether a significant tsunami hazard may exist at a particular coastal location or over a stretch of coastline. If the hazard is found to be

Meeting held at Bangben School, Ranong in March 14, 2007 to explain about tsunami disaster and evacuation plan



Probabilistic tsunami hazard for the northeastern Indian Ocean for three return periods (From P. Somerville, Hong Kie Thio & Gene Ichinose, 2005, Probabilistic Tsunami Hazard Analysis, a report by personnel communication)

significant, then further analyses can be performed, such as:

- Probabilistic tsunami run-up and inundation calculations at the site based on the probabilistic tsunami wave height at the shoreline
- Probabilistic tsunami loss calculations based on the probabilistic run-up and inundation

In probabilistic ground motion hazard analysis, the estimation of ground shaking level for a specified magnitude and distance from the source is based on ground motion attenuation relations. This kind of approach is not feasible for tsunamis, because fault orientation and ocean bathymetry cause a large variability in the height of the tsunami, which is not a simple function of the distance to the source. To estimate the tsunami height at a particular location along the coast for a given earthquake, they have adopted a waveform excitation and propagation approach instead of trying to develop tsunami attenuation relations. They computed the complete tsunami wave field for each earthquake scenario.

They have carried out preliminary tsunami hazard calculations for the Sumatra-Andaman subduction zone based on the earthquake recurrence model of Peterson et al. (2004), who performed a PSHA for the island of Sumatra and surrounding regions. The calculations use a set of 2,000 scenario earthquakes to provide a probabilistic description of tsunami wave height occurrences in the region. In the figure on top of this page, the probabilistic tsunami wave heights for return periods of 72, 475 and 975 years, corresponding to probabilities of exceedance of 50%, 10% and 5% in 50 years are shown.

At return periods of 475 and 975 years, tsunami heights reach more than 20 m along the entire subduction zone. Away from the subduction zone, the amplitudes are significantly lower, but there is strong variability along the coastline of Thailand. In particular, the highest calculated tsunami amplitudes are at Kao Lak and Phuket, which were hardest hit during the December 26, 2004 earthquake. The high waves along this stretch of shoreline are evidently caused by local bathymetry and topography. This illustrates the usefulness of this method in identifying stretches of coastline that are particularly vulnerable to tsunami damage

Historical tsunami and tsunami deposit data are also important for assessing the tsunami hazard. Past records provide clues to what might happen in the future, such as frequency of occurrence and maximum wave heights. Instrumental and written records do not often span over a long enough time to assess the full range of a region’s tsunami hazards. Therefore V. Brocko (University of Colorado) and P. Dunbar (US National Geophysical Data Center) are developing a Tsunami Deposit Database. For paleotsunami studies in Thailand, Dr. Brian Atwater from USGS is developing regional cooperation and cross-learning with field exercise in Phang-nga to forecast the next tsunami in the Indian Ocean as well as to build capacity for tsunami hazard assessment. The taphonomy of sediments deposited by the Indian Ocean Tsunami along the west coast of the Malay-Thai Peninsula was studied by University of Pennsylvania group (B.P. Horton, A. Hawkes and S. Engelhart). J.R. Schmidt, M.E. Kirby and B.P. Rhodes from California State University studied the Holocene coastal lagoon for paleotsunami deposits at Kamala Beach, Phuket and Tap Lamu, Phang-nga Province, Thailand. At Ban Talae Nok, Ranong province, K. Monecke and A. Moore (Ken State University), J. Beitel and K. Moran (University of Rhode Island) studied the sedimentary characteristics of the 2004 Indian Ocean tsunami. These studies showed the historical tsunami records in the sediment deposits.

CONCLUSION

The tsunami disaster mitigation can be done by mapping tsunami hazard and risk on the vulnerable coasts. The researches on probabilistic tsunami hazard and tsunami recurrence are useful for developing an evacuation plan and coastal zone management. The practical applications of tsunami risk assessment, in both quantitative and qualitative terms, for implementation into mitigation strategies for the terrestrial and marine environments include:

1) Building Codes (potential damage due to wave action and flooding)
2) GIS Mapping
3) Land-use Planning (taking note of wave action & flooding)
4) Disaster Planning (in identified hazard zones)
5) Emergency Management
6) Emergency Personnel Training (necessary aspects relevant to marine situations)
7) Rescue and Response (cargo, tourist, inter-islands fishing community, marine situations related to shipping, recreational boating)
8) Insurance Needs
9) Community Education
10) Simulated Tsunami Drill and Exercises

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Drought Monitoring Using Remote Sensing and Memories of Stay at the Asian Institute of Technology, Thailand

I had been seconded to the Asian Institute of Technology (AIT), Thailand, from ICUS as a long-term Japan International Cooperation Agency (JICA) expert and Visiting Assistant Professor for two years since February 2005. Just after coming back to ICUS, I moved to Kyoto University in March 2007. In this article, I report my research activities in AIT and the history of collaboration between AIT and Japan.

DROUGHT MONITORING USING REMOTE SENSING

The northeastern part of Thailand has periodically experienced severe droughts. One definition of drought, agricultural drought, is said to occur when there is insufficient soil moisture to meet the needs of a particular crop at a particular time. Drought monitoring around Thailand, Laos and Cambodia, especially agricultural drought, is becoming increasingly important.

Remote sensing is capable of monitoring drought because it simultaneously detects spectral data from the surface of a wide area. Actually, several physical parameters can represent the severity of drought condition. Roughly divided, optical region (visible to infrared regions) and microwave region can be used to detect such parameters. For example, the Surface Energy Balance Algorithm for Land (SEBAL) predicts land moisture indicators such as Bowen-ratio and evaporation fraction from visible, near-infrared and thermal-infrared radiances through surface energy balance equation. On the other hand, microwave sensor is better to detect volumetric soil moisture and water body rather than optical sensor because the dielectric constant of water in microwave region can be easily discriminated from dielectric constants of other matters. The author examined techniques required to estimate soil moisture from Synthetic Aperture Radar (SAR) data, which is one of the active microwave remote sensing.

The author has installed equipments and measured soil moisture at several paddy fields in Buriram Province, northeastern Thailand from October 2005. Japanese Earth Resources Satellite-1 (JERS-1)/SAR images observed from 1992 to 1998 were available around field measurement sites. Firstly, the Integral Equation Method (IEM), which models scattering of microwaves between different matters, was used. In the present research, surface roughness was measured by leveling. Autocorrelation length of surface roughness, a quite difficult parameter to measure, was stably calibrated. By applying the IEM model to temporal JERS-1/SAR images, temporal change of soil moisture was estimated. Then, soil moisture distribution was mapped from 1992 to 1998. Long-term observation is quite indispensable to represent the regional trend of soil moisture distribution. It was found that temporal JERS-1/SAR data are quite informative about regional characteristics of soil moisture.

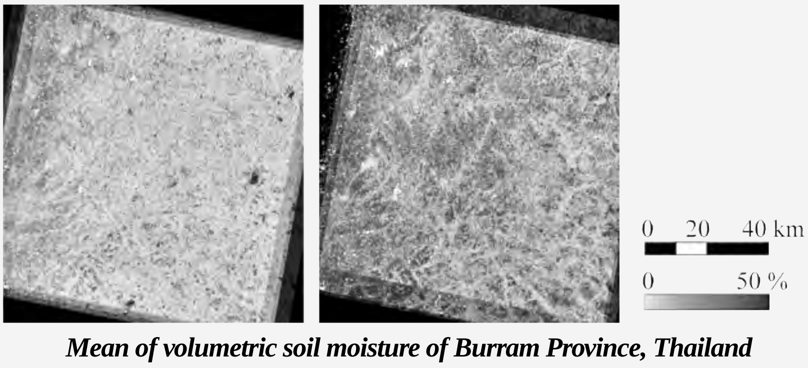
From time to time, high expectations are given to real or near-real time monitoring using remote sensing. However, in Thailand, it is quite difficult to obtain cloud-free optical image, and accordingly, difficult to exactly understand the surface conditions on a daily basis. Early drought warning system cannot be achieved without optical remote sensing. While SAR can detect at all-weather conditions and nighttime, the frequency of the observations, dozens of days, is low. Due to such long recurrent periods, SAR cannot be utilized for the real/near-real time monitoring. However, SAR images are highly capable of mapping distribution of potential soil moisture. The author expects that using both SAR data and optical data, it would be possible to better prepare for droughts.

COLLABORATION BETWEEN AIT AND JAPAN

Dispatching JICA experts to AIT by Japanese Government started in 1969. Long-term experts, i.e. with longer than six months stay, amounted to 118 persons. Lately, Japan started to gradually withdraw support to AIT. Eventually, it was decided that I would be the last long-term JICA expert dispatched. Other than me, there are other Japanese faculty members, four directly hired by AIT and four seconded by other institutes of Japan including Dr. Kato from ICUS.

In spite of this, the Japanese Government is still interested in contributing to the human development of South and Southeast Asia, and recognizes that AIT can be a partner to meet this purpose. Collaboration between AIT and many Asian universities has become more and more active in terms of research and education. Moreover, many master students of AIT are eager to study in Japan and obtain Ph.D. degrees with the support of Japanese Government scholarships. Actually, the Department of Civil Engineering, the University of Tokyo has welcome many students from AIT. With consideration of these different levels of interactions, I believe that AIT and Japanese universities will continue to collaborate in the future.

(By J. Susaki,
Graduate School of Engineering,
Kyoto University)



Mean of volumetric soil moisture of Burram Province, Thailand in dry season (Upper: March and April) and rainy season (Lower: July and August)

IIS — Chula Unisearch Workshop for Urban Safety

The first joint workshop between the Institute of Industrial Science (IIS), The University of Tokyo and the Civil Engineering Department, Chulalongkorn University was held at the Engineering Building of Chulalongkorn University on February 27, 2007. Fifty-seven participants attended the workshop.

The workshop began with opening speeches by Professors Y. Yasuoka and P. Lukkunaprasit. The following topics were presented:

- *'Seismic Hazard Mitigation — The Thailand Experience' by Prof. Panitan Lukkunaprasi.*
- *'Fire Egress Analysis for Buildings' by Assistant Prof. Thanyawat Pothisiri.*
- *'Importance of Maintenance of Concrete Structures for Urban Safety' by Prof. T. Uomoto.*
- *'Blast Load Test on Ferro cement Bomb Baskets' by Dr. Thanakorn Pheeraphan.*
- *'Satellite Observation Network for Environment and Disaster Monitoring in Asia' by Prof. Y. Yasuoka.*
- *'Rainfall Estimation by Remote Sensing Instruments' by Dr. Virat Chatdarong.*
- *'Urban transportation Safety: Current Situations and Improving Strategies' by Assistant Prof. Kasem Choocharukul.*

The workshop was closed with a speech by Prof. Uomoto. At the end of the workshop, it was agreed to hold the similar workshop at least once a year from now on. The participants were mostly engineers from industries and research institutes of Thailand.

(By T. Uomoto)

Symposium on Japanese Contribution to Worldwide Disaster Mitigation

On January 18, 2007, the symposium entitled "From Japan to the World: Initiatives to reduce seismic vulnerability" was held at the Kobe International Convention Center. Six presentations were delivered:

- Ms. M. Suzuki, Shanti Volunteer Association: "What has SVA recently done for natural disaster mitigation in developing countries?"
- Mr. M. Yoshitsubaki, Citizens Towards Overseas Disaster Emergency: "CODE's activities for addressing the recovery of affected people: What is safe and secure housing?"
- Prof. K. Meguro, ICUS, The University of Tokyo: "US$100 Retrofitting Method for Masonry Houses: Recent activities"
- Dr. M. Takashima, Fuji Tokoha University: "Development of a New Tsunami Disaster Mitigation System Considering the Regional Characteristics in the Indian Ocean Rim Countries"
- Prof. K. Okazaki, National Graduate Institute for Policy Studies: "Japanese Government Activities for Improving Low Earthquake Resistant Structures in Developing Countries"
- Prof. J. Kiyono, Kyoto University: "Cooperation Activities for Soil Testing and Disaster Education Supporting Activities between Japanese and Indonesian University Students"

After the presentations, discussion was opened. Because the number and frequency of seismic events is relatively low, the importance of sharing experiences was highlighted. It was also mentioned that funding for disaster mitigation is limited and affects the sustainability of non-governmental agency organizations.

(By K. Meguro)

RNUS Activities

Inspection of Reinforced Concrete Bridges exposed to Marine Environment in Thailand

RNUS conducted a project for the inspection of reinforced concrete bridges exposed to marine environments. Five bridges in 3 provinces in Eastern Thailand, namely Samutprakan, Chonburi, and Chanthaburi, were investigated. The aim of this project is to collect data about reinforced concrete bridges in Thailand, especially related to their durability. The project was led by Mr. Pakawat Sancharoen, currently a doctoral candidate at the Graduate School of Civil Engineering, the University of Tokyo, with the collaboration of a group of undergraduate students from Rajamangala University of Technology Thanyaburi, Thailand. This project was financially supported by the Central Research Institute of Electric Power Industry, Japan.

RNUS Seminar

Dr. Wonsiri Punurai, Lecturer of the Department of Civil Engineering, Faculty of Engineering, Mahidol University delivered the presentation 'An Introduction to Ultrasonics and Its Application for Characterization of Cement-Based Material' for the RNUS seminar held on February 8, 2007. She introduced the fundamental principles of ultrasonic waves with examples of their application in Concrete Engineering. The seminar received a remarkable interest from graduate students, researchers, as well as instructors of the School of Engineering and Technology (STE), Asian Institute of Technology (AIT).

(By R. Sahamitmongkol)

Locations of the bridges targeted by RNUS study

Inspection team taking sample to determine chloride concentration

Dr. Wonsiri Punura (second from left), with Instructors of the STE, AIT

The First IIS Alumni Party was held in Bangkok

The first IIS Alumni party was held in Bangkok on February 26, 2007. It was attended by 17 member including Prof Y. Yasuoka, Prof. T. Uomoto, Dr. Y. Kato and Dr. R. Sahamitmongkol and was held at the Pathumwan Princess Hotel, Bangkok. As this was the first IIS Alumni party outside of Japan, Prof. Y. Yasuoka made an opening speech on behalf of the Director General of IIS, Prof. M. Maeda.

The participants introduced themselves and selected Prof. Suvit as the first president of the IIS Alumni Bangkok branch. It was also agreed to hold such party once every one or two years.

(By T. Uomoto)

Group photo of the participants at the end of the party

Prof. Meguro promotes earthquake disaster mitigation in Iran

Prof. K. Meguro participated in the "Workshop on Strengthening Earthquake Resistant Capacity of Masonry Houses in Iran" jointly organized by the Building and Housing Research Center (BHRC), the Japanese Ministry of Land, Infrastructure, and Transportation (MLIT), the Japan Bank for International Cooperation (JBIC), the Infrastructure Development Institute (IDI), and The University of Tokyo at BHRC, Teheran, on March 14, 2007. The event was attended by approximately sixty participants including representatives of the Kerman Recovery Reconstruction Agency, the Japan International Cooperation Agency, JBIC, the Foreign Affairs Ministry of the Japanese Government, Iranian academicians, and professional engineers. The workshop was opened with speeches from Prof. Heidarinejad (BHRC), Mr. N. Yamane (MLIT), and Mr. H. Matsunaga (JBIC). After them, the following presentations were delivered:

- Mr. M. Sugahara: "Earthquake disaster-prevention measures in Japan"
- Dr. T. Tsugawa: "Latest earthquake resistant and damping technology in Japan"
- Mr. Eng. Zamani: "Results of static loading test on masonry wall specimens reinforced by PP-mesh"
- Dr. Hasan Moghadam: "Practical retrofitting experiments for masonry buildings"
- Mr. Eng. Honarbaksh: "Practical retrofitting experiments for Iranian public schools"
- Prof. K. Meguro: "PP-mesh technology and its availability/ applicability for masonry houses"
- Mr. Salehi, Deputy Governor of Kerman Province: "Earthquake disaster control policy and specific countermeasures in each province"

During the workshop, greetings from the Japanese Embassy, delivered by Mr. T. Yawata, were conveyed .

The proposal of retrofitting adobe/masonry houses by PP-meshes was welcomed by the audience as an alternative to solve the problem of many low earthquake resistant houses which is currently the largest issue for earthquake disaster mitigation in Iran. The Iranian research community expressed its eagerness to explore this option and assess the feasibility of adopting it. After the 1991 Manjil Earthquake, adobe houses have been officially but unsuccessfully banned in Iran. Therefore, it is a great accomplishment that discussions on the possibility to retrofit adobe structures to prevent their collapse have started in Iran.

(By K. Meguro)

BNUS Activities

Armenitola Governmental High School is situated in the most densely and hazardous area of Old Dhaka. In order to increase the knowledge base and make the students fully aware of their status during and after a disaster, BNUS has provided, for the last couple of months, different earthquake related trainings that may help in reducing the losses due to an earthquake .

The short course on First Aid trained 77 students of class VI to IX from Nov. 30 to Dec. 2, 2006. Each day they underwent a 3-hour training on First Aid. The general knowledge on primary treatment and special care of injuries especially with casualty due to earthquake was given emphasis in this program.

Next, the search and rescue (SAR) training program on how to deal with casualty after a disaster was considered. Thirty-three students out of 77 first aid trainee students were selected for instruction from December 10 to 12, 2006. Here the students learnt about different stages of SAR, different styles of rescue from a damage sector of a building, technique of stretcher use with casualty, casualty evacuation with fireman using a chair knot, technique of debris cleaning, etc.

Finally, a safety drill on the whole scene due to an earthquake and the duties of the public was demonstrated by the trained students at Armenitola Governmental High School, Dhaka on February 23, 2007 to have a clear cut view of the earthquake situation. One hundred fifty students participated in the drill. The program was carried out under the leadership of already trained 33 students. The guardians and the school authority were present in the program, in which the students presented their duties before, during and after an earthquake. To increase awareness, each school student was given an awareness poster.

(By M. Ansary)

Participants in the Safety Drill on Earthquake

ICUS Expands its Collaboration Network

Three new Memorandums of Understanding (MOUs) were signed between ICUS and the Department of Civil Engineering of the Shibaura Institute of Technology, Japan; the Global u-City Construction & Information (Gucci) Hub Department of Civil Engineering (BK21), Han Yang University, Korea; and the Department of Construction Engineering, National Kaohsiung First University of Science and Technology, Taiwan. The objectives of these agreements are to foster the exchange of researchers, information, and academic materials, to conduct joint researches, and to organize academic meetings, symposia, and workshops.

All these three institutes have very close research interests with ICUS and we are looking forward to having a fruitful collaboration among us.

(By P. Mayorca)

Scholars from National Kaohsiung First University of Technology in a previous visit to ICUS

Delegation from Shibaura Institute of Technology during visit to ICUS

Professors Byung-Wan Jo and Taketo Uomoto after signing MOU

Dr. Shinji Tanaka joins ICUS

Dr. S. Tanaka joined ICUS from March 1st, 2007. He received his Master degree from the University of Tokyo in 1999. After working as a researcher at the National Institute for Land and Infrastructure Management, he became a Research Associate at the Institute of Industrial Science, and obtained his Doctor of Engineering Degree from The University of Tokyo in 2007.

Dr. Shinji Tanaka

His major research field is traffic engineering, and his research interests are traffic control, operation, management and traffic behavior analysis. In his doctoral dissertation, he analyzed the influence of on-street parking on traffic flow, proposed a new on-street parking management scheme with creating parking spaces on street, and evaluated it by traffic simulator and driving simulator. Joining ICUS, he will conduct researches for a sustainable city from an aspect of traffic and transport.

(By T. Uomoto)

ICUS Activities

- *Prof. Uomoto visited Rheinisch-Westfälische Technische Hochschule Aachen University, Dusseldorf, Germany from February 10 to 14 together with Dr. Kato. They attended a seminar at the Bundesanstalt fur Materialforschung und -prufung (BAM.)*
- *Prof. Uomoto and Dr. Kato visited the Bosporus Channel Tunnel construction site at the Bosporus Strait, Istanbul, Turkey from February 14 to 18, and held meetings with relevant personnel .*
- *Prof. Uomoto attended the joint workshop between the Institute of Industrial Science (IIS), The University of Tokyo and the Civil Engineering Department, Chulalongkorn University held at Bangkok, Thailand on February 27. He also joined the IIS Alumni party was held in Bangkok on February 26.*
- *Prof. Meguro attended the High Level Meeting arranged by the Japan Science and Technology Agency, the National Research Institute for Earth Science and Disaster Prevention, the Ministry of Construction and Urban Development, the Research Center for Astronomy and Geophysics and the World Seismic Safety Initiative in Mongolia from February 6 to 8. He made a presentation on "Seismic Damage to Brick and Weak RC Structures."*
- *Prof. Meguro visited Teheran, Iran to attend the "Workshop on Strengthening Earthquake Resistant Capacity of Masonry Houses in Iran" held in March 14. He introduced there the latest developments of PP-band retrofitting for masonry houses.*
- *Dr. Kato stayed at AIT for his research work and teaching duties at RNUS from January 29 to March 2.*
- *Dr. Kanada visited Korea from March 11 to 16 to deliver the lecture entitled "Recent new NDT method for infrastructures" at the Han Yang University and the Korea Highway Corporation.*
- *Dr. Sahamitmongkol stayed at AIT for his research work and teaching duties at RNUS from December 29, 2006 to March 24, 2007.*
- *Prof. Byung-Wan Jo, Director of the Global U-City Construction and Information (GUCCI), Hub Department of Civil Engineering (BK21), Han Yang University, visited ICUS on February 22 to sign a memorandum of understanding with ICUS.*
- *A delegation of scholars from Shibaura Institute of Technology visited ICUS on March 8. ICUS members briefly introduced their research topics. Future possible research collaboration directions were discussed.*
- *After 3 years of research activities, the RC-39 Committee held its last meeting to summarize its work output on March 28. After it, Prof. Amano delivered the speech: "Examples of cooperation with an academic institution: ICUS, IIS, The University of Tokyo."*

Editor's Note

I have worked as the director of ICUS since April 2001 and I am retiring from ICUS at the end of March, 2007. In these six years, many problems occurred related to urban safety, such as Niigata-Chuetsu Earthquake (Japan, 2004), terrorist attacks on the World Trade Center (US, 2001), asbestos problems (Japan, 2005), Sumatra Earthquake and Tsunami (Indian Ocean Rim, 2004), faked building design scandal (Japan, 2005), among others. Even in March this year, two large earthquakes, the Notohantou earthquake (Magnitude : 7.1) in Japan and another in Indonesia (Magnitude : 6.4), killed people as reported by newspapers and TV programs.

It is impossible to eliminate all the hazards which may happen in the world. All we can do is reduce the number of deaths and other damage due to these hazards by ensuring people use infrastructure safely enough. After the Sumatra Earthquake, people and governments in South and South East Asia started projects to monitor tsunamis in the Indian Ocean, to teach the people about the tsunami hazard, and to warn people after an earthquake as soon as possible. Actually, when a smaller earthquake occurred in Indonesia after the Sumatra Earthquake, people living on the coastal lines tried to run away from the shores having the tragedies of the Sumatra Earthquake fresh in their minds.

Although ICUS members have been working very hard to reduce the negative impacts of hazards, it is not an easy task to accomplish. During my stay at ICUS, we tried to concentrate mostly on preventing disasters by all means. Some of the outputs of these works have already been published as reports, and some are still undergoing, such as a new disaster management system for the Hospital of the University of Tokyo and seismic strengthening of important buildings in the smaller cities in Japan.

I would like to thank all ICUS members for supporting me during these six years and I hope ICUS will continue its works to produce a much safer world from now on.

(By T. Uomoto)

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp.

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IMPORTANCE OF TECHNICAL AND SOCIAL PROBLEMS TO PREVENT FALSE STRUCTURES FOR URBAN SAFETY

By

*Taketo UOMOTO**

INTRODUCTION

In November 2005, a big shock struck Japanese society through newspapers, radios and TV programs. Mr. Hidetsugu Aneha, a first-class certified architect confessed that he faked records to make substandard buildings look like they met Japan's anti-earthquake requirements. He mentioned that he began faking earthquake safety data around 1998, when a developer asked him to cut costs by reducing the amount of steel reinforcement below the compulsory minimum in a Tokyo apartment project. The newspapers mentioned that at least 99 structures which he designed may collapse even in a moderate earthquake.

Such news had never been reported in Japan. The people, who bought houses paying large amounts of money, lost everything except the commitment to return the bank loan. If such a disaster was caused by a natural hazard (earthquake, tsunami, flood, fire, etc.), Japanese people and government would surely try to help the victims by all means. But in this faked design case, it is not easy to persuade the people of our country to support the victims.

PROBLEMS RELATED TO FALSE WORKS

The problems related to false works reported by newspapers, magazines, etc. can be classified as follows:

- Group 1: Mistakes by engineers and workers
- Group 2: False works due to insufficient knowledge
- Group 3: Intentional false works knowing that they are difficult to be detected

It is difficult to eliminate all problems belonging to Group 1. Any

Collapsed RC bridge due to the 1995 Kobe Earthquake

Corrosion of steel due to the use of sea sand as fine aggregate

person can make a mistake but this is of particular concern for engineers. Considering this, most of the specifications, guides, instructions and books are published showing both how to prevent mistakes and how to check the accuracy of the results. If we look at some of the books, we can easily find data showing the percentage of "error" based on numerous data surveyed from many construction works. As an example, the design codes give the standard error in bar arrangements, form arrangements, etc.

Workers and engineers, especially those without sufficient knowledge and experience, may easily create problems belonging to Group 2. In 1960's and 1970's, chloride induced corrosion of steel reinforcing bars due to sea water were reported by researchers, but concrete engineers were not much concerned about the chloride contained in sea sand which was used as fine aggregate. As a result, many important concrete structures, such as railway bridges in the western part of Honshu, deteriorated within 20-30 years, as shown in the picture on the upper left corner of this page. In the late 1980's when evidences of "alkali-aggregate reaction of concrete structures" were reported to the Japanese concrete society, neither concrete engineers nor concrete researchers believed in the problem. Most civil engineers and concrete engineers in Japan thought that alkali-aggregate reaction did not occur in our country. Teachers and professors teaching concrete technology explained that no problems of alkali-aggregate reaction have been reported in Japan that far.

Cracks on retaining wall due to the use of reactive aggregates

As a result, many concrete structures which used reactive aggregate extensively cracked even when provided with steel reinforcement. The figure above is an example of this.

The "Aneha" problem is the typical example of Group 3. Maybe it was not such from the beginning, but as the system consistently failed to detect Mr. Aneha's faulty works, he may have realized the system flaws and how to take advantage of them. Similar problems are "addition of water" to ready mixed concrete at the site, lack of bond length of anchoring bars for anti-falling apparatus, etc. The details of these problems are explained in the following section.

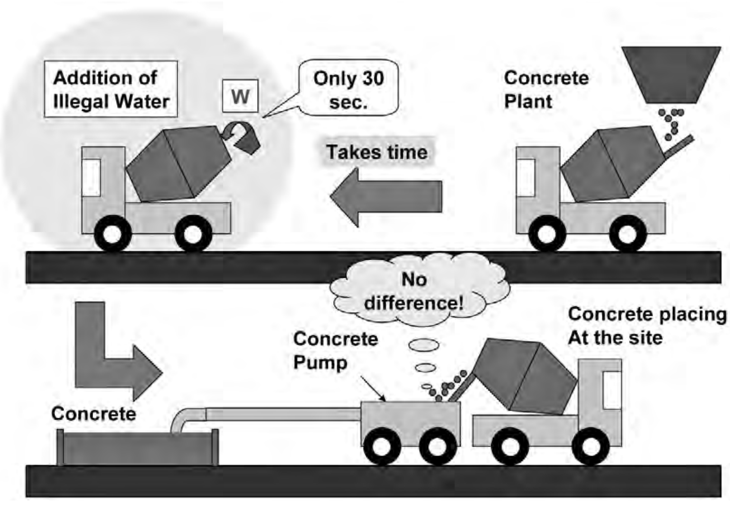
PROBLEMS OF "WATER ADDITION" AND "ANCHORING BARS"

Addition of illegal water to ready mixed concrete

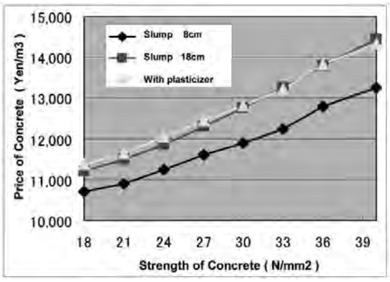
Addition of water to ready mixed concrete has been strictly prohibited in Japan. But due to several reasons, such false works can be found at some of the construction sites. As shown in the figure below, when ready mixed concrete is carried from the concrete plant to the site, it often takes more than 30 minutes due to traffic conditions. As a result, the concrete slump reduces due to the evaporation of mixing water especially in hot climate. Since 1970's, it is common to use concrete pumps to cast the concrete in place. The pumpability of concrete is mainly governed by the fluidity and segregation resistivity of concrete. Generally speaking, it is easier to convey the concrete with higher slump to the casting place than lower slump concrete. To increase the slump of transferred concrete, addition of water is the easiest and it does not imply any additional cost. Addition of such illegal water to concrete can be done within 30 seconds without being discovered by the engineers at the site. Even when additional water is added to the conveyed concrete, it is difficult to find out the amount by regular inspection methods.

As shown in the figure on the upper left corner of next page, if we have to increase the slump of concrete from 8cm to 18cm, with the same concrete strength, the cost increment will be about ￥1000 per cubic meter. This is about 8% for a concrete of 30N/mm2 strength even when plasticizer is used. This cost increment is not affordable by the client nor by the constructor. On the other hand, water addition increases the slump at no cost, but reduces the concrete strength about 15% and also the concrete durability.

Considering these evidences, the



Illegal addition of water to ready mixed concrete



Price versus strength of concrete with different slumps (2003)

Ministry of Construction introduced a method to inspect the water content of concrete by Non-Destructive Testing (NDT) since 2003. Although the NDT measuring apparatus is not always accurate enough, such a system may reduce the "illegal addition of water" to certain extent.

Anchor bolts for seismic safety

When the 1995 Kobe Earthquake occurred, many bridge piers were destroyed due to enormous force acting on the structures and many bridge girders fell off from the piers by the seismic force as shown in the cover of this newsletter issue. The cars on the bridge easily fell down from the bridge even after the earthquake.

To prevent such a disaster several types of apparatuses, such as the ones shown in the photos on the upper right corner of the page, were installed to the existing piers to prevent the falling of the bridge girders and maintain the structures for a longer period of time.

To install such apparatuses, anchor bolts must be embedded into the existing piers by coring the concrete to the specified depth. The existing structures have been used for as long as 50 years and design drawings are not available in some cases. Even when design drawings are still available, the bar arrangements in the actual structure may not coincide well with the drawings.

When drilling is done, there is a high possibility that the core drill may hit the embedded steel bars. What did the workers do in this case? They behaved in two ways as shown in the figure on the right:

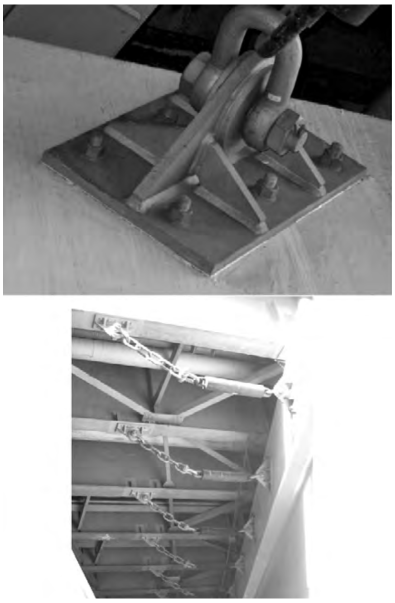
1) Stop the drilling at the depth of the steel bars.
2) Drill the concrete and steel to the specified depth.

As a result, some anchored bolts lack bond length, and some reinforcing bars in the structures were cut. In Case 1, anchor bolts may not be strong enough against seismic forces, and the pier strength is reduced to form cracks in Case 2.

The Ministry of Construction mentioned that about 2% of the whole anchor bolts used in road bridges had problems so far and they asked the contractors to reinstall the false anchor bolts. To prevent such problems, inspection must be done properly. One of the most effective method is to utilize NDT. The inspection must be done before and after the installation of anchor bolts. Ultrasonic method may be useful to inspect the length of bolts and electromagnetic method may be useful to detect the steel bars in concrete before drilling.

SYSTEMS TO BE SETUP

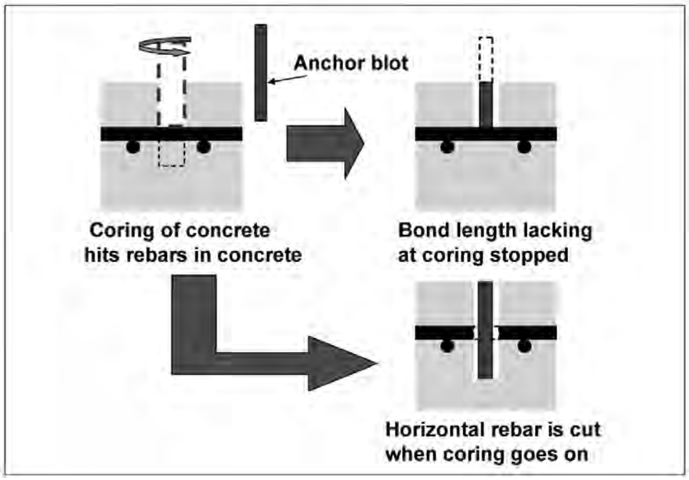
As explained above, many problems are occurring at the site. Until now, the systems being used in our country are all based on Japanese culture and ethics in the believe that people will not try to do bad things, unless by accident. But the evidences presented above gave a big warning to our culture: ethics is no longer sufficient and "learning makes a good man better and an ill man worse". A new system must be studied not only from a technical point of view but also by incorporating the systems related to law, economics, insurance, etc.



Apparatus to prevent the fall of bridge girders

Civil engineers have been working to offer better facilities to make the human society comfortable. "Safety", "Serviceability", "Durability", and "Esthetics" are the major requirements of the structures through out their service life. To deal with the problem, civil engineers have been working to offer better and safer structures to the society. But the efforts we have been making may not be enough. Maybe we have to widen our field to study not only technical problems but also insurance, law, economics, etc. in order to discover and eliminate faked works which may not have been revealed yet.

**** Professor,***
Shibaura Institute of Technology
and Former ICUS Director



Drilling concrete to install anchor bolts

Prof. Meguro appointed ICUS Director

It is with a great honor and deep sense of commitment that I accept the appointment as ICUS Director following Prof. Uomoto's retirement from the University of Tokyo. I would like to take this opportunity to extend our center gratitude and especially my own for his great leadership under which ICUS has grown and become a leading institution addressing urban safety issues by carrying out advanced research, disseminating information, and also by helping create a network of experts in the field.

I have had the great opportunity to be a founding member of ICUS predecessor, the International Center for Disaster-Mitigation Engineering and also ICUS itself. During these 17 years of involvement with both centers, many disasters have occurred worldwide and I have had several opportunities to visit the affected sites and have a direct contact with those situations. These experiences have helped me to realize the importance of urban safety and its issues. During this period, I have also been very lucky to build a worldwide network of outstanding experts who share the same concerns and have enriched my understanding of the problems with their opinions.

Prof. Meguro receives the post of ICUS Director from Prof. Uomoto.

To all ICUS network members, I would like to thank very much for your support until now. We, at ICUS, are really looking forward to continuing and starting collaborative activities together. Please do not hesitate to contact us and we will try to assist you and do our best in spite of the limitations of our human resources.

(By K. Meguro)

12th Open Lecture was held

The 12th ICUS Open Lecture was held at IIS and attended by approximately 130 participants. The title of the lecture was "ICUS Activities to Achieve a Safer Urban Environment -Past achievements and future directions-." ICUS was established in April 2001 with the objective of promoting fundamental and collaborative research, networking and information dissemination related to various aspects of urban safety engineering towards creating a safe urban environment in the 21st century. In this Open Lecture, achievements of the first six years of ICUS and its focus for the future were discussed.

Dr. Ooka gave the welcome speech after which the following presentations were given:

- Prof. Taketo Uomoto, Shibaura Institute of Technology and Former ICUS Director, "Urban Safety and Concrete"
- Prof. Yoshifumi Yasuoka, IIS, the University of Tokyo, "Observation and Assessment of the Urban Environment and Disasters"
- Prof. Kimiro Meguro, ICUS Director, "Towards Urban Safety, Hard and Soft Approaches- from a Domestic and International Viewpoint"

Professors T. Uomoto,Y. Yasuoka, and K. Meguro delivering their lectures

Additionally, video messages from three ICUS network members were displayed:

- Dr. Dushmanta Dutta, Lecturer, Monash University, Australia
- Dr. Tan Kiang Hwee, Associate Professor, National University of Singapore
- Prof. Mehedi Ansary, Bangladesh University of Engineering and Technology

The closing remarks were given by Prof. Yasuoka. After the Open Lecture a small party was held and attended by approximately 60 people.

(By P. Mayorca)

ICUS Open House

ICUS joined the IIS Open House which was held for three days, from May 31 to June 2. In this event, our institute is open to experts and the public to share its research outcomes with the visitors. Overall 6,000 people visited Komaba research campus. A theme of the ICUS was "Towards the Establishment of a Sustainable Urban System." All laboratory members participated and displayed their panels showing their research activities. Topics included diagnosis, repair, and strengthening of concrete, earth, and underground structures, diffusion of contaminants in urban areas, need of disaster resilient water cycle systems for sustainable societies, analysis of traffic jam, the challenge to integrate countermeasures to achieve earthquake disaster resilient urban systems, and others. The open house was also an opportunity to introduce the 2006 Annual Report as well as RNUS and BNUS activities. Reports and newsletters were handed to visitors. Almost 200 people visited ICUS exhibition. An ICUS Quiz was prepared following the success of last year issue. About 90 people participated in the quiz and got prizes such as photo stands, picture books, ICUS special calendars, small bags, and key holders.

