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ICUS の活動記録
（2009-2010）

ICUS Report 58

2012.3

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の活動記録

(2009-2010)

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1. はじめに

東京大学生産技術研究所（以下では本所）国際災害軽減工学研究センター（INCEDE: International Center for Disaster-Mitigation Engineering）の後継研究センターとして,2001 年 4 月に設立された都市基盤安全工学国際研究センター（ICUS: International Center for Urban Safety Engineering）も 2011 年 3 月末で 10 年間の時限を迎えた. 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.

「先端研究」としては,「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」を掲げ,本所で蓄積された過去の研究成果と新しい研究との融合によって,21 世紀の安全で快適な都市システムの実現に向けて活発な研究活動を展開してきた. これらの活動から,海外では,特にアジア諸国においては,ICUS は都市基盤の安全を研究するセンターとして,広く認知された存在になった. これまでの 10 年間にわたる ICUS の研究活動に対してご支援をいただいた国内外の多く研究機関と友人たちに深く感謝の意を表す.

ICUS では,設立以来の活動実績と設立 9 年目に実施した国内外の専門家による外部評価結果に基づいて,2011 年 4 月以降の研究センターのあり方について議論を続けてきた. そして,最終的に,本所執行部からの意見も頂戴した上で,研究活動の連続性と関連研究機関との信頼関係の持続性のために,新生 ICUS として活動を継続することになった.

研究センター継続のための活動実績評価をはじめとする本所が求める全ての条件をクリアし,晴れて 2011 年 4 月 1 日より,新生 ICUS として再スタートを切った. この度、新体制のスタートと共に ICUSReport 2011-04(No.58)に 2009、2010 年の 2 年間をまとめ報告書とした。

2 大学における都市基盤安全工学と ICUS

わが国が高度経済成長期を経て,世界の経済大国になり得た要因の一つとして,社会基盤施設の充実があることは皆が認めるところである. しかし,膨大な道路,水道,港湾等の社会基盤施設を整備し,絶大な権力を誇ったローマ帝国は,これらの施設の維持管理費用の増大に伴って財政難に陥り,最後にはローマの再建を諦めてコンスタンティノープルに遷都したが,やがて滅んでしまった. この歴史が物語るように,社会基盤施設の充実は,社会の繁栄・成熟をもたらすとともに,衰退・滅亡へと導く,両刃の剣であることがわかる.

人々が豊かで安全に暮らす環境をもたらす社会基盤施設を取り巻く環境は,時代や社会情勢で変化するが,その役割自体が変化するのではない. 変化するのは,あるいは変化させなければならないのは,それらの整備・管理・運営法であることを,私たちは歴史から学ぶことができる.

新生 ICUS は,少子高齢化,財政健全化（緊縮財政）,高度技術社会,環境負荷低減,地方分権,縮小均衡などを特徴とする 21 世紀のわが国において,人々が豊かに安全に暮らす都市環境を実現し継続するための課題の抽出と解決策を提案すること,すなわち「持続可能な都市システムの構築」を目的としている. この目的は,先進国はもちろん,途上国においても将来確実に同様の課題を抱える状況の中で,課題先進国としてのわが国が国際的に期待される役割を果たすことでもあると考えている.

過去 10 年間の ICUS の活動を踏まえ,新生 ICUS は従来の研究 3 部門を見直して,「①災害安全社会実現学」「②国土環境安全情報学」「③成熟社会基盤適応学」の 3 つを新たな研究分野のコアとして,「先端研究の推進」,「ネットワークの構築」,「情報の収集と配信」を通して,上記の目的を果たすべく国際的な活動を展開していく. また上記の 3 研究分野では,現代社会が抱える課題を踏まえた上で,それぞれ以下のような研究を実施していく.

① 各種のハザードから人々が豊かに安全に暮らす都市環境を実現し継続するための課題の抽出と解決策の提案.

② 頻発する異常気象に見られるような気候変動下の世界において,各種の広域ハザードの影響を軽減し,人々が豊かな自然環境を享受しながら共生する国土環境を実現し,持続させるための課題の抽出と解決策の提案.

③ 成熟した社会基盤施設整備の先に訪れる危機（衰退・滅亡）から,人々の豊かな生活を守り抜くための課題の抽出と解決策の提案.

3. ICUS の取り組んできた活動

3.1 ICUS の 2009 年 4 月から 2011 年 3 月に至る 2 年間の活動年表

ICUS の 2009 年 4 月から 2011 年 3 月に至る 2 年間の学内，学外活動を示す．ICUS 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 2009 年 4 月から 2011 年 3 月に至る 2 年間の学内，学外活動を示す.

ICUS の 2009 年 4 月から 2011 年 3 月に至る 2 年間の活動

2009 年	・第 16 回 ICUS オープンレクチャ「都市環境向上への地盤工学の取組み」(2009 年 4 月 6 日) ・日本リモートセンシング学会後援 (2009 年 5 月 21 日) ・生研公開 (2009 年 5 月 29-30 日) ・首都高ウォッチィング (2009 年 6 月 9 日) ・ICUS 学生セミナー (2009 年 6 月 25 日) ・第 2 回日韓タイ合同学生セミナー (2009 年 7 月 6-7 日) ・第三者評価委員会 (2009 年 8 月 4-5 日) ・第 8 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(USMCA2009) 仁川市・韓国 (2009 年 10 月 15-16 日) ・第 17 回 ICUS オープンレクチャ「安全・安心だけでないまちづくり-重要伝統的建造物群保存地区の耐震対策-」(2009 年 11 月 4 日) ・大橋ジャンクション見学会 (2009 年 1 月 26 日)
2010 年	・ナンヤン大学・ICUS セミナー (2010 年 4 月 26 日) ・第 18 回 ICUS オープンレクチャ「交通安全と ITS」(2010 年 4 月 27 日) ・生研公開 (2010 年 6 月 3-5 日) ・ICUS 学生セミナー (2010 年 7 月 13 日) ・第 3 回日韓タイ合同学生セミナー (2010 年 7 月 29-30 日) ・第 9 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(USMCA2010) 神戸市・日本 (2010 年 10 月 13～15 日) ・第 19 回 ICUS オープンレクチャ「建設産業の将来像　～海外・環境戦略と産業構造～」(2010 年 11 月 10 日) ・第３回タイ生研同窓会 (2010 年 11 月 27 日) ・モンゴル研究者来日 (2011 年 1 月 14-21 日)

東畑郁生　教授

土橋浩　氏

今村聡　氏

第 16 回 ICUS オープンレクチャ
「都市環境向上への地盤工学の取組み」
(2009 年 4 月 6 日)

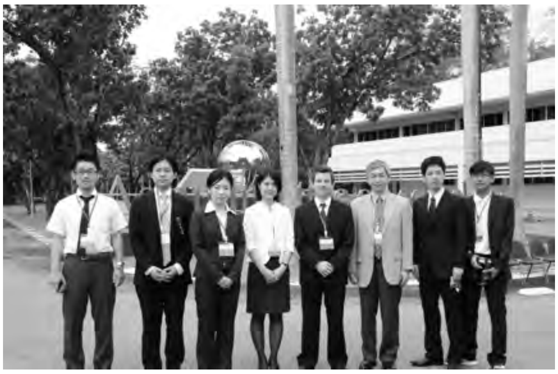
日本リモートセンシング学会
(2009 年 5 月 21 日)

生研公開
(2009 年 5 月 29-30 日)

首都高ウォッティング
(2009 年 6 月 9 日)

ICUS 学生セミナー
(2009 年 6 月 25 日)

RC67 活動開始
(2009 年 6 月~)

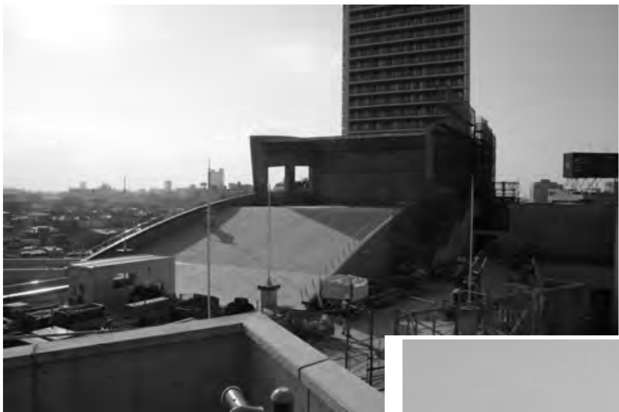


第 2 回日韓タイ合同学生セミナー
(AIT・タイ 2009 年 7 月 6-7 日)

第三者評価委員会
(2009 年 8 月 4-5 日)

第8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
USMCA2009 仁川市・韓国
(2009 年 10 月 15-16 日)

第 17 回 ICUS オープンレクチャ
「安心・安全でないまちづくり」
(2009 年 11 月 4 日)



大橋ジャンクション見学
(2009 年 1 月 29 日)

ナンヤン大学（ｼﾝｶﾞﾎﾟｰﾙ）・ICUS セミナー
(2010 年 4 月 26 日)

第 18 回 ICUS オープンレクチャ
「交通安全と ITS」
(2010 年 4 月 27 日)

東大・清華ウィーク
(2010 年 5 月 12-14 日)

生研公開
(2010 年 6 月 3-5 日)

ICUS 学生セミナー
(2010 年 7 月 13 日)

第 3 回日・韓・タイ学生セミナー
(AIT, タイ 2010 年 7 月 29 日)

第 8 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
USMCA2010 神戸市・日本 (2010 年 10 月 13-15 日)

第 19 回 ICUS オープンレクチャ
「建設産業の将来像　~海外・環境戦略と産業構造～」
(2010 年 11 月 10 日)


堺孝司　教授


千葉利宏　氏


小澤一雅　教授

RNUS/ICUS セミナー / タイ生研同窓会
(2010 年 11 月 27 日)

モンゴル研究者来日,日本の防災施設等を見学
(2011 年 1 月 14-21 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

・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～2011 年 3 月 31 日)
・桑野　玲子	准教授	(2006 年 4 月 1 日～　)
・ヘンリーマイケル	特任研究員	(2010 年 4 月 1 日～　)


横田　弘


加藤　佳孝


桑野　玲子


Henry Michael Ward

2) 都市防災・安全工学部門

・目黒　公郎	教授	
	センター長	(2008 年 4 月 1 日～　)
・市橋　康吉	客員教授	(2009 年 5 月 1 日～　)
・大原　美保	准教授	(2008 年 4 月 1 日～　)
・加藤　孝明	准教授	(2010 年 4 月 1 日～　)
・川崎　昭如	特任研究員	(2010 年 4 月 1 日～7 月 15 日　)
	特任准教授	(2010 年 7 月 16 日～　)
・沼田　宗純	助教	(2009 年 4 月 1 日～　)
・近藤　伸也	特任研究員	(2010 年 4 月 1 日～　)


目黒　公郎


市橋　康吉


大原　美保


加藤　孝明

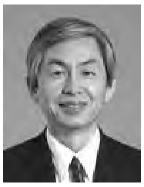

川崎　昭如


沼田　宗純


近藤　伸也

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～　)
・腰原　幹雄	准教授	(2008 年 4 月 1 日～　)
・黄　弘	准教授	(2008 年 8 月 1 日～ 2009 年 6 月 30 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～　)
・プラナブ・バルア	特任助教	(2008 年 11 月 1 日～2009 年 12 月 31 日)


沢田　治雄


腰原　幹雄


黄　弘


田中　伸治


遠藤　貴宏


Pranab J. Baruah

5) 事務局

・吉本　英子	事務補佐員	(2002 年 9 月 1 日～　2011 年 3 月 15 日　)
	学術支援職員	(2011 年 3 月 16 日～　)
・森　主門		(2009 年 4 月 1 日～　2009 年 10 月 31 日　)


吉本　英子

6) 顧問研究員

・魚本　健人	独）土木研究所　理事長	(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　知的財産部長	(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　准教授	(2006 年 4 月 1 日～)
・徳田　俊夫	株式会社大林組　タイ事務局	(2005 年 5 月 1 日～)
・鶴田　俊	秋田県立大学工学部　教授	(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	(2007 年 6 月 1 日～)


瀬戸島正博


天野 玲子


Sudhir Misra


Ansary Mehedi Ahmed


Dutta Dushmanta


須崎 純一


徳田 俊夫


鶴田 俊


Tan kiang Hwee


Worsak Kanok-nukulchai

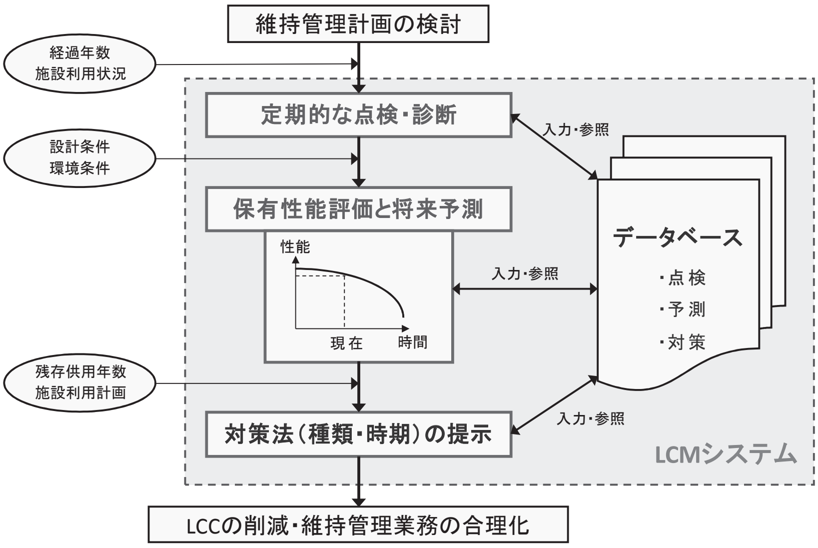

加藤 絵万

3.2.2　各部門及び ICUS としての活動

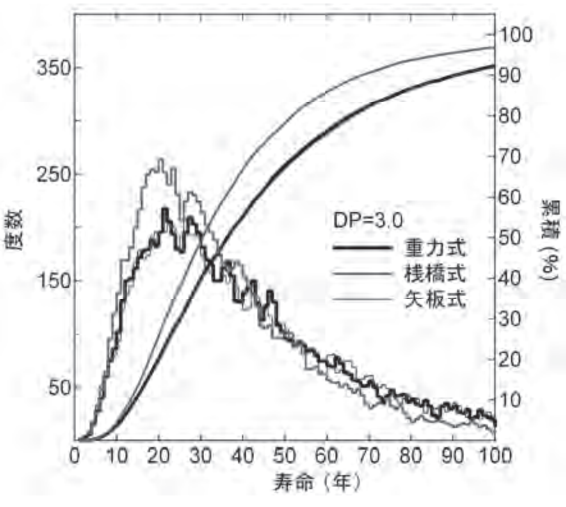
3.2.2.1　サステナブル・エンジニアリング部門

1) 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行かねばならない．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劣化が時間的・空間的に変動して進行した場合の予測寿命の分布を確率モデルにより表現し，予測結果の精度に関する検討などを進めている．



ライフサイクルマネジメントの流れ

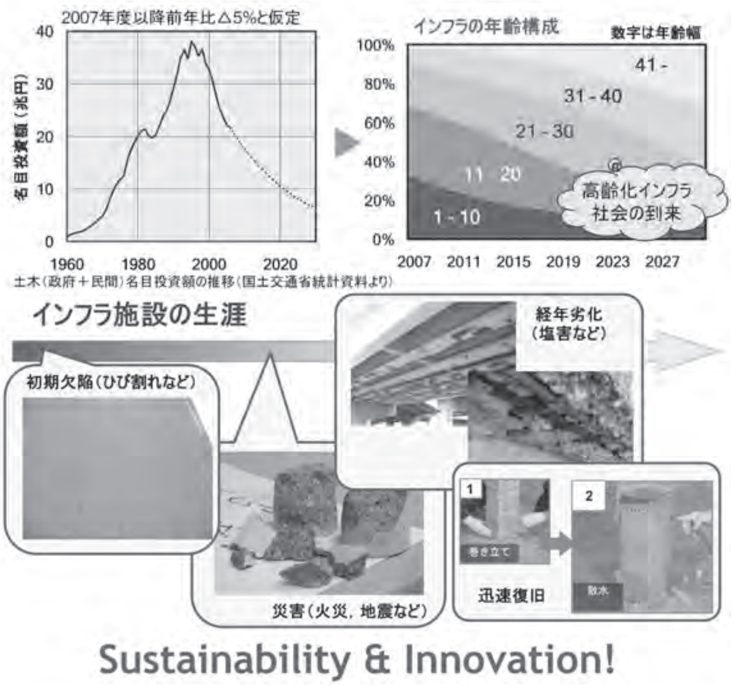


わが国の係留施設の劣化度代表値（DP）をパラメータとした予測寿命の分布

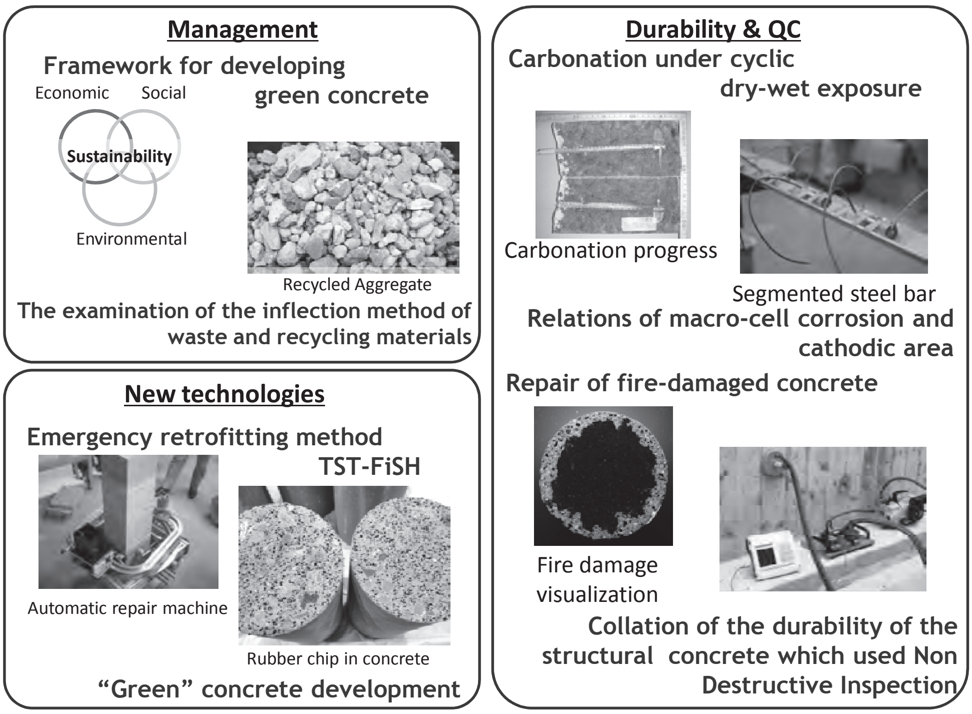
2) 加藤佳孝研究室　(建設材料マネジメント)

加藤佳孝研究室では，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．



加藤佳孝研究室の研究対象

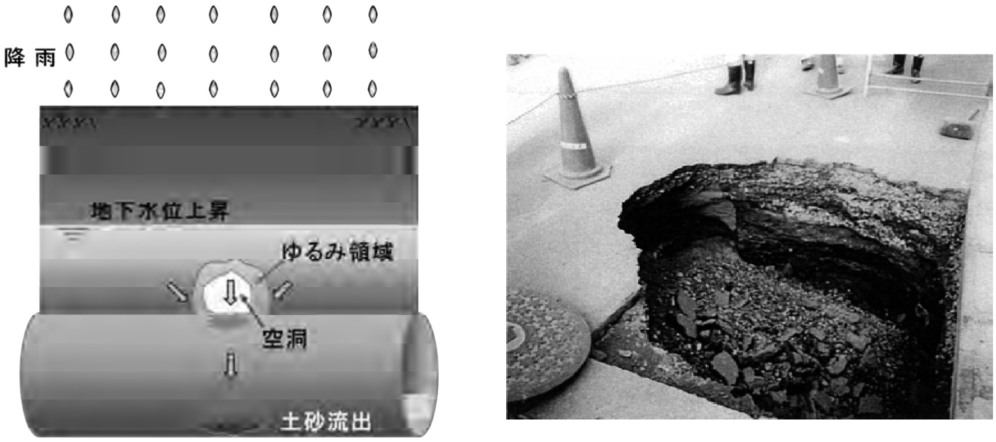


研究成果の一例

3) 桑野研究室　(地盤機能保全工学)

桑野研究室では，高精度な室内試験による地盤材料の力学特性評価のような土質力学の基礎的研究,地中構造物や土構造物の長期挙動や合理的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,土壌微生物を利用した地盤強化という異分野と協同した挑戦により地盤機能の新しい展開を模索している.

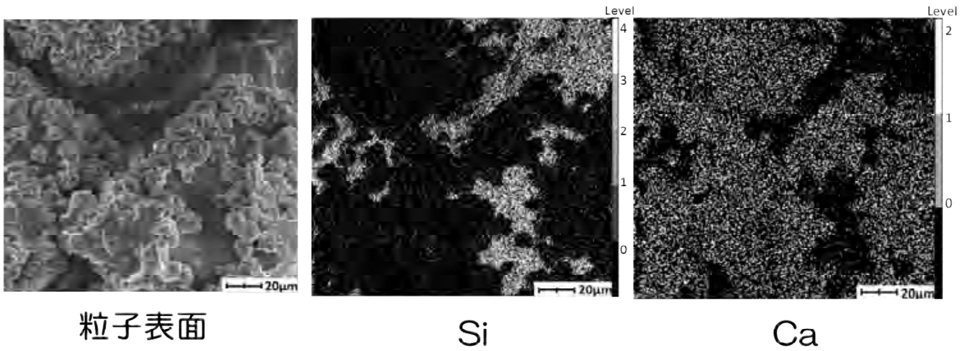
土構造物の健全性評価に関する研究では,都市部で頻発する道路陥没事故の主要因と考えられる地中埋設管の老朽化や破損に伴う周辺地盤のゆるみに着目し,実態調査や模型実験などにより地盤内空洞と周辺のゆるみの生成･進展メカニズムについて調べた.本研究によって得られた知見は,浅層部の埋設管のみならず,深度 15mのシールドトンネル掘削時の上部地盤陥没の際の原因究明および対策検討でも活用された.今後は埋設管の地震時液状化対策と組合せた土砂流出対策として,長期に安定した低強度改良土を提案することが課題である.



地中埋設管の破損とそれに伴う路面陥没

地中埋設管の合理的更新方法に関する研究では,今後急激な増加が予想される老朽地中埋設管に対して,現状で必ずしも設計方法が確立していない非開削更新の設計合理化を検討している.そのためには,長期にわたって埋設された地中埋設管の残存耐力や土圧や荷重の作用状態を解明する必要がある.本課題は実務上の要請が特に強く,得られた成果は埋設管のライフサイクルコスト低減に寄与すると期待される.

微生物機能を利用した地盤機能向上に関する研究は,土壌や地下水内に生息する一般細菌を利用して地盤固化を試みるものでまだ緒についたばかりである.それほど強い改良強度を必要としない埋設管埋設材料や既存の土構造物の強化,液状化対策など,広範囲に安価な地盤改良が必要な場合の低エネルギー技術開発を目指している.



尿素分解菌の代謝により粒子表面に生成した炭酸カルシウム

3.2.2.2　都市防災・安全工学部門

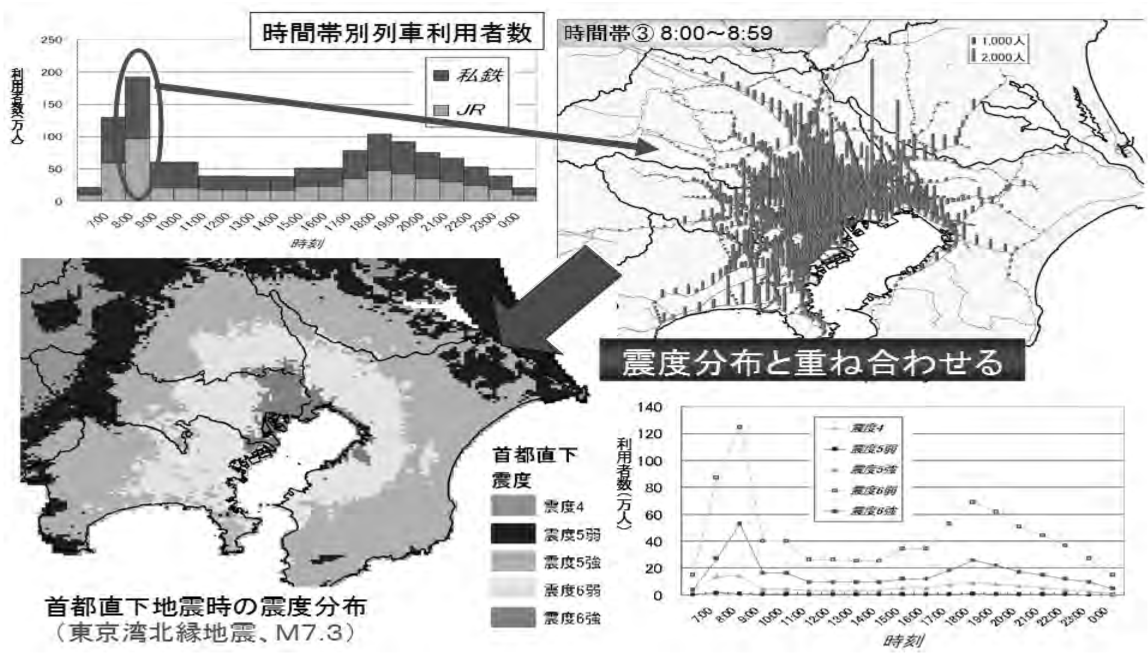
1)目黒研究室　(都市震災軽減工学)

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

新しく提案した IT トリアージシステム（TRACY）を用いた実証訓練

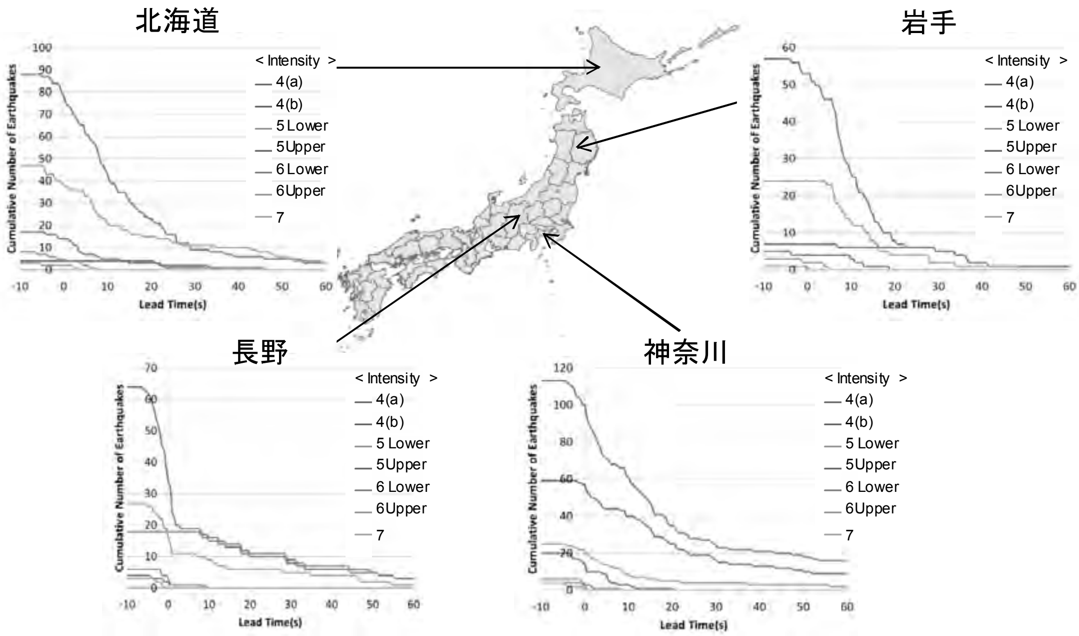


首都直下地震時の震度分布と鉄道利用者の分布の関係
中央防災会議想定の東京湾北端地震による震度分布と時間帯別の鉄道利用者の分布を比較すると,ピークの時間帯（午前 8～9 時）で，震度 6 以上の地域に約 178 万人の鉄道利用客が存在していることが判明した.

2) 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おり,近年は，災害予警報の効果的な活用法に関する研究や,災害対応における情報利用に関する研究に取り組んでいる.

災害予警報の一つに,2007 年 10 月から一般提供が開始されている緊急地震速報がある.緊急地震速報は予想最大震度が 5 弱以上の地震の際に発表されるため，実際に緊急地震速報が提供される機会が限られ，将来的な緊急地震速報の減災効果を理解しづらい状況にある．そこで，大原研究室では，過去に観測された地震データを用いて，緊急地震速報の導入により期待される猶予時間創出効果を全国的に評価することにより,情報の生産から利用までの総合的な戦略の研究を行っている.海溝型地震や活断層型地震などの地域における地震発生特性を踏まえた上で,緊急地震速報による効果が特に高い地域を抽出するとともに,将来的な地震計の増設や解析時間の短縮などの技術革新により,緊急地震速報の効果がどのように変化しうるかも評価した.これらの結果に基づき,緊急地震速報の効果を最大限に活用するための戦略を提案している.また,2008 年岩手･宮城内陸地震などの近年の地震発生の際には,緊急地震速報の発表状況を調査し,緊急地震速報受信者を対象とした受信後の対応行動に関する意識調査も行っており,情報の受け手側の課題に関する研究も行っている.情報の生産から利用までの過程を総合的に管理することで,防災情報の効果的な活用方策につながると考える.



緊急地震速報により期待される猶予時間

3) 加藤孝明研究室　(地域安全システム学)

加藤孝明研究室の研究テーマは，地域の安全を支えるシステムの構築にある．大きく以下の４つに大別できる．①都市の脆弱性の構造を解明する理論研究，②対策を社会の中で考える実践研究，③計画者（プランナー）の立場からの災害復興準備・復興計画に関する研究，④安全・安心社会の実現を支援する技術の開発，である．

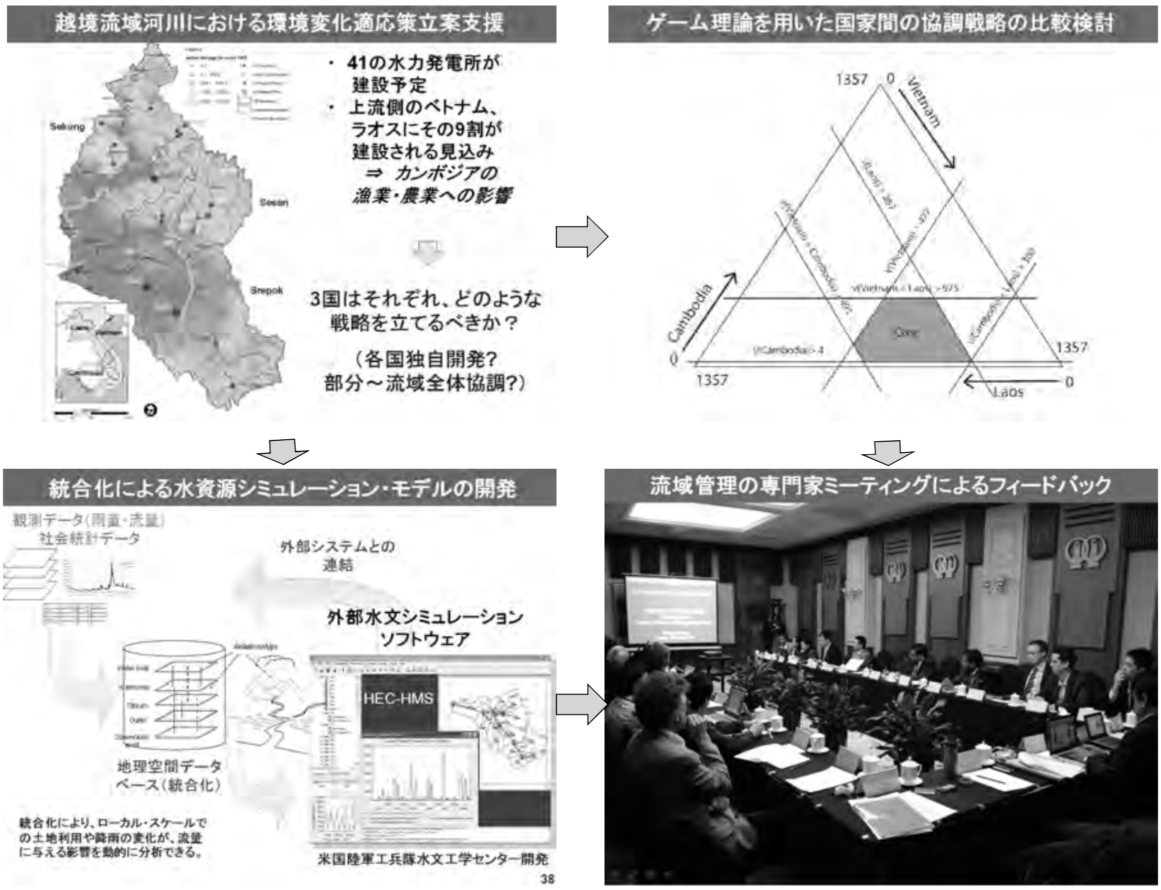
対象とするハザードは，地震，及び，気候変動に伴う水害ハザードとし，都市計画の視点を主軸に据え，研究を進めている．実用的視点を重視し，いずれの研究テーマも社会の中で明確に位置づけ，実用化を視野に入れる．自治体，NPO，民間等，学外組織との協働・連携による研究も多い．

加藤孝明研究室の研究テーマ構成

4) 川崎研究室　(流域環境変化適応学)

防災と流域環境管理の両面からの研究アプローチにより,世界規模での気候変動や人間活動の変化をふまえた,流域～都市～人のの空間スケールでの適応策や地域計画の立案に資する,問題解決型の研究を推進している.生研 ICUS,タイのアジア工科大学（AIT）,そして,国際連合大学という国際研究ネットワークを活かして,東南アジアを対象として,環境と防災の両面からの幅広い研究活動を展開している．現在は,大メコン流域圏(GMS)による地域統合構想や多数のダム開発,土地利用改変などの環境変動を踏まえた流域国家間のエネルギー融通や国際協力,地域開発について研究している.一例として,3 つの越境支流域をまたがるラオス・カンボジア・ベトナムの 3 カ国における 2040 年までの土地利用変化モデルを構築し,将来のエネルギー需要を加味した,ダム開発における最適協調策をゲーム理論により分析した（下図）.

また,災害リスクの軽減と都市熱環境の改善のための都市空間デザイン研究として,環境・エネルギーと防災の問題を融合的に捉え,住宅への耐震性雨水貯留槽の設置による環境・防災・経済面での総合評価手法を開発している（対象地：神奈川県伊勢原市）.

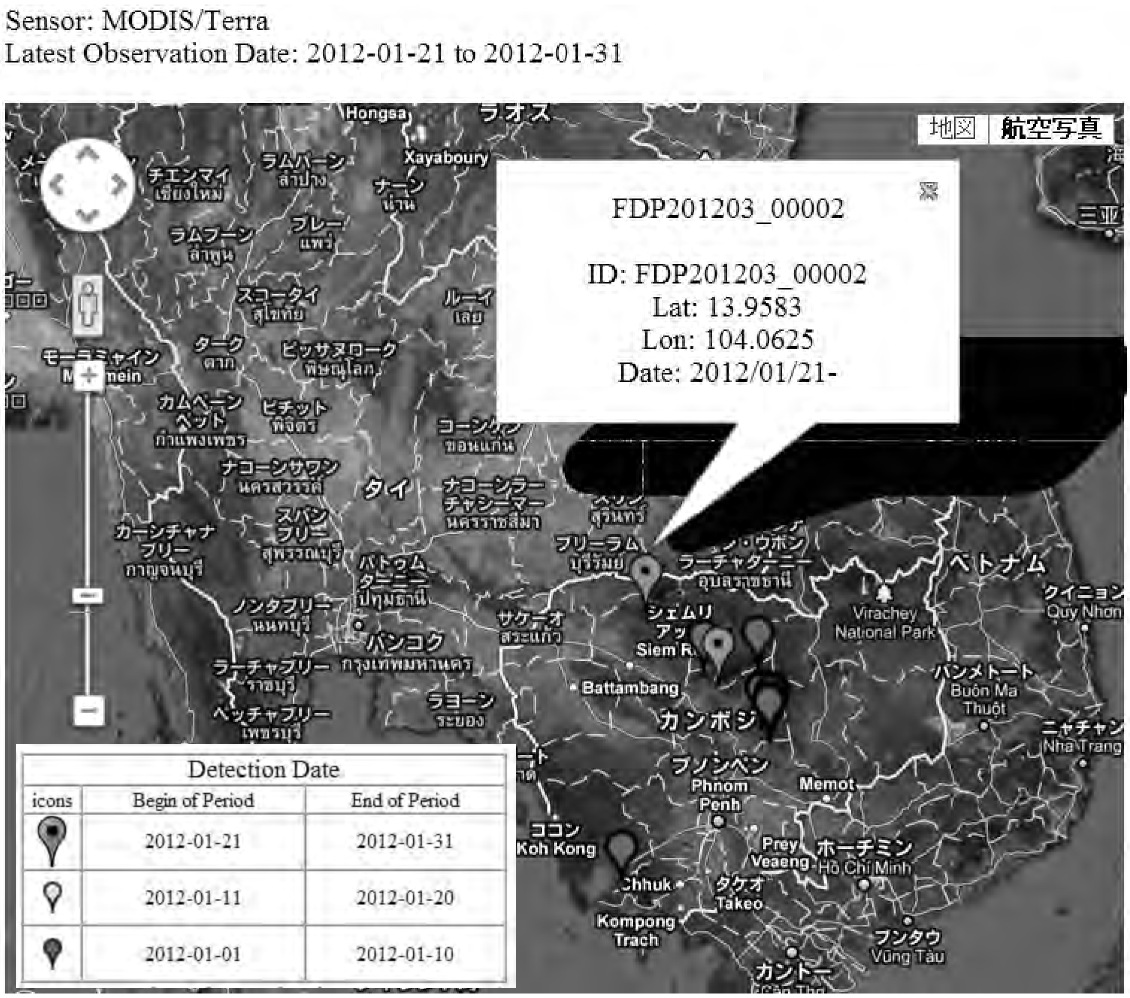


2010年中国北京で開催（主催：国際連合大学）。
メコン流域5カ国および開発関連国10カ国の専門家が集結

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)

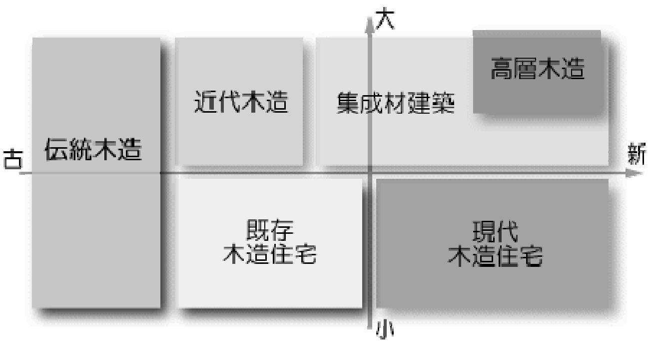
沢田研究室ではリモートセンシング技術を利用し，陸域生態系や都市環境の評価手法,自然災害の監視技術などの実用化研究を行っている．これには, 対象物に応じた様々なセンサによる計測(モニタリング)と，取得したデータから有用な情報を抽出するためのモデル構築(モデリング)が含まれる．対象としている空間スケールは，実験室レベルから都市・地域レベル，さらには大陸・全球レベルまで幅広い．また，可視・近赤外・熱赤外の波長帯をはじめ,波長分解能の高いハイパースペクトルセンサやレーザースキャナによる計測，高解像度航空デジタル写真など，対象物に応じて様々な波長帯のデータを利用している.



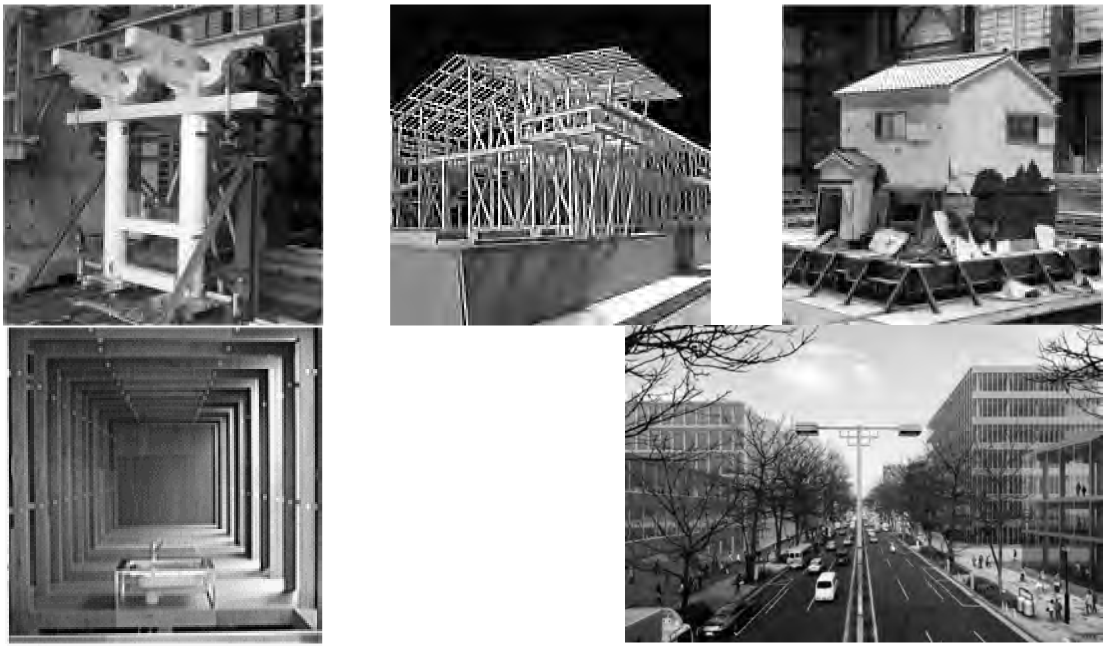
MODIS 衛星センサによるインドシナ半島の森林開発自動検知（タイ・AIT 受信データによる）
Aqua 人工衛星 MODIS センサによる大陸レベルの衛星画像（生産技術研究所受信データ）

2)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．



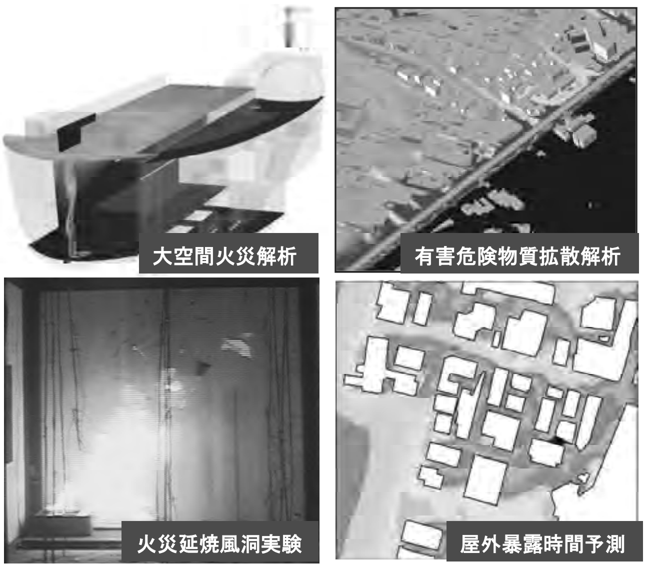
腰原研究室の研究テーマ



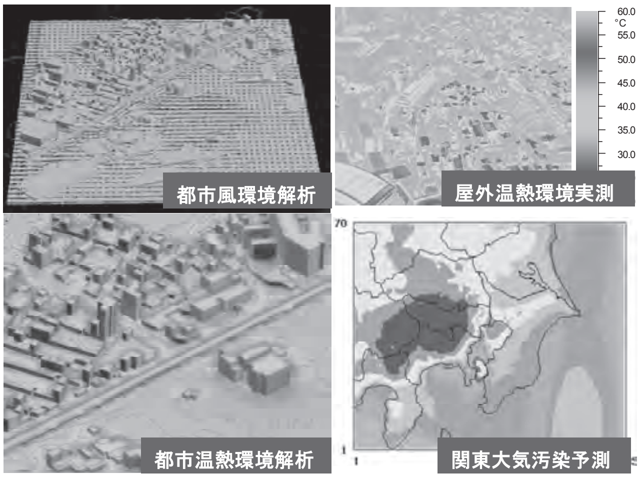
木質構造建築

3) 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．



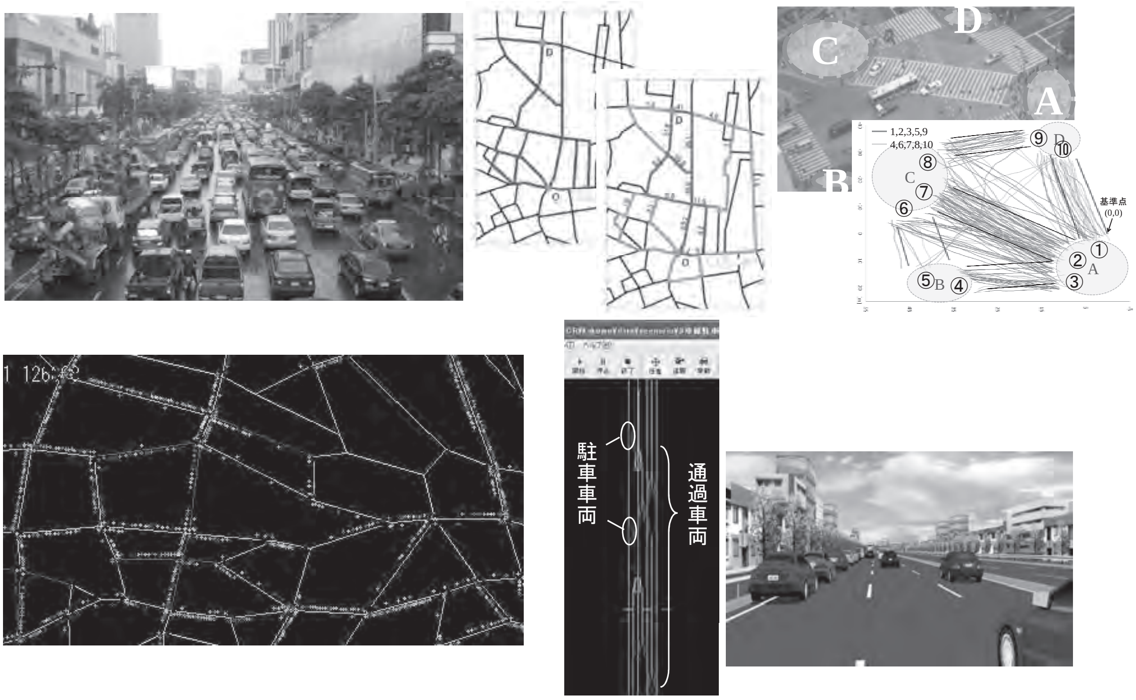
都市建築安全



都市建築環境

4) 田中研究室 (都市交通マネジメント)

交通は都市の社会・経済活動を維持する上で不可欠な存在であるが，交通事故・交通渋滞・排出ガスなど解決すべき課題は多い．また，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．さらに，災害時に交通は避難・救援・支援・復旧・復興の各段階で極めて重要な役割を担うものであり,この機能を災害時にも最低限維持することは重要な課題である.当研究室では交通施設の管理・運用や利用者の誘導といったマネジメントを通じて，交通に関わる諸問題を解決する方策を見出すため,観測調査やシミュレーション等の手法を用いた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 RC62

(財)生産技術研究奨励会の特別研究会として平成 20 年度に発足した「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」の活動を，平成 21，22 年度も継続した.変状機構検討 WG (WG1) と点検・計測技術検討WG (WG2) に分けて活動した. WG1では，具体的な構造物（地下埋没ボックスカルバート構造物，テールアルメ擁壁）を対象として，「地盤と構造物の相互作用を考慮した変状機構（変状原因・作用機構・劣化機構）の整理」，「地盤と構造物の相互作用を考慮した性能評価および劣化予測に必要となる情報の整理」を実施した. WG2 は，WG1 での検討結果に基づき，想定される変状を評価するための計測，モニタリング手法に関する調査・検討をおこなった. 調査結果等は，平成 21－22 年度報告書としてまとめた.

参加企業一覧
平成 21,22 年度

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

16 社

RC62 研究会の様子

3.2.3.2　RC67

平成21年度に，新たに「環境にやさしい」は法当か？「環境配慮型社会へのCSR活動とその評価に関する研究会 RC-67」を発足した．研究会の目的は，企業の社会的責任と訳される CSR (Corporate Social Responsibility) の活動は，企業が自発的に，企業が自ら永続性の実現とともに，持続可能な未来を社会とともに築いていく活動である，企業経営の根幹にかかわる姿勢の現れを示す．日本では社会とともにどのような視点で CSR を捉え，いかに具体的な活動を展開するべきか，確立した考え方を持つ企業はまだまだ少ないと言える． RC67 では，世界的に通じるCSRの考え方に立ちながら，特に，近年関心が高まっている地球環境問題に関わる日本企業の国内外でのCSR活動の実態を調査，検討し，CSR活動の指針をしますことを目標としている． 平成 21 年度は，CSR 活動を各社の環境報告書から読み込み，そのリストを作成して特徴を業種別に検討した．その中から森林を対象とするCSR活動に着目して研究会をすすめた． 平成22年度は，代表的な企業にヒアリングに伺い，森林に関する CSR 担当者の生の声を聴くことを心掛けた．活動の規模，継続性，活動の評価(PDCA)，環境教育，地域貢献，林業経営支援，水土保全，生物多様性などのキーワードを用いて活動を評価し，活動の向上に資する評価シートを提案した．21 年度，22 年度それぞれ報告書としてまとめた.

参加企業一覧
平成 21 年度

三菱製紙株式会社	東日本高速道路株式会社
中日本高速道路株式会社	株式会社　高速道路総合技術研究所

4 社

平成 22 年度	
三菱製紙株式会社	株式会社　高速道路総合技術研究所
中日本高速道路株式会社	
3 社	

講演題目と講演者所属 (報告会)

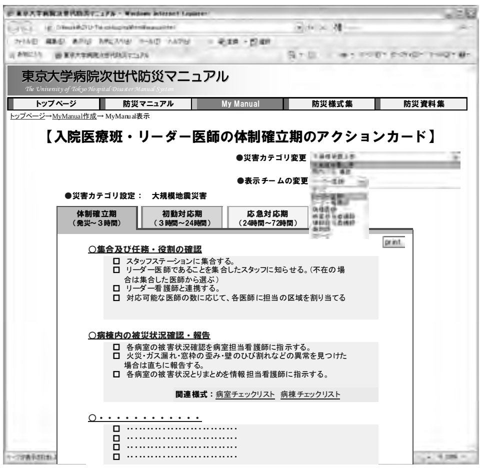
	氏名・所属	講演題目
2011 年 5 月	大川幸樹氏　林野庁計画課長補佐	国際森林年の意義と森林の重要性


RC67 研究会の様子

3.2.3.3　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，2007 年～2009 年度にかけて,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た.災害拠点病院は,災害時に地域の救護所等で対応できない重症者に対処する義務を負う.東大病院は,災害時の広域避難場所である東京大学キャンパス内に立地している点で,他の災害拠点病院とは異なる特殊性も有している.そこで,東大病院の状況を踏まえた上で,東大病院の防災マニュアルのあり方を検討するとともに, 次世代型の防災マニュアルシステムの基本設計を行った．リーダー医師・看護師および一般の医師・看護師は,災害時の対応について,アクションカード形式でマニュアルを理解することができる.アクションカードの一つ一つのアクションをクリックすると,タスクカード画面に遷移し,その詳細を画面でみることができる.マニュアルの内容は,WEB 上で更新･追加することができ,自分に関わる部分を抽出して自分専用のマニュアルを作成することもできる.

トップページ



アクションカード画面

タスクカード画面

タスクカード更新画面

病院向け次世代型防災マニュアルの仕様設計

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．2009 年度から 2010 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
2008 年四川大地震の復興調査	2008.8.13-17	四川省・成都・都江堰　(中華人民共和国)	加藤孝明
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）の立ち会い)	2009.5.21-22	北海道苫小牧	桑野玲子，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	桑野玲子が国土交通省路面保全検討委員会メンバーとして参加
カウラック地区における被災地復興調査	2009.9.19-24	プーケット(タイ王)	目黒公郎
パダンの災害調査	2009.10.15-20	パダン (インドネシア)	沼田宗純
ジョグジャカルタで当該地に適した PP-バンド耐震補強法の開発と普及のための現地調査	2010.9.25-10.4	バンダアチェ・ジョグジャカルタ (インドネシア)	目黒公郎

2008 年四川大地震の復興調査	2011.3.7-13	四川省・成都・都江堰　(中華人民共和国)	加藤孝明
東北関東大震災被害調査	2011.3.26-27	岩手県内	沼田宗純
東北関東大震災被害調査	2011.3.29-4.3	宮城県内・岩手県内	目黒公郎
東北関東大震災現地調査	2011.3.11-4.1	福島県立医科大学病院	大原美保

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.

Wicaksono, R.I. and Kuwano, R. (2009), “Small Strain Stiffness of Toyoura Sand Obtained from Various Techniques in Laboratory Measurements”, Earthquake Geotechnical Engineering Satellite Conference, TC4 of ISSMGE

Wicaksono, R.I. and Kuwano,R. (2009), “Small Strain Stiffness of Uniform Granular Materials Based on Dynamic and Static Measurements”, Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering, ICSMGE 2009, Alexandria, pp.287-290.

Kuwano,R. and Ebizuka,H. (2010), Trapdoor tests for the evaluation of earth pressure acting on a buried structure in an embankment, Proc. 9th International symposium on new technologies for urban safety of mega cities in Asia, USMCA, Kobe, October 2010, CD-ROM.

Suwal,L.P., Kuwano,R. and Sato,T. (2010), Introduction of Trigger Bimorph Method: Transducer for Elastic Wave Measurement in Laboratory Specimens, Proc. of 12th International Summer Symposium, International Activities Committee, JSCE, pp.151-154.

Suwal, L.P. and Kuwano,R. (2011), Small Strain Stiffness Measurement of Sand and Gravel Using Disk Shaped Piezo-Electric Transducer, Proceeding of 5th International Conference on Earthquake Geotechnical Engineering, CD-ROM.

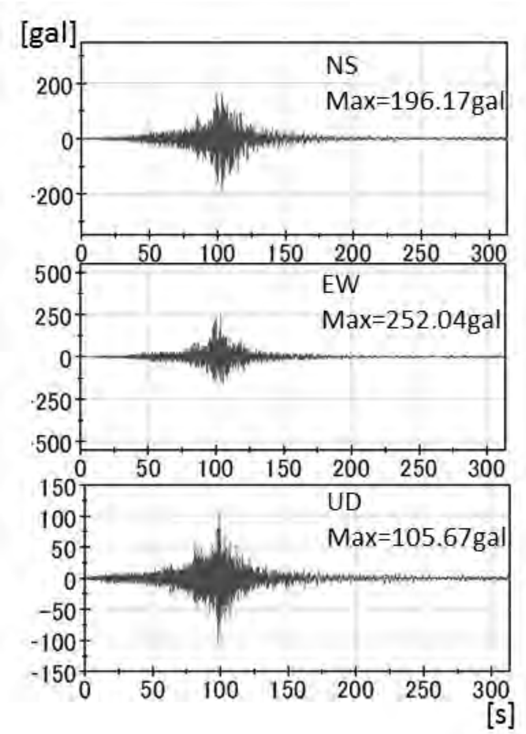
3.3.1.3　生研建物の地震モニタリングシステム

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．

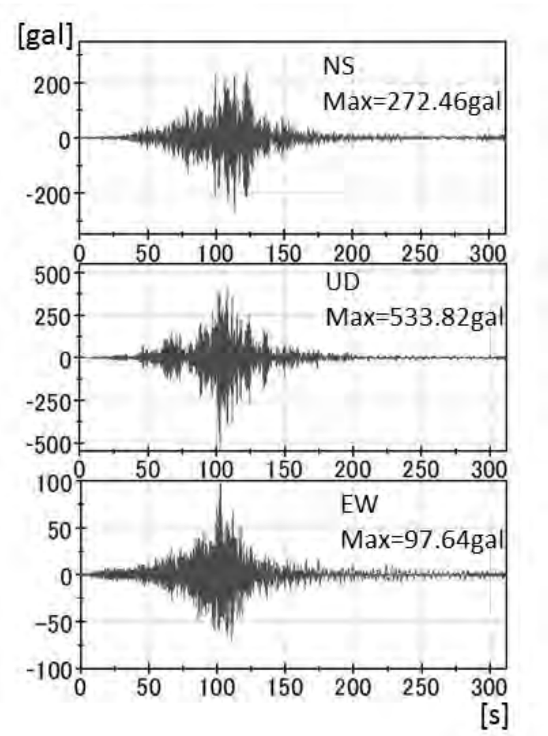
2009 年 8 月 11 日 5 時 7 分頃に,静岡県の駿河湾（御前崎の北東,約 40ｋｍ付近）を震央とする震源深さ約 23km,マグニチュード 6.5 の地震が発生し,最大震度 6 弱(静岡県伊豆市,焼津市,牧之原市,御前崎市)が観測された．　F 棟高層棟の 8 階に設置した IT 強震計では,東西方向で最大加速度 62.28gal を記録し,計測震度は 4.0 となった．グランドの地表において地震応答観測・解析装置が観測した地震波形では,最大加速度は東西方向で 28.67gal である．

2011 年 3 月 11 日 14 時 46 分頃に，三陸沖（牡鹿半島の東南東，約 130 ㎞付近）を震源とする震源深さ約 24 ㎞，マグニチュード 9.0 の地震が発生した．この地震により，宮城県栗原市では最大震度 7 が観測され，東北・関東地方に甚大な被害が生じた．F 棟高層棟の地上 8 階に設置した IT 強震計では,東西方向で最大加速度 533.82gal を記録し,計測震度は 6 弱（計測震度 5.8）となり，地震計設置後に最も大きな加速度となった．グランドの地表では,最大加速度は東西方向で 252.04gal であった．以

下に,記録された波形を示す.本地震以降も,引き続き観測を続けている.