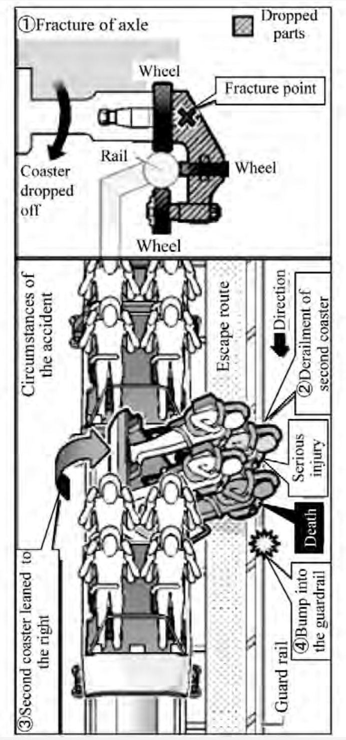
Open House attendees of all ages participated in ICUS Quiz

(By R. Kuwano)

A Woman Died in Roller Coaster Accident

A woman was killed and 19 other people were injured when a roller coaster derailed on May 5, 2007. The six-car stand-up roller coaster derailed and bumped into the guard rail at Expoland in Suita, Osaka Prefecture.

The accident was caused when a wheel axle on the second coaster broke. Expoland carries out routine visual checks on the roller coaster every February under legal guidelines, and usually disassembles and inspects the ride on a voluntary basis around the same time. But the axle had not been replaced since the roller coaster was introduced in March 1992. Other amusement parks that use coasters have regularly inspected or replaced axles.

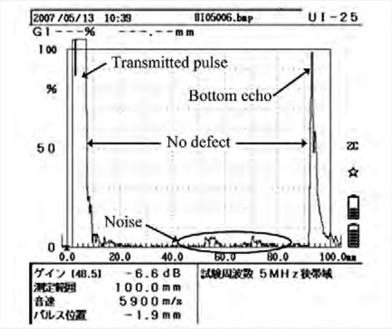


Summary of the accident (reproduced with permission of Asahi Shimbun)

According to Japanese Industrial Standards (JIS), ultrasonic or magnetic-particle inspections should be conducted on coaster axles at least once a year. Many amusement parks fail to conduct these nondestructive inspections. As a result the Ministry of Land, Infrastructure and Transport, through prefectural governments, asked amusement parks nationwide to conduct an emergency checkup of their roller coasters by May 18, 2007.

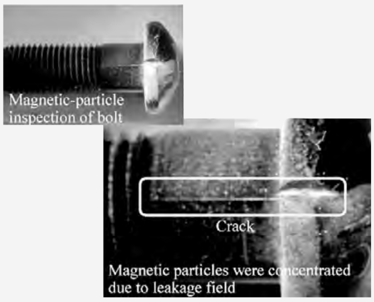
Ultrasonic and magnetic-particle methods are commonly used to inspect the parts of coasters. Ultrasonic method can be used to detect inner defect. The probe emits ultrasonic from one end of the wheel axle and then the bottom echo is detected. If there is a defect in the axle, flaw echoes reflect from defects before the bottom echo.

Magnetic-particle inspection can be used to detect surface-breaking or near-surface cracks. If the ferromagnetic material has no defect, most of the magnetic flux is concentrated below the material's surface. However, if a defect, which interacts with the magnetic field, is present, the flux is distorted locally and 'leaks' from the surface of the specimen in the region of the flaw. Fine magnetic particles, applied to the surface of the specimen, are attracted to the area of flux leakage, creating a visible indication of the defect.



Ultrasonic waveform (no defect)

Magnetic-particle inspection of axle



Magnetic-particle pattern

According to the report from Japan Building Equipment and Elevator Center Foundation, 26 people were killed and 255 people were injured by amusement equipments such as roller coasters or swings from 1977 to 2006.

The Ministry of Land, Infrastructure and Transport is now preparing detailed inspection guidelines for amusement facilities to prevent such accidents. After this, periodical nondestructive inspections or permanent certified staff may be required at all amusement parks. It is argued that it is too costly and not suitable to have such strict regulations for low speed coasters.

(By H. Kanada, Inspection and Measurement Division, Nippon Steel Techno Research Corporation)

Delegation from Tsinghua University visits ICUS

On June 29, 2007, a delegation of 13 representatives belonging to various Chinese governmental and academic institutions, led by Prof. Weicheng Fan, visited ICUS in order to sign the Memorandum of Understanding (MOU) between ICUS and the Center for Public Safety Research, Tsinghua University, for promoting research and education activities in the field of Urban Safety Engineering. These centers will be hosting the Eighth International Symposium on “New Technologies for Urban Safety of Mega Cities in Asia” next year. The signature of this MOU will strengthen the relationship between these two parties and bolster collaborative activities in the region.

(By R. Ooka)

MOU exchange

Delegation of Tsinghua University during its visit to ICUS

BNUS Activities

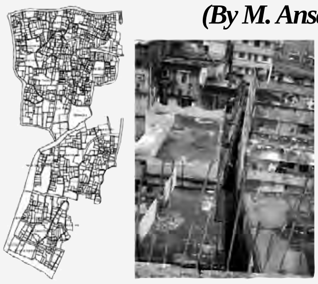
For the last few months, Bangladesh Network Office for Urban Safety (BNUS) is involved in the community awareness program. Recently, BNUS members attended a workshop on 'Mason Training and Hollow Block Laying' organized by the Housing and Building Research Institute, Ministry of Works, Government of Bangladesh. It was expected to increase the quality of construction at the community level.

Around 60% of buildings in Bangladesh are masonry structures. At present, BNUS is planning to undertake a project to assess the vulnerability of un-reinforced masonry structures (URM) in the cities of Bangladesh. To carry out this project, BNUS is planning to use the existing Universal Testing Machine (UTM) and the Compression Testing Machine (CTM) of the BUET. The UTM capacity is 1800kN (400kips) and gauge constant is 0.2 mm; the capacity of CTM is 700kN (160kips) and gauge constant is 0.2 mm. Using UTM and CTM, shear strength, joint strength, failure mode, etc. of masonry panels will be evaluated.

BNUS is also developing the earthquake evacuation plan for the Ward No. 68, Old Dhaka, the most dense and vulnerable part of Dhaka city. Old Dhaka is seismically vulnerable due to its high population density, narrow road networks, unplanned development, vulnerable structures, low preparedness, etc. To have an effective evacuation plan, vulnerability data of the existing buildings in the target area have been collected. A GIS based evacuation plan will be generated based on the existing site condition, i.e. buildings, road network system, evacuation places, etc., applying different evacuation techniques. The whole area will be segregated into different groups according to the vulnerability and capacity of evacuation places. Finally, a 3D elevation model of the area showing the escape route and the shortest path to the evacuation site from each specified group will be prepared.

(By M. Ansary)

Compression Testing Machine



Study area map and typical road channel with nearby buildings

RNUS Activities

Inspection of Fired Factory in Rayong Province

RNUS researchers, in collaboration with King Mongkut's Institute of Technology North Bangkok, inspected a fire affected factory in Rayong Province (Eastern part of Thailand). The compressive strength of concrete in column was evaluated with a Schmidt's Hammer and ultrasonic wave propagation technique. Samples from the roof truss in the fire affected zone were taken and tested to evaluate its residual tensile capacity. The loading capacity of the structure then was confirmed by numerical analysis.

Measurement of ultrasonic wave propagation velocity in RCcolumn at fire affected zone (left) and roof truss numerical simulation result (right)

RNUS Seminar

The RNUS seminar on 'Remote Sensing and Traffic Management for Urban Safety' was held on May 10, 2007. Two instructors from the University of Tokyo kindly delivered lectures to AIT students and researchers.

Dr. Wataru Takeuchi gave the lecture entitled 'Remote Sensing of Environment and Disaster over Asia with IIS/AIT Satellite Network' which clearly illustrates how remote sensing techniques can be applied to various field such as agriculture and flood protection.

Dr. Shinji Tanaka delivered the talk entitled "ITS Technologies and Researches for Urban Traffic Management" which illustrates several measures that can be applied to improve the traffic safety with some easy-to-understand simulation.

(By R. Sahamitmongkol)

Dr.Takeuchi delivering his lecture

Research Committee on BCM suitable for Japanese Society is launched

The Research Committee 58 (RC-58) was launched on April 1st, 2007 for a two-year period. The topic of this committee is "Business Continuity Management (BCM) Systems Suitable for Japanese Society". Business are faced with many threats to the continuance of their trade. Therefore, preparing organizations to actively plan to avert those threats or to reduce their effects, the so-called BCM, has been getting increasing attention. Traditional BCM models have been mainly developed for western developed countries. However, Japan is confronted with particular situations such as the high likelihood of natural disasters, high population density, and also its own cultural background. Therefore, this RC-58 is intended to explore suitable BCM systems for Japan.

To this end, approximately 15 companies from various sectors of Japanese society have joined the research committee. However, additional participants are still welcomed. For additional information regarding RC-58 please visit: http://icus.iis.u-tokyo.ac.jp/index-j.htm.

(By P. Mayorca)

Changes in ICUS staff

FAREWELL TO THREE ICUS MEMBERS

Professor Taketo Uomoto, Visiting Professor Reiko Amano and Dr. Hisashi Kanada retired from ICUS on March 31st, 2007.

Prof. Uomoto is a founding member of ICUS and its director for six years. He retired from the University of Tokyo and became a Professor at the Shibaura Institute of Technology. He is currently an ICUS Advisor Researcher.

Visiting Prof. Amano joined ICUS in March 2003. She has been actively involved in the development of water screens for fire protection, disaster manuals for various institutions and a website to promote public facilities retrofitting. Prof. Amano is currently an ICUS Researcher.

Dr. Kanada became an ICUS member in August 2005. During his stay, he continued his research on Non-Destructive Test Methods for concrete structures. In addition, he was in charge of the edition of reports, the secretariat of the Research Committee 39, and also participated in joint activities between ICUS and the University of Tokyo Hospital.

We would like to thank them all for their great contribution to our center and wish them all the best.

WELCOME TO DR. WORAKANCHANA

Dr. Kawin Worakanchana joined ICUS as project researcher from April 1, 2007. He obtained his Ph.D. degree from the University of Tokyo in September 2005 and was a Ph.D. fellow at Meguro laboratory before joining ICUS.

Dr. Kawin Worakanchana

His research interest includes the numerical simulation of structural fracture and collapse behavior under earthquake and fault action. He received the Excellent Young Researcher Award during the Fifth International Symposium on New Technologies for Urban Safety of Mega Cities in Asia.

His doctoral research involves the study of the failure mechanism of concrete structures under fault-induced ground surface rupture and deformation. He developed the Voronoi Applied Element Method (VAEM). Compared to previous Applied Element Method, the VAEM element shape is random therefore it can better fit non-rectangular domains, reduce the crack directional bias and allow element size variation. VAEM was used to study the behavior of dams, soil deposits, buildings and concrete pipes under fault action.

Recently, he is involved in the development of the 3-D AEM for modeling unreinforced and retrofitted masonry structures using PP-band.

(By K. Meguro)

ICUS Activities

- *Prof. Meguro traveled to Bangkok, Thailand together with Dr. Tanaka from May 9 to 11 to visit RNUS offices and meet Prof. Worsak and Prof. Hanaoka at AIT.*
- *Prof. Meguro visited Jakarta, Indonesia from June 20 to 23 to attend the 3th Association of Pacific Rim Universities / Association of East Asian Research Universities Research Symposium "Earthquake Hazards around the Pacific Rim".*
- *Dr. Ooka visited Helsinki, Finland from June 9 to 14 to attend Clima 2007 and Roomvent 2007.*
- *Dr. Ooka traveled to Los Angeles, USA from June 23 to 28 to attend the 2007 Annual Meeting of the American Society of Heating, Refrigerating and Air-Conditioning Engineers .*
- *Dr. Ooka visited Cairns, Australia from June 30 to July 5 to join the 12th International Conference on Wind Engineering.*
- *Dr. Kato stayed at AIT for his research work and teaching duties at RNUS from April 17 to May 15. He officially finished his appointment at AIT on May 15.*
- *Dr. Tanaka visited Berkeley, USA from June 24 to 30 to attend the World Conference on Transport Research Society.*
- *Dr. Sahamitmongkol stayed at AIT for his research work and teaching duties at RNUS from April 2 to May 28 and from June 4 to July 26.*
- *A meeting to explain the objectives and scope of the Research Committee 58 was held on April 25.*
- *The 12th Open Lecture was held on April 25. Its topic was "ICUS Activities to Achieve a Safer Urban Environment -Past achievements and future directions-".*
- *A student seminar attended by all ICUS laboratory members was held on May 29.*
- *ICUS participated on IIS Open House from May 31 to June 2.*
- *ICUS members participated in the Highway Watching Tour which was carried out on May 23 under the leadership of the Metropolitan Expressway Co., Ltd.*
- *The Research Committee 58 (RC-58) held its first meeting on June 19. The objective of the meeting was to introduce the working methodology and to exchange opinions regarding the topics of interest.*
- *A delegation of scholars from Tsinghua University led by Prof. Weicheng Fan visited ICUS on June 29.*

Awards

- *Prof. Meguro received the "Continuing International Contribution Award" from the Japan Society of Civil Engineering on May 25, 2007 for his continuous efforts towards disaster mitigation worldwide.*
- *Dr. Ooka received the "Award of Excellency in Research" at the International Conference on Sustainable Building Asia (SB07 Seoul) on June 28, 2007 for the paper "Design of the Outdoor Thermal Environment for a Sustainable Riverside Housing Complex Using a Coupled Simulation of CFD and Radiation Transfer."*

Editor's Note

There was a big step in ICUS this April. Prof. Uomoto, the former director of ICUS, retired and Prof. Meguro was appointed as the new director. Both have devoted themselves to ICUS growth for the past six years, from its very beginning. It is certain that their continuous contributions has led ICUS to the current situation, active research work by members and associates, and extensive network established in Asia. However, in spite of the fact that engineers/researchers have made enormous efforts so far, there seem to be still many pitfalls in the urban safety.

Prof. Uomoto pointed out in the main article of this newsletter the problem of the false works and structures. This is a severe warning that relying on the engineers' ethics may not be always effective. I am afraid to say that this concern is not only in the field of urban engineering. Recently, it has been revealed that the safety in food was also threatened. Fujiya, one of the biggest confectionary makers in Japan, used old expired dairy goods for making cakes. A meat shop called Meathope sold false beef disguised with pork and chicken.

Apart from these man-made disasters, nature often shows us big energy beyond our control. Even in the recent months, there have been several incidents which have shaken us, the Noto Hanto Earthquake in March, the explosion of a spa facility due to the leakage of natural gas in the center of Tokyo in June, and the Niigataken Chuetsu-oki Earthquake in July. We cannot completely prevent casualties from flooding or slope failure caused by every year's typhoons and heavy rain. All of these unfortunately kill people and each time we learn a lesson. They also make us realize again that we can never spare efforts in seeking urban safety.

(By R. Kuwano)

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp.

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Institute of Industrial Science
The University of Tokyo

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Distress in the Tarmac

By

*Worsak Kanok-Nukulchai**

Last October, when the first sign of rutting was spotted in five of the six taxilanes and in one taxiway at the newly opened Suvarnabhumi International Airport, the Engineering Institute of Thailand (EIT) assigned a team of experts to join the preliminary investigation. The investigation revealed that the damage was caused by the premature failure of asphalt base course due to the separation of asphalt binder from aggregate surface in the presence of moisture, commonly known as "stripping". It was quite evident from the milled damage area that water seeped from the sand blanket underneath the cement-treated base (CTB) through expansion joints. The author summarized the technical facts about this tarmac distress after this matter was blown out of proportion by the politically-oriented media hype early this year.

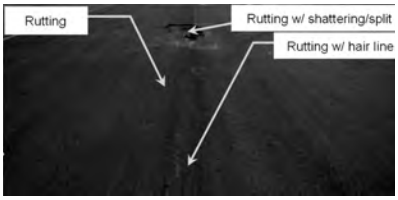
PAVEMENT STRUCTURE

Suvarnabhumi airport covers an area of 20,000 rai (3,200 hectares). In its first phase, the airfield serves its hourly 112 flights with two runways, six taxiways and six taxilanes. The tarmac consists of three layers of asphalt concrete, namely the base course (23 cm thick), the binder course (6 cm thick), and the wearing course (4 cm thick). Underneath are four layers of the cement-treated base (CTB), 18 cm. thick each, sitting on top of the sand blanket (approximately 80 cm thick) left over from the ground improvement process.

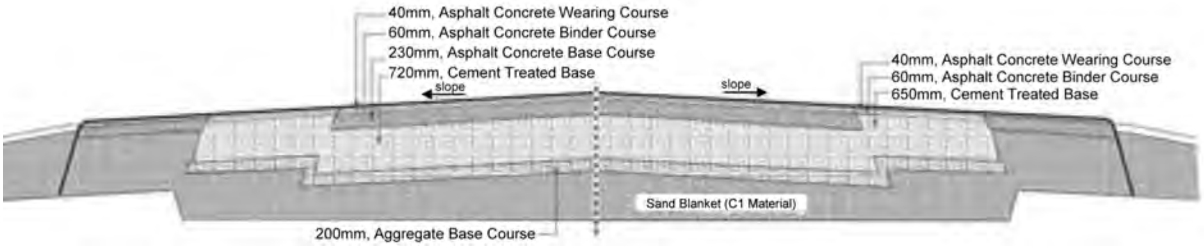
Overview of east runway, taxiways and the drainage system, Suvarnabhumi Airport, Thailand

OBSERVATION OF DISTRESS

On 27 October 2006, around 3 weeks after the official opening of the airport, the first signs of distress were spotted at several locations in the taxiways and taxilanes, in the form of rutting, rutting with shattering and split, and rutting with hairline cracks. Since then, a similar pattern of failure has developed heavily in five of the six taxilanes and along the east parallel taxiway. Although both runways are still in good structural condition, plastic deformation of the asphalt wearing course was observed near the takeoff position. This location is normally under maximum load when the plane takes off with full load of fuel. The high shearing stress that causes plastic deformation



Typical observation of distress



Structure of Taxiway Pavement laid on top of Bangkok preloaded consolidated soil

was imposed by braking, accelerating or turning traffic. Plastic deformation is greatest at high temperature especially for the AC 60/70 binder grade used in this case. The occurrence of the plastic deformation at this location appears to be common phenomenon and only requires a routine maintenance to repair the distress.

TEST OF THE CORE SAMPLE

Initial investigation was made by coring the asphalt concrete pavement at a diameter 100 mm throughout its 33 cm thickness from the damaged areas. The following observations can be made:

- All core samples from damaged area show evidence of asphalt stripping at the base course, a typical effect of soaking water, while core samples from undamaged areas show good condition.
- The water had infiltrated into and confined in the asphalt concrete base course for a long period. Thus, the base course has been immersed in and impaired by the water.
- As a result of asphalt stripping, asphalt binder was separated from aggregate surface, leading to premature loss of strength and stability of the base course.
- The load of the aircraft had then impaired the failed asphalt concrete pavement, causing rutting on the surface.

CTB VISUAL INSPECTION

Based on the core samples, laboratory tests have indicated the correct job mix and aggregate gradation of the asphalt concrete material. This was also confirmed by a separate test at the Highway Department.

To expose the cement-tested base (CTB) for visual inspection, an area of asphalt concrete pavement was milled at the damaged area of the taxilane. It was evident that there was no sign of damage or subsidence in the CTB. However, traces of water seepage were clearly observed along the rim of the expansion joints in the CTB. This evidence of seepage further hinted that a large quantity of water might still be trapped in the sand blanket.

TEST PIT

On January 31, a test pit was dug on Taxiway T11, where damage was found to be extensive. After the excavation went through CTB and exposed the top surface of the sand blanket, water seeped through the sand immediately until the water level reached about 20 cm above the sand blanket (or roughly at +0.0 MSL). The water stayed at that level even when attempt were made to clear the water.

Interestingly, to prove that water in the sand blanket is fully confined with no connection outside, a deep excavation was made nearby, but outside the pavement area. After the excavation, the dug hole was completely dry. No sign of water from the sand blanket had receded into this empty hole.

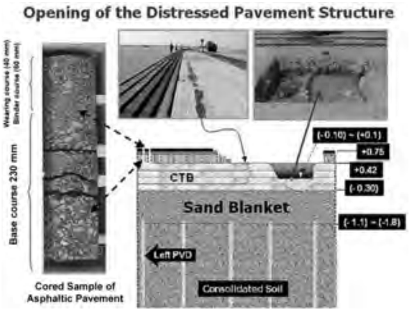
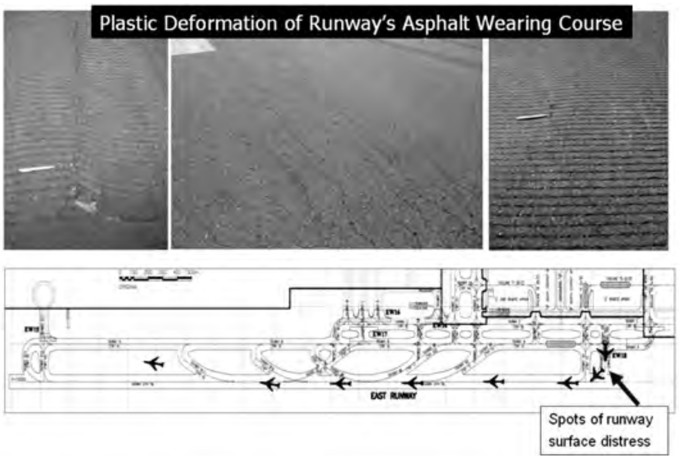


Illustration of milled pavement in the taxilane T11, a core sample of asphalt concrete, trace of the water seepage at CTB joint and the test pit.



Surface deformation of the runway

Excavation to test the connectivity of the trapped water.

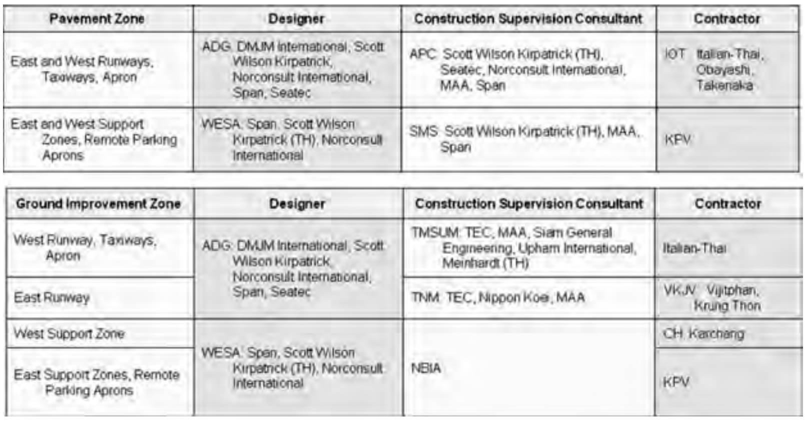
Meanwhile, Highway Department experts have tested the samples of sand and CTB from this test pit and reported that all materials tested have met the standards.

HOW WAS THE WATER TRAPPED?

Based on the official report of the investigation committee appointed by Airports of Thailand Public Company (AOT), the following reasons had been given as possible causes for the trapped water:

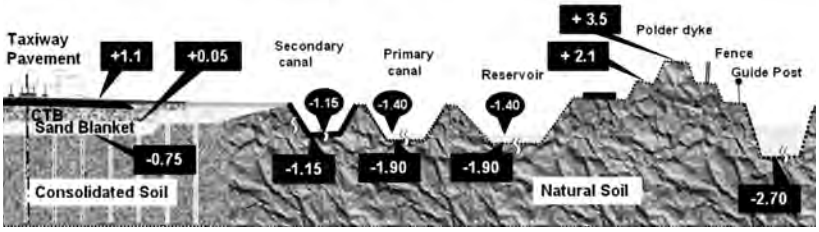
1. Runoff of rainfall water was collected and retained within the airport compound in the pockets of sand used to fill fishponds, swamps and waterways prior to the airport construction. Water from this source might find its way into the sand blanket.
2. Surface water spilled from the drainage canals, during the flooding period, over the top soil around the unpaved neighborhood into the sand blanket.
3. Surface water once trapped underground was not able to escape due to the lack of a subsurface drainage system. This was aggravated by the blockage of culverts and other underground structures.
4. Based on soil boring records, thin sand layers may exist originally within the soft clay layer at a level about 10 metres deep. Some of these sand layers may cross path with the leftover PVD, thus allowing running shallow ground water to seep upward into the sand blanket.

Parties involved in the construction and design of Suvarnabhumi Airport, Thailand



Pavement Zone	Designer	Construction Supervision Consultant	Contractor
East and West Runways, Taxiways, Apron	ADG: DMJM International, Scott Wilson Kirpatrick, Norconsult International, Span, Seatec	APC: Scott Wilson Kirpatrick (TH), Seatec, Norconsult International, MAA, Span	IOT: Italian-Thai, Obayashi, Takenaka
East and West Support Zones, Remote Parking Aprons	WESA: Span, Scott Wilson Kirpatrick (TH), Norconsult International	SMS: Scott Wilson Kirpatrick (TH), MAA, Span	KPV

Ground Improvement Zone	Designer	Construction Supervision Consultant	Contractor
West Runway, Taxiways, Apron	ADG: DMJM International, Scott Wilson Kirpatrick, Norconsult International, Span, Seatec	TMSUM: TEC, MAA, Siam General Engineering, Upham International, Meinhardt (TH)	Italian-Thai
East Runway		TNM: TEC, Nippon Koei, MAA	VKJV: Vijitphan, Krung Thon
West Support Zone	WESA: Span, Scott Wilson Kirpatrick (TH), Norconsult International	NBIA	CH. Karchang
East Support Zones, Remote Parking Aprons			KPV



Profile of the flood protection and the drainage system

On the last point, some geotechnical experts argued against this possibility. At the end of the PVD preloading, the extra surcharge consisting of crushed rocks was removed. Thus, it is no longer possible for water to move up to the surface through the PVDs against the hydraulic gradient and against gravity at the end of consolidation process.

In addition, there is hydraulic back-pressure from the trapped water in the sand blanket making it impossible for such hydraulic upward flow to occur.

FLOOD PROTECTION AND THE DRAINAGE SYSTEM

As the airport site is located in the floodway of Bangkok's eastern suburbs, it requires both effective flood protection and drainage systems. The aim is to prevent flooding from flash floods, as well as to drain away rainwater in the catchments of the airport compound. The design of the polder system includes the perimeter polder dike, internal drainage system, two pumping stations and a perimeter road.

Basically, the internal drainage system for runoff water consists of:

1. The unlined primary canals and reservoirs both with the bed at -1.90 m MSL. Based on the design criteria, water level in the primary canals and reservoirs must be maintained not higher than -1.40 m MSL.
2. The secondary canals with concrete linings. The canal bed of the secondary canal is -1.15 m MSL. It is designed to be dry except during the raining.

The primary and secondary canals are interconnected by ditches to ensure that the runoff water from the pavement area will flow under gravity towards the two pumping stations located at the south corners of the site. In the operating manual, water in the primary canals and reservoirs must always be controlled at the pumping stations to ensure that the water level is maintained at -1.40 m MSL or lower.

With the design assumption that no rain water runoff can leak into the sand blanket, no subsurface drainage system exists to systematically drain trapped water from the sand blanket. This might be a weakness in the design criteria of the airfield pavement.

WHAT'S NEXT?

In its press release issued on 15 February 2007, the Engineering Institute of Thailand (EIT) strongly recommended that, similar to a first-aid treatment, trapped water should be drained out urgently to minimize the potential spread of cracks on taxi lanes, taxiways, and even on runway. It is important that water in the primary canals and reservoirs must always be controlled at the pumping stations to ensure that the water level is strictly maintained at -1.40 m MSL or lower based on the operation manual.

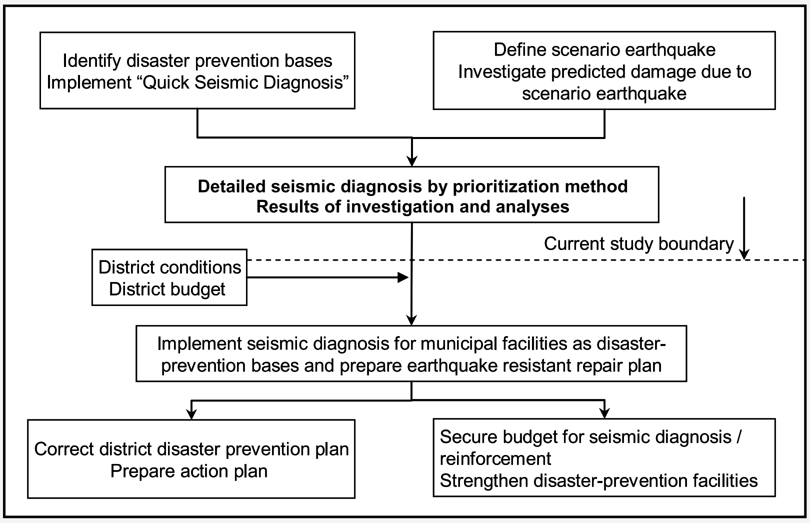
**** Ph.D., Professor***
Dean, School of Engineering & Technology
Asian Institute of Technology
and
Vice President of the Engineering Institute of Thailand

A method to prioritize the seismic retrofitting of disaster-prevention bases

INTRODUCTION

Many earthquakes are expected to occur in Japan in near future, and relevant authorities have planned and executed various measures to minimize damage. Prior measures aimed at reducing damage are considered to be more effective in mitigating the impact of earthquake disasters than post-disaster measures. In particular, it has been reported that the most effective method is to strengthen buildings and structures to make them earthquake resistant. However, it is not easy for municipalities with limited budgets to strengthen their many facilities. As a result, action has been delayed even for disaster-prevention base facilities. A study is presently being carried out to establish a methodology to prioritize actions on facilities for district disaster-prevention bases in a municipality considered likely to suffer most damages caused by the Tokai, Tonankai and Nankai earthquakes. This article briefly introduces this prioritization methodology.

It is worth mentioning that this study is being carried out as a joint project among three sectors: industry (Kajima Co.), academia (The University of Tokyo) and government (Ministry of Internal Affairs and Communications).



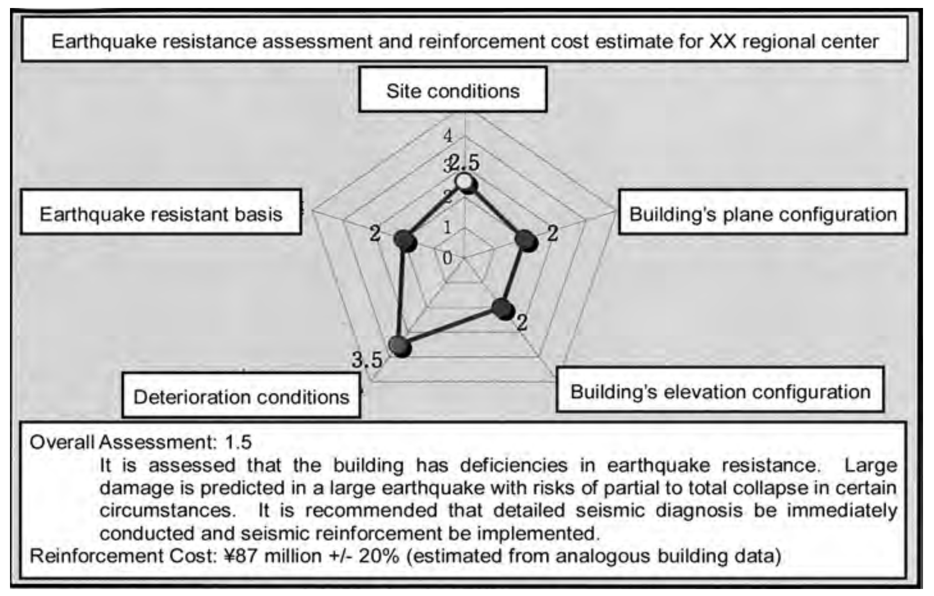
Investigation flow

INVESTIGATION METHOD

The investigation flow is shown in the figure above. At first, the method for prioritizing facilities for district disaster-prevention bases is developed. Next, the municipality should take the responsibility of preparing a disaster prevention plan and budgeting the seismic strengthening of its facilities based on the prioritization study results.

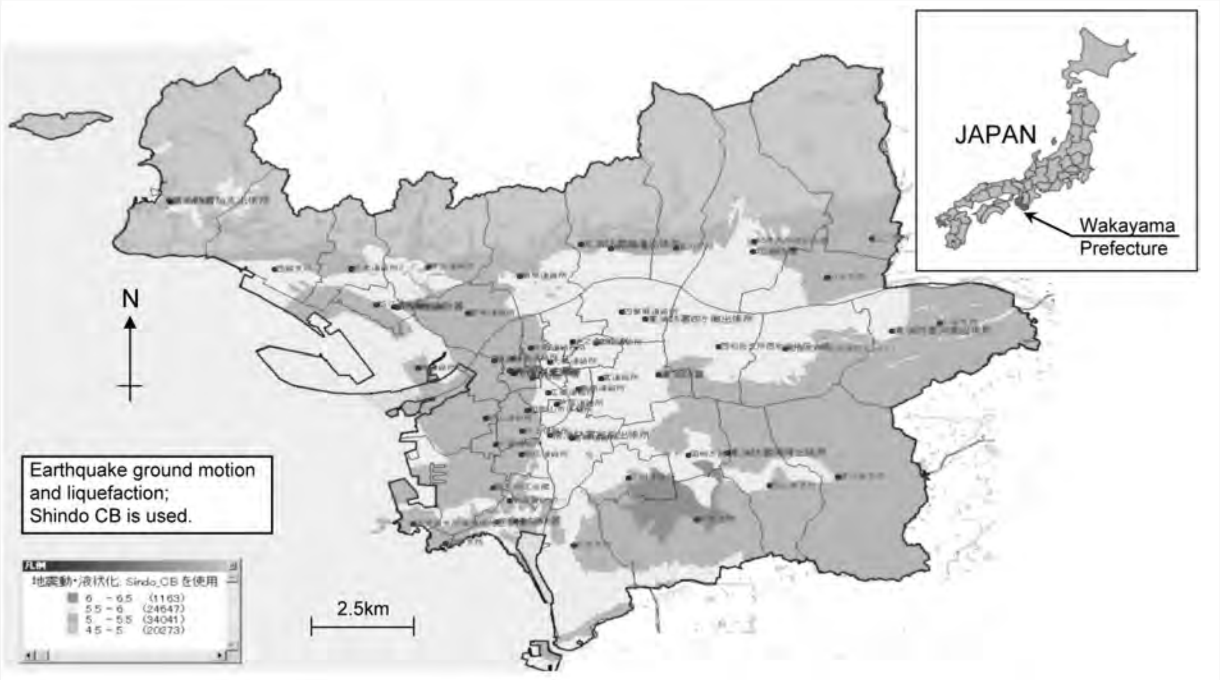
IMPLEMENTATION OF QUICK SEISMIC DIAGNOSIS

In order to budget for earthquake-resistant strengthening of facilities in district disaster-prevention bases, it is necessary to estimate the cost in line with the reinforcement plan based on a detailed seismic diagnosis. However, a large budget is already necessary for detailed seismic diagnosis (several million yen / facility). As a result, it has been decided to employ a "questionnaire-type Quick Seismic Diagnosis" that



Overall Assessment: 1.5
It is assessed that the building has deficiencies in earthquake resistance. Large damage is predicted in a large earthquake with risks of partial to total collapse in certain circumstances. It is recommended that detailed seismic diagnosis be immediately conducted and seismic reinforcement be implemented.
Reinforcement Cost: ¥87 million +/- 20% (estimated from analogous building data)

Example of Quick Seismic Diagnosis results



Distribution of seismic intensity and locations of disaster-prevention base facilities

has been developed from the results of many detailed seismic diagnoses.

Then, 165 facilities for district disaster-prevention bases have been assessed. In addition to the individual assessments of elements such as site, building, deterioration, etc., overall assessment can be made based on 10 grades.

INVESTIGATION OF PREDICTED DAMAGE DUE TO SCENARIO EARTHQUAKES

The subject municipality worked on the development of a hazard map of scenario earthquakes (the Tokai, Tonankai and Nankai Earthquakes). This took place the preceding year. This map, an example of which is shown in the next page, displayed hazard level by seismic intensity, tsunami, landslide disaster, etc. using GIS. The current study utilized the above GIS data to identify hazard information at each disaster-prevention facility's location.

INVESTIGATION OF PRIORITY IN SEISMIC-RESISTANT STRENGTHENING POLICY

The 165 facilities that have various roles as disaster-prevention bases are varied: fire stations, city hall, branch city offices, health centers, shelters, stockpile storehouse, etc. Of these, 61, which will be utilized for key functions of paramount importance when a disaster occurs, i.e. "control and execute measures", "dispatch and gather information", "help and rescue" and "temporary recovery," have been identified and their priorities investigated. Specific procedures are as follows:

1. *Extract digital data of seismic intensity, tsunami, landslide disaster and liquefaction at the locations of these 61 disaster-prevention base facilities using GIS data.*
2. *Exclude from the investigation items facilities that have high risks of tsunami or landslide disaster. Add supplementary notes on liquefaction for reference only.*
3. *Derive correction factor which converts the seismic intensity at each location to the external force.*
4. *Obtain seismic hazard Z by dividing correction factor by the assessment score of "Quick Seismic Diagnosis" X.*
5. *Give priority in order from large seismic hazard Z obtained above to smaller (the larger the number, the higher the priority).*

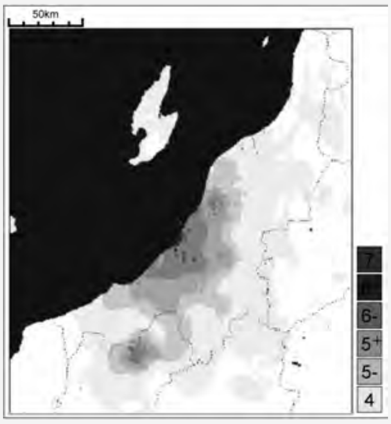
CONCLUDING REMARKS

In this investigation, priority has been determined considering the hazard and the earthquake resistance of the facility. The priority assessment is based on whether structural health can be maintained when a disaster occurs. However, the health of a disaster-prevention base assessment should be based not only on the structure's health but also on various factors such as accessibility, sustainability of lifeline function, surrounding population, wooden building ratio, etc. These are items to be investigated in the future. However, a method for utilizing the hazard map and prioritizing disaster-prevention bases for earthquake-resistant strengthening can be obtained from the results of this study. Uploading the study results to the website of FDMA (Fire and Disaster Management Agency) is under planning in order to contribute to realizing earthquake-resistant strengthening of disaster-prevention bases in municipalities.

(By R. Amano,
Former ICUS Visiting
Professor)

Earthquake hits Niigata Prefecture

The Niigata Chuetsu-Oki (Niigata Chuetsu Offshore of Niigata Prefecture) Earthquake (magnitude: 6.8; focal depth: 17km), Japan, occurred at 10:13 on July 16, 2007. The earthquake shook Niigata and neighboring prefectures and was felt as far away as Tokyo. Kashiwazaki City, Iizuna and Kariwa villages registered the highest seismic intensity equal to 6+ on the Japan Metereological Agency (JMA) Scale. Due to this earthquake, strong ground motions up to 1019 Gals were recorded. Fourteen people were killed, 1,259 houses totally collapsed, and more than 40,000 houses were affected, mostly older wooden structures.



JMA seismic intensity distribution

Landslide at JR Oumigawa Station

Old wooden structures collapsed at Kashiwazaki city

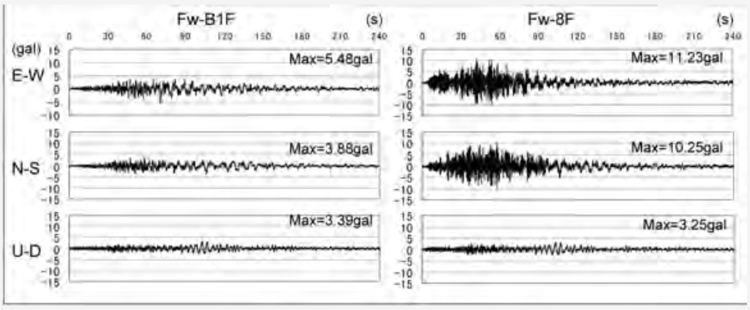
Meguro laboratory (ICUS) dispatched a reconnaissance team to the affected sites to investigate damages from July 21 to 22. Our group investigated Kashiwazaki City, where damage was the largest, the Japan Railway (JR) Oumigawa Station surroundings, Kariwa village and the Kashiwazaki-Kariwa nuclear plants. Weak houses collapsed, lifelines were disrupted, and many landslides and liquefied sites were observed. At JR Oumigawa Station, the route was closed due to a huge slope failure. Little damage was reported at the Kashiwazaki-Kariwa nuclear power station, which is located part on a hard site and part on sand fill. Although at the latter, liquefaction, landslides, and ground subsidence were observed, structures, which were supported on pile foundations, were not severely affected. In spite of a fire that broke out at an electrical transformer and a radioactive gas leakage, the overall performance of the facility was considered good.

(By Hiruma, Meguro Lab)

Niigata Chuetsu-Oki Earthquake strong ground motion recorded at IIS

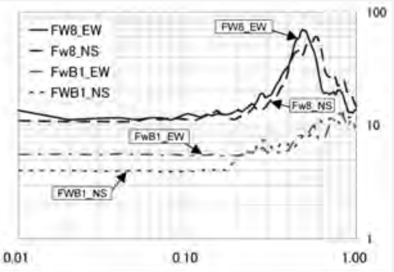
ICUS installed a system for monitoring the dynamic behavior of IIS buildings this year. It consists of 18 accelerometers and a computer server for collecting data using the intranet. IIS buildings were divided into four: the west and east wings of Buildings B-C-D, the west and east wings of Buildings E-F. There are joints between Building D and E, and between east and west wings. Accelerometers were installed at the basement, 2nd, 4th, 6th, 8th floors of the west and east wings of Building B, C/D, E/F, and F. The sampling rate is set to 100 Hz and the observation resolution is 0.2 Gal.

Accelerometer



Comparison of accelerographs recorded at the basement and 8th floor

Our monitoring system observed the dynamic response of IIS buildings due to the Niigata Chuetsu-Oki Earthquake. The figure on the top right corner shows the accelerographs recorded at the basement and 8th floor of Building F. The maximum accelerations in east-west (E-W) direction were 5.4 Gals and 11.2 Gals at the basement and 8th floor, respectively. JMA seismic intensity calculated by structural response was equal to 2.3 and 2.8 at the basement and 8th floor, respectively. Stronger vibration was observed on the higher stories of the buildings.



Acceleration response spectra

The spectrum of E-W and N-S accelerations measured at the 8th floor of the west wing of Building F were calculated. From them it was estimated that the natural periods of the building were 0.48s in E-W direction and 0.58s in N-S direction. From the data recorded at the point between Building C and D (i.e. C/D), natural periods were estimated as 0.43s in E-W direction and 0.52s in N-S direction. This data confirmed that the dynamic characteristics of Building B-C-D and Building E-F are slightly different.

(By M. Y. Ohara)

The Mw. 8.0 Pisco Earthquake hits Peru

On August 15, 2007 a Mw. 8.0 earthquake hit the central coast of Peru at 6:40PM (local time). As of September 30, 519 fatalities and almost 1,300 injured people were reported by the National Institute of Civil Defense (INDECI). The most affected cities were Pisco, Chincha, and Ica where intensities as high as MM VII and strong ground motions lasting almost three minutes were reported. The table below summarizes the earthquake effects.

Collapsed houses	75,861 units
Affected houses	92,828 units
Collapsed schools	643 classrooms
Affected schools	635 classrooms
Collapsed health facilities	14 units
Affected health facilities	112 units
Collapsed bridges	2 units
Affected bridges	4 units

HOUSING DAMAGE

According to the latest housing census, more than 50% of the houses were made of adobe without any type of reinforcement in the affected region; among them 70% were more than 25 years old. Consequently, they performed badly exhibiting cracks at wall intersections, partial wall collapse and complete collapse as shown in the photos below. Few houses, were reinforced by either external coatings (existing structures) or inner cane reinforcement (new constructions). These performed well and showed no damage.

Adobe houses in the areas affected by the earthquake (top: non-reinforced, bottom: retrofitted)

The second most popular housing material in the earthquake affected areas is confined masonry. These structures are mostly made of clay bricks and reinforced concrete confinements. If built following good design and construction practices, they are seismic resistant. However, many bad practices were evidenced by this earthquake. The most common were the use of bricks with horizontal alveolus for load bearing walls (locally called pandereta and prohibited by the code in this region), lack of confinement of parapets and façade walls, insufficient wall density, badly distributed stiffness (in plan and elevation), and a poor understanding of the confined masonry construction procedure. Another deficiency found was the lack of steel reinforcement in the confining beam or the lack of confining beams altogether.

PUBLIC FACILITIES

Most of this earthquake fatalities occurred in public buildings and approximately 30% of them at the San Clemente Church in Pisco. These structures are very old and thus do not comply with the current building codes. There is no legislation that requires retrofitting them to meet the latest code revisions.

The infrastructure quality of schools and hospitals was very diverse. Those built following the design codes performed very well whereas those which did not failed. At the San Juan de Dios hospital in Pisco, the buildings which had just been finished before the earthquake did not suffer any damage whereas the remaining units dating from the 30's were left useless.

148 people attending a mess died at the San Clemente Church in Pisco

Top: School at Los Molinos, Ica. Note that columns in the 1st and 2nd floor are either not aligned or interrupted. Bottom: Hospital at Pisco, where 80% of the houses were affected, suffered no damage.

Privately owned public facilities such as hotels did also suffered extensive damage.

CODE ENFORCEMENT AND LAND USE

Although building codes for adobe, masonry, reinforced concrete and a seismic design code are enacted in Peru, in practice most of the houses do not with them. As in many other developing countries, self construction is widespread in Peru. In order to improve the quality of the building stock, programs to train masons may be one of the key points to overcome this situation.

Inadequate land use is also an issue. Vulnerable areas in many cities have been already identified by programs such as the Sustainable City Program carried out by INDECI. Hazardous locations at the affected areas coincide very well with the most damaged locations. However, putting this findings into practice still takes too long time.

The author was a member of the team dispatched by the Japan Society of Civil Engineers and the Japan Association of Earthquake Engineering, which was led by Dr. Jorgen Johansson, to evaluate earthquake damages. The full report of the survey findings is available at http://shake.iis.u-tokyo.ac.jp/Peru2007/JSCE_JAEE_Report/Index.htm

(By P. Mayorca)

2007 Flood in Bangladesh

The floods of 2007 started at the end of June. Due to heavy rainfall over the north and northeast part of the county, Rangpur, Kurigram, Gaibandha and Netrakona Districts were inundated. According to Flood Forecasting Warning Centre (FFWC) of Bangladesh Water Development Board (BWDB), as of the morning of the August 20, rivers were flowing above their respective danger levels at 8 stations in the districts of Manikganj, Dhaka, Rajbari and Kishorganj. Between the morning of the August 19 and 20, water levels fell at 33 stations and rose at 25 stations and were unchanged at 3 with a total of 61 stations reporting.

In a normal year, the open water extent of Sirajganj was 40% whereas in August 2007, it was found to be 61%. In 1998, it was estimated as 81%.

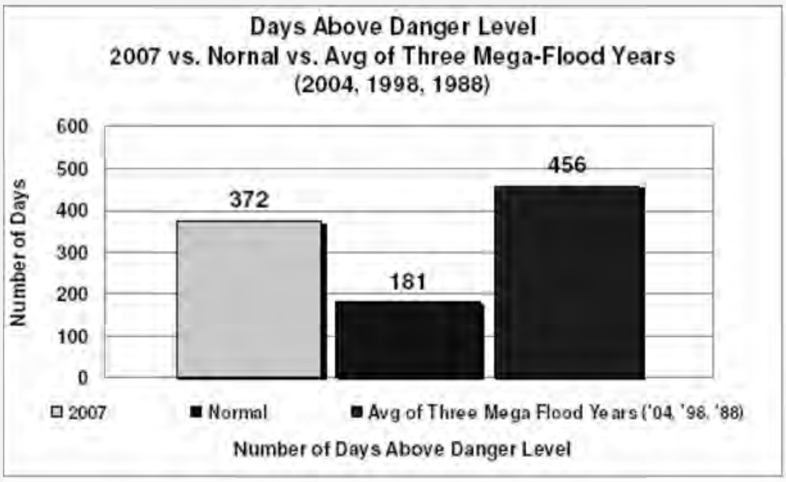
About 80% of Sunamganj area was under open water extent in August 2007 and it was 70% in a normal year. Flood will be reduced in most of the areas and water level will be below the danger level except some part of the central region of the country.

The damage assessment according to the FFWC is presented in the table below.

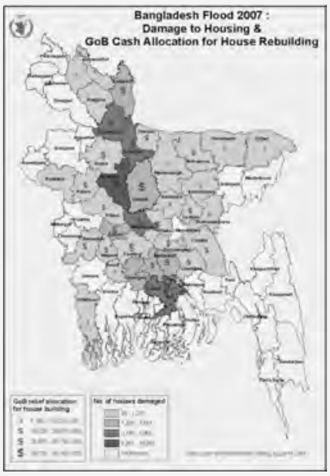
Total no of affected districts:	39 (out of 64)
No. of affected upazilas:	241
No. of population affected:	10 Million
People death in the districts:	700
Population in shelter:	294,146
Total approximate loss:	USD 400 Million

At an August 19 meeting for development partners in Dhaka, the Government encouraged donors to provide assistance for flood response and monetary support.

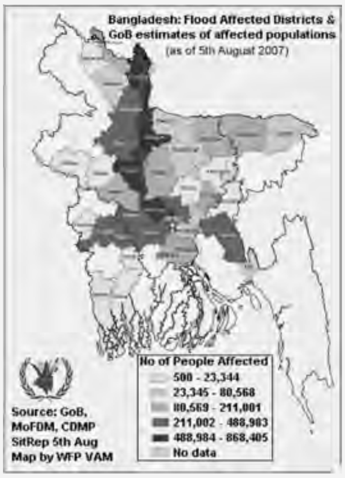
(By M. Ansary)



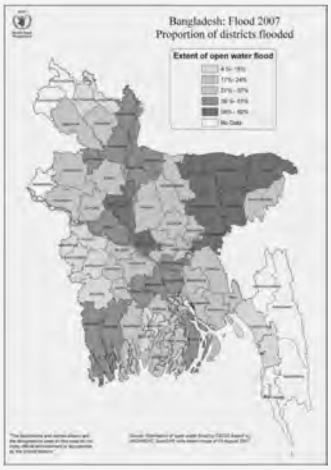
How does the 2007 flooding compare to previous years?
(From: UN WFP Bangladesh Report. 2007 Floods vs. Floods of Previous Years: Historical Perspective Analysis, 29.08.2007)



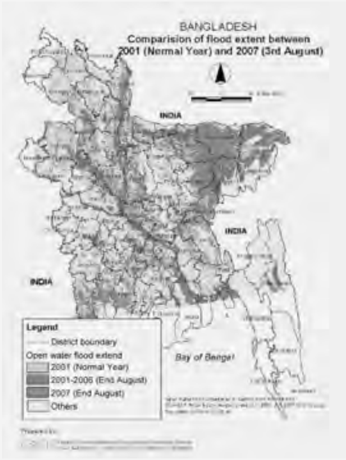
Number of houses damaged
(From: UN WFP Bangladesh Bulletin, Hazard EARLY WARNING & Humanitarian Response, Issue 34/2007)



Population affected
(From: UN WFP Bangladesh Bulletin, Hazard EARLY WARNING & Humanitarian Response, Issue 30/2007)



Proportion of districts flooded
(From: UN WFP Bangladesh Bulletin, Hazard EARLY WARNING & Humanitarian Response, Issue 32/2007)



Comparison of flood between a normal year and 2007
(From: CEGIS Report. Flood Situation, Aug. 2007, 11.08.2007)

RNUS Activities

ICUS and RNUS participated in Thailand Science and Technology Fair 2007

From August 8 to 19, 2007, ICUS and RNUS participated in the Thailand Science and Technology Fair 2007. Prof. K. Meguro, Dr. W. Takeuchi, Dr. R. Sahamitmongkol, Dr. K. Worakanchana and Ms. A Suwannasuk as representatives of the University of Tokyo (UT) presented ICUS latest in-house technology for urban safety engineering. The highlight of the booth consisted of the new proposal for earthquake disaster reduction using a touch screen workstation system and the non-destructive testing of concrete flaws using an infrared camera.

During the exhibition, the UT booth was warmly welcomed by crowds of Thai people. The number of total participants during the whole period of the exhibition was expected to exceed 1 million. In this special occasion, it was our great honor that HRH Princess Maha Chakri Sirindhorn visited our booth and heard the presentation from Prof. Meguro and Dr. Kawin on August 10 in the official opening ceremony day.

Dr. Raktipong, Dr. Takeuchi, Prof. Meguro and Dr. Kawin (from left to right) during the Opening Ceremony

Participants visited the booth of the University of Tokyo.

RNUS and GIC donated a forest fire monitoring system with remote sensing to GISTDA in Thailand

On September 12, 2007, Dr. Takeuchi and Dr. Vivarad Phonekeo from Geo-Informatics Center (GIC) at AIT visited Dr. Chaowalit Silapathong from Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand to install and donate a MODIS-based hotspot information detection and distribution system. This system is developed by Prof. Yoshifumi Yasuoka and Dr. Takeuchi research group and is designed to monitor hotspot information such as forest fires, volcanic activities and field burning twice a day from space with remote sensing techniques. Satellite data used in this study is a suit of MODIS data received at IIS in Tokyo and AIT in Bangkok currently working as a Southeast and East Asia Satellite Observation Network (SEASON). SEASON is designed to monitor both environment and disaster phenomena such as forest fire, flooding, heat island issues, vegetation health, sea surface temperature, atmospheric pollution and so on, over Asian region with continental scale in a near-real time fashion (http://webmodis.iis.u-tokyo.ac.jp/). This is conducted on behalf of a memorandum of understanding (MOU) signed among IIS, AIT and GISTDA and is financially supported by the Japan Science and Technology Agency (JST) under the research project “Solution Oriented Research for Science and Technology (SORST)” initiated by Prof. Yoshifumi Yasuoka from Oct. 2005 to Mar. 2007. This is expected to be a first step to strengthen a relationship among IIS, AIT and GISTDA to bridge science and technology. Further efforts are conducted to explore more collaborations on knowledge and technology transfer aspects.

RNUS participates in Mini-project and Workshop on Application of Remote Sensing and GIS

On September 17 and 19, 2007, Dr. W. Takeuchi was invited to give a presentation on “Remote Sensing of Fires, Principles and its Operational Use.” He also participated in the group discussion during the Mini-project and Workshop on Application of Remote Sensing and GIS held by Geoinformatics Center (GIC) in AIT. Participants in this mini-project are from many Asian countries including Bangladesh, Bhutan, Cambodia, Indonesia, Laos, Myanmar, Philippines, Sri Lanka and Vietnam. RNUS also had a chance to establish good relations with many participants for future information exchanging.

(By K. Worakanchana)

Dr. Takeuchi’s presentation

RC-58 held its second meeting

The Research Committee 58 (RC-58) held its second meeting on August 2nd. RC-58 was launched under the topic “Business Continuity Management (BCM) Systems Suitable for Japanese Society.” Businesses are faced with many threats to the continuance of their trade and planning to avert those threats or to reduce their effects has been getting increasing attention. Japan is confronted with particular situations such as the high likelihood of natural disasters, high population density, and also its own cultural background. BCMs need to be designed considering these conditions.

The first activity of the committee is to review the existing BCM related literature produced in Japan and abroad. For this purpose, three working groups (WGs) have been created: WG1: comparison of foreign documentation; WG2: comparison of domestic documentation related to governmental agencies; and WG3: comparison of domestic documentation related to private businesses. Interim and final reports will be prepared and a report, available to the committee members, will be published with the findings of the three WGs.

(By P. Mayorca)

Disaster Drill held at the University of Tokyo Hospital

ICUS is leading a joint working group (WG) on disaster management manual system for the University of Tokyo Hospital considering its role as disaster base hospital in cooperation with the hospital and the Division for Environment, Health and Safety. A disaster drill was held at the hospital from 13:30 on September 4, 2007. The total number of the participants, doctors, nurses, and administrative staffs, amounted to more than 400. About 100 students of the Faculty of Medicine were given special make-up and joined as mimic patients as a part of the lecture of emergency medicine. In the drill, the occurrence of the Tokyo Metropolitan Earthquake with magnitude 7 was assumed. The probability of this earthquake stricking in the coming 30 years is evaluated to be 70% by the Headquarters for Earthquake Research Promotion, Japanese Government.

The drill consisted of two parts. The first half was the training for checking the safety of patients, staffs and facilities in each ward of the hospital just after the earthquake and reporting the results to the disaster command center. The training for extinguishing fire and evacuation of severely-injured patients were also done on the 12th floor. Mimic patients were transported on stretchers specially designed for emergency transportation in the staircase from the 12th to the 6th floor. After that, they were evacuated with the firehouse ladder truck to the ground. The training of safety checking of buildings and lifelines was also carried out by the administrative staff. Based on the reports from each ward and section, the disaster command center decided that the hospital had capability for accommodating disaster victims transported from outside.

Transportation by ambulances

Transporting patients in staircase

Rescue by ladder truck

The latter half of the drill was the training of triage and treatment for external disaster victims. Triage is the medical activity for sorting patients according to the severity of their injuries in order to provide maximum medical treatment under the restriction of medical resources. The mimic disaster victims were classified into four categories: Black: dead or severely injured and not expected to survive; Red: severely injured to be treated urgently; Yellow: moderately injured, and Green: Slightly injured after the first and second triage. Training of first-aid treatment was also done. In this year, a monitoring camera system was installed in the hospital so that staff members in the disaster command center could assess the whole hospital situation.

As a part of the preparation for the drill, E-leaning system for doctors and nurses on emergency responses in disaster base hospital was developed by Dr. M. Yoshimura Ohara and other members of the WG in order to increase their emergency response capacity. The learning program consists of three parts: first is the leaning of priorities of emergency medical response through decision-making simulation; second is the leaning of triage method; and third is the leaning of practical technique of triage and treatment through decision-making simulation. Users can learn by accessing the system through the intranet in the hospital. 242 doctors and 879 nurses finished learning before the drill.

Disaster command center

Training of second triage of mimic patient

The drill preparation was achieved by our joint WG. ICUS members and students of Meguro Laboratory recorded all the actions with video cameras and will prepare a documentary DVD in the near future. Our joint WG will continue the research for increasing emergency capacity of the hospital using the lessons of the drill.

(By M. Y. Ohara)

Summarizing results of safety check in ward command center

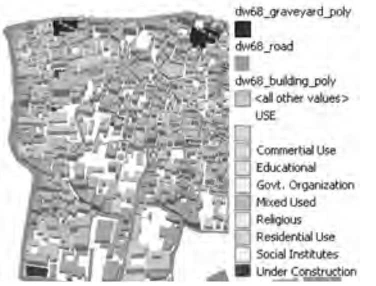
Training of treatment of mimic patient

BNUS Activities

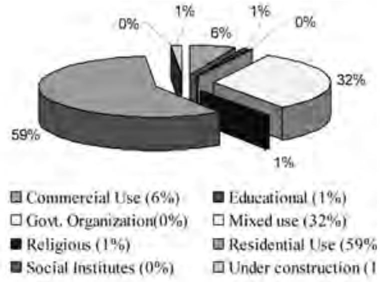
The development of a GIS based earthquake evacuation plan for old Dhaka is ongoing. BNUS is analyzing the compiled data to have an effective plan for the target area. Initially, the land use distribution pattern of the study area is evaluated. It is found that the residential and mixed type land use is predominant there. It is interesting to notice that the 3 storied buildings are more in number followed by 2 storied buildings in the study area.

Research is also going on to assess the existing un-reinforced masonry (URM) structures against lateral force such as earthquake. For that purpose, a pilot laboratory test has been performed. In this case, diagonal tension and off axis compressive loads were applied. It was observed that in case of diagonal tension only end crushing occurred. Off axis compressive load was applied at various inclinations. In case of diagonal tension only shear stresses are produced whereas in other sample distributed stresses are both normal and shear.

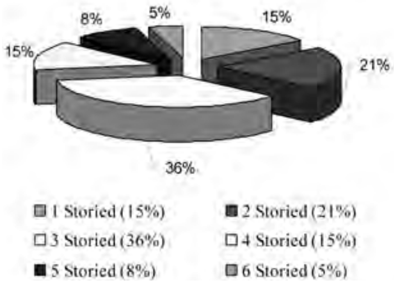
(By M. Ansary)



3D-model with land use



Land use patter of the study area



Building distribution on story basis

Test arrangement

ICUS Activities

- *Prof. Meguro traveled to Bangkok, Thailand from Aug. 8 to 11 to attend the Bangkok International Trade and Exhibition Center which was held from Aug. 8 to 19.*
- *Prof. Meguro visited Taipei, Taiwan from Sept. 1 to 3 to join the Taiwan–Japan Workshop on the Earthquake Early Warning System.*
- *Dr. Tanaka stayed at RNUS and TRE, Bangkok, Thailand from Sept. 3 to 7.*
- *Dr. Mayorca traveled to Peru from Sept. 4 to 28 to survey damages due to the 2007 Pisco Earthquake as a member of the team sent by the Japan Society of Civil Engineers and the Japan Association of Earthquake Engineering.*
- *Dr. Worakanchana stayed at AIT for his research work and teaching duties at RNUS from June 8 to Oct. 26.*
- *ICUS dispatched a team to survey the damages from the Niigata Chuetsu Oki Earthquake led by Prof. Meguro from July 21 to 22.*
- *RC-58 research committee met on Aug. 2nd.*
- *ICUS and RNUS represented the University of Tokyo in the Thailand Science and Technology Fair 2007, which was held from Aug. 8 to 19 in Bangkok.*
- *ICUS participated in the University of Tokyo Hospital disaster drill on Sept. 4.*
- *ICUS co-organized the "Earthquake Early Warning System Symposium" held on Sept. 22. Approximately 100 people joined the event.*

Awards

- *Dr. Ohara and Mr. Sathiparan, who is a Meguro laboratory PhD candidate, received the "Best Research Award" for their papers "A Consideration on Land-Use Control Plan along Active Faults in a Depopulating Society" and "Parametric Study on Diagonal Shear Behavior of Masonry Wall Retrofitted by PP-band Mesh," respectively, at the 26th meeting of the Japan Society of Natural Disaster Science held at Hokkaido University on September 25-26.*
- *Mr. Michael Henry from Kato Laboratory obtained the Furuichi Award on September 28 for his excellent Master Degree Thesis entitled "Influence of Re-curing Condition on Damage and Recovery of Mortar Exposed to Fire."*

Editor's Note

From this July to September, big earthquakes struck Niigata, Japan, Peru, and Indonesia, floods hit Bangladesh and a bridge collapsed in Minnesota, US. These disasters dealt a huge blow to the countries both socially and economically. In Japan, main infrastructure was established about forty years ago and it has been deteriorating more and more with time. Once we suffer a big earthquake especially in Tokyo Metropolitan area, the national function may be shattered by the destroyed infrastructure. While public investment budget is shrinking, the significance and necessity of effective maintenance of these infrastructures has been strongly pointed out by many academic experts.

A new cabinet was inaugurated on Sep. 26, 2007 in Japan. New Prime Minister, Mr. Fukuda pledged in his first policy speech to enforce a political shift to the policy development with emphasis on our national safety and security, especially the realization of the nation where no disaster generates any casualties. I hope this policy shift will become true.

(By S. Miyazaki)

Frequent bridge maintenance is strongly required on main routes in Tokyo Metropolitan Area

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp.

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Institute of Industrial Science
The University of Tokyo

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TRAFFIC ACCIDENTS
- ANOTHER DISASTER IN URBAN SAFETY -

By

Shinji TANAKA

Have you ever experienced a traffic accident (regardless of its severety) in your life? If not, you are a relatively lucky person. However, if you think of your family members and friends, you may not be able to belong to the lucky group any more. Actually, the probability of one person encountering a fatal traffic accident in his/her life is 0.5%. The probability becomes 53.4% for injury accidents and much more for non-reported accidents. Looking at these figures, you can realize your good fortune so far, which, nevertheless is not guaranteed in the future. There were two serious traffic accidents in Japan in 2006. One took place at an intercity motorway in the middle of a rainy night. A truck slipped, spun, and stopped with its front turned back blocking the carriageway. Thereafter, 20 vehicles collided with it one right after the other. As a result of this accident, 4 fatalities and 10 injuries occurred.

The other tragic accident occurred similarly in the night. A drunk driver collided with a car, at the top of an over-sea bridge, from behind. The car, carrying the five members of a family, dived into the sea due to the impact and the 3 children in the rear seats were killed. This accident, widely covered by the media, resulted in a revision of the Road Traffic Law to toughen the penalty for drunken driving.

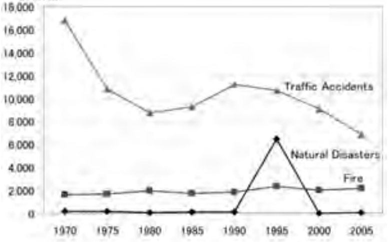
TRAFFIC ACCIDENTS
- HUMAN DISASTER -

When we think of disasters, we easily picture natural disasters, such as earthquakes, typhoons, floods, tsunamis and so on. All of them seriously impact our society at once and therefore it is of course quite important to prepare for them. However, if we assess the severity of disasters by the number of deaths, traffic accidents result in more fatalities than any natural disasters every year in Japan as shown in the graph below (although there is a decreasing trend). We all remember the Hanshin-Awaji Earthquake Disaster or the Sumatra Tsunami Disaster very clearly, but few of us remember yesterday's fatal traffic accidents. I think these should be regarded as man-made disasters affecting urban safety. We should start to tackle them to realize a comprehensive urban safety.

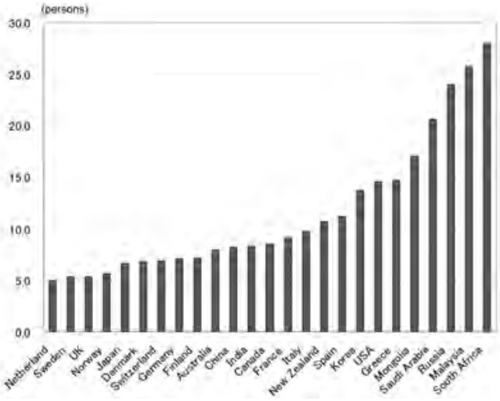
Serious traffic accidents in 2006
Copyright: The Mainichi Newspapers (left) and The Yomiuri Shimbun (right)

TRAFFIC ACCIDENTS
IN THE WORLD

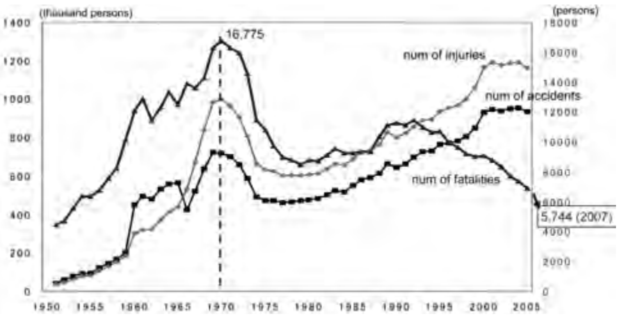
First, let us review the situation of traffic accidents in the world. As for



Number of fatalities
caused by disasters



Number of fatalities per 100 thousand persons



Trend in the number of traffic accidents in Japan

the number of fatalities by traffic accidents in different countries, the top three deadliest countries are China, India, and the United States. The first two are the most populated and the last one is the most motorized country. However, if you see the same numbers in relative terms, i.e. number of fatalities per 100 thousand persons, as shown in the graph on the top of this page, the situation becomes different. China and India are now ranked in the middle, and the most dangerous countries are South Africa, Malaysia and Russia. On the other hand, northern European countries such as Netherland, Sweden, the United Kingdom and Norway, which are regarded as keen on safety measures, are in the safest group. Japan is a relatively safe country next to them. Actually, the Japanese government set a goal in 2003 "to reduce traffic fatalities to less than 5,000 a year and to realize the safest traffic society in the world." If the number achieves this, then "the safest" might become true. These figures suggest that Japan has fewer problems on the traffic safety issue.

TRAFFIC ACCIDENTS IN JAPAN

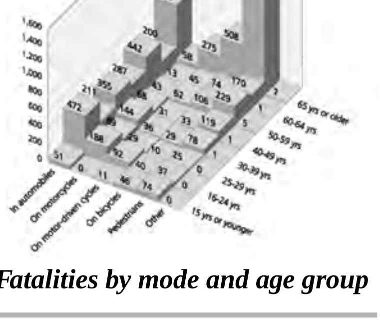
Then, can we be relieved with the current situation? The above graph shows the trend of traffic accidents, fatalities and injuries in Japan. There was a peak in 1970, when the number of fatalities was 16,775. This serious situation was often called "traffic war". After that, the government and the police made a lot of efforts to reduce traffic accidents by, for example, providing sidewalk or cross-over bridges for pedestrians, putting on traffic signals at intersections, making it mandatory to use seat belt, etc. Vehicle manufacturers also improved their products recently by equipping them with airbags, impact absorption bodies and so on. Thanks to these countermeasures, the number of fatalities reduced drastically to 5,744 in 2007, which is about one third of the peak value.

However, if you see the number of injuries or accidents, they have not decreased in the last 5 years. This is one recent trend of traffic accidents in Japan. Of course, as the volume of vehicles is growing rapidly, it is not easy to reduce the number of traffic accidents. Therefore, we need some other countermeasures to realize "the real safest traffic" or "zero-accidents society".

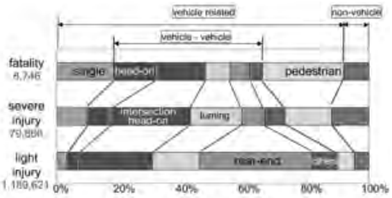
ACCIDENTS BY AGE GROUPS

Let us see more specific problems. The bottom left side graph shows the number of fatalities by age group. The dominant age group is "65 and older", which accounts for 44.2% of fatalities. (Young people group situation was worse in the 80s but it has improved nowadays). Actually, the fatality ratio of elderly people in traffic accidents is extremely high (2.30%) compared with other age groups (0.32 - 0.56%). This means, traffic accidents involving elderly people are likely to become fatal ones. Also, Japanese society itself is aging more and more, therefore, the number of licensed drivers who are 65 years old and older is about 8 million today and will double to 17 million in 2030. This transition may cause more serious problems.

Fatalities by age group



Fatalities by mode and age group



Types of accidents by severity (2001)

ACCIDENTS BY MODE

If you see the fatalities by transportation mode, bottom right side figure in the previous page, the largest is in vehicles (41.3%) and the second is pedestrians (28.6%). Actually, the percentage of pedestrian fatalities out of the total has been increasing from 2000. And, the percentage of elderly people (over 65) is also increasing.

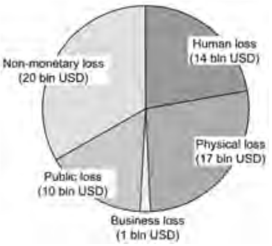
The graph of fatalities by age groups and transportation modes suggests that elderly pedestrians are at significantly high risk, followed by elderly people in vehicles or on bicycles. From these results, you may understand the necessity of traffic safety countermeasures especially for elderly people, and pedestrians.

TYPES OF ACCIDENTS

Then, what type of accidents are most serious? The figure above shows the types of accidents by severity, that is, fatality, severe injury and light injury. From this, we can see that: pedestrian, single and head-on accidents are major fatal accidents. Rear-end accidents are the largest light injury accidents. Intersection head-on is relatively high in all categories. Different types of countermeasures depending on the accident type are necessary.

SOCIAL LOSS BY TRAFFIC ACCIDENTS

Finally, how much social cost or loss do traffic accidents cause? The Cabinet Office in Japan conducted a research project to estimate the social loss caused by traffic accidents. It classified the loss into five categories, that is, human loss, physical loss, business loss, public loss and non-monetary loss. Here, human loss means medical care cost or salary loss, physical loss means car / structure damages, business loss is caused by worker's absence, public loss is the cost for ambulances, police and cleaning, and non-monetary loss means mental loss like pain, sorrow and trouble.



Composition of social loss caused by accidents (2007)

According to the result, the total loss including non-monetary loss was approximately US$60 billion in 2007 and the composition is shown in the graph above. Non-monetary loss occupies quite a large share (35%), which comes mainly from fatal accidents. Even though the number of fatalities becomes less than 6,000, we have to continue efforts to reduce them so that social loss is reduced too.

If we see the monetary part by severity, then the loss due to injury accidents especially lighter ones is the hugest because their number is quite large. In any sense, losses are enormous and continue every year.

RESEARCHES TO IMPROVE TRAFFIC SAFETY

To solve the problems mentioned above and to improve the traffic safety, we are conducting researches from the viewpoint of traffic engineering. One of the topics introduced here is about signal control improvement.

Generally in signal control, we need some clearance time (between yellow and red lights) to clear the traffic from the intersection when the signal phases change. At this moment, a lot of traffic accidents like head-on, rear-end and pedestrian occur. Therefore, the clearance time is key to improve traffic safety in urban signalized intersections. We observed actual traffic flows at several intersections using video cameras and examined whether the current signal settings are appropriate to ensure traffic flows in different directions.

The same can be said on pedestrian signals. Currently, pedestrian signal clearance time (flashing signal) is determined by half the crossing road length and as a result a lot of pedestrians remaining on the road when the signal turns to red. Here, we also conducted field observations and analyzed pedestrian walking behavior. Then discussed the feasibility of a new pedestrian signal control method to reduce the number of remaining pedestrians.

Driving simulator analysis

We sometimes use a driving simulator to analyze driver's behavior when he/she is faced with a yellow signal and puzzled whether to go or not, which is called "dilemma situation". As the driving simulator can record precise data of vehicle and driver, we can analyze his/her behavior in detailed for instance reaction time, vehicle's deceleration, etc. After doing this, we would like to propose an advanced signal control which reduces such dilemma situation.

TOWARDS SAFER TRAFFIC

Traffic accident are the most important issue to be solved in transportation problems, and will continue to be in the future. Japan's efforts achieved a considerable reduction in the number of traffic fatalities from the peak, but there are still lots of casualties due to traffic accidents. Furthermore, there are still many developing countries which do not have very basic traffic safety facilities like pedestrian sidewalk and traffic signals. We must continue looking for a better solution to achieve a safer traffic, and would like to contribute to safety improvement in other countries with our experiences.

Data Source:
Cabinet Office, National Police Agency, Fire and Disaster Management Agency, Japan Automobile Manufacturers Association

ICUS joins the Chiba Experimental Station Open House

ICUS joined the Chiba Experimental Station Open House which was held on November 9. Overall 750 people visited the exhibition. ICUS theme was "Towards the Establishment of a Sustainable Urban System." Laboratory members participated and displayed their panels showing their research activities. Topics included earth and underground structures, diffusion of contaminants in urban areas, and analysis of traffic jam among others. RNUS and BNUS activities were also introduced. Reports and newsletters were handed to visitors as well as small flashlight key holders.

(By P. Mayorca)

ICUS Exhibition at Chiba Experimental Station Open House

13 Open Lecture was held

The 13th ICUS Open Lecture was held at IIS on October 2 and attended by approximately 140 participants. The title of the lecture was "Safety for Urban Infrastructure –Crisis management and disaster control based on Intelligence–." In this Open Lecture, we focused on the role of information and intelligence for the safety of the infrastructure. Three speakers were invited from each industry, government and academia.

Prof. Meguro, the ICUS Director, gave the welcome speech after which the following presentations were given:

- Prof. Hiroyuki Morikawa, Research Center for Advanced Science and Technology, the Univ. of Tokyo, "Information Communications Technology (ICT) infrastructure for security and safety based on ubiquitous computing"
- Mr. Yukio Toho, Senior Manager of Disaster Countermeasures Office, NTT, "Disaster risk management of NTT group –Availability of ICT for disaster control"
- Mr. Mitsuo Uehara, Director General for Crisis Management, City of Yokohama, "Management strategies for crisis of Yokohama City"

The closing remarks were given by Prof. Yasuoka. After the Open Lecture a small party was held and attended by approximately 60 people. The speakers and all participants actively exchanged their opinions in the lecture and the party.