地上での加速度波形

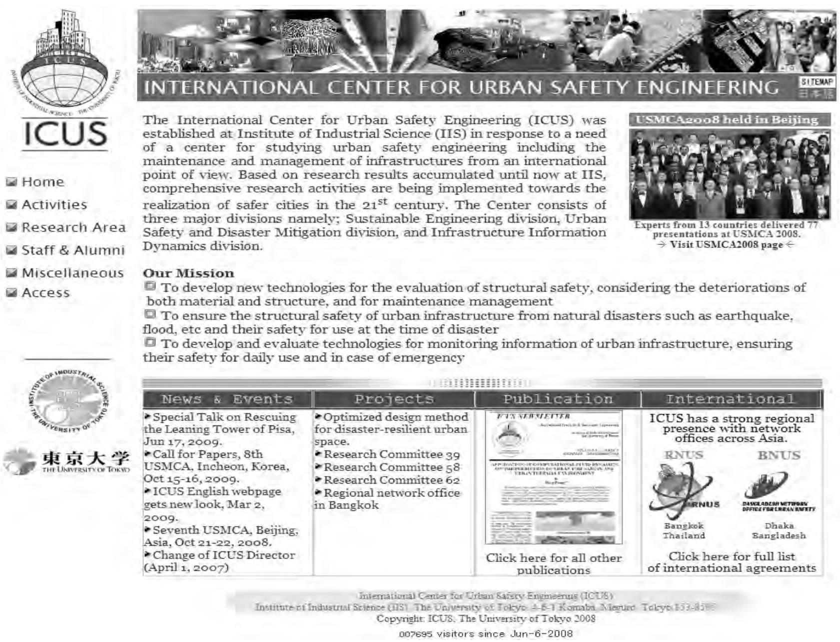


F 棟 8 階での加速度波形

2009 年地上（左）と F 棟 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 サイトで公開してる．日本語版と英語版が準備されており，各種行事の案内，活動報告,出版物の案内,Newsletter の掲載をおこなっている．RNUS, BNUS の web サイトともリンクし，海外経典での成果も閲覧可能となっている．アドレスは，**http://icus.iis.u-tokyo.ac.jp/**



ICUS　ホームページ

3.3.3　公開講演会

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．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．2009 年 3 月から 2011 年 3 月の 2 年間では，「都市環境向上への地盤工学の取組み」,「安全･安心だけでないまちづくり-重要伝統的建造物群保存地区の耐震対策-」,「交通安全と ITS」,「建設産業の将来像　～海外・環境戦略と産業構造～」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.

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す.

日時	主催タイトル	講演者氏名	所属	題目
2009 年 4 月 3 日	都市環境向上への地盤工学の取組み	東畑郁生 土橋　浩 今村　聡	東京大学教授 首都高速道路㈱ 大成建設㈱	廃棄物地盤の工学的特性とその利用可能性 首都高速中央環状線プロジェクト 二酸化炭素削減に向けた技術開発の取組み
2009 年 11 月 4 日	安全・安心だけでないまちづくり	苅谷勇雅 河合直人 後藤　治	小山工業高等専門学校長 建築研究所 工学院大学教授	文化財として保存すべきもの 住宅として守るべきもの 文化財保存と安全性の両立
2010 年 4 月 27 日	交通安全と ITS	桑原雅夫 西田　泰 赤羽　弘和 山田　勝規	東北大学教授/前 ITS センター長 科学警察研究所交通科学部長 千葉工業大学教授 日産自動車 IT&ITS 開発部	先進モビリティ研究センターの交通安全への取り組み 交通事故分析に基づくＩＴＳへの期待 情報化と市民参加による地域交通安全 ITS 自立型･強調型運転支援システムの最新動向
2010 年 11 月 10 日	建設産業の将来像～海外・環境戦略と産業構造～	堺　孝司 千葉利宏 小澤一雅	香川大学教授 (有)エフプランニング 東京大学教授	21 世紀における建設産業の役割－地球環境問題の視点から－ 建設産業の明日を考える インフラチームジャパンを世界へ

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.

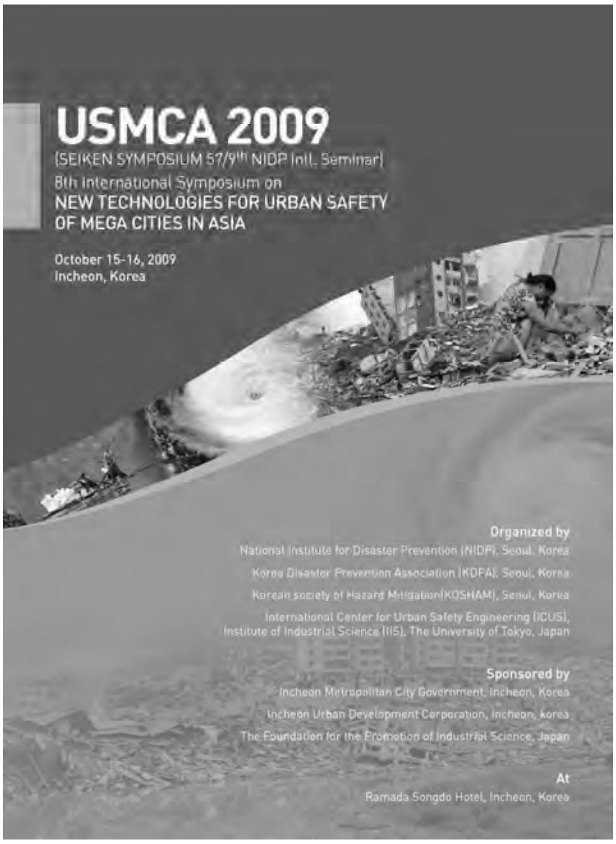
- Urban Disaster Mitigation
- Safety and Security Assessment of Urban Infrastructure
- Space Technologies and GIS for Monitoring and Assessment of Urban Safety
- Planning and development of urban infrastructure
- Threat reduction and consequence management
- Environmental impact assessment of urbanization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

以下に, 2009 年 4 月から 2 年間に開催したシンポジウムの概要を記す.

・2009 年
　・概要

第 8 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 (USMCA2009)	
Venue	Ramada Songdo Hotel, Incheon, Korea
Date	Oct. 15-16, 2009
Co-organizers	・ National Institute for Disaster Prevention (NIDP), Seoul, Korea ・ Korea Disaster Prevention Association (KDPA), Seoul, Korea ・ Korean Society of Hazard Mitigation (KOSHAM), Seoul, Korea
Sponsors	・ Incheon Metropolitan City Government, Incheon, Korea ・ Incheon Urban Development Corporation, Incheon, Korea ・ The Foundation for the Promotion of Industrial Science, Japan ・ Global Center of Excellence for Sustainable Urban Regeneration, The Univ. of Tokyo

・第 8 回　ICUS シンポジウム開催案内パンフレット



パンフ

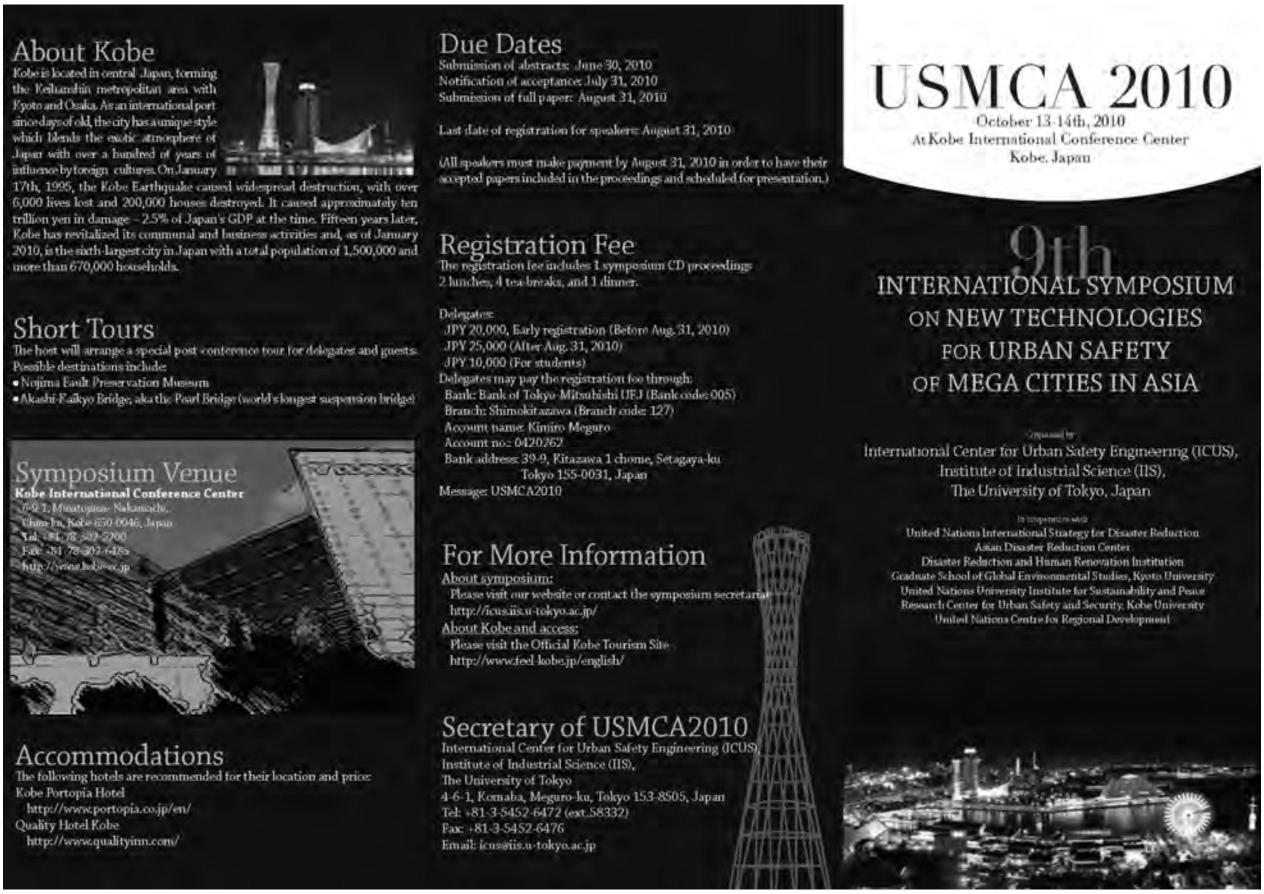
・総参加人数：216 名
　日本：42 名　　他国：174 名

・2010 年

・概要

第 9 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ンポジウム(USMCA2010)	
Venue	Kobe International Conferece Center, Kobe, Japan
Date	Oct. 13-15, 2010
Co-organizers	none
Sponsors	・Global Center of Excellence for Sustainable Urban Regenearaion, The University of Tokyo, Japan ・The Foundation for the Promotion of Indsutrial Science, Japan ・Meet in Kobe 21, Japan

・第 9 回　ICUS シンポジウム開催案内パンフレット



パンフ

・　総参加人数：125 名

日本：65 名　他国：60 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 70 余ケ国, 在日本大使館・領事館および約 1300 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 2009 年 4 月から 2011 年 3 月までに発行した刊行物のリストを記す.

・ICUS Newsletter Volume 9, Number 1－ Volume 10, Number 4
・ICUS Report　No. 37-54
・SEIKIEN SYMPOSIUM
・RC62
・RC67
・Annual Report
・ICUS パンフレット
・ICUS カレンダー

ICUS Newsletter
2009

VOLUME9 NUMBER 1, APRIL - JUNE 2009	
Massively Parallel Simulation of CO2 Geologic Storage	Satoshi Imamura and Hajime Yamamoto, Taisei Corporation Ltd.
Ground Cave-in in Golf Course	Reiko Kuwano,ICUS
VOLUME 9 NUMBER 2, JULY - SEPTEMBER 2009	
Modeling Volcanic Risk in Tokyo	Christina Magill, Risk Frontiners, Macquarie University, Sydney, Australia
Flood Damage in Japan	Miho Ohara, ICUS
Report on the West Java Earthquake on September 2, 2009	Teddy Boen, World Seismic Safety Insitiative / Danny Hilman Natawidjaja, Indonesian Institute of Sciences
Report on Suruga Bay Earthquake, Japan	Muneyoshi Numada, ICUS
Robust Optimum Design for Smoke Control System using CFD and Genetic Algorithms	Hong Huang, Center for Public Safety Research, Tsinghua University, China
Survey on a New Tsunami Disaster Mitigation System	Kimiro Meguro, ICUS
VOLUME 9 NUMBER 3, OCTOBER - DECEMBER 2009	
Preservation of Historical Architecture and Compliance with Today's Safety Laws	Osamu Goto, Professor, Kogakuin University
The 2009 Samoa Earthquake Induced Tsunami: A Quick Survey from the Field	S. Koshimura, Professor, Tohoku University
Japan's Expected Role for Transboundary Collaboration in the Mekong Region	Akiyuki Kawasaki,ICUS
Survey of September 30, 2009 Sumatra Earthquake	Muneyoshi Numada, ICUS
VOLUME 9 NUMBER 4, JANUARY - MARCH 2010	
Earthquake Countermeasures for Safer future in Korea	Waon-Ho Yi, Director, National Institute for Disaster Prevention/Prof. , Kwangwoon University, Korea
Integration of Advanced Technologies for Construction, Environmental Protection, and Safety in the Yamate Tunnel	H. Dobashi
Tour of the Uemachi Terrace, a Potential Disaster Area	Muneyoshi Numada, ICUS
15 years after the Kobe Earthquake: Basic Step for Earthquake Disaster Reduction and the Necessity for an Integrated Disaster Management Strategy	Kimiro Meguro, ICUS

2010

VOLUME 10 NUMBER 1, APRIL - JUNE 2010	
Expectations for its Based on Traffic Accident Analysis	Yasushi Nishida, Director, Department of Traffic Science, National Research Institute of Police Science
Exploring Environmental Change Adaptation Covering Disaster Management Aspects using Watershed as a Unit	Akiyuki Kawasaki, ICUS
VOLUME 10 NUMBER 2, JULY - SEPTEMBER 2010	
Restructuring of Urban Areas and Modernization of Rural Areas during Post-Earthquake Reconstruction	Takaaki Kato, ICUS
Flooding of the Indus River in Pakistan	S. Nazir
2010 Darfield (Canterbury) Earthquake – Initial Report	G. MacRae, Professor, University of Canterbury
VOLUME 10 NUMBER 3, OCTOBER - DECEMBER 2010	
The Role of the Construction Industry in the 21st Century Considering Global Environmental Issues	Koji sakai, Professor, Kagawa University, Takamatsu, Japan
Volcanic Eruption in Merapi, Indonesia, on October 26,2010	Silvia F. Herina, Research Institute for Human Settlements, Agency for Research, Indonesia Ministry of Public Works
Sustainable Concrete Considering the Japanese Context	Michael Henry, ICUS
VOLUME 10 NUMBER 4, JANUARY - MARCH 2011	
Eastern Japan Struck by Magnitude 9.0 Earthquake and Massive Tsunami	Kimiro Meguro, ICUS
Risk management of cultural heritage in Kyoto	Kenzo Toki, Professor and Director, Research Center for Disaster Mitigation of Urban Cultural Heritage, Ritsumeikan University, Japan
2011 Christchurch Earthquake – quick report from the field	Yoshiaki Nakano, Prpfessor, IIS, The University of Tokyo
Seminar on "Current Seismology and Related Urban Safety Engineering Researches in Mongolia	Y. Ichihashi, ICUS
Symposium on forefront and challenges of water resources management in Bangkok, Thailand	A. Kawasaki, ICUS

・**ICUS Report**

2009

ICUS REPORT2009-01

2nd Joint Student Seminar on Civil Infrastructures July 6, 2009

ICUS REPORT2009-02

ICUS ACTIVITY REPORT Summarizing the Activity of Triennuium (2006-2008)

ICUS REPORT2009-03

ICUS 第三者評価委員会報告書

ICUS REPORT2009-04

RNUS Annual Report 2008 Seismic Hazard Assessment in Thailand

ICUS REPROT2009-05

2009 New Technologies for Urban Safety of Mega Cities in Aisa

ICUS REPORT2009-06

第 16 回 ICUS オープンレクチャ　都市環境向上への地盤工学の取組み

ICUS REPORT2009-08

第 17 回 ICUS オープンレクチャ　安全・安心だけでないまちづくり-重要伝統的建造物群保存地区の耐震対策-

ICUS REPORT2009-10

長期的津波監視の維持を重視した相互的津波防災戦略モデルの提案と発展途上国への導入

ICUS REPORT2009-12

BNUS Annual Report-2009

2010

ICUS REPORT2010-01

3rd Joint Student Seminar on Civil Infrastructures July 30-31, 2010

ICUS REPORT2010-02

ICUS External Evaluation Committee Report / ICUS 第三者評価委委員会報告書

ICUS REPORT2010-03
Forefront and Challenges of Geospatial Technologies for Environment and Disaster Management in Southeast Asia
ICUS REPORT2010-04
2010 New Technologies for Urban Safety of Mega Cities in Asia
ICUS REPROT2010-05
加藤（佳）研究室　研究活動リポート　2002 年―2011 年
ICUS REPORT2010-06
Properties and sustainablility evaluation of green concrete utllizing waste and recycled materials
ICUS REPORT2010-07
第 18 回 ICUS オープンレクチャ　交通安全と ITS
ICUS REPORT2010-08
Forefront and Challenges of Water Resources Management in Southeast Asia
ICUS REPORT2010-09
BNUS Annual Report-2010

RC62, RC67
2009
ICUS COMMITTEE REPORT2009-01
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　平成 20 年度報告書
ICUS COMMITTEE REPORT2009-02
環境配慮型社会への CSR 活動とその評価に関する研究会　平成 21 年度報告書
2010
ICUS COMMITTEE REPORT2010-01
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　平成 21-22 年度報告書
ICUS COMMITTEE REPORT 2010-02
環境配慮型社会への CSR 活動とその評価に関する研究会　平成 22 年度報告書

Annual Report
Annual Report 2008 年度 日本語版　　Annual Report 2008 年度 英語版
Annual Report 2009 年度 日本語版

- ICUS 紹介ビデオ(日本語/英語)

ICUS 紹介ビデオ

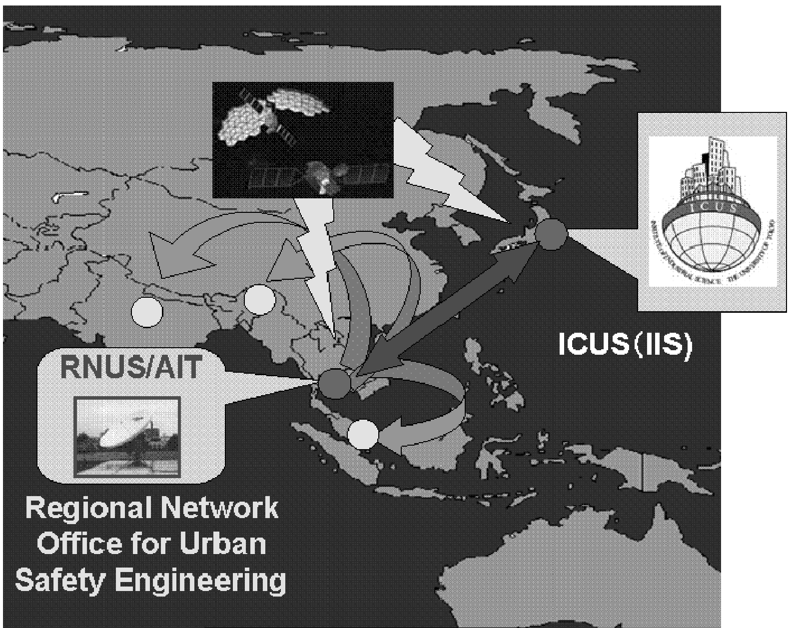
3.4　都市の安全性向上のためのネットワークの形成

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, 都市の安全性向上を目的にネットワークの形成にかかわる各種の活動を国内外で実施している.

ICUS のネットワーク

3.4.1　研究協力協定の締結

2011 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), タマサート大学（タイ）,韓国防災研究所（韓国）と研究協力協定を締結している.



ICUS の研究協力協定先

協定先一覧			
調印日	協定側	代表者	国名
2002.10.29	School of Civil Engineering, Asian Insititute of Technology	Dean Worsak Kanok-Nukulchai	Thailand
2003.2.21	Bangladesh Earthquake Society (BES)	Member Secretary Mehedi Ahmed Ansary	Bangladesh
2003.2.21	National Center for Earthquake Engineering (NCEE) Department of Civil Engineering Bangladesh University of Engineering & Technology (BUET)	Co-cordinatior Mehedi Ahmed Ansary	Bangladesh
2004.10.20 protocol	Indian Institute of Technology Kanpur	Director Sanjay GDhande	India
2005.3.28	Department of Civil Engineering, National University of Singapore	Head Fwa Tien Fang	Republic of Singapore
2005.3.29	College of Engineering, Nanyang Technological University	Dean Lim Mong King	Republic of Singapore
2005.3.29	Protective Technology Research Centre, School of Civil and Environmental Engineering, Nanyang Technological University	Director Pan Tso-Chien	Republic of Singapore
2006.1.18	港湾空港技術研究所 LCM 研究センター	センター長 横田弘	日本
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
2006.10.18	Sirindhorn International Institute of Technology Thammasat University	Director Sawasd Tantaratana	Thailand
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
2007.2.22	Global U-City Construction & Informaiton (Gucci) Hub Department of Civil Engineering (BK21) Han Yang University	Director Byung-Wan Jo	Korea
2007. 3.6	Department of Construction Engineering, National Kaohsiung First University of Science and Technology	Chairman Tai-Ping Chang	Chinese Taipei
2007.6.29	Center for Public Safety Research, Tsinghua University	Director Weicheng Fan	People’s Republic of China
2008. 3.18	School of Applied Sciences and Engineering Monash University, Gippsland Campus	Head Samuel B. Adeloju	Australia
2009. 6.30	National Institute for Disaster Preventin (NIDP), National Emergency Management Agency	Director Waon-Ho Yi	Korea

3.4.2 Network Office for Urban Safety の活動

3.4.2.1 Regional Network Office for Urban Safety: RNS

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．

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

主な活動

2009 年度
プロジェクト
- Seismic Hazard and Vulnerability Mapping of Dhaka, Chitagong & Sylhet City Corporation
- Master Plan for Earthquake and Building Collapse Hazard Prevention and Mitigation　(Phase 1)

セミナー
- 2nd Joint Student Seminar on Civil Infrastructures on July 6-7, 2009
- Lecture on “Introduction of ICUS activities and remote sensing study in regional scale” on December 18, 2009, Prof. H. Sawada, ICUS

出版物
- RNUS annual report 2008-2009

2010 年度
プロジェクト ・セミナー
-RNUS Seminar on **“** Fiber Reinforced Concrete **”on** June 30, 2010 at AIT

- 3rd International Joint Student Seminar on Civil Infrastructures on July 29-30, 2010 at AIT
- Forefront and Challenges of Geospatial Technologies for Environmental and Disaster Management in Southeast Asia on November 27, 2010 at Phatumwan Princess Hotel, Bangkok
- Forefront and Challenges of Water Resources Management in Southeast Asia on January 29, 2011 at Novotel Bangkok Fenix Ploenchi, Bangkok

出版物
- Forefront and Challenges of Water Resources Management in Southeast Asia
- Forefront and Challenges of Geospatial Technologies for Environment and Disaster Management in Southeast Asia
- 3rd Joint Student Seminar on Civil Infrastructures

3.4.2.2 Bangladesh Network Office for Urban Safety: BNUS

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．

主な活動

2009 年度

プロジェクト
- Seismic Microzonation for Cox’s Bazar Municipal Area
- Earthquake vulnerability assessment at Old Dhaka
- Strong Motion Monitoring System in Bangladesh: 2007 to 2009
- Geophysical surveys at Srimangal area, Sylhet
- Analysis of climate change phenomena in Bangladesh

ワークショップ
- SAARC training course on “earthquake risk mitigation” on March 30- April 4, 2009
- SAAEC training program on “climate change adaptation and disaster risk reduction in south Asia on July 9-15, 2009
-Workshop on “disaster risk reduction through schools” on August 3-4, 2009
-`Regional workshop on “reducing earthquake risk through comprehensive preparedness and mitigation planning” on December 10-12, 2009
-` One day workshop on “fire hazard in Bangladesh and remedial measures” on February 10, 2010

出版物
- BNUS annual report－ 2009

2010 年度

プロジェクト
- Assessment of RC bridges using Ground Penetrating Radar and Microtremor
- Assessment of low lands of Dhaka city using CPT, Microtremor and SPT
- Assessment of highrise buildings in Dhaka for Fire
- Strong Motion Monitoring System in Bangladesh: 2009 to 2011

ワークショップ
- Training course on “ Application of GIS for natural hazard and risk assessment ” on September 25-29, 2010
-Workshop on “Risk resilient infrastructures: role of education and training” on November 13-14, 2010
- Lecture course and seminar on “Urban building fire mitigation and safety issues in Asian mega cities: Bangladesh chapter” on December 21-23, 2010
- Workshop on “ Fundamental concepts of fire fighting and formulation of legislation regarding hazardous fire ” on January 20, 2011

出版物
- BNUS annual report－ 2010

3.5　スタッフ海外出張記録

2009 年度

教官名	期間	場所	用務
目黒公郎	4/10-12	Incheon/Korea	To attend a meeting on the management of USMCA2009
	4/7-9	Chengdu,/China	Invited lecture by Sichuan Provincial Government
	10/13-17	Incheon/ Korea	USMCA2009
	3/12-16	Jakarta/Indonesia	To promote low-cost retrofitting methods
	3/17-22	Dhaka/Bangladesh	To attend the ground-breaking ceremony and workshop at BUET
沢田治雄	7/5-8	Bangkok/Thailand	To attend the Joint International Student Seminar on Civil Infrstructure
	8/5-16	Sao Paulo, Manus/ Brasil	To investigate on changes in carbon budget in Brasil Amazon
	9/5-11	Helsinki, Joesu/ Finland	To make a presentation at the Finnish-Japanese Seminar
	10/12-13	Soul/Korea	To make a presentation in Korea Forest Research Institute
	10/13-17	Incheon/Korea	USMCA2009
	10/17-21	Beijing/China	To attend the Asian Conference for Remote Sensing
	11/20-12/1	Sao Paulo, Manus/ Brasil	To Attend CADAF project
	2/26-28	Beijing/China	To attend an international workshop
	3/17-22	Dhaka/Bangladesh	To attend the ground-breaking ceremony and workshop at BUET
	3/22-25	Bangkok/Thailand	To visit RNUS and GISTDA
市橋康吉	10/12-17	Incheon/Korea	USMCA2009
	3/17-22	Dhaka/Bangladesh	To attend the ground-breaking ceremony and workshop at BUET
桑野玲子	9/30-10/9	Alexandria/Egypt	To make a presentation at the 17th International Conference on Soil Mechanics and Geotechnical Engineering
	10/13-16	Incheon/Korea	USMCA2009
加藤佳孝	10/12-17	Incheon/Kora	USMCA2009
黄　弘	7/11-20	Beijing/China	To visit Tsinghua University
	10/13-16	Incheon/Korea	USMCA2009
腰原幹雄	4/10-12	Incheon/Korea	To attend a meeting on the management of USMCA2009
	6/24-29	Istanbul/Turkey	International Symposium on Timber Structures
田中伸治	7/5-12	Bangkok/Thailand	To attend the Joint International Student Seminar on Civil Infrstructure
	10/13-16	Incheon/Korea	USMCA2009

	12/3-8	Dhaka/Bangladesh	To make a presentation at the GCOE seminar
遠藤貴宏	10/11-13	Soul/Korea	To make a presentation at Pukyong University
	10/13-17	Incheon/Korea	USMCA2009
	11/20-12/1	Sao Paulo, Manus/ Brasil	To Attend CADAF project
沼田宗純	7/5-9	Bangkok/Thailand	To attend the Joint International Student Seminar on Civil Infrstructure
	10/13-14	Incheon/Korea	USMCA2009
	10/15-20	Padang/Indonesia	To investigate earthquake damage
Baruah	10/12-17	Incheon/Korea	USMCA2009
吉本英子	10/12-17	Incheon/Korea	USMCA2009

2010 年度

教官名	期間	場所	用務
目黒公郎	4/14-23	Lhasa,Harbin/China	To site survey and teach of the PP-band retrofitting method
	9/25-10/4	Jakarta/Indonesia	To survey on the development of PP-band method
	10/13-17	Incheon/ Korea	USMCA2009
	11/27-29	Bangkok/Thailand	To attend a half day symposium and IIS alumni
	2/4-7	Bangkok/Thailand	To maek a lecture on earthquqke preparedness
沢田治雄	5/19-26	Sao Paulo, Manus/ Brasil	To oversee the start of the project on carbon dynamics of the Amazonian forest
	10/30-11/3	Hanoi/Vietnam	To make a presentation at the 31st Asian Conference on Remote Sensing
	12/19-21	Beijing/China	To visit Tsunghua University
	1/5-11	Bangkok/Thailand	To meet and investigate on foresets in the Mekong region
	2/3-9	VientianeLaos	To attend the meeting of ofrest manatement and natural disasters
桑野玲子	6/26-7/3	Zurich/Switzerland	To attend the 7th International symposium on Physical Modeling in Geotechnics
	1/8-17	Santiago/Chile	To attend the 5th International Coference on Earthquake Geotechnical Engineering
加藤佳孝	10/3-6	Delft/TheNetherlands	To attend the 2nd International Symposium on Service Life Design for Infrastructure
	11/28-12/1	Taipei/Taiwan	To attend the 4th Asian Concrete Federation International Conference
加藤孝明	8/13-18	Suchuan.China	To investigate on the post-disaster reconstruction after the 2008 Wenchuan Earthquake
	3/7-12	Chengdu,Cichuan/ China	To investigate
川崎昭如	5/16-23	Bangkok/Thailand	To oversee RNUS activites
	11/15-12/14	Bangkok/Thailand	To oversee RNUS activites
	12/23-	Bangkok/Thailand	To oversee RNUS activites
	1/1-13	Kunming,Jinghong/ Chia, Vientian/Laos, Phnom Penh/ Cambodia	To research investigation
	3/10-19	Amsterdam/Holland, London/England	To research works
田中伸治	7/10-15	Lisbon/Portugal	To make a presentation at the World Conference on Transportation Research 2010
	7/16	Bangkok/Thailand	To attend the Joint Student Seminar on Civil Infrastructure
遠藤貴宏	5/19-6/2	Sao Paulo,Manus/ Brasil	To oversee the start of the project on carbon dynamics of the Amazonian forest and conduct equipment training
	12/1-1/31	Pusan/Korea	To investigate on the existing conditions of LiDAR

			research
沼田宗純	4/14-23	Lhasa,Harbin/China	To site survey and teach of the PP-band retrofitting method

3.6　スタッフ受賞記録

2009 年度

名前	研究室	年月	受賞名	授与機関名
細尾誠	桑野研究室	2009.9	第 64 回年次学術講演会優秀講演者賞	社団法人土木学会
鈴木将充	加藤佳研究室	2009.9	第 64 回年次学術講演会優秀講演者賞	社団法人土木学会
German Alberto Pardo	加藤佳研究室	2009.9	第 64 回年次学術講演会優秀講演者賞	社団法人土木学会
Beltran-Galvis, A.L.	桑野研究室	2009. 9	第 11 回 International Summer Symposium 優秀講演者賞	社団法人土木学会
Cokorda, B.P.D.	桑野研究室	2009. 9	第 11 回 International Summer Symposium 優秀講演者賞	社団法人土木学会
Pranab Jyoti Baruah, 遠藤貴宏	ICUS, 沢田研究室	2009.10	優秀論文賞	紙パルプ技術協会
櫻井光太郎	目黒研究室	2009.10	Young Award USMCA 2009	USMCA 2009
細尾誠	桑野研究室	2009.11	第 44 回地盤工学研究発表会優秀論文発表者賞	社団法人地盤工学会
櫻井光太郎	目黒研究室	2010.3	優秀講演者賞	7thAnnual International Conference on Urban Earthquake Engineering

2010 年度

名前	研究室	年月	受賞名	授与機関名
目黒公郎	目黒研究室	2010.4	平成 22 年度科学技術分野の文部科学大臣表彰科学技術賞（開発部門）	文部科学省
桑野玲子	桑野研究室	2010.5	地盤工学会論文賞	社団法人地盤工学会
高東熙	桑野研究室	2010.5	1st place in the poster presentations	The 7th International Conference on Physical Modeling in Geotechnics
早川健司	加藤佳研究室	2010. 7	優秀講演賞	社団法人日本コンクリート協会
佐藤真理	桑野研究室	2010. 8	優秀発表賞	社団法人地盤工学会
牧之段浩平	大原研究室	2010.9	日本自然災害学会学術発表優秀賞	日本自然災害学会
牧之段浩平	大原研究室	2010.9	優秀講演賞	社団法人土木学会
マイケルヘンリー	ICUS	2010.9	優秀講演賞	社団法人土木学会
高石孟	目黒研究室	2010.9	優秀講演賞	社団法人土木学会

川崎昭如	ICUS	2010.10	地理情報システム学会賞（研究奨励部門）	一般社団法人　地理情報システム学会
佐藤真理	桑野研究室	2010.10	Young Award USMCA2010	USMCA2010
細尾誠	桑野研究室	2011.03	古市賞	東京大学社会基盤学専攻同窓会
佐藤真理	桑野研究室	2011.03	古市賞	東京大学社会基盤学専攻同窓会
沼田宗純	目黒研究室	2011.03	優秀発表賞（若手セッション）	第 8 回都市地震工学国際会議

付録　　ICUS の活動を振り返る関連資料

A.　業績リスト等
B.　研究論文
C　 Newsletter

人事一覧

A.　業績リスト

2010 年度

<u>生研報告，生産研究等</u>

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2010/01/22 週刊朝日 正しい防災知識で効果的な地震対策を

2010/01/22 毎日新聞 命助け合い優しさ

2010/01/22 神戸新聞 防災教育を検証

2010/01/19 建設通信新聞　朝刊 都市型災害から身を守る防災講演

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2010/01/14 岐阜新聞 被災後の生活再建　基盤失わぬために　地震保険で家守る

2010/01/14 山形新聞「耐震＋保険」で　住宅再建円滑に
2010/01/13 秋田さきがけ 地震被災後の生活再建　家を失わない仕組みが重要
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2010/01/11 佐賀新聞　我が家を失わないために　耐震補強と保険で備え
2010/01/10 神奈川新聞　住まいの再建を円滑に　耐震と保険をセット
2010/01/09 山梨日日新聞　震災住宅の再建　新たな仕組み模索
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2010/01/04 目黒公郎　愛媛新聞　住宅再建　新たな形模索
2010/01/04 目黒公郎　千葉日報　再建を円滑にする仕組みを
2010/01/01 目黒公郎　よこはま都市消防　横浜市木造住宅建替等促進事業支援セミナー
2009/12/29 目黒公郎　下野新聞　阪神大震災から15年　住宅再建、円滑な仕組みを
2009/12/28 目黒公郎　日刊工業新聞　14学協会フォーラム：地震災害軽減向けた配信と社会との連携テーマ
2009/12/09 目黒公郎　毎日新聞(朝刊)12面　備える　家具の転倒防止策5　被害を想定した配置必要
2009/11/15 目黒公郎　日本テレビ　6:30ー 6:45　新ニッポン探検隊！ 私の家は大丈夫？迫る巨大地震に備えよ
2009/11/05 目黒公郎　日本住宅新聞　建物の問題で亡くなった人は95%以上に上る
2009/11/01 目黒公郎　福島民報(朝刊)31面　在京者団体赤べこ会　会津を第二の古里に大災害時の"疎開"あっせん
「犠牲者の声なき声に学ぶ」
2009/10/29 目黒公郎　読売新聞(朝刊)32面　囲碁と防災　ともに学ぶ　31日、来月1日足立でフォーラム
2009/10/27 目黒公郎　毎日新聞(朝刊)28面　検証5年　中越地震は問う　5　住宅の耐震化普及へ続く試行錯誤
2009/10/17 目黒公郎　TOKYO MX TV　夜7時放送　耐震補強が命を守る　迫り来る首都直下地震

2009/08/30 目黒公郎　朝日中学生ウィークリー　防災週間　朝中読者が東大の研究室を訪問　災害を想像する力を鍛える
2009/08/28 目黒公郎　東京新聞(朝刊)23 面　2009 防災特集　地震　「高層難民」どう救う「何ができる?」イメージを
2009/05/18 目黒公郎　保険毎日新聞(朝刊)6 面　ICUS・「日本社会に適した BCM のあり方」成果報告会
2009/01/18 目黒公郎　毎日新聞　白昼震災　牛歩の住宅耐震

大原美保
2009/02/13 毎日新聞「首都直下地震　重症者、病床の 5 割超に　10 災害拠点病院」
2009/01/21 日本経済新聞「首都直下地震、重症患者、殺到の恐れ　東大准教授ら分析、病院の能力以上に」
2009/01/18 秋田魁新聞「災害拠点病院に重症者が集中、混乱」
2009/01/18 東奥日報「首都直下地震被害を想定、分析　重症者集中　病院が混乱　事前の態勢整備不可欠」
2009/01/18 宮崎日日新聞「Ｍ７．３首都直下地震の重症者　病院対応能力超す恐れ　東大准教授ら」
2009/01/17 茨城新聞「首都直下地震　病院、対応能力超える」
2009/01/17 南日本新聞「災害拠点病院パンクの恐れ　東京湾北部地震を専門家分析」
2009/01/17 福井新聞　首都直下地震被害想定を分析　対応力上回る病院続出 研究者「連携、体制強化を」
2009/01/17 山陰中央新報「東京湾北部地震起きたら…　重症者集中拠点病院まひ」
2009/01/17 日本海新聞「対応能力超える病院続出　首都直下地震　重症者集中　被害想定を研究者分析」
2009/01/17 長崎新聞「対応能力を超える病院続出の可能性　「東京湾北部地震」専門家が被害想定分析」
2009/01/17 佐賀新聞「「東京湾北部地震」で被害想定」
2009/01/16 共同通信「対応能力超える病院続出　首都直下地震、重症者集中」
2009/01/16 信濃毎日新聞「Ｍ７．３「東京湾北部地震発生」なら　災害拠点病院 対応困難に」
2009/01/16 東京新聞「東京湾北部地震発生なら　拠点病院限界超す患者」
2009/01/16 山形新聞「対応能力超える拠点病院続出か　東京湾北部地震　被害想定し分析」
2009/01/16 静岡新聞「首都圏直下地震 対応能力超える病院 重症患者が集中」
2009/01/16 埼玉新聞「首都直下地震 対応できぬ病院続出　研究結果 災害拠点に重症者集中」

腰原幹雄

2010/01/06　日刊木材新聞　東京では5階建て共同住宅建設へ

2009/12/25　日刊木材新聞　都市での木造建築の可能性啓蒙

2009/12/22 FM ヨコハマ　E-ne! -good for you-　古河電工 presents　エシコン

2009/12/06 TV 朝日　奇跡の地球物語　日本建築　今に生きる先人の知恵

2009/06/21 NHK 総合　科学者ライブ　グリーン・テクノロジーで未来を救え！ SAVE THE FUTURE

LIFE-CYCLE MANAGEMENT OF CONCRETE STRUCTURES

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Abstract

A concrete structure has to maintain its structural performance over required levels. It can be achieved both with sufficient durability design and maintenance work based on the concept of life-cycle management. This paper presents the concepts of life-cycle management for formulating and subsequently modifying the life-cycle scenario regarding structural performance assurance in relation to the initial durability design.

Keywords: life-cycle management, structural performance, design, maintenance, scenario

1. INTRODUCTION

A concrete structure has a long lifetime and must be expected to meet demands during its lifetime that cannot be foreseen. Concrete and steel reinforcement tend to deteriorate due to physical and chemical agents and loss of structural performance or even structural collapse may be consequences. At the initial design of a concrete structure, designers make several assumptions, in which probably worst conditions are considered with certain safety margins, so that the structure can keep its structural performance over required levels. Serious deterioration of structural members may be caused by insufficient durability design with optimistic assumptions against materials deterioration and by lack of proper maintenance after construction of the structure.

To meet these facts, it is extremely important to pursue collaboration between design and maintenance. Based on the performance-based design concept, structural performance of concrete structure should be assured over the design service life. For this purpose, the life-cycle management is necessary to present the methodologies how the structural performance would be kept over the minimum limits during the design and maintenance stages. Accordingly, the life-cycle management is a process which seeks to ensure that the service life of a concrete structure will equal or exceed its design life, while taking into account the life-cycle cost of the structure, and, if required, its life-cycle environmental impact [1].

This paper presents the concept and the framework of the life-cycle management as a part of service life planning which will be applied for realizing rational and strategic maintenance of structure.

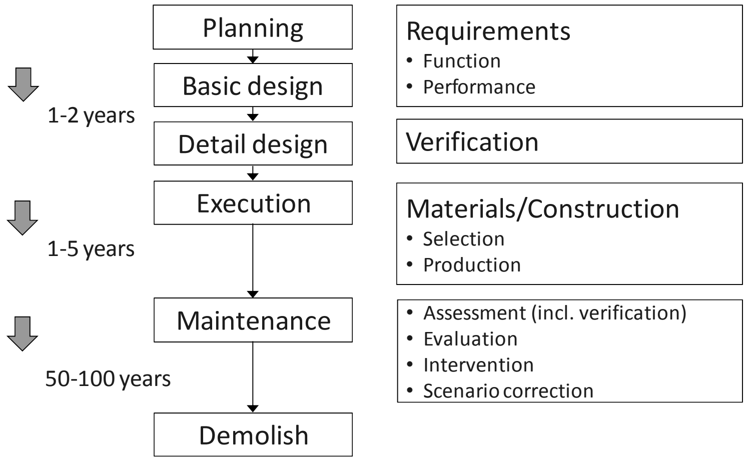

Fig. 1 Life-cycle of a structure

2. SERVICE LIFE OF STRUCTURE

The service life of structure is made up of all the activities that go into planning, basic and detailed designs, execution including material selection, production and construction, maintenance including assessment and intervention, and decommissioning as shown in Fig. 1. The life-cycle management is an integrated concept to assist in activities managing the total life-cycle of structures to realize sustainability. In other words, the life-cycle management is a process to ensure the structural performance during the design service life of a concrete structure and eventually its design life will equal or exceed its design life.

In the process of the life-cycle management, the most important work is to formulate and to correct the scenario of performance assurance. During the design stage before starting construction work, the service life design will be applied to predict the durability and performance degradation. For example, the basic design concepts for concrete structures have been specified in the standards of ISO 2394 [2], ISO 19338 [3], etc. The fundamental concept on how the structural performance should be ensured must be well considered based on conditions, design service life, structural characteristics, material properties, difficulties in assessment and intervention, social and economical importance, etc. This concept and the procedure to ensure structural performance are clarified at the planning of a structure as a performance ensuring scenario. In general, structures can be roughly categorized as those with free maintenance, those with preventive maintenance, and those with corrective maintenance. Designers and/or owners of the structure should formulate a maintenance plan taking into account individual situation based on the performance ensuring scenario.

During the maintenance stage, maintenance engineers will initially follow the scenario that had been assumed at the design stage. For realizing strategic maintenance work, as mentioned earlier, a maintenance strategy or a scenario should be properly formulated during the durability design of structure before construction. Importance and substitutability of structure and difficulty of maintenance work should be well taken into account for the strategy-making. Furthermore, to realize the strategic maintenance, the comprehensive life-cycle management is one of the key technologies. The life-cycle management formulates scenarios for future maintenance work based on the initial durability design level and is followed by verification and/or modification of the scenarios. The scenario will, therefore, be created in consideration of the following items:

- Environmental characterization
- Assumption in conceptual and initial design
- Result of verification during detailed design
- Specification
- Initial cost estimation
- Maintenance scenario and methodologies of the life-cycle management
- Performance requirements
- Service life estimation
- Life-cycle cost
- Environmental cost
- Obsolescence, demolition and reuse

The performance ensuring scenario specifies with linking the initial structural performance level (design and execution) with performance recovery methods during service life (maintenance) as schematically shown in Fig. 2. Correction of the scenario reflecting the actual situation of the structure and chages in circumference conditions.

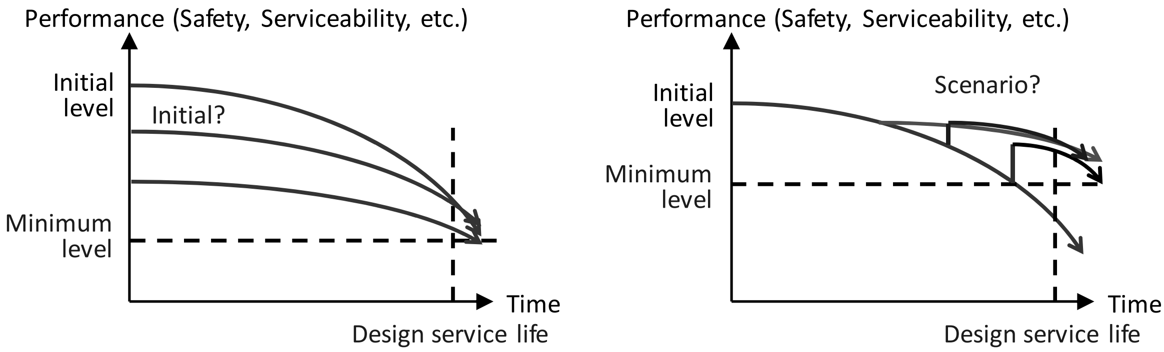

Fig. 2 Scenario of ensuring performance by the combination of initial performance level and performance recovery strategy

3. LIFE-CYCLE MANAGEMENT

3.1 Overall concept

The service life of a structure is subject to the degradation of structural members. Maintenance is the major strategy to counter the degradation, which 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 structural performance degradation, the most appropriate method of intervention 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 Fig. 3, which is based on the life-cycle management (LCM) concept [4]. The life-cycle management includes 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 intervention based on life-cycle cost minimization or performance maximization under budget capping. The life-cycle management and a related scenario can only address foreseeable changes and risks based on some assumptions.

The life-cycle management system is composed of the following 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 intervention
- Decision of action among proposed alternatives of interventions
- Correction of scenario for further life planning

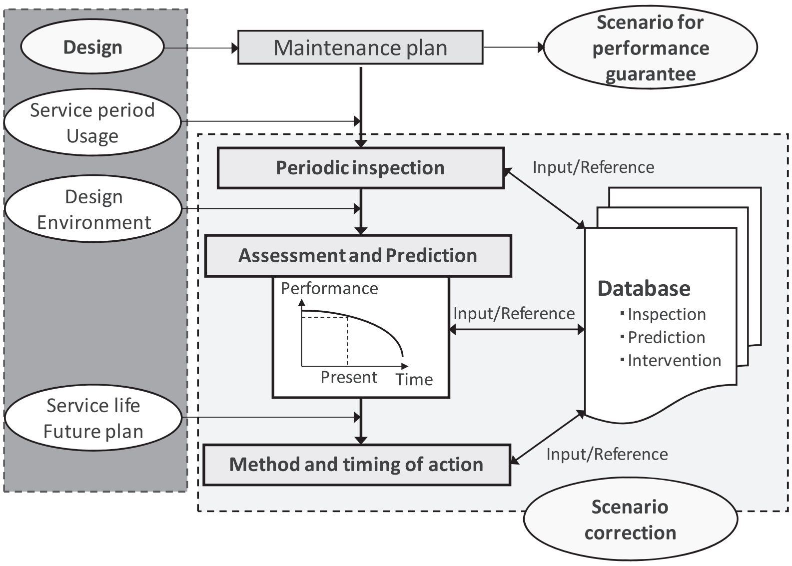

Fig. 3 Life-cycle management procedure

3.2 Assessment and prediction

Assessment can be made by the condition-based concept and the performance-based concept [5]. As mentioned earlier, the performance-based concept should be applied for performance assessment, but generally needs costs, advanced techniques, etc. Thus, the condition-based assessment is reluctantly accepted because of its feasibility. The grading system has been often applied, in which the state of deterioration is visually evaluated and judged using the deterioration grade. 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.

If the relationship between structural performance (structural capacity) and the grade of deterioration could be found even tolerate margins of errors, the intervention could be discussed with using the deterioration grade [6].

Since deterioration of concrete members is induced and accelerated mainly by chemical agents, the ingress and transportation of those agents are predicted as main indices for durability performance. For example, chloride ion accumulation is simulated with Fick's law of diffusion and carbonation depth is estimated with the square-root method. However, 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 calculation parameters is not so easy [4]. The uncertainties in service life predictions depend on the quality of the data available and the appropriateness of assumptions. The variations with time of the concentrations of each chemical agent, and the intensity of each physical agent, to which each component may be exposed in a specific time should be determined.

Those facts indicate that it is practically rather difficult to accurately predict the progress of deterioration and remaining structural capacities by only using the relevant theories. Instead of this, some probabilistic models such as the Markov model and the survival analysis model may be of use. This approach is of use to understand the overall tendency of deterioration in consideration of its variation by the experienced progress of deterioration.

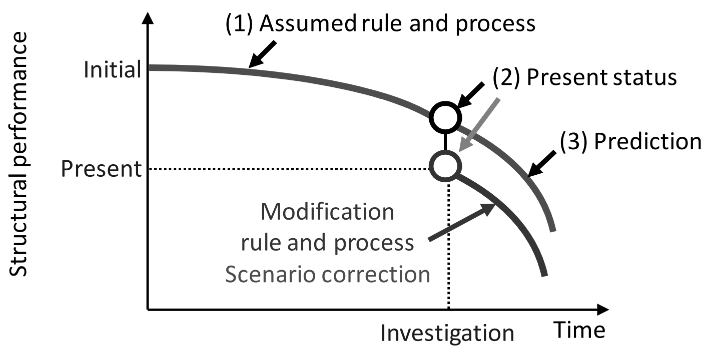

Fig. 4 Scenario correction by modifying rules and processes of performance degradation

3.3 Scenario correction

Some theoretical rules and/or simulation models are used for the prediction of deterioration progress of concrete structural members. However, as described earlier, the other probabilistic models may have potentials for use in the future progress of deterioration and/or degradation during the maintenance stage. Based on the data and assessment results, the rule and process of deterioration and/or performance degradation have to modified and the scenario be corrected for further prediction, which is shown in Fig. 4. Accordingly, the interpretation from the virtual world (design) to the real world (maintenance) should be established its methodology.

3.4 Decision based on life cycle cost

If member failures might cause hazards to safety, possible failures should be categorized by their consequences. To reduce the risk of failure occurring within the design life when the consequences of failure are judged to be critical, it may be necessary to require particularly long design lives for specific members or to strengthen the requirements for inspection and maintenance. To determine the maintenance strategy or to consider the appropriate timing and method of intervention, estimation of life-cycle cost (LCC) is one of the best indices. The life-cycle cost 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 intervention are totaled.

Life-cycle cost estimation enables comparative cost assessments to be made over a specified period of time. Being able to compare the costs of alternative scenarios allows selection of the most economic overall design and maintenance strategy (scenario). Initial costs include directly related to the structure including design, construction, and installation. Future costs include all operating costs and costs of maintenance, inspection, replacement, demolition and refurbishment.

The life-cycle cost is calculated based on various assumptions, but it provides important information needed for making decisions about the future direction of maintenance. The life-cycle cost 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. It is necessary, therefore, to formulate 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.

Figure 5 shows an example of the life-cycle cost calculations under various scenarios [7]. The figure indicates that preventive maintenance strategy is most economic, which is about one-third of the most costly scenario.

In addition to financial costs, the scenario may be evaluated from the viewpoint of environmental costs.

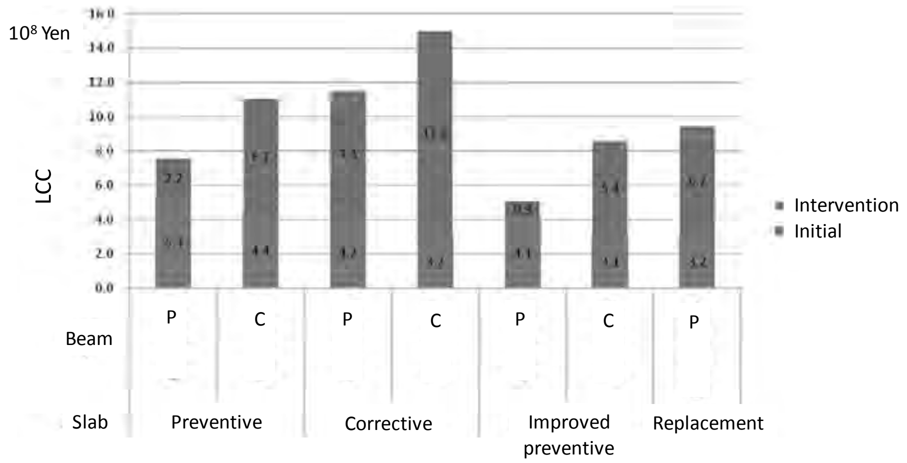

Fig. 5 LCC estimation for evaluating the life cycle scenarios

4. CONCLUDING REMARKS

The life-cycle management system including prediction of the progress of deterioration has been developed and being implemented for maintenance of concrete structures. The authors expect that rational and effective maintenance is realized so that the life-cycle cost reduction and performance maximization can be attained. This may make it possible to realize sustainability of concrete structures.