(By S. Miyazaki)

Prof. Hiroyuki Morikawa

Mr. Yukio Toho

Mr. Mitsuo Uehara

ICUS activities recognized domestically and internationally

ICUS laboratory member received Mondialogo Engineering Award

The Mondialogo Engineering Award invites engineering students in developing and developed countries to form international teams to propose projects to improve the quality of life in the developing world. Every year, ten Mondialogo Engineering Awards and 20 Honorable Mentions are given. This year 801 project proposals were submitted. To participate in the Mondialogo Engineering Award, the University of Tokyo, Oxford University (UK), Nepal Engineering College (Nepal), and Indian Institute of Technology Mumbai (India) worked together, exchanged ideas and submitted a proposal entitled "Improving the structural strength under seismic loading of non-engineered buildings in the Himalayan region."

After a competitive evaluation, this project was selected as one of the top ten Mondialogo Engineering Award and €20,000 were received to implement the proposal.

ICUS awarded the 2007 University of Tokyo (UT) President's Award

Dr. M. Y. Ohara, Dr. S. Miyazaki, and Prof. K. Meguro received the 2007 University of Tokyo President's Award for "Development of Portable Disaster Manuals and E-learning System on Emergency Responses in the University of Tokyo Hospital." This award is given to faculty members who greatly contributed to improve the environment of the University. ICUS participated in the working group on disaster management manual system for the University of Tokyo Hospital with the University of Tokyo Hospital and the Division for Environment, Health and Safety. Portable disaster manuals for doctors and nurses were developed and practically used at a disaster drill held in September, 2007. An E-learning system to learn about emergency responses was also developed and 242 doctors and 879 used it before the drill. An awarding ceremony was held on Dec 21, 2007 at the auditorium in the University.

(By N. Sathiparan , Meguro Laboratory member and M.Y. Ohara)

2007 UT President's Award Ceremony

USMCA 2007 was held at Dhaka, Bangladesh

Mr. Tapan Chowdhury, Hon. Adviser delivering the Chief Guest Speech

Prof. Worsak presenting a Plenary Lecture

Bangladesh Network Office for Urban Safety (BNUS), BUET, Bangladesh and ICUS organized the Sixth International Symposium on New Technologies for Urban Safety of Mega cities in Asia, USMCA 2007, at Dhaka on December 09-10, 2007. The co-organizers of this symposium were the Foundation for the Promotion of Industrial Science (Japan), Center of Excellence, The University of Tokyo (Japan), and Center for Environment and Geographic information Services (Bangladesh).

The two-day long symposium program was arranged in two keynotes and plenary sessions and ten technical sessions. Two keynote speeches and five plenary lectures were delivered by invited distinguished academicians and researchers from several Asian countries. The symposium was inaugurated by Mr. Tapan Choudhury, Advisor of Food, Energy and Disaster Management Ministry of the Government of Bangladesh. Prof. Mehedi Ahmed Ansary, Project Director of BNUS and chairman of USMCA 2007 organizing committee, delivered the welcome speech followed by the opening speeches of HE Masaki Inoue Ambassador of Japan in Bangladesh, Professor Tsuneo Katayama, President of the International Association of Earthquake Engineering, Prof. Jamilur Reza Choudhury, President of Bangladesh Earthquake Society and Prof. A.M.M. Safiullah Vice-chancellor, Bangladesh University of Engineering and Technology.

Keynote lectures were given by Prof. Tsuneo Katayama and Prof. Jamilur Reza Choudhury. Plenary speakers were Prof. Kenji Ishihara, Chuo University (Japan), Prof. Worsak Kanok-Nukulchai, Dean of the School of Engineering & Technology, Asian Institute of Technology (Thailand), and Professors T. Uomoto, Y. Yasuoka, and K. Meguro.

Sixty-eight papers were presented in technical sessions covering a wide range of issues in the areas of urban safety including: safety assessment and monitoring of existing infrastructure; advanced technologies for assessment of urban safety; maintenance, retrofitting and rehabilitation of structures; disaster management; tsunamis, flood, and environmental risk assessment; and urban road safety. Several presentations were made on newly developed advanced tools and methodologies for addressing these issues.

ICUS prepared the Excellent Young Researcher Award to encourage activities of young researchers in the field of urban safety engineering. The winners of this award were: Ms. Afifa Imtiaz (Bangladesh University of Engineering and Technology) and Dr. Ema Kato (Port and Harbor Research Institute, Japan).

The next symposium will be held at Tsinghua University in Beijing, China, on October 21-22, 2008. Abstracts are invited by June 22, 2008. Further information will be posted in ICUS web site soon.

(By M. Ansary)

Ms. Yoshimoto with BNUS staff

Prof. Choudhury presenting a Keynote Lecture

Young researchers with Prof. Meguro and Prof. Ansary

RC-58 held meeting

The Research Committee 58 (RC-58) held its third meeting on October 17, 2007. It is working under the topic "Business Continuity Management (BCM) Systems Suitable for Japanese Society." This time, Prof. Hiroaki Maruya from the Institute of Economic Research, Kyoto University delivered a lecture on "Meaning of Business Continuity Plan (BCP) and Its Recent Trend." He talked about the lessons from the recent earthquakes and manmade disasters in Japan, political background of BCP in Japan and abroad, concrete process of making BCP. He also addressed the importance of disseminating BCP to small and medium-sized enterprises and introduced his recent activity for developing a step-up guide instructing how to adapt BCP in small and medium-sized enterprises. The committee members are now reviewing the existing BCM related literature published in Japan and abroad.

(By M. Y. Ohara)

Prof. Hiroaki Maruya

BNUS Activities

Workshop on Sharing Knowledge on Last-Mile Warning: Community-based Last-Mile Warning Systems

The workshop was held in Dhaka on October 25, 2007, jointly hosted by the Bangladesh Network Office for Urban Safety (BNUS) and LIRNEasia, Sri Lanka. Prof. Dr. A.M.M. Safiullah, Honorable Vice-chancellor of BUET, and Mr. K. M. Massud Siddiqui, Director General of Disaster Management Bureau (DMB), were present as the chief and special guests in the inaugural session, respectively. The workshop was moderated by BNUS Project Director Prof. Dr. Mehedi A. Ansary.

Presentations were delivered by Prof. Rohan Samarajiva, Executive Director of LIRNEasia, Mr. Md. Nasir Ullah, Director, Cyclone Preparedness Program, Mr. Nuwan Waidyanatha, Project Manager, LIRNEasia, Ms. Natasha Udu-gama, Project Dissemination Manager, LIRNEasia, Prof. Aftab Alam Khan, Department of Geology, Dhaka University, Mr. Sujit Kumar Debsarma, Meteorologist and System Manager, Bangladesh Meteorological Department, Dr. Ashutosh Sutra Dhar, Dept. of Civil Engineering, BUET, and Dr. S. Rangarajan, Senior Vice President, World Space (Satellite Radio).

Workshop participants

BUET 60th Anniversary celebrations

60 years celebration of engineering education in Bangladesh

July 2007 marked the 60th anniversary of the establishment of the erstwhile Ahsanullah Engineering College, the first institution for producing graduate engineers in Bangladesh, which then followed a glorious path to become a premier institution of excellence in engineering education in Bangladesh known as the Bangladesh University of Engineering and Technology (BUET).

A series of events were arranged to celebrate this memorable events. A fair was inaugurated at December 28, 2007 and continued until December 31. BNUS had participated actively in this fair. BNUS activities were presented as well as BNUS/ICUS joint publications. A number of visitors were interested in the mock drill which was organized by BNUS in collaboration with the Bangladesh Red Crescent Society. Some posters made by BNUS were also distributed among the visitors to build up awareness against natural disasters.

(By M. Ansary)

Damage due to Cyclone SIDR in Bangladesh

Cyclone SIDR, a category 4 storm, developed over the Bay of Bengal and struck the coast of Bangladesh on the evening of November 15, 2007. With winds of up to 240 km/hr and associated tidal surges of several meters, it killed over thousands of people and destroyed houses, crops, vegetables and plants alike along its trail of devastation over an area of thousands of square kilometers. Due to the complex of deltas on the coast, these tidal surges have penetrated deeply and extensively inland, compounding the already existing problems from seasonal flooding. SIDR, was one of the 10 fiercest cyclones that hit the region between 1876 and 2007.

As of December 31, 2007, the Government of Bangladesh official (MoFDM) report illustrates that the number of death caused by SIDR has risen to 3,363 affecting 8.9 million people of 2 million families. 871 people are still missing. These casualties and damage to houses, livestock, crops, educational institutions, roads and embankments have been reported from 1,950 unions of 200 upazilas of 30 districts. Most deaths and damages have been attributed to the storm surge. These figures could still be conservative. Disaster preparedness may have had an important mitigating effect as 3.2 million people were evacuated from the coastal areas.

The cyclone has partially or totally damaged more than one million dwellings and also essential service infrastructure. Delivery of aid is slow due to the immense logistical difficulties and the sheer scale of devastation. Roads to some areas are still impassable. Survivors are thronging moving vehicles in the belief that aid is being delivered. This is restricting the movement and accessibility on roads and increasing journey times for relief workers. With crop plantations wiped out, people will not be able to sustain themselves in the coming months. Waterborne diseases are now starting to take root in areas where there is no clean drinking water. The early winter cold and fog is further worsening living conditions .

(By M. Ansary)

SIDR path over Bangladesh

Small shops, businesses, and market areas were damaged along the road side

RNUS Activities

ICUS renewed contract of RNUS with AIT

ICUS and the Asian Institute of Technology (AIT), Thailand, agreed to renew the Memorandum of Agreement to continue their cooperating program in RNUS reaffirming their strong commitment and determination to make the urban environment safer. The contract signing ceremony between ICUS Director, Prof. Meguro and the Dean of School of Engineering and Technology, Prof. Worsak Kanok-nukulchai, was held on December 9, 2007 during the USMCA2007 at the Sheraton Hotel, Dhaka.

Contract signing between Prof. Meguro and Prof. Worsak Kanok-Nukulchai

Since its establishment, RNUS, in cooperation with the Asian Institute of Technology, has carried out many successful joint researches and projects in the areas of urban safety disaster management, sustainable engineering and infrastructure management including the "Study on Application of Fly Ash as Concrete Ingredient in Thailand & Japan," "Evaluation of Water Use in Irrigated Paddy Fields in Eastern Part of Thailand Using Remote Sensing and Meteorological Data," "Urban Flood Inundation Modeling in Mekong River Basin Using a Physically Based Surface-River Model," etc.

(By K. Worakanchana)

Dr. Hiroshi Yokota joined ICUS

We would like to welcome warmly Dr. Hiroshi Yokota as Visiting Professor of ICUS from November 1, 2007. He is Executive Researcher and Director of Life Cycle Management Research Center for Coastal Infrastructures, Independent Administrative Institution of the Port and Airport Research Institute.

He graduated from the Department of Civil Engineering, Tokyo Institute of Technology in 1978 and obtained his Doctor of Engineering Degree in February 1993 from the same institute.

Prof. Hiroshi Yokota

His research interest includes structural concrete including structural design and performance verification of civil infrastructure. His recent research targets are life-cycle management of existing structures including maintenance and repair methodologies, prediction of progress of structural performance degradation, and durability enhancement.

(By K. Meguro)

ICUS Activities

- *All ICUS members attended the 6th International Symposium on New Technologies for Urban Safety of Mega cities in Asia from Dec. 7 to 12.*
- *Prof. Meguro visited Stockholm, Sweden from Oct. 21 to 23 to attend the meeting of the Global Facility for Disaster Reduction and Recovery (GFDRR).*
- *Prof. Meguro and Dr. Ohara attended the 2nd International Conference on Urban Disaster Reduction which was held in Taipei, Taiwan from Nov. 26 to 30.*
- *Prof. Meguro attended the meeting of the board of directors of the World Seismic Safety Initiative held in Singapore from Dec. 1 to 6.*
- *Dr. Ooka visited Tsinghua University, Beijing, China, from Nov. 19 to 24 to meet Professors Yi Jiang, Yingyin Zhu, and others for discussing about urban environment and energy issues.*
- *Dr. Ooka visited Seoul, Korea from Nov. 25 to 27 to attend a seminar of international experts to which he was invited.*
- *Dr. Kuwano visited Chongqing, China from Nov. 3 to 10 to join the 3rd Sino-Japan Geotechnical Symposium.*
- *Dr. Tanaka participated in the World Congress on Intelligent Transportation Systems which was held at Beijing, China from Oct. 10 to 15.*
- *Dr. Worakanchana stayed at AIT for his research work and teaching duties at RNUS from Dec. 1 to Feb. 28.*
- *The 13th Open Lecture was held on Oct. 2.*
- *The Research Committee 58 met on Oct. 17 and Dec. 13 to report on each working group progress.*
- *ICUS joined the Chiba Experimental Station Open House on Nov. 9.*
- *The student seminar was held on Nov. 30. Approximately 20 students joined the event.*

Awards

- *Dr. Ohara, Dr. Miyazaki, and Prof. Meguro, received the University of Tokyo President's Award for the "Development of Portable Disaster Manuals and E-learning System on Emergency Responses in the University of Tokyo Hospital" on Dec. 21.*
- *Dr. Ooka received the Best Paper Award at the International Conference of Sustainable Building 2007 held in Taipei, Taiwan, on Nov. 10 for his paper "Study on the Prediction of Indoor Humidity Distribution with Coupling Simulation of CFD and Vapor Diffusion Analysis through Building Materials."*
- *Mr. N. Sathiparan, Meguro Laboratory graduate student, received the Mondialogo Engineering Award as a member of the team which submitted the proposal "Improving the structural strength under seismic loading of non-engineered buildings in the Himalayan region."*
- *Mr. R. I. Wicaksono, Kuwano Laboratory graduate student, received the Best Presentation Award at the 9th International Summer Symposium of the Japan Society of Civil Engineers for his paper "Small Strain Stiffness of Clean Sand and Gravel Based on Dynamic and Static Measurements."*

Editor's Note

In this trimester, we have again witnessed the devastating effects of natural disasters. Bangladesh was hit by SIDR Cyclone which left a path of devastation. I would like to hereby express our deepest sympathies to the affected population on behalf of ICUS.

During the period of this volume, we could successfully hold the USMCA-6 thanks to the efforts of our Bangladeshi colleagues at BNUS and BUET and all the participants. In this symposium we were able to exchange opinions, discuss different problems in our urban environment, and strengthen collaboration ties among experts in the field.

As mentioned by Dr. Tanaka in the main article of this volume, traffic accidents are one of the major issues of urban safety. To address this and other similar problems, we need to first investigate the phenomena and single out the problems that require attention. Then, we should define concrete and quantifiable goals and finally design plans to reach those goals. With this approach, Japan has been able to reduce the number of traffic related fatalities to one third of its peak values, which were reached some 40 years ago.

Urban safety problems need to be addressed from several viewpoints. Of course, it is necessary to solve the technical issues, such as improving the quality of the vehicles in the case of traffic safety. However, it is also equally important to create regulations and educate the public. Learning from past experiences and sharing lessons is very useful as well. We do hope that together with our Newsletter readers, we will create a safer urban environment.

(By K. Meguro)

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp.

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International Center for Urban Safety Engineering

Institute of Industrial Science
The University of Tokyo

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FLOW SLIDES OF UNDERWATER SAND DEPOSITS IN JAMUNA RIVER BED

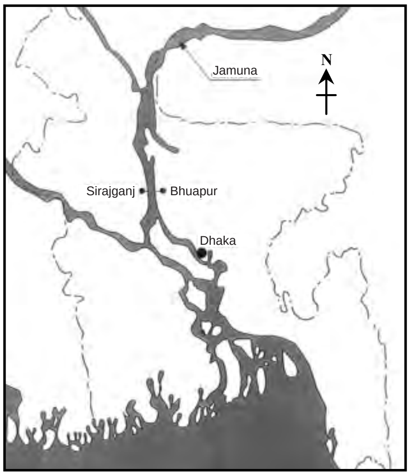
By

*Kenji Ishihara**

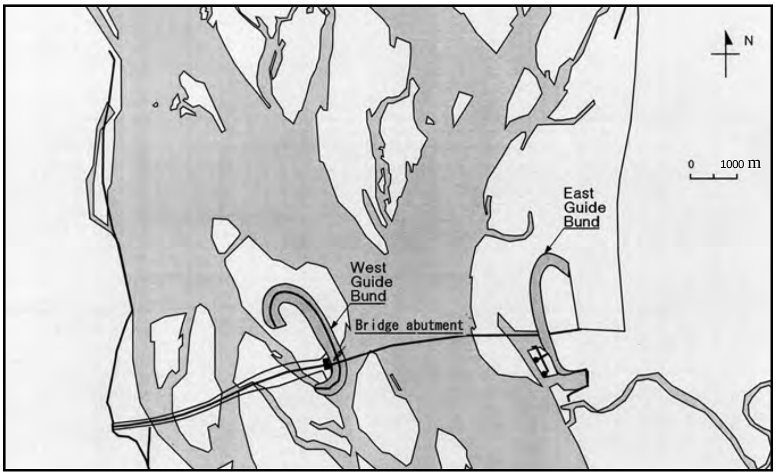
In the middle reach of the Jamuna River in Bangladesh, about 110km northwest of Dhaka, a 4.8km-long bridge called Bangabandhu Bridge connecting the towns of Sirajganj and Bhuapur was planned and constructed in 1995-1999. Its location is shown in the bottom left figure. The Jamuna is a shifting braided river, consisting of numerous channels which change their width and course significantly with the seasons. Thus, training the river to ensure that it would continue to flow under the bridge corridor was the most difficult technical challenge against the project.

As shown in the more detailed map in the bottom right figure, the width of the river channel was about 11km. This area is the vast expanse of flood plain and has suffered severe destruction over the years due to intense flooding over the river channel and its surroundings. Devastation was particularly conspicuous at the time of the flooding in 1987 and 1988. In some areas, river channels are purported to have shifted their courses overnight through several hundred meters. The tendency of the drift is reported to have been westwards whereby involving a huge amount of sandy soils removed by scouring in the riverbed in the west side of the Jamuna River.

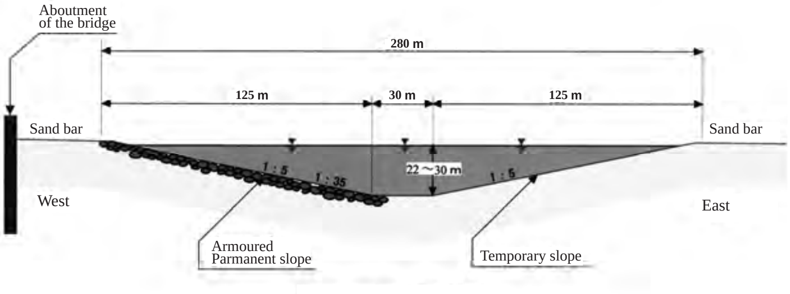
In the large project to construct a long-stretch bridge, it was considered mandatory to protect the bridge abutment, to implement some countermeasures against the deleterious effects due to scouring, and to control the river channel. With this aim, construction of guide bunds was planned on both sides of the river as shown in the bottom right figure. Of particular importance was the construction of the West Guide Bund, as it was intended to protect the bridge abutment behind the river from scouring or erosion of the riverbed. The construction consisted of excavating the riverbed by dredging the sand with ships and placing erosion-protecting armors such as geotextiles and stones over the underwater slopes on the west side. A typical cross section with an armored slope is shown in the figure on top of this page. The location and



General location map

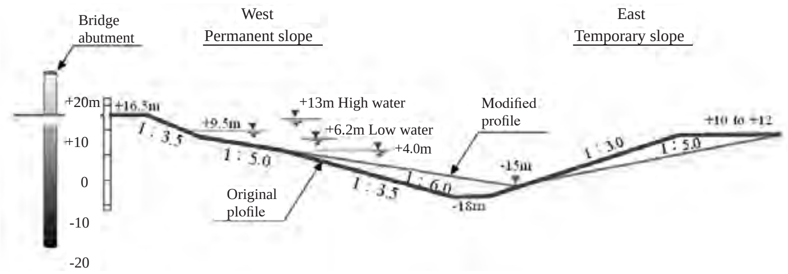


Locations of the Guide Bunds in Jamuna Bridge site



Cross section 1400-1800

Cross section for the dredging of West Guide Bund for the bridge at Jamuna River site



East-west section through West Guide Bund Channel (from Hight et al. 1999)

horseshoe-shaped plan view of the Guide Bunds are displayed at the bottom of this page. The trench varying from 22 to 30m in depth was dug below water by means of cutter-suction dredgers which were operated from ships at the site of each guide bund. The sand slope being spread behind the abutment zone after dredging work is shown in the bottom right photo.

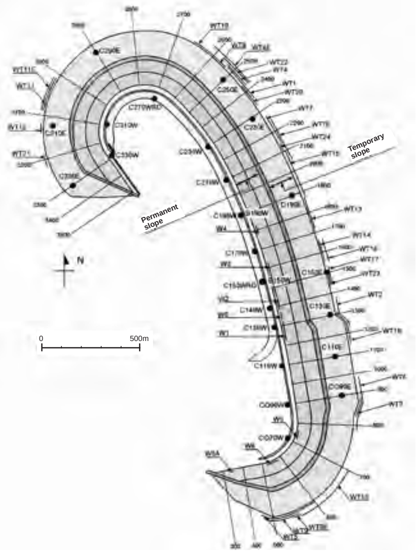
The West Guide Bund was constructed at the site of a recently formed sand island as seen in the figure in the bottom right of the previous page. The materials forming the dredged slopes were composed of young, rapidly deposited sediments. The detailed plan view of the excavation is shown in the figure on the top of this page and a typical section (E-W section) across the dredged channel is displayed in the figure below of it.

The slope on the west side was to be protected by a geotextiles-stone armor against the scouring, because the bridge abutment was to be installed to the west of the West Guide Bund. Thus, the underwater slope on the west side designated as “permanent slope” was designed so as to have a gentle slope of 1:5.0 in the middle portion. On the contrary, the slope on the east side of the dredged channel was to be left unprotected. Even though slides may occur and the sand bar may disappear in the future due to scouring or erosion, it was considered a big matter. Thus, the eastern slope was designed to form a steeper slope with an angle of 1:3.0 and designated as “temporary slope” in the left hand figure.

The dredging work began northwards in October 1995 from the southern rim of the sand bar. As the dredging proceeded, slope failures occurred on the permanent slope on November 19th in 1995 and another on November 22nd. On December 3rd, 1995, the largest-in-scale slide took place on the permanent slope. This slide covered an area of about 150m wide and 150m long over the permanent slope. Afterwards many failures were found to have occurred on the temporary slope in 1996. Many of these slides caused the delay of construction work. The most serious concern was the failures on the permanent slope, because they had to be repaired to construct an erosion-free slope. In recognition of the instability with an angle of 1:3.5, the cross section design on the permanent slope was changed so as to have a slope of 1:6.0 near the bottom. For the temporary slope, the angle was changed from 1:3.0 to 1:5.0 as illustrated in the figure by Hight et al. shown on this page. Then, the dredging work to full depth was resumed to finish excavation of the trench.

A detailed analysis of the possible causes of the slides, based on the results of in-situ and laboratory tests using the sand secured from the site was performed. It was found that the presence of mica minerals in the sand was the potential cause leading to the wide-spread slides in the dredged underwater slopes.

**** Professor, Chuo University***



Locations of slides in the West Guide Bund

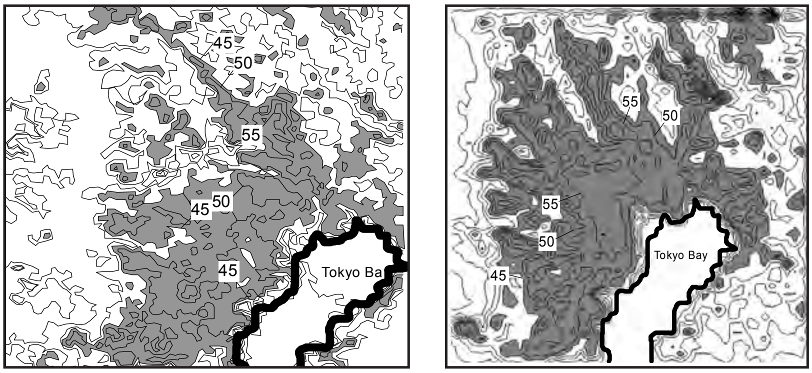
Sand slope behind the abutment zone

Numerical Simulation of Environmental Problems

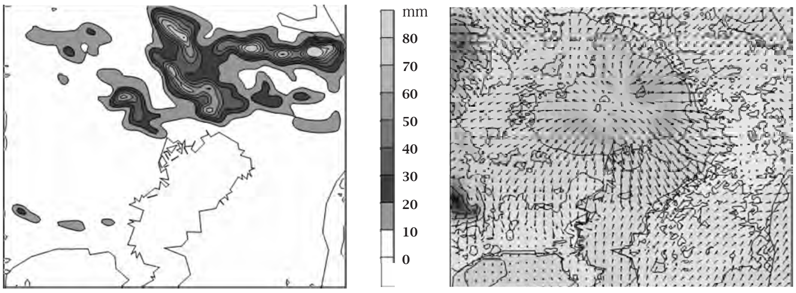
In recent years, more attention has been paid to environmental problems, such as global warming, abnormal weather, urban heat island, air pollution, floods, soil and ground water pollution, biodiversity decrease, etc. In order to settle these problems, firstly, it is very important to predict these phenomena. The recent improvement of computer performance has enabled numerical simulations of various environmental phenomena and promoted the development of various environmental models. For example, the future global temperature can be predicted with some accuracy based on the future conditions of the CO_2 emissions. The global meteorological model can also predict abnormal weather occurring with the global warming.

In urban areas, not only in Japan but all over the world, the urban heat island and air pollution are becoming serious problems. It is possible to determine the reasons behind the heat island phenomena using numerical simulations. The figures on top of this page show a comparison of ground surface temperature over Tokyo metropolitan area according to artificial satellite measurements and numerical simulations. The simulation result agrees fairly well with the measurement. The urban heat island sometimes causes disasters such as local heavy rain. An example of prediction is also shown. This prediction can be used for taking countermeasures for floods. The effects of countermeasures for heat island can also be estimated with the aid of numerical simulations.

To predict air pollution is also very important to guaranty healthy and safe human lives in urban areas. The figure on the right shows the ozone concentration over Kanto area in Japan by a coupled simulation of meteorological and chemical reaction models. In this result, the photochemical reaction is considered. The other figure shows the pollutant dispersion from an expressway. Micro climate models can represent the detailed pollutant distribution in the complex urban geometry. This visualization technique is very useful to image pollution problems.



Comparison of ground surface temperature (July 24, 1995, 13:00)
— left: measured, right: numerical simulation —

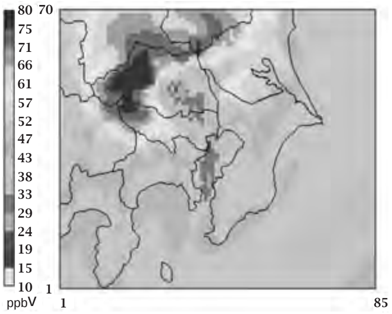


12 h total rain fall **Horizontal Wind Velocity Vector**

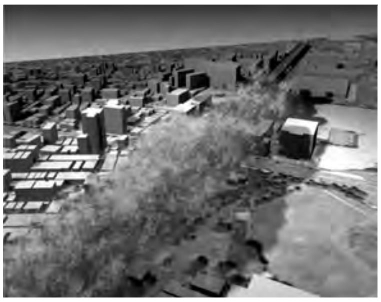
Prediction of local heavy rain (August 15, 2005, 12:00~24:00)

Many environmental problems described above are dominated by transport phenomena, which include convection, diffusion, radiation, hydrodynamics and permeation. Although environmental phenomena have a large variety, the physical principle which describes them is common. It is possible to synthesize various simulation models on one platform. This is a future subject of study in order to settle various urban problems.

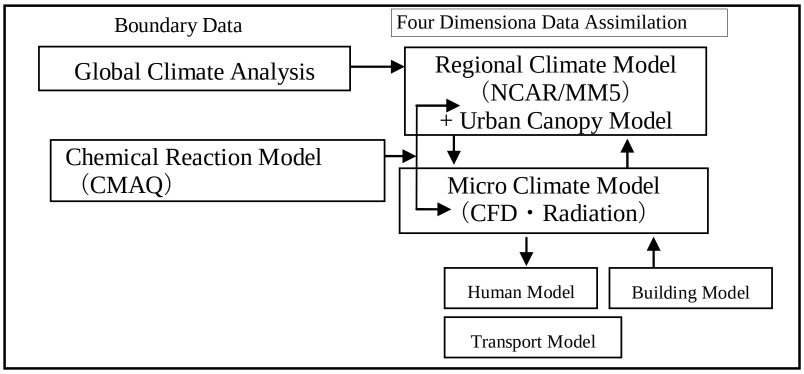
(By R. Ooka)



Ozone concentration over Kanto Area, Japan



Air pollutant dispersion from expressway



Comprehensive climate model for assessing environmental problems

Recipients of the 2007 USMCA Young Researcher Award Present Their Research Topics

Ms. A. B. Afifa Imtiaz and Dr. Ema Kato received the Excellent Young Researcher Award for performing outstanding presentations and research in the 6th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia (USMCA) held on December 9-10, 2007 in Dhaka, Bangladesh. Ms. Imtiaz presented the paper “Visual Screening Methods for Earthquake Vulnerability Assessment” whereas Dr. Kato introduced her research “Variation of Corrosion Characterization of Reinforcing Bar in Existing RC Structures.” In this issue, these outstanding researchers briefly present their study findings.

Ms. Imtiaz , Graduate Student, Civil and Geotechnical Engineering Department (BUET)

Dr. Kato, Senior Researcher, Port and Airport Research Institute

Visual Screening Methods for Earthquake Vulnerability Assessment

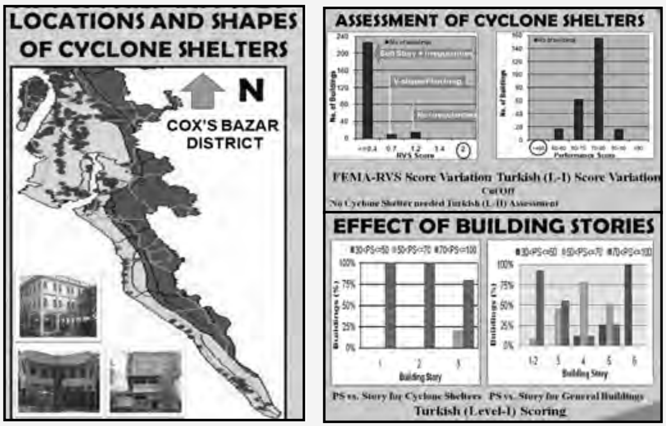
This paper deals with the investigation of two pre-earthquake screening methods for rapid evaluation of seismic vulnerability profiles of the existing building stocks. One of the objectives of the study was to identify, inventory and rank all high-risk buildings in a specified region so that a strategy for prioritizing interventions could be deviced. It also compared existing methods in order to develop a guideline for an ideal screening method in the context of Bangladesh. The methods employed were FEMA-RVS, developed by The US Federal Emergency Management Agency (FEMA) and the Simple Survey Procedure, developed after the 1999 earthquake in the cities of Kocaeli and Düzcec in Turkey.

Both methods were used in the research for seismic vulnerability assessment of buildings of Cox’s Bazar district in Bangladesh. The paper critically examined and compared the two methods with reference to the seismic assessment of structures in Cox’s Bazar by identifying the key parameters contributing to the vulnerability assessment and the suitability of the methods for Bangladesh. The study concluded that both methods have limitations in terms of incorporating the parameters relevant for Bangladesh and many other countries. Fine-tuning of the significantly contributing technical aspects of these procedures can lead to the development of an ideal Rapid Visual Screening Procedure which would provide more reliable assessment of the seismic vulnerability of the buildings and form the basis for determining need for more complex vulnerability assessment.

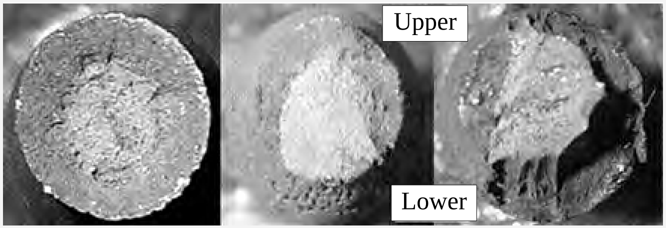
Variation of Corrosion Characterization of Reinforcing Bar in Existing RC Structures

It is important to characterize the corrosion profile of a reinforcing bar embedded in concrete when it has suffered from chloride-induced deterioration. In a real structural member, a reinforcing bar is not uniformly corroded. Although this variation will affect its mechanical properties, an actual corrosion profile has been rarely investigated in real structures and available information is insufficient.

In this study, corrosion profiles of reinforcing bars taken from reinforced concrete slabs of an open-type wharf that has been in service under marine environments for 29 years were investigated. The weight loss of reinforcing bars in the slabs showed extremely large variations along the axis of the bar. The cross-sectional loss of the lower half of the piece was larger than that of the upper half because of the existence of the interfacial transition zone formed due to bleeding. Moreover, tensile tests of corroded reinforcing bars showed that the unevenness of cross-sectional loss had an influence on the mechanical properties because of the lopsided action of tensile stress.



Cyclone shelter earthquake vulnerability evaluation



No corrosion

Cross-sectional loss Ave. 0.8%, Max. 2.0%

Cross-sectional loss Ave. 1.7%, Max. 8.2%

Reinforcing bars at breaking sections

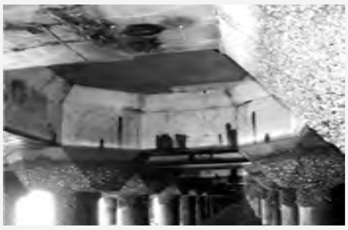
Research committee on technologies for evaluation of aging infrastructure performance degradation (RC-62) is launched

Infrastructure supporting our everyday life is constructed with various kinds of materials, such as concrete, soil, steel, etc. Structural performance of the infrastructure will degrade due to material deteriorations during service, and sometimes may reach their minimum requirement levels. Therefore, it is necessary to implement a suitable maintenance strategy on the infrastructure based on regular assessments of the structural performance during the service period. Unfortunately technologies capable of evaluating quantitatively the structural performance have not yet been well established although lots of research works have been tried to investigate their applicability for prototype structures. Furthermore, no research work has been done to evaluate the performance of an entire structure from its foundation to main body.

In consideration of the above-mentioned situations, this research committee will start a systematic investigation on the state-of-the-art technologies for the performance evaluation of infrastructure. This will include the assessment of existing measurement and evaluation techniques that are actually being applied in the fields of concrete, ground, and steel. Transfer and application of the latest technological developments from one field to another and integration of all these technologies will be addressed. The committee will also attempt to predict future needs for technological developments in these fields.

The committee organizers are Prof. H. Yokota, Dr. R. Kuwano, Dr. Y. Kato, and Dr. T. Endo.

(By Y. Kato)



Deterioration of pier due to salt attack

Cave-in in road due to the deterioration of underground pipe

RC-58 held meeting

The Research Committee 58 (RC-58) met on March 27. The aim of this committee is to propose guidelines for developing suitable business continuity management (BCM) systems suitable for Japan. In recent years, BCM systems and business continuity plans (BCP) have become increasingly popular. Many guidelines to prepare BCPs have been published in Japan. However, these were originally developed in Europe and US and have been adopted without careful consideration of Japanese conditions such as organization characteristics, social environment, target emergency situations, among others. Because of this, even when BCPs are prepared, a real capability and effective BCM system cannot be implemented. Considering this problematic, ICUS has established the RC-58 and regular meetings have been held with the member companies to discuss these issues.

In the latest meeting, each of the three working group (WG) outcome was introduced. WG-1 discussed the differences among the guidelines in Europe and US and those in Japan. WG-2 compared the Japanese Cabinet Office Guidelines with that of other Japanese Government agencies and WG-3 did the same but the comparison was done with private sector companies. Based upon this year discussion, RC-58 published a report.

After the WG reports, an invited speaker, Mr. Keiichi Ichikawa, delivered the lecture “How can information technology be used to implement a good BCP/BCM?” Mr. Ichikawa is President of Rescue Now Co. Ltd., the first Japanese disaster IT company providing BCP consulting services. He presented the experiences he had when he started his company and its current situation as well as his business model idea. After his lecture, a small gathering was held in which participants exchanged ideas and questions were answered.

(By K. Meguro)

Mr. Keiichi Ichikawa

Announcement of USMCA-7

The 7th International Symposium on New Technologies for Urban Safety of Mega Cites in Asia will be held on October 21-22, 2008 in Tsinghua University, Beijing, China, The symposium is jointly organized by ICUS, Institute of Industrial Science, The University of Tokyo and The Center for Public Safety Research, Tsinghua University. This symposium is organized to provide a forum for decision makers, practicing professionals and researchers to share their expertise in diverse areas such as infrastructure planning and development, application of new technologies, nondestructive evaluation of structures, rehabilitation methods, among others.

Abstracts are welcomed by June 22 and notification of acceptance will be sent by July 20. Full papers must be submitted by August 31, 2008, which is also the early bird registration deadline.

For information regarding this symposium please contact Dr. Wenguo Weng, Center for Public Safety Research, Tsinghua University, Beijing, 100084, P.R. China. (USMCA2008@tsinghua.edu.cn) or visit the following URL: http://www.ep.tsinghua.edu.cn/USMCA2008.

(By R. Ooka)

RNUS Activities

RNUS, GIC, Kyoto University and the University of Tokyo carry out field survey in Thailand

On January 10, 2008, Drs. Takeuchi, Worakanchana (ICUS) and Suzaki (Kyoto University), carried out a field survey at Buriram, northeast of Bangkok. The objective of this field survey was to install soil moisture and temperature probes to validate data along with an estimation of soil moisture using active microwave satellite data for the mitigation of drought impact.

RNUS Seminar

Drs. Takeuchi and Worakanchana organized a seminar on the topic "Toward a partnership on disaster management and remote sensing/GIS technologies" at AIT Center on February 8, 2008. The objective of this seminar was to create the environment for remote sensing/GIS and disaster managing specialists to exchange their opinions, point of views and information.

The seminar started with opening speeches by Professors Kanok-nukulchai and Meguro followed by presentations from ten speakers from AIT, GISTDA, IIS, ICUS, JAXA Thailand and Kasetsart University (For more information see www.set.ait.ac.th/rnus/rnusnew). After this, the closing speech was given by Prof. Yashiro, vice president of IIS. Most of the audience in this seminar was from Thai Government organizations.


Group photo of speakers and organizers at RNUS seminar

Survey and Interview for Sustainable Tsunami Disaster Mitigation System Project in Phuket

Prof. Meguro led the team joined by Drs. Takashima and Worakanchana to collect data and interview people for a Sustainable Tsunami Disaster Mitigation System for the Indian Ocean Region Project on February 9-10, 2008. During this trip, the research team visited Mr. C. Sukban, Deputy Mayor of Pathong Municipality, Ms. P. Nootmorn, Director of Andaman Sea Fisheries Research and Development Center, Ms. S. Pinpradab, Director of Tourism Authority of Thailand and Mr. C. Kerdsom, Head of Phuket Disaster Prevention and Mitigation Office.

Short Seminar on Transportation at Chulalongkorn University

A half day seminar focusing on transportation research was held on March 25, 2008 at Chulalongkorn University. The welcome address and opening speech were delivered by Dr. T. Tongthong, Head of the Civil Engineering Department, Chulalongkorn University. Two speakers from the University of Tokyo made presentations: "Urban railway network planning in Tokyo" by Dr. H. Kato and "Feasibility study of peak-hour road shoulder usage in urbanized motorways" by Dr. S. Tanaka. The closing speech was given by Dr. K. Choocharukul.

(By S. Tanaka and K. Worakanchana)

The Center for Integrated Disaster Information Research was created

The Center for Integrated Disaster Information Research (CIDIR) was established at The University of Tokyo on April 1st, 2008. It was launched for integrating humanities and scientific research on disaster information by the Interfaculty Initiative in Information Studies, the Earthquake Research Institute, and the Institute of Industrial Science (IIS). A symposium was held for disseminating the objectives of CIDIR establishment at IIS on March 12 and attended by more than 200 participants. A press conference was held before the symposium.


Welcome speech by Prof. Maeda, Director General of IIS


Panel discussion panelists


Audience snapshot

The symposium started with welcome speeches by Prof. Syunya Yoshimi, Director General of Interfaculty Initiative in Information Studies, Prof. Syuhei Okubo, Director General of the Earthquake Research Institute, and Prof. Masafumi Maeda, Director General of the Institute of Industrial Science. Then, Prof. Yoshiaki Kawata, Kyoto University and Prof. Atsushi Tanaka, Director of CIDIR, gave presentations on the future prospective of the research activities in CIDIR.

The latter part of the symposium was a panel discussion on "the effective use of disaster information for Tokyo Metropolitan Earthquake and expectation for CIDIR." Six panelists and one chairman, Noboru Yamazaki, who is the commentator of Japan Broadcasting Corporation joined. The panelists were Mr. Koji Ikeuchi, Cabinet Office, Prof. Kazuki Koketsu, Earthquake Research Institute, Prof. Kiyoshi Takano, CIDIR, Prof. K. Meguro, ICUS, in addition to Prof. Kawata and Prof. Tanaka who were the presenters in the initial part. ICUS wishes for a collaborative relationship between ICUS and CIDIR.

(By M. Ohara)

BNUS Activities

Short Course

The Directorate of Continuing Education (DCE), Bangladesh University of Engineering and Technology (BUET), in association with BNUS arranged a short course entitled “Disaster and Conflict—What shall we do on it?” The course was held on March 15-16, 2008 with the objectives of successfully managing the situation of natural or man made disasters; developing a scientific method to mitigate disaster casualties; sharing practical experience of SIDR cyclone from the engineering point of view; and making a comprehensive plan for solving urban flooding, earthquake, etc.

A total of forty three people from different organization participated . Prof. Dr. A.M.M. Safiullah, Vice-Chancellor of BUET was present as the Chief Guest in the certificate distribution ceremony. He handed over the completion certificate to the participants, who expressed their feelings on this course. Some of them requested the organizer to arrange such kind of training more as it is the current key issue.

Short course certificate award ceremony

Building Earthquake Resistant Masonry Houses

Most of masonry houses in Bangladesh are not capable to resist small to moderate earthquakes. This is due to the lack of knowledge on how to build an earthquake resistant house. BNUS has been working on this problem for a long time and is in the final stage of publishing an Earthquake Resistant Construction Manual for Mason Training. After it is completed, BNUS will arrange mason training programs in the believe that masons are the key for making earthquake resistant masonry houses.

Prof. Tamura and Japanese Embassy Staff visited BNUS

Kyoto University Professor, Dr. Takeshi Tamura, visited BNUS on March 3, 2008. Mr. Asai, Head of Cultural Wing of Japanese Embassy and Ms. Fujimoto of the NPO Asia SEED accompanied him. They were briefed on BNUS activities. Ms. Jahan introduced the School Earthquake Safety Program and Mr. Das explained the microtremor and Ferroscan survey conducted on the BUET buildings. Prof. Ansary informed them about early warning system in the coastal region in Bangladesh and about the Mason Training Program.

Partial view of school students

SESP in Anandamoyee Girl’s High School

BNUS arranged a School Earthquake Safety Awareness Program (SESP) in Anadamoyee Girls’ High School situated in ward 68 at old Dhaka. It was attended by around 200 students and was launched on March 24, 2008. Ms. Azijun Nessa, the High School Headmistress, delivered the opening speech and thanked BNUS for selecting her school for such a program. The Chief Guest, Prof. Ansary explained the need for earthquake safety awareness program. A video clip depicting a deadly earthquake was shown to the students, who were much impressed and became eager to learn more about earthquakes and how to tackle them. More of such programs were requested by the school authority. The First Aid Training for the school students will commence when the school reopens.

(By M. Ansary)

ICUS Activities

- *Prof. Meguro visited Thailand from Feb. 7 to 11 to give a presentation at the RNUS Seminar and join the IIS Alumni party. He also made a field survey to Phuket, together with Drs. Takashima and Worakanchana, to collect data and interview people for the project Sustainable Tsunami Disaster Mitigation System for the Indian Ocean Region.*
- *Prof. Meguro traveled to Riyadh, Saudi Arabia to deliver a Keynote Lecture at the Symposium on Disaster Management and Safety of Buildings in Arab Countries.*
- *Dr. Ooka visited New York, USA, to participate in the 2008 American Society of Heating, Refrigerating and Air-Conditioning Engineers Winter Meeting from January 19 to 24.*
- *Dr. Ooka attended the Alliance for Global Sustainability (AGS) Annual Meeting 2008 in Boston, USA, from Jan. 28 to Feb. 1.*
- *Dr. Ooka traveled to Seoul, Korea from Feb. 27 to 29 to inspect the present situation of ground water use for air conditioning and others.*
- *Dr. Tanaka stayed at AIT for his research work and teaching duties at RNUS from Jan. 21 to Feb. 16 and Feb. 26 to March 29.*
- *Dr. Worakanchana stayed at AIT for his research work and teaching duties at RNUS from Dec. 1 to Feb. 21 and Mar. 11 to 26.*
- *Dr. Worakanchana visited Dhaka, Bangladesh from Mar. 15 to 22 to plan a survey to assess the vulnerability of existing building stock.*
- *RC-58 committee held a general meeting on March 27.*

Awards

- *Dr. Ooka received the Best Poster Award Certificate for his work: “Proposal of New Model House Design with Energy Efficiency for Riyadh in Saudi Arabia” at the AGS Annual Meeting 2008 on Jan. 30.*
- *Mr. Tetsuro Fujita received the Tanabe Award for his paper “A Meta-game Analysis of Effective Strategies for Social Movement -The cases of NEN-O EXPWY and Sanbanze Wetlands-” on March 25.*

Editor's Note

Today, May 19, I am at Shenyang, China to join an international workshop. This afternoon at 2:28pm all the people in China prayed silently for the people who died in the huge earthquake that occurred in Sichuan Province a week ago (May 12). In the workshop, presentations were also stopped and all the participants prayed silently for three minutes. The number of lives lost in the event is more than 40,000 at the moment and it is increasing as time passes. Last month a big hurricane attacked Myanmar and also many lives were lost. How can we prevent these disasters? Can we reduce damage? The role of ICUS is getting larger and larger.

I retired from the University of Tokyo last March. During these ten years at the Institute of Industrial Science I had the opportunity to work at ICUS for five years. I appreciate all ICUS members and ICUS affiliated members who kindly and strongly supported me during these years. Also, I would like to thank all ICUS newsletter readers for their contribution to ICUS. I am now working at the National Institute for Environmental Studies and my mission is still to find ways to improve our society and to realize a sustainable society. It has not changed at all from ICUS days. I hope that I can continue collaborating with old friends. Thank you again!

(By Y. Yasuoka)

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp.

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ICUS NEWSLETTER

International Center for Urban Safety Engineering

Institute of Industrial Science
The University of Tokyo

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REMOTE SENSING FOR MONITORING URBAN SAFETY AND ENVIRONMENT

By

*Yoshifumi Yasuoka**

Monitoring of urban safety and environment requires measurements of a wide variety of variables covering physical, chemical, biological, or geographical aspects. Furthermore, it needs to regularly observe extensive areas. A comprehensive and efficient monitoring system may not be realized with conventional ground observation methods only.

Remote sensing is an observation tool to identify objects or measure their characteristics without directly contacting them. Recent developments in remote sensing technologies have been remarkable and very rapid. Observations with one meter spatial resolution and one nanometer spectral resolution from space are also realized. These may provide an efficient tool to observe a wide range of land surface, atmosphere and ocean variables over extensive areas at regular intervals.

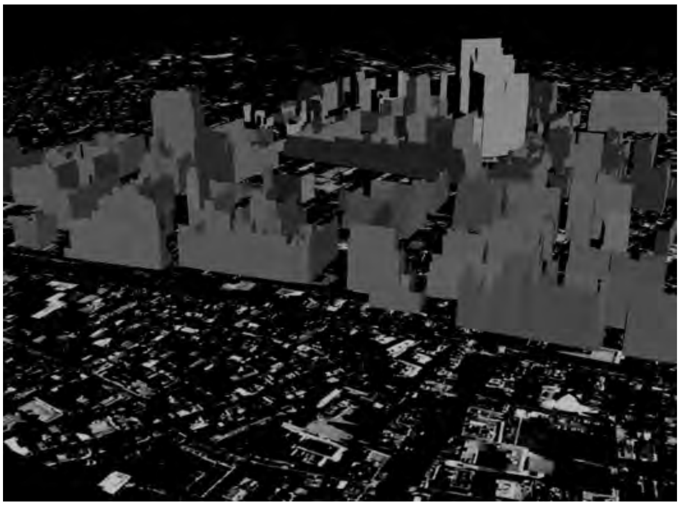
In this article, new technologies in remote sensing are surveyed, and their applications are introduced, with emphasis on the monitoring and assessment of urban safety and environment.

REMOTE SENSING

Remote sensing utilizes electromagnetic radiation as a media for the measurement. The measurement principle in remote sensing is based on the fact that all matter reflects, absorbs, penetrates and emits electromagnetic radiation in a unique way with respect to wavelength. This unique characteristic of radiation is called spectral signature of matter, and it enables to identify objects, or quantify their characteristics.

In remote sensing, the reflected or emitted electromagnetic radiation from a target is detected by a device called a "remote sensor." Cameras or scanners are typical examples of these. A vehicle to carry the sensor is called a "platform," and satellite or aircraft are usually used. Remote sensing from satellites or aircraft enables us to observe a wide range of variables over extensive areas at regular intervals.

The performance of a remote sensor is determined by various specifications including spectral range, spectral resolution, spatial resolution, observation width (swath), or obser-



3-D city model of Hongo Campus, The University of Tokyo, obtained from IKONOS and ALS data

vation frequency. Different types of remote sensor have been developed with respect to these specifications. The table on top of this page summarizes the specifications of typical remote sensors used for environmental and disaster monitoring. High spatial resolution sensors such as LANDSAT TM, SPOT HRV, or IKONOS are used for local or regional observation, whereas low spatial resolution, but wide coverage and high observation frequency sensors such as NOAA/AVHRR, ADEOS/OCTS, and TERRA/MODIS are used for continental or global scale vision.

Specifications of typical remote sensors

Satellite	Sensor	Wavelength (μm or GHz)	No. of bands	Spatial Res. (m)	Swath (km)	Cycle (day)
LANDSAT	TM	0.45-12.5	7	30	180	17
SPOT	HRV	0.50-0.89	4	10-20	60	26
ERS-1	SAR	5.3 GHz	1	20	100	35
JERS-1	OPS	0.52-0.86	4	18	75	44
JERS-1	SAR	1.275 GHz	1	18	75	44
IKONOS	Pan/MSS	is./Near-infrared	1/4	1-4	11	11
ALOS	AVNIR-2	0.42-0.89	4	10	70	46
ALOS	PRISM	0.52-0.77	1	2.5	70/35	46
NOAA	AVHRR	0.58-12.5	5	1000	2700	0.5
ADEOS	AVNIR	0.40-0.92	4	8 – 16	80	41
ADEOS	OCTS	0.40-12.5	12	700	1400	41
TERRA	ASTER	0.52-11.3	14	15 – 90	60	16
TERRA	MODIS	0.66-14.2	36	250-1000	2330	16

NEW TECHNOLOGY DEVELOPMENT IN REMOTE SENSING

High-spatial resolution observation

Spatial resolution is one of the most important sensor characteristics in remote sensing. It has been dramatically improved in the last 20 years, and, today, one-meter spatial resolution is realized with satellite sensors. From these images, individual buildings or tree canopies can be identified from space. High spatial resolution observation enables us to retrieve more detailed information on human settlements, land surface characteristics or topography from remotely sensed data. The figure below shows an example of building distribution detected from IKONOS image with one meter spatial resolution over the central area of Tokyo, Japan. In this image very fine spatial structures of the buildings and the roads are identified.

Hyper-spectral observation

Number of spectral channels in conventional remote sensors has been limited to 10 or at most to several tens in satellite and airborne systems. New hyper-spectral sensor systems have the capability of observing land surface in a couple of hundreds of channels. For example, the Hyperion on EO-1 has 256 channels. Airborne sensor systems such as CASI and AVIRIS have more than 200 channels and their spectral wavelength resolution is as narrow as several nanometers. Data from the hyper-spectral sensors have indicated the possibility of observing new urban risk variables, including concrete degradation, or vegetation stress conditions, which could not be observed by the conventional sensors.

Microwave range observation

With optical remote sensing, we can not observe the ground through cloud or haze. Microwave remote sensing has the advantage of all weather observation due to its longer wavelength. This observation capability enables us to monitor land surface conditions regularly even in heavily clouded regions including tropical regions or high latitude regions. A Synthetic Aperture Radar (SAR) is a typical microwave sensor which enables high spatial resolution observation. Microwave remote sensing has also the capability of monitoring precipitation and soil moisture.

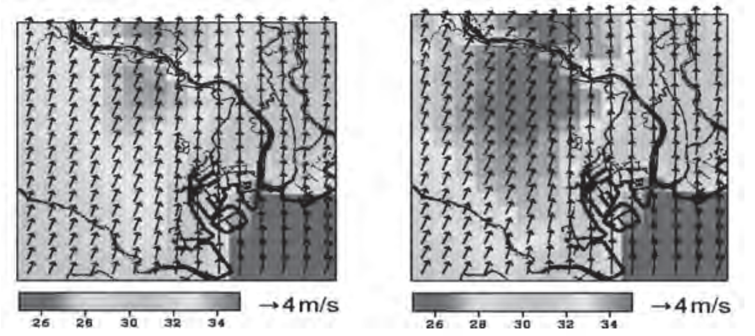
Distribution map of buildings over Shinjuku area, Tokyo, extracted from IKONOS image (color represents the building inventory number)

3-D Observation

Laser ranging technology enables us to observe the height of the targets from space. For example, Airborne Laser Scanner (ALS) can be used to monitor 3-D structures of buildings and trees with high accuracy. Today integration of high spatial resolution satellite data (e.g. IKONOS) and the topographic data from ALS enables us to produce detailed three dimensional data which is very useful for disaster or environmental assessment in urban areas.

Coupling remote sensing with modeling

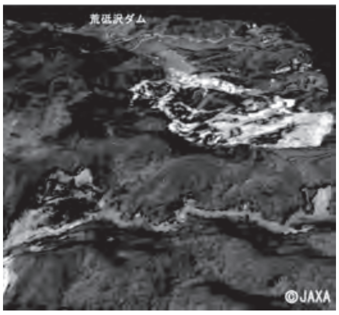
Remote sensing may provide effective information on the current status of environment or disasters, however, it can not predict the future. Physical models are required to predict the future. Recent developments in modeling of atmosphere, ocean and land have been very rapid and model prediction of the earth system has been getting accurate. Still there is a prediction error since the earth system is too complicated to be modeled. Effective integration between remote sensing and modeling may significantly reduce model simulation error since remotely sensed distribution of system parameters may be used for boundary conditioning, assimilation/nudging or validation. There have been studies to integrate remote sensing and modeling to improve model prediction and estimation. The figure on the top left corner of the next page depicts an example of heat island model simulation in Tokyo coupled with remotely sensed land cover distribution. It was shown that the accuracy of the estimated land surface temperature was significantly improved by integrating vegetation distribution observed by satellite data with a meso-scale climate model.



With integration between remote sensing and modeling

Without integration (only with modeling)

Simulation of land surface temperature with integration of remote sensing and modeling



Earthquake damaged area observed by ALOS AVNIR-2 and PRISM (from JAXA website)

APPLICATIONS OF REMOTE SENSING TO URBAN MONITORING

Environment and disaster variables for urban safety monitoring measured by remote sensing range from physical, chemical, biological to socio/economic variables. They also vary from practical/operational to research level. Examples of parameters are summarized as follows.

- *Practical level*

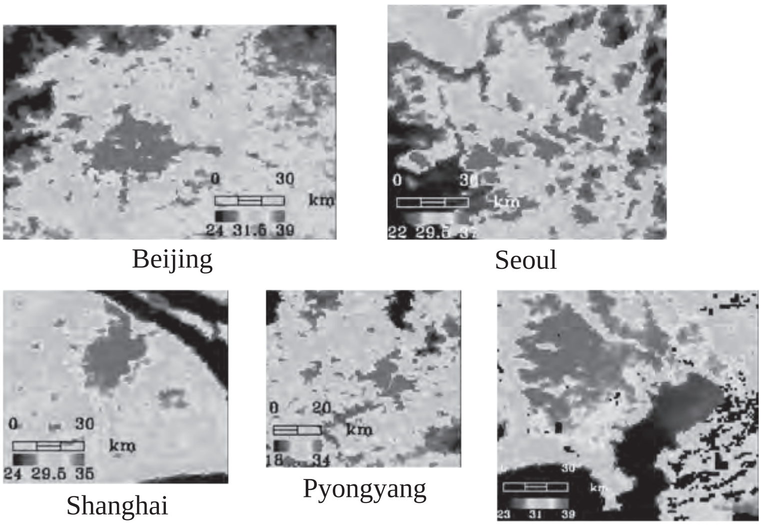
Land: land surface temperature, topography (Digital Elevation Model), 3-dimensional structures of buildings and vegetations, land cover classification, vegetation classification, vegetation index (Normalized Difference Vegetation Index, etc.), soil index, human habitats
Water: surface temperature, water quality including suspended sediment and chlorophyll, surface wind-vector, sea-ice
Atmosphere: temperature, water vapor, cloud
Others: precipitation

- *Research level*

Land: detail land cover classification, detail vegetation classification, soil type classification, soil moisture, LAI (Leaf Area Index), biomass, tree height, canopy structures, NPP (Net Primary Productivity), CO_2 flux (NEP: Net Ecosystem Exchange), chlorophyll/lignin/cellulose in tree canopy
Water: chlorophyll (high accuracy), algae
Atmosphere: CO_2, CH_4, water vapor, ClO, NO_x, SO_x, O_3, aerosols

The figure on the bottom of this page depicts land surface temperature distributions in Asian mega cities obtained from MODIS data. They are critical in assessing urban heat island which has been a serious issue in most of Asian mega-cities.

The figure above shows land surface conditions and 3-D structures over the area damaged by the 2008 Iwate-Miyagi earthquake observed by ALOS AVNIR-2 and PRISM sensors. These variables might not be obtained without new remote sensing technologies.



Beijing

Seoul

Shanghai

Pyongyang

Tokyo

Land surface temperature maps over Asian cities obtained from MODIS data

CONCLUSIONS

Urban safety monitoring with remote sensing has potential advantages as follows:

- it does not disturb the object in measurement
- it can cover extensive areas in a short time
- it can measure parameters in the same spatial and temporal scale for any area of the world
- it can cover land, ocean and atmosphere areas where we can not get into and where we can not do direct observation.

Development of remote sensing technology has been very rapid, and today various types of remotely sensed data are available, ranging from high spatial resolution data for local monitoring to wide coverage data for regional/global monitoring. It is still difficult to realize operational and practical monitoring with only remote sensing or only ground observation. It is expected that an integrated environment and disaster monitoring system for urban safety assessment will be accomplished.

Executive Director, National Institute for Environmental Studies and former ICUS Professor

Prof. Sawada: 35 years with remote sensing progress

I started my new post as professor of ICUS on April 4, 2008. Before that, I had been working as Principal Research Coordinator for International Issues in the Forestry and Forest Products Research Institute (FFPRI), an incorporated administrative agency, in Tsukuba. My specialized field is remote sensing and forest information including geographic information system (GIS).

At the age of a sophomore, I read about infrared photography on a newspaper and decided to join the Department of Forestry of the University of Tokyo for studying forest remote sensing. After I obtained my Master's degree there, I started working as a researcher of FFPRI in 1978. I worked also as adjunct and part-time teacher at the University of Tokyo and the University of Tsukuba from 1990 to1994 and 1996 to 2003, respectively.

After developing software systems for processing Landsat images for a few years, I studied radar remote sensing for about a year in the University of California at Santa Barbara. In 1986, the French Government allowed me to stay as a visiting scientist for a year at the International Institute of Vegetation Map of the University of Toulouse.

It is my honor to introduce my research projects in the past on this occasion.

1) Mapping and resource evaluation of natural forests: Very little information on natural forest is available because of the problem of accessibility. Satellite images and aerial photography were used to evaluate typical natural forest resources. Distribution and available volume of trees were determined by integrating remote sensing and GIS data.

2) Development of early detection and early warning system for forest fire: We installed the NOAA satellite receiving system in Indonesia and developed the early detection system for suppressing fires in 1997. Based on this experience, a similar system was set up in Japan to monitor the South East Asian countries. These operational information systems using remote sensing brought us the Ministers Prize of the Ministry of Education, Culture, Sports, Science and Technology of Japan in 2001.

3) Information for land management of the Mekong River Basin: The Mekong is an international river which flows through China, Laos, Myanmar, Thailand, Cambodia and Vietnam. Because the development of cities and living environment depend on availability of water resources, watershed management is a very important issue. We clarified the environment conditions of the last 20 years using the flux tower data and satellite data, such as NOAA, SPOT and LANDSAT. We were awarded the national order by Cambodian Government for this activity.

These results were applied to estimate carbon fixation of forest for the Kyoto Protocol under the United Nations Framework Convention on Climate Change. As an ICUS member, I would like to promote studies on monitoring of environments under climate change, which have big influence on urban safety.

(By H. Sawada)

Fire spread risk map of Japan

Upgrading the seismic performance of wooden buildings

I got my Ph.D degree from the Department of Architecture, Graduate School of Engineering, the University of Tokyo in 2001. My research interest is wooden structures and wood engineering for buildings.

Japan has a longstanding heritage of wooden buildings. At the same time, Japan is a country beset by earthquakes. Wooden houses in Japan have suffered great damage caused by strong earthquakes.

Many types of wooden buildings were built long time ago in Japan. One of the wooden building category is the detached wooden house. These houses, built especially over 30 years ago, have the problem that they have poor seismic capacity and are damaged by earthquakes. Targets of my research group are the seismic diagnosis and reinforcement methods for existing wooden houses. To clarify the seismic performance of existing wooden houses, we conducted full-scale shaking table tests and evaluated damages of existing wooden houses after earthquakes. At the same time, it is important to create awareness among homeowners about the danger of earthquake so that a good housing stock can be prepared.

In other categories, traditional wooden buildings are not only buildings but also cultural assets in Japan. Traditional wooden buildings like shrines, temples, town houses (Machiya) and folk houses (Nouka) were built by carpenters who were not structural engineers. They built them using empirical, not engineering, knowledge. Recently the seismic performance of traditional wooden buildings is gradually made clear. Even there are some seismic elements that we cannot make clear yet, traditional wooden buildings can be reinforced.

To upgrade the seismic performance of wooden buildings, different ways should be taken according to the category of the buildings. A simplified design method is required for detached wooden small houses and a more sophisticated method could be used for traditional wooden buildings. Researches on both aspects should be made.

(By M. Koshihara)

Full-scale shaking table test

Preservation of districts with groups of historic buildings "Narai-juku"

RC-62 held meeting

The Research Committee 62 (RC-62), "Technologies for Evaluation of Aging Infrastructure Performance Degradation," held its first meeting on June 24, 2008. In order to evaluate present and future performance of infrastructure, knowledge from two or more specialized fields, such as material science, structural engineering, geotechnical engineering, and so forth is necessary. Although these studies have been performed separately in each field, an appropriate methodology for combining these results has not yet been developed. ICUS has established RC-62 in order to consider this problem and regular meetings will be held with the member companies from various specialized fields in civil engineering in order to build relationships and create the environment for joint action. Self-introductions by committee members will be done from the first to the third meetings.

On this occasion, Mr. Kurita and Mr. Inada (Shimizu Corporation), Mr. Sato (Sankyo & Co., Ltd.), Mr. Amano (Hozen Maintenance & Management Engineering Co., Ltd.), Dr. Odabe (Sumitomo Osaka Cement), Mr. Kado (Osmos Technology Association) and Mr. Koike (Geo Search) introduced themselves.

(By Y. Kato)

RC-62 meeting snapshot

14th Open Lecture was held

Recently, people are thinking more often about climate change and getting anxious about how our urban life will be affected by it. Furthermore, the Intergovernmental Panel on Climatic Change (IPCC) was awarded the Nobel Peace Prize last year. For these reasons, ICUS focused on climate change and urban safety issues in the 14th ICUS Open Lecture entitled "How does global warming change urban environment?"

Approximately 150 participants attended the lecture. Three well-known professors delivered lectures addressing the followings topics: "what kind of changes our society will cause in the future," "what kind of life adaptation and relief measures are the best solutions," and "what we shall tackle immediately."

Dr. Y. Yasuoka, former ICUS Professor and now Executive Director at the National Institute of Environmental Studies, moderated the lecture, and Prof. Meguro, ICUS Director, gave the welcome speech. Speakers were:

- Prof. Mimura, Ibaraki University and leader author of the IPCC fourth assessment report working group.
- Prof. Hanaki, the University of Tokyo and leader researcher of measures for reducing greenhouse gas emissions.
- Prof. Sawada, former Forestry and Forest Products Research Institute member and currently ICUS Professor. Prof. Sawada is a leader in the field of forest research to tackle global warming.

The closing remarks were given by Dr. Yasuoka. After the Open lecture, a small party was held and attended by approximately 60 people.

(By T. Endo)

Prof. N. Mimura

Prof. K. Hanaki

Prof. H. Sawada

ICUS joins IIS Open House

ICUS jointed the IIS Open House which was held for three days, from May 29 to 31. In this event, our institute is open to the public and experts to share our research outcomes with the visitors. Overall 8,500 people visited Komaba Research Campus. A theme of ICUS was "Towards the Establishment of a Sustainable Urban System."

All laboratory members participated and displayed their panels showing their research activities. Topics included: "Simulation of seismic vulnerability of cities, houses and rooms", "Life-cycle management of port infrastructure", "Sustainable urban infrastructure", "Long term behavior of ground and buried structures", "Concept of disaster intelligence infrastructure", "Building with natural construction materials", "Urban traffic management", and "Satellite observation system for urban ambient environment and disaster." The open house was also an opportunity to introduce the 2007 Annual Report as well as RNUS and BNUS activities. Reports and newsletters were handed to visitors. Almost 250 people visited ICUS exhibition.

(By Y. Kato)

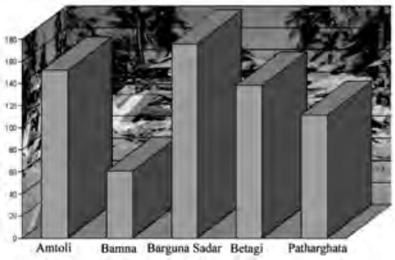
Prof. Sawada explains the principles of remote sensing and its applications to potential future scientists

BNUS Activities

Post Disaster Survey SIDR Cyclone, Bangladesh

A BNUS team visited SIDR affected area (Barguna and Pathuakhali districts) from May 5 to 12, 2008 to make a post disaster survey. The team met local authorities: District Commissioners (DC), Upazila Nirbahi Officers, District Relief and Rehabilitation Officers, Executive Engineers, Assistant and Upazila Engineers of the Water Development Board and Local Government Engineering Department, and NGOs (Bangladesh Red Crescent Society, Cyclone Preparedness Program, and others.)

The authorities shared their experience in tackling the situation during and after SIDR. The team also interviewed local people who were affected by the disaster. Damage data was collected and compiled. On the basis of this data and practical experience, an analysis was performed. The figures below show road damage in different upazila in Barguna.



Comparison of damage at different upazila in Borguna district

Meeting with DC, Patuakhali

Mason Training Manual for Bangladesh

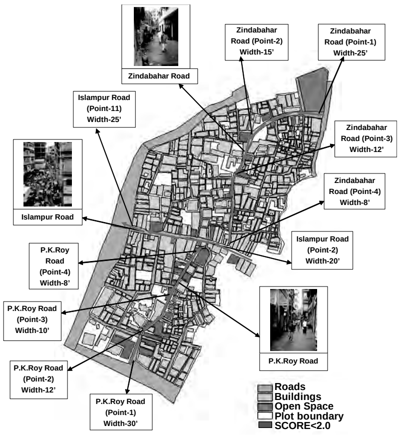
BNUS has developed a manual for mason training in Bangla. Bangladesh has no institution for educating masons. Thus, this is the first step to develop trained masons in Bangladesh. The feature of this manual is that trainer and trainee can store this material and detailed training description.

The manual consists of nine chapters, which are: earthquake and its background, site selection, foundation construction (masonry and frame structures), masonry wall building, masonry roof and slab building, quality control, maintenance and reconstruction, and retrofitting. The key role for constructing an earthquake resistant building is generally played by the mason. So, well trained masons are essential.

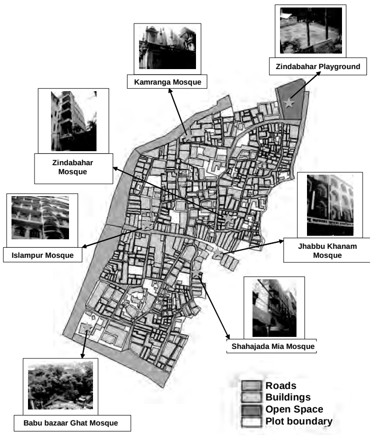
Community Based Earthquake Evacuation Plan for Old Dhaka (Ward No. 68)

The lower portion of Ward No. 68 has been analyzed. Three evacuation paths and seven evacuation centers are identified. The vulnerability of evacuation centers was determined using the FEMA-RVS and Turkish methods. The average road width of Islampur road, P. K. Roy lane, and Zindabahar 2^{nd} lane are 6, 3, and 4.5 meters, respectively. Widening of roads at different points and methods to prevent building collapse are also suggested to ensure effective evacuation. The figures below show the findings of this study.

(By M. Ansary)



Evacuation paths showing road widths at different point



Evacuation centers

RC-58 held two meetings in this trimester

The Research Committee 58 (RC-58) is working under the topic "Business Continuity Management (BCM) Systems Suitable for Japanese Society." Its activities started last year and 13 companies joined this year. The first and second meeting of this fiscal year were held on May 23 and June 17, 2008, respectively.

Last year, the committee members reviewed the existing BCM related literature and made a comparative study. This year, they were divided into three working groups in order to discuss the following topics: 1) the suitable BCM for private companies, 2) the suitable BCM for local governments and 3) suitable methods for evaluating BCM. These three working groups will continue their discussions until the next regular meeting, which will be held in September.

Snapshot of three RC-58 working groups during their discussions and opinion exchange

(By M. Y. Ohara)

RNUS Activities

Liaison meeting at Japanese Embassy

Dr. Tanaka attended the 1st liaison meeting held in Japanese Embassy in Bangkok on June 20, which aims at promoting information exchange and collaborative activities among Japanese organizations working in the field of science and technology. The participants were from the Japan Aerospace Exploration Agency, Japan Society for the Promotion of Science, Japan External Trade Organization, National Institute of Information and Communications Technology, Tokyo Institute of Technology, Osaka University, United Nations Economic and Social Commission for Asia and the Pacific, and AIT.

In this meeting, activities of each organization were introduced and issues in conducting research and education outside of Japan were discussed.

RNUS signed professional consulting services contract

RNUS/AIT team signed a contract for professional consulting services on June 2, 2008 for the project entitled "Seismic Hazard and Vulnerability Mapping of Dhaka, Chittagong and Sylhet City Corporation Areas." This project is a part of the Comprehensive Disaster Management Program (CDMP) of the Government of Bangladesh, supported by the United Nations Development Programme (UNDP), Department for International Development Bangladesh, and the European Commission to increase the level of earthquake disaster preparedness in the important cities in Bangladesh. The project will be executed by a joint venture including consultants, universities, and NGOs.

RNUS/AIT will be responsible for seismic vulnerability and risk assessment. The scope includes: supervising field survey of more than 20,000 buildings, identifying dynamic characteristics of more than 100 representative buildings, assessing the seismic vulnerability of typical buildings and lifelines by numerical analyses and estimating potential losses from possible earthquake scenarios using the GIS-based software package HAZUS.

(By K. Worakanchana and S. Tanaka)

Changes in ICUS staff

Prof. Sawada and Dr. Koshihara joined ICUS

ICUS welcomes Prof. Sawada and Dr. Koshihara who joined our center on April 1, 2008 as Professor and Associate Professor, respectively. They belong to the Infrastructure Information Dynamics Division.

Prof. Sawada field of expertise is remote sensing and forest information including geographic information system. Dr. Koshihara specializes in earthquake resistance of wooden structures and retrofitting methods. They have introduced their researches in this volume of ICUS Newsletter.

Dr. Ohara is promoted

ICUS would like to congratulate Dr. Miho Ohara who was promoted to ICUS Associate Professor on April 1, 2008 and also started to work as Associate Professor for the Center for Integrated Disaster Information Research (CIDIR), Interfaculty Initiative in Information Studies, The University of Tokyo from June 1, 2008.

CIDIR was jointly established by Interfaculty Initiative in Information Studies, The Earthquake Research Institute, The Institute of Industrial Science (IIS) in April 2008 in order to integrate disaster information research results in the University of Tokyo. She is expected to act as a bridge between CIDIR and ICUS, IIS.

Dr. Ohara graduated from the Department of Civil Engineering, The University of Tokyo and joined ICUS as Research Associate in April 2003. She obtained her Doctor of Engineering Degree in September 2005 from the University of Tokyo.

Her research interests are urban disaster mitigation strategies and education. Recently, she is developing E-learning system for increasing disaster response capacity of the staff members in medical facilities and universities.

(By K. Meguro)

Prof. Haruo Sawada

Dr. Mikio Koshihara

Dr. Miho Ohara

ICUS Activities

- *Dr. Kato attended the 1st International Symposium on Life-Cycle Civil Engineering, which was held in Varenna, Italy from June 9 to 16.*
- *Dr. Tanaka stayed at AIT for his research work and teaching duties at RNUS from April 1 to May 1, May 12 to 24, June 16 to 26, and July 2 to 20.*
- *Dr. Tanaka visited Hong Kong from May 18 to 19 to hold a research meeting on dynamic traffic operation.*
- *ICUS organized the 14th Open Lecture entitled "How does global warming change urban environment?" on May 9.*
- *ICUS joined the IIS Open House from May 29 to 31.*
- *RC-58 held general meetings on May 23 and June 17, 2008.*
- *RC-62 held general meeting on June 24, 2008.*

Editor's Note

In this trimester, there were two huge natural disasters, one is the Cyclone Nargis hitting Myanmar and the other is the Sichuan Earthquake which occurred in China. Both disasters caused enormous victims and still a lot of people are suffering from refugee life. We would like to express our sincere sympathies to people affected by these disasters. Although the events themselves had huge impacts, problems after the events, such as, troubles and delays in accepting foreign assistance offers, etc. were also revealed. These post-event activities are very important in disaster management, and we have to make efforts in this area, too.

Cyclones and earthquakes are typical natural disasters which cause huge damage in our daily life. However, as our society develops and connects intricately, factors which affect urban safety are also increasing much more than before.

After the retirement of Prof. Yasuoka, who made great contributions to ICUS from its beginning, we welcome new members, Prof. Sawada and Dr. Koshihara from this April. Their researches are introduced in this volume. ICUS is expanding its research field more widely and this variety of activities is the advantage of our center. Taking these opportunities, we would like to keep our organization active and try to tackle new challenges for a better society and urban environment.