ACKNOWLEDGMENT

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地盤陥没未然防止のための地盤内空洞・ゆるみの探知に向けた基礎的検討

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概　要

近年都市部で頻発している道路陥没は，多くの場合老朽埋設管の破損部等から土砂が流出することに起因し，社会的損失が大きいにもかかわらず，対症療法的な対策が中心となっているのが現状である。陥没にははっきりした原因が特定できない場合も多いが，現象の解明よりも復旧が急がれるという実務上の要請もあり，陥没を引き起こすような地盤内空洞・ゆるみの生成・進展のメカニズムには不明な点が多い。

路面下の地表近傍で顕著な空洞が存在するような陥没寸前の状態においては，地中レーダー探査技術により比較的高い確度で探知可能であるが，空洞が深層部にある場合，空洞・ゆるみの境界が不明瞭な場合，輻輳した地下埋設物と空洞・ゆるみ部が渾然としている場合などは，探知技術の限界により問題箇所の検出が困難な場合が多い。本研究では，地盤陥没を未然に防止するための探査手法を高精度化するために，地盤内空洞・ゆるみの形成過程を明らかにし空洞・ゆるみのパターンを類型化すること，さらに陥没に至る“危険な”空洞・ゆるみを抽出することを目指している。小型及び中型土槽を使用し，底面の開口部から土砂を流出させ模型地盤内に空洞・ゆるみを作製し，そのメカニズムを調べた。また，大型ピット内地盤の模擬空洞・ゆるみの探査実験を行い，空洞周りのゆるみに着目した探査の可能性を検討した。

キーワード：陥没，土砂流出，空洞，ゆるみ，探査

1.　はじめに

近年都市部では道路陥没が頻発している。その多くは地中埋設管の破損部等からの土砂流出による地盤内空洞に起因し，その中でも下水管渠施設の老朽化に伴う道路陥没は年間約4700件(平成19年度)にも上る(国土交通省[1])。最近では，地中レーダー探査技術を用いて路面下空洞を定期的に探知することにより一定の成果があがっているものの，地盤内空洞・ゆるみの生成・進展要因や成長速度などの基本的メカニズムに不明な点が多いため，対症療法的な対策が中心となっている。実際の陥没や空洞箇所では，土砂流出の径路となりうる水みち等が明確に確認できない場合も多く，小規模陥没・空洞の場合は原因不明のまま復旧を急ぐこととなるのが実情である。桑野ら[2]は、老朽下水管の破損に起因する道路陥没の発生メカニズムを、実態調査および小型模型実験で検討し、地盤内空洞とその周辺のゆるみ領域の評価方法を提案した。ここでは埋設下水管上部に発生する比較的浅層部の地盤内空洞を主な対象とした。

土砂流出及びそれに伴う空洞の芽が地中深いところで発生した場合，条件によっては空洞が大きく成長し大陥没に至る危険がある。最近の例として，2008 年 5 月，1970年代に造成された大阪府阪南市住宅地の市道で 8 m×5 m×深さ 5m の陥没が発生し，その後の阪南市の調査で地下15mの深さに残置された古い貯水槽に破損部から土砂が流入しているのが見つかった[3)4)]。2009 年 4 月には，北海道安平町のゴルフ場フェアウェイで，深さ 5m，直径 1～7m の陥没孔が突然発生し，上を歩いていた人が落下する死亡事故が起きた。陥没箇所はかつて沢地形上に大規模な盛土造成をしたところで，北海道警察の開削調査により，旧河道に沿った地中の水みちにより地中内部で長年の間に浸食が進んだ形跡が発見された。

舗装路面下の地表近傍で顕著な空洞が存在するような陥没寸前の状態においては，現状のレーダー探査技術により比較的高い確度で探知可能であるが，空洞が深層部にある場合，空洞・ゆるみの境界が不明瞭な場合，輻輳した地下埋設物と空洞・ゆるみ部が渾然としている場合などは，探知技術の限界により問題箇所の検出が困難となっている。本研究では，前述のような“大陥没に至る危険のある深層部空洞”の探知手法を提案するため，地盤内空洞・ゆるみの形成過程を明らかにし空洞・ゆるみのパターンを類型化すること，さらに陥没に至る“危険な”空洞・ゆるみ

を抽出することを目指している。なお，ここでいう“深層部”とは，道路下空洞探査のために使用される地中レーダーの適用範囲を超える深度を称している。通常路面下空洞探査に使用されるパルス波レーダーでは，路面下 1.5～2m を超える深さには対応が困難と言われている。

2.　空洞･ゆるみのパターンと定量評価

堀井ら[5)]，桑野ら[6) 7)]，小橋ら[8)]は，図 1 に示すような小型土槽を用いて下水管破損部周辺に形成される空洞・ゆるみを想定した土砂流出模型実験を実施し，地盤材料と土砂流出特性の関係や，空洞周辺のゆるみ部の密度低下の定量評価について検討した。豪雨時の合流管破損部からの雨水の漏出，および降雨停止時の土砂の引き込みを想定し，土槽底板中央に設けた開口部を通してモデル地盤内に給排水を繰返すことにより空洞を形成させ，給排水サイクル毎の排土量測定と，写真撮影による地盤変状の記録を行った。Mukunoki ら[9)]は，同様の土砂流出実験結果について X 線 CT 装置を使って 3 次元的に評価した。その結果，地盤材料によっては空洞周辺のゆるみ領域は広範囲に達し，ゆるみ形状やゆるみの度合に特異性があることがわかった。

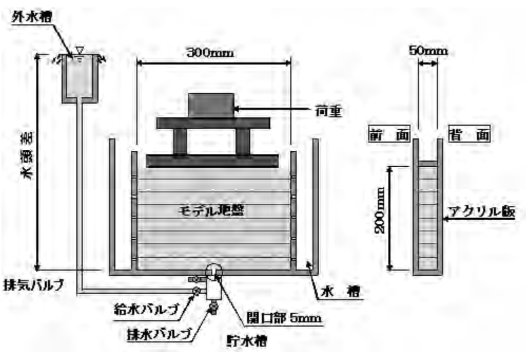


図1　土砂流出実験用小型土槽

図 2 に，豊浦砂（均等な粒度を持つ細砂）と山砂（従来埋設管の埋戻しによく使われている，細粒分を 10%程度含む砂質土）のモデル地盤内に形成した空洞と周辺のゆるみ領域の典型的な例を示す。豊浦砂地盤内には比較的小さな空洞の上部に 15%程度密度低下したゆるみ領域が急速に進展した。一方，山砂地盤では空洞周辺のゆるみ領域の範囲は限定され進展速度も遅いものの，密度低下は 50%程度と大きく減少している。なお，空洞は土が完全に亡失している領域，ゆるみは色砂により地盤の変状が見られる領域のことで，両者とも土槽前面からの目視観察で確認した。なお、土槽前面と背面から撮影した空洞・ゆるみ形状には相互に大きな差異がないことを確認し、変形が平面ひずみ状態であると想定している。地盤内部では前面あるいは背面の観測面よりも空洞がえぐれるように大きく発達する可能性もあるものの（逆の場合は観測面から容易に判別可能）、円筒土槽および X 線 CT 画像を用いて地盤内部の変状を詳細に検討した場合[8)]と本研究のような薄型土槽を用いた場合で、各地盤材料についてほぼ同様の土砂流出特性が得られていることから、空洞形状および地盤変状は土槽奥行き方向に一様と考えてさしつかえないと判断した。

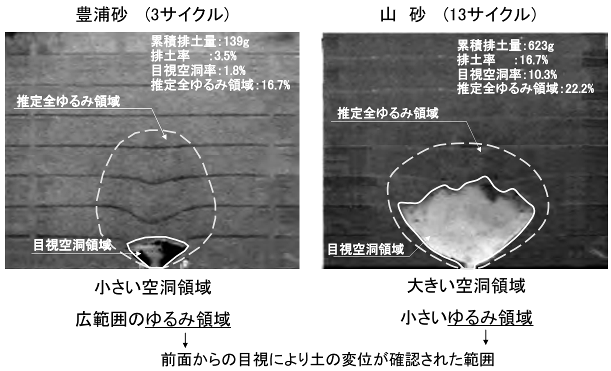


図2　土砂流出実験による空洞・ゆるみ形成の特徴

表1　ゆるみ領域の評価のための指標

指標	定義	図 2 に示す具体例における各指標の値	
		豊浦砂 3 ｻｲｸﾙ	山砂 13 ｻｲｸﾙ
排土率	対象領域*地盤全体の乾燥重量に対する累積排出土の乾燥重量の割合	3.5%	16.7%
目視空洞領域（率）	対象領域に対する，空洞領域の割合（図 2 実線内）	1.8%	10.3%
推定全ゆるみ領域（率）	対象領域に対する，目視から推定したゆるみ領域の範囲（空洞部を含む）の割合（図 2 破線内）	16.7%	22.2%
推定ゆるみ領域（率）	対象領域に対する，目視から推定したゆるみ領域の範囲（空洞部を含まない）の割合【推定全ゆるみ領域－目視空洞領域】	14.9%	11.9%
空洞に対するゆるみ領域の割合	空洞領域に対する，ゆるみ領域の拡がり度合【推定ゆるみ領域／目視空洞領域】主に空洞上方へのゆるみの到達度合を示す	8.3	1.2
ゆるみ程度	推定ゆるみ領域の地盤部のゆるみ度合【（排土率－目視空洞率）／推定ゆるみ領域】	11%	54%

*　対象領域は，モデル地盤のうち開口部を中心として幅25cm，高さ20cm

ここで，空洞・ゆるみ領域の範囲や，ゆるみの度合を定量的に把握するために設定した指標を表 1 に示す。図 2 の具体例における各指標の値を参考値として合わせて示している。ただし，排土率，目視空洞領域（率），推定全ゆるみ領域（率），推定ゆるみ領域（率）の各指標は，対象領域の取り方により値が変わるので，その絶対値に工学的意味は無いといえるであろう。“空洞に対するゆるみ領域の割合”は，空洞周辺（主に上方）に，どの程度の範囲までゆるみ領域を伴うかを表していて，豊浦砂では 8.3，山砂では 1.2 と，豊浦砂では空洞上方に広範囲にゆるみが進展することを示唆している。ゆるみ程度は，空洞周辺のゆるみ領域の乾燥密度が健全部と比べてどの程度低下して

いるかを割合で示した指標で，土砂流出実験で測定された排土量から，空洞からは100%の土砂が，ゆるみ領域内からは一様に一定割合の土砂が流出したという仮定の下で算出している。

また，図2に示す豊浦砂と山砂における，空洞とゆるみの関係を給排水サイクルに対してプロットしたものを図3に示す。それぞれゆるみ程度を15%，および50%程度と仮定して排土率を計算したものと実測の排土率がよく一致していることから，空洞形成のごく初期から陥没間際の終末期まで空洞周辺のゆるみ領域からの土砂流出の傾向は一定であることを示している。

このように，地盤材料によって，空洞・ゆるみのパターンや，空洞の拡大速度，ゆるみ程度が異なることがわかった。空洞のみならずゆるみ領域の特性に着目することにより，空洞探知に有用な情報が得られる可能性があるといえる。

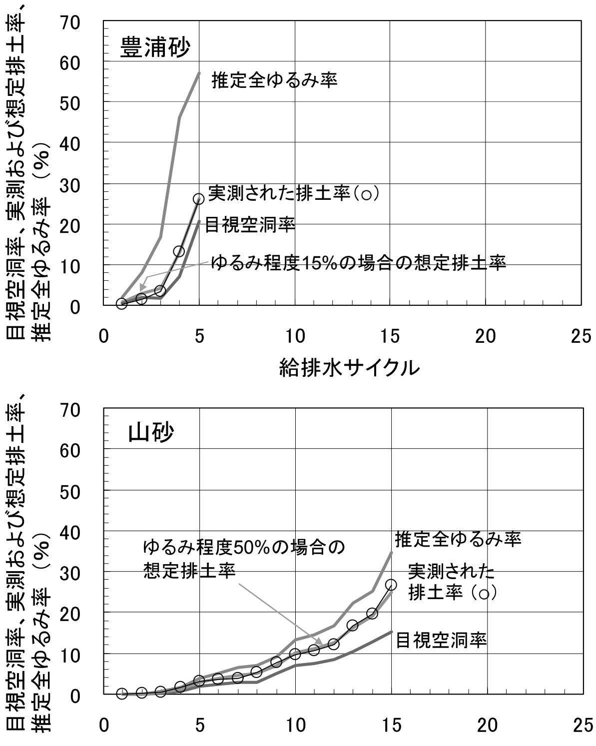


図3　豊浦砂と山砂の土砂流出特性

3.　実験の概要

深層部に生成した空洞が周辺にゆるみ領域を伴って地表付近まで拡大・進展するプロセスを詳細に調べるために，水の浸透方法が異なる2種類の土砂流出実験を行った。また，ゆるみ領域の探知の可能性を調べるために模擬空洞・ゆるみの探査実験を行った。各種実験の概要を表2に示す。

表2　各種実験の概要

	装置・地盤	目的・概要
給排水繰返し土砂流出実験	小型土槽	土槽底板中央の開口部を通してモデル地盤内に給排水することにより空洞を形成させる。2章で紹介した実験と同様に，豪雨時の合流管破損部からの雨水の漏出，および降雨停止時の土砂の引き込みを想定している。 各種地盤材料の土砂流出特性を調べると共に，地盤の密度や初期含水比の影響を検討した。
定水位土砂流出実験	中型土槽	土槽側部に設けた外水槽の水位を一定として，土槽底板中央の開口部から土砂流出させる。 降雨時に地下水位が上昇し下水管破損部へ水が流入する状況の想定の他，地下の水みちによる浸食で形成される地盤内空洞も本パターンに近いといえる。 レーダー探査装置をモデル地盤上部に設置し連続的に計測した。
模擬空洞・ゆるみ探査実験	大型ピット内地盤	大型ピット内モデル地盤に模擬空洞・ゆるみを作製し，レーダー探査，表面波探査，コーン貫入試験を実施した。 路面からの非破壊探査で特有のパターンのゆるみ領域を検知できるかどうかをテストした。

4.　小型土槽による給排水繰返し土砂流出実験

4.1　実験方法

実験装置は図1と同じものを使用した。長さ30cm，奥行き5cm，高さ20cmの小型土槽内に模型地盤を突き固めで作製し，土被り60cm相当の上載圧を載荷した。この際2.5cm毎に水平方向に色砂を敷設し地盤変形を観察する目安とした。土槽底部中央には5mm幅の開口部を設置し，開口部から水を給水，一定時間経過後排水するという過程を繰り返した。一度の水の給水量は、サイクル初期段階において開口部周辺 5cm 程度の範囲内に水が浸透するように設定し、約100mlとした。水の給水後排水が完了するまでを1サイクルとし，サイクル毎の排土量（流出した土の乾燥重量）測定と，写真撮影による地盤変状の記録を行った。空洞が土槽内で十分に拡大したこと，または地盤上部まで地盤の変形が到達したことを確認して実験を終了した。地盤材料には，豊浦砂（D_{50}＝0.17mm），5号珪砂（D_{50}＝0.4mm），江戸崎砂（D_{50}＝0.22mm，細粒分含有率3%），レキ混じり火山灰質土（D_{50}＝0.7mm, 細粒分含有率17.5%）を用いた。各材料の粒度は図4に示すとおりである。また，各材料の物理特性およびモデル地盤の条件を表3に示す。

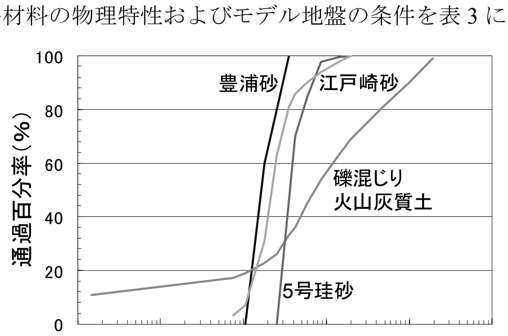


図4　給排水繰返し土砂流出試験に用いた地盤材料の粒度

表 3　給排水繰返し土砂流出実験のモデル地盤条件

材料	土粒子密度 (g/cm³)	最大最小間隙比	実験ケース	モデル地盤初期条件 乾燥密度 (g/cm³)	モデル地盤初期条件 含水比 (%)
豊浦砂	2.62	0.95，0.64	T(14,60)	1.48	14
			T(14,80)	1.54	14
5 号珪砂	2.64	0.81，0.56	K(10,60)	1.59	10
			K(05,80)	1.64	5
			K(10,80)	1.64	10
江戸崎砂	2.69	1.29，0.87	E(0,80)	1.38	0
			E(8,80)	1.38	7.8
			E(16,80)	1.38	15.5
礫まじり火山灰質土	－	－		1.42	16.1

4.2　各地盤材料の土砂流出特性

図 5 に給排水繰返し土砂流出試験における給排水サイクルごとの排土率をプロットした。ここで T は豊浦砂，K は 5 号珪砂，E は江戸崎砂を指し，括弧内の数字は地盤作製時の初期含水比と相対密度である。平均粒径が大きく粒度が悪い材料ほど（5 号珪砂，豊浦砂，江戸崎砂の順），また，密度が小さく初期含水比が大きいほど，土砂流出が急速に進む傾向が現れている。ただし、E(8,80)と E(16,80)では、給排水サイクルの初期段階では E(16,80)の方が排土率が高いが、9 サイクル目で逆転している。概ね、初期含水比が大きい地盤の方が、給排水サイクル初期において空洞が速く発達しそのまま崩壊に至る傾向があるものの、給排水サイクルを繰返し空洞が大きく発達して周辺地盤への水の浸透が進むと、地盤の初期含水比の影響がもはや支配的ではなく、本ケースのように実験後半で流出土量が逆転する場合があると考えられる。

礫混じり火山灰質土のケースでは，レキが 5mm 幅の開口部に引っかかるため土砂流出の障害となり顕著な空洞が形成されずに推移したが，レキに沿って透水径路が広範囲に急速に進み，水みちに沿って細粒分が流出する様子が観察された（図 6）。図中破線で囲んだ箇所は初期状態から礫周りに締固めがやや不十分で不均質な部分が認められたが、給排水サイクルを繰り返すとそのような箇所を中心に小さな空洞・ゆるみが点在する結果となった。したがって，図 5 にみられる排土率の傾向から土砂流出しにくい材料と判断することは危険と考えられる。

別途，X 線 CT 装置および円筒状の土砂流出実験土槽を用いて豊浦砂地盤の空洞・ゆるみ形成を観察したケース[7]でも，ゆるみ領域内部は均一に密度低下しているわけではなく，図 7 に見られるように蜂の巣状に砂が抜けていることが確認されており，土砂流出は水みち径路に沿って不均質に生じる現象と考えられ，水みちとゆるみの形成は密接に関連すると思われる。

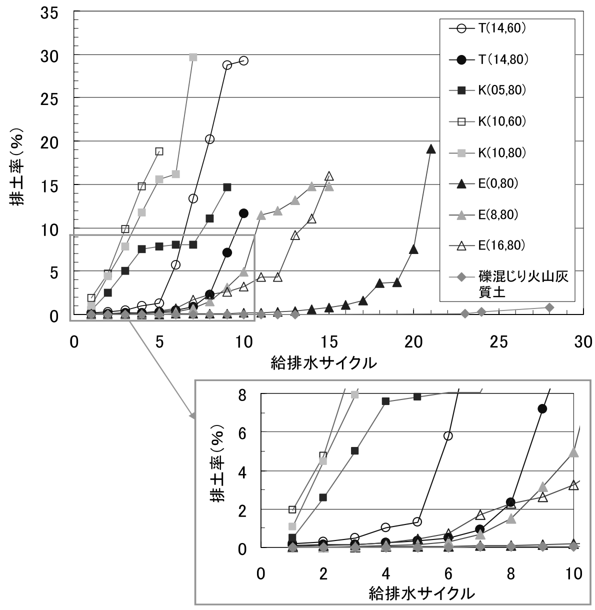


図5　給排水繰返し土砂流出試験における各地盤材料の土砂流出

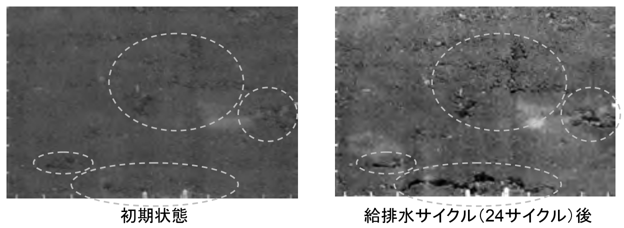


図6　レキ混じり火山灰質土に形成された不均質で広範囲のゆるみ

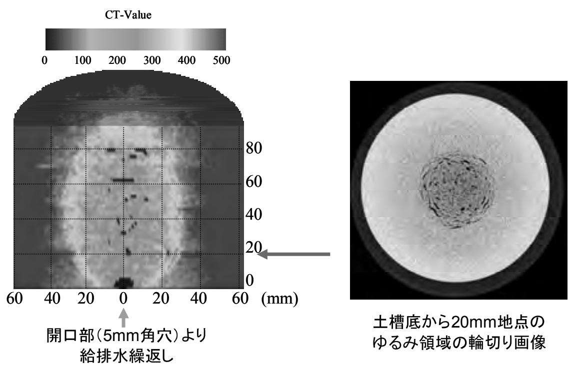


図7　豊浦砂地盤に給排水繰返し土砂流出実験を実施した際の給排水繰返し3サイクル目におけるX線CT画像によるゆるみ領域内部の観察（小橋ら[8]に加筆）

豊浦砂，珪砂，江戸崎砂をそれぞれ相対密度 80%で締固めた地盤で実施した土砂流出試験における空洞とゆるみの発達状況を図 8 に示す。概ね，排土率の変化と似たような傾向を示している。珪砂地盤では，空洞周辺のゆるみを目視で確認することができなかった。豊浦砂は江戸崎砂に比べて広範囲のゆるみが発達している。推定ゆるみ領域と目視空洞領域の比（最終サイクルを除いた平均）は，豊浦砂で 8.4，江戸崎砂で 2.2 である。また，ゆるみ程度は豊浦砂が約 13%，江戸崎砂は 43〜55%となった。

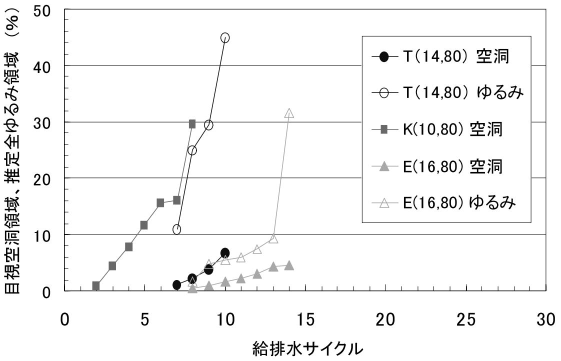


図8　空洞およびゆるみの発達状況

江戸崎砂 E(8,80)のケースにおいて，開口部から排出される土の細粒分含有率の推移を調べたところ，図 9 のようになった。給排水サイクル初期は排出土量が微量であったため（図 5 参照），2～5 サイクル，6～8 サイクル，9～11 サイクルにおける排出土をまとめて細粒分含有率を分析した。江戸崎砂の細粒分含有率が約 3%であるのに対して，流出土砂には初期段階から 5%を超える細粒分が含まれていて，サイクルを経る毎に増大している。給排水サイクルの初期の段階から，流出土砂の細粒分含有率が原地盤よりも有意に高く，空洞・ゆるみが顕著でない段階から細粒分の流出が始まっていることが確認された [10]。

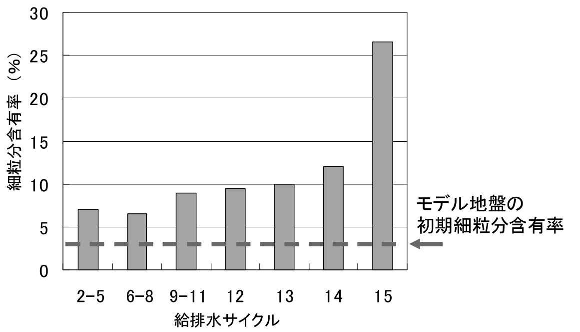
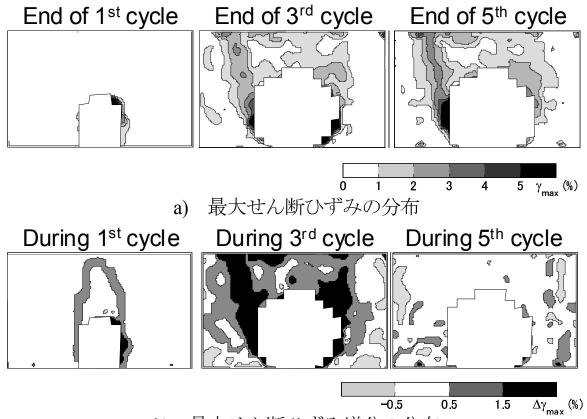


図9　江戸崎砂の土砂流出試験（E(8, 80)）における流出土砂中の細粒分含有率の推移

5 号珪砂の地盤では，土砂流出に伴い空洞は発達したが，空洞周辺のゆるみは目視で確認することができなかった。そこで，地盤変状の撮影した画像を PIV 手法で解析し給排水サイクルに伴うひずみ分布を求めた [11]。図 10 に，K(10,60)のケースにおける 1，3，5 サイクルの最大せん断ひずみ分布と各段階ごとのひずみ増分の分布を示す。なお，最終的に空洞となるような地盤変位が著しい箇所（開口部直上）は解析範囲から除外した。給排水サイクルの初期から開口部上方および斜め上方向に広範囲にひずみが発達している様子が観察された。



a)　最大せん断ひずみの分布

b)　最大せん断ひずみ増分の分布

図10　5号珪砂（K(10,60)）の給排水繰返し土砂流出試験における地盤のひずみ分布

4.3　給排水繰返し土砂流出実験で得られた主な知見

土砂流出源から水の出入りが生じる給排水繰返し土砂流出試験により以下の知見が得られた。

・地盤材料により土砂流出や空洞拡大の速度，空洞周りのゆるみ領域の特性が異なる。同じ地盤材料では，密度が小さく初期含水比が大きいほど土砂流出が急速に進む傾向がある。

・珪砂地盤では，目視では空洞周りのゆるみは生じていないように見えたが，PIV 手法を用いて詳細に地盤のひずみ分布を調べると空洞上方及び斜め上方に広範囲に変形が発達している様子が確認された。

・空洞やゆるみの形成が顕著に現れない実験初期段階から細粒分の流出が始まっている。

・レキ混じり土では水みちがレキに沿って不均質に発達し細粒分が流出することによって広範囲に急速にゆるみが生じた。豊浦砂のゆるみ領域内部で観察される蜂の巣状の土砂流出の状況と考え合わせると，ゆるみ形成は内部におそらく脈状に形成される水みち径路と密接に関連すると思われる。

5.　中型土槽による定水位土砂流出実験

5.1　実験方法

実験装置を図 11 に示す。土槽の大きさは長さ 200cm，幅 50cm，高さ 120cm であり，この土槽内に豊浦砂を相対密度 80%，初期含水比 6%の条件で突き固め模型地盤を作製した。地盤高さは 1.1m で 10cm ごとに観測用の色砂層を設置した。土槽の左右には水槽が設置してあり，本実験では外水槽の水位を管理して，水槽から土槽へ水を浸透させた。土槽の底部中央には 5mm 幅の開口部を設置した。実験手順としては水位を上げ一定時間静置したのち開口部を開放して土砂流出を起こし，土砂流出が収束してきた後に開口部を閉じて水位をさらに上昇させるという作業を繰り返した。また地盤表層部にレーダー探査機（500MHz：深度 1.5mにて広がり 0.5m×0.5m×厚さ 0.1

m以上の空洞が検知可能）を設置し，連続的に信号を送受信することで空洞形成や陥没発生の予兆の検知を試みた。実験終了後にはコーン貫入試験を行った。

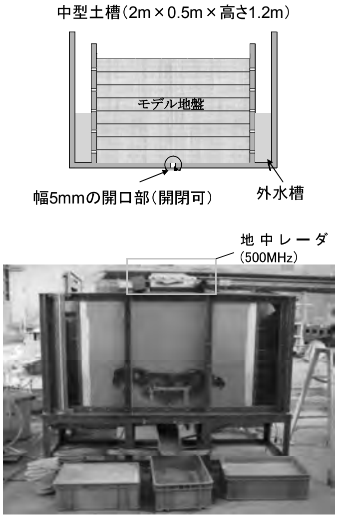


図11　定水位土砂流出実験用中型土槽

5.2　　土砂流出とゆるみ特性

外水位を土槽底面から10cmに保って開口部を開放し土砂流出を開始した。約25分経過後土砂流出量が収束してきたため，開口部を閉めて外水位を20cmに上げ約2時間水を浸透させた後，再び開口部を開放した。さらに約20分経過後開口部を開けたまま外水位40cmに上げ空洞上部まで大きく地盤が崩壊するまで，約2時間実験を継続した。図11，12に見られるように，空洞の拡大は水平方向が卓越した。地下水面以下では飽和した地盤が開口部に向かって安息角付近ですべり破壊し，空洞拡大に伴って空洞上部の地盤が不安定になり徐々に崩落するという現象が見られた。コーン貫入試験は，図12に示すように土槽中央から5か所，15cm以深まで行ったが，いずれの場所でも明確な違いはなく，少なくともコーンを貫入した深さまでは顕著なゆるみ領域はないと推測される（図13）。ただし，地盤内の水の浸透方向や空洞の成長の様子から側方部でゆるみが生じている可能性は考えられる。なお、貫入位置④と⑤ではコーン貫入による撹乱で空洞天井部分が崩落しコーンが空洞部に突き抜けてしまったため、10～15cm深さで貫入抵抗がゼロと記録された。レーダー探査では，空洞やゆるみの進展，空洞内部の土砂崩壊等に応じて何らかの信号の変化を捉えられたが，詳細は検討中である。土槽開口部からの給排水繰返し試験の場合と異なり，空洞・ゆるみの進展方向は水平方向が卓越していた。水の浸透状況が空洞・ゆるみのパターンに支配的であるといえ，このような状況では，豊浦砂でも上方に広範囲なゆるみ領域を伴わないまま空洞が大きく発達する可能性がある。

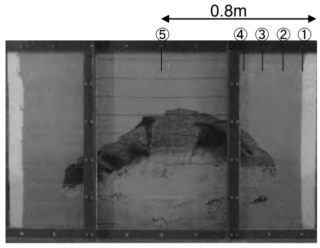


図12　試験後の空洞状況とコーン貫入試験位置

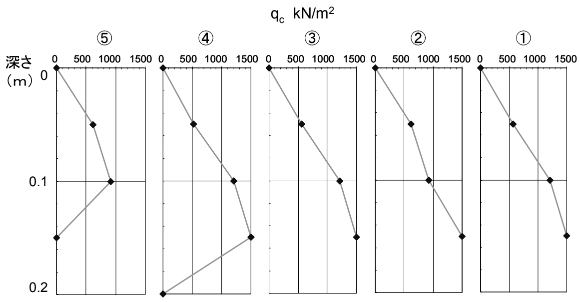


図13　コーン貫入試験結果

5.3　　空洞の拡大過程

本実験では，水位を最大40cmとし定常的に土砂と水を排出させた。排出土量の推移は図14に示すとおりで，水位の上昇と共に流出が速くなっている。

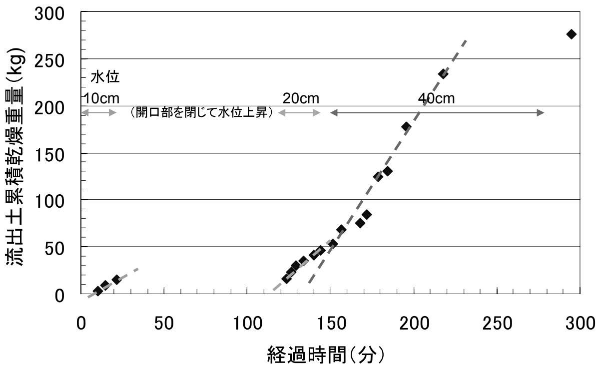


図14　定水位土砂流出実験における排出土砂量の推移

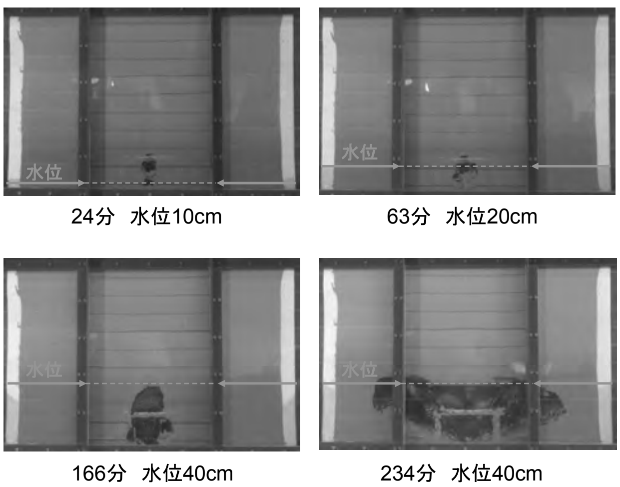


図15　定水位土砂流出実験における空洞拡大の様子

空洞が拡大する様子を図 15 に示す。土槽底面から 10cm 間隔で色砂を設置している。給排水繰返し実験の際と同様に，最初は開口部直上の土砂が排出されそれに伴う小空洞およびゆるみが発生した。水位の上昇に伴って，空洞の側面は開口部に向かって安息角で傾斜し，天井部は不飽和砂のサクションおよび土のアーチングの作用でかろうじて安定を保っている様子であった。空洞の上端は、地盤が飽和している水面付近までは容易に発達した。時折空洞天井部から崩落する土砂は水位が保持されている限り速やかに排出された。

図 15 に見られるような空洞拡大のプロセスは，地中の深層部に何らかの理由で発生した空洞が，土砂の継続的な流出先がある限り，地下水面に応じて水平方向に卓越して発達し，やがて大空洞・大陥没に至る危険性を示唆している。前節の給排水繰返し土砂流出試験で生成した空洞と異なり，豊浦砂地盤においても空洞上方に顕著なゆるみを伴わずに空洞が拡大するため，ゆるみのパターンを空洞探知に利用するのが困難なケースといえる。2009 年 4 月の北海道安平町ゴルフ場陥没の例も本ケースに近く，図 16 に示すような空洞形成・拡大メカニズムが推定されている。さらに，浸食されやすい土質，地下水位の季節変動や雨水浸透などが空洞の進展を助長する要因になりうると考えられる。

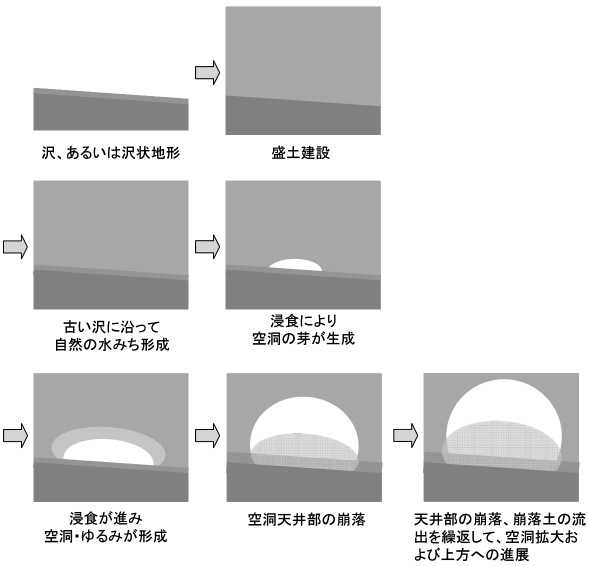


図16　古い沢上に造成した盛土内に非意図的に生成した水みち（ソイルパイプ）による浸食の拡大過程の推定

5.4　定水位土砂流出試験で得られた主な知見

モデル地盤側方の水位を一定に保持し土砂流出源（開口部）から水と土砂の流出を定常的に許す実験を実施したところ，外水位と土砂流出速度に相関が見られた。また，水の浸透方向に沿って，空洞の拡大は鉛直上方よりも水平方向に卓越した。給排水繰返し試験の場合と異なり，豊浦砂地盤でも空洞上方に顕著なゆるみ形成を伴わない。図 17 に給排水繰返し試験と定水位土砂流出試験における空洞とゆるみの拡大パターンを模式的に示す。水平方向に発達した空洞は，天井部の不安定化および崩落，崩落土の流出を繰返し，さらに拡大する様子が観察された。

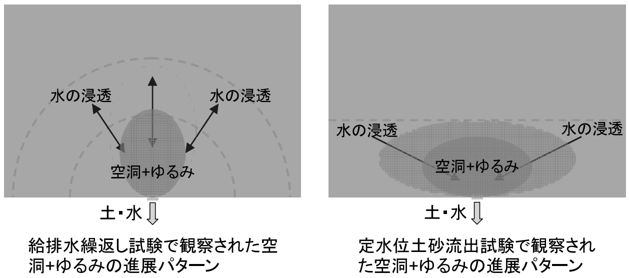


図17　水の浸透と空洞・ゆるみ形成パターンの関係

6.　模擬空洞・ゆるみ探査実験

6.1　実験方法

幅 5m，深さ 4.2mの大型ピット内地盤に，図 18 のように模擬空洞を作製した。埋戻し材料は川砂を用い，埋戻し部底部に氷を設置し湯水をホースによって注入することで氷を融解させて人工的に空洞やゆるみを発生させた。湯水の注入は、氷の融解を促す目的の他に、氷部の空洞上方に水を浸透させてゆるみ部分を作製するという意図がある。主として上下方向の水の浸透に伴って細粒分流出が発生しゆるみが拡大するという観点から、小型土槽による給排水繰返し土砂流出実験と空洞・ゆるみ形成メカニズムは似通っていると考えられる。

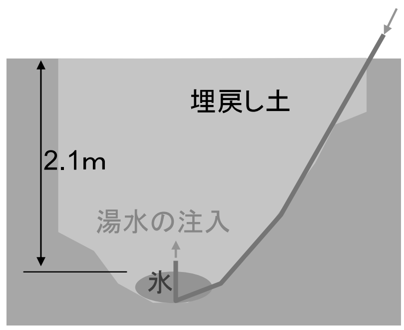


図18　模擬空洞・ゆるみの作製方法

6.2　陥没の状況とゆるみ検知の可能性

湯水注入から約 1 時間後に図 19 に示すような陥没が発生した。湯水注入前と注入後に各地盤においてレーダー探査（250MHz : 深度 3mにて広がり 1m×1m×厚さ 0.3m以上の空洞が検知可能）と表面波探査を実施し，実験終了後コーン貫入試験も行った。陥没発生位置とコーン貫入試験位置を図 20 に，レーダー探査結果とコーン貫入試験結果を図 21，図 22 にそれぞれ示す。

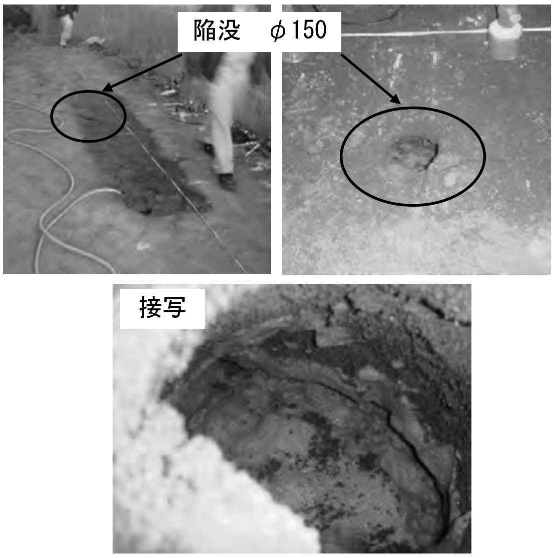


図19　陥没状況

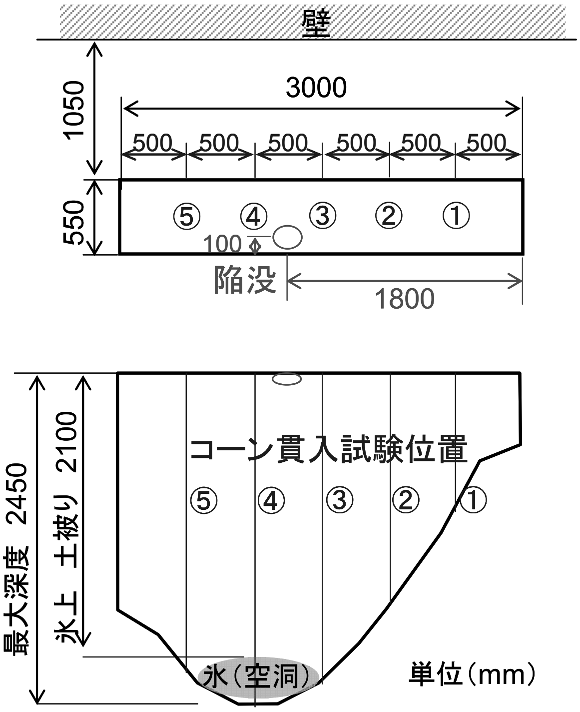
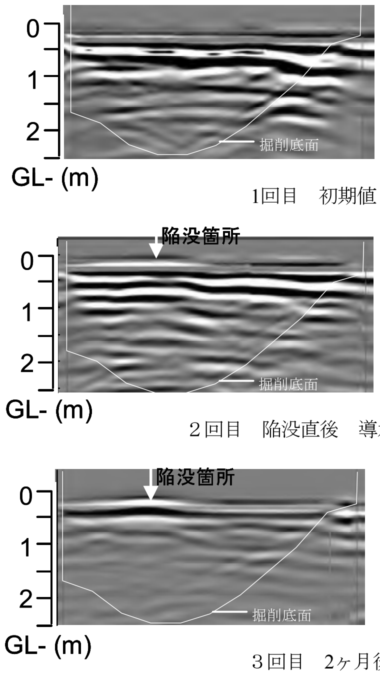


図20　陥没発生位置およびコーン貫入試験位置



空洞･ゆるみは非検知
底面～上部にわたる層状の信号は，川砂埋戻し作業のものと考えられる。

1回目　初期値

空洞･ゆるみは非検知
点在する部分的な強い信号は，導水で生じた水分によるものと考えられる。

２回目　陥没直後　導水と同日

空洞･ゆるみは非検知
陥没付近に強い反射信号があるが，空洞信号ではない。

３回目　2ヶ月後

図21　地中レーダー探査結果

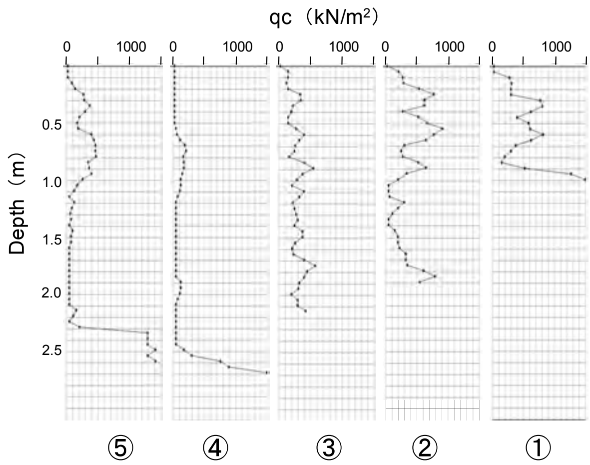


図22　陥没直後のコーン貫入試験結果

図 21 に示すように，埋め戻し後，陥没発生後，2 か月経過後のいずれのレーダー探査についても，空洞は検知されなかった。しかしながら，図 22 に見られるように，コーン貫入試験では，陥没位置周辺で貫入抵抗が著しく低く，埋戻し地盤のゆるみが確認された。地表までゆるみが到達していることから，氷塊溶解部の空洞は崩壊し，もはや顕著な空洞の形態を成していないと考えられる。

本実験では，「ゆるみ」という地中の微細な変化を検出する方法として，陥没前後の時系列変化による地中レーダーの反射強度の差分に着目し，新たに差分解析を試みた。数値化した反射強度の差分を各データ間で算出し，その値をレーダー解析システムに読み込み解析するもので，本実験では 1～3 回目各データ間の 3 ケースで行った。各データ間の差分解析データのうち，初期値～陥没直後(1～2 回計測差分)の差分レーダデータとコーン貫入抵抗値のプロット図との比較を図 23 に示す。このデータおよび他の差分解析データから，陥没付近の強い部分的な信号，右側中層部の掘削底面付近の部分的な強い信号，中間層に点在する部分的な信号の各部位において何らかの変化による信号が確認された。また図 23 では，強度差分がある（信号

が確認される）箇所でコーン貫入抵抗値に変化があることも読み取れた（瀬良ら[12)]）。なお，陥没発生前後で表面波探査も実施した。地盤内の氷の融解に伴うゆるみの生成とともに表面波の位相速度が変化する様子が見られたが，ゆるみ領域を特定するまでには至らなかった。

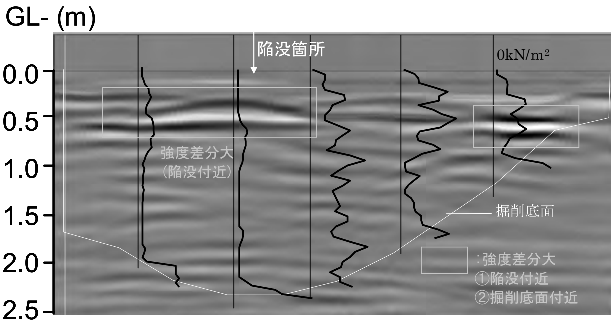


図23　1～2回（初期値～陥没直後）レーダー計測差分データとコーン貫入抵抗の比較

6.3　　模擬空洞・ゆるみの探査実験で得られた主な知見

大型ピット内の地盤に埋設した氷塊を融解させて人工的に作製した陥没・ゆるみの探査実験を実施した。地中レーダー探査において，通常の探査・解析方法では地盤のゆるみは検知されなかった。しかしながら，ゆるみ形成前後に取得した信号の差分を解析することにより，空洞の形態をなさない地盤のゆるみを検知できる可能性があることがわかった。

7.　　まとめと今後の課題

7.1　　本研究で得られた主な知見

本研究では，地盤内空洞・ゆるみの形成過程を明らかにし，空洞・ゆるみのパターンを類型化することにより，陥没に至るような“危険な”ゆるみを抽出することを目指している。これまでのところ得られた主な知見は以下の通りである。

- 土砂流出実験により，地盤内に形成される空洞および空洞周辺のゆるみの定量的評価が可能である。
- 地盤の種類や条件により，土砂流出・空洞拡大の速度，空洞周りのゆるみ領域の特性が異なる。また，地盤内の水の浸透方向によって，空洞・ゆるみの形成パターンが異なる。土砂流出源（空洞）付近で水が上下方向に浸透する場合は、空洞は鉛直上方に進展する傾向があり、水が水平方向に浸透する場合は空洞成長も水平方向に卓越する。
- 地盤内空洞・ゆるみの拡大の主要因は，大別すると，①飽和度上昇に伴うサクションの低下および有効応力の低下，②浸透破壊，③細粒分の流出，④空洞拡大に伴う地盤の不安定化等と考えられる。土砂の流出はゆるみ領域内の水みちの形成と不可分であり，特に細粒分の流出は空洞やゆるみの形成が顕著でない段階から始まっている。
- 地中レーダー探査においてゆるみ形成前後の信号の差分を解析することによって，ゆるみを検知出来る可能性がある。

7.2　　実現象との対応及び今後の展望

地盤陥没は，地盤内に自然にあるいは人工的に生成した空洞が崩壊することにより起こる。実際には，明らかな空洞形成を伴わなくても地盤内ゆるみが進展・拡大し陥没にいたることもあるようである。

通常，陥没の原因となる空洞周辺（特に上方）には，地盤のゆるんだ部分（密度低下部）が広がっている。砂質土の場合は 10～20％程度の密度低下部が空洞上部に急速に広範囲に進展し陥没に至る。均質な地盤で特異な水みちの影響が無い場合，土砂流出源の空洞部から鉛直上方に煙突状に地盤のゆるみが進展していることが多い。従って，陥没部を地表で埋め戻しても再陥没する可能性がある。

細粒土では，ゆるみの進展は遅いが，飽和状態下に長期間晒されると土砂流出が起こり，ゆるみが進展する可能性がある。空洞が深層部に生成した場合，知らず知らずのうちに大きく成長し，突然大規模な陥没を起こす危険性がある。いずれの場合も，土砂流出を防止するには土粒子どうしが接着している固結材料（改良土など）を埋設材料に用いるのが有効と思われる。

浅層部に存在する空洞・ゆるみは，その原因が特定できる場合は，適切に対処することにより再陥没に対する安全性も確保できる。しかし，その土砂流出源が不明の場合は，深層部空洞・ゆるみの進展・拡大の末期症状の現れかもしれないという危険性を認識する必要がある。そのような深層部の空洞（病気）を的確に診断するために，浅層部に達している“ゆるみ”（症状）を有効な判断材料として活用していきたい。

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Study on the detection of underground cavity and ground loosening for the prevention of ground cave-in accident

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Abstract

Local subsides or cave-in's of the ground often occur in urban area. The complicated underground situation as well as the necessity of urgent restoration do not usually allow full investigation for the real cause. The detailed mechanism of the phenomenon has not been, therefore, well understood.

Cave-in is usually initiated by the formation of cavity in the ground due to soil loss. When the location of the cavity is deep in the ground, the detection of the cavity is not easy. Then it is possible that the hidden cavity expands for a long time to eventually cause sudden large-scale collapse. In this study, characteristics of formation/expansion of cavity and surrounding ground loosening are investigated, aiming at effectively indicating dangerous pattern of cavity and loosening.

Key words: cave-in, erosion, cavity, loosening, exploration

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社会的視座と階層化意志決定法に基づく コンクリートの持続可能性評価の枠組みの構築

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本研究では，利害関係者の社会的視座を考慮したコンクリートの持続可能性評価の枠組みを提案した．利害関係者の持続可能性に関する意見は一般的に定性的な表現であるため，これを定量化し評価に用いるために階層化意志決定法を適用した．社会的視座に基づく重要な指標を選定するために社会調査を実施し，調査結果に基づいて重視する指標の変化が評価結果に与える影響を検討した．異なる設計シナリオを設定し，コンクリートの持続可能性を相対的に評価した結果，設計シナリオにしたがって，適切な配合条件が選定できることを示した．

Key Words : *sustainability, concrete, sociology of technology, analytic hierarchy process*

1. はじめに

(1) コンクリート産業における持続可能性の背景

持続可能性あるいは持続可能な発展は，1987年の国際連合（UN）ブルントラント報告である「Our Common Future」で，「将来世代のニーズを損なうことなく，現世代のニーズを満たす開発」とはじめて定義された[1]．これは，1992年の国連環境開発会議によって提案され，2005年の国連総会によって正式なものとされた．環境，経済，および社会という持続可能性の「3側面」を統合したものとして可視化（指標化）されている[2]．このような持続可能性の可視化の目的は，3側面間のつながりと，これまで互いに相容れないと見なされてきた概念を統合することの重要性を示すことにある．例えば矢口[3]は，3側面は並列ではなく，環境的持続可能性を前提とし，経済的持続可能性を1つの手段とし，社会的持続可能性を最終目的・目標とする関係性をもつと指摘している．3側面の関係のあり方は，様々な議論がなされているところではあるが，環境を犠牲にして経済的要因が重視されてきた過去に対し，環境側面の重要性を高めることによって，3側面のバランスを回復することが重要であることは共通した認識であると言える．

コンクリートは，市民生活の質を改善するために必要な社会基盤整備の基本的な建設材料であるため，水に次いで世界で2番目に多く利用されている材料である[4]．コンクリートの構成材料の製造，運搬，施工，維持管理，解体の各段階で多くの環境負荷が発生する．例えば，世界のCO_2排出量の約7%は，ポルトランドセメントの製造に由来していると考えられている[5]．コンクリートの製造では，年間110億トンを超える砂，れき，砕石，および1兆リットル以上の水が消費されている[6]．また，世界中で建物の解体から生じるコンクリートや組積みの廃棄物は，10億トンを超えると見積もられている[7]．これらは，温室効果ガスや粒子状物質の排出に加えて，運搬と製造，大気汚染，コンクリートの粉じんによる健康問題などにも関係している．以上のように，一般的に環境負荷量が多いと認識されているコンクリート産業にとって，今後の持続可能な活動は極めて重要な視点であるため，環境負荷を低減し，より持続可能な生産方式へ移行することで，社会的にも大きな便益をもたらす可能性がある．

これまでにも，コンクリート産業の持続可能な発展のために，さまざまな戦略が提案されてきた．たとえば，産業廃棄物や再生コンクリートの利用による資源消費量の削減，ポルトランドセメント利用の抑制，代替結合材料の利用，混和剤の利用による配合設計の最適化などによるCO_2排出量の削減，長期的な資源消費量と排出量を削減するための新設コンクリート構造物の高耐久化，既設構造物の耐用年数を延長するための維持管理の実施，

環境負荷の少ない工法の選定，およびコンクリート技術と教育におけるホーリスティックアプローチの採用といった戦略が挙げられる[4), 5), 6), 8)]．コンクリート産業にとって重要なことは，これらの環境負荷低減戦略を実践しつつ，建設材料としての優位性を維持することにある[9)].

(2) 問題意識と論文の構成

コンクリート産業にかかわらず，実施している活動の持続可能性を評価するためには，当然，評価手法が必要となる．これまでにも様々な持続可能性指標が提案されてきている[例えば3)]．建設産業においてもいくつかの評価システムが提案されており，例えばグリーンビルディング評価システム（LEED）[10)]などを利用することができるが，これらのシステムは建設全体を網羅的に評価するものであり，コンクリートに特化したシステムではない．コンクリートの環境側面評価に関しては，土木学会のコンクリート構造物の環境性能照査指針（試案）[11)]などが既に提案されているとともに，ISOのTC71/SC8 [12)]では，コンクリートおよびコンクリート構造物の環境マネジメントの規格作成が進められている．これらの枠組みの特徴は，環境側面のみを取り扱っている点にある．参考文献[3), 13)]で指摘されているように，「持続可能性指標の正否はそれを利活用する者の価値観・目的によって異なり，指標をより客観化するには指標の作成過程からより多くの利害関係者の参加が不可欠である」という視点が，持続可能性を評価するためには重要である．すなわち，コンクリートの持続可能性を評価するためには，コンクリート産業に関連する利害関係者の考え方を考慮することが重要となる．コンクリート産業は多数の利害関係者からなり，各々が独自の価値観や考え方など（以下，視座と称す）に基づき目標を定め，持続可能性に関する活動に努めている．このような活動を共通の枠組みで評価するための1つの有効な手段としてボトムアップ・アプローチがあり，これによって，利害関係者ごとの視座の相違を検討することが重要である[13)].

持続可能性に配慮したコンクリート（以下，サステナブルコンクリート）は，コンクリート産業の持続可能な活動を改善するうえで重要な役割を果たすと考えられる．しかし，持続可能性の概念と同様に，サステナブルコンクリートを構成または定義するものは何かということが明確にされていないことが問題である．

本研究では，技術形成プロセスの可視化[14)]に着目し，サステナブルコンクリートの形成に必要な視点を整理し，その結果に基づきコンクリートの持続可能性評価の枠組みについて考察する．また，利害関係者の社会的視座に基づく意見は定性的な表現が多いため，これを定量化するために適用した階層型意志決定法についても概説する．さらに，持続可能性評価の枠組みの考察に基づいて，具体的にコンクリートの持続可能性を評価するための指標や，それぞれの指標に付与される重要度を定量化するために社会調査を実施した．最後に，事例として数種類のコンクリートの持続可能性評価について考察する．

2. 持続可能性評価の枠組み

(1) サステナブルコンクリートの可視化

コンクリートは，ローマ帝国時代に用いられていた無筋コンクリートから，科学的な知見に基づいて設計された自己充填コンクリート，自己治癒コンクリート，または複数微細ひびわれ型繊維補強材料のような最新の材料まで，数千年にわたる歴史を持つ技術である．基本材料は依然として同じであるが，知識の進歩によって，コンクリート構造物を設計・建設するために利用される技術が向上している．本節では，知識体系の変化とコンクリート技術の関連性に関する検討から，サステナブルコンクリートの技術形成プロセスを可視化し，これを通してコンクリートの持続可能性評価に重要な視点について考察する．

一般的に，技術または人工物は，ある目標を達成するために人間によって作られるものである．成果として明瞭に可視化される人工物は，ある媒体と人工物の設計情報によって形成され，設計情報自体は，経時的に構築される情報と知識の蓄積によって形成される（Fig.1の上図参照）[14)]．この考え方にしたがえば，コンクリートは，Fig.1の下図に示すように，コンクリートを構成する媒体（材料），知識および設計情報によって形成される．コンクリートの基本的なパラダイムはローマ帝国の時代から変化しておらず，構成材料は，セメント，水，骨材（細骨材と粗骨材），および混和材料であり，製造に利用される情報は，配合設計と練混ぜ方法である．コンクリートの設計，材料，配合，試験方法などに関する100年以上にわたる研究成果と経験が集積された知識を，設計情報に変換することによって，古代コンクリートから近代コンクリートへと劇的な変化をもたらしているのである．

知識，媒体，設計情報，および結果としてもたらされるコンクリートの関係をより明確に理解するために，コンクリートの高強度化に関する過去60年間の経緯を例に取り考察する．Bentur[15)]が要約したように，高強度コンクリートを実現するための重要な視点は，強度と水結合材比の関係に関わるものである．水結合材比の低下に伴い強度が増加することは周知の事実であるが，同時に練混ぜ水の減少にともないワーカビリティーが低下するため，練混ぜ，圧送，打設などの施工性が低下する．しかし，高性能AE減水剤の開発によって，ワーカビリティ

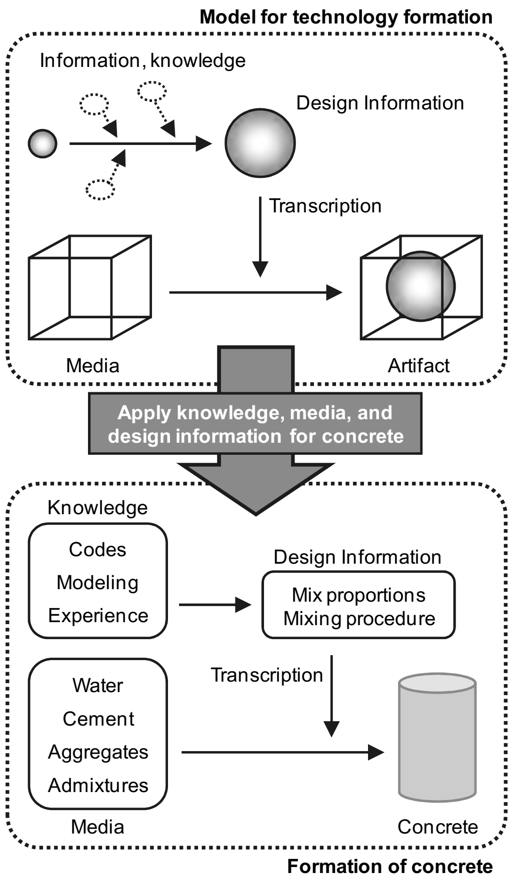

Fig.1 Formation of concrete based on a model for technology formation.

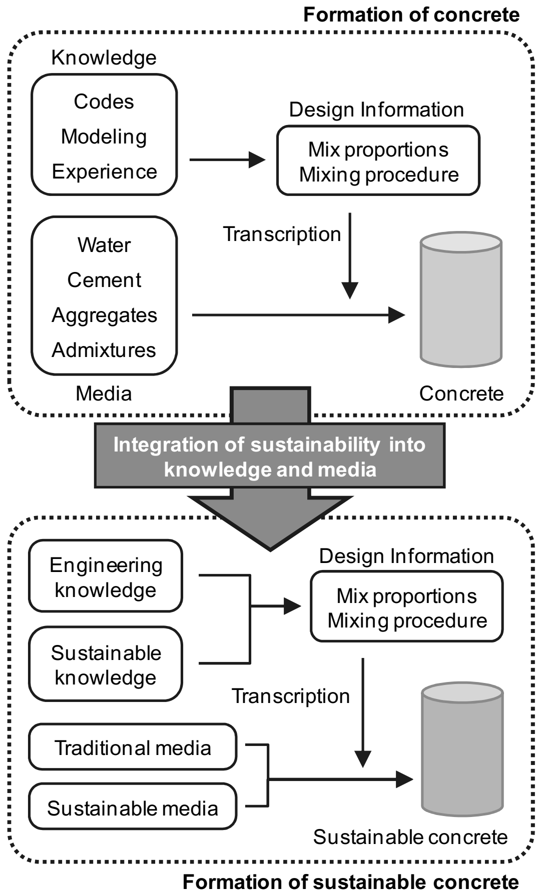

Fig.2 Formation of sustainable concrete by integrating sustainability.