(By S. Tanaka)

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp

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The University of Tokyo

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CONTRIBUTION OF FORESTS TO SOLVING GLOBAL WARNING ISSUES

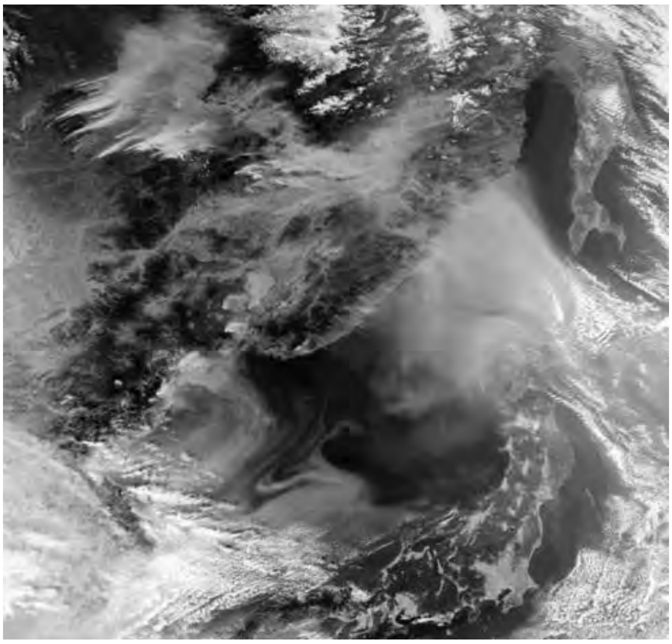
By

Haruo Sawada*

Forests provide timber, fuel wood and non-timber forest products for our daily life. At the same time, forests provide various ecosystem services. Various solutions based on technical improvement have been tried to address the negative influence of global warming on citizens. However, these measures are not advanced enough to save natural forests. According to the Kyoto Protocol, Japan is expected to reduce CO_2 emissions by 6.0%. 60% of them, that is 3.7%, is expected from the forest sector through forest sinks. Japan has developed the forest management information system, which introduced various types of GIS and satellite data, for that purpose. We are requested to submit appropriate methodologies to make the emission reduction from deforestation and forest degradation effective in the world for the post Kyoto Protocol. Forests could play as a generous donors for selfish people until the global environment issues arise in the world. Many forests are now under the impact of global environment changes. How can we return the favor to the forest ecosystem through countermeasures to global warming?

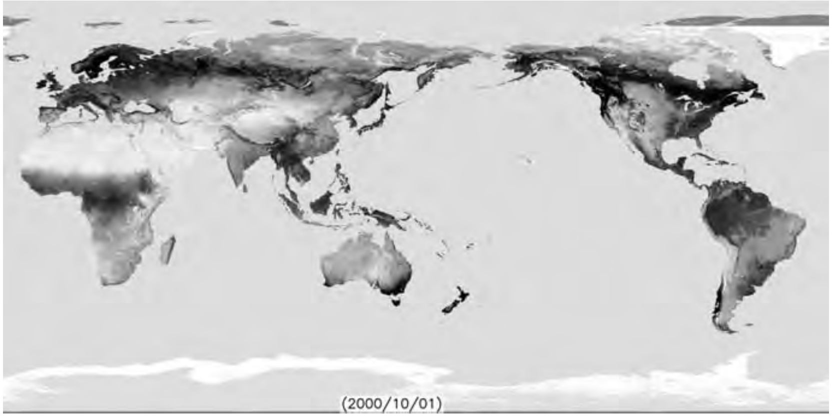
Human beings keep prospering on the Earth supported by natural environment and forests are indispensable for sustaining such conditions. Although many cities have developed on forested land, we are still supported by the photosynthesis of natural vegetation. While human activities contribute to climate changes in many direct and indirect ways, CO_2 emissions from human activities are considered the largest anthropogenic factor affecting climate change.

Various solutions based on technical improvement have been tried to address the negative influence of global warming on citizens. However, these measures are not advanced enough to save natural forests. History shows that the destruction of the surrounding natural environment brought the collapse of prosper cities.



Smoke from forest fires in Siberia covers northern Japan (observed by MODIS/MAFFIN)

Forests provide timber, fuel wood and non-timber forest products for our daily life. At the same time, they provide various ecosystem services, for example, sequestering carbon from the atmosphere, conserving biodiversity, preventing landslides, purifying water, and providing recreation sites. Forest environmental services also include the regulation of the water cycle and climate, soil formation, and nutrient recycling. While forest products are widely known, importance of forest services is often not well recognized. However, it becomes important to evaluate these environmental services, so that decisions for forest land use are based on the true worth of forests.



Noise-free NOAA color composite image of the world in early October 2000, created by Vegetation Index (NDVI), and surface temperature (Green color: dense leaves, Pinkish color: no leaves, and white color: snow and ice)

FOREST SITUATION IN THE WORLD

Forests are the most productive terrestrial ecosystems, which makes them attractive for climate change mitigation. Forests cover a total of 40 Mkm^2 (about 30% of all land in Earth) with 42% in the tropics, 25% in the temperate, and 33% in the boreal zone. Changes in vegetation cover affect surface energy and water balances at the regional scale, from boreal to tropical forests. In every region, fire causes big problems, changing vegetation covers and emitting gases to the atmosphere. The densities of CO_2, methane and N_2O in the atmosphere have been increasing since 1970s. Main sources of CO_2 increment are considered to be the use of fossil fuel (two thirds) and land use changes including deforestation (one third). Accurate assessment of trends in forest carbon balance requires long-term monitoring of many replicate plots or very large plots. For assessing the global land-atmosphere flux, a modeling study is also required, because observation sites for ecosystem carbon fluxes are too sparse and forest ecosystems are too heterogeneous to assess the global net flux with sufficient accuracy.

Tropical forests

Tropical forests

During the past two decades, the CO_2 flux caused by land use changes has been dominated by tropical deforestation. Tropical lands are found to be either carbon neutral or sink regions, despite widespread deforestation. This implies carbon uptake by undisturbed tropical ecosystems. However, forest clearing is a large contributor to the land use change component of the atmospheric CO_2 budget. Extreme events can cause mass mortality of individuals and contribute significantly to determining structures in ecosystems.

Drought plays an important role in forest dynamics and causes big forest fires. An example occurred during the 1997 to 1998 El Nino event, when large fires in the Southeast Asia are estimated to have released 0.8 to 2.6 GtC. Fire frequency and intensity are critical to climate change and land use. A shift from tropical rainforest to savannah would result in a net flux of carbon from the land surface to the atmosphere. The future evolution of the CO_2 budget in forest land is, therefore, of critical importance.

Temperate forests

Although the temperate forest area is smaller than the two other regions, forests are expanding and play as sinks for CO_2. According to the Forest Resource Assessment 2005 of the Food and Agriculture Organization of the United Nations, China is the leading country in forest plantation over the last decade. Many modeling studies have demonstrated that land cover changes have local and regional climate impacts on temperature and precipitation changes. However, current literature cited in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) has large discrepancies in conclusions. For example, Snyder et al. found that removal of northern temperate forests gave a summer warming of 1.3°C and a reduction in precipitation of 1.5 mm/day. Conversely, Oleson et al. reported that removal of temperate forests in the USA would cool summer temperatures by 0.4 to 1.5° C and probably increase precipitation, depending on the model and prescription of vegetation. The discrepancy between these two studies was caused by different assumptions.

Boreal forests

The spatial impact of insect damage is significant comparing to fire in some ecosystems, especially in boreal forests. Spruce bud worm (SBW), for example, defoliated over 20 times the area burned in eastern Ontario between 1941 and 1996. Models indicate increased boreal forest reduces the effects of snow albedo and causes regional warming. The IPCC AR4 pointed out that migration of boreal forest northward into tundra would initially lead to an increase in carbon storage in the ecosystem due to the larger biomass of trees compared to that of herbs and shrubs. However, over a longer time (e.g., centuries), changes in soil carbon would need to be considered to determine the net effect.

KYOTO PROTOCOL

Role of forest for Kyoto Protocol

The UN Framework Convention on Climate Change was adopted in 1992 to address global warming. The 3rd session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP3) was held in Kyoto in 1997. The Kyoto Protocol was adopted there. The Protocol stipulates that 38 countries will reduce their greenhouse gases, including CO_2, to total emissions 5.2% below the 1990 level during a period from 2008 to 2012. For example, reduction below 1990 levels of 8% is required for the EU, 7% for the U.S., 6% for Japan, and 0% for Russia.

The Japanese government decided the General Principles to cope with global warming in June 1998. According to these General Principles, energy-derived CO_2 emissions control is to be 0%, the emissions control of methane, etc., is to be –0.5%, reduction through technical innovation, etc., is to be –2.0%, reduction by forest sinks is to be –3.7%, the emissions control of chlorofluorocarbon substitutes, etc., to be +2%, and the use of the Kyoto mechanisms is to be –1.8%, which will be a total of –6%. Because the reduction by forest sinks is set to be –3.7% out of the total -6.0%, more than 60% of reduction of CO_2 is expected from the forest sector in Japan.

Japanese forest management for Kyoto Protocol

Forest area is about 24.8 million ha, which is 67% of the total land area in Japan. Considerable parts of forests, about 10 million ha, have been planted since 1950s. However, 80% of planted forest are immature and require adequate care, such as pruning, weeding, thinning, etc. In the Kyoto Protocol, the national target for forest carbon sink is 13Mt-C (47Mt-CO_2). At the first commitment period, 'Forest Management' under Kyoto Protocol article 3.4 was defined as follows: *'Forest management' is a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological, economic and social functions of the forest in a sustainable manner.* Considering the concept of that definition, Japan enhances forest management practices focusing on sustainability of forest productivity as well as multiple function of forest. The Forest Management concept in IPCC AR4 is as follows: *"In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fiber or energy from the forest, will generate the largest sustained mitigation benefit."* Related to these activities, the Forestry Agency developed the forest management information system which introduced various types of GIS data. The system is composed of orthophotos with 1m resolution in 1990, ortho-images of SPOT satellite with 2.5m resolution, Landsat images with 28.5m resolution, forest boundary maps, field sampling data, elevation data as well as forest inventory records. Land cover changes were interpreted at every 500m of all over the country and the Japan National Forest Inventory System with 4km grid is also combined with this system. Japan adopts the stock change method to evaluate the carbon fixation in forest during the five years of the Kyoto Protocol, which was just started last April (2008-2012).

REDD for Post Kyoto Protocol

Just before the Kyoto Protocol started in 2008, the COP13 was held in Indonesia. One of the main discussion targets was emission reduction from deforestation and forest degradation (REDD). It aims to strengthen stopping deforestation rather than promoting plantation because very few projects are accepted as Clean Development Mechanism (CDM) plantation in the Kyoto Protocol although the concept of the CDM plantation was accepted. Furthermore, it is considered that to stop deforestation is much easier and more effective than plantation. The Center of International Forest Research organized the meeting. Here, I introduced two statements of the summaries as follows:

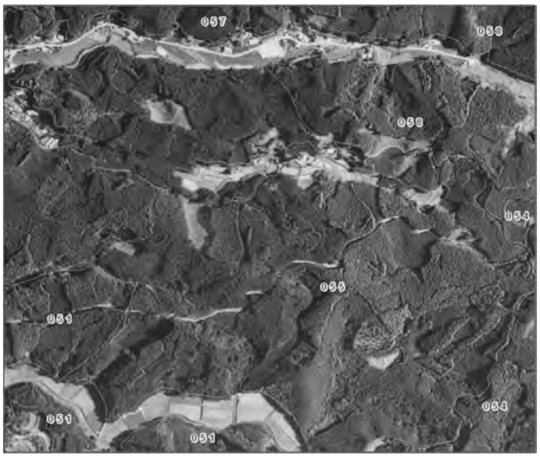
1. We need better data on forest degradation and better methods for monitoring change in carbon stocks overall, particularly with respect to forest degradation and peat lands.
2. We need new methods for assessing the vulnerability of forest ecosystems to climate variability and change.

We are requested to submit appropriate methodologies to make REDD effective in the post Kyoto Protocol world. Many researchers of forest remote sensing sector are focusing their activities on these REDD issues.

CONCLUSION

Forest provides the land for human beings to settle and develop cities. People cut the trees around the city and use woods and non-timber products for their consumption. Forests could play as generous donors for selfish people until the global environment issues arise in the world. Many forests are now under the impact of global environment changes. How can we return the favor to the forest ecosystem?

**** ICUS Professor***



Orthophoto with 1m resolution used as the base data of Forest Information in Japan for the Kyoto Protocol

Towards more earthquake resilient built environment in the aftermath of the 2008 Sichuan Earthquake

On May 12, 2008, a Mw7.9 earthquake hit the Sichuan Province in China causing almost 90,000 fatalities and missing, more than 350,000 injured, and leaving almost 5 million people homeless. First of all, I would like to hereby express our condolences to the affected people. The earthquake focal depth was less than 10km and the fault plane area estimated was approximately 300 by 30 kilometers. As a result, a huge region is supposed to have been subjected to Japanese Meteorological Agency Intensities 6+ or more although information in this respect is still limited.

Building damage was widespread. Mass media promptly pointed out that design and construction problems and corruption were to blame for such huge damage. Although I have no information on these factors, it is important to recognize that the intensity of the shaking was so strong that even buildings constructed following the Chinese Seismic Design Code experienced damage and failure.

Soon after the Sichuan Earthquake, the Central Disaster Management Council, Japanese Government, released the estimate of damage expected in case inland earthquakes occur under Osaka and Nagoya Plains. These events are expected to be magnitude 7.6, with an energy release equivalent to about one fourth of that of Sichuan Earthquake. The numbers are somber: 42,000 people would die due to shake and fires, 560,000 structures would collapse due to the shake, and some 400,000 structures more would be lost by other effects including fires. This points out that Japan too, will face a huge catastrophe if a strong earthquake hits under a heavily populated region.

Devastating damage caused by the 2008 Sichuan Earthquake (Photo courtesy of Prof. K. Konagai)

House model retrofitted with PP-band mesh in Kashmir area

Japanese academic societies and their Chinese counterparts are discussing ways to collaborate for the reconstruction of the earthquake affected areas and several cooperation projects have started. In my research group, we have been working on a technique for retrofitting existing low earthquake resistant adobe/masonry houses which can also be used for new constructions. I believe that it can be very useful for the reconstruction. With this technique, adobe/masonry walls are wrapped on both sides with Polypropylene (PP-band) meshes which are then attached with passing through wire connectors. These bands are commonly used for packing and are inexpensive, durable, strong, and world-wide available. After the meshes are installed, the walls are plastered with mud or mortar, in case of adobe or masonry, respectively.

After the 2005 Kashmir Earthquake, a PP-band retrofitted house model was constructed to demonstrate the people in Muzaffarabad, one of the severest hit cities. A workshop to explain basic earthquake engineering and how to make houses stronger by PP-band meshes was carried out. During the workshop, two 1/6 model houses, one retrofitted and the other not, were shaken. Participants, which included government officials, practitioners, decision makers, researchers, NGO/NPO leaders and personnel, funding agencies personnel, mass media, and the general public, were greatly impressed by the improved performance.

Together with the previous initiative, the research group led by Prof. Mikiko Ishikawa, The University of Tokyo, has proposed to the local government of Dujiangyan a basic plan for the restoration of their city. I worked with Prof. Ishikawa on this project as a member of her group.

(By K. Meguro)

ICUS visited PARI

ICUS members visited the Life Cycle Management (LCM) Research Center, Port and Airport Research Institute (PARI) which is located near Yokohama on August 20, 2008. In 2006, LCM-PARI and ICUS exchanged a Memorandum of Understanding. In November 2007, Dr. Hiroshi Yokota, LCM center director, became ICUS Visiting Professor.

PARI's main goals are to facilitate the smooth and efficient construction of ports and airports and researching, developing, and improving technologies for constructing ports and airports in Japan. PARI (http://www.pari.go.jp) has four departments: Research Planning and Administration Department, Marine Environment and Engineering Department, Geotechnical and Structural Engineering Department, and Construction and Control Systems Department, and thee centers: Airport Research Center, Tsunami Research Center and LCM Research Center.

Six facilities with advanced and unique technologies were visited: Large Hydro-Geo Flume (LHGF), Intertidal flat experimental facility, Intelligent wave basin for maritime environment, Unmanned underwater working system, Underwater 3D Shake Table, and Large Scale Structure Testing Facility. Partnership between ICUS and PARI was reinforced through this visit.

(By T. Endo)

ICUS members visiting PARI

RC-62 held meeting

The Research Committee 62 (RC-62), "Technologies for Evaluation of Aging Infrastructure Performance Degradation," held its second and third meetings on July 17 and August 21, 2008. Self-introductions were given by members continuing those of the first meeting. In these two meetings, Mr. Sugiyama (Chuo Kaihatsu Corporation), Mr. Hida (K & T Consultant), Mr. Yanase (Just Co., Ltd.), Mr. Sato and Mr. Hamada (Toa Corporation), Mr. Gomi (Nissan Rinkai Construction Co., Ltd.), Dr. Endo (ICUS), Mr. Fukuura (Taisei Corporation), Mr. Sugano (Tanekaka Civil Engineering & Construction Co., Ltd.), Mr. Shimizu (CTI Engineering Co., Ltd.), Mr. Tsunekuni (Tokyo Electric Power Services Co., Ltd.) and Mr. Ito (Tokyu Construction) introduced themselves and their research interests. Self-introductions of all members were finished. The activities of working groups are scheduled to begin this October.


Meeting snapshot

(By Y. Kato)

RNUS Activities

RNUS visited Bangladesh for seismic vulnerability and risk assessment project

The RNUS/AIT team comprised of Prof. Fumio Yamazaki, from Chiba University, Dr. Pennung Warnitchai and Dr. Kawin Worakanchana visited Dhaka and Chittagong from June 29 to July 2, 2008. The main objectives of this trip were to investigate project progress, conduct visual inspection for building and lifeline system, and provide recommendations for lifeline assessment methodology as part of the RNUS project "Seismic vulnerability and risk assessment of Dhaka, Chittagong and Sylhet city corporation area."


RNUS/AIT team visited

On the first two days, the team joined the meeting held by the Asian Disaster Preparedness Center (ADPC) team, project counterpart in Dhaka, to discuss and learn about the project progress on building and lifeline system assessment, identification of dynamic behavior of buildings, quality control of survey, etc. The team also visited Prof. Jamilur Reza Choudhury, Marco Corsi and A.S.M. Maksud Kamal, members of the Technical Advisory Group of the project at Brac University and Disaster Management and Relief Bhaban, respectively, to discuss the project methodology.

On July 1, the team departed to Chittagong to meet Prof. Md. Jahangir Alam at Chittagong University of Engineering and Technology to learn about the progress of the building and lifeline inventory survey in Chittagong. Then, the team went to the field for investigating the accuracy of the collected building inventory. On July 2, the team visited the Water Supply and Sewerage Authority in Chittagong to interview, investigate and obtain the available potable water lifeline data.

RNUS held seminar

RNUS held a seminar which dealt with topics of "Remote Sensing" and "Urban Public Transport" on Sept. 16, 2008. In this seminar, three invited Japanese professors delivered special lectures:

- "Observation of environmental conditions of land cover in the Mekong River Basin based on Remote Sensing and field data" by Prof. Haruo Sawada (ICUS)
- "Bus Rapid Transit and Transit Oriented Development in the context of developing countries' urban transport" by Prof. Fumihiko Nakamura, Yokohama National University
- "Urban public transport development and environment" by Dr. Toshiyuki Okamura, Yokohama National University

A couple of dozens of students and staffs from the remote sensing and the transportation engineering field joined, and they had lively discussions after the presentations.

(By S. Tanaka and K. Worakanchana)

RC-58 members report their activities

In the framework of the Research Committee 58 activities, the working group WG-1b is studying district continuity plans (DCP) in case of a disaster. WG1b invited Mr. S. Mori, Secretariat of Tokyo Central Station Commuter Corps and had a discussion on a suitable DCPs on August 6.

The activity of Tokyo Central Station Commuter Corps is a good example related to DCP. In case of the Tokyo Inland Earthquake, many terminal stations are expected to fill with the refugees who can not return home due to the traffic disruption and congestion. Tokyo central station is one of these terminal stations.


Overview of Tokyo station and its vicinities

Commuter Corps was established in 2002 by companies in the area surrounding Tokyo central station in order to provide support for numerous refugees in case of Tokyo Inland Earthquake. It was authorized by Chiyoda Ward, Tokyo in 2004. As of August 2006, 63 member companies engage in activities.

(By M. Ohara)

Joint Student Seminar on Civil Infrastructure

The Joint Student Seminar on Civil Infrastructure was held at the Asian Institute of Technology in Bangkok, Thailand, on July 3 and 4, 2008. This seminar provided an opportunity for students from Japanese, Korean, and Thai universities to gather and share their research work. A wide variety of research topics was covered, from soil engineering and disaster mitigation to concrete engineering and traffic management. Five students from the University of Tokyo and one from the Tokyo Institute of Technology attended (from left to right in the photo): Naoki Sorimachi (Meguro Lab), Tomoya Kawasaki (Tokyo Institute of Technology), Hiroaki Ebizuka (Kuwano Lab), Michael Henry (Y. Kato Lab), Hiroaki Nishiuchi (Kuwahara Lab), and Yusuke Matsumura (Takeuchi Lab).

Guest professor and student presentations were given on the first day. On the second day, seminar participants visited the city air terminal and airport rail link construction site, an elevated light-rail project with service from the international airport to downtown Bangkok. The project manager gave a presentation about the construction methodology before giving a tour inside the city air terminal, which is under construction.

Student seminar participants during visit to construction site in Bangkok

Overall, the seminar was a chance for the students to meet and exchange ideas with people of different backgrounds and cultures. Some of the Japanese students presented for the first time outside of Japan, so it was a good chance to improve English communication as well as presentation skills. In addition, the construction site visit demonstrated the large difference in construction styles between different countries.

I would like to thank the International Center for Urban Safety (ICUS) for providing this opportunity for us to travel abroad and share the research work being conducted at the University of Tokyo with other people.

(By M. Henry, Kato Laboratory member)

BNUS Activities

Roundtable meeting was held

A roundtable meeting on the Establishment of the BUET-Japan Institute of Disaster Prevention and Urban Safety was held in the ITN Conference Room, at the Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka on August 23. The meeting was chaired by the honorable Vice Chancellor of BUET, Prof Dr. M. M. Shafiullah, and moderated by Prof. Ansary.

Presentations on the overview of the establishment of the institute by Dr. Raquib Ahsan, Associate Professor, Dept. of Civil Engineering, BUET, and on the proposed building structure based on the utilities and equipments required by Dr. K. Shabbir Ahmed, Professor, Dept. of Architecture, BUET, were given. After these presentations, opinions of stakeholders on the need and usability of such an institute in BUET and suggestions of stakeholders on the finalization of a mutual Memorandum of Understanding (MoU) were exchanged.

Members from several relevant institutions participated in the meeting. All agreed that this institute is a demand at this time and will be very fruitful as a link between academicians and professionals. They also agreed that BUET has the credibility and achievements to establish it.

Earthquake vulnerability reduction for urban areas

This research aims to analyze the issues related to physical urban vulnerability, particularly in Chittagong city, to arrive at strategies or policy based solutions that are necessary to support the redevelopment of urban areas, in Chittagong and Bangladesh, and how hazard motivated land use planning reduce earthquake risk.

Risk assessment analysis has been done at Nondon Kanon area. An alternative design solution is proposed showing the possibilities of earthquake vulnerability reduction and also rethinking the concept of Floor Area Ratio. Along with other supportive suggestions this exercise ends with designing earthquake resistant public facilitate buildings (schools), which may be used as a post disaster shelters .

Vulnerability of Nondon Kanon area evaluated with RADIUS

Prof. Abdul Jabbar Khan delivering his lecture

Lecture was held

BNUS organized a lecture on Raincut Erosion Control in Chittagong Hilly Areas on August 28, 2008, at ITN Conference Room of the Civil Engineering Building, BUET, Dhaka. Prof. Abdul Jabbar Khan from the Dept. of Civil Engineering, BUET delivered a lecture on the application of Geojute – a special type of woven type open mesh jute geotextiles, for protection against raincut erosion of hilly areas. After the presentation a roundtable meeting was held. The assistants appreciated the efforts and initiatives taken for examining the applicability of geojute.

(By M. Ansary)

Delegation from UN-ESCAP visited ICUS

On July 24, 2008, ICUS welcomed three guests from United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP) located in Bangkok, Thailand. Prof. Meguro, ICUS director, and Dr. Wataru Takeuchi discussed disaster related issues with Dr. Xuan Zengpei, Director of Trade and Investment Division, UN-ESCAP, and his Japanese colleagues, Mr. Takao Akutsu and Ms. Atsuko Okuda. They were very interested in ICUS activities, especially a low-cost building retrofitting technology using plastic bands, a 3D-GIS-visualization system and a manual to support safe evacuation. Low cost technologies and knowledge transfer are key points in disaster relevant issues over Asia-Pacific countries, which are under the responsibility of UN-ESCAP. Prof. Meguro delivered an hour presentation and it was followed by another hour discussion. At the end, it was concluded that ways to carry out collaboration work between UN-ESCAP and ICUS, through RNUS office in AIT, should be sought.

(By W. Takeuchi)

Snapshot of the working meeting

ICUS welcomes Dr. Hong Huang

We would like to welcome warmly Dr. Hong Huang as Associate Professor of ICUS from August 1, 2008.

He graduated from the Department of Chemical Engineering, Zhejiang University, China, in 1994 and obtained his Doctor of Engineering Degree in September 2000 from the Department of Chemical System Engineering, The University of Tokyo.

Dr. Huang's research focuses on various aspects related to urban safety and environmental issues. Based on numerical simulations, experiments and field measurements, his studies are designed to simulate, explain and design the air, thermal, and wind environment as well as fire safety over multi-spatial and multi-temporal axes from human scale, indoor, outdoor to meso-scale. His final goal is contributing to planning safety strategies and ensuring a safe and sustainable society.

Dr. Hong Huang

(By K. Meguro)

ICUS Activities

- *Prof. Meguro visited Dhaka, Bangladesh from Aug. 26 to 28 to discuss the future of BNUS with Prof. M. Ansary and to meet with Dr. Maksud at the Asian Disaster Preparedness Center.*
- *Prof. Sawada traveled to Beijing, China from July 6 to 11 to make a presentation on the "Seasonal Changes of Forest Environment in the Mekong Rive Basin" at the International Convention Center.*
- *Prof. Sawada stayed in Bangkok from Sept 15 to 19. During his visit, he held primary meetings on collaboration at the Survey Engineering Department of Chulalonkorn University, the Faculty of Forestry of Kasetsart University and the Geographic Information and Space Technology Development Agency. He also participated in an RNUS organized seminar and made a presentation on "Observation of Environmental Conditions of Land Cover"*
- *Dr. Kuwano traveled to Atlanta, US, from Sept. 21 to 26 to attend the 4th International Symposium on Deformation Characteristics of Geomaterials.*
- *Dr. Tanaka stayed at AIT for his research work and teaching duties at RNUS from July 2 to 20, Aug. 18 to 28, and Sept. 11 to 19.*
- *Dr. Tanaka attended the Intelligent Transport Systems Asia-Pacific Forum which was held in Singapore from July 14 to 18.*
- *Dr. Takeuchi visited the Asian Institute of Technology from Aug. 4 to 9 to hold meetings with personnel there. He also visited AIT from Sept. 15 to 23 to participate in an RNUS sponsored seminar.*
- *Dr. Kawin stayed at AIT for his research work and teaching duties at RNUS from June 28 to July 25 and Aug. 18 to Sept. 9.*
- *Dr. Kawin visited Dhaka, Bangladesh from Aug. 25 to 31 for a preliminary survey and training of the Asian Disaster Preparedness Center team in Dhaka for developing the lifeline inventory.*
- *The Joint Student Seminar on Civil Infrastructure was held at the Asian Institute of Technology in Bangkok, Thailand, on July 3 and 4.*
- *RC-62 held general meetings on July 17 and Aug. 21.*
- *ICUS members visit the Port and Airport Research Institute on Aug. 20.*
- *Prof. Meguro and Dr. Ohara participated in the preparation and execution of a disaster drill was held at The University of Tokyo Hospital on Sept. 9. Other ICUS members also participated in the drill.*
- *RC-58 held general meetings on Sept. 29. During this meeting, each working group reported their activities. After this, Mr. Hajime Kagiya, Itabashi District Section Manager, made a presentation on business continuity plans for local governments.*

Awards

- *Mr. Michael Ward Henry, from Kato laboratory, received the encouragement award from the Japan Concrete Institute on July 11 for his research "Evaluation of re-curing for the recovery of high-strength mortar exposed to fire."*

Editor's Note

Urban safety is often threatened by huge cyclones, typhoons, earthquakes, and so on. In addition to these natural disasters, as introduced in the main article of this volume, global warming is another aspect relating to urban safety even if it is an environmental problem. For example, we fear that the global warming will have a great impact on the intensity of environmental actions to infrastructure. Cyclones and typhoons may be strengthened due to global warming. Also, sea level rise will affect the functions of infrastructure along coast lines.

Because CO_2 emissions from human activities are considered the largest factor affecting global warming, all of us have to take actions to reduce emissions. This includes preserving forest. As Professor Sawada mentioned, finding ways to build a sufficient forest ecosystem is eagerly required. As you find in this volume of the newsletter, the ICUS has carried out lots of collaborative activities with overseas countries. In particular, countries in the Asian temperate and tropical zones will be greatly affected by the global warming. We wish to contribute more to those countries to ensure the safety of people living there.

Dr. Paola Mayorca has served many years as one of our editorial staff of the Newsletter. This Newsletter may be the last issue edited by her because she will start her new life in Norway in this coming November. We would like to extend our sincere appreciation to her great efforts and contributions.

(By H. Yokota)

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp

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APPLICATION OF COMPUTATIONAL FLUID DYNAMICS ON THE PREDICTION OF URBAN FIRE SAFETY AND URBAN THERMAL ENVIRONMENT

By

*Hong Huang**

In recent years, urban safety and urban environment are gaining increasing attention for sustainable urban design. Computation Fluid Dynamics (CFD) models have been indispensable and effective tools for studying urban fire safety and urban thermal environment. Here, it is shown how a CFD model is applied to predict urban fire and its spread in a modeled urban area by coupling the model with combustion, radiation and firebrand scattering mechanism models. Urban thermal environment is then predicted by a developed numerical simulation program with adaptability to complex urban areas.

Simulation of fire in a room using CFD model

Urban thermal environment analysis using CFD coupling with radiation model

Urban problems, such as, urban safety, urban heat island and urban air pollution is becoming more and more serious due to the progresses of mega cities. The revolutionary progress in Computational Fluid Dynamics (CFD) modeling makes it possible to model urban boundary layer problems. The figures in the right show some CFD numerical simulation examples. In this article, it is shown how a CFD model can be effectively applied in studying urban fire safety and urban thermal environment. The model can predict urban fire and its spread (scattering of firebrands) by integrating relevant processes of turbulent combustion, radiation and firebrand scattering in a simulated urban area. To analyze urban thermal environment, a numerical simulation methodology with adaptability to complex urban areas is developed. The methodology takes into account the convection, radiation and conduction processes in the area under investigation.

APPLICATION ON URBAN FIRE SAFETY

The factors that can cause urban fire spread are contact fire, radiation, convection and firebrands. From investigation of past urban fires, fire spread often occurred by fire-brands, especially in case of fires that cause extensive damage. However, there are few findings on the properties and mechanisms of firebrands because there are many uncertain factors, such as meteorological conditions, combustion conditions in the building that is on fire, types of building materials, and so on. In this article, for effective prediction of urban fire and firebrand scattering, the CFD model is suitably coupled with turbulent combustion model, radiation model and firebrand scattering model.

Model description

Both the density and the temperature in the fire plume fluctuate widely. Therefore, the assumption of an incompressible fluid (Boussinesq approx.) does not hold, and the plume must be considered as a compressible fluid. Thus, the Favre-averaged process is introduced here for all the transport equations. A modified k-ε model for compressible reciprocating engine flow is used. A fire model is required to close the governing equations. One of the common methods is to replace the fire region by a volumetric heat source (or sometimes heat flux). However, a combustion model that accounts for the chemical reactions between fuel and oxygen must be included to describe the actual fire more closely. Therefore, combustion in the gaseous phase is modeled using the eddy dissipation combustion model here, which is widely used in fire modeling. The chemical reaction rate is proportional to the turbulence eddy decay rate and minimum concentration of the fuel or oxygen.

Radiation plays an important role in the combustion process. It is solved here in parallel with the governing equations. The discrete transfer method is used to provide the radiation source term for the energy equation of the gas phase and the radiation flux to the solid surface.

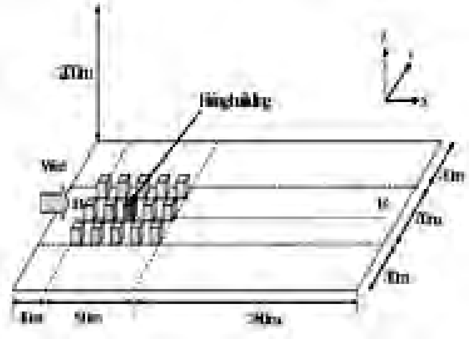
In reality, it is not feasible to model all the physical processes of firebrand scattering at one time due to its complexity. Here the processes are modeled as follows. The behavior of firebrands in the airflow can be considered to obey an air-solid two-phase flow. Therefore, the scattering of firebrands can be presented by the Lagrangian transport equation.

Firebrands have various complex shapes (spherical, cylindrical and board shape, etc.), and it is very difficult to evaluate the drag force for all shapes. Here, firebrands are assumed to be spherical and the diameter used in the Lagrange equation is represented by the Stokes diameter of the firebrands. Firebrands are collected from a fire wind tunnel experiment and their Stokes diameters are determined from their densities and the terminal velocities.

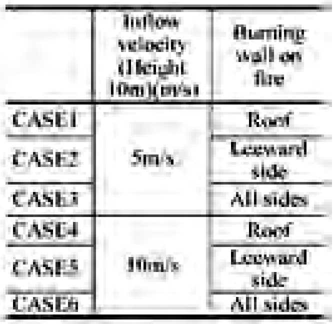
Real urban scale fire simulation

An urban fire simulation in a modeled urban area has been conducted. Figure below shows the calculation area which is X×Y×Z = 510 m × 110 m × 200 m. The size of each building is set to be 10 m × 10 m × 10 m, and the building interval is also set to be 10m. There are fifteen buildings (5×3) and the building on fire is shown. The flow rate of the combustible gas is controlled from the burning face to get a heat release of 1.6 MW/m^2. The inflow wind velocity is assumed as 5.0m/s and 10.0m/s at 10 m height. based on the investigation of Wakayama Shirahama Spa Fire which occurred in 1998. The wind profile is given according to 1/4 profile for urban area. The Stokes diameters of the firebrands are set to be 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7 cm, which are generated at the same generation ratio from firing building. The simulation cases are shown in table below.

Analysis Domain



Simulation cases



	Inflow velocity (Height 10m)(m/s)	Burning wall on fire
CASE1	5m/s	Roof
CASE2		Leeward side
CASE3		All sides
CASE4	10m/s	Roof
CASE5		Leeward side
CASE6		All sides

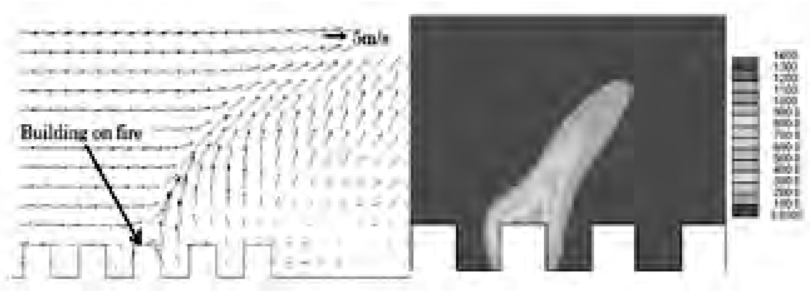
Examples of vertical wind distribution and temperature distribution in the center section (section B-B') are shown. The thermal plume is strongest for the all burning cases, the one of roof fire is stronger than that of sidewall fire. The influence on the sky is little for sidewall fire, though strong rising flow is seen between the buildings. When the inflow wind velocity is higher, the thermal plume is suppressed and greatly inclines to the leeward side, which increases the risk of the fire spread to the neighboring buildings.

The examples of the firebrands scattering results are shown in the figure (see next page). The results show that firebrands can influence a wide area in each case, all kinds of firebrands scatter over 100 m due to the rising flow. The firebrands with diameter of 0.2 cm can scatter 400 m or more. Comparing with Case 3 (inflow wind velocity 5 m/s), the scattering distances increase for Case 6 (inflow wind at 10 m/s). This is because, though the rising flow in Case 6 is a little weaker, the firebrands are raised to the sky by rising flow and then follow the wind in the sky which is stronger in Case 6.

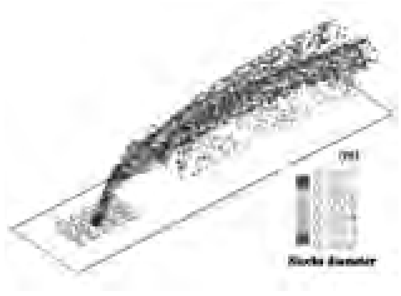
APPLICATION ON URBAN THERMAL ENVIRONMENT

Urban thermal environment simulation method

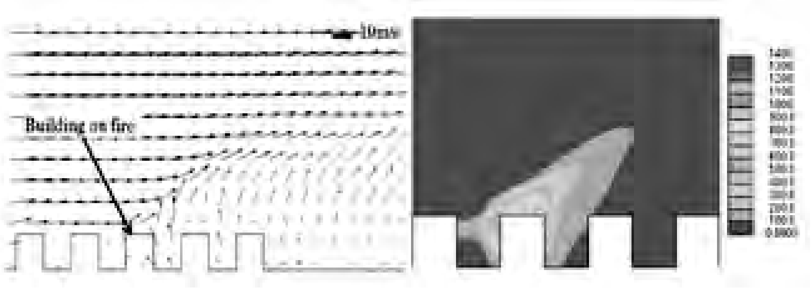
The urban thermal environment numerical simulation is based on a



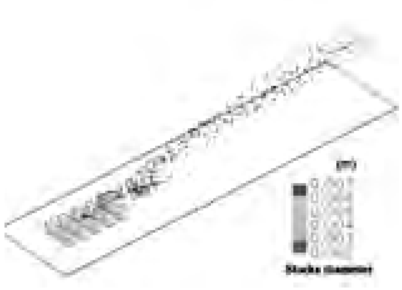
Case 3 (Burning face: all sides)
Vertical wind & temperature distribution
(Section B-B', Inflow wind velocity: 5 m/s)



Case 3
Firebrand trajectories



Case 6 (Burning face: all sides)
Vertical wind & temperature distribution
(Section B-B', Inflow wind velocity: 10 m/s)

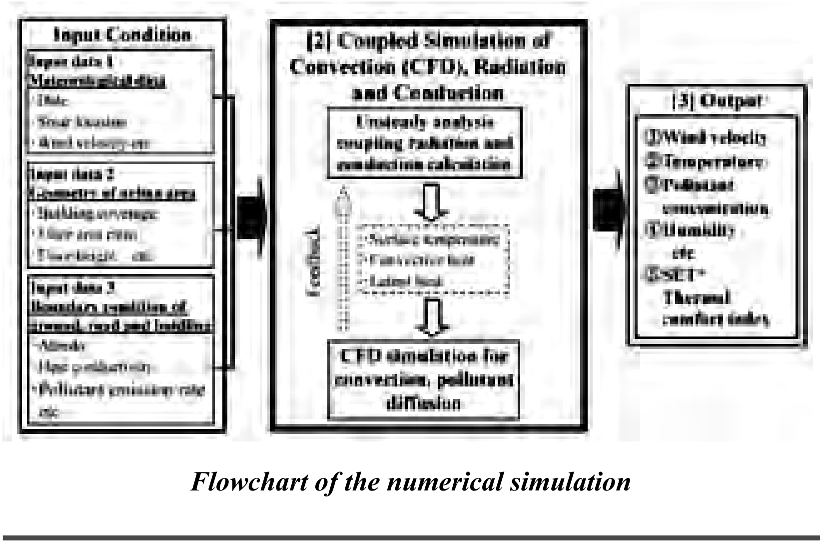


Case 6
Firebrand trajectories

method coupled with three-dimensional CFD analysis, three-dimensional radiation analysis, and one-dimensional heat conduction analysis. Figure below shows the flowchart for this numerical simulation. First, boundary conditions are set up from various input conditions. Second, a three-dimensional radiation calculation is performed. Then, temperature distribution inside the ground or wall is calculated by solving an unsteady one-dimensional heat conduction equation. Three-dimensional coupled convection and water vapor transportation calculations are performed continuously by adding new boundary conditions for the surface temperature distribution of the ground and wall, and air-conditioning heat load obtained from the radiation and conduction calculation. The coupled simulation of convection, radiation and conduction is then completed by repeating these operations in series. This numerical simulation adapts for an unstructured computational grid suitable for a complex urban area.

Real urban area simulation

The simulation object is shown in the frame enclosed by broken lines in the figure below, where the Shinjuku (Tokyo, Japan) DHC (District Heating and Cooling Systems) center (next to Shinjuku Park Tower, a 52-storey building) is located. Field measurements of out-door thermal environment were taken here on



Flowchart of the numerical simulation

Measurement and study area

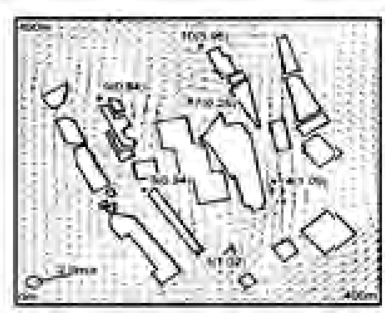
August 20-22, 2003 to investigate the influence of the heat release from the DHC center on the surrounding thermal environment. Target date and time for the analysis is August 22 on 13:00. Figure below shows the simulation results for the horizontal distribution of wind velocity and measurement results at a height of 1.5 m. As an overall tendency, the simulation results show good agreement with the measurements. The velocity of the wind decreases close to the building, and a vortex is formed on the north side of the Shinjuku Park Tower (around measurement point 7). The vertical distribution in section A-A' (refer to figure 'Measurement and study area') is shown. It shows that a strong rising flow is formed by the influence of upward exhaust from the cooling tower. It implies that the heat and vapor released from the DHC system are blown upwards into the sky.

The horizontal distributions of temperature and absolute humidity at a height of 1.5 m are shown. It can be seen that the temperatures are higher around measurement points close to buildings and places where the wind velocity is weak. We can see that the measured results and the simulation results are in good agreement. The vertical distribution at section A-A' is shown. It can be seen that temperature stratification occurs around the buildings and the ground due to heat flux from the buildings and the ground in vertical direction. It is also thought that there is little influence on the thermal environment at the pedestrian level because the heat and vapor are expelled from the cooling tower high up into the sky. This agrees with the measured result that there is little difference between the temperature and humidity on the windward and leeward sides of the area.

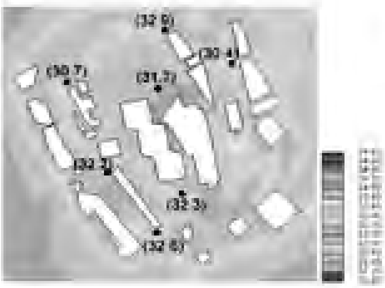
CONCLUSION

In this research, in order to investigate the urban fire safety and urban thermal environment, CFD modeling has been applied. To predict urban fire and scattering of firebrands in a modeled urban area, the CFD model was coupled to turbulent combustion model, radiation model and firebrand scattering model. The results show that when the inflow wind velocity was comparatively slow, the size of the thermal plume became significant, and when the inflow wind velocity was high, the thermal plume was suppressed and greatly inclined to the leeward side, which increased the risk of fire spread to neighboring buildings. The firebrand could scatter over a wide area of more than 400m. In order to simulate the thermal environment, we developed a numerical simulation program which could be adapted to complex urban areas and coupled with convection, radiation and conduction processes. Applicability of the program was tested in a real urban area. Comparison of the measured and simulated results for temperature, humidity and wind velocity confirmed the effectiveness of the tool for assessing complex urban thermal environment.

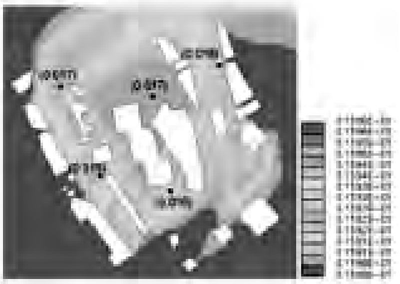
ICUS Associate professor



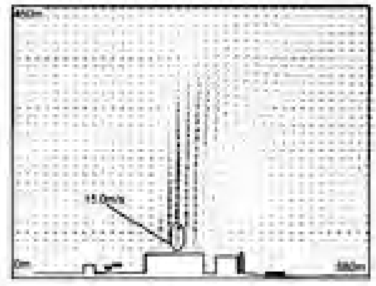
Horizontal wind distribution (m/s) (at 1.5 m height)
( ) : measured wind velocity



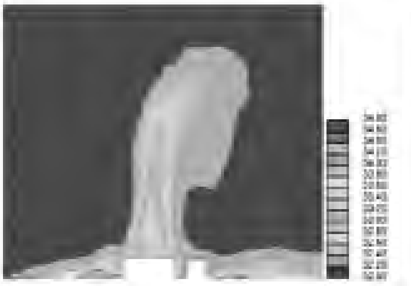
Horizontal temperature distribution (˚C)(at 1.5 m height)
( ) : measured temperature



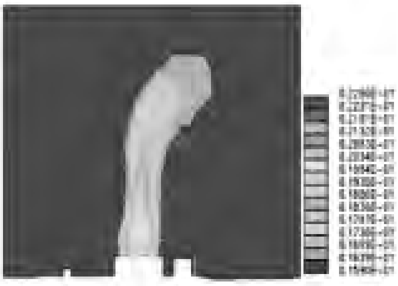
Horizontal absolute humidity distribution (kg / kg of dry air)
(at 1.5 m Height)
( ) : measured absolute humidity



Vertical wind distribution in A-A'section (m/s)



Vertical temperature distribution in A-A'section (˚C)



Vertical absolute humidity distribution in A-A'section (kg/kg of dry air)

Research Committee 62 (RC62) held meeting

Research Committee 62 (RC-62), "Technologies for Evaluation of Aging Infrastructure Performance Degradation" held its forth meeting on December 2, 2008. In order to evaluate present and future performance of infrastructure, knowledge from two or more specialized fields, such as material science, structural engineering, geotechnical engineering, and so forth is necessary. Although these studies have been performed separately in each field, an appropriate methodology for combining these results has not yet been developed. ICUS has established RC-62 in order to consider this problem, and regular meetings have been held with the member companies from various specialized fields in civil engineering in order to build relationships and allow for joint action.

Two working groups (WG) were lunched under this committee and the target of each WG is structure (WG-1) and ground (WG-2), respectively. Moreover, WG-1 is composed of 3 sub-WGs, namely, evaluation of structural performance (SWG-1), sensing technologies (SWG-2) and integration of ground and structure (SWG-3). In this meeting, action plans of each WG and SWG were introduced and discussed. State-of-the-art report of each field will be published for the next year's activity. After the WG reports, an invited speaker, Prof. F. Katsuki, delivered the lecture "Structural Health Monitoring for Concrete Structures". Prof. Katsuki is a Professor of Shibaura Institute of Technology and an authority of sensing technologies for evaluating the performance of existing concrete structures. He presented the research outcomes of the subcommittee on structural health monitoring for concrete structures under the JSCE (Japan Society of Civil Engineering) Concrete Committee. After his lecture, a small gathering was held in which participants exchanged ideas and questions were answered.

(By Y. Kato)

15th ICUS Open Lecture was held

The 15th ICUS Open Lecture was held on October 6, 2008, which welcomed approximately 120 participants. Lectures were focused on ports and airports in Japan and the world with the title of "Strategy for ports and airports as bases of traffic and physical distribution". We have been facing a difficult situation for port and airport improvement due to many aspects of requirement under budgetary limitations. Among them, it is particularly important to take into account international trade as well as environmental preservation and disaster mitigation. During this Open Lecture, we discussed the policies on how to ensure the functions and international standpoints during port and airport improvement, how to promote the efficiency of physical distribution at ports as a part of global warming countermeasure, and how to maintain the functions and performance of port and coastal infrastructures.

Prof. Kimiro Meguro, ICUS Director, addressed the opening of the Lecture. Brief presenter profiles of three distinguished presenters and respective titles of presentation were as follows:

Dr. Takashi Nanba, Director of Planning Division, Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT); "Reduction of environmental burdens by improving efficiency of a physical distribution system through ports".

Prof. Hiroshi Yokota, ICUS Visiting Professor and Executive Researcher at the Port and Airport Research Institute; "Infrastructure management in port and coastal areas"

Mr. Kazushige Umeyama, Deputy Director General, Kanto Regional Development Bureau, MLIT; "Extension project in the Tokyo International Airport (Haneda Airport)"

The closing remarks were delivered by Prof. Yokota. After the Lecture a convivial party was held and attended by approximately 100 participants. They actively carried out further discussion and exchange of views there.

(By H. Yokota)

Dr. T. Nanba

Prof. H. Yokota

Mr. K. Umeyama

Disaster Drill held at the University of Tokyo Hospital

Disaster drill was held at the University of Tokyo Hospital from 13:30 on September 9, 2008. ICUS is leading a joint working group (WG) on disaster management manual system for the University of Tokyo Hospital considering its role as the disaster base hospital with the University of Tokyo Hospital and the Division Environment, Health and Safety. The scenario of the drill was discussed and prepared in the WG.

In the drill, occurrence of a Tokyo Metropolitan Earthquake with magnitude of 7 was assumed. The Drill consisted of 2 parts. The first part was the training for checking the safety of patients, staffs and facilities in each ward of the hospital just after the earthquake and reporting the results to the disaster command center. The training of extinguishing fire and evacuation of severely-injured patients were also done. Based on the reports from each ward and sections, the disaster command center decided that the hospital have the capability to accommodate disaster victims transported from outside.

In order for the disaster command center to understand the capability of the hospital quickly after the disaster, the reports from each ward of the hospital to disaster command center should be done smoothly. And, the results, such as the number of injured people, should also be summarized quickly. This year, viewer system for disaster command center to check the total situation of the hospital was developed and used in the drill. Staffs in 30 wards of the hospital inputted their damage situation in spreadsheets and brought the files to the disaster command center. Each data was inputted in the database and damage situation of each ward was plotted and shown on the viewer system. Real-time data of the total damage in the hospital was shown on the system. Some of the wards failed to input the checking sheets. But most of the 30 wards succeeded in reporting to command center.

Triage drill

The second part of the drill was the training of triage and treatment for outside disaster victims. Triage is the medical activity for sorting patients according to the severity of their injuries in order to provide maximum medical treatment under the restriction of medical resources. The mimic disaster victims were sorted to be Red; Severely-injured to be treated urgently, Yellow; Moderately-injured, Green; Slightly-injured after the first and second triage. Training of first-aid treatment was also done.

Yellow: moderately injured patient

Last year, e-learning system for doctors and nurses on emergency responses in disaster base hospital was developed by Dr. M. Ohara and other WG members in order to increase their emergency response capacity. This year, the contents of the learning system was expanded and used as a preparation for the disaster drill. Advanced learning contents especially for the nurses of emergency and critical care medicine was developed. It consists of five parts explaining procedures such as how to prepare for accommodating injured people, how to do the first and second triage for injured people.

Our joint WG is working according to the three years' research plan from 2007 to 2009. In 2009, WG aims to develop a new disaster manual for hospitals based on the lessons learnt from the drill.

(By M. Ohara)

RC58 Activities

The Research Committee 58(RC-58),"Business Continuity Management (BCM) System Suitable for Japanese Society", held its third and fourth regular meetings on September 29 and November 10, 2008.

This year, RC-58 were divided into three working groups (WGs) in order to discuss the following topics: 1) WG-1a researched the ideal way of BCP (Business Continuity Plan) and BCM for the private sector companies in Japan, 2) WG-1b did the same but the target was for public sectors. 3) WG-2 researched on the ideal evaluation methodology for BCP and BCM.

At the third regular meeting, each working group gave a presentation of the interim report. At the fourth meeting, they reported their research progresses.

Besides these activities, invited speakers delivered some lectures. So far, municipality, bank, local companies and individual disaster prevention organizations have given lectures.

Based upon these activities, RC-58 members will publish a report of the current year 2008.

RC58 regular meeting snapshot

(By Y.Hiruma, Meguro lab.)

USMCA 2008 was held in Beijing, China

Experts from 13 countries delivered 77 presentations at the USMCA 2008, Beijing

Center for Public Safety Research (CPSR), Tsinghua University, Beijing, China and ICUS organized the Seventh International Symposium on New Technologies for Urban Safety of Mega Cities in Asia, USMCA 2008, in Beijing on 21-22 October, 2008. The symposium aimed to provide a forum for decision makers, practitioners and researchers to share their expertise in diverse areas for better urban safety management.

Prof. Weicheng Fan inaugurated the symposium

The two-day symposium program was arranged in four keynote sessions and ten technical sessions. Ten keynote speeches and seven plenary lectures were delivered by invited distinguished academicians and researchers from premier academic and public institutions in Asia and around the world. The symposium was inaugurated by Prof. Weicheng Fan, Director of CPSR, Tsinghua University and chairman of USMCA 2008 organizing committee. Prof. Hu Dongcheng (Vice President, Tsinghua University, China), Prof Jaehne Richard (University of Illinois, USA) and Prof. Kimiro Meguro (Director of ICUS) gave the opening speeches.

In the keynote speeches, Prof. Fan introduced the frontier research on public safety in China. Studies on Myanmar Cyclone and Sichuan Earthquake were presented by Prof. Shibayama (Yokohama National University, Japan) and Prof. M. Ishikawa (The University of Tokyo, Japan) respectively. Prof. M. Tamura (Yokohama National University, Japan) gave a speech on the industrial safety engineering. Prof. Y. Yasuoka (National Institute of Environmental Studies, Japan) presented the new technology of remote sensing application. Researches on disaster management and maintenance of structures were reported by Prof. Jaehne (University of Illinois, USA), Prof. T. Sakata (Tokai University, Japan) and Prof. T. Uomoto (Shibaura Institute of Technology, Japan). Strategy for efficient use of earthquake early warning system was introduced by Prof. Meguro.

Sixty papers were presented in technical sessions covering a wide range of issues in the areas of urban safety including: Emergency Management for Urban Disasters, Advanced Technologies for Monitoring, Assessment & Management of Urban Safety, Risk Assessment, Prediction and Early-warning of Urban Disasters, Safety Assessment of Existing Infrastructure, Environmental Impact Assessment due to Rapid Urbanization, Evacuation Management for Urban Safety, and Rehabilitation and Retrofitting of Urban Structures against Disasters.

Excellent Young Researcher Award was prepared to encourage activities of young researchers in the field of urban safety engineering. The winners of this award were: Mr. Navaratnarajah Sathiparan (The University of Tokyo, Japan), Ms. Gai Chengcheng (Tsinghua University, China), Ms. Xue Wen (Zhejiang University, China), Dr. Akiyuki Kawasaki (The University of Tokyo, Japan), Ms. Kawagoe Yuko (Waseda University, Japan).

Young researcher awardees with Prof. Meguro and Prof. Zhang

The Asia-Pacific Association for Public Safety Science and Technology was launched in this symposium to promote the interchange of the safety science and technology in the region. The chairman of the first session is Prof. Fan, the vice-chairman is Prof. Meguro.

The next symposium will be held at National Institute for Disaster Prevention in Seoul, Korea. Further information will be posted in ICUS web site soon.

(By H. Huang)

Field visit to the Haneda Airport Extension construction site

On October 28, a field visit to the construction site of D-Runway, Haneda Airport (Tokyo International Airport), was organized by Prof. Yokota and Dr. Kato. This airport, which currently has three runways, serves mostly domestic and a few international flights for the Tokyo Metropolitan area. As of 2007, the annual number of passengers was 66.8 millions, the 4th busiest in the world after Atlanta Hartsfield-Jackson, Chicago O'Hare, and London Heathrow. When the extension is completed by the fall 2010, the annual airport traffic capacity will reach 407 thousands, almost 40% more than the current 296 thousands. The facility has been designed for 100 years service life and it is specified that no major maintenance works are required in the first 30 years, although inspection is necessary. The construction, which is currently the largest on-going project in Japan, demanded an investment of US$6billion and almost 2,000 companies are involved.

The development, which mainly consists on the construction of a 2,500m-long runway and a taxi way, has several technical challenges. For instance, the layout and configuration were decided so that ship traffic in Tokyo Bay was not obstructed. The runway is a combination of reclamation works and precast slabs over pile-jacket foundation. Because part of the new runway will be located in the mouth of the Tama River, special detailing of the pile foundation was necessary to avoid affecting the river ecosystem.

Prefabricated 30m high jacket unit

The construction of the piled portion of the runway consists of three stages. First, preceding piles are driven in the seabed. Then, jacket units, as shown in the photos, are installed on top of the driven piles and they are connected with grout. Each jacket unit covers an area of 45 m x 63 m and has six piles. Finally, precast slabs are put on top of the jacket units and connected with cast-in place concrete. In the end, the slab will be one of the widest slabs in the world constructed without joints. Almost 1,200 preceding piles, 198 jacket units, 10,700 pre-stressed precast concrete slabs, and 7,000 UFC (ultra high strength fiber reinforced concrete) slabs will cover the 520,000 m^2 of the pier. To meet the design condition of no major maintenance in the first 30 years of service, a cover of titan plates for slabs and a cover of stainless steel for the splash and tidal zones of the piles and cathodic protection were specified.

Installed jacket units

The Haneda Airport extension project is one of the latest examples of how engineering overcomes the challenges of creating sustainable infrastructure for improving human life with limited impact on the environment.

(By P. Mayorca)

ICUS joined the 14th World Conference on Earthquake Engineering

Exhibition at the conference

The 14th World Conference on Earthquake Engineering was held at the Beijing Jiuhua International Conference and Exhibition Center in China from October 12 to 17.

This conference is held every four years and many researchers in the field of Earthquake Engineering gather from all over the world. More than 2,000 researchers and engineers registered and over 3,000 people attended the conference.

ICUS joined the conference as one of the 71 exhibitors. During five days, ICUS introduced its research activities by panels and monitors in its booth. Especially, PP-band retrofitting technologies for masonry structures and its promotion system were explained and videos of shaking table experiments were shown at the booth. Visual system for Urban Earthquake Risk Assessment using 3-D Micro GIS Analysis was also demonstrated at the booth. The system can show vulnerability risk ranks of each district of the Tokyo Metropolitan area in an interactive way with the 3-D urban view. Many participants visited ICUS booth and received printed materials introducing the latest research results.

(By M. Ohara)

ICUS booth at exhibition

RNUS Activities

ICUS Director joined Expert Group Meeting at UN-ESCAP, Thailand

On 19 November 2008, Prof. Meguro, Director of ICUS, gave the presentation on "Advanced technologies for total disaster management" during the Expert Group Meeting (EGM) on WSIS+5 and Emerging Issues in Asia and Pacific organized by the Information and Communications Technology and Disaster Risk Reduction Division of the United Nations Economic and Social Comission for Asia and the Pacific (UNESCAP) at the United Nations Conference Center, Bangkok, Thailand. The presentation given by Prof. Meguro was a part of the EGM to exchange knowledge and experiences among the participating experts at technical, institutional and policy level. This EGM was organized under the theme of WSIS+5 regional review, key and emerging trends in Asia and the Pacific including ICT(Information and Communication Technology) capacity building, ICT and disaster risk management, food security and ICT.

Workshop on Transportation Researches for Urban Safety

RNUS organized "Workshop on Transportation Researches for Urban Safety" at Rama Garden Hotel on December 11, 2008 under the sponsorship of ICUS. It was a one-day workshop with a total of 11 presentations. The objectives of this seminar were to share and exchange knowledge, information and opinions among transportation researchers and practitioners in order to understand critical transportation problems in Asian cities, and to find better solutions for the current problems in transportation engineering.

Participants at IIS Thailand Chapter Alumni party

The seminar started with an opening speech by Dr. S. Tanaka, Regional Network Office for Urban Safety (RNUS). It was followed by list of presentations from Prof. F. Nakamura (Yokohama National University), Prof. Y. Kumagai (Kochi Tech of University), Dr. T. Yoshii (Kyoto University), Prof. M. Kuwahara (University of Tokyo), Dr. P. Raothana-chonkun (Burapha University), Dr. P. Taneerananon (Prince of Songkla University, Thailand), Prof. T. Nakatsuji (Hokkaido University), Dr. H. Hamaoka (Akita University), Dr. R. Horiguchi (i-Transport Lab.), Dr. S. Narupiti (Chulalongkorn University) and Dr. A. Sumalee (Hong Kong Polytechnic University). A total of 57 participants in the seminar were from governmental sections, consulting companies and universities in Thailand.

IIS Thailand Chapter Alumni Party 2009

IIS (Institute of Industrial Science) Thailand chapter alumni party 2009 was held at RAMA garden hotel on 12 December 2008. Ten participants joined the party including Prof. M. Kuwahara and Dr. S. Tanaka who were rep-resentatives from IIS. During the party, there was discussion on the future of alumni activities.

(By K. Worakanchana, RNUS)

More than 50 participants joined the RNUS Workshop on December 11, 2008

BNUS Activities

BNUS Conducts Earthquake Intensity Surveys

BNUS conducted earthquake intensity survey for two earthquakes. The first survey was conducted for a small earthquake along Bangladesh-India border, on 5 July 2008 at 22:55 PM Bangladesh local time. The earthquake had a magnitude of M4.1(source: ASC-India website) and was centered at 6.4 kms WNW of Rajshahi, Bangladesh. At least 30 buildings developed cracks and a 6-storey building tilted in the division (photo below). BNUS team visited the areas around the earthquake source, Rajshahi City, Chapainawabganj, Godagari, Saroda, Baghmara, Keshore, Natore and Tanore from July 16 to 19 and 27, 2008 and conducted surveys for intensity through a pre-formatted questionnnaire to a total of 200 inhabitants of the area. From the collected data, intensities of different locations were estimated. The survey results indicate that the people living in Rajshahi and adjacent areas could feel the shaking, with shaking of light furniture, doors and windows, gentle oscillation of hanging objects were also noticed in some cases. The intensity of the quake estimated from the survey was MMI scale V at Rajshahi, Chapainawabgonj, Baghmara, Keshore and Tanore, IV at Godagari, Saroda and III at Natore.

Tilting of 6-story building in Rajshahi (5-Jul-2008 quake)

The second survey was conducted for a light earthquake (Mb4.9, ASC-India website) in northern Bangladesh, on 27 July 2008 at 00:51 Bangladesh local time. The epicenter was at ENE of Mymen-singh and it was felt in many parts of Bangladesh causing several injuries and considerable panic. Using a pre-formatted questionnaire, since July 29 to August 04, 2008, BNUS team surveyed 100 inhabitants of Mymensingh town and nearby areas, namely, Agricultural University Premises, Haluaghat, Jaymangal, Nalitabari, Nakla, Dhobaura, Sherpur, Durgapur and Netrakona. From the collected data, intensities of different locations were estimated. The survey results indicate that, the tremor lasting between 5-10 seconds, was strong enough to awaken the most of the sleeping people, shake light furniture, gently oscillate hanging objects and make showpieces fall down from shelves. Some students in Mymensingh Agricultural University were injured due to the panic from the earthquake with cracks due to this earthquake observed in almost all student residential halls. The intensities of the quake estimated from the survey were VI- VII at Mymensingh, VI+ at Haluaghat and Dhobora , VII- at at Sherpur, V at Durgapur and IV at Netrakona.

Organizing Training Program for Masons on Constructing Earthquake Resistant Buildings

Generally in Bangladesh masons do not have any knowledge about earthquake resistant buildings. On 16th October 2008, BNUS started a three-day training program for masons to provide them with such knowledge by training them about arrangement and formation of various necessary structural requirements for construction of earthquake resistant buildings along with quality control and maintenance. For example, they were given knowledge about forming collar in partition walls to give it stiffness and integrate it with the beam column to resist lateral force during earth-quake, and about placing vertical rods in the partition walls. An introduction to earthquake defi-nition, how it occurs, and earthquake history of Bangladesh were also given. The theoretical training course concluded with a written examination. After the training the masons also built a small structure consisting of 10 feet x 10 feet small rooms providing earthquake resistant reinforcement with base footing. To strengthen a existing weak building to be earthquake resistant, the training also provided ideas about retrofitting, such as, method of bolting, jacketing, beam column casing, split and bandage.

Practical training to masons participants

BNUS Participated in the National Workshop on Hospitals Safe from Disasters

A National Workshop on Hospitals Safe from Disasters was organized on 29th October 2008, the International Day for Disaster Reduction-2008, by Disaster Management Bureau of Bangladesh. Mr. A. K. M. Abdul Awal Majumdar, Additional Secretary, Ministry of Food and Disaster Management was the Chief Guest of the program. The workshop was chaired by Mr. K. R. Siddiqui, Director General, Department of Relief and Rehabilitation. Lectures were presented by experts in the technical session on the issues regarding the safety of hospitals from disasters. Dr. M. A. Ansary, Professor, Dept. of Civil Engineering, BUET and Director, BNUS moderated the technical session as the session chair. BNUS displayed panels on the earthquake safety issues, non destructive testing of buildings etc. and distributed awareness posters and booklets in the program.

(By M.A. Ansary, BNUS)

A New Building Constructed Using Wood-blocks

A new wooden small building was built in front of the Institute of Industrial Science (IIS) building in Komaba Research Campus of the University of Tokyo. The building has been built with Japanese Cedar grown in Kishu, Wakayama Prefecture. This new building construction system is masonry with wooden blocks. With this construction system, a house in a small site can be built using small and light wooden blocks which can be conveniently carried by a single person. Small wooden blocks can be made from resulting timber after thinning out a forest. As the timbers thinned out are thin or curved, it has been thought that they are not useful for timber buildings. But with this construction system these thinned timber can be innovatively used to construct new wooden buildings and houses.

Inside the wooden building

Left: Laying out the wooden-blocks
Right: The wooden building with IIS building in the backdrop

For this construction system, Mr. Kohki Hiranuma, an architect leading the firm Hs WorkShop-ASIA, was awarded the 'Ministry of Land, Infrastructure, Transport and Tourism, Chief of Housing Bureau Prize' in year 2005 competition of "New Building Construction System for housing using thinned out Timber". The wooden building in Komaba Research Campus was built after verification of structural safety by the static loading test conducted by Dr. M. Koshihara, ICUS Associate Professor and technical support team from Housing and Wood Technology Center (HOWTEC), Japan. All wooden blocks used in the wooden building were generously sponsored by Wakayama Prefecture. The building is open to general public from 8:00am to 8:00pm through Monday to Saturday. Everyone is welcome to experience this unique wooden space by using it for taking a rest, relaxing, holding a meeting or a party.

(By M. Koshihara)

ICUS Welcomes Dr. Pranab J. Baruah

We would like to warmly welcome Dr. Pranab J. Baruah to ICUS from November 1, 2008. Since his joining as a researcher at the University of Tokyo in April 2002, he has been working in various research projects related to global ecosystem (carbon budget) modeling and satellite remote sensing applications.

Prior to joining ICUS, he was a researcher at Integrated Research System for Sustainability Science (IR3S) where he contributed to various international collaboration programs, and studied on food safety & security as well as business case perspective of climate change mitigation measures.

Dr. Baruah received his PhD degree from Tsukuba University, Japan for his research on aquatic remote sensing at the National Institute of Environmental Studies (NIES), Japan. He holds a M.Engg. from Asian Institute of Technology, Thailand and B.Engg. (Civil) from Assam Engineering College, India.

(By K. Meguro)

ICUS Activities

ICUS members participated and presented at the USMCA 2008, Oct 21-22, 2008 in Beijing, China.

Prof. K. Meguro, Assoc. Prof. M. Ohara, Assoc. Prof. H. Huang, Dr. P. Mayorca, Dr. Worakanchana participated in the 14th World Conferences on Earthquake Enginee-ring, Oct 12-17, 2008, Beijing, China.

From Nov 18-22, 2008, Prof. K. Meguro attended UN-ESCAP program in Thailand to give special and keynote lectures.

Dr. S. Tanaka participated in the ITS World Congress, Nov 16-24, New York, USA. During Oct 14-19, Oct 24-29 and Dec 8-19 , 2008, he carried out his research and teaching duties at RNUS, Thailand.

Dr. K. Worakanchana stayed in AIT for his research work and teaching duties between Oct-24 to Dec-14 and Dec-26 onward.

Awards

Dr. Paola Mayorca was awarded "Outstanding Paper Award" at the 14th World Conference on Earthquake Engineering, Beijing, 2008, for her design of PP-band retrofitted adobe/masonary structures.

Editor's Note

A once in a 100 years economic depression has come to haunt almost the entire world starting with the bankruptcy of Lehman Brothers in September, 2008. Even giants like Toyota and Sony are feeling the pinch with losses, and large-scale restructuring is being executed. The very fact that the financial infrastructure has a big influence on the world is recognized again. However, the current unprecedented events in world economy shows us some important facts and teaches us an important lesson: that a system is generally not so criticized while it is effectively operated. It is also true that, critical opinions about its operation always exist though these opinions are often small in number. An important thing therefore is to always listen to various opinions because we cannot forecast the future with absolute certainty. Now, there is a grave concern that due and urgent attention to environ-mental problems is decreasing with this economic downturn. If we let this fear become real, we will fail again, this time in our environmental front and in an irreversible all-out way.

We in ICUS are continuously concerned with the problems in urban environment that will support more than half of humanity in coming decades. Focusing on Urban Safety, all subjects relevant to it constitutes ICUS activity. Here, we always try to offer the best or better solution to the society based on recognition of the current problems and forecast of future problems through scientific means. As it is possible that our forecast result may have an unexpected outcome similar to the present devastating happenings in the financial world, it is extremely important for us to always review the result of an examination. We believe that, modesty, recognition of such limitations and a listening ear to criticisms are key to influential, effective and sustainable solutions to the ills of the society.

(By Y. Kato)

If you would like to contribute an article to ICUS newsletter or have any comments or suggestions, please contact the editorial committee at icus@iis.u-tokyo.ac.jp. Any article within the scope of urban safety engineering and management will be considered for publication after internal peer review by the editorial committee. To know the scope of ICUS activities, please visit ICUS homepage at http://icus.iis.u-tokyo.ac.jp/

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**Institute of Industrial Science
The University of Tokyo**

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FRAMEWORK AND METHODOLOGY OF PUBLIC SAFETY

By

Weicheng Fan[1, 2], Yi Liu[1] & Wenguo Weng[1]

Governments all over the world are attaching increased importance to emergency management due to recent public emergency incidents, such as, the Indian Ocean Tsunami, double benzene plant explosion at Jilin Petrochemical Company in China, SARS outbreak in China, Hurricane Katrina in USA, 911 terrorist attack in USA, and the recent Wenchuan Earthquake in China. Our current society is probably becoming weaker to safeguard itself from these incidences. Highly developed technology is giving human society more convenience while bringing about more of these public emergency incidents. The assurance of public safety needs the supports of science and technology and public safety issues are posing challenges to scientific researchers. At present, it is still somehow difficult to provide a general view of public safety research due to its complexity. It is a multi-subsystem, multi-level, multi-function system, and the systems and factors involved are often non-linear, dynamic and uncertain. One existing question has been that, what is the connotation and extension for public safety research?

Public safety research triangle

Looking into the whole process of the emergency and its response, one can identify three key topics: the emergencies, the acceptors, and the response and its management. What links the topics is the so-called “hazard elements”. Based on such ideas, the framework of public safety research is symbolized as a triangle shown in the left figure. Figure below shows an example of a public safety response platform with simulation of a chlorine leakage accident.

FRAMEWORK OF PUBLIC SAFETY RESEARCH

The hazard elements have forms of matter, energy and information. The way hazard elements induce emergency is to reach or exceed the critical value or meet with some

A public safety response platform showing simulation of a chlorine leakage accident

activators. For example, the earthquake's hazard element is crustal motion with the form of energy. Earthquake occurs when the crustal motion reaches a certain intensity, i.e. energy reaches a critical value.

The hazard element of a hazard material leakage accident is the hazardous materials with the form of matter. When the hazardous material mass exceeds the capacity of tank (critical value), or there are some cracks causing explosion (activator), the hazardous materials leakage accident would take place. One of the factors for society's panic about hazard elements is the rumors in various information forms. If the information mass reaches a critical value, or some inducing factors happen, the society's panic may occur.

The emergency refers to those disasters or events that will bring damages to human beings, physical objects, the social system and the natural environment. The emergencies behave as extremely huge or destructive actions of "hazard elements". The evolution of emergency obeys some certain laws, and study of emergency is normally to find the type, the intensity, and the temporal and spatial variation of the emergency's actions on the acceptors. The acceptor means the objects which receive the actions produced or released or carried by the emergencies. The acceptors are normally represented as human beings, substances (such as buildings, facilities, life-lines, etc.), and operational, social and economical systems. Acceptors' failure has two forms: body destruction or function failure. Failures of acceptors may cause unexpected release or activation of "hazard elements", which may induce secondary disasters forming the incident-chain-effects. We can think about the acceptors of earthquake as an example. The acceptors of earthquake include human beings, substance of buildings and lifeline system, and system of environment and society, etc. Body destruction and function failure of the human beings are death and injured, and behavioral ability decreases, respectively. For substance, the body destruction is building collapse and tube crack, and the function failure is no residency and no water, etc. The function failure of systems takes the form of ecosystem destruction and society function loss, etc. Fire is the often-occurred secondary incidents due to gas tube cracks from earthquake. It is evidenced that gas tube is the acceptor of earthquake and the gas inside behaves as the hazard element of fire. Unexpected delivery of "hazard elements" due to acceptor's destruction is the direct reason of secondary incidents. Studies of acceptor focus on the states variation, the failure criterion, the vulnerability and reliability, and strengthen method for acceptors. The response and management refers to all of mankind's interventions aiming to disaster prevention and mitigation. It includes evaluation, preparedness, response and recovery, etc. It could be performed on the emergencies or on the acceptors, so as to reduce emergencies' actions or strengthen acceptors or break down the incident chain effect. The way of response and management for the original catastrophes are obviously different from that for the secondary hazards due to the different initial and boundary conditions. Studies of response and management are to find suitable manner, strength, time and scale to perform mankind's interventions for both emergencies and acceptors.

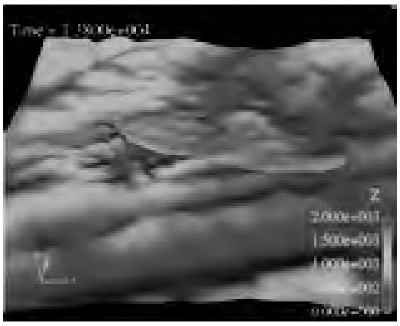
In summary, the core of the researches is to study the behaviors of hazard elements. That is, how the hazard elements convert to emergencies, how the hazard elements act on acceptors by emergencies, and how the failed acceptors cause incident-chain-effect via the hazard elements. Thereby one knows how to perform well-timed emergency management appropriately.

METHODOLOGY OF PUBLIC SAFETY RESEARCH

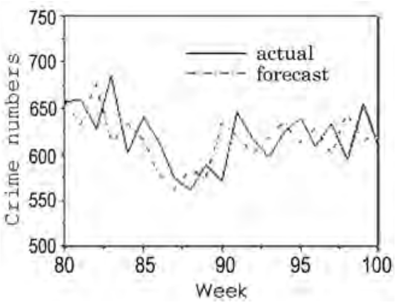
The methodologies of the above studies include five aspects of deterministic, stochastic, sensor-based methods, complex system approach, and combined methods.

The usual deterministic methods include experiments and simulations. Laboratory gravity currents are frequently used to model the dynamics of avalanches, accidental dense gas releases, and fire propagation. 3-D fluid dynamical models are used to simulate hazardous gas leakage. First, grids of landform and city zone are built. Second, number computation is carried out to get the hazardous gas distribution, and then the results are embedded into GIS. Bottom left figure shows results of sulfureted hydrogen gas blowout simulation. The flow rate is 200,000m^3/h, and the concentration at mouth of well: 0.12 kg/m^3.