ーを損なうことなく低水結合材比のコンクリートの製造・施工が可能となった．加えて，マイクロフィラーを用いることで，高強度化とワーカビリティーの向上が実現することも，現在では周知の事実である．このようにマトリックス強度が増加し骨材強度を上回るようになると，さらなる高強度化のためには，高強度な骨材が必要となる．すなわち，高強度コンクリートの形成は，マイクロフィラー，高性能AE減水剤，高強度骨材のような特殊な材料（媒体）と，セメントとマイクロフィラーの粒度分布特性や高性能AE減水剤の添加量に関する知識などの配合設計に関する情報，の両者がなければ説明することはできない．このような媒体や知識の開発が徐々に進むことで，高強度コンクリートが実際に利用できるようになったのである．

従来，普通コンクリートの材料設計の際に，持続可能性に関する側面は検討されていない．その主な理由は，規準類に持続可能性に関する規定が含まれていないからである．したがって，サステナブルコンクリートの形成は，Fig.2に示すように，持続可能性に関する知識や媒体と，従来のコンクリート技術の知識や媒体との統合化によって実現できると考えられる．

これまでのサステナブルコンクリートに関する提案のほとんどは，一般的に考慮されてきた強度や耐久性に加えて環境側面を考慮しており，主にCO_2排出量の削減と再生材や廃材の利用の2つが環境性指標として検討されてきている．ポルトランドセメントはCO_2の主要な発生源であるため，一般的なCO_2排出量削減シナリオは，セメントに代えて大量のフライアッシュ[5]または他の代替結合材料を利用することや，高性能AE減水剤を使用して単位水量および単位セメント量を減らすこと[4]に重点が置かれている．前者ではフライアッシュが持続可能な媒体として機能するが，後者では持続可能な媒体は存在しない．双方の事例において，持続可能性に関する知識はCO_2排出量削減であり，その他の要求性能（強度や耐久性など）を満足する適切な配合や製造手順を策定するためには技術的知識が必要となる．これら双方の例は，CO_2排出量を削減するだけでなく，資源消費量も削減している．これは，Mehta[8]によれば，コンクリート産業における持続可能な開発の基盤の1つと考えられている．再生材や廃材利用の規定には，再生骨材のような持続可能な媒体の利用も含める必要もあるが，粗骨材の製造時に発生するCO_2排出量は，再生骨材の場合よりも少ない場合[11]があるため，再生骨材の利用がCO_2排出量の増加をもたらす場合もあることはよく知られている．低品質

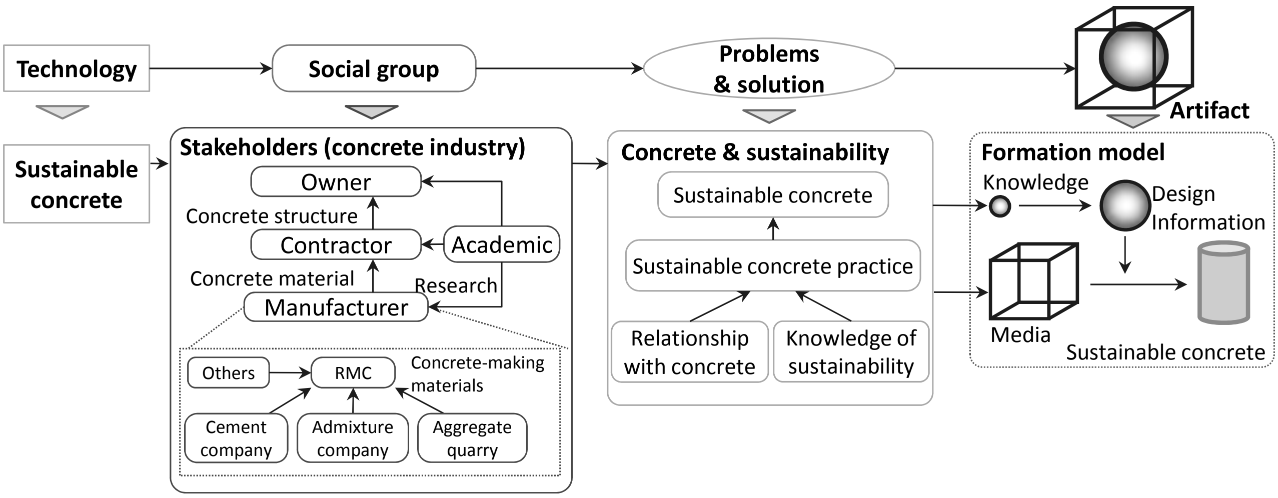

Fig.3 Framework for sustainable concrete based on a technology formation model and SCOT concept.

の再生骨材は，普通骨材とほぼ同様のCO_2排出量であるが，その品質は高品質の再生骨材よりも低い．したがって，サステナブルコンクリートの開発のためには，これらのトレードオフに関する新たな知識が重要となる．この再生骨材に関する例は，次の3つの要点を示している．すなわち，環境性を構成する項目間のバランス，環境性以外の従来考慮されてきている性質（以下，一般性質と称す）を構成する項目間のバランス，および環境性と一般性質の間のバランスを取る方法である．

資源消費量を削減する他の方法として，高耐久コンクリートがあり[8]，この場合，耐久性を持続可能性と規定することで，持続可能性に関する知識は従来の技術知識に統合される．その結果，高耐久コンクリートの設計は，その他の持続可能性に関する事を考慮することなく，サステナブルコンクリートとして評価されることになる．

このように，サステナブルコンクリートの実現に向けて多くのコンセプトや具体的な手法が提案されているが，残念ながら，それらの手法が広く利用されているとは言い難い状況にある．コンクリート産業には，様々な利害関係者が存在し，各々が異なる視座に立っているため，統一的なサステナブルコンクリートの評価基準を選定することが，非常に難しいことによると考えられる．

(2) サステナブルコンクリートの開発プロセス

前節では，従来の技術知識と持続可能な知識を統合することが，サステナブルコンクリートの開発に必要であるが，異なる指標間のバランスや，コンクリート産業内の利害関係者間の対立に起因する妥当な評価基準選定の難しさについて提起した．利害関係者間の対立問題を考察する場合，一般に，科学技術社会学の手法が広く用いられている．

技術の構成主義的社会学者らは，技術開発のプロセスを説明するために，技術の社会的構築（SCOT）を広く利用している．SCOT理論では，技術は，市場の需要などの要因ではなく，主として関連する社会集団（利害関係者）間の相互関係に起因して開発される[16]，とされている．技術の利害関係者は，開発される技術（人工物）に関する問題と解決策について，さまざまな視座に立つ者である．技術開発プロセスは，利害関係者が人工物に関する問題と解決策を検討し，利害関係者間で交渉しながら進められていく（Fig.3中の上図参照）．このプロセスは，利害関係者間に生じる相互関係にしたがうため複雑となり，具体の技術開発に応じてその詳細なプロセスは異なるが，Fig.3ではプロセスを単純化した形で示した．

SCOT理論をサステナブルコンクリートの開発に適用するためには，最初に利害関係者を特定することが必要である．利害関係者は，コンクリート産業を含む多様な社会集団であり，コンクリートの材料や構造物の製造プロセスにおいて果たす役割に応じて，Fig.3に示すように分類され，主要な利害関係者は，「発注者」，「請負者」，「製造業者」，および「研究機関」の4者である．なお，社会基盤施設の場合，国民の利害は発注者が代弁すると一般に考えられる．製造業者は，さらに，生コンクリートプラント（RMC）用のコンクリート原料を生産するグループに分類される．

次の段階は，利害関係者が有している問題を特定することである．これらの問題は，産業内で共通している場合や，利害関係者と対象技術（サステナブルコンクリート）との相互関係，持続可能性に関する知識水準など，さまざまな問題に関わる可能性がある．ここで，本研究で対象としているサステナブルコンクリートは，コンクリート産業における持続可能な活動の1つの側面に過ぎず，構造設計や工法など，必ずしもコンクリートがサステナブル材料でなくとも，産業全体として持続可能な活動を実践することは可能である．それぞれの利害関係者

は，異なる形でコンクリートと相互に関係し，異なる目標を持つため，これらの問題と解決策の検討も必要であるが，本研究では材料側面にのみ着目する．なお，具体的な内容については，次章のアンケート調査によって検討する．

最終段階は，Fig.3に示すように，利害関係者ごとの視座を，サステナブルコンクリートの形成モデルに統合することである．利害関係者の視座は，サステナブルコンクリートを形成するために利用される知識と媒体の一部であり，これらの知識と媒体が決定すれば，設計情報が確定され，サステナブルコンクリートの評価基準を特定することができる．この時，利害関係者間の視座の相違に応じて，利害関係者全体において交渉する必要が生じる可能性もある．

(3) 階層化意思決定法（AHP）

利害関係者の視座には，サステナブルコンクリートに対する各人の価値観が反映されており，各人の視座に基づくサステナブルコンクリートの定義は，一般には定性的な表現となる．ここで，コンクリートの持続可能性の評価に各人の視座に基づく意見を利用するためには，定性的表現を定量的データに変換する必要がある．階層化意思決定法（AHP）は，複雑な意志決定のための多基準の枠組みであり，意思決定の問題を，目標に向けた定量化可能な要素とそれらの関係および代替案からなる階層構造としてモデル化することである[17]．目標に向けた要素の重みは，定性的または定量的な判断基準を利用して，要素を2つ1組で相互に比較することによって特定される．これらの判断基準は，数値に変換して階層内の要素の重みを特定するために利用することができ，また異なる要素間の比較が可能となる．重みは，階層内の要素の重みと代替案の特性に基づき，目標達成のためのさまざまな代替案にも同様に適用することができる．また意志決定は，さまざまな代替案の重みを分析することで可能となる．AHPは，異なる指標間のバランスを考察する上でも利用することができ，たとえば，政府がCO_2排出量を20%削減するという目標を設定した場合，評価プロセスにおいて，CO_2排出量の削減に対し，ほかの要因よりも大きな重みを加えることができる．

3. 指標選定のための社会調査

前章では，コンクリートに関する持続可能性評価を実現するために，サステナブルコンクリートの開発プロセスを，サステナブルコンクリートの可視化およびSCOT理論に基づき検討した．この結果に基づき，具体的に評価するための指標や指標間の重み付けに利害関係者の視座を反映するために，日本のコンクリート産業における持続可能な活動と材料に関し，2段階の調査を実施した．最初に，インタビュー調査によるトップダウン・アプローチを用いて，サステナブルコンクリートの活動や材料に関する定性的概念を整理体系化し，次に，アンケート調査によるボトムアップ・アプローチによって，評価に使用する指標やそれぞれの指標に付与される重要度を定量的に調査した．ここで，具体的な持続可能性指標の選定および指標間の重み付けは，アンケート調査によって行うが，アンケート対象者は，必ずしも持続可能性評価に関して十分な知識を有していない可能性がある．そのため，アンケート調査で選定された指標の妥当性を確認するために，持続可能性に関して十分な知識を有する識者を対象としてインタビュー調査を実施した．

Table 1 Sustainable concrete practice indicators.

Stakeholder	Indicators
Academic	LCC, LCCO2, durability, recyclability, environmental impact, resources, energy, waste, project-dependent
Owner	LCC, LCCO2, durability, recyclability, environmental impact, service life
Contractor	LCC, LCCO2, durability, recyclability, ease of maintenance and inspection
Manufacture	LCC, LCCO2, durability, environmental impact, social benefit, workability, reliability, constructability, LCA

(1) インタビュー調査

インタビュー調査は，日本のコンクリート産業に携わる13名を対象とした．内訳は，研究機関が4名，製造業者（生コンクリートプラント，化学薬品会社，セメント会社，高炉セメント会社）が4名，請負者が3名，発注者が2名である．

インタビュー内容は，(a)対象者の属性情報の確認と，(b)コンクリートの持続可能性評価指標，の大きく2つで構成した．(a)属性情報の確認では，対象者のコンクリートとの関係および持続可能性に関する知識レベルに関して確認を行った．(b)持続可能性評価指標では，コンクリートの持続可能性を評価するために必要な項目および今後必要な対応に関してインタビューを実施した．

持続可能性評価指標に関するインタビュー調査結果の概要を，利害関係者毎にまとめてTable 1に示す．若干の違いは確認できるが，ライフサイクルコスト（LCC），ライフサイクルCO_2（LCCO2），耐久性，リサイクル可能性などの項目が共通していることがわかる．インタビュー結果に基づき評価項目および今後必要な対応についてとりまとめた結果をFig.4に示す．サステナブルコンクリートの実践は，LCC，耐久性，LCCO2のような評価基準，耐久性評価手法やインベントリーデータ構築のような評価を実施するために必要な活動，および規準整備

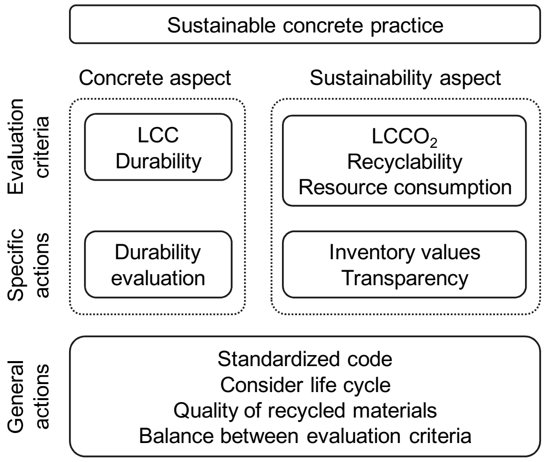

Fig.4 Concept for sustainable concrete practice from interview phase.

のような一般的な活動で構成される．なお，調査対象者は，持続可能性を考慮していない現状の枠組みでは，自らの役割や責任が，経験，規準，指針，規則などによって明確にされているため，コンクリート産業における自らの役割および他者との相違を明確に理解していた．しかし，持続可能性を実現するための産業の役割が曖昧であるため，対象者らは，持続可能性に関する自らの具体的な役割や責任を理解しておらず，持続可能な活動がどのようなものであるべきかについては，ほとんど全員が同様の考えを共有していた．すなわち，持続可能な活動全般に関する一般概念を共有しているに過ぎないと考えられる．このことは，ライフサイクルコスト分析やLCCO2の計算手法，および規準や指針を整備することが，重要であることからも伺える．

(2) アンケート調査

アンケート調査の目的は，コンクリートの持続可能性評価において，重視すべき点を定量的に分析することである．アンケート内容は，(A)属性情報，(B)一般性質に関する質問，(C)一般的な持続可能性に関する質問，(D)コンクリートの持続可能性評価指標に関する質問，の大きく4つで構成した．(A)属性情報では，対象者の所属，経験年数，主な業務内容などに関して調査した．(B)一般性質では，一般性質のみを対象としたときの各項目の重要度に関して調査した．(C)一般的な持続可能性では，一般論としての持続可能性の各項目の重要度に関して調査した．(D)コンクリートの持続可能性評価では，一般性質および持続可能性の各項目の重要度に関して調査した．なお，コンクリートの一般性質と持続可能性の側面の重要度については，4段階（1：重要でない，2：ほとんど重要でない，3：ある程度重要である，4：非常に重要である）評価で調査を実施した．コンクリートの一般

Table 2 Concrete performance parameters and sustainability indicators forevaluating sustainable concrete materials.

Concrete character parameters (JSCE)	
Aspect	Parameters
Chemical	Adiabatic temperature rise
Strength	Strength
Durability	Rate factor of carbonation, diffusion coefficient of chloride ion, resistance to freezing/thawing action, resistance to chemical attacks, resistance to alkali-aggregate reaction, coefficient of water permeability, fire resistance, shrinkage property
Fresh properties	Workability, pumpability, setting property
Cost	Initial cost, life cycle cost
Sustainability indicators (UN CSD)	
Aspect	Indicators
Social	Equity, health, education, housing, security, population
Environmental	Atmosphere, land, oceans/seas/coasts, fresh water, biodiversity
Economic	Economic structure, consumption/production patterns
Institutional	Institutional framework, institutional capacitys

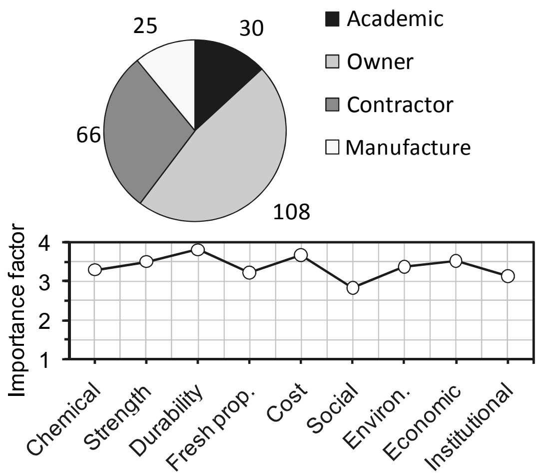

Fig.5 Distribution of survey respondents (top) and survey response importance factors (bottom).

性質はコンクリート標準示方書[18]を参考とし，持続可能性は国連の持続可能な開発委員会の指標の枠組み[19]を参考として設定した．これらをまとめたものをTable 2に示す．

回答者の分布をFig.5に示す．全部で229の回答が得られ，47.2%が発注者，28.8%が請負者，13.1%が研究機関，10.9%が製造業者であった．サステナブルコンクリートを評価するための一般性質と持続可能性の側面の重要度に関する調査の回答もFig.5に示す．これらの結果から，「耐久性」が4点中3.8で最も高く評価された．そのほかの評価の高い側面は，3.7の「コスト」，3.5の「強度」と「経済性」，3.4の「環境性」である．一般性質の側面は，全体として持続可能性の側面よりも評価が高かっ

Table 3 Importance factors from survey by stakeholder.

Aspect	Academic	Owner	Contractor	Manufacturer
Strength	3.3	3.5	3.6	3.3
Durability	3.6	3.8	3.8	3.6
Cost	2.9	3.7	3.8	3.5
Environmental	3.4	3.4	3.4	3.2
Economic	3.2	3.4	3.6	3.4

た．「社会性」のみがサステナブルコンクリートにとって「ある程度重要である」に達していないことがわかる．

アンケート調査の結果とインタビュー調査段階で重視された点を考慮して，「強度」，「耐久性」，「コスト」，「経済性」，および「環境性」をサステナブルコンクリートの評価指標として選定した．「化学的性質」，「フレッシュ性状」および「制度面」は，インタビュー調査の結果でほとんど重視されていないことと，一般性質および持続可能性の側面の他の指標と比較して，アンケート調査結果の評価も低いことから，本研究ではこれらの3つを指標として選定しなかった．選定された5つの指標は，3つの一般性質の指標と2つの持続可能性の指標で構成されている．国連の枠組みにしたがえば，環境性には大気（排出量，大気汚染など）や土地利用など，経済性には生産と消費のパターン（再生利用）や取引などが含まれる．コストを一般性質として区分したのは，国連の枠組みの経済性は，一般的な経済システムに重点を置いていることによる．

利害関係者毎にまとめた重要度係数をTable 3に示す．利害関係者間に若干の相違があることがわかる．ここで，この相違が統計的に有意なものであるか，あるいは標本グループ内の変動によってもたらされたものであるかを明確にするために，一元配置分散分析（ANOVA）と事後分析（シェッフェの方法）を行った．「コスト」を除くすべての側面には，利害関係者間に統計的に有意な相違はなかった（5%の有意性）．コストに関しては，発注者，請負者および製造業者の重要度係数は，研究機関の重要度係数よりも高く，また発注者の重要度係数は製造業者よりも高かった．コストの重要度に関して若干の相違はあるが，全体として，利害関係者間に視座の相違はほとんどないといえる．これは，アンケート内容が具体的なプロジェクトを想定せず，一般論に基づく回答であったことや，コンクリート産業全体として，持続可能性評価に関して具体的な経験が無いことによると考えられる．このことは，持続可能性に関する十分な知識を有する識者を対象としたインタビュー調査結果が，現状では，ほとんど全員が持続可能な活動全般に関する一般概念を共有していたことからも理解できる．今後，持続可能性に関する活動や評価が具体化され，各自の経験に基づいて自らの役割や責任を明確に認識した状況で調査を行った場合は，今回とは異なる結果が得られると思われ，今後も継続的に調査していく必要がある．

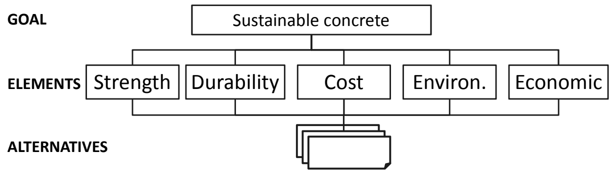

Fig.6 AHP hierarchy with aspects and alternatives.

Table 4 Pair-wise comparison values for different design scenarios.

Design scenario	Target criteria importance
Scenario 1	Durability (high importance)
Scenario 2	Environmental, economic (high importance)
Scenario 3	Cost (high importance)
Scenario 4	Durability, environmental (high importance) Economic (meduium importance)

(3) AHPの評価階層

調査結果から，コンクリートの持続可能性評価の階層は，Fig.6のように構築できる．この階層において，「目標」はサステナブルコンクリートであり，調査結果から特定された側面が「要素」を構成し，目標を満足するさまざまなコンクリート配合が「代替案」となる．

4. コンクリートの持続可能性評価事例

(1) 設計シナリオ

調査結果に基づいて選定された指標において，指標間の相対的な重要度はほぼ同等であった．これは，前記したようにアンケート内容が具体的なプロジェクトを想定せず，一般論に基づく回答であったことによると考えられる．実際のプロジェクトでは，すべての指標を同等の重要度で扱う場合も，ある特定の指標を重視する場合もあり得る．そこで，重視する指標の変化がコンクリートの持続可能性の評価結果に及ぼす影響を検討するために，例としてTable 4に示す4つの設計シナリオについて考察する．本研究では，一例として4つの設計シナリオを設定しているが，これは，調査で最も高く評価されていた耐久性を重視した場合（設計シナリオ 1），従来の評価では考慮されてこなかった環境性，経済性を重視した場合（設計シナリオ 2），研究機関以外で高く評価されたコストを重視した場合（設計シナリオ 3），および一般性質と持続可能性の側面のバランスを考慮した場合（設計シナリオ 4）とした．実際は，プロジェクトの目的や請負者による技術提案などによって，何れの指標を高位

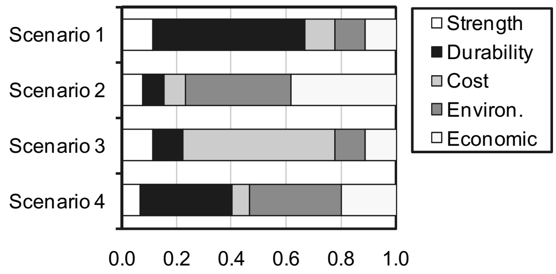

Fig.7 Weights of criteria for different design scenarios.

と設定するかは異なる．明確に指標間の重要度の差が設定されないプロジェクトでは，全ての指標の重みを同一として検討することとなる（設計シナリオ0）．

設計シナリオ 1は，耐久性の重要度を高位に，ほかの指標の重要度を低位に設定する．設計シナリオ 2は，環境性と経済性の重要度を高位に，強度，耐久性，およびコストの重要度を低位に設定する．設計シナリオ 3は，コストの重要度を高位に，ほかの指標の重要度を低位に設定する．設計シナリオ 4は，耐久性と環境性の重要度を高位に，経済性の重要度を中位に，コストと強度の重要度を低位に設定する．なお，高位，中位，低位の相対的な重要度はそれぞれ5，3，1とした．

Fig.7に，それぞれの設計シナリオにおいて，評価指標間の一対比較により相対的なAHPの重みを計算し，各指標の総合が1.0となるように正規化した結果を示す．設計シナリオ 1と3では，高位の重みが55.6%，低位の重みが11%，設計シナリオ 2では，高位の重みが38.5%，低位の重みが7.7%，設計シナリオ 4では，高位，中位，低位の重みがそれぞれ，33.3%，20.0%，6.7%と計算された．

(2) コンクリートの配合と特性

評価指標と，設計シナリオごとの相対的な重要度係数を設定したが，本節ではこれらの結果を用いて，具体的にコンクリートの持続可能性を評価するために，配合と特性の設定を行う．水セメント比50%，28日強度が40MPa程度のコンクリートを標準的なコンクリートとし，骨材種類（普通骨材，再生骨材 H，再生骨材 L），混和材（フライアッシュ，高炉スラグ微粉末）による内割り置換，水結合材比（W/B）の影響，を考慮した5つのケースを設定した（Table 5）．なお，強度と耐久性は設計時の性能照査の結果に基づき，配合設計の段階では明確な要求値（設計基準強度や特性値）が存在する．そのため，標準的なコンクリート以外の4ケースでは，28日強度が40MPa以上，耐久性は標準的なコンクリートと同等以上の品質が得られるコンクリートを実験により確認し選定した．配合条件をTable 6に示す．

コンクリートの持続可能性を評価するためには，設定した5つの指標を，具体的な数値で表現する必要がある．

強度は圧縮強度の計測値，コストはコンクリート1m^3

Table 5 Case studies.

Series	W/B (%)	Aggregate type	Cement replacement
WB50-NA (No.1)	50	Normal	-
WB50-HG (No.2)	50	Recycled (high)	-
WB30-LG-FA (No.3)	30	Recycled (low)	Fly ash (50)
WB50-NA-BS (No.4)	50	Normal	Slag (45)
WB50-HG-BS (No.5)	50	Recycled (high)	Slag (45)

Table 6 Concrete mix proportions.

Concrete series	(kg/m^3)							
	W	C	FA	BS	S	NA	LG	HG
No.1	171	342	-	-	746	1015	-	-
No.2	171	342	-	-	746	-	-	1015
No.3	165	275	275	-	590	-	856	-
No.4	171	188	-	154	742	1010	-	-
No.5	171	188	-	154	742	-	-	1010

W: water, C: Ordinary Portlan cement, FA: JIS typeII fly ash, BS: blast furnace slag, S: river sand, NA: normal aggregate, LG: typeL recycled aggregate, HG: typeH recycled aggregate

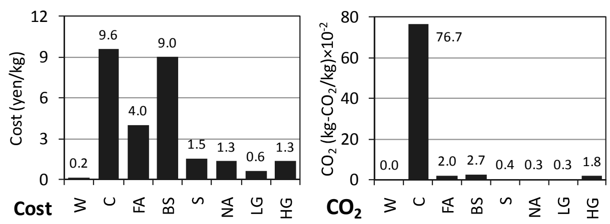

Fig.8 Cost (left) and CO_2 emissions (right) of concrete-making materials [11].

の材料費とし，構成材料の単価から配合を考慮して計算した．材料単価は積算資料（（財）経済調査会）を参照し，記載の無い材料に関しては材料を取り扱っている会社へのヒアリング調査によって決定した．なお，水は東京都水道局の情報を参照した．設定した構成材料の単価をFig.8に示す．

耐久性を支配するコンクリートの物理量は，対象とする劣化機構に応じて，中性化速度係数や塩化物イオンの拡散係数など異なるが，多くの場合，コンクリートの物質移動特性の影響を受ける．そこで本研究では，透気試験結果から簡易的に耐久性を定性的なランク付けすることとし，低位，中位，高位をそれぞれ1，2，3とランク付けした．なお，耐久性指標の影響が大きい設計シナリオにおいて，定性的なランク付けを1，3，5とした場合の結果と傾向としては大きく変わらないことは確認している．透気試験結果の数値を直接用いない理由は，透気係数と耐久性の関係が必ずしも線形関係を示さないことによる．

CO_2排出量は，国連の持続可能性指標の枠組み[19]の環

Table 7 Properties of concrete mixes.

Concrete series	Strength (MPa)	Durability (qualitative)	Cost (yen/m^3)	CO_2 emission (kg-CO_2/m^3)	Raw material (vol.%)
No.1	44	Moderate	5810	267.9	100
No.2	44	Moderate	5810	282.9	62.5
No.3	40	High	5205	221.0	52.8
No.4	42	High	5705	153.9	94.7
No.5	42	High	5705	168.8	57.4

Table 8 Weights of criteria for diffrenet concrete mixes.

Concrete series	Strength	Durability	Cost	CO_2 emission	Raw material
No.1	0.206	0.125	0.194	0.154	0.137
No.2	0.206	0.125	0.194	0.146	0.219
No.3	0.188	0.250	0.217	0.187	0.260
No.4	0.200	0.250	0.198	0.268	0.145
No.5	0.200	0.250	0.198	0.245	0.239
Total	1.0	1.0	1.0	1.0	1.0

Table 9 Weights of concrete mixes by design scenario 0.

Series	S.	D.	C.	En.	Ec.	Total
No.1	0.041	0.025	0.039	0.031	0.027	0.163
No.2	0.041	0.025	0.039	0.029	0.044	0.178
No.3	0.038	0.050	0.043	0.037	0.052	0.220
No.4	0.040	0.050	0.040	0.054	0.029	0.212
No.5	0.040	0.050	0.040	0.049	0.048	0.226

S.: strength, D.: durability, C.: cost, En.: environmental, Ec.: Economy

境側面の「大気」に属するとともに，コンクリートの環境影響の主要な指標として広く利用されている．加えて，インタビュー調査結果からも，CO_2排出量の重要性は共通の認識となっている．そこで，環境性はCO_2排出量で表現した．各配合のCO_2排出量は，土木学会によって提案された手法[11)]に基づき，Fig.8に示す構成材料の排出量原単位を用いて計算した．

環境性と同様に，国連の枠組みを参照するとともに，コンクリート産業で広く利用可能であることに着目し，経済性の指標として，天然資源の使用割合（体積割合）を選定した．また，インタビュー調査においても天然資源の使用割合は，CO_2排出量のようにインタビュー対象者全てに共通した認識ではないものの，その重要性が指摘されていた．

Table 7に，各指標の数値を示す．この数値を用いて，各指標について配合間の一対比較により相対的な重要度係数を求め，得られた各配合の相対的な重要度係数の総和が1.0となるように正規化した結果をTable 8に示す．なお，強度および耐久性はTable 7の数値が高い場合，コスト，CO_2排出量，天然資源の使用割合はTable 7の数値が低い場合，相対的重要度係数は大きくなる．

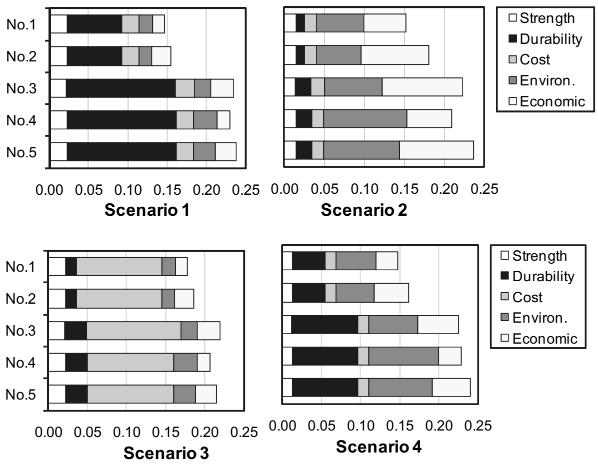

Fig.9 Weights of concrete mixes by design scenario.

(3) AHPの計算結果

設計シナリオ 1～4の考察の前に，指標間の重要度が同一の場合（設計シナリオ 0）の計算結果をTable 9に示す．今回設定した配合は，強度と耐久性は設計時の要求値に基づいているため，指標間の重要度が同一の場合は，コスト，環境性，経済性に優れた配合の重みが高く計算されていることがわかる．

Fig.7およびTable 8の結果を用いて，設計シナリオごとの5種類のコンクリートの相対的な重みを計算した結果をFig.9に示す．

設計シナリオ3を除くすべての設計シナリオにおいて，No.5（WB50-HG-BS）の配合が最高値を示し，重みの約24%を占めている．この配合の評価が高いのは，耐久性が高く，ほかの配合と比較してCO_2排出量と天然資源の使用割合とのバランスが良好なためである．高炉スラグ微粉末を用いることの利点は，高水結合材比でフライアッシュよりも高い28日強度を達成するため，結合材量，すわなちCO_2排出量を削減できることである．

設計シナリオ 3では，No.3（WB30-LG-FA）の配合が最高値を示し，重みの約22%を占めている．これは，フライアッシュの価格が比較的安いことによる．現状では，フライアッシュは一般的な建設材料として流通していないため，今回，ヒアリング調査によってその価格を決定しているが，今後その価格は変動する可能性はある．

粗骨材として再生骨材 Hを用いた場合，高炉スラグ微粉末の使用の有無にかかわらず，天然資源の使用割合が低下するため，経済性の重みが大きく変化していることがわかる．

再生骨材 Lを用いた場合，同一水粉体比で比較すれば，一般的に強度および耐久性は大きく低下する．今回のケーススタディでは，28日圧縮強度が40MPa程度となることが前提条件であり，加えて強度発現が緩やかなフライアッシュを使用しているため，結果として水粉体比が低下し，標準的なコンクリート（No.1）よりも耐久性が改

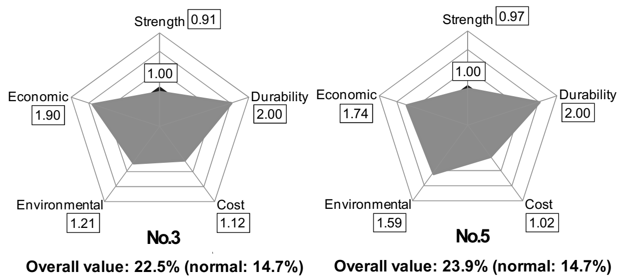

Fig.10 Weights of concrete mixes (scenario 4) normalized by general-use concrete.

善している．フライアッシュなどの環境負荷の低い粉体を用いない場合，水粉体比の低下は普通ポルトランドセメントの使用量の増大，すなわちCO_2排出量およびコストを増大させることになる．しかし，フライアッシュを利用して普通ポルトランドセメントの使用割合を抑えることによって，これらの増大を相殺することができる．

ここで，5つの指標間のバランスを視覚的に理解しやすくするために，標準的なコンクリート（No.1）の結果で正規化したレーダーチャートの例をFig.10に示す．本来，材料の持続可能性を評価する場合，標準的な材料と代替案間の相対的な比較だけでなく，当該材料の持続可能性の絶対評価が望ましい．そのためには，絶対的な基準の設定が必要となるが，コンクリートについてその基準を設定するのは容易ではない．なぜなら，生態系とは異なり，回帰すべき「持続可能な」状態として表示できる歴史的な基準点が存在しないからである．そのため，コンクリートの基準点の設定は，産業が進むべき方向を見据えて設定することが望ましいと考えられる．現状から明らかなように，コンクリート産業のみならず全ての産業において，環境負荷をより一層軽減する必要があるため，少なくとも，現在用いられている標準的なコンクリートよりも持続可能な材料を目指す必要があり，この意味において，本研究では，標準的なコンクリートを基準として設定した．

設計シナリオ 4におけるNo.3とNo.5を一例として掲載したが，両者ともに強度を除くすべての評価基準において基準を上回っている．No.5は，コストおよび経済性でNo.3よりも劣っているが，環境性の評価が高く，総合評価としては僅かではあるがNo.5が高くなっている．

5. おわりに

コンクリートの持続可能性を評価するために，技術形成プロセスの可視化に着目し，技術の社会的構築（SCOT）理論と階層化意志決定法（AHP）に基づく，持続可能性評価の枠組みを提案した．利害関係者の社会的視座に基づいて評価基準を選定することにより，持続可能性を定義するうえでの問題点を解決した．提案した評価の枠組みを用いて，日本のコンクリート産業におけるコンクリートの持続可能性評価を実施した．本研究では，材料側面の持続可能性評価を対象としてアンケート調査により具体的な指標の選定や，指標間の重み付けを実施しているが，本研究と同様な手順で調査を実施することで，例えば，コンクリート構造物の持続可能性評価も実施可能であると考えられる．

インタビューおよびアンケート調査結果から，コンクリートの持続可能性を評価する指標として，強度，耐久性，コスト，環境性，および経済性が選定された．現状では利害関係者間の視座の違いはそれほど大きくなく，コストの重要度に関して若干の違いが見られた．今後，持続可能性に関する活動や評価が具体化され，各自の経験に基づいて自らの役割や責任を明確に認識した状況で調査を行った場合は，今回とは異なる結果が得られると思われ，今後も継続的に調査していく必要がある．

重視する指標の変化が評価結果に与える影響を把握するため，4つの設計シナリオを設定し，異なる5種類のコンクリートの持続可能性を相対的に評価した．設計シナリオにしたがって，適切な配合条件が選定できることが明らかとなった．

本研究で提案した評価の枠組みは，コンクリートの製造・施工プロセスのさまざまな段階の意思決定に，社会的視座を組み込むための一般的な手法であるが，具体的に検討した事例は材料側面のみを対象としているとともに，いくつかの単純化を行っている．わが国のフライアッシュと高炉スラグ微粉末の利用状況を見ると，高炉スラグ微粉末はフライアッシュよりもはるかに広く利用されており，国内市場の約24%を占めているのに対し，フライアッシュはわずか0.4%に過ぎない．このような材料入手の容易さなどは，本来重要な視点であり，材料の代替案を比較するために利用したAHP階層に考慮する必要があり，今後も継続的に検討する必要があると考えている．

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ASSESSMENT FRAMEWORK FOR SUSTAINABLE CONCRETE BASED ON SOCIAL PERSPECTIVES AND ANALYTIC HIERARCHY PROCESS

Yoshitaka KATO and Michael HENRY

This research proposed a framework for assessing concrete sustainability which is based upon the concept that technology is defined by stakeholders' perspectives and which applied Analytic Hierarchy Process to translate these perspectives into quantifiable assessment values. A survey was conducted to identify important criteria, and several "design scenarios" were introduced which represent different value systems by varying criteria importance. Concrete materials with varying environmental impact were then assessed to observe the effect of different value systems and material properties, and it was found that the concrete with better properties was generally selected as most sustainable regardless of the design scenario.

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An assessment framework based on social perspectives and Analytic Hierarchy Process: A case study on sustainability in the Japanese concrete industry

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A B S T R A C T

This research introduces a framework for assessing concrete sustainability which is based upon the concept that technology is defined by stakeholders' perspectives and which applied Analytic Hierarchy Process to translate these perspectives into quantifiable assessment values. A survey was conducted to identify important criteria, and several "design scenarios" were introduced which represent different value systems by varying criteria importance. Concrete materials with varying environmental impact were then assessed to observe the effect of different value systems and material properties, and it was found that the concrete with better properties was generally selected as most sustainable regardless of the design scenario.

Introduction

Sustainability and concrete

Sustainability, or sustainable development, was originally defined by the Brundtland Report "Our Common Future" to the United Nations (UN) in 1987, in which it was defined as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). It is popularly visualized as the integration of the "three pillars" of sustainability: environment, economy, and society – a concept proposed by the UN Conference on Environment and Development in 1992 and formalized by the UN General Assembly in 2005 (United

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Nations, 2005). Visualization of sustainability in this fashion is intended to demonstrate the connection between the three pillars and the importance of integrating concepts which were viewed as mutually-exclusive in the past. Furthermore, this model shows that greater emphasis is being placed on economic factors at the expense of the environment, so it is necessary to restore balance between the pillars by increasing the importance of environmental factors.

Sustainable practice is a critical issue for the concrete industry, which has come under increasing pressure due to its environmental impact. Most notably, up to 10% of the world's CO_2 emissions can be attributed to concrete production and transportation (Sakai, 2009). Furthermore, concrete production was estimated to consume more than 11 billion tons of sand, gravel, and crushed rock per year in addition to over one trillion liters of water by Mehta (2001), and worldwide generation of concrete and masonry rubble from construction demolition was estimated to exceed one billion tons by Lauritzen (1998) – and these numbers have grown substantially over the subsequent decade due to increases in population and infrastructure development, particularly in Asia. These are in addition to other greenhouse gas and particulate matter emissions related to air pollution, health concerns from concrete dust, and more. As concrete is the world's second most-used resource after water (Sakai, 2009) – and a fundamental component for infrastructure construction necessary to improve quality of life – any reduction of these impacts could have widespread benefits for easing environmental burden and moving towards more sustainable construction systems.

A variety of strategies for sustainable practice in the concrete industry have been proposed. These include reducing resource consumption by utilization of industrial waste and recycled concrete; reducing CO_2 emissions through decreased usage of Portland cement, utilization of alternative cementitious materials, and optimized mix design by applying chemical admixtures; enhancing the durability of new concrete construction to reduce long-term resource consumption and emissions; implementation of maintenance management schemes to extend the service life of existing structures; selection of low-impact construction methods; and taking a holistic approach in both concrete technology and education (Malhotra, 1999; Mehta, 1999, 2001; Sakai, 2009). However, the competitiveness of concrete as a construction material must be maintained while implementing these strategies (ACI BACSD, 2005).

Means of evaluating sustainability are necessary in order to determine whether practices are more or less sustainable and to evaluate the state of a system; this is achieved through sustainability indicators (SI), which are typically used to evaluate different aspects of a system, with the total trend of all the indicators providing some idea of how sustainable a system is. There is a wide variety of green building evaluation systems available for assessing sustainability in the construction industry, but although the usage of concrete can help improve the final rating in these systems there is no specific consideration or evaluation of concrete. Concrete-specific standards include the International Organization for Standardization's (ISO) sub-committee on *Environmental management for concrete and concrete structures*, which is currently under development, and the Japan Society of Civil Engineer's (JSCE) "Recommendation of Environmental Performance Verification for Concrete Structures (Draft)," which provides general environmental principles across all phases of a concrete structure's life cycle (JSCE, 2006). As can be seen from the titles, however, these specifications focus primarily on environmental impact aspects only. Furthermore, these approaches to measuring sustainability – as well as any attempt at a generalized definition of sustainability itself – neglect a critical aspect of a greater issue: that sustainability is a human vision with human values, and it varies depending on who is applying it and under what conditions it is being applied (Bell and Morse, 2008). The concrete industry is composed of many stakeholders, each of which have their own perspectives and goals, and any attempt to implement sustainable practice, materials, and assessment of those practices and materials will require consideration of the stakeholders' input and negotiation between their differing goals and restrictions. Considering these varied perspectives, one means of establishing sustainability assessment criteria is through a bottom-up approach, whereby the stakeholders define sustainability and determine the assessment criteria, as they may be the best-placed to do so since they will be tasked with implementing sustainability (Bell and Morse, 2008). Tackling the issue of sustainability in this fashion will require the development of assessment systems which integrate the social perspectives on sustainability with the technical execution necessary to carry out those perspectives into practical application.

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Objectives

The objective of this research is to develop a framework for assessing the sustainability of concrete materials which considers the social perspectives of stakeholders and apply it considering a case study on the Japanese concrete industry and a set of concrete materials. Sociology of technology is used to construct this framework, first by establishing a conceptual model for sustainable concrete from technology management theory, then combining that model with a social model for how technology is constructed and the Analytic Hierarchy Process, which is used to convert the human value systems into quantifiable assessment criteria. The proposed assessment framework is then applied through an investigation into the social perspectives of stakeholders in the Japanese concrete industry and the assessment of a group of concrete materials with varying approaches to reducing environmental impact.

Research significance

The purpose of this assessment framework is to integrate social perspectives on sustainability into the concrete technology development and assessment process, and is intended to provide engineers and managers in the concrete construction field with a methodology for selecting the most sustainable alternative when faced with a set of possible courses of action – for example, different mix proportions, different construction methodologies, and so forth. Although the example given in this paper focuses on the selection of the most sustainable material – an example of application at the material production level, for ready-mix concrete producers – the general framework is flexible and can be adapted to any stage of the construction process, from design to construction to maintenance.

Development of assessment framework

Sustainable concrete materials play an important role for improving sustainable practice in the concrete industry. However, the same problem exists for sustainable concrete as exists for the concept of sustainability itself: what constitutes or defines sustainable concrete?

Visualizing sustainable concrete

Concrete is a technology with a history which spans thousands of years, from the basic unreinforced concrete of the Roman Empire to modern materials such as self-compacting concrete, self-healing concrete, or high performance fiber reinforced cementitious composites, which have been micromechanically designed or chemically engineered. Although the basic materials remain the same, advances in technology have increased the knowledge base used to design and build concrete infrastructure. This section discusses the dependency of concrete on knowledge and design information and proposes how to visualize the development of sustainable concrete.

A technology, or artifact, is something which is made by humans to achieve human goals. Visualized simply, an artifact is formed by the transcription of design information onto media or materials, and the design information itself is an accumulation of information and knowledge built up over time (Yoshida and Yashiro, 2007). The formation of concrete can thus be visualized by modifying that model with the media, design information, and knowledge necessary to develop concrete, as illustrated in Fig. 1. The basic paradigm for concrete has not changed since the times of the Roman Empire: the media utilized for concrete are cement, water, aggregates (fine and coarse), and admixtures, and the design information used to make concrete are the mix proportions and mixing procedure. Modern design information is the product of over a hundred years of research and experience, which has resulted in modern design codes, material specifications, mixing guidelines, models, and testing standards and procedures which have fundamentally changed modern concrete from the basic form of its ancient precursor. It is the development of this knowledge and its application to the design information (and, by extension, the media) which has produced concrete of a different form.

In order to demonstrate more clearly the relationship between knowledge, design information, media, and the resulting concrete material, a simple example will be given considering the increase in concrete compressive strength over the last 60 years. As summarized by Bentur (2003), the difficulty

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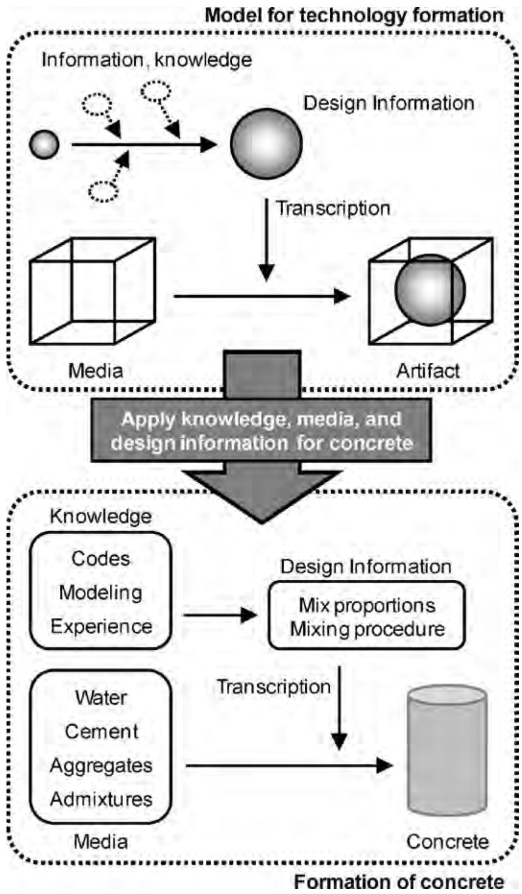

Fig. 1. Formation of concrete based on a model for technology formation.

in achieving high-strength concrete is related to the relationship between strength and the water–binder ratio of the concrete. It is widely known that decreasing the water–binder ratio increases strength; however, this also reduces the amount of mixing water and thus the workability is also reduced, making mixing, pumping, placing, and so forth difficult to perform. However, the development of super plasticizers (high-range water reducers) made concrete with low water–binder ratio possible without compromising workability. In addition, the importance of microfiller (such as silica fume) for achieving high packing density by filling void space was also understood, as was the importance of cement and microfiller grading control. However, if the strength of the mix becomes higher than the coarse aggregates, then specialized aggregates need to be used to match the added strength of the matrix. From this example, the dependency of strength on the design information and media can be clearly seen. High-strength concrete could not be achieved without specialized media – microfiller, super plasticizers, high-strength aggregates – or without knowledge regarding the proper mixing proportions – grading of cement and microfiller, dosage of super plasticizers. As the development of these media and knowledge advanced over time, concrete with higher compressive strength could be practically used.

For normal concrete, there is typically no consideration of the sustainable aspects when designing the material, as codes have not contained specification of environmental or sustainable performance. Sustainable concrete should, therefore, be formed from the integration of sustainable knowledge and media with the traditional concrete engineering knowledge and media, as shown in Fig. 2. The

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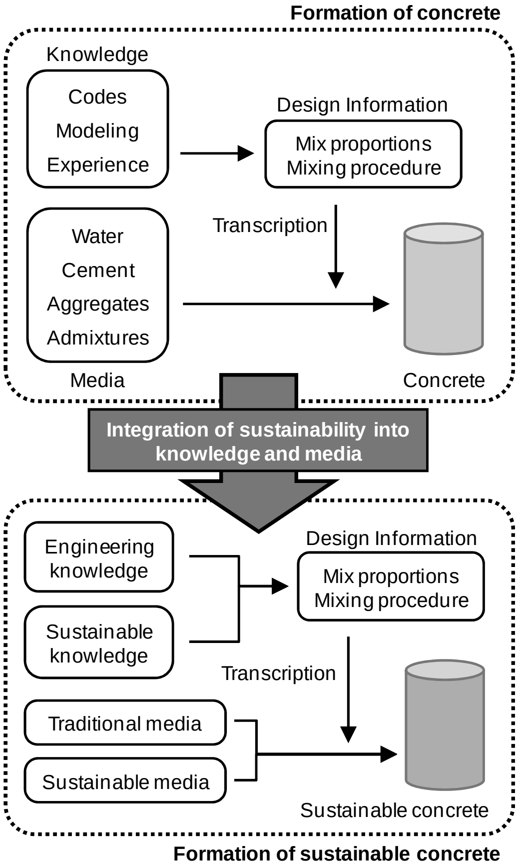

Fig. 2. Formation of sustainable concrete by integrating sustainability.

integration of sustainable knowledge will come from the specification of sustainable performance for the concrete mixture; for example, specifying a certain level of CO_2 reduction will require inventory knowledge for calculating CO_2 emissions. Although sustainability contains a large number of aspects, it is most likely that the environmental performance will be considered more than others since current actions focus primarily on the environmental impact.

Focusing on the environmental aspect only, most proposals for sustainable concrete practice consider the reduction of CO_2 and the use of recycled and waste materials as the two primary environmental performances. Since Portland cement is the main source of CO_2, reduction scenarios typically focus on reducing the amount of Portland cement used in concrete, either by replacing cement with high volumes of fly ash (Malhotra, 1999) or other alternative cementitious materials or utilizing super plasticizers to reduce the amount of mixing water and thus the amount of cement (Sakai, 2009). In the first case, fly ash acts as sustainable media, but in the second case there is no sustainable media; for both cases, the sustainable knowledge is CO_2 reduction, and engineering knowledge is then required to develop the proper mix proportions and procedures for producing concrete with the necessary performance. Both of the previous examples not only reduce CO_2 emissions but also conserve concrete-making materials and reduce material consumption – one of Mehta's (1999) foundations for sustainable development in the concrete industry. Specifying the use of recycled and waste materials may also require the use of sustainable media such as recycled aggregates. However, the production of normal coarse aggregates emits less CO_2 compared to recycled

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aggregates (JSCE, 2006). Therefore, the use of recycled materials may cause an increase in the CO_2 emissions; furthermore, the mechanical performance of low-grade recycled aggregates, which have roughly the same CO_2 emissions as normal aggregates, is lower than that of higher-grade recycled aggregates, so new knowledge about the trade-off in performance between these two is necessary for the development of sustainable concrete. This example with recycled aggregates demonstrates three key points: how to balance different environmental considerations, how to balance different mechanical performances, and how to balance the environmental with the mechanical.

Another approach to reducing material consumption is by increasing the durability of concrete materials (Mehta, 1999). By specifying durability as a sustainable performance, the engineering and sustainable knowledge are combined into one area of concrete engineering knowledge. The design of high-durability concrete could then proceed without any other sustainable input, since durability was defined as sustainable performance at the knowledge level.

Many different approaches to sustainable concrete have been proposed, but so far these types of materials have not seen wide-spread use. In addition, there is uncertainty in selecting which knowledge criteria to apply for assessing sustainable concrete because there are a wide variety of stakeholders related to concrete, each of which look at concrete from a different perspective.

Assessment framework

The previous section proposed that sustainable concrete be developed by integrating engineering and sustainable knowledge, but raised the question of how to select which knowledge criteria are used for assessment due to differing performance characteristics and conflicts of interest between the stakeholder groups within the concrete industry. The sociology of technology may be useful for answering the question of how to deal with conflicting stakeholder groups.

The Social Construction of Technology (SCOT) is used by constructivist sociologists of technology to explain how technological development occurs. In SCOT theory, technological development proceeds primarily due to the interactions between relevant social groups (stakeholders), rather than other factors such as market demand (Pinch and Bijker, 1987). The stakeholders for a technology are those which possess some perspective on the artifact, with each group holding a different perspective on the problems and solutions related to a target technology. The development process proceeds as the stakeholders define and negotiate their problems and solutions in the context of the meaning they apply to the artifact. Although this process is not linear (it follows the complex social interactions which occur between the stakeholders), a simple linear representation is given in Fig. 3.

The first step in adapting the SCOT concept to sustainable concrete is to select the target technology and identify the relevant social groups. Since this research is focused on sustainable concrete materials, the target technology is shown as "sustainable concrete" in Fig. 4. The stakeholders are the different social groups which comprise the concrete industry, and are broke down as shown in Fig. 4 based on their role in the process of producing concrete material or structures. The four primary

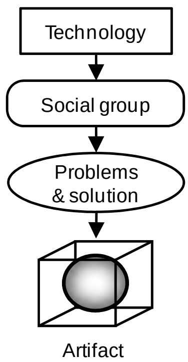

Fig. 3. SCOT concept of technology development.

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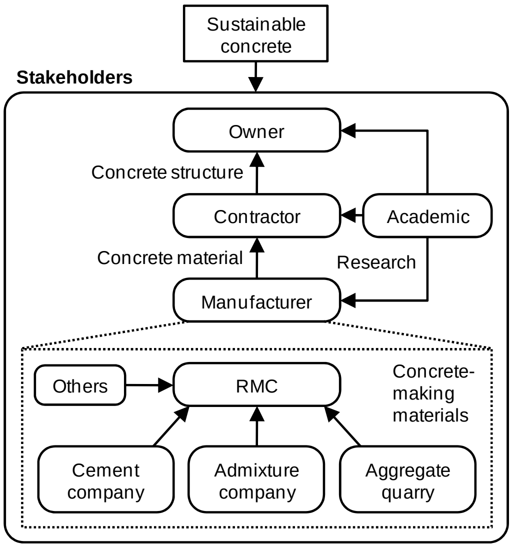

Fig. 4. Stakeholders relevant to sustainable concrete.

stakeholders are the "owner," "contractor," "manufacturer," and "academic." The manufacturer group can be further broken down into sub-groups which produce the concrete-making materials for the ready-mix concrete plant (RMC) which produces the actual concrete. The owner group also contains a variety of distinct sub-groups, such as government (public infrastructure); railway, utility or transportation companies (private infrastructure); the research centers which serve those groups, consultants, and so forth.

The next step in adapting the SCOT model is to identify the problems and solutions held by the relevant social groups. These problems and solutions represent the unique perspectives held by each social group. For the development and assessment of sustainable concrete, the perspective on sustainable materials is the primary interest, as shown in Fig. 5. However, the problems and solutions for sustainable materials may be related to different problems, such as general sustainable concrete practice in the industry itself, the stakeholder's specific interaction with concrete, and the level of

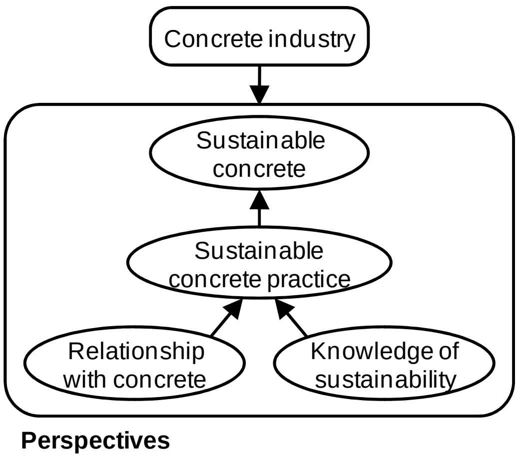

Fig. 5. Evaluating stakeholders' perspectives and key topics.

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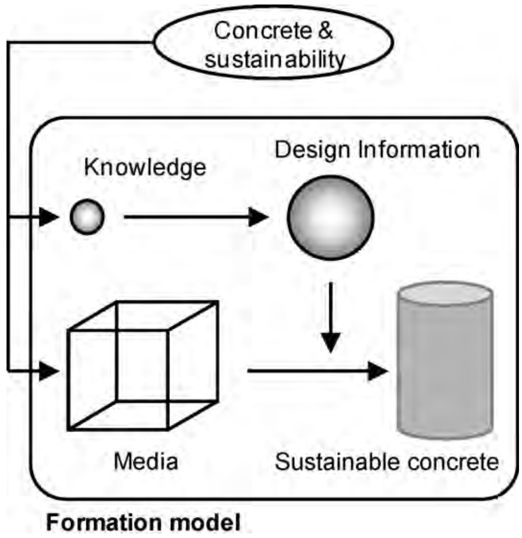

Fig. 6. Integrating the stakeholders' perspectives into the formation model.

knowledge of sustainability. As shown in Fig. 4, the stakeholders all perform different roles in the production of concrete infrastructure; in addition, the perspective on sustainable materials may also be greatly affected by the level of knowledge of sustainability. Finally, sustainable concrete material is just one aspect of the overall need for sustainable practice in the concrete industry. While concrete materials do contribute to the industry's environmental impact, there may be other means of adopting sustainability in practice that do not necessarily affect concrete materials directly, such as structural design or construction method. Since each stakeholder interacts with concrete in a different way and has a different target, consideration of these problems and solutions is necessary.

The final step in adapting the SCOT model is to integrate the problems and solutions – the perspectives – given by the stakeholders into the formation model for sustainable concrete, which is illustrated in Fig. 6. Part of the stakeholders' perspectives on sustainable concrete is the knowledge and media used for making sustainable concrete, which may come from either or both their relationship with concrete and the knowledge of sustainability. Once these knowledge and media are decided, the design information can be established and the assessment criteria of sustainable concrete determined. However, as mentioned in the discussion on SCOT, it may be necessary to negotiate the differences between the perspectives of different stakeholders before a single form of the technology can be settled upon.

Analytic Hierarchy Process

The perspectives given by the stakeholder groups represent human value systems applied to the concept of sustainable concrete. In order to integrate these perspectives into the formation model, it is necessary to convert them from qualitative to quantitative data which can be used for assessing concrete sustainability. Analytic Hierarchy Process (AHP), a multi-criteria framework for making complex decisions, was applied to perform this conversion. The premise of AHP is to model a decision-making problem as a hierarchy composed of quantifiable elements and their relations and alternatives towards a goal (Saaty, 1999). The weights of the elements towards the goal is determined by comparing elements against each other in pairs using qualitative or quantitative judgment values, which are converted to numerical values that can be used to determine weights for the elements in the hierarchy and allows comparison between different elements. Weights can be similarly applied to the various alternatives for achieving the goal, based upon the weights of the elements in the hierarchy and the characteristics of the alternatives, and a decision can be made by analyzing the weights of the different alternatives. AHP can

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be used to overcome the difficulty in finding balance between different performance criteria by defining that balance from the perspectives held by the stakeholder groups. For example, if the government establishes a goal of reducing CO_2 emissions by 20%, then the reduction of CO_2 emissions could be given higher weight in the material assessment process than other factors, such that a reduction in CO_2 could outweigh reduced performance in other aspects.