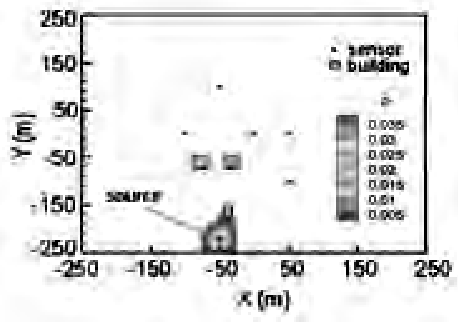
Unfortunately, the deterministic method is not practicable for all kinds of emergencies, and some have to recur to stochastic models. Crime forecasting is a new research field of public safety. It is difficult to forecast crime with deterministic method due to its complexity. With 110 CAD



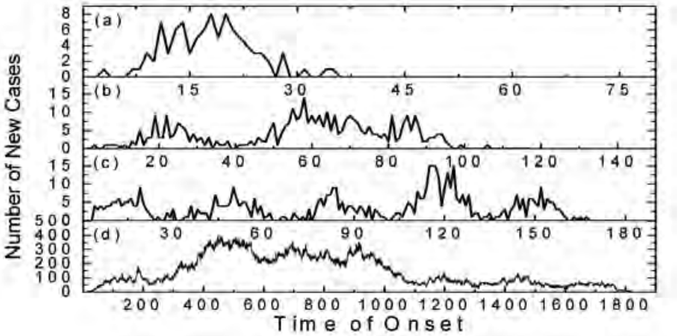
Sulfureted hydrogen gas blowout simulation result



Property crime and its forecasting trend (by week)



Joint distribution of the source location on the plane



Example time series of newly infected cases

crime data, time series model can be designed and short-term forecasting of property crime can be made. Two steps are designed to build the models. The first step is model recognition, and the next is to determine the model order and parameters. Based on the actual crime data, we can use moving average with the order of 1. The right figure on page 2 gives the forecasting trend and is consistent with the actual ones by week.

Sensor-based methods are also important tools for public safety research. Information captured by detection apparatuses and analyzed is used to understand the temporal and spatial variation of disaster. The relationship between logged forest fire and droughts caused by El Niño are studied using coarse- and high-resolution optical and radar satellite imagery. When the materials accidentally release in a densely populated urban center, it is important to predict the transport characteristics of the consequences. So it is necessary to develop an approach to determine the source location and its strength by an array of independent sensors distributed in the urban areas, combined with environment conditions, e.g. wind direction, wind velocity. A method of Markov Chain Monte Carlo sampling based on Bayesian inference is developed to determine the hazardous materials source using sensor data. Top left figure shows the joint distributions of the source location on the plane with this method.

Complexity in public safety results in more applications of complex system approach. Complex network theory is one of the most useful methods to study disease outbreak and rumor spread in groups. It is also frequently used to study the robustness and resilience of lifeline systems with the existing form of network. The human travel has scaling law and the social group has evolution self-optimization characteristics. Forest fire is an example of self-organized critical behavior. Decision-making is the key problem of emergency response and management, and the complex system approach (game theory, neural network, etc.) is usually used to understand the decision-making task. To explore the effects of human travel patterns on the spatio-temporal dynamics of large scale epidemics, heterogeneous spatial metapopulation networks is constructed with the scaling laws of human travel, i.e. $p(r) \sim r^{-(1+b)}$ and $p(tw) \sim tw^{-(1+a)}$. Top right figure gives the example time series of newly infected cases. The simulation results show that the occurrence probability of global outbreaks or the survival probability is significantly dependent on the characteristic travel distance, the characteristic waiting time and the memory effects of human travel.

It is not easy to solve a public safety problem using only one of the above four methods due to its complexity. It has frequently a case that a main method performs with some other methods as supplements, i.e. combined methods. Information from sensor-based method is usually used for determination of some parameters for deterministic method, and modification of the data for stochastic method. Node or link dynamics using the deterministic model is useful to understand the whole network mechanism with the complex system approach. Some models in the complex system approach are usually built by embedding the deterministic, stochastic and sensor-based methods. Integrated risk analysis is a typical case with the combined method. The occurrence probability of emergency is based on stochastic methods, and the evolution sequel of emergency is from deterministic methods. Failure effects of acceptor are frequently based on deterministic methods. Consideration of response and management are possibly based on sensor-based methods and complex system approach, etc.

CONCLUDING REMARKS

It should be noted that natural disasters and human-activity induced incidents are common enemy of humans, and public safety is a general problem all over the world. Public safety research is complex in the framework, and has extensive problems to be solved. International cooperation and exchange among the countries should be enhanced, so as to perform efficient cooperation when facing catastrophes.

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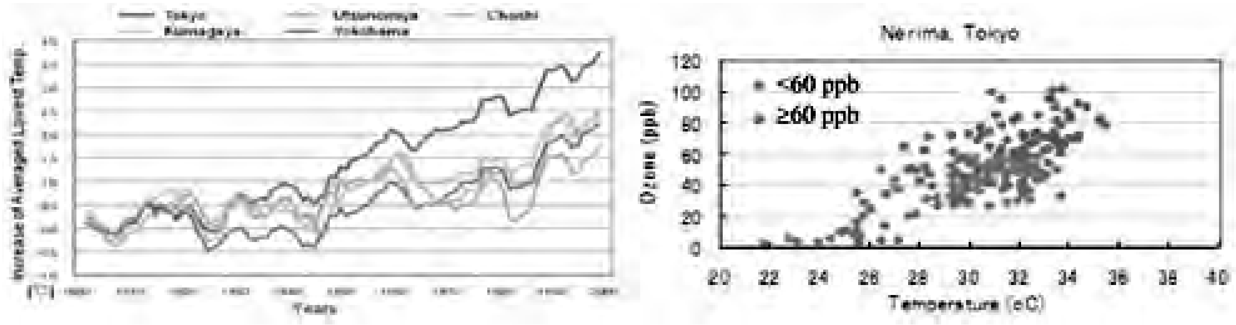
[2] State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, PR China

Relationship between Surface O_3 and Urban Heat Island Effect in Tokyo



Change of averaged lowest temperature in some cities of Japan (left) and relationship between surface ozone and temperature at every hour from 8:00 to 14:00 JST in August 2005 based on MM5/CMAQ simulation (right)

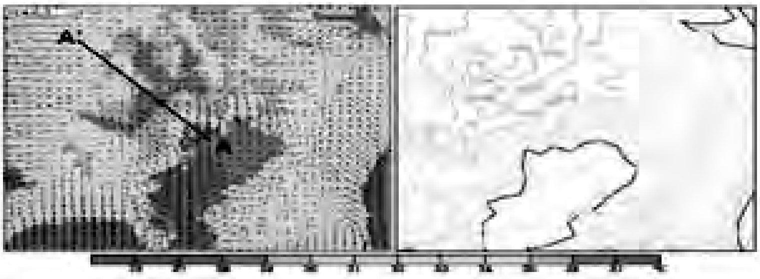
Urban air pollution has been increasing due to climate change and urban heat island. Ozone (O_3) is one of the pollutants currently drawing the most attention. It is a secondary pollutant produced as result of complex non-linear interaction between chemistry reactions and dominant climatic processes. Although only about 10% of earth's ozone are found in the troposphere, which is often referred to as surface ozone, it is recognized as one of the most serious pollutants detrimental to both human health and the environment.

According to measured data from National Institute for Environmental Studies, Japan, the concentration of most of air pollutants is decreasing in Tokyo Metropolitan area. However, the concentration of photochemical oxidant has not achieved the environmental quality standards (one-hour value of 0.06 ppm or less). This phenomenon is a very important research topic. Some factors for this increase of stratospheric ozone have empirical proof, e.g. the relationship between increase of air temperature due to global warming and Urban Heat Island (UHI) with increase in ozone concentration as shown in the figure above.

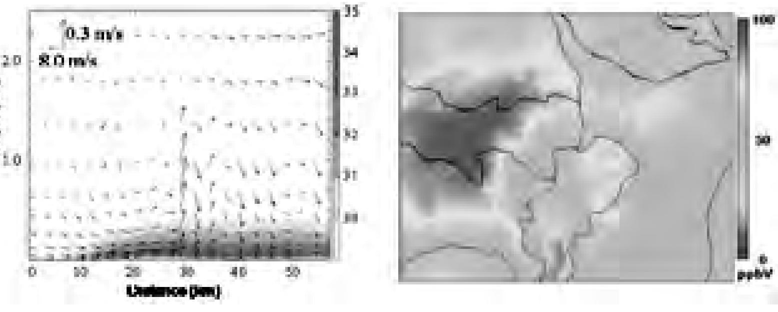
High temperature on UHI days is one of the climatic factors that has strong effect on stratospheric O_3 formation during summertime by increasing photolysis rates of ozone production and the production of ozone precursors, such as NOx and VOC. Indirectly, meteorologically stagnant conditions that accompany high daytime temperature also affect O_3 formation. In top right figure, the surface ozone simulated by mesoscale model at Nerima ward of Tokyo in August versus air temperature shows lower O_3 concentration at low temperature (less than 27˚C), but increasing significantly with increasing temperature, exceeding standards (>60ppb) above 28˚C. The figures below illustrate impact mechanism of UHI on ozone concentration in Tokyo Metropolitan area. High temperature associated with UHI causes pressure deficiency over the city. Air flow from suburban area meets sea breeze at city and goes up. This updraft of heat island circulation acts like a wall preventing the penetration of sea breeze inland, resulting in high O_3 concentration over city area.

The effect of climate conditions on air pollutions in general and ozone concentration in particular is very complex involving macroscale to mesoscale factors. It is also affected by many climatic factors and phenomena as well as its interaction. Therefore, to assess urban atmospheric environment, it is important to develop a comprehensive climate model in which the complex interaction among topography, city building environment, land use, anthropogenic emissions, etc. must be considered. This is our primary research interest in near future.

(By R. Ooka)



Simulation result from MM5 model at 12 JST August 4;
Left: 10m-temperature (˚C) and 10m-wind; Right: surface pressure (mb)



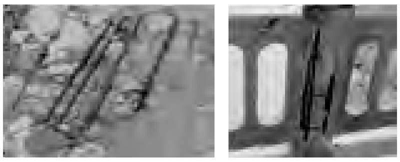
Simulation result from MM5 /CMAQ model at 14 JST August 4;
Left: circulation vector in the plain of A'-A; Right: O_3 concentration (ppbV)

At the USMCA2008, Beijing, PR China, five researchers were selected as winners of Young Researcher Award. In this volume of ICUS Newsletter, two among them introduce their award-winning research briefly below.

Co-effect of Initial Curing Conditions and Exposure Environments on Coastal Concrete Durability

For the concrete infrastructure along coastline, the chain reaction of corrosion of the reinforcement, cracking of concrete, spalling-off of cover concrete and the deterioration of structure performance are due to the chloride attack. Moreover, in some warm areas like Tokyo Bay, Japan or Hangzhou Bay, China, concrete structures are subjected to chloride ingression rather than freezing-thawing cycle or carbonization. In these situations, the apparent diffusion coefficient and chloride accumulation in the cover concrete are often used to estimate the durability state and predict the life span of the structures.

Initial curing is a beginning process in the service life of concrete structures and is a critical process to form a dense concrete micro-structure. Besides the effect from initial curing condition, following exposure environment needs to be considered in the study of concrete durability, since all the concrete infrastructure are exposed into real service environment after curing.



Reinforcement corrosion and concrete spalling-off from chloride attack

To discuss the combined effects from initial curing conditions and the following exposure environments on chloride moving properties in concrete, a six-month onsite exposing test that investigated concrete cured under different conditions was carried out. The testing results show that, (1) initial chloride-suction and the chloride moving ability in saturated-cured concrete are obviously weakened, (2) lack of pore water in the cover concrete, which is caused by wet-dry cycle from exposure, would reduce the chloride moving ability in concrete.

With this, it is inferred that the coupling effect of initial curing condition and following exposure environment should be taken into account in the durability design of concrete structures located in marine environment.

(By X. Wen,
Zhejiang University, PR China)

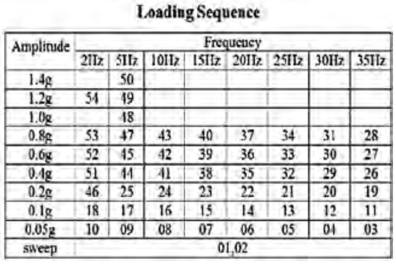
Shaking Table Test of Timber Roof Masonry House Models Retrofitted by PP-Band Meshes

To investigate the seismic performance of masonry houses and effectiveness of PP-band retrofitting technique, two models were built in the reduced scale of 1:4 using unburnt bricks as masonry units with a cement/water ratio of 33%. Model dimensions were 933mm x 933mm x 720mm with 50mm thick walls in all models. One of the buildings was retrofitted with PP-band mesh. Simple sinusoidal motions of frequencies ranging from 2Hz to 35Hz and amplitudes ranging from 0.05g to 1.4g (as shown in the table) were applied to obtain the dynamic response of the models.

For non-retrofitted specimen, no major cracks were observed upto run 21. At run 28, crack was observed at one of the top corner of the door opening and it propagated up to top layer of the wall, upon which cracks widened with each successive run. At run 44, large amount of cracks were observed, exciting cracks widened and connection between adjacent walls became weak. In case of walls perpendicular to shaking direction, part above the door opening was totally separated from the specimen. At that point, the roof was only supported by two walls, which were in the direction of shaking. Therefore, due to walls subjected to out-of-plane load; there were bursts outwards in shaking direction. This finally led to the structure collapse.

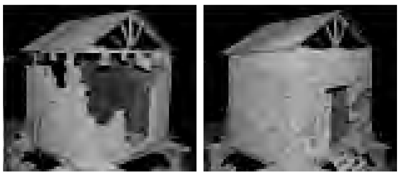
For retrofitted specimen, from run 25, new cracks appeared and cracks widened with each successive run. Although the PP-band mesh kept the structure integrated during the shaking, it allowed the sliding of the bricks along these cracks to some extent. At the final stage of the test, at run 52, virtually all the brick joints were cracked and the building had substantial permanent deformations. However, building did not loose the overall integrity and stability, and collapse was prevented even in such high intensity shaking.

(By N. Sathiparan,
The University of Tokyo)



Loading Sequence

Amplitude	Frequency							
	2Hz	5Hz	10Hz	15Hz	20Hz	25Hz	30Hz	35Hz
1.4g		50						
1.2g	54	49						
1.0g		48						
0.8g	53	47	43	40	37	34	31	28
0.6g	52	45	42	39	36	33	30	27
0.4g	51	44	41	38	35	32	29	26
0.2g	46	25	24	23	22	21	20	19
0.1g	18	17	16	15	14	13	12	11
0.05g	10	09	08	07	06	05	04	03
sweep	01,02							



Non retrofitted & retrofitted model after run 45(right) and run 52(left)

Making Adobe and Brick Houses Stronger to Withstand Earthquakes

PP-band retrofitted model house built in Kashmir region after devastating earthquake in 2005

Adobe, or sundried mud blocks, and bricks, oven burnt clay blocks, have been used for many centuries to construct houses all over the world. In developing countries, where construction materials are costly and labor is relatively inexpensive, they are preferred over reinforced concrete or steel. Many of these houses are constructed by the house owners themselves or unskilled masons, mainly because of resource constraints.

During the last century many lives have been lost due to earthquakes. Collapse of adobe/brick houses, also called masonry houses, caused more than 60% of these deaths, mostly in developing countries. In the earthquake damage surveys that I had the opportunity to join, the situation I could observe was very similar regardless of the country. While poorly constructed masonry houses collapse killing their inhabitants, well constructed ones protect their occupants. Lack of know-how on "good construction" practices, risk unawareness, and limited resources, have resulted in a huge seismic vulnerable housing stock.

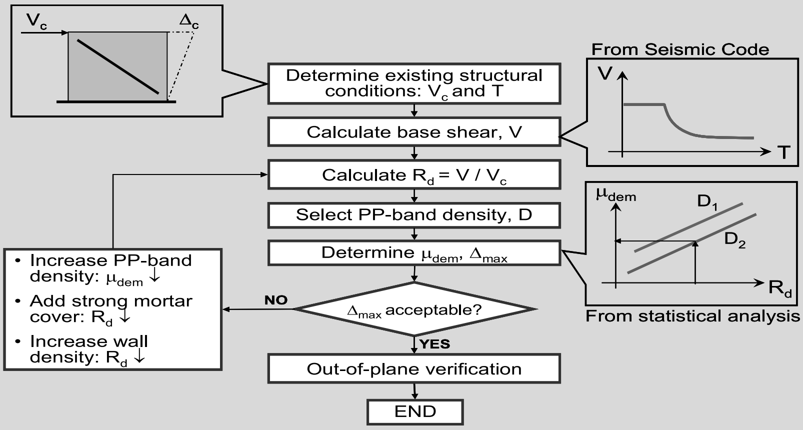
Addressing this situation is essential to reduce casualties in future earthquakes and to preserve existing housing stock thus reducing material losses. However, this problem presents a great challenge. On one hand, a technical solution that can be easily implemented and is economically viable is necessary. On the other, raising awareness and creating an environment that encourages people to retrofit their houses are essential.

During my stay at the University of Tokyo, first at Meguro Laboratory and then at ICUS, I was involved in developing a solution to this problem together with a team of researchers led by Prof. Kimiro Meguro. The proposal is to use inexpensive and widely available plastic straps, known as PP-bands in the industry, to retrofit low earthquake resistant masonry houses. Walls are wrapped with meshes, made of these bands, on both sides. Inner and outer meshes are attached with wire connectors so that bricks/adobes are confined inside them. Finally, they are plastered to protect the meshes and provide a smooth finishing to the walls.

Experiments and numerical simulations have shown that PP-band meshes improve the seismic performance of poor earthquake resistant masonry houses. This is mainly achieved by increasing the structure ductility and energy dissipation capacities. Under moderate ground motions, PP-band meshes provide enough seismic resistance to guaranty limited and controlled cracking of the retrofitted structures. Under extremely strong ground motions, they are expected to prevent or delay the collapse, thus, increasing the survival ratio.

In order to effectively promote retrofitting with PP-band meshes, simple recommendations regarding amount of reinforcement, arrangement, and detailing, are necessary. Because the people who will actually install them are either the house owners or relatively untrained masons, it is important that the essence of the method is condensed in a set of few "rules of thumb". Behind it, a design procedure, such as the one outlined in the figure below, should be carried out. With it, it is possible to find out the necessary reinforcement for a particular seismic demand, considering the structure original capacity and acceptable displacements, i.e. ductility demand. Experimental observations and numerical simulation results should also be incorporated when preparing the "rules of thumb" mentioned before.

Although increasing the seismic strength of the many existing vulnerable masonry houses is not easy or achievable in a short time span, it is the only way to guaranty the sustainable development of the regions where these are widely used and where earthquakes are common. I am very grateful for the great opportunity that I had to make a small contribution to addressing the problem of low earthquake resistance masonry houses, at the University of Tokyo and ICUS.



Methodology proposed for PP-band mesh retrofitting design

(By P. Mayorca, DNV Norway)

18th Seiken Forum Was Held at IIS

Left: A forum snapshot
Right: Professor H. Sawada in his closing speech

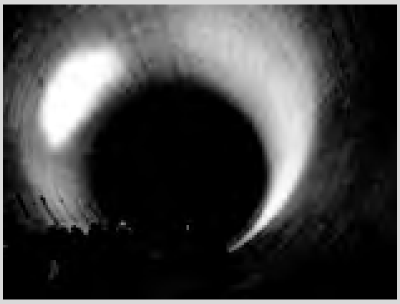
The 18th Seiken Forum was successfully held on March 9-10, 2009 at the Institute of Industrial Science (IIS), The University of Tokyo. This year the forum focused on "Collection and Usage of Meso-scale Information of Environment and Disaster Risk using Remote Sensing Technology".

There is a persistent lack of information exchange among various research fields, such as, hydrology, crop yield prediction, forest management, disaster mitigation in spite of using similar remote sensing technology. A total of six sessions on microwave remote sensing, evaluation of disaster risk, environmental monitoring, land use, ecological monitoring and thermal environment were organized in the forum. There were approximately 100 participants in the forum and 31 presentations were delivered in 2 days. In the disaster risk session, researches on development of UAV (unmanned airborne vehicle) based disaster monitoring system, ASTER image database for volcanoes, estimation of agricultural damage by natural disaster using satellite data (2008 cyclone damage in Myanmar), estimation of forest and land fire risk using multi-criteria decision analysis and GIS in west Kutai district of East Kalimantan, estimation of reduction in tsunami inundation flux by costal forest in Hambantota district of Sri Lanka and production and verification of land surface water coverage map by using AMSR-E, etc. were presented. During the forum, information exchange was actively done. All participants recognized that an approach from different perspectives such as advanced technology and disaster issues is most important for solving various problems. Several participant expressed their interest to join the Seiken forum next year. The closing remarks were delivered by Prof. Haruo Sawada.

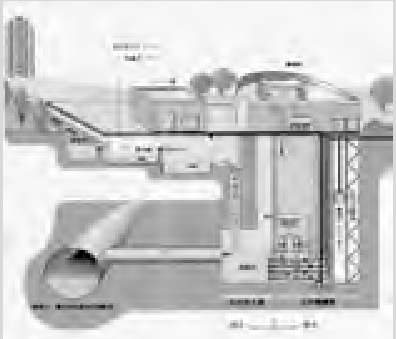
(By T. Endo)

Visit to Flood Control Reservoir in Tokyo

The Ministry of Education, Culture, Sports, Science and Technology (MEXT) has been leading a special project for mitigation of metropolitan earthquake disaster since 2007. Prof. K. Meguro and Dr. M. Ohara are involved in the study group for "Establishment of widespread crisis management and mitigation system" and "Developing efficient information sharing system for disaster-related organizations". The study group has general meetings every three months for sharing disaster information in Tokyo metropolitan area among over 100 researchers involved in this project. The general meeting was held on January 6-7, 2009. On the first day, we visited one of the densely built-up residential areas for understanding its earthquake disaster risk. After that, we visited a flood control reservoir at the Zenpukuji-kawa river which is one of the flood disaster mitigation facilities in Tokyo. This is a tunnel over 50 m beneath the National Ring Road 7 in Tokyo and it can store 540,000 m^3 of flood water from Zenpukuji-kawa river. The length of the tunnel is 4.5 km and its inside diameter is 12.5 m. When the typhoon No. 22 attacked Tokyo area in October, 2004, this flood control reservoir took in flood water and the number of damaged houses due to the typhoon was limited only to 46. One can realize the mitigation effect of the flood control reservoir by considering that the number of damaged houses was 3,117 in case of Typhoon No.11 in 1993 with the same manitude. On the second day, we had a workshop on multiplied effects from disasters on society.



Inside the flood control reservoir



Flow of water to the reservoir

(By M. Ohara)

Visiting Chengdu: An earthquake effected area in Sichuan Province of China

From January 2nd to 5th, 2009, Prof. Kimiro Meguro, Director of ICUS and Dr. N. Sathiparan, the University of Tokyo, visited Chengdu in respond to invitation by China Development Research Foundation (CDRF). This visit began at the city of Chengdu, which was accessible by air from Beijing International Airport. The Shuangliu Airport is about 12km from the Chengdu city center. Chengdu is located in the Sichuan Province and is the center of China's Southwest culture, government and economy.

On-site instruction given by Prof. Meguro at Luobuzhai Village

Same day a meeting was convened to discuss and coordinate trip activities. The participants to the meeting were Prof. K. Meguro, Dr. N. Sathiparan, Mr. Lu Mai, Secretary General, CRDF, and several members of CDRF. The objectives of the trip and the roles of both organizations were discussed at length.

Day 2 started with travel from Chengdu to Sichuan earthquake affected area along the road. Most of the people were still living in temporary accommodations at the time of visit.

Around noon, a meeting was convened with Mr. Zhang Tongrong, Governor of Wenchuan County. He explained about the government of Wenchuan County activities for on-site rehabilitation and reconstruction in Wenchuan. Also, he requested Prof. Meguro to provide technical support on this issue.

Prof Meguro and Mr. Zhang after long discussion

Afternoon, visit was made to the Luobuzhai Village and Buwazhai Village; which are mostly affected by the earthquake in Wenchuan Country. Prof. Meguro introduced the PP-band method to local people. Most of the instructions were giving by the aid of image and video, and it had a strong impact on local people.

After the village visits, Prof. Meguro gave a presentation entitled "Implementation of earthquakes safer housing through technological and social approaches" at Wenchuan County government office. The meeting was attended by around 30 participants; those were mainly government officials and some local leaders from Luobuzhai and Buwazhai Village.

Day 3 started with travel from Sichuan earthquake affected area to Chengdu. Along the way earthquake damage inspections were conducted. Afternoon, a seminar on "Advanced Seismic Technology for Scientific Post-earthquake Reconstruction" was organized by CDRF and Sichuan Construction Department at Chengdu XiangYang Hotel conference hall. The objective of the seminar was to provide details on advanced technology for construction of buildings in earthquake prone regions. The seminar was attended by around 400 participants.

Prof. K. Meguro was the Special speaker invited by CDRF. His speech on simple and economical retrofit method for masonry houses and its promotion systems let audience impress. His talk emphasized the essential elements for creating houses that would be less susceptible to earthquake damage. Employing images and video based on actual experiences and introducing data from a number of earthquake disaster areas, Prof. Meguro led the audience through an easy to understand presentation. He concluded his presentation by emphasizing the need to focus on creating safer built environment which will drastically reduce structural damage and human casualties from future earthquakes.

The proposal of retrofitting masonry houses by PP-band meshes was welcome by participants as a good technology to solve the problem in non-engineered structures in earthquake prone region.

Presentation given by Prof. Meguro

On day 4, the visit ended with brief meeting with CDRF members in the morning before leaving from Shuangliu Airport to Tokyo.

(By N.Sathiparan)

Student Receives Award for Bachelor Thesis

Prof. Hotate, Dean, School of Engineering awarded the prize to Ms. Sato.

Ms. Mari Sato of Kuwano Lab is awarded Dean's Prize of School of Engineering.

Ms. Mari Sato, an undergraduate student of Civil Engineering Department, the University of Tokyo, received the Dean's Prize of School of Engineering for her outstanding Bachelor thesis. The prize is awarded to the best student in all engineering departments. She is the first winner of the prize in the Civil Engineering Department. In the graduation ceremony held in March 24, 2009, the prize was awarded by Prof. Hotate, Dean of School of Engineering.

She conducted her undergraduate project research under the supervision of Dr. R. Kuwano. She performed a series of experiments to explain how the underground cavity forms, expands and eventually causes cave-in. Field investigations were also carried out to explore ground loosening formed around the cavity. Outcomes of the study can be an important clue to develop a novel technique to detect a hidden ground cavity which can be a source of large scale ground cave in.

(By R. Kuwano)

RNUS Activities

Promotion of PP-band technology in Yogyakarta, Indonesia

During 7-15 February 2008, Dr. Kawin Worakanchana joined the JICA expert team consisting of Mr. Masayuki Watanabe and Mr. Masato Kuroda to promote the poly propylene (PP) band retrofitting technique in Yogyarkata, Indonesia.

The team started the trip by visiting Klaten and Kotagede districts to investigate what the condition of the damaged buildings and their reconstruction was after the 2006 Java Earthquake. In both districts, some damaged buildings were still left unrepaired. In Klaten, the team observed that most of the damaged structures have been replaced with lightly reinforced concrete structures. The local government of Yogyakarta has provided 15 milllion Rupiah (approximate 1425 US$) to each family whose house was destroyed during the earthquake. We found by interviewing local people that this fund could only contribute to re-build some parts of a damaged house. In Kotagede, which is the old city located in Yogyarkata, most of the structures which collapsed have been reconstructed and retrofitted. During the trip, we visited Omah UGM wall, which is an ancient structure. It was heavily damaged during the 2006 earthquake. During our visit, some parts of the structure were being repaired by the fund given by a private company.

Top: The visiting team
Bottom: Demonstration of PP band retrofit

The team organized several meetings and participated in seminars to promote the PP-band retrofitting method. We expected that this retrofitting technique will provide the people with a cheaper alternative method to save their lives from building collapse. In this occasion, the team was honored to be granted a presentation on PP-band technology in front of His Royal Highness Pembayun.

Finally, the team has reached an agreement with Dr. Ir. Soeleman Saragih to retrofit the Omah UGM wall with the PP-band retrofitting technique. This place will be used as museum in the future and we planned to use this place as a prototype for people who are interested in retrofitting their house with PP-band technology.

Progress report on the Master Plan for Earthquake Disaster Mitigation and Building Collapse Prevention project

RNUS joined AIT and Panya consultant team to present the results from progress report on Master Plan for Earthquake Disaster Mitigation and Building Collapse Prevention Project in Thailand to the Department of Disaster Prevention and Mitigation (DDPM). The team consists of Dr. Pennung Warnitchai, Dr. Kawin Worakanchana and Mr. Kasidi Vichitugsornpong. The topic of this presentation from the AIT side mainly focused on the acqusition of earthquake source data and geological data for microzonation, building and infrastructure inventory.

After the presentation, DDPM was satisfied with our progress report. The team is now preparing the draft final report which will be submitted in May 2009.

(By K. Worakanchana)

BNUS Activities

Interviewers with Prof. M.A. Ansary (left)
Interview with J.R. Choudhury, Vice Chancellor, Brac University (top right) and
Md. K.A. Khan, Deputy Chief Coordinator, Cyclone SIDR Operation (bottom right)

BNUS continues interview survey on cyclone SIDR management in Bangladesh

BNUS performed interview survey from November 26 to December 07, 2008, in Dhaka on the role of Standing Orders on Disaster (SoD) of Bangladesh and the Cyclone SIDR management operations. The interviews were conducted to the policy makers and personnel associated with cyclone management activities in some organizations such as, Disaster Management Bureau, Directorate of Relief and Rehabilitation, Bangladesh Red Crescent Society (BDRCS), Cyclone Preparedness Programme (CPP) and Comprehensive Disaster Management Programme. Earlier BNUS performed a similar survey from May 5 to May 12, 2008 at local level administrations and cyclone management authorities in two Districts of Patuakhali and Barguna, which were worst affected by cyclone SIDR 2007. The current survey is the continuation of a previous research by BNUS. The interview surveys in Dhaka were performed jointly with Mr. Taiki Kou, an undergraduate student of Meguro Laboratory and affiliated to Department of Urban Earthquake Disaster Mitigation Engineering, ICUS. Mr. Kou is working on "Disaster management operation by governments in case of Cyclone SIDR in Bangladesh". Through the interviews discussions were held on various issues such as historical changes of disaster management plan and SoD in Bangladesh, cyclone management operation flow of Ministry of Food and Disaster Management, information flow and sharing, maintenance of logistics, efficiency of cluster approach during disaster stage, current action plans, CPP and BDRCS activities, relief works, plans and activities regarding cyclone shelters and so on.

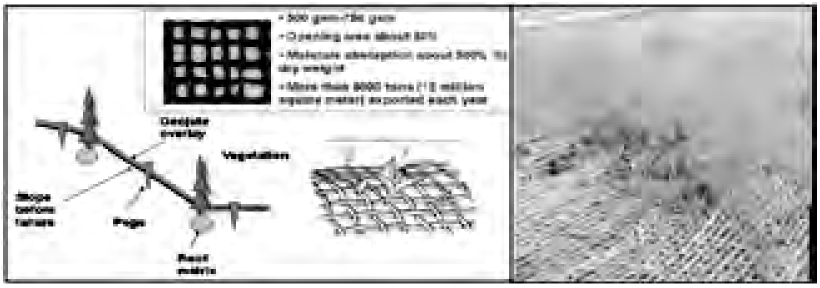
BNUS works on rain-induced erosion control in Bangladesh

In recent years, there is common occurrence of rain induced hilltop erosions or landslides in greater Chittagong and the adjacent rolling areas including the Chittagong Hill Tracts of Bangladesh. Loosening of topsoil by rainwater during heavy rainfall from deforestation and cutting of the hills was found to be main cause of these landslides.

On August 18, 2008, a total of 11 persons were killed and more than 30 were injured in a landslide in Motijhorna area in the port city of Chittagong. In June 2007, a landslide at Mati Jharna colony of Lalkhan Bazar, right in the heart of Chittagong, killed 128 people when a hill collapsed on to an adjacent slum. Statistics show more than 300 people have been killed in landslides in Chittagong in recent years. These occurrences have posed yet another challenge to the engineering know-how, administrative decisiveness and mass awareness in Bangladesh. To investigate these landslides and find a probable solution, BNUS organized a field visit for the experts/researchers to some landslide areas of Chittagong district from September 10 to 11, 2008. The team consisted of Dr. Abdul Jabbar Khan, Professor and Dr. Raquib Ahsan, Associate Professor, Department of Civil engineering, Bangladesh University of Engineering and Technology. Later, Prof. Khan presented his findings as well as a couple of recent projects implemented by 16 Engineering Construction Battalion at Rangamati area using Geojute for rain-induced erosion control under his guidance.

Geojute is a bio-engineering solution to rain-induced landslide. It is biodegradable, locally available in Bangladesh and cheaper than other available methods. The jute nettings spread over seeded slopes shield the soil and seeds from the impact of rain drops, minimise runoff and slow down its velocity, maintain the capacity of soil to absorb water and retain soil moisture. Once seeds germinate and grow through the gaps in the fabric to cover the area, Geojute nets starts to degrade. Geojute is also suitable for slopes with high erodability where mechanical methods prove unsuitable.

(By M. A. Ansary)



<u>Left</u>: Schematic of Geojute application on degraded slope;
<u>Right</u>: Vegetation growing through Geojute

ICUS Activities

- Prof. K. Meguro, Director, ICUS, visited the earthquake affected areas of Chengdu, PR China during January 2-5. He made a keynote speech at the seminar in Beijing titled "Advanced Seismic Technology for Scientific Post-earthquake Reconstruction" in a seminar arranged by China Development Research Foundation and Sichuan Construction Department. (please refer page 8 for details). He again visited Beijing, China from March 8 to 9 to attend 2nd Japan-China Forum. From March 14 to 16, he visited BNUS in Dhaka, Bangladesh.
- Prof. H. Sawada visited Khon-kaen, Thailand from January 7 to 12 to join and present at the Workshop on Monsoon Asia Tropical Forest Carbon Dynamics and Sustainability. From March 14 to 20, he visited Bangladesh University of Science and Technology (BUET), Dhaka, Bangladesh and carried out an observational survey of natural environment of Dhaka and around.
- Dr. Tanaka stayed in Bangkok, Thailand during the period of January 14-27, February 12-28 and March 2-27 to carry out his teaching and research duties as a co-ordinator of RNUS at AIT. During February 14-17, he visited Dhaka, Bangladesh to carry out a survey of traffic flow in Bangladesh.
- Dr. Worakanchana remained in AIT till March 1 to carry out research and teaching duties.

Research Committee (RC) Activities

Prof. K. Meguro, Director, ICUS presided over the concluding meeting of RC-58 (left). Seated next is Prof. H. Sawada and Dr. S. Miyazaki; Dr. M. Soejima presented the findings of Working Group-2 (center). RC-58 members at a group photo shoot (right)

Starting in year 2007, 13 companies joined the Research Committee 58 (RC-58) to work on "Business Continuity Management (BCM) Systems Suitable for Japanese Society." The industry-university collaboration research group concluded and presented their final research findings in a meeting on March 30. Three working groups carried out extensive interactive discussion, presentation and research on: 1) suitable BCM systems for private companies, 2) suitable BCM systems for local governments and 3) suitable methods for evaluating BCM. The final report of RC-58 research outcomes will be published in April, 2009. RC58 will hold a forum on April 21 to report its results to the general public and to host a special lecture by Dr. S. Nishikawa, Ministry of Land, Infrastructure, Transport and Tourism.

Research Committee 62 (RC-62) held its meeting on March 17 and is preparing the interim report to be submitted in May.

Awards

Asian Concrete Federation (ACF) conferred its Best Presentation Award in January to Prof. H. Yokota, ICUS Visiting Professor, for his splendid presentation of the paper on *Chloride Ingress in Cracked Concrete with Water Repellent Treatment* and his invaluable contribution during the 3rd ACF International Conference held in Ho Chi Minh City, Vietnam on 11-13 November 2008.

Call for papers

USMCA 2009, Incheon S. Korea, October 15-16 2009

ICUS is happy to announce that, *the 8th International Symposium on New Technologies for Urban Safety of Megacities in Asia (USMCA2009)* will be held in Incheon, South Korea on October 15-16, 2009. Organized by ICUS, National Institute for Disaster Prevention (NIDP) and Korea Disaster Prevention Association (KDPA), the symposium will bring together expertise in areas of design, construction and maintenance of urban infrastructure and those engaged in the development of new tools that could be used for implementation of safer built environment in urban areas. Focusing on 10 key areas relevant to urban safety in Asian megacities, the Symposium will provide a forum for decision makers, practicing professionals, and researchers to share their expertise. For more information and submission of abstracts, visit the USMCA2009 webpage below.

http://www.usmca2009.org/

Mark your calendar, Join us at Incheon, Korea

Editor's Note

There are many old cherry blossom trees in the Komaba Ⅱ research campus of the University of Tokyo where Institute of Industrial Science is located, and we could enjoy the cherry blossoms in full bloom again this April. In Japan, cherry blossom season coincides with the start of a new fiscal year and new students start their campus life with full of hopes. Recently, IPCC (Inter-governmental Panel for Climate Change) reported that, the global warming induced by human activities are affecting natural environment and phenomena. The impact on natural environment is one of our/humanity's biggest concerns. Although, under the Kyoto Protocol, Japanese government has started several activities to reduce 6% of CO_2 *emission from the baseline of 1990, these activities are not sufficient and have not been successful yet. Environmental condition is becoming much worse as indicated by the article by Dr. Fan and his colleagues. As the front of cherry blossom flowering goes north, the new influenza which caused numerous deaths in Mexico also threatened Japanese populace. Also as it spread quickly in Japanese mega cities, it influenced our daily life. Considering these situations, there are many challenges to deal with these problems related to urban environments as well as natural disasters for safety of life. We again recognize the importance of ICUS activities and determine to do our best to achieve fruitful solutions for urban safety. These ideas and thoughts came up to me while I was enjoying and under the cherry blossom trees in full bloom. I cordially invite you to visit our campus to see the old trees by yourself next year, which will bring you plenty of hopes.*

(By H. Sawada)

If you would like to contribute an article to ICUS newsletter or have any comments or suggestions, please contact the editorial committee at icus@iis.u-tokyo.ac.jp.

Any article within the scope of urban safety engineering and management will be considered for publication after internal peer review by the editorial committee. To know the scope of ICUS activities, please visit ICUS homepage at http://icus.iis.u-tokyo.ac.jp/

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