Application of assessment framework

In order to investigate the applicability of the proposed assessment framework, a two-part social investigation on the perspectives on sustainable practice and materials in the Japanese concrete industry was conducted. The objective of this investigation was to first establish a general qualitative concept for sustainable concrete practice and materials with a top-down approach through in-depth interviews, then quantitatively investigate the importance given to different parameters and indicators for assessing sustainable materials with a bottom-up approach using surveys. These perspectives were then applied to the assessment of a variety of concrete materials with varying approaches to reducing environmental impact using AHP.

Interviews on sustainable concrete practice

The interview phase of the study was conducted with 13 members of the Japanese concrete industry, with four from the academic group (public and private universities), four from the materials group (ready-mix plant, chemical company, cement company, and slag cement company), three from the contractor group (general construction contractors), and two from the owner group (infrastructure research institutes). It was found that, although people had a clear idea of their role in current practice in the Japanese concrete industry, and thus clear differences in goals, they all shared a similar concept for what sustainable practice should be. Sustainable concrete practice could be divided into concrete engineering and sustainability components, as shown in Fig. 7, with assessment criteria such as life cycle cost (LCC), durability, and life cycle CO_2 ($LCCO_2$); specific actions for implementing those criteria such as the need for durability evaluation methods and the establishment of inventory data; and general actions such as the implementation of standardized codes for defining sustainable concrete practice, consideration of the full life cycle, and so forth. The reason all interviewees had the same general concept for sustainable concrete practice may be due to the lack of understanding of their role and responsibilities in practicing sustainability. When asked about current concrete practice, the interviewees had significantly different responses depending on their role in the manufacturing, production, and construction process; that is, their responsibilities are clearly outlined by experience, codes, guidelines, regulations, and so forth. However, because their

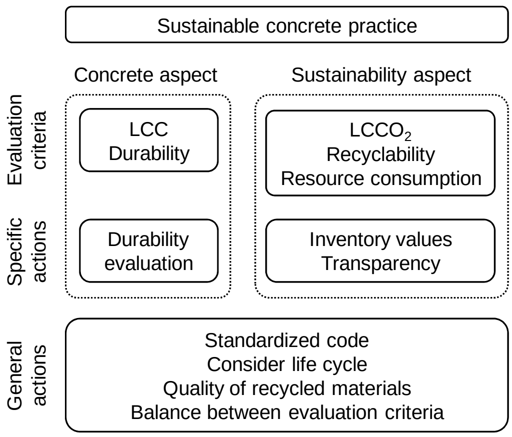

Fig. 7. Concept for sustainable concrete practice from interview phase.

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Table 1
Concrete performance parameters and sustainability indicators for evaluating sustainable concrete materials.

Concrete performance parameters (JSCE)	
Aspect	Performance parameters
Chemical	Adiabatic temperature rise
Strength	Strength
Durability	Rate factor of carbonation, diffusion coefficient of chloride ion, resistance to freezing/thawing action, resistance to chemical attacks, resistance to alkali-aggregate reaction, coefficient of water permeability, fire resistance, shrinkage property
Fresh properties	Workability, pumpability, setting property
Cost	Initial cost, life cycle cost
Sustainability indicators (UN CSD)	
Aspect	Indicators
Social	Equity, health, education, housing, security, population
Environmental	Atmosphere, land, oceans/seas/coasts, fresh water, biodiversity
Economic	Economic structure, consumption/production patterns
Institutional	Institutional framework, institutional capacitys

roles and responsibilities in an industry practicing sustainability are vague, the interviewees only share a concept of what sustainable practice might be without understanding what specific role they should serve. This is supported by the need to establish standardized codes and guidelines for different aspects of sustainable practice, such as life cycle cost analysis or calculation of $LCCO_2$ emissions, which would provide engineers with a clearer understanding of how to take action and what action to take.

Survey on concrete sustainability assessment

Since the interview phase gave a qualitative concept for sustainable practice, the objective of the survey phase was to quantitatively identify important aspects for assessing sustainable concrete. This survey asked Japanese concrete industry members to indicate the importance level of concrete performance and sustainability aspects for sustainable concrete on a scale of 1–4, where 1: no importance, 2: little importance, 3: some importance, and 4: high importance. The concrete performance aspects were taken from the Japan Society of Civil Engineers (JSCE) and the sustainability aspects were taken from the UN Committee on Sustainable Development's indicator framework and are summarized in Table 1 (United Nations, 2001; JSCE, 2005).

The distribution of survey respondents is given in Fig. 8. In total, 229 responses were received, with 47.2% in the owner group (private and public infrastructure owners such as railway and power companies and public agencies), 28.8% in the contractor group, 13.1% in the academic group, and 10.9% in the materials group (material manufacturers such as fibers or bonding agents and cement and admixture companies). The survey responses on the importance of the concrete and sustainability aspects for assessing sustainable concrete are also given in Fig. 8. It can be seen from these results that "durability" is the highest-rated aspect at 3.8 out of 4. Other highly-rated aspects include "cost" at 3.7, "strength" and "economic" at 3.5, and "environmental" at 3.4. The concrete aspects are generally rated higher than the sustainability aspects. Only "social" was indicated as having less than "some" importance for sustainable concrete. Considering the survey results and the criteria emphasized in the

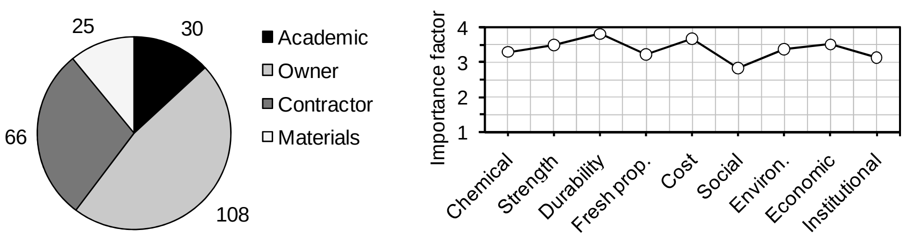

Fig. 8. Distribution of survey respondents (left) and survey response importance factors (right).

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Table 2
Importance factors from survey by stakeholder.

Aspect	Academic	Owner	Contractor	Materials
Strength	3.3	3.5	3.6	3.3
Durability	3.6	3.8	3.8	3.6
Cost	2.9	3.7	3.8	3.5
Environmental	3.4	3.4	3.4	3.2
Economic	3.2	3.4	3.6	3.4

interview phase, "strength," "durability," "cost," "economic," and "environmental" were selected as assessment criteria for sustainable concrete. They cover three concrete parameters and two sustainability indicators. Following the UN's framework, environmental aspects include atmosphere (emissions, air pollution, etc.), land use, and so forth; and economic aspects include production and consumption patterns (recycling), trade, and so on. Cost was selected as a concrete material property because the UN's framework for "economic" focuses more on general economic systems, whereas cost is a basic material property.

The importance factors are given by stakeholder group in Table 2. It can be seen that there was some difference between the stakeholders, so to clarify whether this difference was statistically significant or caused by variation within the sample groups one-way analysis of variance (ANOVA) and post-hoc analysis (Scheffé's Method) were used. There was no statistically-significant difference (at 5% significance) between the stakeholders for any of the aspects except for "cost," where the importance of the owner, contractor, and materials groups were higher than the importance factor for the academic group, and the importance factor for the contractor group was also higher than that for the materials group. Therefore, although there was some disparity regarding the importance of cost, it was concluded that overall there was little difference in the perspectives between the stakeholders and the selected criteria were sufficiently representative of the stakeholders' perspectives.

AHP assessment hierarchy and design scenarios

The hierarchy for assessing the sustainability of the concrete materials can be constructed as shown in Fig. 9. In this hierarchy, the "goal" is sustainable concrete, the different aspects identified through the social investigation make up the "elements" of the hierarchy, and the concrete mixes being investigated are the "alternatives" for meeting the goal.

Although the social investigation identified the criteria which should be used for assessing concrete sustainability, the relative importance between the criteria was not explicitly evaluated – that is, since the highest-ranking criteria were selected, their relative importance appears roughly equal. In order to examine the effect of differing importance levels driven by different value systems on the overall assessment of concrete sustainability, a set of four design scenarios was proposed, as summarized in Table 3. These scenarios focus on the importance given to the criteria when conducting pair-wise comparisons. In the case of the "high durability" design scenario, the durability aspect is given "strong importance" when compared to the other criteria, whereas the other criteria are all given "same importance" when compared to each other. A design scenario strongly emphasizing sustainability

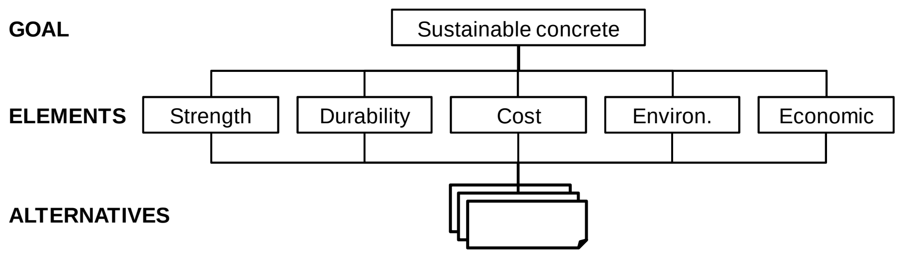

Fig. 9. AHP hierarchy with aspects and alternatives.

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Table 3
Pair-wise comparison values for different design scenarios.

Design scenario	Target criteria importance
High durability	Durability (strongly important)
Sustainability > concrete	Environmental, economic (strongly important vs. strength, durability, cost)
Low cost	Cost (strongly important)
Life cycle sustainable performance	Durability, environmental (strongly important vs. strength, cost; weakly important vs. economic) Economic (weakly important vs. strength, cost)

criteria over concrete criteria would place "strong importance" on environmental and economic criteria when comparing them with strength, durability and cost, and "same importance" when comparing the sustainability criteria against each other or the concrete criteria against each other. The "low cost" design scenario is similar to the "high durability" design scenario in that it places importance solely on a single aspect – in this case, cost. Finally, the "life cycle sustainable performance" design scenario is intended to place more balance between different aspects: durability and environmental criteria are given "strong importance" against cost and strength and "weak importance" against economic criteria, and economic criteria are given "weak importance" over cost and strength."

From these pair-wise comparisons, the relative AHP weights given to the criteria in each of the design scenarios could be calculated, as shown in Fig. 10. For the "high durability" and "low cost" design scenarios, 55.6% of the weight is given to durability and cost, respectively, with 11.1% for the other criteria. When placing higher emphasis on sustainability aspects in the "sustainability" design scenario, 38.5% weight is given to each of environmental and economic criteria and 7.7% to each of the concrete criteria. The "life cycle sustainable performance" design scenario places 33.3% weight each on durability and environmental, 20.0% on economic, and 6.7% on the remaining two. Comparing the weights for each design scenario, the effect of different importance in pair-wise comparisons on the weight carried by each aspect in the AHP hierarchy can be clearly seen.

Concrete proportions and properties

The sustainability of five different concrete mixes was examined. A target 28-day strength of 40 MPa was selected to represent a general-use situation, and the slump and air content will not be considered for simplicity. These concrete mixes are given in Table 4, and examine several different factors: the effect of water–binder ratio (30% vs. 50%), the effect of aggregate type (normal vs. low-grade recycled vs. high-grade recycled), the effect of fly ash replacement (none vs. 50%), the effect of blast furnace slag replacement (none vs. 45%), and the effect of combining fly ash and blast furnace slag with recycled aggregates. Water (W), normal Portland cement (C), JIS type-II fly ash (FA), blast furnace slag (BS), river sand (S), normal aggregates (NA), and low-grade (LG) and high-grade (HG) recycled aggregates were used. The complete mix proportions are given in Table 5.

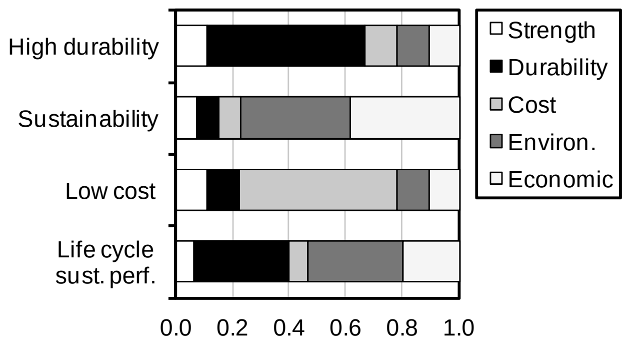

Fig. 10. Weights of criteria for different design scenarios.

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Table 4
Concrete mixes.

Concrete series	Water–binder ratio	Aggregate type	Cement replacement
WB50-NA	50	Normal	–
WB50-HG	50	Recycled (high)	–
WB30-LG-FA	30	Recycled (low)	Fly ash (50)
WB50-NA-BS	50	Normal	Slag (45)
WB50-HG-BS	50	Recycled (high)	Slag (45)

Table 5
Concrete mix proportions.

Concrete series	(kg/m^3)							
	W	C	FA	BS	S	NA	LG	HG
WB50-NA	171	342	–	–	746	1015	–	–
WB50-HG	171	342	–	–	746	–	–	1015
WB30-LG-FA	165	275	275	–	590	–	856	–
WB50-NA-BS	171	188	–	154	742	1010	–	–
WB50-HG-BS	171	188	–	154	742	–	–	1010

For each of the criteria in the AHP hierarchy a representative property was selected based on the available test results and appropriateness for the criteria. Air permeability is a durability indicator which is often used for evaluating surface concrete durability. Cost is the basic cost per cubic meter of concrete. CO_2 emissions are used to represent the environmental criteria because CO_2 emissions belong to the "atmosphere" theme in the environmental aspect of the UN sustainability indicators framework and are widely used as the primary indicator of concrete environmental impact. Finally, the percentage of recycled materials is used for evaluating the economic impact; this property comes from the "consumption and production patterns" UN theme in the economic aspect, which includes recycling and resource consumption.

Table 6 gives the properties of the concrete mixes for the five representative criteria. Durability was qualitatively evaluated based on the measured air permeability values because the relationship between air permeability and durability is not linear. The costs were calculated from the mix proportions and the material costs given in Fig. 11, which were obtained from a catalog of material costs in Japan (Sekisan-shiryou). In the case of fly ash, the cost may vary so a private company was contacted and the cost of fly ash estimated based on their response. For blast furnace slag, the cost was estimated by consulting a slag cement company. The cost for low-grade recycled aggregates was estimated from the price of recycled crushed stone used in road beds, and the cost for high-grade recycled aggregates was set as equal to that of normal aggregates. The cost of waster was taken from the Tokyo Metropolitan Bureau Waterworks. The CO_2 emissions for each mix were determined from the mix proportions and the emissions per material component given in Fig. 11, as determined by the Japan Society of Civil Engineers (JSCE, 2006). Finally, the recycled materials volume was calculated as the percent volume occupied by fly ash, blast furnace slag, and/or recycled aggregates. In the case of the high-grade recycled aggregate concrete mixes (WB50-HG, WB50-HG-BS), the strength, durability,

Table 6
Properties of concrete mixes.

Concrete series	Comp. strength (MPa)	Durability (qualitative)	Cost (yen/m^3)	CO_2 emissions ($kg\text{-}CO_2/m^3$)	Recycled vol. (%)
WB50-NA	43.5	Moderate	5810	267.9	0.0
WB50-HG	43.5	Moderate	5810	282.9	37.5
WB30-LG-FA	39.7	High	5205	221.0	47.2
WB50-NA-BS	42.4	High	5705	153.9	5.3
WB50-HG-BS	42.4	High	5705	168.8	42.6

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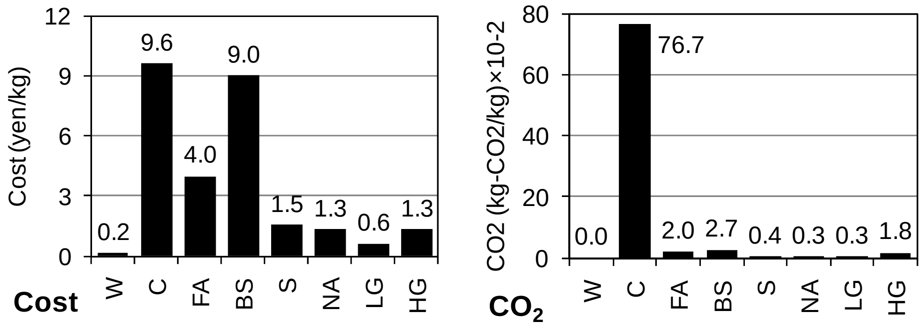

Fig. 11. Cost (left) and CO_2 emissions (right) of concrete-making materials.

and cost were estimated assuming that the performance and cost of high-grade recycled aggregate is identical to that of normal aggregate; only the CO_2 emissions and recycled volume were re-calculated to consider the differences in those characteristics.

AHP calculation results and discussion

From the material properties and criteria weights, the weights of each concrete mix towards achieving the goal can be calculated for each design scenario. These results are summarized in Fig. 12.

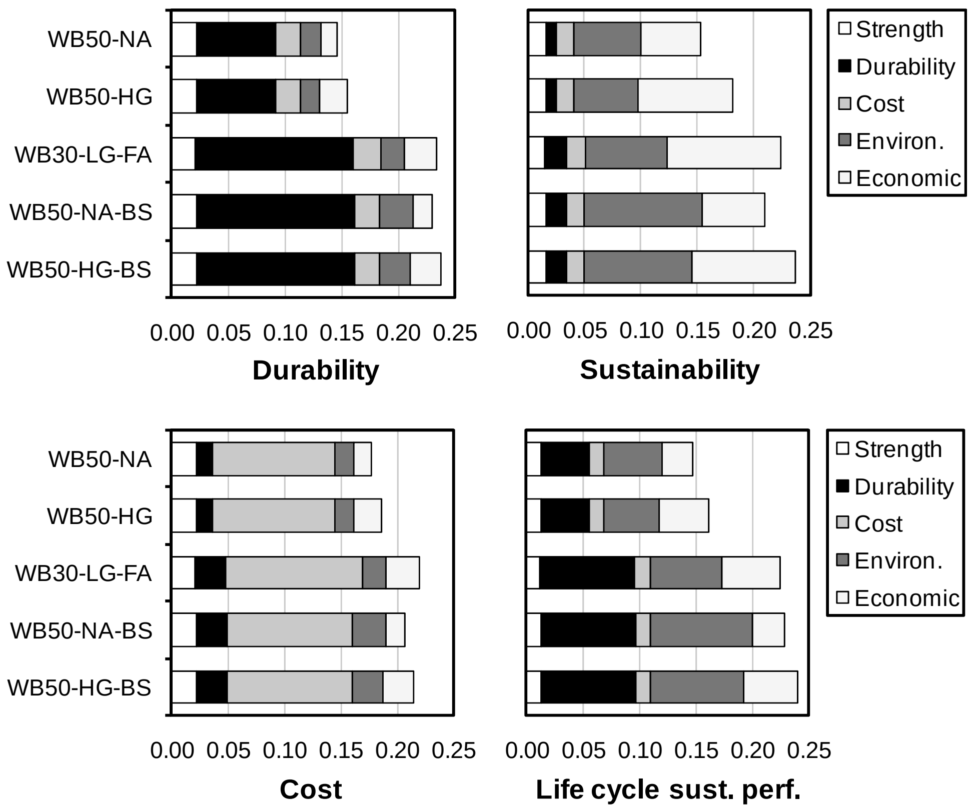

Fig. 12. Weights of concrete mixes by design scenario.

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For all of the design scenarios except the ‘‘low cost’’ scenario, the WB50-HG-BS mix has the highest value, with nearly 24% of the weight. This mix is the highest-rated because of its high durability and the good balance between CO_2 emissions and volume of recycled materials relative to the other mixes. In the ‘‘low cost’’ scenario, the WB30-LG-FA mix has the highest value, with nearly 22% of the weight. In this case, the lower cost of fly ash increases the value of the WB30-LG-FA concrete mix. The cost of fly ash, although cheaper than blast furnace slag in this investigation, may vary greatly (in the case of Japan) due to its regional availability, as it is not widely used; blast furnace slag, however, is much more widely available and thus has a more stable price. Overall, the advantage of slag is that it can achieve higher strength than fly ash by 28 days at higher water–binder ratios, reducing the volume of binder and thus CO_2 emissions.

It can be seen that in all the scenarios except ‘‘low cost’’ there is a larger difference in the final weights of the mixes, whereas in the ‘‘low cost’’ scenario the weights of the materials are much more closely grouped. This may be attributed to the similarity in cost between the concrete mixes, which do not vary as much relative to each other as the other assessment criteria do. In particular, qualitatively evaluating durability results in a large difference in the weights between moderate- and high-durability materials, which is caused by the qualitative pair-wise comparison. This difference is particularly pronounced for the ‘‘high durability’’ and ‘‘life cycle sustainable performance’’ design scenarios, which place high importance on durability, thus greatly increasing the value of the mixes with high durability.

For slag and non-slag concrete, changing from normal aggregates to high-grade recycled aggregates increases the total value, since the difference in CO_2 emissions is not large but the increase in recycled materials is very high. This is due to the relative importance in CO_2 emissions compared to recycled aggregates; for all the design scenarios, these two aspects were given either equal or only weakly different importance, so the increase in CO_2 emissions is outweighed by the increase in recycled materials. For low-grade recycled aggregates, low durability is generally expected but, based upon experimental results, the combination of fly ash and recycled aggregates appears to improve the durability of concrete containing low-grade recycled aggregate, which increases the value of low-grade vs. high-grade recycled aggregates. However, in order to achieve similar strength levels, the matrix strength has to be increased by decreasing the water–binder ratio. This increases the amount of binder materials and, consequently, the CO_2 emissions and cost. However, the usage of fly ash at the lower binder ratio may offset these increases.

Comparison to baseline condition

When assessing the sustainability of concrete materials, it is necessary not only to determine the relative sustainability between potential material alternatives but to also identify whether the properties of that material are moving towards overall sustainability. Therefore, it is useful to visually observe the distribution of the concrete material properties relative to a baseline condition, or a reference state, which can provide an indication of overall direction. Setting a baseline condition for the concrete industry is not easy because, unlike ecological systems, there is no historical reference point which can be labeled as a ‘‘sustainable’’ state to return to. Rather, the baseline condition should be set by looking forward and considering the direction the industry should move towards. As it has already been established that the concrete industry needs to become more sustainable and reduce its environmental impact from its current state, sustainable concrete should look to meet or exceed the performance of the general-use concrete in the areas identified for assessing sustainability.

The WB50-NA series can be considered representative of the general-use concrete mix proportions and properties. The values of the WB30-LG-FA and WB50-HG-BS mixes in the life cycle sustainable performance design scenario are normalized against the baseline condition in Fig. 13 to illustrate the change in the mix properties relative to the baseline. It can be see that both materials exceed the minimum requirement of the baseline condition in all of the measured criteria except for strength; however, the strengths of all materials were relatively similar so this tendency is not significant. A comparison of these two distributions shows that the WB50-HG-BS concrete has higher value than the WB30-LG-FA concrete on the environmental aspect due to the lower CO_2 emissions, but also has less value for cost and economic criteria due to higher material cost and less volume of recycled materials. The total overall value, however, is slightly higher for the WB50-HG-BS mix.

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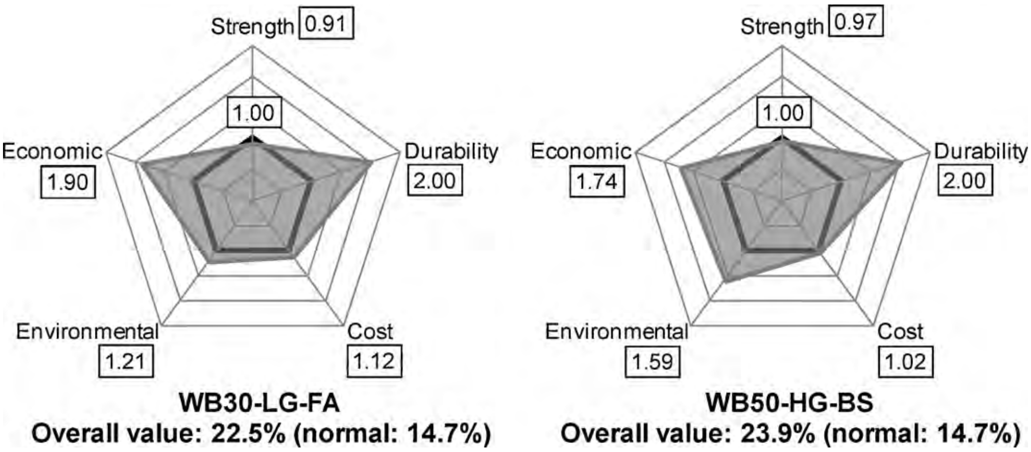

Fig. 13. Weights of concrete mixes (life cycle sust. perf.) normalized by general-use concrete.

Further research

The framework proposed in this work provides a general-use means for integrating social perspectives into decision-making at various stages of the concrete manufacturing and construction process. The example provided here, however, focused only on the material manufacturer's case, and several simplifications were made which should be more fully explored in future research works. The first is with regards to the AHP hierarchy used to compare the material alternatives. It was implicitly assumed that the weight of using fly ash and blast furnace slag is the same – that is, the means by which CO_2 emissions and raw material consumption were reduced was not included in the hierarchy's assessment elements. However, in the case of Japan, blast furnace slag is much more widely used than fly ash, comprising approximately 24% of the domestic market, compared to only 0.4% for fly ash (JCA, 2008), but the domestic conditions and availability of the materials utilized in the concrete mixes was not considered in the assessment. In order to improve the framework's flexibility to represent not only different social perspectives but also regional differences such as material availability, domestic market, and so forth, the AHP hierarchy should be improved to incorporate these elements in the assessment process.

Another simplification was performed when the difference in perspectives between stakeholders was assumed to be represented only by the importance factors obtained from the social investigation. Although a fundamental aspect of SCOT theory, the underlying social principal from which this framework was constructed, is that the development process occurs through the interaction and negotiation between the conflicting perspectives of the stakeholder, that conflict was resolved in the example only by comparing the statistical deviation of the importance factors and selecting the one considered to be most controlling based upon the relationship between the stakeholders. In reality, although the surveyed stakeholders had little conflict in their concept for sustainable concrete practice and materials and the importance for different assessment criteria, how to achieve this concept may differ greatly depending on the stakeholder group. As mentioned earlier, since there is a lack of specifications and guidelines outlining the role and responsibilities of each stakeholder group for practicing sustainability, they may share a common vision while lacking a concrete idea of how to achieve that vision. Future investigations into this topic should therefore attempt to isolate what barriers exist for each stakeholder group and how to overcome any conflicts which occur.

Conclusion

In order to provide a means for assessing concrete sustainability, this paper proposed an assessment framework based upon social theory of technology and AHP. By basing the selection of

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assessment criteria on the social perspectives of the stakeholders, this framework attempts to overcome the difficulty in defining sustainability by deriving its definition from the stakeholders who exist within the system in which the criteria must be implemented. Through social theory and AHP, these perspectives can be identified and converted from qualitative to quantitative data, thus providing engineers, managers, and decision-makers in the concrete industry with hard numbers upon which to base their material development and assessment processes.

Through an example application targeted at the ready-mix concrete manufacturer, the relative sustainability of different concrete mixes was assessed. This assessment was based upon the social perspectives of stakeholders in the Japanese concrete industry, which were evaluated via a social investigation. From these perspectives, a basic AHP hierarchy was constructed which consisted of strength, durability, cost, CO_2 emissions, and volume of recycled materials as the assessment elements, and through the application of different design scenarios, which proposed different weighting schemes, comparisons between the assessed materials could be made. However, ultimately it was found that a single concrete mix was generally selected as the best alternative due to its high performance characteristics in each of the assessment criteria categories. It was suggested that this assessment hierarchy should be expanded to include more assessment items which better consider other characteristics of the materials being utilized in the concrete mixes, such as local availability, which may lead to a more flexible hierarchy structure which can better adapt to different social, economic, regional, or other conditions. Furthermore, the properties of the assessed materials only represent laboratory experimental results, and thus practical application in the field may require changes to the material properties which could affect the material performance and, thus, the assessment weights. Again, integration of criteria required for practical application in the field could be one means for expanding the AHP hierarchy to consider a broader range of conditions.

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首都圏の鉄道ネットワークにおける早期地震警報システムによる減災効果の検討

Research on the Effects of Earthquake Early Warning System for Disaster Reduction of Railway Network in Tokyo Metropolitan Area

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Earthquake Early Warning (EEW) system was originally developed and introduced to control a Shinkansen (bullet train) when earthquake occurs; However, this system has also been introduced to conventional lines and private company trains. In this research, the lead time between EEW and the arrival of S-wave was calculated for all the railway networks in the Tokyo metropolitan area assuming the occurrence of the northern Tokyo Bay earthquake, and the effects of disaster reduction were analyzed. As a result, it was shown that the risk to passengers can be reduced drastically using EEW.

Keywords: *disaster reduction, earthquake early warning, EEW, northern Tokyo Bay earthquake, railway*

１．はじめに

(1) 研究の背景

鉄道は，その定時性や安全性から多くの人々の通勤･通学などの手段として用いられ，首都圏での一日の鉄道利用者は約 4,000 万人にも達する [1]．中でも朝夕の通勤･通学ラッシュ時の混雑は激しく，多数の鉄道利用者がネットワーク上に存在している．そのためラッシュ時に地震が発生すれば，多くの乗客が列車内で被災することは確実で，場合によっては地震に起因する鉄道事故によって負傷者や死者が発生する可能性もある．

内閣府中央防災会議 [2]によると，首都直下地震の今後 30 年間の発生確率は 70%と推定され，その中でも東京湾北部地震（M7.3，18 時，風速 15m/s）による人的被害は約 11,000 人（うち交通被害による死者 200 人）と，阪神･淡路大震災を大きく上回る可能性が報告されており，鉄道においても甚大な被害が発生する可能性がある．

このような状況を踏まえ，各鉄道事業者は，高架橋や駅舎の耐震補強や脱線防止装置の開発，地震発生時の運転規制の基準作成など，様々な地震対策を進めてきた．その中でも，近年特に大きな動きを見せている対策が早期地震警報システムの利用である．鉄道の早期地震警報は，地震時に新幹線を制御することを目的に，1960 年代より開発が進められ，実際にシステムの導入もなされてきた．さらに近年では，JR 東日本が在来線にも P 波検知による制御システムを導入し，私鉄各社においても P 波検知による制御システム導入の動きが大変活発化している．

2004年の新潟中越地震の際，上越新幹線が脱線状態で線路上を約1.6km走行したのち停止し立ち往生した光景は衝撃的であったが，この時JR東日本は，地震のP波検知による制御で主要動到達前にき電を停止し，減速を開始することに成功していた[3]．この時は脱線事故を防ぐことはできなかったが，主要動到達前に減速を開始することは，鉄道事故発生のリスクを低減できるとともに，万が一事故が発生した場合でも，被害の影響を軽減できる可能性が高い．

(2) 研究の目的

近年，在来線や私鉄各社においても早期地震警報が飛躍的に普及したのは前述したとおりであるが，これまでの早期地震警報に関する研究では，余裕時間の概念やリスク評価の一般論について述べられているものが多く [4)5)]，鉄道ネットワークレベルの広い領域を対象とした具体的な減災効果の検討はあまりされてこなかった．そこで本研究は，在来線･私鉄各線を対象とし，早期地震警報システムによる減災効果をネットワークレベルで検討することを目的とする．

本研究では，まず地震発生時の鉄道利用者分布を推計し，震度別の滞留人口を算出する．次に，その鉄道利用者分布に基づき，各鉄道事業者が導入している早期地震警報システムによって，各地で入手可能な主要動到達までの余裕時間を推定する．さらに警報の有無による危険率の概念を取り入れることで，早期地震警報システムによる減災効果を検討する．本研究の対象地震は，中央防

災会議で想定される東京湾北部地震(M7.3)[6]とし，余裕時間とは，早期地震警報を受信してから列車に地震の S 波が到達するまでの時間とする．

2．鉄道利用者分布

(1) 鉄道利用者分布の推計

ネットワーク上の鉄道利用者数は，初電から終電まで刻一刻と変化し続けている．午前 5 時前後の初電から 7 時～9 時ごろに訪れる朝の通勤･通学ラッシュまで一気に利用者は増加し，日中いったん落ち着いた後夕方の帰宅ラッシュで再び混雑を迎え，その後終電までゆっくりと利用者数が減少していくのが一般的である．当然地震が発生する時間帯により，人的被害は大幅に変化するものと思われる．

阪神･淡路大震災の原因となった兵庫県南部地震の発生時刻は午前 5 時台であり，運行列車本数，鉄道利用者ともに少ない時間帯であったため，幸い鉄道利用者に死者は発生せず，鉄道利用者には列車の乗客に 55 人，駅構内の旅客に 4 人の負傷者が出ただけであった[7]．

本研究においては，早期地震警報システムの減災効果の検討を行うために，まず地震発生時の鉄道利用者分布を推計する．推計には，国土交通省により 2005 年に実施された第 10 回大都市交通センサスのデータ [8),9)]を用い，首都圏の各駅間の時間帯別滞留人口を算出する．対象範囲および対象路線は図 1 と表 1 に示す通りである．

駅間滞留人口の算出は，まず鉄道 OD 調査 [8)]のデータを用いて駅間ごとに時間帯（センサスデータの時間帯に基づき，日中は 2 時間，その他は 1 時間ごと）による通過交通量の比を算出する．それを基に，国土交通省より公表されている一日の駅間断面交通量のデータ [9)]を 1 時間当たりの断面交通量へと換算し，さらに駅間所要時間

図 1 研究対象地域 [10)]

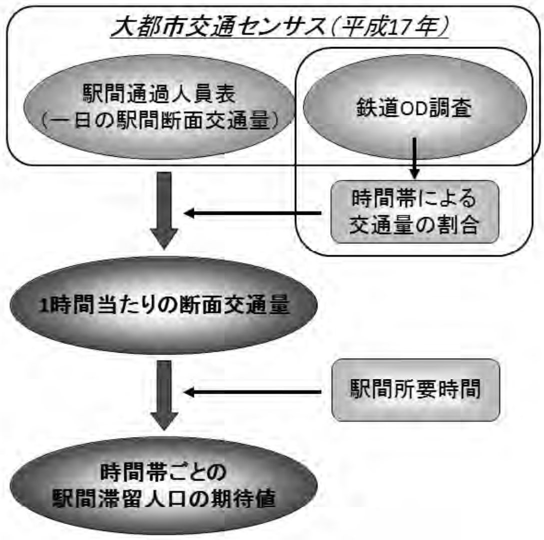

図 2 駅間滞留人口算出のイメージ

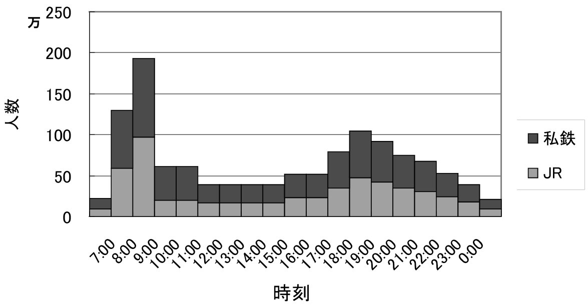

図 3 一日の鉄道利用者数の推移

表 1 対象路線一覧

事業者名	路線名	事業者名	路線名	事業者名	路線名	事業者名	路線名
東日本旅客鉄道	東海道本線	東日本旅客鉄道	東金線	京王電鉄	動物園線	京成電鉄	千葉線
	中央本線		京葉線(1)		相模原線		金町線
	東北本線		京葉線(2)		競馬場線		東成田線
	京浜東北・根岸線		京葉線(3)		井の頭線		千原線
	常磐快速		湘南新宿ライン	東京急行電鉄	東横線	山万	ユーカリが丘線
	常磐線各駅停車		東北新幹線		目黒線	芝山鉄道	芝山鉄道線
	総武線各駅停車		上越新幹線		池上線	新京成電鉄	新京成線
	総武本線	東海旅客鉄道	御殿場線		大井町線	秩父鉄道	秩父本線
	山手線		東海道新幹線		世田谷線	相模鉄道	相模鉄道本線
	南武線	東京都交通局	浅草線		田園都市線		いずみ野線
	南武支線		三田線		東急多摩川線	関東鉄道	常総線
	鶴見線(1)		都営新宿線		こどもの国線		竜ヶ崎線
	鶴見線(2)		大江戸線	西武鉄道	新宿線	総武流山電鉄	総武流山線
	鶴見線(3)	横浜市交通局	横浜市営1、3号線		池袋線	小湊鉄道	小湊鉄道線
	武蔵野線	東京地下鉄	銀座線		西武秩父線	北総鉄道	北総線
	横浜線		丸ノ内線(1)		豊島線	千葉都市モノレール	千葉都市モノレール2号線
	八高線		丸ノ内線(2)		西武園線		千葉都市モノレール1号線
	横須賀線		日比谷線		国分寺線	いすみ鉄道	いすみ線
	相模線		東西線		多摩湖線	鹿島鉄道	鹿島鉄道線
	青梅線		千代田線		多摩川線	江ノ島電鉄	江ノ島電鉄線
	五日市線		有楽町線		拝島線	横浜新都市交通	金沢シーサイド線
	川越線		半蔵門線		狭山線	多摩都市モノレール	多摩都市モノレール線
	高崎線		南北線		山口線	ゆりかもめ	東京臨海新交通臨海線
	成田線	京浜急行電鉄	京浜急行本線		西武有楽町線	東京臨海高速鉄道	りんかい線
	成田支線(1)		逗子線	東武鉄道	伊勢崎線	箱根登山鉄道	箱根登山鉄道線
	成田支線(2)		久里浜線		亀戸線	東葉高速鉄道	東葉高速線
	外房線		空港線		大師線	埼玉高速鉄道	埼玉高速鉄道線
	内房線		京急大師線		日光線	横浜高速鉄道	みなとみらい線
	埼京線	小田急電鉄	小田原線		野田線	首都圏新都市鉄道	つくばエクスプレス
	久留里線		江ノ島線		東上線	伊豆箱根鉄道	大雄山線
	水戸線		多摩線		越生線	東京モノレール	東京モノレール羽田線
	両毛線	京王電鉄	京王線	京成電鉄	京成本線	湘南モノレール	江の島線
	鹿島線		高尾線		押上線	埼玉新都市交通	伊奈線

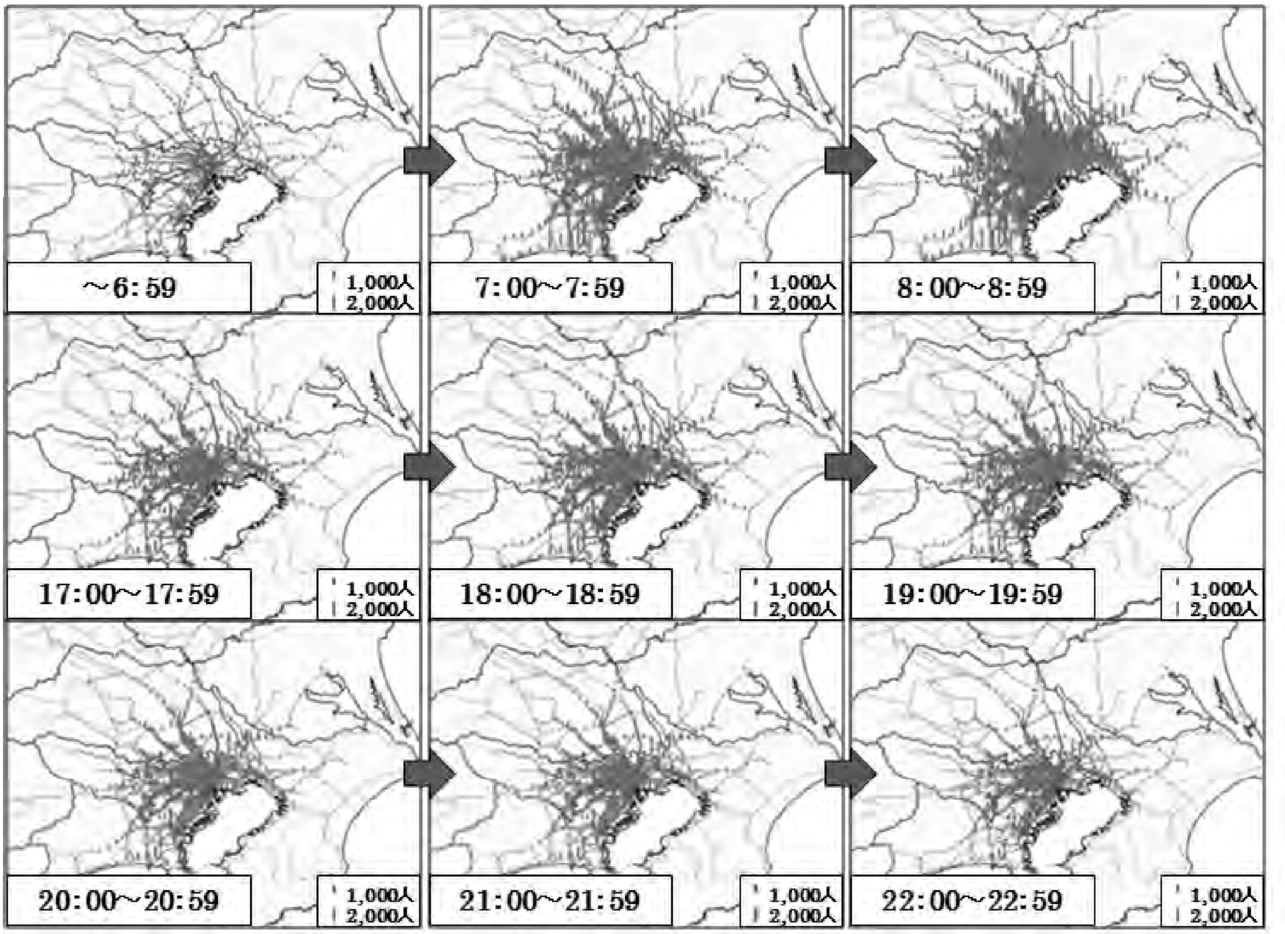

図 4　鉄道利用者分布の推移

を考慮することで，時間帯ごとに駅間滞留人口の期待値を算出する．

(2)　時間帯別鉄道利用者分布

図 3 は，鉄道ネットワーク上の鉄道利用者数の時間推移である．最も鉄道利用者が多い時間帯は，朝のラッシュの時間帯で約 190 万人(8:00~8:59)，夕方で約 105 万人(18:00~18:59)がネットワーク上に存在している．また，図 4 はそれぞれ朝の時間帯，夕方から夜にかけての時間帯の鉄道利用者分布の推移である．

(3)　計測震度別鉄道利用者分布

地震時に鉄道事故が発生するか否かには，列車が受ける揺れの大きさが強く関係している．首都直下地震による東京の被害想定報告書 [11]によると，兵庫県南部地震の際に運行していた列車の，震度別脱線率は表 2 の通りである．

そこで本研究では，図 5 の中央防災会議による東京湾北部地震の想定震度分布 [6]を考慮することにより，震度

表 2　震度と列車脱線率の関係

震度	阪神･淡路大震災時の実態		脱線率
	運行列車本数	脱線数	
7	14	13	92.9%
6強	13	3	23.1%
6弱	65	0	0.0%

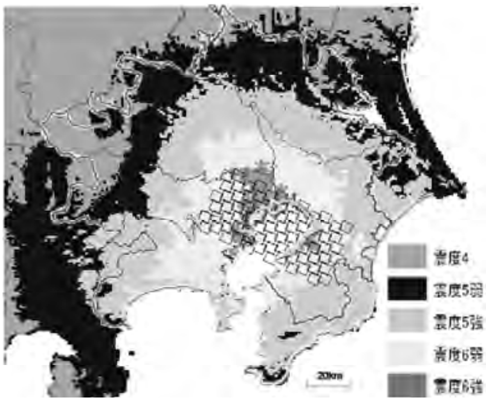

図 5　東京湾北部地震 想定震度分布
(図中の灰線は大都市交通センサスの対象範囲)

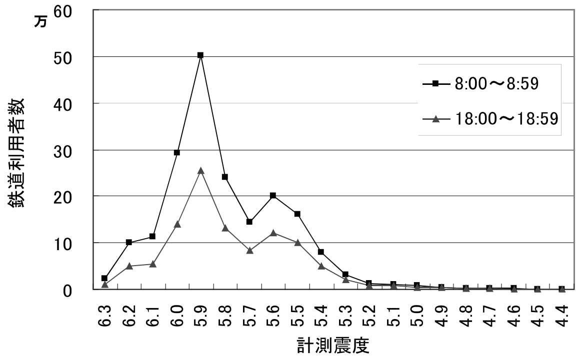

図 6　計測震度別鉄道利用者数

表 3　震度階別鉄道利用者数

震度	8:00～8:59	18:00～18:59
6強	528,657	255,598
6弱	1,248,648	691,987
5強	143,082	91,975
5弱	10,879	7,499
4	133	95

※単位：人

別鉄道利用者数を算出する．各駅間の震度は，両端の駅と，駅間中間点の想定震度の平均値として算出する．

図6は，朝夕のそれぞれ最も鉄道利用者が多い時間帯である8:00~8:59と18:00~18:59の計測震度別鉄道利用者数で，さらにそれを震度階別にまとめたものが表3である．いずれの時間帯も震度6弱以上の範囲内の鉄道利用者が全体の90%以上を占めているのは，人口の集中する都心部の震度が6弱以上であることが大きな要因であるが，震度5弱以下の地域は大都市交通センサスの対象範囲外の地域が多いことも要因の一つである．

３．余裕時間別鉄道利用者数

地震が発生した際に鉄道において人的被害が発生する原因は，以下のようなものが考えられる．

①地震動による列車脱線事故
②地震動により状態変化した線路上を列車が走行することによる列車脱線事故
③構造物の崩壊や対向列車の脱線などによる線路上の障害物による列車事故

いち早く地震の発生を認識し，地震の S 波が列車に到達するまでに列車を減速･停車させることができれば，上記の事故に対して，次のような減災効果が望める．①に対しては主要動到達までに少しでも速度を落とすことにより，事故が発生した場合の被害を抑えることができる．②と③に対しては，主要動到達以降の走行距離を減少させることにより，事故発生のリスクを減少させることができ，さらに①と同様，事故が発生した場合も減速していることで被害を抑えることができる．すなわち，少しでも早く地震発生を認識し主要動到達までの余裕時間を稼ぐことが，人的被害の軽減に繋がるのである．

そこで本研究では，鉄道ネットワーク上での余裕時間別鉄道利用者数の算出を行う．ここで，余裕時間別鉄道利用者数を，「任意の時間以上の余裕時間が与えられる地域にいる鉄道利用者数」と定義する．

(1)　警報システムの条件設定

1960 年代より研究と開発が始まった早期地震警報システムは，当初 S 波の検知により制御が行われていたが，より早く地震を検知できるよう P 波検知による制御へと変化を遂げていき，1992 年に世界初の実用 P 波警報である「ユレダス」が東海道新幹線に導入され，さらに 1996 年には山陽新幹線にも導入された．その後 1998 年に，警報発信までの時間を短縮化した「コンパクトユレダス」が東北･上越･長野新幹線に導入されたが，その一方で，新幹線以外の鉄道では，大阪･名古屋･静岡周辺の一部の新幹線沿線地域でのみ警報システムが導入されているだけであった [12]．しかし，気象庁による緊急地震速報の普及を皮切りに，それまで P 波検知による警報を導入していなかった私鉄各社も続々と警報システムを導入し，JR 東日本でも首都圏では 2007 年から，その他の地域では 2009 年から在来線においても警報システムを導入している．

現在，各鉄道事業者で用いられている早期地震警報システムは，大きく分けると 2 種類がある．1 つは，受信した気象庁の緊急地震速報の内容から，自社の路線への影響を判断して警報を発信するシステムで，大手私鉄をはじめ，多くの私鉄各社が導入している．もう 1 つは，各鉄道事業者が所有する P 波検知地震計により P 波を検知して警報を発信するシステムで，首都圏では JR 東日本と東京メトロがこれを導入している（JR 東日本と東京メトロでは，気象庁による緊急地震速報の情報も併用している [13),14]）．そこで本研究では，各社の警報システムと P 波検知から警報発令までに要する判断時間，ならびに，東京湾北部地震の際にはじめに P 波を検知する地震計の設置位置を表 4 のように仮定し，これを Case1 と定め，余裕時間別鉄道利用者数の算出を行う．しかし，Case1 の条件下では事業者により警報発信時刻が異なるため，情報が最大限に生かされているとは言い難い．そこで Case2 を，いずれかの事業者が発信した警報を事業者間で共有し，全ての列車が受信できるものとする．

表 4　余裕時間算出における仮定（Case1）

警報の種類	事業者	P波検知から警報発信までの時間	用いた検知点
自社 P波検知	JR東日本※1 東京メトロ	1 (s)[13]	東京(JR) 深川(メトロ)
緊急 地震速報	その他の 事業者	7.4 (s)[15),16]※2	江東

※1 JR東日本と東京メトロは緊急地震速報の情報も併用しているが，その情報が有効に利用できるのは震源距離が長い場合であるため，本研究では自社地震計での検知のみを考える
※2 緊急地震速報の第一報発信までの平均時間（5.4s）と各社での判断時間（2.0s）の和

また，想定する東京湾北部地震の震源は点震源（震源位置は北緯 35.563°，東経 139.897°，深さ 29.68km）と仮定し，P 波･S 波の速度は，それぞれ 6.15，3.53(km/s)(表 5 を参考に，深さ 30km までを 4 つの層に分け，各層の上端及び下端の地震波速度の相加平均を地震波の伝播速度とした場合の平均速度)とし，各駅間までの S 波到達時間を算出することで余裕時間別鉄道利用者数を求める．

表 5　代表的な深さの速度 [17]

深さ(km)	P波(km/s)	S波(km/s)
0	4.8	2.5
5	5.8	3.4
10	6.0	3.5
20	6.5	3.8
30	7.0	4.0

(2)　算出結果

8:00~8:59 の震度 6 強および 6 弱の地域における余裕時間別鉄道利用者数を算出した結果が図 7 のグラフであ

る．余裕時間が負のケースは，S 波到達後に警報を受信することを意味する．

Case1 では，震度 6 強の強震地域でも全 53 万人中 41 万人(78%)が S 波到達前に警報を受信することができ，さらにその内の 2.2 万人(4.2%)には 5.0 秒以上の余裕時間が与えられる．警報がない場合に比べ 5.0 秒早くブレーキをかけることが可能となれば，表 6 の通り，60(km/h)で走行中ならば 83(m)，100(km/h)で走行中ならば 139(m)停止距離を短縮でき（緊急停止時の減速度を 4.0(km/h/s)と仮定），警報システムの有意性が見てとれる．

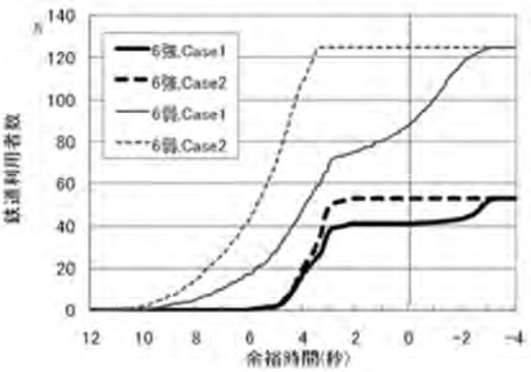

図 7　余裕時間別鉄道利用者数（8:00～8:59）

表 6　得られた余裕時間で短縮可能な停止距離

		余裕時間 (s)				
		1.0	2.0	3.0	4.0	5.0
列車速度 (km/h)	40	11 (m)	22 (m)	33 (m)	44 (m)	56 (m)
	60	17 (m)	33 (m)	50 (m)	67 (m)	83 (m)
	80	22 (m)	44 (m)	67 (m)	89 (m)	111 (m)
	100	28 (m)	56 (m)	83 (m)	111 (m)	139 (m)

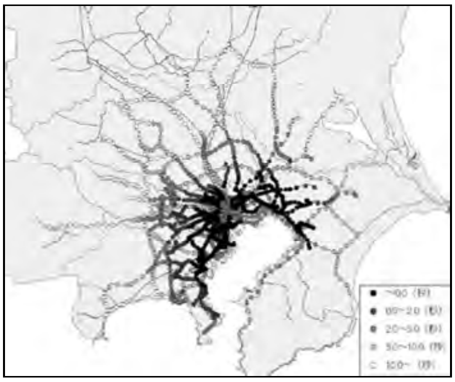

図 8　余裕時間分布(Case1)

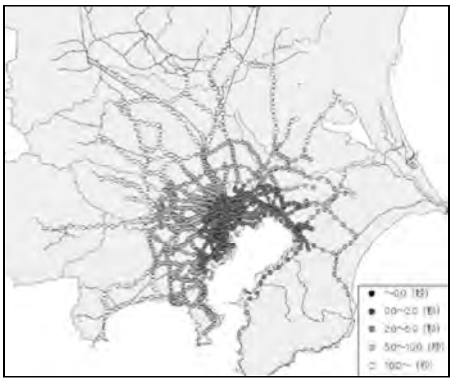

図 9　余裕時間分布(Case2)

さらに Case2 では，震度 6 強全域で 2.3 秒以上の余裕時間が得られ，さらに 5.0 秒以上の余裕時間が得られる地域の鉄道利用者も 2.8 万人(5.3%)へとわずかながら増加する．以上より，いずれかの事業者による警報を全ての列車で共有することにより，首都圏全体での減災効果が高まることがわかる．

また，図 8 と図 9 はそれぞれ Case1，Case2 における，鉄道ネットワーク上の各地点において得ることができる余裕時間の分布である．情報共有によって余裕時間が増加する鉄道利用者が多数存在することがわかる．

4．減災効果の検討

(1)　減災効果検討の指標

第 3 章では，東京湾北部地震が発生した際の，各時間帯の警報システムによる余裕時間別鉄道利用者数を算出した．しかし，警報システムによる減災効果を検討するためにはそれだけでは不十分で，鉄道事故発生のリスク評価指標が必要である．

岩田ら(2008)[5]は，鉄道における早期地震情報の減災効果の定量的評価方法として式[1]を提案している．

$$Rp(Tm) \propto \left(\frac{Dpv_0}{Dsv_{std}}\right) \cdot \left(\frac{\overline{Vpv_0}}{\overline{Vsv_{std}}}\right)^2 \quad [1]$$

ここで，Rp(Tm)は S 波到達後の警報を基準とした P 波検知による警報時の危険率(Tm：余裕時間)，Dsv_{std} は基準速度 V_{std} のときの S 波到達からの停止距離(m)，Dpv_0 は速度 V_0 のときの P 波検知による警報時の走行距離(m)，$\overline{Vsv_{std}}$ は基準速度 V_{std} のときの S 波到達後停車までの平均列車速度(km/h)，$\overline{Vpv_0}$ は速度 V_0 のときの P 波警報後の平均列車速度(km/h)と定義される．すなわちこの指標は，「列車が停止するまでに線路上の障害物や状態変化した線路に遭遇する確率の比」と，遭遇時の「運動エネルギーの比」の積より構成される．運動エネルギーは遭遇時の速度に依存するが，速度は制動開始から停止まで変化し続けるためその平均速度を採用している．

列車の走行速度と制動特性を一定とすると，危険率 Rp(Tm)は P 波検知による警報時の S 波到達時の速度により決定される．ここで，単純化のため列車の走行速度を 40(km/h)および 60(km/h)（首都圏の在来線及び私鉄の表定速度はおおよそ 35~60(km/h)の範囲内であるため，本研究では代表値として 40(km/h)及び 60(km/h)を用いる），緊急停止時の減速度を 4.0(km/h/s)と仮定し，S 波

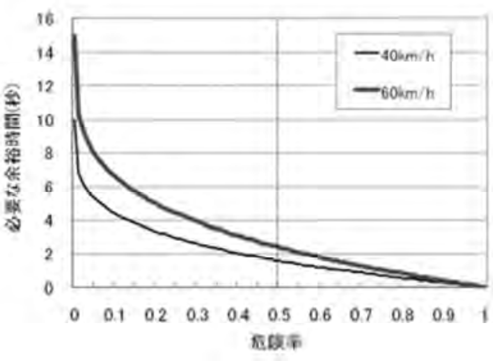

図 10　危険率と必要な余裕時間の関係

到達後の警報時の危険率を 1.0 とすると，危険率と必要な余裕時間の関係は図 10 のようになる．この危険率の概念に基づき，第 3 章で算出した余裕時間別鉄道利用者数から早期地震警報システムによる減災効果の検討を行う．失敗等を考慮しない限り，警報システムの働きにより危険率が小さくなることは当たり前だが，ここでの狙いは，P 波検知によってどの程度危険率を低減できるか，定量的に評価することである．

(2) 危険率軽減効果

図 11 と図 12 は，図 10 の関係を基に，8:00~8:59 の鉄道利用者分布に対して，それぞれ震度 6 強，6 弱地域内の鉄道利用者の危険率低減の割合を示したものである．早期地震警報システムの働きにより，Case1･60(km/h)で走行中の条件では，震度 6 強地域内の 78%の人の危険率が 0.5 以下となり，Case2･60(km/h)で走行中の条件では，98%の人の危険率が 0.5 以下となることがわかる．また震度 6 弱地域では，Case1･60(km/h)で走行中の条件では危険率が 0.5 以下となる鉄道利用者の割合は約 60%に留まるものの，Case2･60(km/h)で走行中の条件では全域の鉄道利用者の危険率は 0.5 を大きく下回る．また，走行速度を 40(km/h)とした場合には，危険率低減の割合はさらに増加し，震度 6 強地域内でも Case2 では全ての利用者の危険率が 0.4 以下となる．なお，図 11 及び図 12 において危険率が 1 になる直前まで縦軸の値が 100%に満たないのは，図 7 に示されるように余裕時間が 0 秒以下となる地域にも乗客が存在するためである．

また，図 13 と図 14 はそれぞれ Case1，Case2 における，鉄道ネットワーク上の各地点における危険率を示したものである．情報共有によって，震源に近い乗客の危険率もほぼ 0.5 以下となることがわかる．

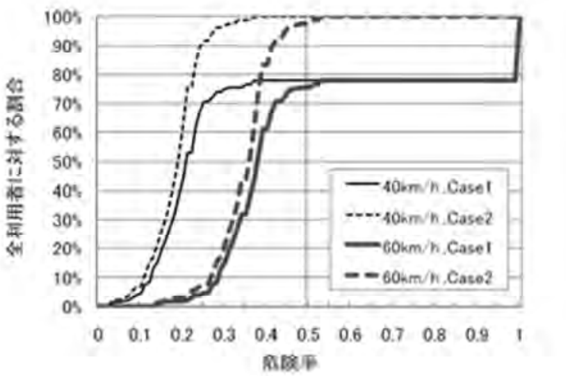

図 11 危険率低減効果（震度 6 強,8:00～8:59）

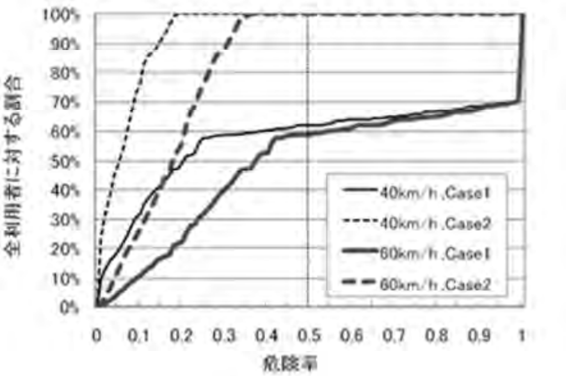

図 12 危険率低減効果（震度 6 弱,8:00～8:59）

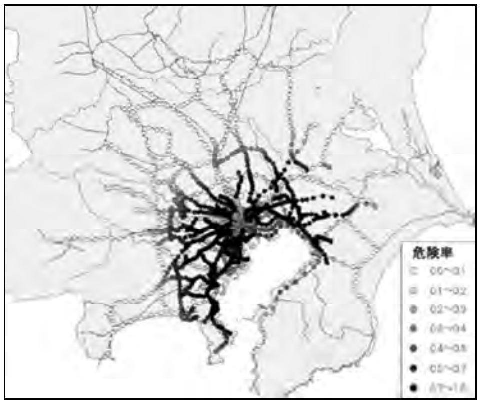

図 13 危険率低減効果の分布(Case1)

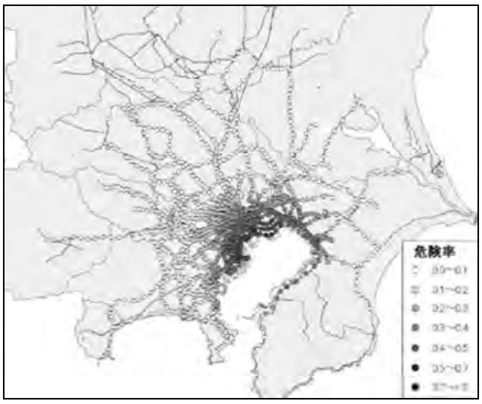

図 14 危険率低減効果の分布(Case2)

さらに図 15 は，時間帯ごとに危険率が 0.5 以下となる利用者の割合を推計したものである．その割合は時間帯によってわずかな増減はあるものの大きな変化を見せることはなく，終日 70%前後の利用者の危険率を 0.5 以下に低減させることができる．

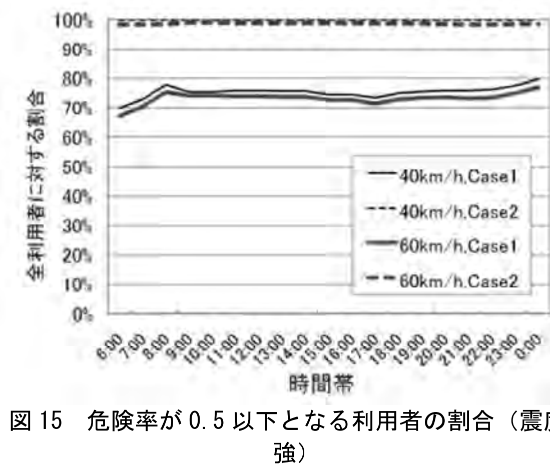

図 15 危険率が 0.5 以下となる利用者の割合（震度 6 強）

5．まとめ

(1) 結論

本研究では，首都圏の鉄道ネットワークを対象として，各時間帯の鉄道利用者分布の推計および余裕時間別鉄道利用者数の算出を行い，警報システムの有無による走行時の危険率を比較することにより早期地震警報による減災効果を検討した．この結果，警報システムにより震度

6 強の強震地域でも大多数の利用者が 2~3 秒以上の余裕時間を得られることが分かり，約 80%もの利用者の列車事故のリスクが半分以下になることがわかった．また，鉄道事業者間で警報を共有することにより，震度 6 強地域ではほぼ全域で 3 秒以上のなるなど，S 波到達の前に警報を受け取れる鉄道利用者がさらに増加し，ほぼ 100%の鉄道利用者の危険率が半減するなど，より高い減災効果を得られることがわかった．

(2)　今後の課題･展望

本研究では，地震時の鉄道における人的被害のリスク評価を，列車脱線事故または線路上の障害物による衝突事故に対してのみ考えて行った．しかし，実際には急制動による衝撃で，列車内に死傷者が発生する可能性もあり，一概により早く減速･停止することが最善とは言い切れない．列車内の安全性の評価の概念も取り入れた上で，警報システムのリスク軽減効果を検討することが望ましい．

また，本研究では駅間滞留人口を各時間帯の期待値という形で表した結果，一日で最も鉄道利用者が多く存在しているのは 8:00~8:59 で，その数は約 190 万人であった．しかしそれらの値はあくまでその時間帯の平均値であり，最大値はさらに高いと思われる．時間帯を細かく刻んで検証をすることで，より精度の高い評価を行うことができると考えられる．

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新潟県中越沖地震における通れた道路マップの提供と プローブカー情報の減災利用実現に向けた課題と展望

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要　約

災害時の救急・救援活動や復旧活動に際して自動車の利用は不可欠であり、道路情報は最も重要な情報の一つである。しかし、大きな災害に際しては、刻々と変化する広域の道路状況をリアルタイムに把握することは容易ではなく、適切な情報が提供されているとは言い難い状況である。本稿では、プローブカー情報の減災利用に関する取り組みの一環として、2007年7月新潟県中越沖地震における「通れた道路マップ」の試験提供の取り組みについて報告するとともに、抽出された課題を提示した。さらに、プローブカーによる道路被害把握の可能性についても実データに基づき検討し、プローブカー情報の減災利用の実現に向けた課題と展望について議論した。

キーワード：　プローブカー、減災、新潟県中越沖地震、道路、情報共有

1. はじめに

災害時における様々な救急・救援活動や復旧活動に際して、移動や搬送手段として自動車の利用は不可欠であり、道路情報は災害時において最も重要な情報の１つである。しかしながら、大きな災害に際しては、広域にわたって同時多発的に被害が発生する一方、道路管理者自身も被災して迅速なパトロールが困難になる､警察は人命救助など優先順位の高い業務が発生するため交通に専念できなくなるなど、道路情報の収集と集約には多くの時間が必要となる[1)]。その上、災害時の道路状況は時々刻々と変化することから、これらの状況をリアルタイムに把握して、提供することは容易なことではない[2)-5)]。そのため、ICTが進展した今日においても、被災地に向かう車両、ボランティア等の一般車両、それぞれに適切な情報が提供されているとは言い難い状況にある[6) 7)]。

近年、航空写真やリモートセンシングによる道路被害の把握の試みが行われている[8)]が、現時点では、

観測頻度の問題や、抽出精度の問題など実用化には解決しなければならない課題が多い。そこで、著者らは災害時の道路状況の迅速な把握を行うために、被災地内を走行する車両の走行データを共有することを考えた。自動車を探査装置して活用する仕組みは、交通工学の分野ではプローブカー[9)]と呼ばれ、信頼性の高い旅行時間の予測[10)]や事故[11)]・異常渋滞[12)]・路面凍結[13)]の検出など様々な利用[14)-16)]が検討されているが、災害時における道路状況の把握への適用はこれまで検討されてこなかった。著者らは、過去の災害時におけるプローブカー情報からその利用可能性を示すとともに、道路情報の集約手段としてプローブカーを活用した場合の効果を数値シミュレーションにより定量的に示し、プローブカー情報の共有を提案してきた[1), 17)]。しかしながら、実災害時での有効性の検討は十分ではなかった。

そこで本稿では、2007年新潟県中越沖地震において、著者らが実施した被災地の復旧活動支援を目的とした通れた道路マップの試験提供について報告するとともに、その活動を通して得られた課題について検討する。次に、プローブカーによる道路被害把握の可能性について検討し、最後にプローブカー情報の減災利用の実現に向けた課題と展望について議論する。

2. プローブカー情報の減災利用

2.1 プローブカーシステム

走行する車両から得られる位置情報や運転挙動などの情報（プローブカー情報）を、サーバーで収集・処理し、配信する仕組みは、一般にプローブカーシステム（**図1**）と呼ばれる。わが国では、2003年秋に本田技研工業が信頼性の高い旅行時間の予測と渋滞回避を目的として、インターナビ・フローティングカーシステムを実用化しており（2007年3月に会員数50万人を超える）、現在、自動車会社に加えて、カーナビメーカーも追随し、日々走行している車両の情報が蓄積・活用されている状況にある。

2.2 プローブカー情報の減災利用の特長

プローブカー情報を減災利用するに当たり、既存の情報提供の仕組みと比して、特長と考えられるものを以下に整理する。

・最新の道路情報を把握できる：地震の余震の影響や台風などの豪雨災害では、時々刻々と被害状況が変化する。プローブカー情報は、被害状況を反映したリアルタイムなデータの収集が期待できる。

・少ない車両でも効果が大きい : 1台でも走行すればその道路が通行可能であったことを意味する。安全性は担保できないが、情報としては少ない台数でも意味を持つ。もちろん、走行する車両の数が増え

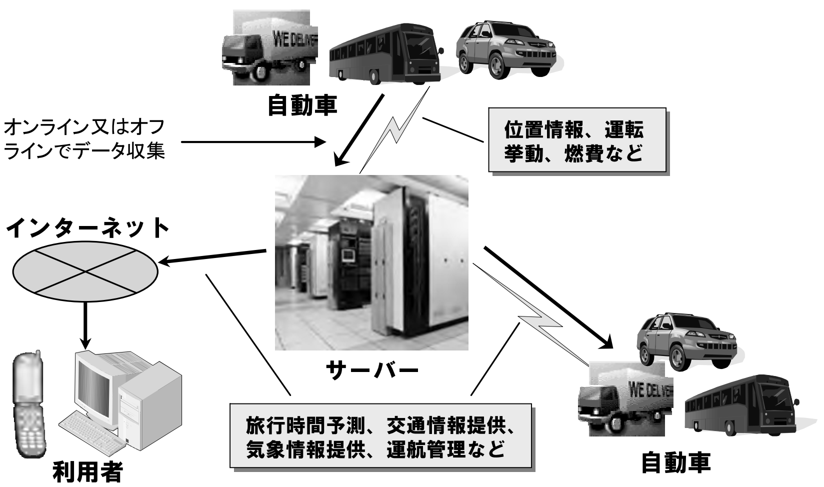


図1　プローブカーシステム

ることで情報のリアルタイム性や信頼性は高まる。

・VICS情報未提供の道路情報がわかる：設定されている約26万のVICSリンクのうち、約18万リンクについてのVICS情報（渋滞度、リンク旅行時間）が提供されていない。プローブカーは車両自身がセンサーとなっているため、幹線道路だけでなく地方道も含めて様々な道路種別の情報を把握することができる。

・車両種別に応じた通行状況の把握：大型車、10トン車など車両種別情報を活用することで、車両種別に応じた通行状況を把握することができる。

・平常時から利用されているシステムである：一般に災害時での利用に特化した仕組みは機能しないと言われている。プローブカーは平常時の信頼性の高い旅行時間予測や渋滞回避の仕組みとして既に実用化されており、災害時においてもシームレスに活用することが期待できる。

・新たな施設投資が不要：平時から利用されているシステムを活用することから、災害時利用のための特別の投資が基本的には不要である。

・災害に対して強い：プローブカー情報は、GPSを搭載した車両に記録される。従って、ライフラインや通信が途絶したとしてもデータそのものが消えることはない。さらに、パケット通信を使用しているため輻輳に強い。仮に携帯電話の基地局が機能停止になった場合であっても、通話可能な地域に移動することでデータの送受信が可能となる。

3. 新潟県中越沖地震における通れた道路マップの試験提供

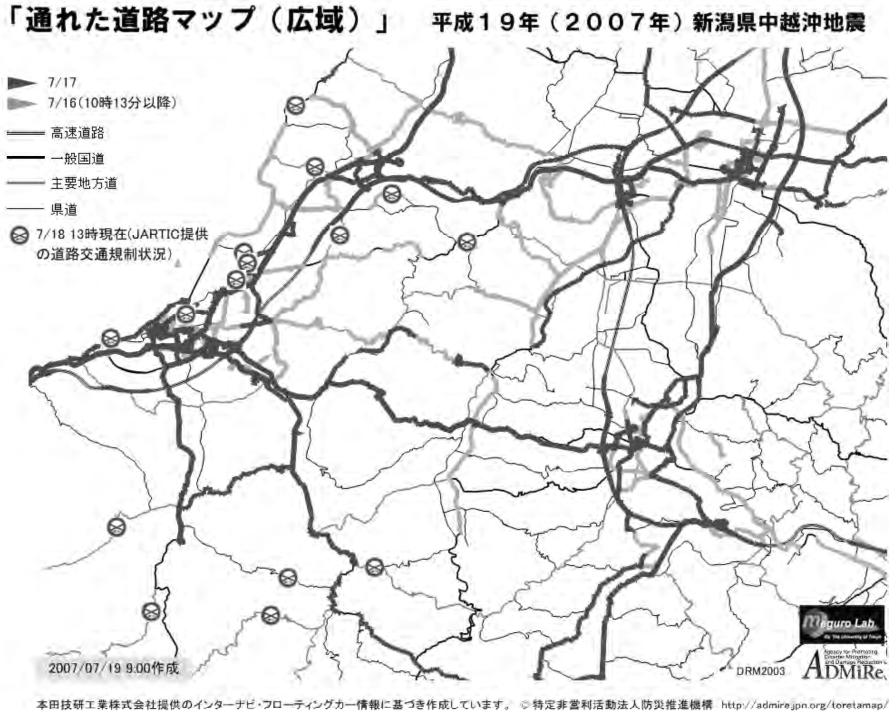
3.1 通れた道路マップ

道路管理者や警察から提供される通行規制の情報は、通常は表形式の規制区間の情報として提供される。そのため、土地勘の無い人間にとっては、規制箇所を地図上で特定することが大変困難な作業となる[1)]。そこで、筆者らは災害時における迅速な道路情報共有の課題を解決するための１手段として、プローブカー情報に着目し、実際に災害時に通行した車両の情報を集約し、「通れる道路」の情報として共有することを考えた。ただし、実際のプローブカー情報は、過去のある時点に、車両がある箇所を通行した（通った）軌跡を意味していることから、「通れた道路マップ」と命名した。

被災地である柏崎市は、平成16年新潟県中越地震の際に、筆者らが災害対応実態調査を実施しており、交流があった自治体であった。地震発生翌々日の7月18日に柏崎市を訪問し、「通れた道路マップ」の試作版を災害対策本部に提示したところ、是非利用したいとの要望があった。その後、本田技研工業株式会社に協力の要請を行い、19日より「通れた道路マップ」を配信することとなった。

本田技研工業株式会社から提供されたプローブカー情報は、車両を識別するIDと経度、緯度、日時、時刻、方位を持っており、15秒間隔でサンプリングされたものである。「通れた道路マップ」は、交通分野で標準的に使用されているDRM（デジタル道路地図）[18)]上にプローブカーの軌跡をプロットした広域版と柏崎市街版の２種類（**図2**）を準備するとともに、プローブカー情報から平均移動速度を算出し、Google Earth上で表示を試みたもの（**図3**）をそれぞれ作成した。通れた道路マップは、**図2**に示すようにプローブカーが走行した軌跡を1日ごとに色分けして表示したものであり、これにより被災地周辺地域でどの道路が通行可能なのか一目で判断できるものとなっている。また、交通規制が実施されている区間は、当然のことではあるが走行軌跡は見られない。色が塗られていない道路が多数見られるが、これが示しているのは、プローブカーが当該道路を走行しなかったということである。ただし、その理由はたまたま当該道路を走行しなかっただけなのか（今回は大部分がこれに相当すると考えられる。）、道路被害のためなのかは、**図2**からのみでは判断できない。

次に、車両の軌跡だけでは混雑状況は判断できないので、各車両の軌跡を平均移動速度別に３段階（青線40km/h以上、黄線20km/h～40km/h、赤線20km/h以下）で表示したものが**図3**である。柏崎市街は、周辺地域に比べて赤っぽく表示されており、渋滞が発生していることがわかる。



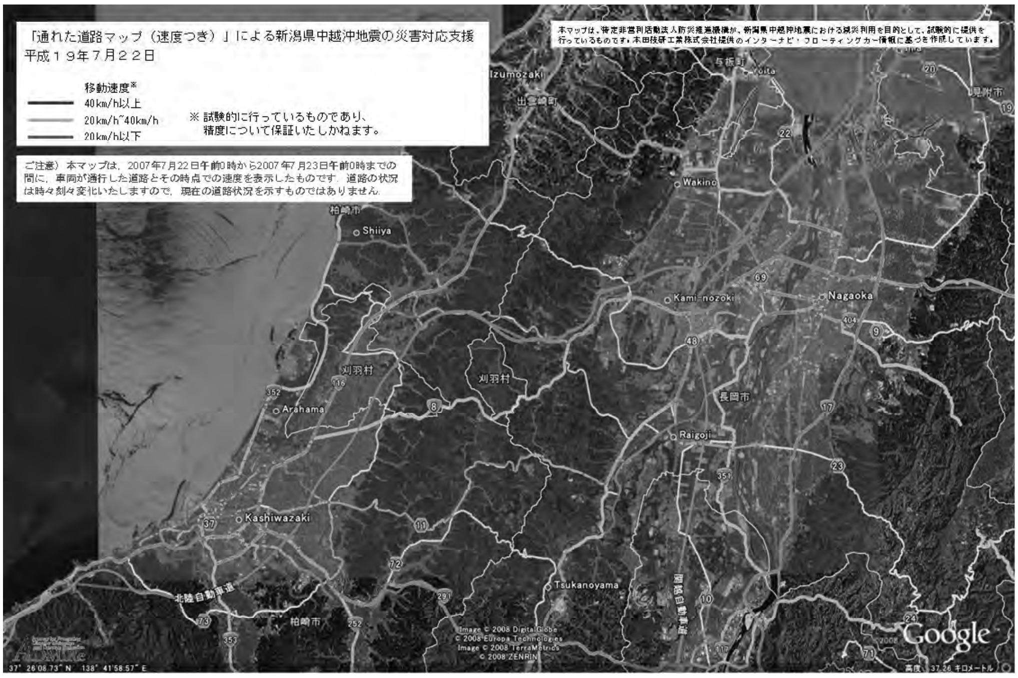
(1) 広域（2007年7月19日9:00作成）

(2) 柏崎市街（2007年7月19日9:00作成）

図2　通れた道路マップ（広域と柏崎市街）

3.2 通れた道路マップの試験提供

作成したマップは、特定非営利活動法人防災推進機構のホームページ(http://admire.or.jp/toretamap/)上で、プローブカーの軌跡は7月19日から、Google Earth上での平均移動速度の表示は7月22日から、それぞれ23



(1) 広域（2007年7月22日）

(2) 柏崎市街（2007年7月22日）

図3　Google Earth上における通れた道路マップ（広域と柏崎市街）

日まで1日1回配信した。なお、通れた道路マップは、Google Earth版も含めてPDFでの提供とした。7月23日には、地域の主要幹線である国道８号線が復旧するなど、配信の必要性がなくなったと判断した。なお、ホームページ上でGoogle Earthのkmlファイルの提供を行わなかった理由は、各車両の位置情報が判別できないようデータを加工する時間的な余裕が無かったためである。

3.3 通れた道路マップの位置づけと得られた課題

(1) わが国で初めての試み

「通れた道路マップ」の試験提供は、実際に発生した災害において、プローブカー情報を用いて道路状況を可視化し、減災利用を試みた取り組みとして位置づけられる。こうした実災害時での減災の取り組みは、わが国では初めての試みであり、以下に示すように課題は少なくないものの、災害時におけるプローブカー情報の共有化の利用可能性や有効性をある程度示すことができたと考える。

(2) 得られた課題

今回の取り組みは、事前に十分な準備と関係機関の合意を得た上で実施したものでないため、多くの課題が挙げられた。DRM上に走行規制をプロットした通れた道路マップは、地名がない、上下線が区別されていない、拡大縮小できない（PDFでの提供のため）、等々、決して使い勝手のいいものではなく、表示の仕方や配信方法など様々な改善の余地が考えられる。また、Google Earth版の通れた道路マップでは、平均移動速度を表示し、道路の混雑状況の可視化を試みたが、これについても上下線の区別や時間帯別の表示などさらなる利便性向上が課題として挙げられる。

一方、地図の活用には事前の周知と理解が必要という指摘や、道路管理者からは道路被害が発生している通行困難な道路へ誘導しているようにとられかねないという指摘や、「通れた道路」というのは、「通れる」ことを保証しているように誤解されるといった指摘があった。

以上のように、実際の情報を配信する取り組みを通して、より具体的な課題が明らかとなった。これらの課題の解決策も含め、実現に向けた課題と展望については、5. で併せて議論する。

4. プローブカー情報による道路状況の把握の可能性

筆者らは、これまで2004年新潟県中越地震や2004年台風16号および23号における浸水被害（高松市）の分析を行い、交通規制箇所や浸水被害箇所とプローブカーの軌跡の関係について検討を行っている[1)]。その結果、規制箇所や浸水被害箇所を走行する車両は基本的にいないことや、規制箇所や浸水被害箇所に遭遇し、Uターンする車両が存在することがわかった。

そこで、これまでの検討をふまえて、新潟県中越地方を対象として、新潟県中越沖地震後におけるプローブカー情報を基に、道路状況の把握の可能性について検討する。新潟県中越沖地震が発生した7月16日10時13分から同日23時59分までの117台のプローブカーを分析の対象とする（**図4**）。解析に当たっては、ESRI社のArcGIS9.1を使用した。

4.1 交通規制状況とプローブカーの軌跡

交通規制情報としては、新潟県警察本部が7月17日午前中に発表した、交通規制状況が表形式で記載された文献19と地図上に規制箇所がプロットされた文献20を用いて検討する。**表1**は、文献19を基に、**図5**に示した柏崎市周辺地域を対象に、この地域内で実施された交通規制箇所をまとめたものである。なお、交通規制が7月17日10時までに解除されたもの、7月17日午前0時以降に開始されたものは、それぞれ除外した。また、**図5**は文献20を基に作成した。まず、対象地域にある10カ所の交通規制箇所のうち9カ所では、プローブカーの軌跡は見られなかった。交通規制箇所9では、1台の車両が走行しているが、交通規制が開始されたのは18時55分であり、この車両が走行したのは10時55分頃であることから、この時点では交通規制がなされていなかったために通行できたものと考えられる。

次に、道路被害と関連するUターンする車両の軌跡を探した。Uターンは、プローブカー情報が有する方位の情報が短時間でかつ、移動距離がほとんどない条件で、約180度変更する場合として抽出した。抽出したUターン車両の中で、道路被害に起因するものと推定できるものを示したものが**図6**である。地震発生から車両Aが約20分後、車両Bが約40分後に国道116号線柏崎市西山町和田付近において、Uターンしていることがわかる。新潟県警察本部の交通規制状況によれば、国道116号線の柏崎市西山町和田では、道路陥没のため、10時15分から16時05分まで全面通行止めが実施されている。**図7**では、16時05分の規制

図4　新潟県中越地方のDRM上にプロットしたプローブカーの軌跡（2007年7月16日）
（各色は各車両の軌跡を示している）

表1　柏崎市周辺の交通規制状況

注）新潟県警察本部7月17日10:00現在発表データ[19]より、図5のエリア内の交通規制箇所を抽出して筆者作成

ID	地域機関	道路種別	路線番号	路線名	箇所名（区間起終点）	規制開始		規制解除		規制の種類	理由	規制実施者
						月日	時間	月日	時間			
1	東日本高速	高速		北陸自動車道	長岡JCT　～　上越IC	H19.7.16	10:15			全止	地震	道路管理者
2	長岡国道	国道	8	8号	長岡市千本町（大積）	H19.7.16	10:44			全止	土砂崩れ	道路管理者
3	柏崎地域	国道	352	352号	柏崎市（西山町）椎谷（大崎）	H19.7.16	10:13			全止	道路陥没	道路管理者
4	柏崎地域	主地	73	鯨波宮川線	刈羽村赤田町方	H19.7.16	18:00			全止	道路陥没	道路管理者
5	柏崎地域	主地	73	鯨波宮川線	柏崎市吉井	H19.7.16	20:15			全止	道路陥没	道路管理者
6	柏崎地域	県道	151	東柏崎停車場線	柏崎市東本町	H19.7.16	18:45			全止	家屋倒壊	道路管理者
7	柏崎地域	県道	215	荒浜中田線	柏崎市荒浜～刈羽村正明時	H19.7.16	18:30			全止	道路陥没	道路管理者
8	柏崎地域	県道	215	荒浜中田線	柏崎市長崎	H19.7.16	18:35			全止	道路陥没	道路管理者
9	柏崎地域	県道	393	礼拝長岡線	柏崎市西山町妙法寺～刈羽村油田	H19.7.16	18:55			全止	道路陥没	道路管理者
10	柏崎地域	県道	433	東長鳥五十土線	柏崎市成沢	H19.7.16	19:00			全止	道路亀裂	道路管理者

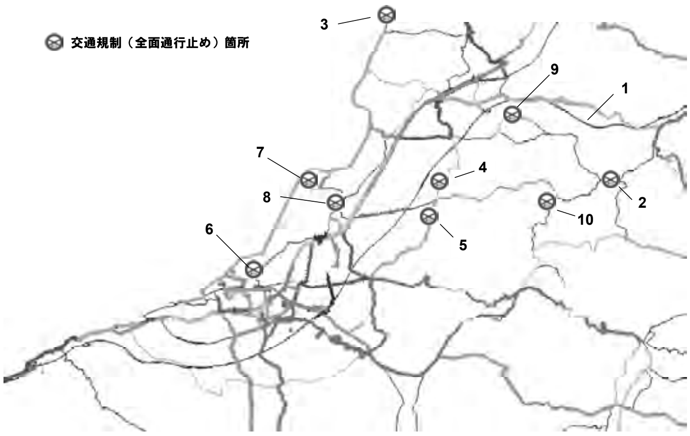


図5　柏崎市周辺のプローブカーの軌跡（2007年7月16日）と交通規制箇所[20]（2007年7月17日9時現在）
（交通規制箇所の番号は、表1のIDと対応）

解除後に車両3台が、道路被害箇所をそれぞれ、16時39分頃（車両C　東→西）、21時12分頃（車両D　西→東）、22時28分頃（車両E　東→西）に通過しており、道路の修繕がなされ、通行可能になったことが示されている。

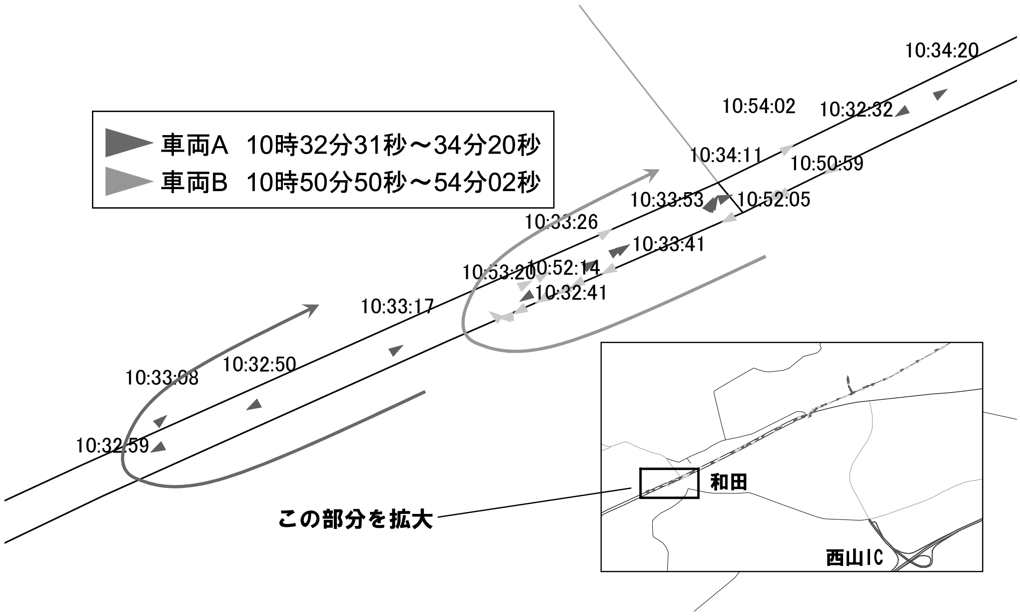


図6　Uターンする車両の軌跡（西山町和田付近）（2007 年 7 月 16 日）

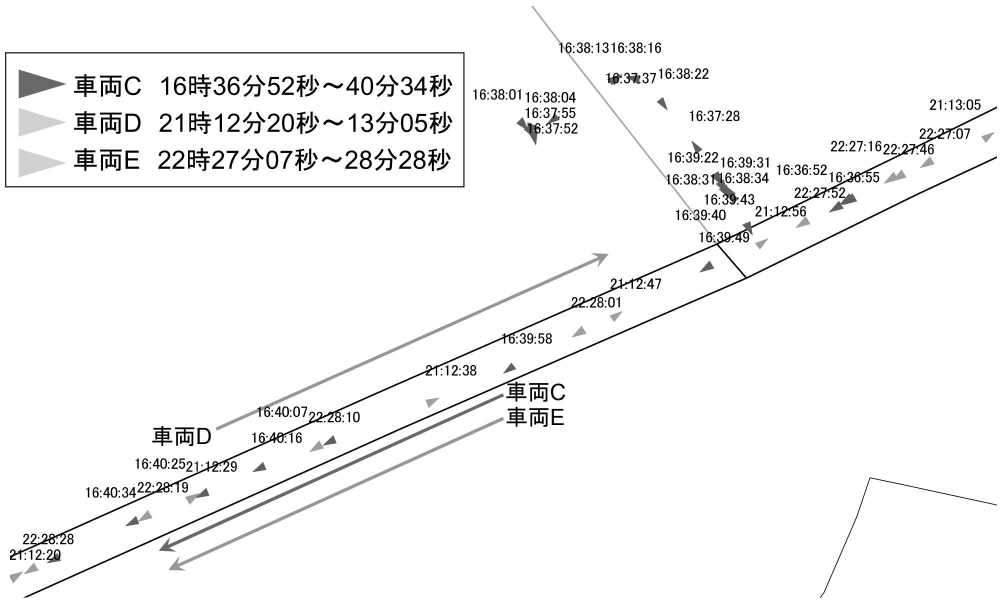


図7　交通規制解除後の走行状況（西山町和田付近）（2007 年 7 月 16 日）

4.2 プローブカー情報による道路被害箇所の把握

新潟県中越沖地震後のプローブカー情報と交通規制箇所の状況を検討した結果、交通規制を実施した道路被害の発生している箇所を走行する車両はなく、プローブカーの軌跡は概ね通行可能な道路と見ることができる。災害直後の、ほとんど道路情報が流通していない時期においては、道路管理者の管轄に関係なく、広域に道路の通行可能状況を判断できる情報が生成できることは、防災関係機関を中心に大変有効であると考える。

一方で、「走行していない道路が被害とは関係なく、単にプローブカーが当該道路を走行しなかった

場合」や「プローブカー情報が交通規制を行う前のものであり、情報が提供された時点では交通規制が既になされている場合」、「Uターン車両が必ずしも道路被害に起因しない場合（安否確認のために出発地へ引き返したり、単に対向車線にある店舗に向かうためなど）」なども考えられることから、情報の確度については一定の限界があることを十分認識する必要がある。ただ、これらの課題についても、複数の車両情報から分析して情報の信頼性を高めるなどの工夫や平常時の走行状況との比較、プローブカーの台数の普及などにより解決される方向の問題であると考える。

5. プローブカーを用いた災害時道路情報配信の事業化に向けた検討と展望

地方自治体やライフライン事業者、警察、消防等の災害対応に、道路情報は欠かすことのできない重要な情報である。しかしながら、災害時には、いわゆる通れない道路情報の収集が容易でなく、その集約に至ってはさらに困難を極めているのが実情である。プローブカー情報を活用すれば、通れる道路情報や通れない道路情報を、現地から直接入手することが可能となる。自動車会社やカーナビメーカーが連携することで、プローブカー情報の集約が可能となる。また、一般車両だけでなく緊急車両の情報を用いることができれば、片側通行可能か、大型車通行可能か否か等、円滑な災害対応に資する道路情報としても利活用することができる。

そこで、筆者らを主として構成される特定非営利活動法人が、プローブカー情報の減災利用研究会[21)]を主催し、減災に資する道路情報の配信に関係する自動車、カーナビ、物流、災害情報配信の各業界を代表する会社の参加を得て、同研究会にて各業界からの話題提供とともに徹底的な議論を行った。

同研究会では、プローブカー情報の減災利用に関する技術的課題について整理した。プローブカーにおける走行データの収集技術については、自動車会社、カーナビ会社の各社で実用化が行われており、基本的な技術は確立されていると言える。しかしながら、各社毎にデータフォーマットが異なっているため、各社の走行データを集約するためには、データの標準化が不可欠である。とはいえ、災害時のみに利用する目的で、各社が連携してデータフォーマットを統一し、データ処理センターを設立、運営するのは現実的ではない。したがって、各社で共有すべき最低限のデータについてのみ、標準データフォーマットとして策定し、互いに共有できる仕組みが望ましいとの結論に至った。一方、現状では情報の共有化に関する法律はなく、法律的課題は存在しないことが確認された。

市販のカーナビでは、道路情報と周辺の基盤情報を用いて、各種サービスが行われている。例えば、大型駐車場へ車を誘導する際には、基盤データとして車載器側に登録されている入り口情報を用いており、また最短経路探索では、基盤データとして車載器側に登録されている道路渋滞統計情報を用いている。したがって、道路基盤情報と道路沿線のハザード情報、そして車両走行情報を組み合わせることによって、道路被害あるいは道路沿線の災害情報を創出し、配信することも可能であると筆者らは考えている。しかし、「通れた道路」をさらに発展させて、可能な限りリアルタイムで走行データを処理、集約した「通れる道路」の情報が提供されても、やはり「通れない道路」の情報を得ることはできない。したがって、「通れない道路」すなわち道路被害箇所を、道路基盤情報と道路沿線のハザード情報、さらに車両の異常走行データを組み合わせて推定することによって道路被害推定情報を創出する研究に着手している[22)]。このような災害情報をプローブカー情報の提供者（会社、ドライバー）に返すことによって、データ提供者にメリットを与えることができる。対象とする災害を地震災害だけでなく豪雨水害や土砂災害等にも拡張すれば、ドライバーが災害に遭遇する確率は高くなり、災害時のデータ提供に限定されたシステムであっても、データの集約と提供を可能とする環境の醸成が期待できると考えている。

このように、筆者らは災害時のプローブカー情報の集約、リアルタイム道路情報の提供に関する事業化に対する様々な支援に加えて、道路被害推定システムの開発による付加価値の創出等、プローブカー情報の減災利用に対して継続的に取り組む所存である。

6. まとめ

本研究では、プローブカー情報の減災利用の特長を整理し、2007年新潟県中越沖地震後のプローブカー情報の減災利用に向けた取り組みとして実施した「通れた道路マップ」の試験提供について紹介した。

次に、プローブカー情報から道路状況の把握の可能性について検討し、一定の限界はあるものの概ね災害時の判断に資する道路情報を生成することが可能であることを示した。また、プローブカー情報の減災利用の事業化を目的として、自動車、カーナビ、物流、災害情報配信の各業界を代表する会社の参加を得て実施した研究会における検討結果について報告した。

プローブカー情報は、災害対応に不可欠である災害時道路情報の収集、集約を容易にすることによって、迅速な災害対応を支援し、減災に貢献できる大きな可能性を有している。今後とも筆者らはプローブカー減災利用の事業化の支援活動や技術開発を、継続的に実施する所存である。

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Issues and Future Prospect on Practical Use of Probe Vehicle Data for Disaster Reduction -Provision of the Vehicle Tracking Map in the 2007 Niigataken Chuetsu-oki Earthquake-

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ABSTRACT

Road information is one of the most important information for vehicles of emergency service, rescue and other disaster response organizations. However, it is difficult to get ever-changing road status of wide area in real-time, and sufficient road information is not provided in actual disasters. In this paper, we report the experimental provision and its problems of the vehicle tracking map in the 2007 Niigataken Chuetsu-oki earthquake, as part of effort to apply probe vehicle data to disaster reduction. We indicate possibility of road damage estimation using probe vehicle data by real data analysis. Issues and future prospects for application of probe vehicle data to disaster reduction are discussed.

Key Words: Probe Vehicle, Disaster Reduction, The 2007 Niigataken Chuetsu-oki Earthquake, Road Information, Information Sharing

J-ALERTによる緊急地震速報の防災行政無線放送の効果に関する研究

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和文要約

2007 年 10 月 1 日から緊急地震速報の一般提供が開始され、2008 年 6 月 14 日に発生した岩手・宮城内陸地震ではテレビ・ラジオ等で緊急地震速報が伝達された。J-ALERT（全国瞬時警報システム）を介した防災行政無線による放送も、緊急地震速報の伝達手段の一つである。岩手・宮城内陸地震は、主要動の到達の前に緊急地震速報が発表された初めての地震であるとともに、J-ALERT を介して防災行政無線から緊急地震速報が放送された初めての事例でもあった。本研究では、J-ALERT により緊急地震速報が放送された山形県東田川郡庄内町を対象として、緊急地震速報の聞き取り状況、聞き取り後の行動に関するアンケート調査を行った。調査票は町内の約 800 世帯に配布し、591 の回答を得た（回収率 73.9%）。防災行政無線放送で緊急地震速報を聞いた人は、テレビで見聞きした人の 2 倍以上となり、広く情報を伝えるには防災行政無線が有効であることが確認された。しかし、放送後にはテレビ・ラジオで情報収集をしようとした人が最も多く、身を守る・周囲に声をかけるなどの行動は促進されておらず、今後は望ましい行動についての周知が必要であると考えられた。

キーワード：緊急地震速報、岩手・宮城内陸地震、J-ALERT

1．はじめに

2007 年 10 月 1 日から緊急地震速報の一般提供が開始され、テレビ・ラジオ等のメディアで情報が伝達されている。J-ALERT（全国瞬時警報システム）を介した防災行政無線による放送も、緊急地震速報の伝達手段の一つである。J-ALERT とは、対処に時間的余裕のない事態に関する緊急情報を人工衛星を利用して地方公共団体等に送信し、市町村の防災行政無線同報系を自動起動することで、住民に瞬時に伝達するシステムである。J-ALERT により送信される情報は、気象警報、津波警報、緊急火山情報、緊急地震速報などの自然災害に関する情報の他、弾道ミサイル発射、ゲリラ・特殊部隊攻撃、大規模テロなどである。本システムは消防庁が国民保護の目的で普及を進め、2007 年 2 月から情報の送信を開始している。消防庁（2009）によれば、2009 年 1 月 9 日現在で、受信のみを含めると、43 都道府県及び 150 市区町村において運用されている。

2008 年 6 月 14 日の岩手・宮城内陸地震は、主要動の到達の前に緊急地震速報が発表された初めての地震であるとともに、J-ALERT を介して防災行政無線から緊急地震速報が放送された初めての事例でもあった。防災行政無線放送が行われた地域は、宮城県栗原市・岩手県陸前高田市・山形県東田川郡庄内町の 3 市町である。このうち、宮城県栗原市では、緊急地震速報が伝達されたのは主要動の到達後であったが、岩手県陸前高田市・山形県東田川郡庄内町では主要動到達の前に緊急地震速報が受信された。この地震での緊急地震速報に対する住民行動については、桶田・田中（2008）が岩手県と宮城県内の

市町に対して電話調査を行った他、中島ら（2008）が盛岡市・仙台市・福島市民を対象としてインターネットアンケート調査を行った。これらの既存調査では、主な情報入手手段はテレビであったと報告されている。しかし、現状では、テレビ等は電源をつけていないと情報を受信できないなど制約もあるため、屋外にいる住民も含めてより広い対象者に情報を伝達できるという観点で、J-ALERT を介した防災行政無線放送の意義は大きいと考える。よって、本研究では、緊急地震速報の効果的な伝達についての研究の一環として、J-ALERT による防災行政無線放送に着目し、放送が行われた地域での局所的なアンケート調査を行い、放送効果を検証する必要があると考えた。

以上より、東京大学大学院情報学環総合防災情報研究センター(CIDIR)では、庄内町役場の協力を得て、2008 年10 月に町民を対象として「地震時の防災行政無線放送に関するアンケート調査」を行った。調査票では、緊急地震速報の聞き取り状況、聞き取り後の行動に関する質問を行った。本論文ではその結果を報告する。

2．J-ALERT による放送内容

山形県東田川郡庄内町（以下、庄内町と略す）では、2008 年 4 月 1 日に J-ALERT の運用を開始した。開始にあたっては、町内の広報誌（広報しょうない）3 月号で告知するとともに、町内の自治会長に対する説明も行った。庄内町は、2005 年 7 月 1 日に北部の余目町と南部の立川町が合併して誕生した。地震時には、北部の余目地域にデジタル屋外拡声器 6 つ、南部の立川地域にアナログ屋外拡声器 44 つが設置されており、今後はデジタル化とともに高密度化も進めている。

6 月 14 日午前 8 時 43 分の岩手・宮城内陸地震は、庄内町での J-ALERT の運用開始後、２ヶ月半後であった。また、庄内町では、7 月 24 日午前 0 時 26 分に発生した岩手県北部を震源とする地震時も防災行政無線放送が行われた。これら２地震は発生時間が異なる２つの事例であり、両事例を比較することにより、多くの示唆が得られると考えられる。

庄内町資料（2008）に基づき、両地震での J-ALERT 起動から放送までの流れを表 1 にまとめるとともに、放送のタイミングを地震波形のデータに重ねて表示した。用いた地震波形は、防災科学技術研究所の強震ネットワーク K-NET の新庄市内の観測点 YMT002 のものである。YMT002 は K-NET の設置点のうち、庄内町に最も近い。6 月の地震での K-NET 新庄での計測震度は 3.9、7 月の地震では 2.7 であった。6 月の地震では、庄内町が予測震度 5 弱となったのは緊急地震速報の第 7 報と遅かったため、J-ALERT の起動は庄内町役場本庁舎への地震到達の 10 秒後となり、チャイム音（8 秒間）と「大地震です、大地震です」（6 秒間）という放送の終了は揺れ到達から 44 秒後となった。図 1 からも、揺れがおさまった時点で住民が放送を聞いたと推測される。6 月末に全国的な起動基準が震度5弱以上から震度4以上に下げられたため、7 月の地震では J-ALERT は予測震度 4 で起動し、概ね主要動到達直前に放送できた。J-ALERT 起動から放送開始まで現状では一般的に十数秒の時間を要するなどの技術的課題は存在するが、起動基準の引き下げが、より早い情報伝達につながったと考えられる。

表 1 ：J-ALERT 放送までのプロセス

	2009/6/14			2009/7/24		
	時間	経過時間(秒)	庄内町へのP波到達後の経過時間(秒)	時間	経過時間(秒)	庄内町へのP波到達後の経過時間(秒)
震源での地震発生	8:43:45	0	−19	0:26:35	0	−16
一般向け速報配信	8:43:55	10	−9	0:26:56	21	5
消防庁からの通報(震度4)	8:43:56	11	−8	0:26:45	10	−6
庄内町庁舎へのP波到達	8:44:04	19	0	0:26:51	16	0
消防庁からの通報(震度5弱)	8:44:13	28	9			
J-Alert起動	8:44:14	29	10	0:26:48	13	−3
防災行政無線の放送開始	8:44:26	41	22	0:26:58	23	7

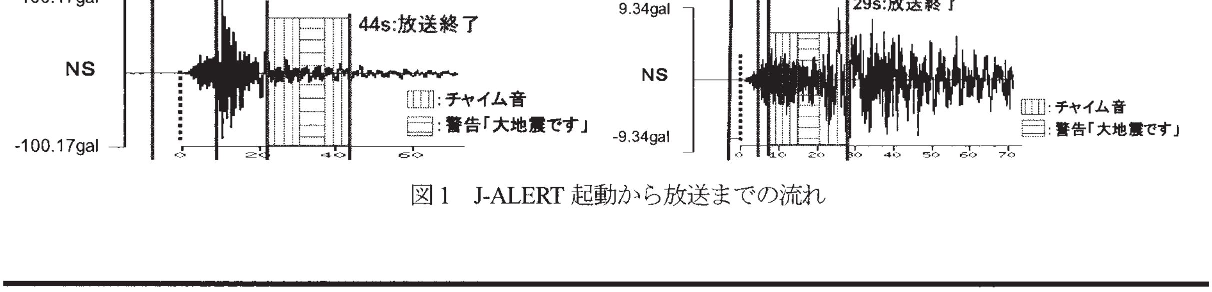

図 1　J-ALERT 起動から放送までの流れ

3．調査の方法と回答者の概要

地震後、庄内町役場のご協力を仰ぎ、8 月末に住民代表の方へのグループインタビューを行い、地震時の防災行政無線放送に関する意見を伺った。これらのご意見を踏まえて、町民を対象とした「地震時の防災行政無線放送に関するアンケート調査」の調査票を作成し、10 月に町内の 27 集落の全戸 800 世帯に調査票を配布し、世帯ごとに回答してもらった。調査票の配布・回収にあたっては、町内自治会長・行政区長の方々の協力を得た。有効回答数は 591 で、回収率は 73.9%であった。

回答者 591 名の概要 を以下に記す。回答者 565 人の 57.2%が男性、42.8%が女性となり、年齢構成は図 3 に示す通りである。回答者 551 人の住宅は、木造 2 階建ての戸建て住宅が 79.9%、木造平屋建てが 16.3%、木造の集合住宅が 1.8%であり、その他の住宅形式はほとんどいなかった。家族に、ひとりで歩けない要介護の方、乳幼児、保育園・幼稚園児・小学生がいる回答者の割合は、それぞれ 13.7%、7.8%、23.6%となった。

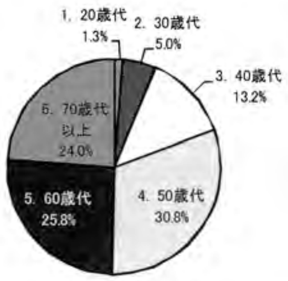

図 3　回答者の年齢構成（N=559）

回答者のうち、過去の災害経験がある人は図 4 に示す通りである。また、各種の災害に対する不安感を尋ねたところ、図 5 の通りとなり「非常に不安である」または「少し不安である」割合は地震で最も高くなった。「6 月の地震の前から、緊急地震速報を知っていたか」については、図 6 に示す通り、48.7 %が「名前も、「大きな揺れを直前に予測する情報」だということも知っていた」と回答した。中島ら（2008）が盛岡市・仙台市・福島市民に対して行った調査では、「名前も内容も知っていた」人は約 6 割、名前だけ知っていた人は約 3 割であった。この調査結果と比較すると、庄内町では「名前も内容も知っていた」人が 1 割程度少なかった。

「6 月の地震より前に、テレビ・防災行政無線の両方で流されることを知っていた」人は 27.3%、「防災行政無線のみを知っていた」人は 12.9%であった。性別、年齢層、過去の地震経験の有無（図 4）、地震への不安感（図 5）でクロス集計を行い、カイ二乗検定を行った結果、性別と年齢層で有意な差が見られた。「テレビ・防災行政無線の両方で流されることを知っていた」人は男性に多く、「防災行政無線のみを知っていた」は 50 歳代以上で多くなった。防災行政無線による放送を知った経緯については、65.4%が「庄内町の広報誌で見た」、23.2%が「行政区長または自主防災組織役員から聞いた」と答えている。若年齢層も含めて、様々な年齢層に情報が行き渡るように周知する必要があると考えられた。今回の防災行政無線放送が J-ALERT によるものであったことを知っていたのは図 9 に示す通り 8.7%に留まり、J-ALERT の認知度が低いことがわかった。

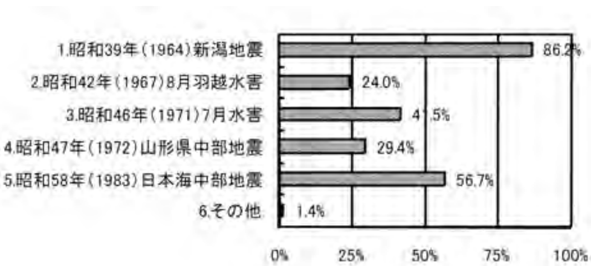

図 4　回答者の災害経験（N=487）

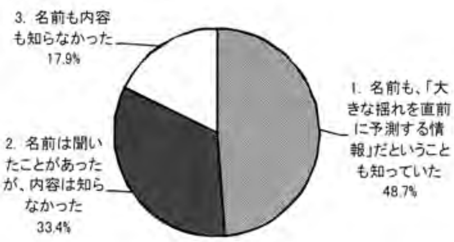

図 6　緊急地震速報の認知度（N=530）

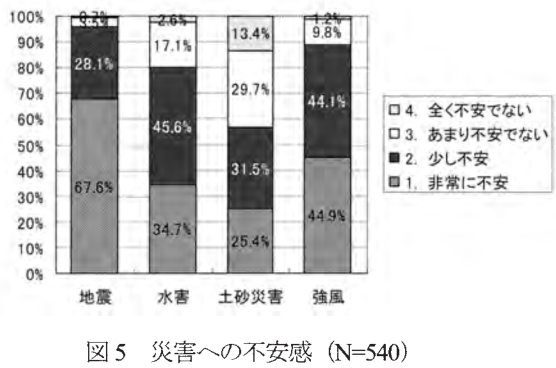

図 5　災害への不安感（N=540）

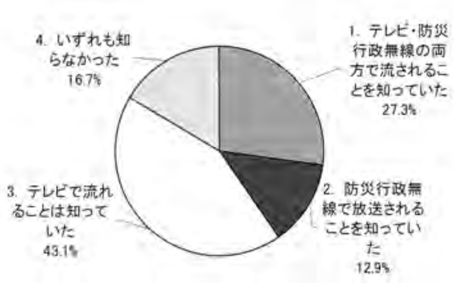

図 7　緊急地震速報の放送手段の認知度（N=534）

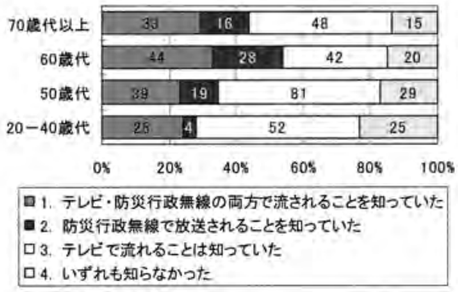

図 8　年齢別の放送手段の認知度（N=521）

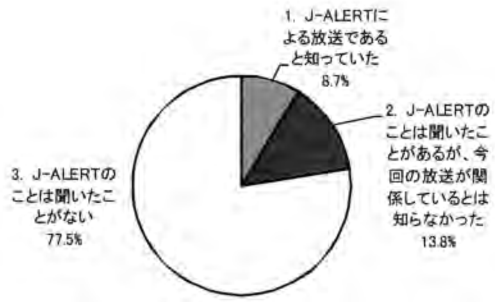

図 9　J-LAERT 放送の認知度（N=530）

4．住民の聞き取り状況

6 月 14 日の岩手・宮城内陸地震と 7 月 24 日の岩手県北部を震源とする地震について、地震発生時にどこにいたかを尋ねたところ、図 10 の通りとなった。6 月 14 日・7 月 24 日の天候はともに曇りであった。7 月の地震は深夜に発生したため、自宅にいた人が 79%と 6 月より多くなった。「地震が起きた時に何をしていたか」を尋ねたところ、図 11 の通りとなり、6 月の地震時は「仕事や家事をしていた」「テレビを見ていた」人が多いものの、7 月の地震時は「寝ていた」人が多かった。

6 月 14 日の岩手・宮城内陸地震と 7 月 24 日の岩手県北部を震源とする地震について、どのようにして緊急地震速報を聞いたかを尋ねたところ、表 2 に示す通りとなった。6 月 1 は防災行政無線を聞いた人が 63.9%おり、テレビで聞いた 31.2%の人の約 2 倍となった。7 月 24 日も同様に防災行政無線を聞いた人が 50.9%おり、テレビで見たと答えた 16.7%の人の 2 倍以上となった。7 月 24 日は深夜のために防災行政無線で聞いた割合がさらに高くなったと考えられる。テレビは現状では電源が入っていないと放送が伝わらないため、広く情報を伝えるには防災行政無線が有効であることが確認された。

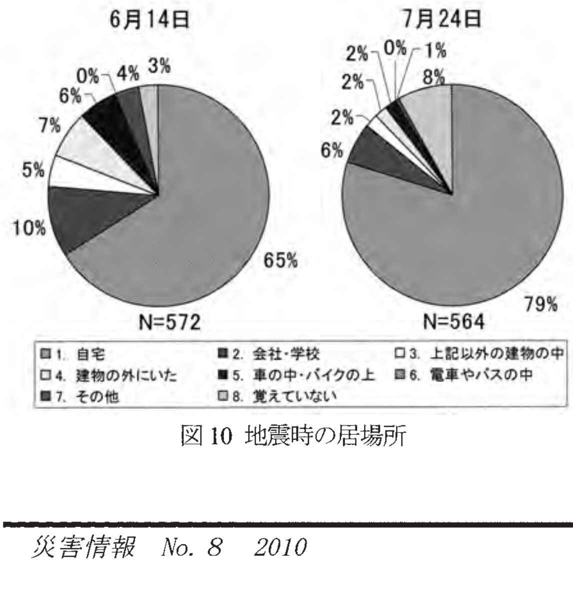

図 10 地震時の居場所

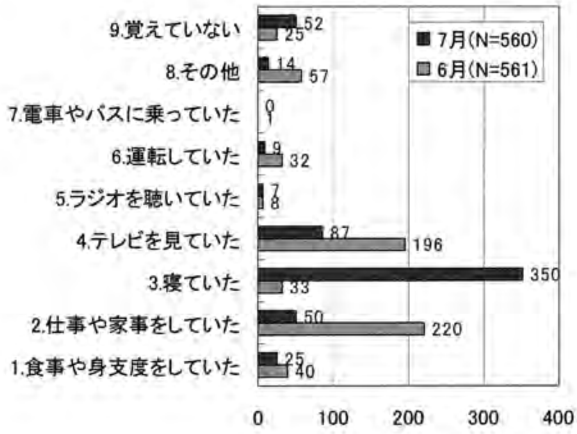

図 11　地震時の行動

表 2　防災行政無線及びテレビでの聞き取り状況

6月		テレビで見た はい	テレビで見た いいえ	計
防災行政無線放送を聞いた	はい	128 24.1%	212 39.8%	340 63.9%
	いいえ	38 7.1%	154 28.9%	192 36.1%
	計	166 31.2%	366 68.8%	532 100%

7月		テレビで見た はい	テレビで見た いいえ	計
防災行政無線放送を聞いた	はい	56 10.5%	216 40.4%	272 50.9%
	いいえ	33 6.2%	229 42.9%	262 49.1%
	計	89 16.7%	445 83.3%	534 100%

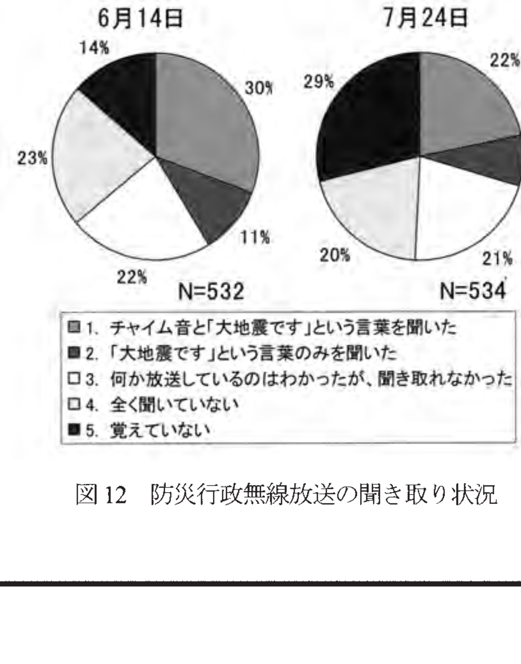

図 12　防災行政無線放送の聞き取り状況

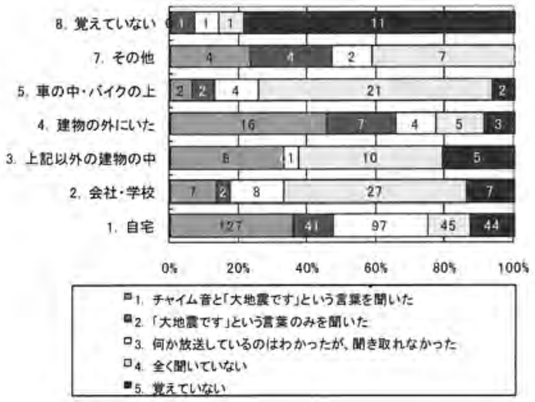

図 13　回答者の居場所と防災行政無線放送の聞き取り状況

6 月 14 日の地震では、図 12 に示す通り、回答者の 30%がチャイム音と「大地震です」という言葉の双方を聞き、11%が「大地震です」という言葉のみを聞いた。7 月 24 日の地震では回答者の 22%がチャイム音と「大地震です」という言葉の双方を聞き、8%が「大地震です」という言葉のみを聞いた。図 13 は、6 月の地震時における回答者の居場所（図 10）と聞き取り状況の関係である。建物外にいた場合は、チャイム音または言葉を聞き取った回答者が 66%と最も多かった。自宅にいた場合は、47%がチャイム音または言葉を聞いたが、この割合は会社・学校内で 18%、車中やバイク上で 13%と小さくなった。仕事中や運転中には防災行政無線放送を聞き取りにくかったことがわかる。また、聞き取り状況についてクロス集計とカイ二乗検定を行ったところ、回答者の住まい、性別では統計的に優位な差は生じなかったものの、回答者の年齢層では優位な差が確認された($p=0.003<0.1$)。これより、図 14 に示す通り、70 歳以上の高齢者では、放送が聞き取りにくい可能性があることが確認された。

「防災行政無線の放送は揺れの前か後か」を尋ねると、図 15 の通りになった。6 月の地震では、放送を聞いた人の 52%が「揺れている途中に」、37%が「揺れがおさまった後」に放送を聞いたと答えた。7 月の地震では、主

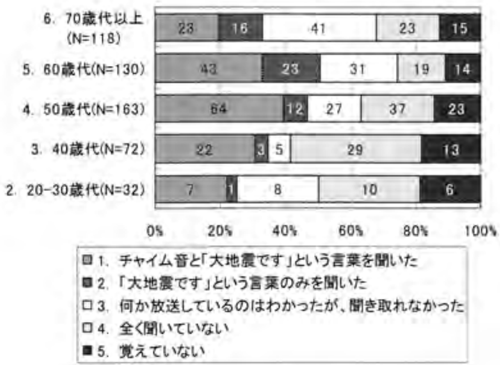

図 14　回答者の年齢層と防災行政無線放送の聞き取り状況

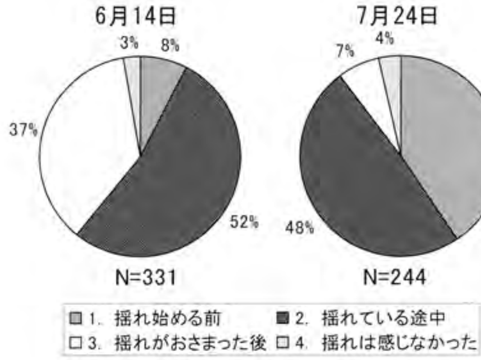

図 15　放送時の揺れの状況

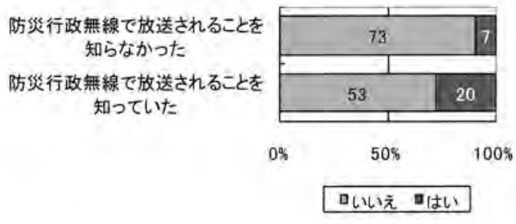

図 16　7 月の地震で「間もなく大きな地震が来る」と認識した割合

要動到達直前に放送が完了したため、放送を聞いた人の 41%が「揺れ始める前に」、48%が「揺れている途中」に放送を聞いたと答えている。

また、7 月の地震で「チャイム音と言葉」または「言葉のみ」を聞き取った回答者（図 12）153 人に対して、「間もなく大きな地震が来ると思ったか」を尋ねたところ、事前に防災行政無線放送が流れることを知っていた人の方が、「間もなく大きな地震が来る」と認識した割合が大きくなった（図 16）。ここで、事前に防災行政無線放送が流れることを知っていたかどうかでカイ二乗検定を行ったところ、統計的にも有意な差が確認された($p=0.003<0.1$)。一方、性別、年齢層、地震への不安感、過去の災害経験では統計的に優位な差は生じなかった。しかし、「事前に防災行政無線放送が流れることを知っていた」人 73 人中、「間もなく大きな地震が来る」という認識に結びつけて理解できた人は約 20 人（27%）に留まり、その割合は限定的である。聞き取り後に瞬時に対応行動を行うためにも、チャイム音への理解度を高める必要があると考えられる。

5．住民の行動

続いて、揺れがおさまるまでの行動も尋ねた。6 月の地震では図 15 に示した通り、揺れている途中またはおさまった後に放送が行われたため、ここでは 7 月の地震時の行動に焦点を当てる。図 17 は、7 月の地震時に防災行政無線で緊急地震速報のチャイム音か音声放送を聞いた人 157 人と「何か放送しているのはわかったが、聞き取

れなかった」または「全く聞いていない」人214人が、揺れがおさまるまでのとった行動を示す。図18は、このうち自宅（図10の選択肢1）にいた人を抽出した結果であり、チャイム音か音声放送を聞いた人147人と「何か放送しているのはわかったが、聞き取れなかった」または「全く聞いていない」人166人の行動である。自宅にいた場合（図 18）では、「テレビ・ラジオで地震情報を知ろうとした」人は、放送を聞いた人の 69.4%、放送を聞いていない人の 57.8%となり、放送の聞き取りの有無にかかわらず最も多くなった。続いて「様子をみた」が放送を聞いた人の41.5%、聞いていない人の36.1%、「家族や周りの人に声をかけた」が放送を聞いた人の25.9%、聞いていない人の 22.3%となった。中島ら（2008）が盛岡市・仙台市・福島市で緊急地震速報の入手手段に関わらず集計した結果によれば、「テレビ・ラジオで地震情報を知ろうとした」は約53%で、続いて「様子を見た」が39%となっており、今回の調査でも同様の順番となった。緊急地震速報を入手しても、テレビ・ラジオでの情報収集が優先されてしまい、瞬時の身を守る行動はあまり行われていなかったことがわかった。

図18において、放送を聞いた場合といない場合でのカイ二乗検定を行った結果、統計的に有意な差が確認されたのは、「テレビ・ラジオで地震情報を知ろうとした(p=0.000<0.1)」、「覚えていない(p=0.000<0.1)」、「戸・窓を開けた(p=0.022<0.5)」「家や建物の外に出た(p=0.044)」であった。放送を聞くことにより、「テレビ・ラジオで地震情報を知ろうとした」が約12%多くなった。調査票設計前に行ったグループインタビューでは、テレビ・ラジオで地震情報を知ろうとした理由として、「「大地震です」と聞こえたが、どういう地震が起きたのか気になりテレビをつけた」という意見が挙げられた。「地震後には震源・震度などの地震速報が放送される」ことへの高い認識が逆効果となり、部分的な情報の入手後における更なる情報探索の欲求につながっていると考えられる。緊急地震速報を聞いたらすぐに被害軽減行動を行う必要がある旨を周知し、認識を改善していく必要があると考えられる。

また、放送を聞くことにより、「戸・窓を開けた」「家や建物の外に出た」が促進されているが、これらの行動は２次災害の危険性もあるため、「身を守る・声をかける」などの行動を優先して行うべきである。グループインタビューでは、「身を守る・声をかける」などの行動を行わなかった理由として、「「大地震です」という一言のみでは、とっさに何をすべきかわからなかった」という声が挙げられ、「行動を指示して欲しい」という意見が見られた。今後は、シチュエーションに応じた望ましい行動に関する周知とともに、具体的な行動に結び着きやすい放送内容の検討が必要であると考えられる。

最後に、「もし、今後、６月に発生した岩手・宮城内陸地震と同じような規模の地震が発生した場合、地震の揺

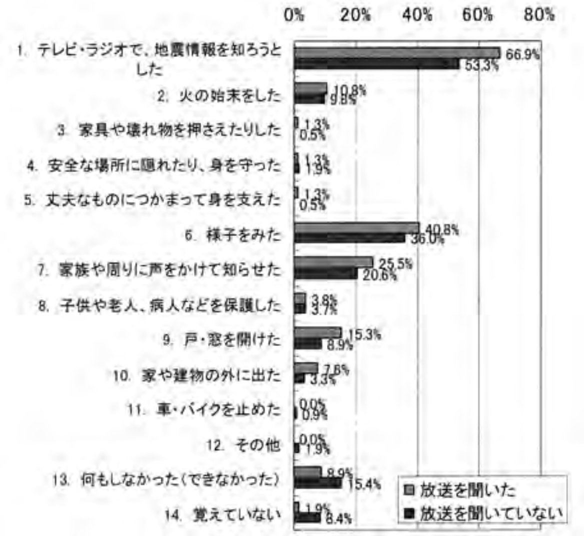

図17　７月の地震での揺れがおさまるまでの行動

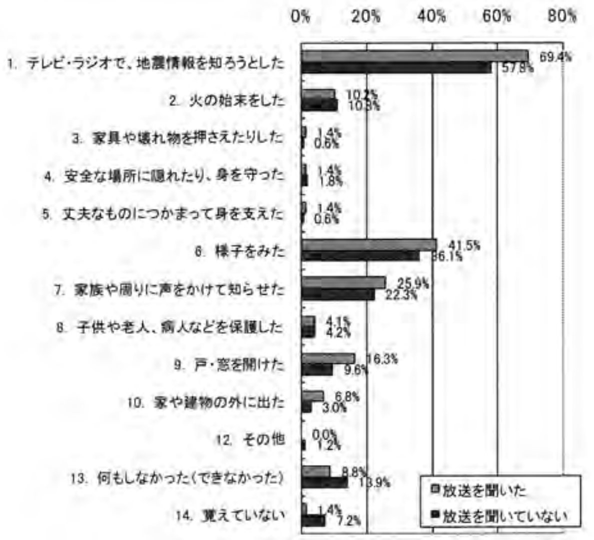

図18　７月の地震での揺れがおさまるまでの行動
（自宅にいた人のみ）

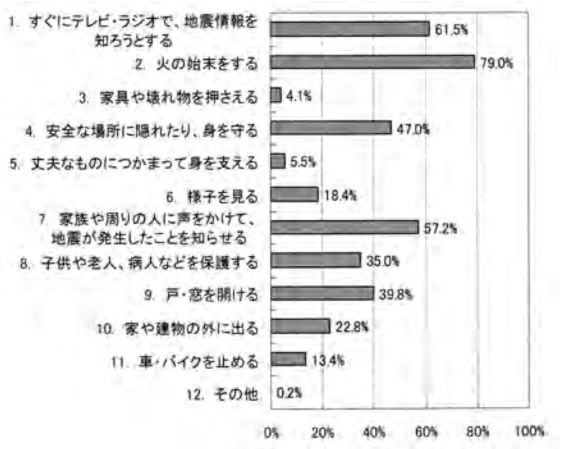

図19　次の地震で行う行動 (N=566)

表3　次の地震で行う行動に対するカイ二乗検定のp値

今後の行動	性別	年齢層	地震経験	地震不安	要援護者
すぐにテレビ・ラジオで、地震情報を知ろうとする	.933	**.003**	.138	.378	.173
火の始末をする	.418	.103	**.000**	.315	*.023*
家具や壊れ物を押さえる	.220	.464	.846	.780	.813
安全な場所に隠れたり、身を守る	*.023*	**.000**	**.005**	**.006**	**.001**
丈夫なものにつかまって身を支える	.663	.063	.377	.223	.082
様子を見る	*.013*	.440	.116	.410	.416
家族や周りの人に声をかけて、知らせる	**.000**	**.000**	*.028*	**.001**	**.008**
子供や老人、病人などを保護する	.355	**.002**	.094	.281	**.000**
戸・窓を開ける	**.000**	.695	*.021*	.385	.050
家や建物の外に出る	.112	.567	.534	.287	.433
車・バイクを止める	.222	.178	.660	.620	.897

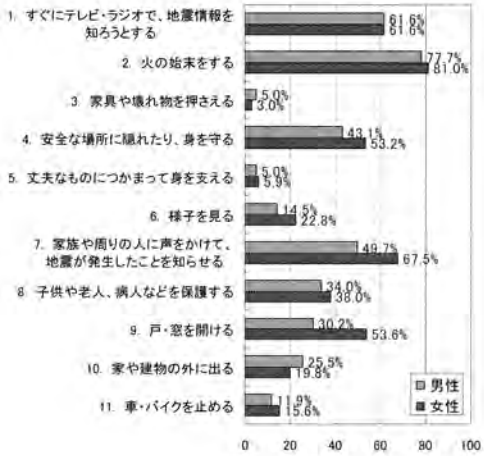

図20　次の地震で行う行動 (男女別、N=566)

れが来る数十秒前に緊急地震速報が入手できていたとすれば、どのようなことをするか？」を尋ねたところ、図19の通りになった。7月の地震は深夜の地震であったため、「火を始末する」が少なかった（図17、図18）のに対し、将来の地震に対する回答では最も多い行動となった。続いて、「テレビ・ラジオで地震情報を知ろうとする」「家族や周りの人に声をかけて、地震は発生したことを知らせる」「安全な場所に隠れたり、身を守る」となった。性別、年齢層、過去の地震経験の有無（図4）、地震への不安感（図5）、要援護者（一人で歩けない要介護の方、乳幼児、保育園・幼稚園児・小学生）の有無による回答差についてカイ二乗検定を行った結果、各ケースでのp値は表3に示す通りになった。表中では、5%有意確率で回答差が見られたものを斜字で、1%有意確率のものを太字で、0%有意確率のものを網掛けの太字で示した。

「すぐにテレビ・ラジオで地震情報を知ろうとする」行動は、高齢の回答者で多くなった。「火の始末をする」は年齢層では有意な差が見られなかったものの、「過去の地震経験がある」場合に特に多くなった。近年は、ガスコンロ等は自動消火装置がついているため、二次災害防止の観点から必ずしも火の始末を行わなくてもよいという指示がなされている。気象庁(2009)の市民向けリーフレットにおいても、家庭で緊急地震速報を見聞きした場合の行動として「無理に火を消そうとしない」ように明記されている。過去の災害経験がある場合、これらの点を誤解しやすい可能性がある。「安全な場所に隠れたり、身を守る」については、特に若年齢層になるほど回答が増え、身体能力による回答差と考えられる。「家族や周りの人に声をかけて、地震が発生したことを知らせる」については、特に女性で多く（図20）、地震への不安感が強い人ほど多くなった。年齢別では70歳代では少なかった。「子供や老人、病人などを保護する」については、要援護者がいる場合に特に多くなった。「戸・窓を開ける」については、特に女性で多くなった。「家具や壊れ物を押さえる」「丈夫なものにつかまって身を支える」「家や建物の外に出る」「車・バイクを止める」については、これらの属性に関しては有意な差が確認されなかった。

6．まとめ

本研究では、緊急地震速報の効果的な伝達についての研究の一環として、J-ALERTによる防災行政無線放送に着目し、山形県東田川郡庄内町の住民を対象とした地震後のアンケート調査を行った。

事前に防災行政無線放送のタイミングと地震波形を比較した結果、J-ALERTシステムの起動から防災行政無線放送開始までの時間短縮、警告音声前のチャイム音の短縮など、技術的な課題が存在することが確認された。

住民へのアンケート結果からは、防災行政無線を聞いた人はテレビで聞いた人の2倍以上おり、広く情報を伝えるには防災行政無線が有効であることが確認された。岩手・宮城内陸地震で防災行政無線放送が行われたのは3市町のみであったが、消防庁は更なる地方公共団体の普及とともに、2009年からはJ-ALERTの受信対象を指定行政機関（気象庁等）、指定地方行政機関（管区警察局等）、その他の国の機関（裁判所等）及び指定公共機関（NHK等）へと拡大している。緊急地震速報の放送手段の一つとして、J-ALERTによる防災行政無線放送の有効利用と住民への周知も図る必要がある。

今回の調査からは、情報の受け手である住民側にもいくつかの課題が指摘された。7月の地震では、揺れ到達の前での防災行政無線放送に成功したにも関わらず、事前に防災行政無線放送が流れることを知っていた人のうち、「間もなく大きな地震が来る」と認識できたのは27%であった（図16）。放送の事前知識がある場合に地震来襲の認識が高くなった点は、事前知識の効果であると考えられるが、「地震が来る」という認識割合は低いのが現状である。また、放送後にはテレビ・ラジオでの情報収集が優先されてしまい、瞬時の身を守る行動はあまり行われていなかった。村越ら（2008）が起震車を用いて行った検証実験では、「緊急地震速報の意味や適切な退避行動に関する知識が、退避行動を効果的にする上で良い影響を与えた」と報告している。今後、瞬時の適切

な対応を可能にするためには、チャイム音・地震来襲・望ましい行動を結びつけて考えることができるよう、受け手側の意識啓発を図る必要があると考えられた。今回の調査では、将来の地震での対応行動について、過去の地震経験を持つ場合に「火の始末をする」人が多くなるなど、受け手側の属性・立場・経験によって、同じ環境下でも行う対応行動に差異が生じる可能性も示された。受け手側の意識啓発を図る際には、これらの傾向を考慮した上での周知活動や教材作成が必要であると考えられた。

東京大学大学院情報学環総合防災情報研究センター(CIDIR)では、引き続き J-ALERT を含めた緊急地震速報の有効活用に関する調査研究を行う予定である。

謝辞：

本研究でのアンケート調査は、庄内町役場総務課防災交通係、町内自治会長・行政区長の方々の協力を得て実施された。また調査票作成段階においては、町内住民の方々にグループインタビューへのご協力をいただいた。ご多忙のところ快く協力していただいたこれらの皆様に感謝を申し上げる。

また、本研究では防災科学技術研究所 K-NET の地震波形をダウンロードして図に用いた。調査および研究の遂行は、東京大学生産技術研究所選定研究の一環として行った。記して、感謝の意を表する。

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A Study on Effectiveness of Earthquake Early Warning by J-ALERT System

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ABSTRACT

Japan Meteorological Agency (JMA) started Earthquake Early Warning (EEW) to the public since October 1, 2007. When the 2008 Iwate-Miyagi inland earthquake occurred on July 14, 2008, EEW was provided to the regions whose intensities of shaking were expected to be more than JMA 4. The warning was widely broadcasted by TV, radio, mobile phones and loudspeakers. It was not only the first earthquake since October, 2007 that EEW could be successfully broadcasted before the arrival of strong tremors, but also the first earthquake that EEW was broadcasted through loudspeakers by J-ALERT system. .

In Shonai Town, Yamagata prefecture, EEW was broadcasted through loudspeakers by J-ALERT system to the residents at the 2008 Iwate-Miyagi inland earthquake. In this research, a questionnaire survey was conducted to understand residents' response to the warning. 800 questionnaire sheets were distributed in the town and 591 answers were obtained. The ratio of the respondents who heard the broadcasting of EEW by loudspeakers was twice as many as those who got EEW by TV. It is verified that broadcasting by J-ALERT system is useful to convey EEW widely at the same time. However, most people tried to get information by TV or radio after hearing EEW. The result of the survey revealed that residents' understanding on proper response to EEW was insufficient and it is necessary to enhance residents' capacity to take proper action after the warning.

Keywords ***:*** *Earthquake Early Warning*、 *The 2008 Iwate-Miyagi Inland Earthquake*、 *J-ALERT*

Survey of September 30, 2009 Sumatra Earthquake

Muneyoshi Numada[1], Shigeru Miwa[2], Ömer AYDAN[3] and Masanori Hamada[4]

ABSTRACT: On September 30, 2009 at 17:16, an intense earthquake (M7.6) occurred just off the western Sumatra coast in Indonesia. The official death toll was confirmed at 739 people, with another 296 people missing and presumed dead, primarily in Padang Pariaman District. A total of 863 people were seriously injured, and 1,356 people slightly injured. Damage to houses was widespread with 121,679 houses severely damaged, 52,206 moderately damaged, and another 57,510 lightly damaged, rendering homeless an estimated 250,000 families (UN OCHA). Japan Society of Civil Engineers (JSCE), Japan Association for Earthquake Engineering (JAEE) and Engineers Without Borders-Japan organized a survey team immediately after the event. The team was dispatched to Indonesia and conducted initial damage assessment in the damaged area. This report outlines the findings obtained from a quick survey (Oct 16-18) of the damaged area.

Key Words: Sumatra Earthquake, Masonry structure, Liquefaction, Tsunami, Disaster survey

INTRODUCTION

On September 30, 2009 at 17:16, an intense earthquake (M7.6) occurred just off the western Sumatra coast in Indonesia (Location: 0.789°S, 99.961°E). The focal depth was 80 km (USGS). The epicenter was 45 kilometers from the port city of Padang, Sumatra. An after shock (M6.2) occurred 22 minutes later, followed by a third quake (M6.8), which struck 225 km southeast of Padang. This continuous shaking caused widespread destruction in the area of Padang Pariaman District. Most inhabitants in the affected areas lost their houses to collapse caused by seismic motion or landslide. The official death toll was confirmed at 739 people, with another 296 people missing and presumed dead, primarily in Padang Pariaman District. A total of 863 people were seriously injured, and 1,356 people slightly injured. Damage to houses was widespread with 121,679 houses severely damaged, 52,206 moderately damaged, and another 57,510 lightly damaged, rendering homeless an estimated 250,000 families, many too frightened to return home (UN OCHA).

Japan Society of Civil Engineers (JSCE), Japan Association for Earthquake Engineering (JAEE) and Engineers Without Borders-Japan organized a survey team (Team leader: Dr. Masanori HAMADA, professor, University of Waseda) immediately after the event. The team was dispatched to Indonesia, and conducted initial damage assessment in the damaged area.

STRUCTURES

Over 300 building were briefly observed in a survey of the Padang and Pariaman area. In **Figure 1** blue sticks mark the observed damaged buildings. Structures affected by this earthquake were primarily low-rise residential masonry, hotel buildings, government offices and industrial facilities.

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The structural type of engineered and non-engineered structures in the affected areas may be classified in three general categories: wooden structure, unreinforced masonry structure, and masonry structure with frame. Residential wooden houses with tile or corrugated steel sheet roof are constructed with a wood frame made up of columns and beams supporting wood joists. The roof is covered with clay tile or thin corrugated steel sheets. Unreinforced-mansonry structures (non-engineered concrete construction) with masonry infill are common in Indonesia. The beams and columns of these buildings are substandard, consisting of small sections lightly reinforced with plain bars. These columns suffered significant damage from the seismic forces. Mansonry structure with frame (engineered reinforced concrete construction) generally well-constructed reinforced concrete frame structures, survived the earthquake with heavy damage in Padang. Damaged masonry and wooden buildings were also observed in the mountaineous Pariaman region.

In **Figure 2**, Photos 1 and 2 show the typical damage to wooden houses and masonry houses constructed with bricks. There were many wooden houses in the damaged area. These structures performed better than brick masonry houses with or without RC slabs and/or columns; however, there were instances of total collapse due to intense ground shaking. Photo 3 shows an old one story masonry building with no reinforced concrete slabs and columns. Low-rise residential masonry buildings are generally constructed with bricks and are either one or two stories. This type of collapse was observed even in areas with high ground acceleration. Newly-constructed buildings with concrete slabs and columns, there is no doubt that when such structural elements are integrated with masonry walls they perform better and prevent the total collapse of the buildings in spite of some structural damage. Photos 4 and 5 show a government office constructed with an engineered structure. Several cases of total collapse or heavy damage were observed. Some hotel structures also totally collapsed as shown in Photos 6 and 7. Photo 7 shows damage to a hotel which was assigned as a vertical evacuation space in the case of tsunami. People could not use this building as an evacuation structure due to its collapse. This damage illustrated the problem with vertical evacuation spaces. Pancake-type collapse was observed in the buildings of China Town, as shown in Photo 8. The concrete buildings with two or more stories either collapsed or were heavily-damaged. These type of reinforced concrete structures are framed structures with integrated or non-integrated in-fill walls.

The South and West Sumatra Earthquake on September 12, 2007, killed 25 people and caused heavy damage in Benngkulu and West Sumatora Provinces along the western shore of Sumatra Island. The structural damage was similar to the damage observed from this earthquake. Earthquake damage to structures has often been connected to the local structural type, and this type of construction is typical of low-cost and affordable housing in Indonesia.

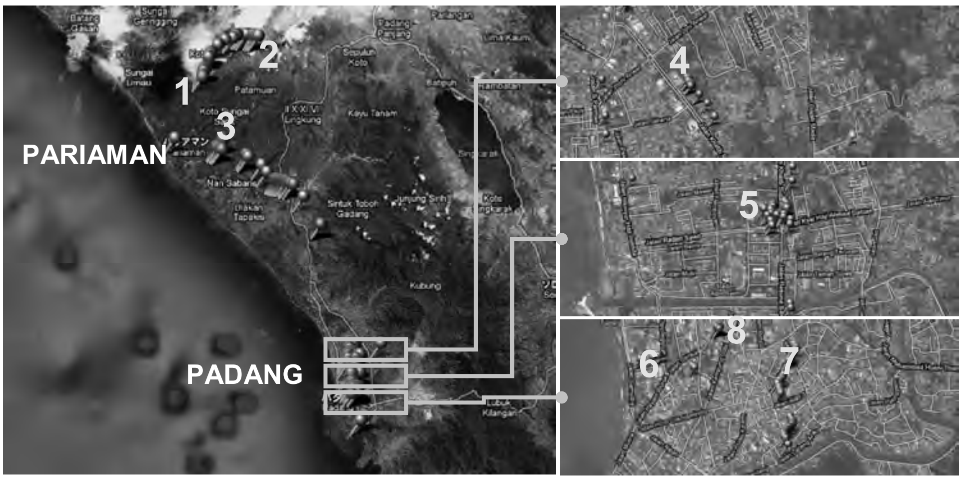

Figure 1. Damaged structures in Padang and Pariaman on Google map

Figure 2. Photos of damaged structures in Padang

BRIDGE

An assessment of 15 bridges in Padang (14 bridges) and Pariaman (1 bridge) found no significant damage from this earthquake (**Figure 3**). The types of bridges in the epicentral area are mainly truss or simple beam bridges (**Table 1**). The earthquake shaking did not cause any visible damage to the bridge, roadways even though they were near the epicenter of the earthquake. Damage to bridges was mainly caused by the failure of approach embankments and uneven settlement of piers. However, almost all bridges were open to traffic with speed limitation.

The most heavily-damaged bridge, Sitinurbaya bridge with concrete type (No. 1), underwent settlement of around 100 centimeters in backfill soil, and lateral deformation of ground due to liquefaction at the pier was observed. However, the pier was not affected by the ground movement. Sitinurbaya bridge was constructed to withstand the seismic motion and liquefaction. Mirang bridge shown in **Figure 4** (No. 4) was constructed as a parallel concrete beam structure. Lateral movement was not observed due to the stopper at the bearing. Settlement of about 20 centimeters at abutment was also observed at Mirang bridge (**Figure 5** (a)). Lateral movement was observed, as well as the collapse of electric lamp on the beam and displacement of 2 centimeters at the bridge's rubber bearing in **Figure 5** (b). The function of road could be maintained with such light damage.

At Bungus bridge (No. 8), damage was observed with over 10 centimeters of lateral movement due to the failure of the stopper, which should reduce lateral movement.

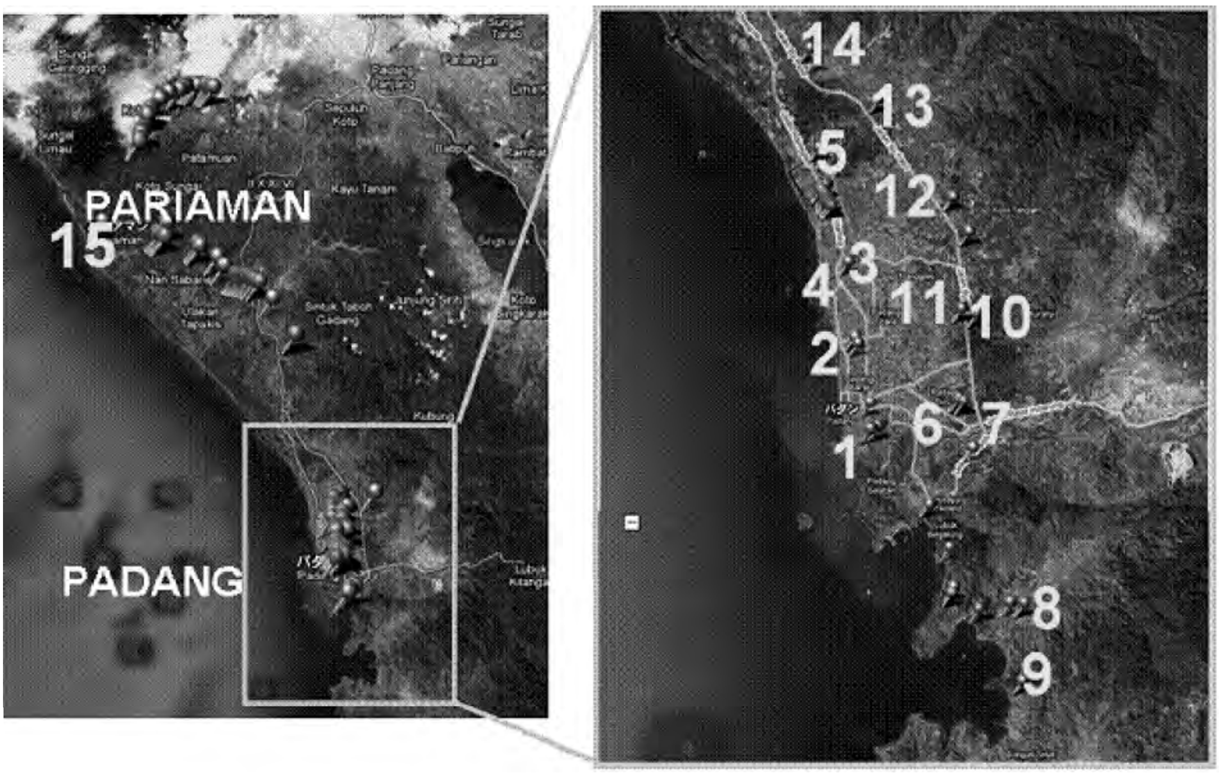

Figure 3. Surveyed bridges in Padang and Pariaman

Table 1. Surveyed bridges in Padang and Pariaman

No	name	type	damage
1	Sitinurbaya	concrete	100cm settle down
2	Purus	truss	10cm settle down
3	Mirang rail way	truss	10cm move at abutment
4	Mirang (a) (b)	concrete	(a) Lump, 2cm move (b) 20cm settle down
5	Muara Panja Linan	concrete	none
6	Lubeg 1	concrete	slightly crack
7	Lubeg 2	concrete	none
8	Bungus	truss	10cm lateral def.
9	Timbalun	truss	none
10	Kuranji	concrete	none
11	Kalawi	truss	Abutment push/ move
12	Sungai Sapih	concrete	Settle down/ 21.5cm lateral def.
13	Lubuk Minturun	concrete	15cm lateral def.
14	Kandis	concrete	Settle down back fill soil
15	Unknown	concrete	Pier crack

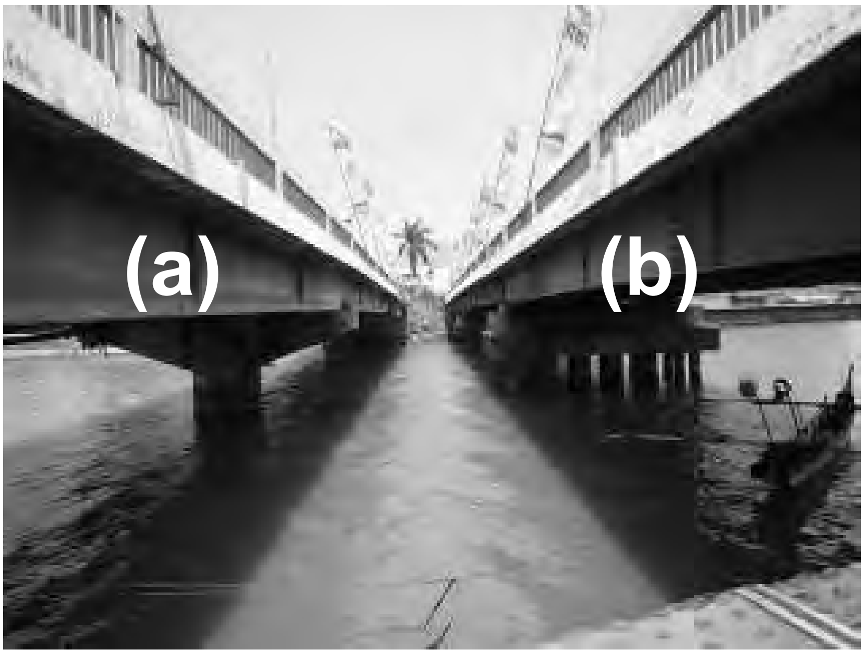

Figure 4. Mirang bridge (No. 4)

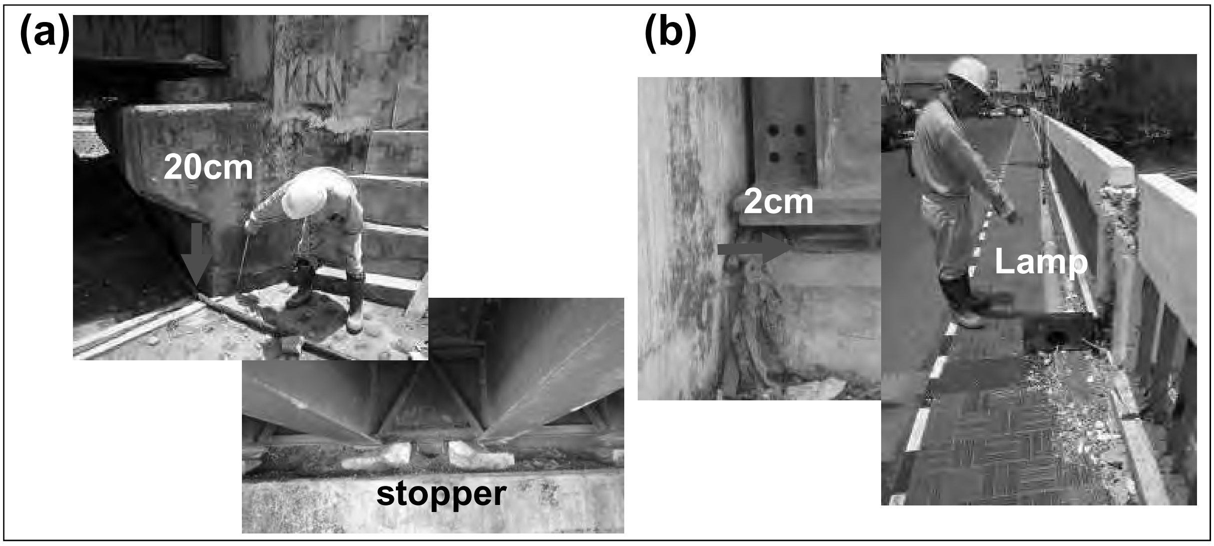

Figure 5. The damage of Mirang bridge (No. 4)

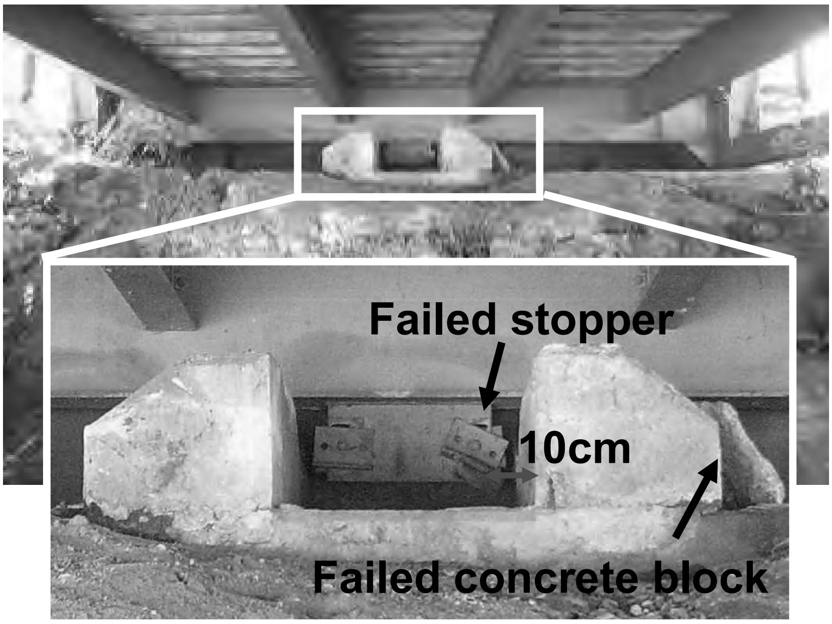

Figure 6. The damage of Bungus bridge (No. 8)

ROAD AND RAILWAYS

During the survey, roads were available to traffic in Padang. Heavy damage to roadways was observed in mountainous Pariaman area. Surface ruptures and embankment failures along the river and slope cut caused damage to roadways at several places in Padang and Pariaman. In particular, slope failures occured in places with volcanic sediments and volcanic soft rocks, such as in the mountainous Pariaman area.

Extensive slope failures were observed along the mountain roads. Some of these roadways were constructed on a thin ridge with soil surface along the river (**Figure 7**), with the failure points on the attacking side of river, where the foot of the slope had lost stability due to erosion by water flow.

Typically, the slope on the attack side may be unstable due to erosion of the foot.

Figure 8 shows a large slope failure of volcanic sediment. Since the volcanic sediment is a type of pumice soil, under water supply it can easily fail on the sliding surface of the clay layers. When the earthquake occurred, a wedding ceremony was being held on the sliding soil mass. This failure caused the deaths of 200 people attending the party. Some rock falls along the road side slope of volcanic geology at Southern Padang area were observed.

Embankment failures of roadways and rivers were also widespread in the area where the ground motions were high. The embankment failures at infilled sections of the roadways were quite severe. Since the ground was more resistant and ground shaking was mild, the translational movements did not cause the total collapse of the embankments. However, the approach embankments of bridges were severely damaged by settlement and lateral spreading of ground at their base, and access to these areas in Pariaman remains difficult.

The railway is normally used for leisure on the weekends. The railway was available on the first weekend after the earthquake. Slight failure of railway embankments was observed: however, they were completely recovered after the first leisure day (**Figure 9**).

Figure 7. Slope failure in Pariaman

Figure 8. Large Slope failure in Pariaman

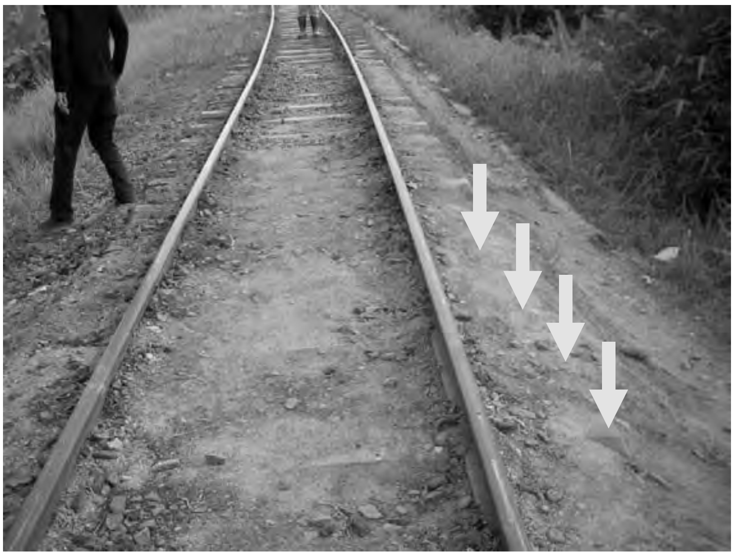

Figure 9. Embankment damage of railway

GEOTECHNICAL DAMAGE

The most remarkable geotechnical damage was caused by liquefaction and accompanying lateral movement. **Figure 10** shows the surveyed area with geotechnical damage along the sea side or the river in Padang and Pariaman.

Lateral flow and/or movement of over 10 centimeters caused damage to several houses on the affected ground at Point 1 (**Figure 11**). The liquefaction sites are located between the coastal line and a small river with ground layers of sand and a shallow ground water level in the marine deposit. Settlement of buildings and foundation damage due to liquefaction-induced ground failure and lateral spreading resulted in the collapse of masonry houses and/or severe cracking walls. The ground liquefaction caused damage due to non-uniform settlement of house foundations. Several houses needed to be supported by bar to prevent collapse due to the inclination of ground foundation (**Figure 11**). Permanent ground deformation caused extensive damage to the wide region.

Liquefaction was also observed at Points 2 and 3 along the river on the sandy ground (**Figure 12**). Sand boils was observed at Points 4 and 5. Since the ground in this region consisted of a sandy layer, liquefaction easily occurred due to intense shaking. Fortunately, no damage occurred at the sea port at Point 4.

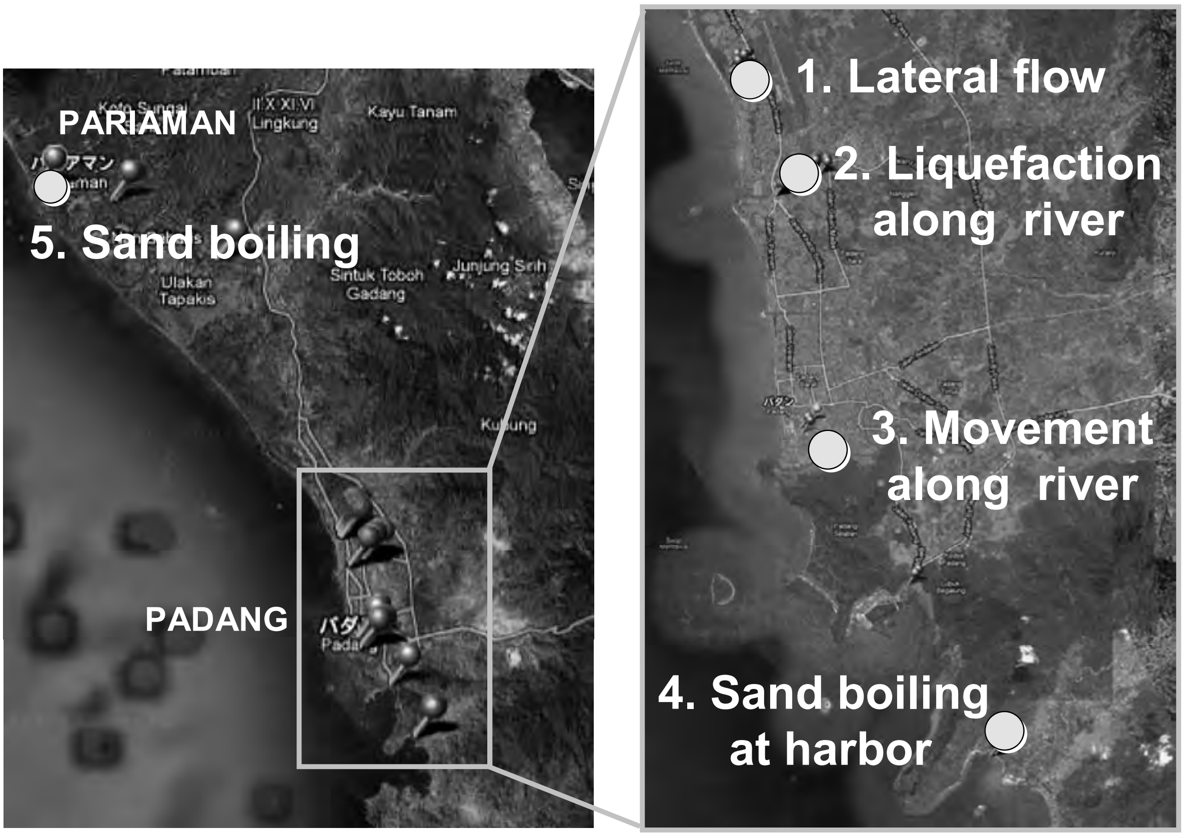

Figure 10. Geological damaged point

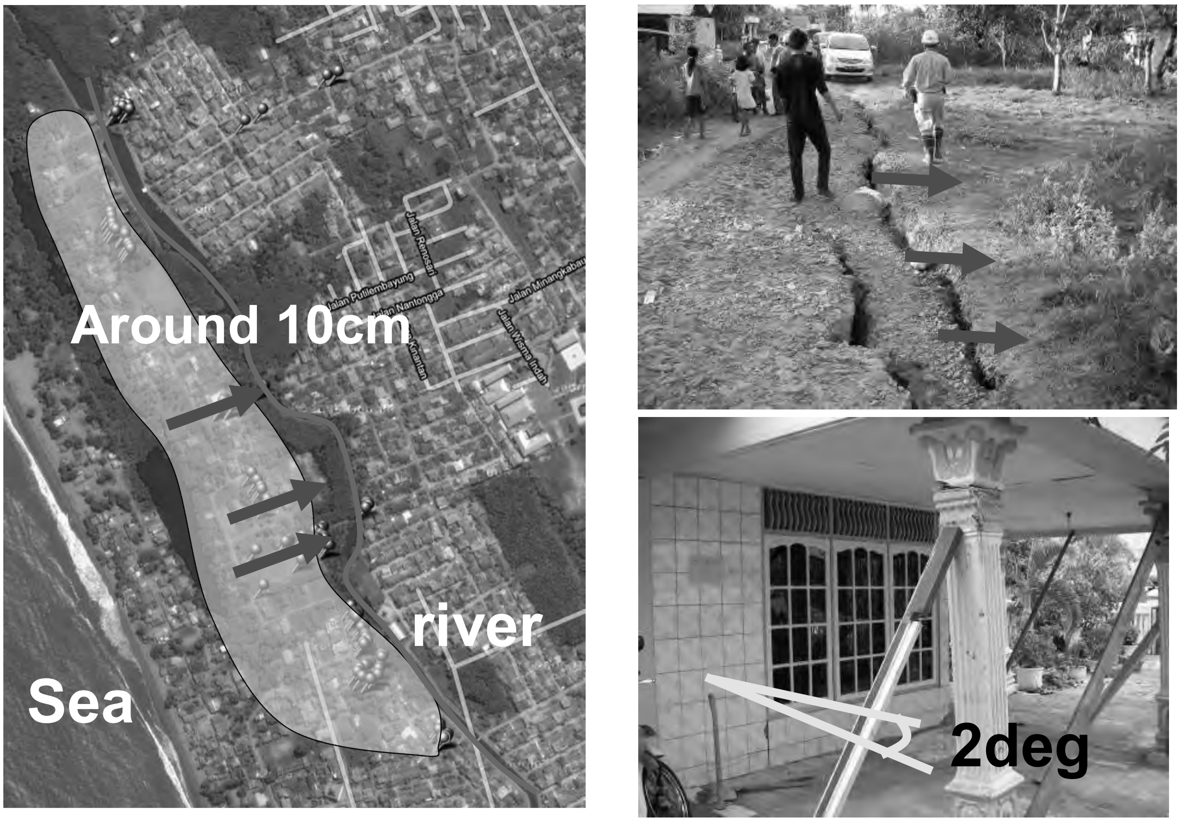

Figure 11. Lateral movement at Point 1 in Figure 10

Figure 12. Liquefaction at Point 2 in Figure 10

INDUSTRIES

Most industrial facilities are located in Southern Padang City. The earthquake did not cause any major damage to industrial facilites except some small scale damage from the inspection of some industrial plants (**Figure 13**).

Two ceramic isolators in electric power station were damaged but repaired two days later, whereas seven to ten days were needed to restore electric power in Padang city.

Two port facilities in Padang were observed. The cement plant and coal storage did not suffer from considerable damage and the economic loss due to the subsidence or lateral movement of coastal line was small. Liquefaction and slight damage at the ferry crossing were observed. No damage was found in the petroleum tank yard.

Figure 13. Industrial place and main industrial facilities

CONCLUSION

In order to prepare for the next event, the estimation and prediction of the risk associated with potential loss is necessary. Under that action, the seismically weak structures such as dwellings, public buildings and tsunami evacuation centers need to be retrofitted. Although damage due to tsunami was not observed in this earthquake, some tsunami evacuation buildings collapsed. Therefore, if tsunami damage occurred, people could not use the tsunami building for evacuation. Although the design codes for masonry and reinforced concrete were revised to include seismic design code in Indonesia, most of the houses do not comply with them. Therefore, it is important to improve the code enforcement system.

Earthquake damage to structures is often related to the local structural type, such as low-cost and affordable housing. The important things to apply such measurement are to consider the local acceptability and/or local availability in Indonesia.

ACKNOWLEDGMENT

This survey was conducted as a part of reconnaissance mission by the Japan Society of Civil Engineers (JSCE), Japan Association for Earthquake Engineering (JAEE) and Engineers Without Borders-Japan. All the members of the reconnaissance team provided me with all available materials, advice and information. I would wish like to express my sincere sympathy to the people affected by this devastating earthquake.

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Development of simulation exercise for emergency response headquarters focused on management by objectives

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ABSTRACT

Disaster Reduction and Human Renovation Institution (DRI) developed a simulation exercise for emergency response headquarters, management by objectives (SEMO), based on the result of several years of experience. The purpose of SEMO is to perform and learn how to manage an emergency response headquarters based on management by objectives. Participants of SEMO follow the whole situation of the crisis event from fragmented information, develop an action plan based on the strong objectives of the organization, and conduct strategic public relations to realize objectives. Management by objectives is one type of management thinking. The authors adapt this thinking to the style of disaster response as an organization based on disaster occurrences. Management by objectives consists of three principles: sharing the common operational picture with all concerned, developing action plan with strong objectives, and conducting strategic public relations. The basic model of SEMO consists of five stages; orientation, team meeting, exercise, simulated press conference, and evaluation. Exercise means the field participants practice management of emergency response headquarters according to management by objectives. To design a real exercise, the basic model is customized based on constrained conditions, characteristics of participants, the object of exercise, and time for exercise. In this case, a training course based on SEMO is conducted at DRI. As a result, participant satisfaction is improved, and participants can understand management by objectives. SEMO is an effective exercise for emergency response officials to learn how to manage an emergency response headquarters.

Keywords: simulation exercise, management by objectives, public relations, common operational picture, incident action plan

1. INTRODUCTION

Disaster Reduction and Human Renovation Institution (DRI) developed a simulation exercise for emergency response headquarters, management by objectives (SEMO), based on the result of several years experience (Kondo, 2009).

The purpose of SEMO is to perform and learn how to manage an emergency response headquarters based on management by objectives. Participants of SEMO follow the whole situation of the crisis event from fragmented information, develop an action plan based on the strong objectives of the organization, and conduct strategic public relations to realize objectives.

Management by objectives is one type of management thinking. The authors adapted this thinking to the style of disaster response as an organization based on disaster occurrences such as the Mid-Niigata Prefecture Earthquake (Kondo, 2006) and Hurricane Katrina (Kondo, 2007). Management by objectives consists of three principles: “sharing the common operational picture with all concerned”, “developing action plan with strong objectives”, and “conducting strategic public relations”.

The basic model of SEMO consists of five stages (Figure 1): “operation”, “team meeting”, “exercise”, “simulated press conference”, and “evaluation”. To design a real exercise, the basic model is customized based on constrained conditions, characteristics of participants, the object of exercise, and time for exercise. “Exercise” means the field participants practice management of emergency response headquarters according to management by objectives.

In this paper, outlines of three principles of management by objectives and an exercise based on SEMO are introduced.

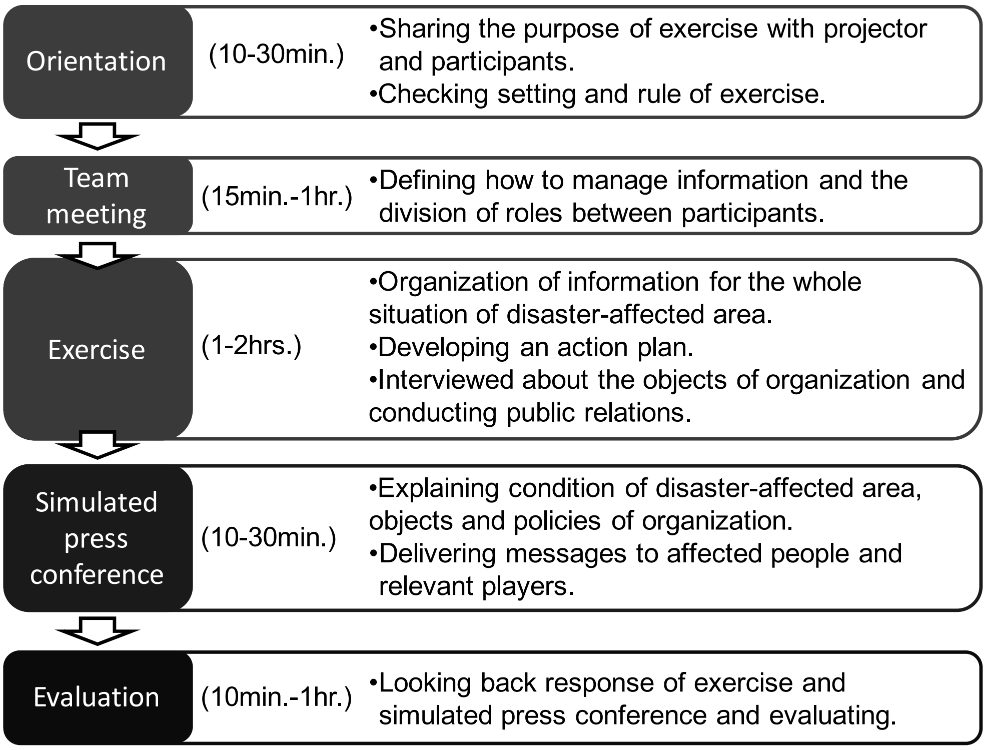

Figure 1: The basic model of SEMO

2. MANAGEMENT BY OBJECTIVES

2.1 Sharing the common operational picture with all concerned

"Information sharing" and "Sharing the common operational picture" are different concepts. "Sharing the common operational picture" is one of the main functions of emergency response headquarters. However, in reality quantified details of disaster affected area are only reported from relevant players. These reports are given to the emergency response headquarters for information sharing, but conditions of the affected area and emergency response information suggestions are more important. Therefore the headquarters should follow the whole situation from fragmented information such as the number of evacuees, staffing in shelters, and the damage level of hospitals.

Figure 2 shows the process for sharing the common operational picture. This process is modeled on disaster response on some local governments in Japan. Headquarters' officers derive internal environment such as "Food and drinking water are stored for only capacity of shelters" and "There is no system to connect shelters with emergency response headquarter", and external environment such as "It is highly possible that some affected people could not live in a shelter" and "It will be high temperature" from the combination of information. Combining internal environment and external environment, "Situation of shelters could not be completely figured out" is recognized by the lack of connection between shelters and emergency response headquarters, and it is easy to estimate that "There are not enough relief supplies at some shelters" because some affected people are not living in shelter and food and drinking water are stored for only the capacity of shelters. Also, because of high temperatures, "Enough drinking water should be obtained" and "There is high risk for food poisoning" become an assignment.

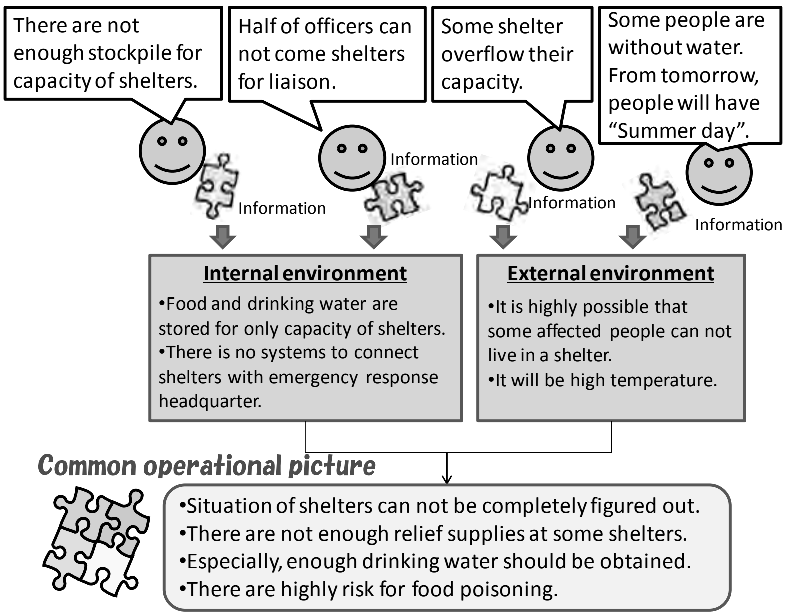

Figure 2: The process for sharing common operational picture

There are three reasons for sharing the common operational picture instead of the fragmented information. First, it is possible to make decisions from the point of view of all affected areas. Second, it is possible to respond proactively with future forecast. Third, it is easy to set objects and to gain understanding of the relevant players. This point will be covered in detail later.

2.2 Developing action plan with strong objectives

It is necessary that emergency response headquarters make an action plan with strong objectives. The action plan is composed of hierarchical attainable objectives and action policies for achieving objectives. "Objectives" makes clear the desired situation for the community with "by when", "who / where", and "how far emergency response headquarters improve". "Action policies" makes clear the direction the organization should go and promote relevant players for achieving objectives. According to the action plan, divisions within the organization should respond and coordinate with other divisions. Figure 3 shows an example of action plan. At first, operations divisions and field sites should consider strong objectives with future forecast from a global point of view, and following that action policies for achieving the objectives are decided.

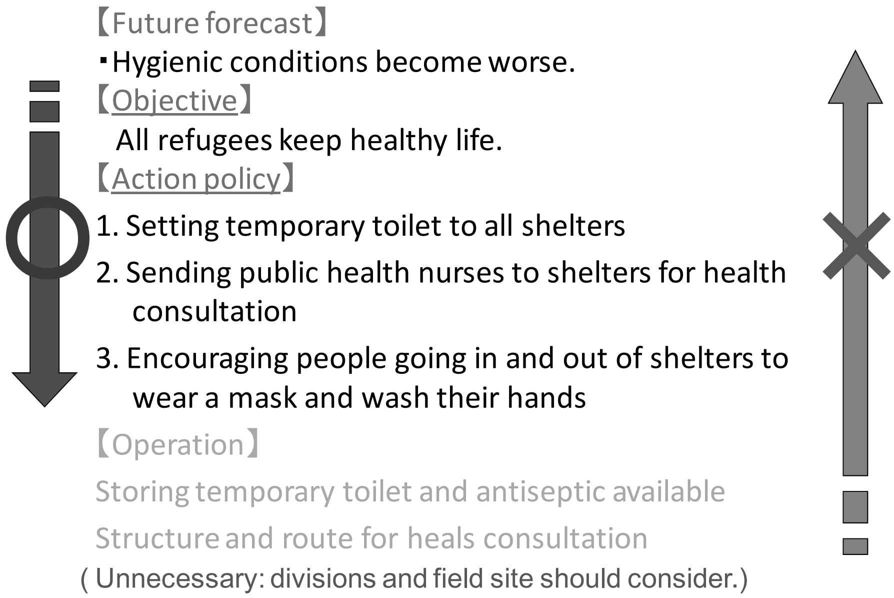

Figure 3: An example of action plan

For making the action plan, there are three points to pay attention to. Firstly, objects are measurable. Objects are clear by when and how far to do, not abstract such as "Quick recovery and reconstruction". Secondly, objects give operations for achieving objectives flexibility. Decision of operations is left to field site. Thirdly, expression of objects is short and to the point. This way, all members easily respond with discipline.

There are four advantages of making an action plan with strong objectives. First, affected people's reliability is improved because they can have a clear vision for the future. Second, action policies are made in top-down style, so staff members understand the position of operations and become a highly-motivated team. Third, it is possible to respond depending on the time and situation because operational decisions for achieving objectives are left to the field site. Forth, emergency response headquarters can get support from relevant organization such as public institution, press, volunteer, and companies because it is easy to understand the contents of action.

2.3 Conducting strategic public relations

A lot of press visit affected area in emergency situations, and emergency response headquarters of local governments become one of the places for press coverage. The more massive and highly concerned the crisis, the more difficult it is to do operations for achieving objectives under the public relations. For example, TV camera comes into the operations place, and the head of division who should lead operations is very busy with press coverage. Almost all local governments do not clearly position public relations as emergency operations and, as a result there is no professional public relations officer at emergency response headquarters in emergency situations.

“Strategic public relations” means putting out the information to citizens aggressively using press for achievement of objectives. This is different from passively answering questions from the press. For instance, when a fire breaks out in a factory due to earthquake, giving only the fact of notice to the press makes it difficult for recipients such as the press and audience to recognize the content and to understand and take actions. Therefore, the press asks about “What will people living around the fire do?” and “What will emergency response headquarter operate in the situation?” The answers for them depend on action plan with strong objectives. For example, it is necessary to know whether the fire on the factory spreads or hazardous materials catch fire for sharing common operational pictures. In the former case, no risk of burst and fire spread is delivered and the message of acting in a level-headed manner is put out. In the latter case, emergency response headquarters delivers a risk of second accident and puts out a message for evacuate procedures. Therefore, the contents of public relations are decided according to action plan and the public relations division and emergency response headquarter should respond together.

3. EXAMPLE OF TRAINING COURSE BASED ON SEMO

To evaluate the effectiveness of SEMO an exercise based on SEMO was conducted at DRI. The main target of this course was the disaster response officer of local government, the purpose was to learn management by objectives. Participants consisted of 13 people from prefectural governments and 26 people from municipality. Operators consisted of 3 people as designers of course and exercise, 5 people as the role of journalist, 3 people as the role of chief, and 3 people as logistic supporters. The length of this course was two days and optional orientation was conducted for applicants to understand the background for designing this course.

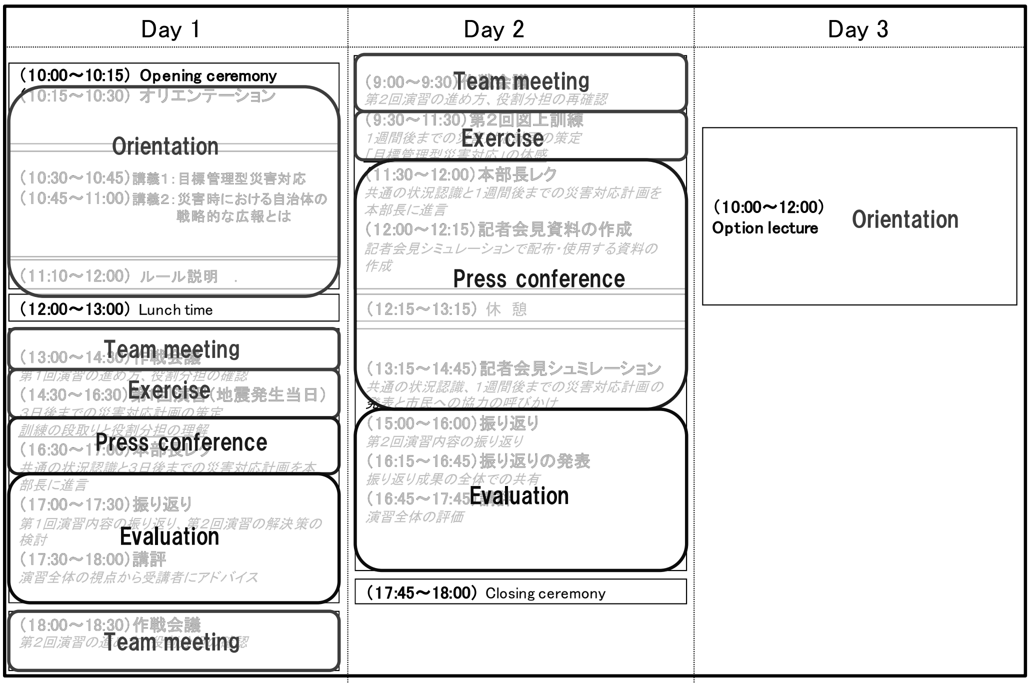

Figure 4: Curriculum of the training course at DRI

Three constrained conditions to design a curriculum are given as follows. First, participants come from all over the country because their area characteristics, frameworks of emergency response headquarter, and working method are different. Second, the rules of the exercise take time to understand. Third, two days are ensured for this training course.

Four concepts to design a curriculum according to constrained conditions are given as follows. First, forming three groups (one prefecture and two municipalities), a participant respond with other participants whose area characteristics, frameworks of emergency response headquarter, and their working method are similar. Second, participants are provided orientation to understand the settings and rules of exercise. Third, participants have time to decide arrangements for response in exercise with team meeting. Forth, the scenario for the exercise is a huge earthquake disaster and the exercise is conducted twice. The purpose of the first try for participants is to get used to the rules of the exercise. For the first exercise, the scenario assumes four hours have passed since the earthquake happened, and participants make an action plan with objectives for three days after the earthquake happened. For the second exercise, the purpose is for participants to realize management by objectives, and the scenario assumes three days have passed since the earthquake happened. Participants make an action plan with objectives for one week after earthquake happened. Figure 4 shows a curriculum of this training course based on these concepts to design. Participants repeat the sequence; “team meeting” “exercise” “simulated press conference” and “evaluation”, twice after first orientation.

In the training course, participants learned the purpose of this course and rules of the exercise with concentration through first team meeting, exercise, and evaluation. In the second exercise, participants respond according to management by objects based on this experience. For example, participants shared common operational pictures such as writing a situation on a post-it and putting the post-it on a whiteboard (Figure 5). They organized action policies according to problems in the affected area for making action plan with objectives (Figure 6), and they conducted strategic public relations using maps with journalists (Figure 7). If some participants had not yet understood the purpose of this training course, then the exercise designers coached them. During the simulated press conference, participants announced their own action plan with objectives one week after earthquake happened to journalists (Figure 8). After the simulated press conference, each group looked back at their response and made a presentation summarizing the content of their self-view according to the three principles of management by objectives. Finally, the roles of journalist and designers of exercise evaluated and commented on the response and presentation of participants.

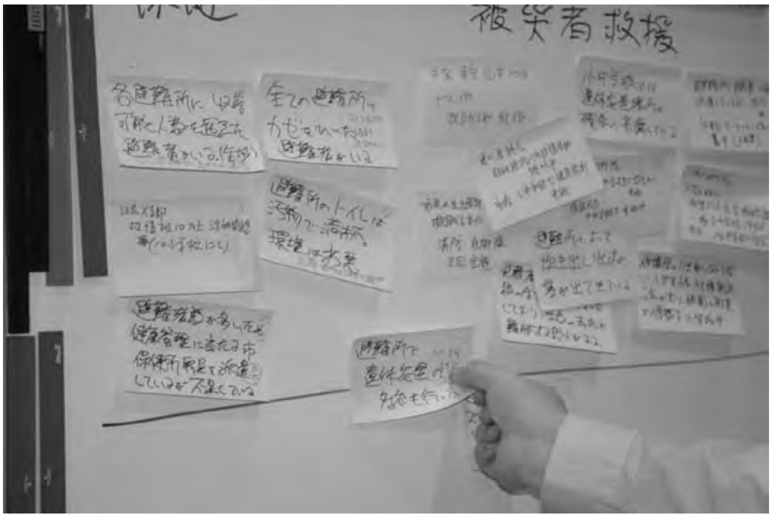

Figure 5: Scene of exercise (Sharing common operational picture)

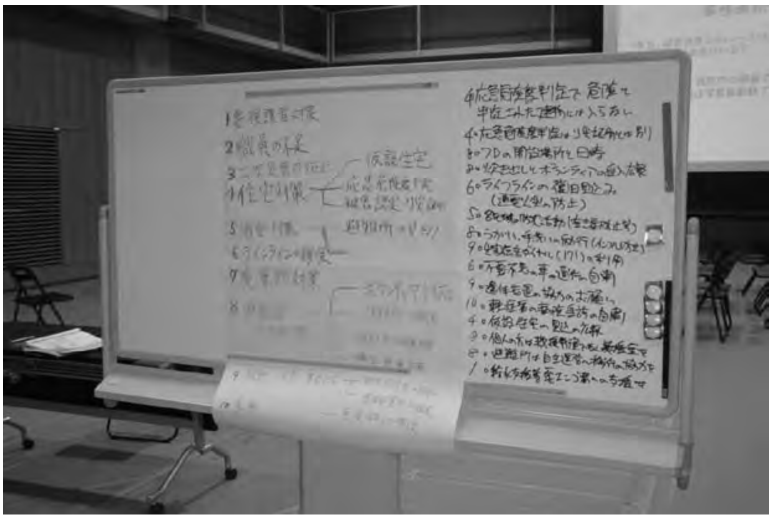

Figure 6: Scene of exercise (Developing action plan with strong objectives)

Figure 7: Scene of exercise (Strategic public relations)

Figure 7: Scene of simulated press conference

From the investigation on participant satisfaction, the average score was 90 out of 100 (quantity of response was 37 people). This shows that the participants were satisfied with the training course at DRI based on the trend that participants had lower satisfaction even when they failed but they were still satisfied with the training course.

The authors also surveyed awareness of management by objectives for achieving the purpose of SEMO. As a result, almost all participants answered they benefited greatly from this training course. Some participant replied that they understand the importance of management by objectives and will try to apply SEMO to their disaster training course of local government.

4. CONCLUSION

DRI developed a simulation exercise for emergency response headquarters, management by objectives (SEMO). In this paper, an outline of three principles of management by objectives and an exercise conducted at DRI based on SEMO were introduced. As a result, participant satisfaction was improved and participants could understand management by objectives. SEMO is an effective exercise for emergency response officials to learn how to manage an emergency response headquarters.

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地震災害における自治体間の相対的な地域災害対応力評価

Evaluation about the Capability of Community-Based Emergency Response against Earthquake Disaster among Municipalities

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This paper proposes a method for evaluation about the capability of community-based emergency response against earthquake disaster among municipalities and considers its implications for promoting risk communication between citizens and local governments. Evaluating the capability of community-based rescue works mitigating house collapse damages and the capability of community-based fire fighting works mitigating fire breaking in case of an earthquake of each municipality in the Tokyo metropolitan area, we conclude that this evaluation method is very effective to promote risk communication although there are some technical problems.

Keywords: *Earthquake Disaster, Capability of Community-Based Emergency Response, Municipality*

1．はじめに

(1) 研究の背景

自然災害のリスク軽減においては，行政・市民・企業等の多様な主体間のリスクコミュニケーションを促進し，自助誘導型のリスク回避と公助・共助の防災投資の最適化を図ることが重要である．

リスクコミュニケーションを促進するためには，適切な災害危険度評価を主体間で共有する必要があるが，現状では以下の点が課題といえる．

①災害危険度評価において重要な情報の多くは自治体が内部情報として所持しており，自治体によって災害危険度評価の取組みや開示の対応が異なる．

②災害危険度評価においては，ハザードと施設等の脆弱性や量がもたらす被害予測だけでなく，自治体やコミュニティレベルでの地域災害対応力を反映することが望まれるが，災害対応は多岐にわたるうえ，データの取得が困難なものもあり，精度の高い評価を行うことは一般的に困難である．

こうした課題に対応する一つの方向性として，一般的に公表されている汎用性の高いデータを用いた簡易な評価手法を開発して，自治体間の相対的な地域災害対応力の差異をある程度の精度で評価する方法があげられる．

例えば，地震による住宅倒壊の被害予測を住宅倒壊率や死亡者・負傷者数として示すだけでなく，地震発生直後において倒壊住宅に対する救助活動が可能な人数を示し，それが他の自治体に比べて高いか低いかを示すことで，一般市民にも地震時の被害状況がイメージしやすくなり、かつ、被害軽減のためにとるべき対策もイメージしやすくなるものと考える．

こうした地域災害対応力の自治体間の相対的評価の情報が，市民を含む各主体において共有されることで，リスクコミュニケーションを促進するきっかけづくりにつながるものと考える．そして，ひとたびリスクコミュニケーションが促進されれば，より正確な災害危険度評価のニーズが高まり，災害危険度評価そのものの精度を高め，開示が促進されていくという好循環のシナリオを想定することができる．

(2) 研究の目的と意義

以上をふまえ，本研究の目的は，地震災害における自治体間の相対的な地域災害対応力を，汎用性の高いデータを用いた簡易な手法を用いて評価し，その意義と課題を明らかにすることである．

本研究に関連する既往研究として，能島 [1)]は，ライフライン施設の地震時脆弱性に関して，「例えば，地震対策の数値目標を設定したり，物理的被害軽減策の限界を踏まえて，行き届かない部分を広域的な災害対応マネジメントで補完するなど，具体的方策の検討ができるようになる」との観点から，埋設管路施設の脆弱性指数を定義して，その簡易評価法を提案するとともに，上水道システムを対象として，全国の現状と経年変化について比較・考察している．

鈴木・林 [2)]は，広域連携を含んだ想定被災域における災害対応の全体的な最適化を実現するためには，南関東全体での災害の全体像をつかむ必要があるとの問題意識から，首都直下地震の外力条件（誘因）にさらされている社会条件（人口・世帯の量，重要社会基盤施設の量）を暴露指標とし，その計数的分析を行うことによって地震が社会に及ぼす潜在的影響を評価し，その暴露指標の地理的分布から，各地域の災害様相や災害対応上の課題について考察している．

ただし，既往研究では，広域的な自治体を単位として地震時の地域災害対応力を評価したものはなく，その点に本研究の意義がある．

(3) 研究の方法

a) 評価の対象とする地震被害

本研究では，評価の対象として，①住宅倒壊，②火災発生の2つの地震被害を対象とする．

b) 評価対象の自治体

評価対象の自治体は，埼玉県，千葉県，東京都，神奈川県（首都圏1都3県）の249市区町村（2009年4月現在）のうち，住宅・土地統計調査の建築年・構造別のデータが公表されている214市区町村とする(1)．

c) 地域災害対応力評価の流れ

地域災害対応力評価は，以下の3つのステップで行う．

・Step-1　被害の推定

首都圏1都3県の市区町村を対象として，地震ハザードに対する相対的な被害推定を行う．

・Step-2　初期対応力の推定

首都圏1都3県の市区町村を対象として，地震発生時の地域住民や自治体の相対的な初期対応力を推定する．

・Step-3　地域災害対応力の評価

Step-1およびStep-2をふまえて，首都圏1都3県の市区町村を対象として，地震ハザードに対する相対的な地域災害対応力を評価する．

d) 評価に用いる指標

①住宅倒壊，②火災発生それぞれに対する地域災害対応力について，汎用性の高いデータを用いた簡易な評価を行う観点から，評価に用いる指標は，図1，図2のとおりとする．

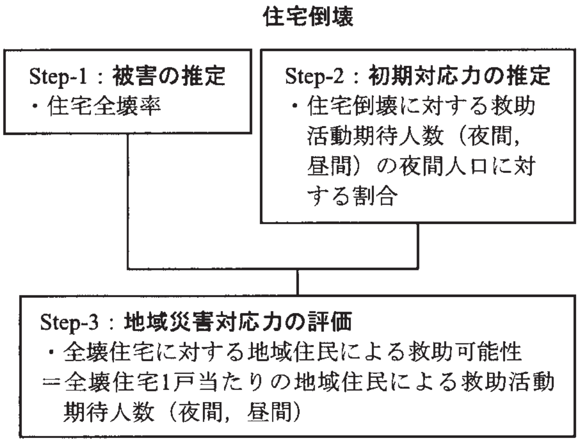


図1　地震時の住宅倒壊に対する地域災害対応力評価（簡易評価）の流れ

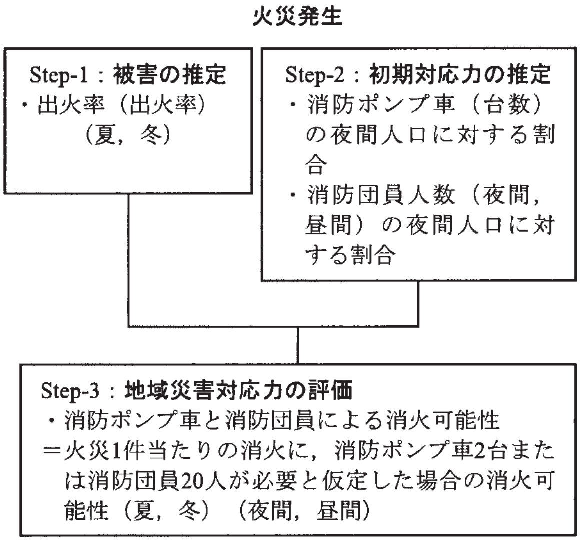


図2　地震時の火災発生に対する地域災害対応力評価（簡易評価）の流れ

2．Step-1　被害の推定

(1) 地震被害の簡易な推定方法

汎用性の高いデータを用いた簡易な地震被害の推定方法を以下に示す．

a) 地震ハザード

地震ハザードは，地震調査研究推進本部の「地震動予測地図」のデータを利用する．本研究では，期間50年，すべての地震「最大ケース」，地表の最大速度を用いた．

地震動予測地図の3次メッシュデータ（1km四方）は，防災科学技術研究所ウェブサイトから入手可能である．なお，以下の分析との関連で，3次メッシュデータを4次メッシュ（500m四方）に分割する．

b) 住宅倒壊

住宅倒壊の被害は，「建築年代別被害関数」を用いて，4次メッシュごとに「住宅全壊率」を推定する．

市区町村別の構造別・建築年代別の住宅総数は，住宅・土地統計調査データ（2003年）を用いる．構造の区別は，「木造」「防火木造」「RC+SRC造」「鉄骨造」「その他」の5区分である．

住宅・土地統計調査データは，統計局ウェブサイトから入手可能である．ただし，サンプル数が少なく構造別・築年別のデータがない市区町村は欠損として扱う(2)。

住宅・土地統計調査の市区町村単位の構造別・建築年代別の住宅総数データを4次メッシュに割り当てる。その際，メッシュ別の人口に応じてデータを割り当てる(3)．

人口データは，国勢調査のメッシュデータ（2005年）を用いる．国勢調査の4次メッシュデータは，統計情報研究開発センターから購入可能である．

「建築年代別被害関数」は，村尾・山崎式[3]を用いる．

メッシュ単位の全壊戸数を市区町村ごとに集計し，「住宅全壊率」を算出する．

c) 火災発生

火災発生の被害は，消防法施行令の用途別の「建物用途別の出火確率」を用いて，4次メッシュごとに「出火率」を推定する．

出火確率の算定には，火災予防審議会・東京消防庁[4]の方法を用いて，地震動強度と建物用途から算出する(4)．

建物用途別の建物総数は，事業所・企業統計調査データ（2006年）を用いる．事業所・企業統計調査データの4次メッシュデータは，統計情報研究開発センターから購入可能である．

「建物用途」は，事業所・企業統計調査データを消防法施行令の用途に読み替えて用いる(5)．

火災予防審議会・東京消防庁[4]の「用途別の火気器具・電気器具からの出火率」では，「夏昼」と「冬夕」の場合が明示されている．そこで，メッシュごとの出火率を，夏の昼と冬の夕それぞれの季節と時間で算定する．

メッシュ単位の火災発生戸数を市区町村ごとに集計し，夏の昼と冬の夕それぞれの「出火率」を算出する．

(2) 地震被害の推定結果

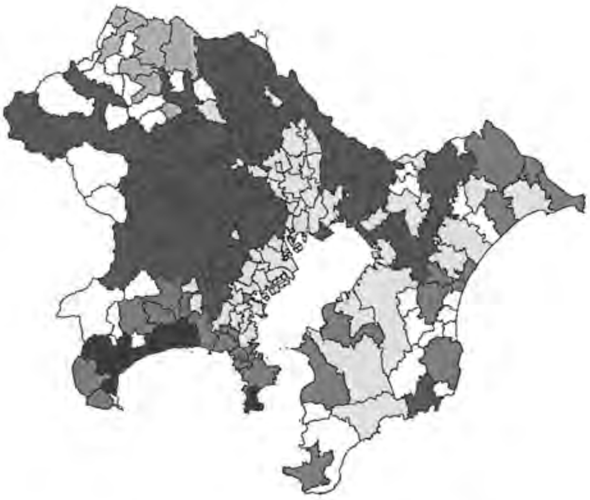
地震被害の推定結果は，以下のとおりである．

a) 住宅倒壊

住宅全壊率をみると（図 3），全壊率 20%以上の市区町村が全体の約 4%，全壊率 10%以上 20%未満が約 10%，合わせて全壊率 10%以上が 14%となっている．

住宅全壊率の高い市区町村は，神奈川県の太平洋側に集中している．これは東海地震の地震動予測の影響が顕著に出ているものと考えられる．

千葉県の太平洋側も住宅全壊率の高いエリアが多い．



	数	割合
1%未満	7	2.8%
1%以上5%未満	121	48.6%
5%以上10%未満	53	21.3%
10%以上20%未満	24	9.6%
20%以上	9	3.6%
評価対象外	35	14.1%
市区町村計	249	100.0%

図 3　住宅全壊率

b) 火災発生

①夏の昼の出火率

夏の昼の出火率をみると（図 4），出火率 0.03%以上の市区町村が全体の約 4%程度となっている．

夏の出火率が高い市区町村は，神奈川県の太平洋側に多い。

東京都や横浜市の都心部の区も出火率が高い．

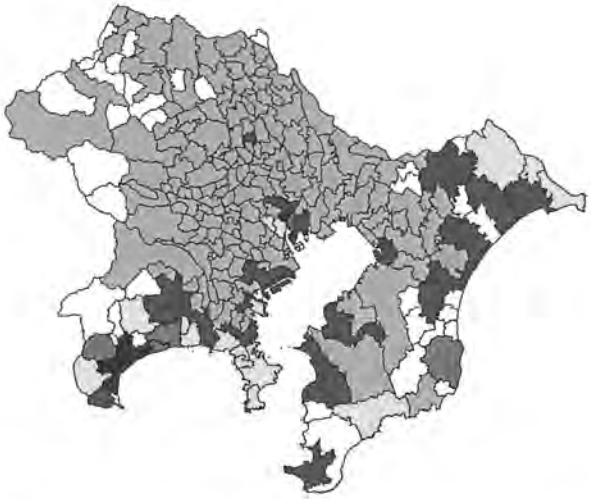
②冬の夕の出火率

冬の夕の出火率をみると（図 5），出火率被害率 0.03%以上の市区町村が全体の約 14%となっている．

冬の夕の出火率と夏の昼の出火率では冬のほうが高いが、市区町村間の相対的なリスクはあまり変わらない．

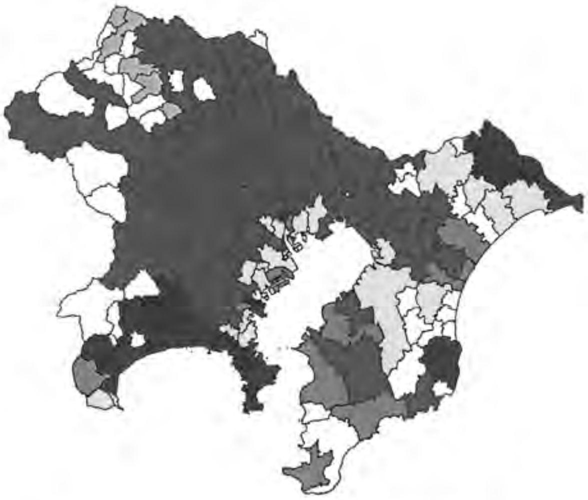
出火率が特に高い市区町村は，神奈川県の太平洋側，千葉県の太平洋側に多い．

東京都、川崎市、横浜市の都心部も出火率が高い．



夏	数	割合
0.01%未満	160	64.3%
0.01%以上0.02%未満	28	11.2%
0.02%以上0.03%未満	16	6.4%
0.03%以上0.04%未満	5	2.0%
0.04%以上	5	2.0%
評価対象外	35	14.1%
市区町村計	249	100.0%

図 4　出火率（夏の昼）



冬	数	割合
0.01%未満	5	2.0%
0.01%以上0.02%未満	154	61.8%
0.02%以上0.03%未満	19	7.6%
0.03%以上0.04%未満	11	4.4%
0.04%以上	25	10.0%
評価対象外	35	14.1%
市区町村計	249	100.0%

図 5　出火率（冬の夕）

３. Step-2　初期対応力の推定

(1) 初期対応力の簡易な推定方法

汎用性のある統計データを用いて，地域住民や自治体消防による初動期の災害対応力（倒壊建物からの救助作業，火災消火活動）を推定する手法を以下に示す.

a) 救助活動期待人数

地域住民による倒壊建物からの救助能力を構成する要素として，以下のものがあげられる.

・人的要因：人口，年齢，性別など
・活動要因：組織，訓練など
・資機材要因：資機材の有無，量など

本研究では，「人的要因」が最も影響が大きい要素であると仮定して，「人的要因」のみを評価する.

阪神・淡路大震災での実態をもとに，各市区町村において救助活動を実施することが期待される人数（定住者のみ）を算出して，その人数が夜間人口に占める割合（以下，「救助活動期待人数割合」）を地域住民の災害対応力とみなす.

阪神・淡路大震災における住民の救助活動実施状況は，火災予防審議会・東京消防庁 [5]を参考に，表 1 のとおりとする．なお，この活動実施状況は以下の特徴をもつ.

・30 代～50 代の男性は，救助活動実施率が高い.
・70 歳以上の高齢者は，活動実施率が低い.

ただし，阪神・淡路大震災の活動実施率は，夜間時の状況での実績である，夜間と昼間では在宅率が異なるため，昼間については，性別の在宅率と活動実施率を考慮して活動期待人数を算出する.

①夜間の活動期待人数

各市区町村の国勢調査（2005 年）の年齢構成別人口から，阪神・淡路大震災の活動実施率をもとに，年代別の夜間の活動期待人数を算出する．年代別の夜間の救助活動期待人数の合計が夜間人口に占める割合を夜間の救助活動期待人数割合とする.

国勢調査（2005 年）の市区町村別データは，統計局ウェブサイトより入手可能である.

②昼間の活動期待人数

夜間の活動期待人数を，年代別・性別活動比率をもとに男女別に振り分け，年代別・性別の活動実施率を算出する.

各市区町村の国勢調査（2005 年）の年齢構成別・性別の従業・通学状況をもとに，「従業も通学もしていない」または「自宅で従業」を「在宅」とみなし，年齢構成別・性別の在宅人口を算出する.

表 1　住民の救助活動実施状況の想定

年代	年代別実施率	性別活動比率 男性:女性
10代	-	-
20代	22.8%	0.76 : 0.24
30代	22.9%	0.72 : 0.28
40代	29.8%	0.72 : 0.28
50代	22.8%	0.63 : 0.37
60代	19.1%	0.74 : 0.26
70代	12.9%	0.75 : 0.25
全年代	22.0%	

年齢構成別・性別の在宅人口から、年代別・性別の活動実施率をもとに，昼間の活動期待人数を算出する[6].
年代別の昼間の救助活動期待人数の合計が夜間人口に占める割合を昼間の救助活動期待人数割合とする.

b) 消防ポンプ車の台数

各市区町村の消防ポンプ車の保有台数は，全国消防長会のウェブサイトで提供されているデータ（2008 年、消防本部別）を利用する[7].

消防本部（消防団）が複数の市区町村で構成されている場合は、夜間人口で案分して，それぞれの市区町村の保有台数とみなす.

c) 消防団員人数

一般住民の初期消火活動については，被害推定の「出火率」に反映されていると仮定して考慮しないこととし，消防団員による初期消火能力のみを考慮する.

消防団員人数は，全国消防長会ウェブサイトで提供されている「定員」のデータ（消防本部別，2008 年）を利用する[7].

ただし，消防団員人数（定員）は夜間人口を前提にしているため，昼間の消防団員人数は，在宅率に比例して減少すると仮定し，昼間の活動期待人数の算出で用いた在宅率で低減する.

消防本部（消防団）が複数の市区町村で構成されている場合は，夜間人口で案分して，それぞれの市区町村の消防団員人数とみなす.

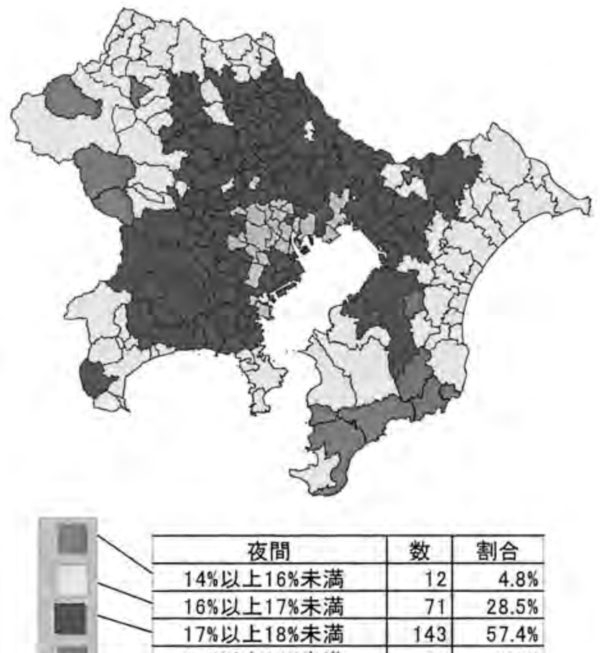
(2) 初期対応力の推定結果

a) 救助活動期待人数割合

①夜間の救助活動期待人数割合

夜間の住宅倒壊に対する救助活動期待人数割合をみると（図 6），17%未満の市区町村が全体の約 34%となっている.

夜間の救助活動期待人数は，東京都心部からの距離と関係があり，距離が遠いほど低い傾向がみられる.



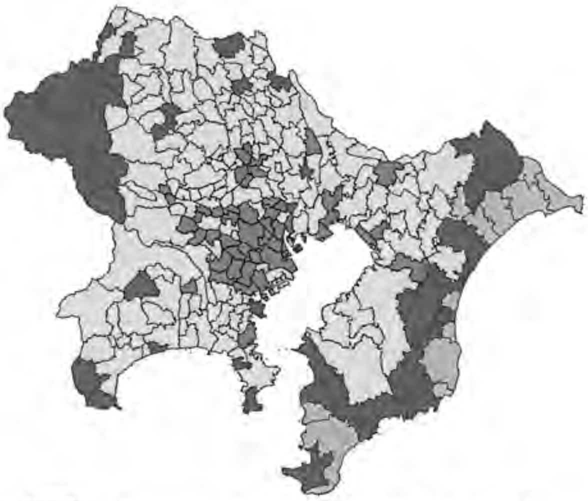
夜間	数	割合
14%以上16%未満	12	4.8%
16%以上17%未満	71	28.5%
17%以上18%未満	143	57.4%
18%以上20%未満	23	9.2%
市区町村計	249	100.0%

図 6　救助活動期待人数割合（夜間）

②昼間の救助活動期待人数割合

昼間の住宅倒壊に対する救助活動期待人数割合をみると（図 7），4%未満の市区町村が全体の約 18%となっている．

昼間の救助活動期待人数は，東京都心部からの距離と関係があり，市区町村間の相対的な比較では，夜間とは反対に距離が遠いほど高い傾向がみられる．

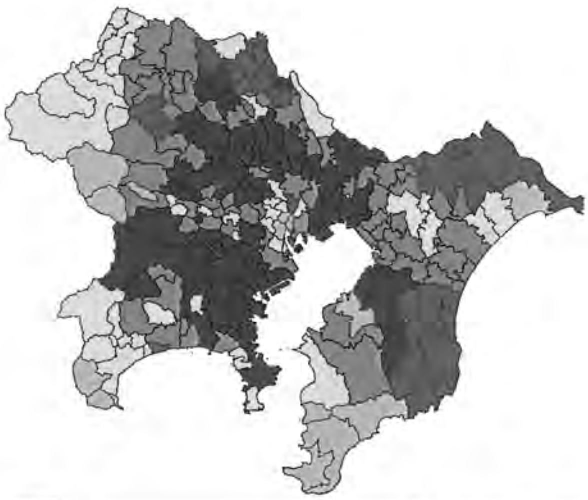


昼間	数	割合
3%以上4%未満	46	18.5%
4%以上5%未満	152	61.0%
5%以上6%未満	39	15.7%
6%以上7%未満	12	4.8%
市区町村計	249	100.0%

図 7　救助活動期待人数割合（昼間）

b) 消防ポンプ車（台数）の夜間人口に対する割合

消防ポンプ車の夜間人口に対する割合をみると（図 8），0.004%未満の市区町村が全体の約 35%と多い．



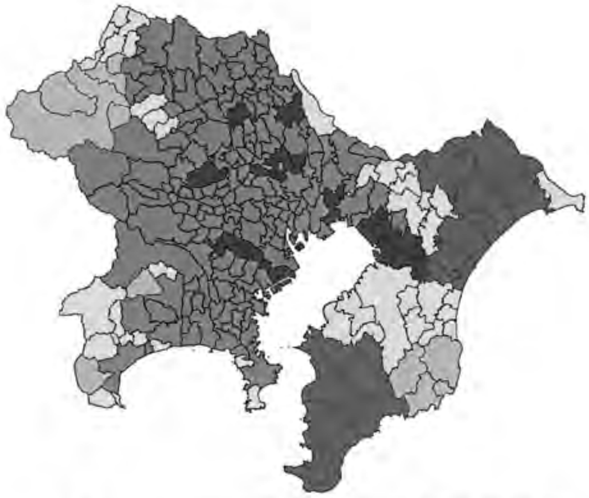
	数	割合
0.004%未満	87	34.9%
0.004%以上0.006%未満	72	28.9%
0.006%以上0.0008%未満	40	16.1%
0.008%以上0.01%未満	35	14.1%
0.01%以上	15	6.0%
市区町村計	249	100.0%

図 8　消防ポンプ車（台数）の夜間人口に対する割合

c) 消防団員人数の夜間人口に対する割合

①消防団員（定員）の夜間人口に対する割合

消防団員（定員）の夜間人口に対する割合をみると（図 9），0.5%未満の市区町村が全体の約 72%となっている．

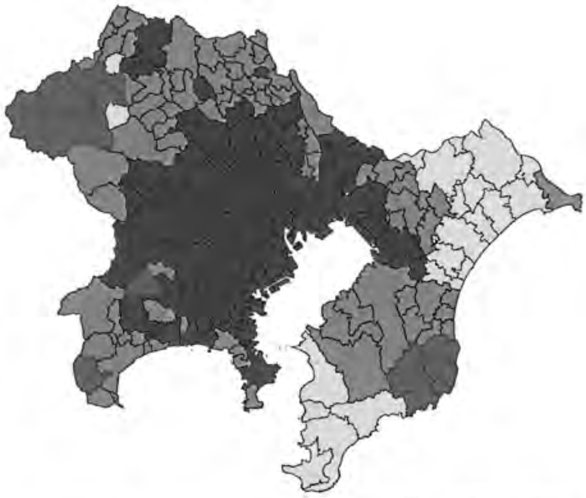


定員	数	割合
0.1%未満	20	8.0%
0.1%以上0.5%未満	159	63.9%
0.5%以上1%未満	39	15.7%
1%以上2%未満	20	8.0%
2%以上3%未満	11	4.4%
市区町村計	249	100.0%

図 9　消防団員（定員）の夜間人口に対する割合

②消防団員（昼間）の夜間人口に対する割合

昼間時の消防団員人数の夜間人口に対する割合をみると（図 10），0.1%未満の市区町村が全体の約 56%となっている．



昼間	数	割合
0.1%未満	139	55.8%
0.1%以上0.5%未満	80	32.1%
0.5%以上1%未満	21	8.4%
1%以上1.5%未満	9	3.6%
市区町村計	249	100.0%

図 10　消防団員（昼間）の夜間人口に対する割合

４．Step-3　地域災害対応力の評価

(1) 地域災害対応力の評価方法

「地域災害対応力の評価」の新しい評価指標として以下の指標を提案する．

a) 全壊住宅に対する地域住民による救助可能性

- **全壊住宅1戸当たりの地域住民による救助活動期待人数**（夜間，昼間別）
＝「救助活動期待人数」（夜間，昼間）／「全壊住宅戸数」

本指標により，全壊住宅1戸当たりの救助活動期待人数が相対的に少ない市区町村については，救助活動期待人数の増加か，住宅の耐震化を進める必要があることを示すことができる．

なお，全壊住宅からの救助活動に必要な地域住民の人数は，全壊住宅の生き埋め・閉じ込め率，全壊住宅1戸当たりの要救助人数，建物の被害状況，救助にかけられる時間などによって異なり，一概に決めることができない．本稿では，発災直後の初期対応として，全壊住宅1戸当たりの救助には，生き埋め・閉じ込めが事前に確認できず実際には要救助者がいない場合や閉じ込めの程度が軽い場合も含めて，平均して地域住民が5人は必要であると仮定して救助可能性の目安とする[(8)]．

b) 消防ポンプ車と消防団員による消火可能性

- **火災1件当たりの消防ポンプ車の台数**（夏，冬別）
＝「消防ポンプ車台数」／「火災発生件数」（夏，冬）

- **火災1件当たりの消防団員の数**（夏の夜間，昼間別および冬の夜間，昼間別）
＝「消防団員人数」（夜間，昼間）／「火災発生件数」（夏，冬）

火災１件当たりの消火に，消防ポンプ車2台または消防団員20人が必要と仮定して，消火可能性を評価することで，「ポンプ車が１件当たり2台以下でも，消防団員と協力すれば対応可能性がある市区町村」，「ポンプ車あるいは消防団員を増加しないと対応できない市区町村」を示すことができる．

なお，火災発生件数は，「夏の昼」と「冬の夕」のみを算出しており，夏の夜間，冬の昼間・夜間に正確に対応していないが，ここではデータの制約上，火災発生件数については夜間と昼間の区別は厳密にせず，夏は「昼」，冬は「夕」の値を用いることにする[(9)]．

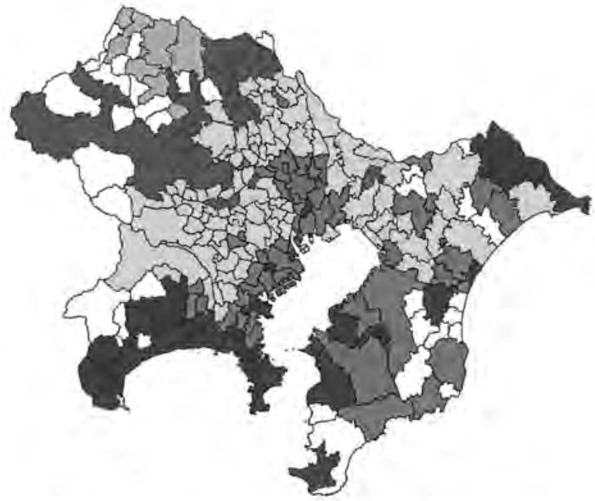
(2) 地域災害対応力の評価結果

a) 全壊住宅に対する地域住民による救助可能性

夜間における救助活動期待人数の全壊住宅 1 戸当たりの人数をみると（図 11），5 人未満の市区町村が全体の約 13%，5 人以上 10 人未満が約 20%となっている．

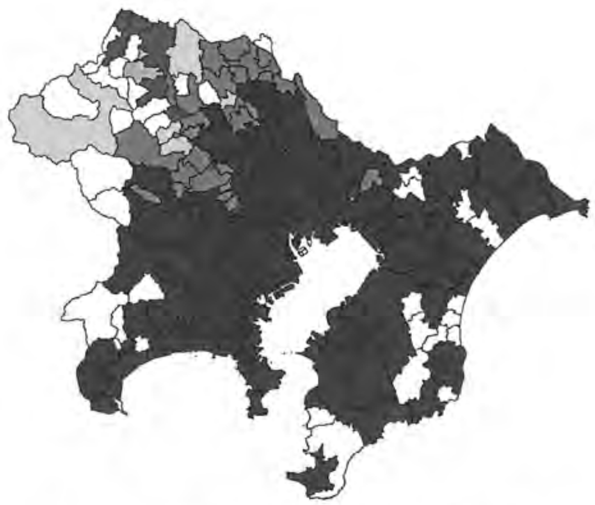
昼間における救助活動期待人数の全壊住宅 1 戸当たりの人数をみると（図 12），5 人未満の市区町村が全体の約 70%となっている．

夜間は，全壊住宅 1 戸当たりの要救助人数が昼間よりも多いと想定できるため，救助活動期待人数の全壊住宅 1 戸当たりの人数は，夜間のほうが昼間より多く必要であると想定できる．しかし，仮に，全壊住宅 1 戸当たり



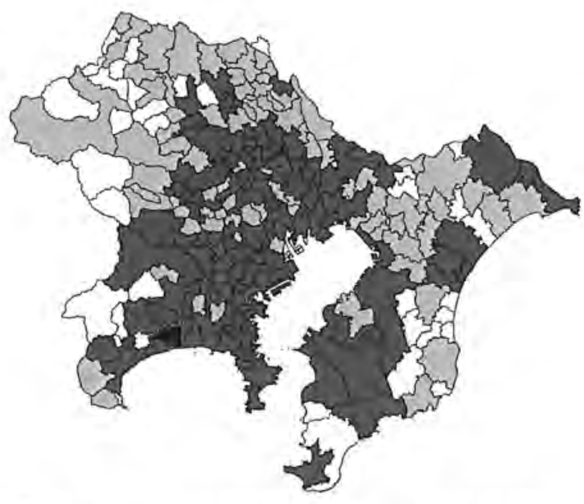
夜間	数	割合
5人未満	33	13.3%
5人以上10人未満	49	19.7%
10人以上20人未満	94	37.8%
20人以上50人未満	31	12.4%
50人以上	7	2.8%
評価対象外	35	14.1%
市区町村計	249	100.0%

図 11　救助活動期待人数の全壊戸数 1 戸当たりの人数（夜間）



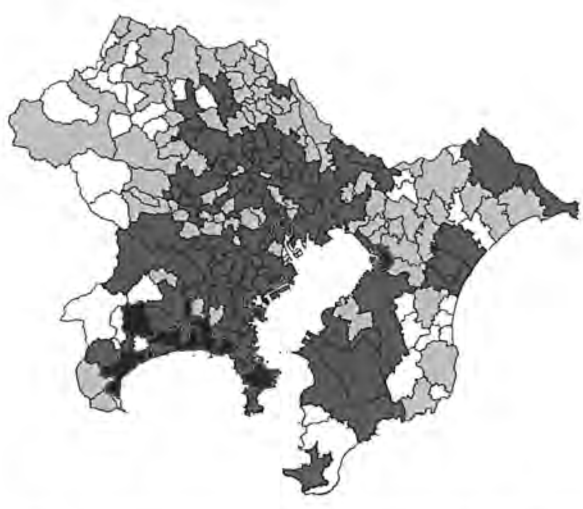
昼間	数	割合
5人未満	175	70.3%
5人以上10人未満	28	11.2%
10人以上20人未満	5	2.0%
20人以上50人未満	5	2.0%
50人以上	1	0.4%
評価対象外	35	14.1%
市区町村計	249	100.0%

図 12　救助活動期待人数の全壊戸数 1 戸当たりの人数（昼間）



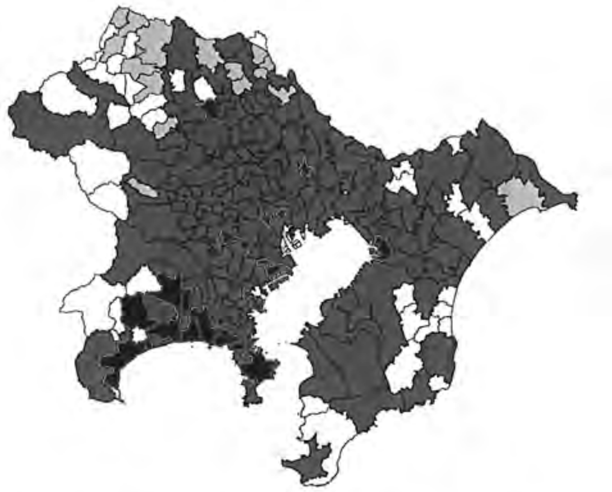
夏の夜間	数	割合
ポンプ車＋消防団員が不足	2	0.8%
対応可能なポンプ車＋消防団員あり	129	51.8%
対応可能なポンプ車2台以上あり	83	33.3%
評価対象外	35	14.1%
市区町村計	249	100.0%

図 13　出火建物１戸当たりの消防ポンプ車と消防団員の数と対応力（夏の夜間）



夏の昼間	数	割合
ポンプ車＋消防団員が不足	16	6.4%
対応可能なポンプ車＋消防団員あり	115	46.2%
対応可能なポンプ車2台以上あり	83	33.3%
評価対象外	35	14.1%
市区町村計	249	100.0%

図 14　出火建物１戸当たりの消防ポンプ車と消防団員の数と対応力（夏の昼間）



冬の夜間	数	割合
ポンプ車＋消防団員が不足	21	8.4%
対応可能なポンプ車＋消防団員あり	178	71.5%
対応可能なポンプ車2台以上あり	15	6.0%
評価対象外	35	14.1%
市区町村計	249	100.0%

図 15　出火建物１戸当たりの消防ポンプ車と消防団員の数と対応力（冬の夜間）

冬の昼間	数	割合
ポンプ車＋消防団員が不足	82	32.9%
対応可能なポンプ車＋消防団員あり	117	47.0%
対応可能なポンプ車2台以上あり	15	6.0%
評価対象外	35	14.1%
市区町村計	249	100.0%

図 16　出火建物１戸当たりの消防ポンプ車と消防団員の数と対応力（冬の昼間）

の救助に必要な地域住民の人数が，夜間は昼間の 2 倍（昼間 5 人，夜間 10 人）であると想定しても，全壊住宅 1 戸当たりの救助活動期待人数が少ない市区町村は，夜間に比べて昼間のほうが多いことがわかる[10]．

b) 消防ポンプ車と消防団員による消火可能性

夏の夜間におけるポンプ車および消防団員の出火建物 1 戸当たりの対応力をみると（図 13），対応可能なポンプ車が 2 台以上の市区町村が全体の約 33%，対応可能なポンプ車＋消防団員がいる市区町村は約 52%となっている．

夏の昼間におけるポンプ車および消防団員の出火建物 1 戸当たりの対応力をみると（図 14），対応可能なポンプ車が 2 台以上の市区町村が全体の約 33%，対応可能なポンプ車＋消防団員が存在する市区町村は約 46%となっている．

冬の夜間におけるポンプ車および消防団員の出火建物 1 戸当たりの対応力をみると（図 15），対応可能なポンプ車が 2 台以上の市区町村が全体の約 6%と少ないが，対応可能なポンプ車＋消防団員が存在する市区町村は約 72%となっている．

冬の昼間におけるポンプ車および消防団員の出火建物 1 戸当たりの対応力をみると（図 16），対応可能なポンプ車が 2 台以上の市区町村が全体の約 6%，対応可能なポンプ車＋消防団員が存在する市区町村は約 47%となっている．

逆に，ポンプ車＋消防団員が不足する市区町村が約 33%となっており，冬の昼間に対応力が弱い市区町村が多いことがわかる．

５．結論

地震災害に関する自治体間の相対的な地域災害対応力評価の意義と課題を以下にまとめる．

(1) 意義

・地震時の地域災害対応力評価について，一般的に公表されている汎用性の高いデータを用いた簡易な評価手法を考案して，自治体間の相対的な差異を明らかにした．特に，新しく提案した指標は，地震時の災害対応力の可能性と限界を示すものであり，一般市民にも地震時の被害状況をイメージしやすく，かつ，被害軽減のためにとるべき対策もイメージしやすい指標となっている．

・一般的に昼間よりも夜間に大地震が発生する場合のほうが被害が大きくなると認識されているが，発災直後の地域災害対応力を考慮すると，災害対応を担う住民が不足する昼間の評価が低い自治体が多いことが示唆された．

・地域災害対応力評価の結果をみると，各自治体の被害想定および初期対応力の状況に応じて，地域災害対応力を強化する（例えば，救助期待活動人数を増加させる，ポンプ車や消防団員を増加するなどの）対策で地震被害の軽減がある程度期待できる自治体と，ハザードに対する被害そのものを軽減する（例えば，住宅の耐震性や耐火性を高めるなどの）対策を進めない限り，地震被害の大幅な軽減は見込めない自治体があることがわかる．こうしたことが自治体間の相対的な評価としてわかるだけでも，地震被害軽減に向けたリスクコミュニケーションに大きく寄与するものと考える．

(2) 課題

・本研究で提案した評価手法は，入手可能なデータにもとづく簡易な評価方法であるため，評価の誤差も大きくなることが見込まれる．しかし，評価の誤差を定量的に示すことは困難である．そこで，評価の前提条件・仮定，具体的な評価方法を適切に開示したうえで評価結果を公表することが重要となる．

・関連して，評価の諸条件（パラメーター）を自由に変えて結果を簡便に比較できるようなシステムの構築が望まれる．

・住宅倒壊の被害推定については，「全壊」だけではなく，「圧壊」を対象にすると，救助の必要性がより明確になる可能性がある．また，全壊（圧壊）住宅戸数をもとに要救助人数を推定することで，救助活動に必要な人数の評価がより明確になるものと考える．これらは今後の研究課題としたい．

・地域災害対応力評価では，データの入手可能性を考慮して評価項目を限定した．本来は，もっと多様な項目を評価すべきであり，今後の研究課題としたい[11]．

謝辞

本研究は，東京大学公共政策大学院，株式会社損害保険ジャパン，株式会社損保ジャパン・リスクマネジメント（現 NKSJ リスクマネジメント株式会社）との共同研究「自然災害のリスク評価とリスクコミュニケーション～情報共有による自助誘導型リスク回避と公助・共助の防災投資最適化の研究～」（2008 年 10 月～2009 年 9 月，研究代表者：金本良嗣教授）の成果の一部をもとに，筆者らが発展させたものである．ここに共同研究の関係各位に記して謝意を表したい．

補 注

(1) 住宅・土地統計調査は抽出調査であるため，サンプル数の少ない自治体（35 市町村）の建築年・構造別のデータは，推定誤差の問題もあり公表されていない．

(2) 欠損データとせず，隣接する複数の市区町村のデータの平均値を用いるといった対応もありうる．

(3) 住宅・土地統計調査の構造別・建築年代別の住宅戸数は，市区町村単位のデータであるが，地震動予測はメッシュデータを利用できるので，住宅戸数密度に応じたきめ細かい被害予測を行うために，国勢調査のメッシュ単位の人口に応じて住宅戸数を割り当て，メッシュ単位での住宅倒壊率を算定することとした．なお，便宜的に，構造別・建築年代別の住宅の割合は，同じ市区町村内であれば，どのメッシュにおいても同一であると仮定している．また，国勢調査は 4 次メッシュデータを利用できるので，地震動予測地図の 3 次メッシュデータは，4 分割しても分割後のメッシュはすべて同じ地震動であると仮定して 4 次メッシュに分割している．

(4) 出火率の算定では，火災予防審議会・東京消防庁（文献 4）の「用途別の火気器具・電気器具からの出火率」を用いた．当該文献では「震度」に対する出火率が提示されているため，本稿では，内閣府の地震被害想定支援マニュアルの「表 4-4-1 震度と地表最大速度の関係」をもとに地震動を地表最大速度から震度に変換して活用した．なお，出火の要因として，建物用

途別の出火のほかに，全壊建物からの出火や化学薬品からの出火も想定できるが．本稿では，入手可能なデータの制約から建物用途別の出火のみを考慮する．全壊建物からの出火や化学薬品からの出火の想定については今後の検討課題としたい．

(5) 事業所・企業統計調査データの用途コード（セル番号）の消防法施行令の用途（消防法コード）への読み替えは，補注表1のとおりとした．

補注表1　事業所・企業統計調査の用途コードと消防法の用途コードの対照表

建物用途	事業所・企業統計調査のセル番号	消防法コード
映画館	388	1
共同住宅木造	−	10
共同住宅非木造	−	11
病院	268	12
診療所	271, 274, 277	13
寄宿舎	259	14
保育所	295	15
幼稚園	331	16
小学校　＋中高	316, 319, 322	17
大学	325	18
公衆浴場	379	19
キャバレー	250	2
工場木造	022*0.5（022の半分を割り当て）	20
工場非木造	022*0.5（022の半分を割り当て）	21
事務所	001−(388+268+271+274+277+259+295+331+316+319+322+325+379+250+022+247+181+256)	22
住宅	住宅総数	23
料理店	247*0.3（247の3割を割り当て）	3
飲食店油鍋使用	247*0.3（247の3割を割り当て）	4
飲食店油鍋不使用	247*0.4（247の4割を割り当て）	5
百貨店	187	6
物品販売店舗	181−187（181から187を引く）	7
旅館木造	256*0.5（256の半分を割り当て）	8
旅館非木造	256*0.5（256の半分を割り当て）	9

(6) 例えば，A市の20代の夜間人口が10,000人の場合，20代の夜間の救助活動期待人数は，年代別実施率（22.8%）から，2,280人と推定できる．さらに，20代の性別活動比率をもとに，20代の男性と女性の夜間の活動期待人数を算出すると，それぞれ1,733人，547人となる．仮にA市の20代の夜間人口のうち，男性が4,500人，女性5,500人とすると，A市の20代男性の活動実施率は38.5%，20代女性の活動実施率は9.9%と推定できる．年代別・性別の活動実施率は，夜間も昼間も同一であると仮定して，20代の性別の在宅人口と活動実施率から，20代の男性と女性の昼間の活動期待人数を算出する．

(7) ただし，東京消防庁の消防団別のデータは，ウェブサイトでは提供されていないため，東京消防庁から直接データを入手した．

(8) 既往文献をみても，阪神・淡路大震災において地域住民による救助活動に関して，救助に要した人数・時間に関するデータは明確ではない．参考として，村上（文献6）は，消防署職員による救助所用人員・時間を調査しているが，「木造戸建住宅」の場合，「ひとりを救出するのに（生死によらず）要する出動人員・時間」は，平均3.7（東灘消防署分），6.5（東京消防庁分）となっている．これは，消防署職員が5人いても，ひとりを救出するのに平均で1時間程度を要していることを示している．なお，救助活動期待人数が被災により減少する可能性も考えられるが，そもそも救助活動期待人数は，地域住民の一部（約2割程度）であり，住宅倒壊による被害を受けていない，あるいは被害受けていても軽微な被害の住民に該当すると仮定する．

(9) 季節と時間に応じた火災発生件数のより正確な推定（簡易推定）は，今後の検討課題としたい．

(10) 参考として，夜間における救助活動期待人数の全壊住宅1戸当たりの人数が，昼間における救助活動期待人数5人未満／戸の市区町村の割合（70%）とほぼ等しくなるのは，夜間の救助活動期待人数が20人未満／戸，つまり救助に必要な地域住民の人数が，夜間は昼間の4倍（昼間5人，夜間20人）の場合であり，その市区町村の割合は全体の約71%となる．

(11) 総務省消防庁は，「地方公共団体の地域防災力・危機管理能力評価指針」をもとに，2005年に全国の市区町村を対象とした「災害対応への取組状況」調査（質問項目約800問）を実施している．この調査データは非公開だが，調査の結果概要では以下の項目に着目しており，今後，地域災害対応力を検討する際の参考になると考える．

1) 市区町村における防災体制の整備，2) 情報連絡体制の現況，3) 災害時要援護者への支援，4) 物資等の備蓄，5) 避難勧告・指示の基準，6) 市区町村と防災関係各組織との連携，7) 教育・訓練，8) リスクの把握と活用

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ウェブマッピングによる大規模災害対応支援の新動向：2010年ハイチ地震の分析と考察

New movement on the web-mapping utilization for disaster response in the Haiti earthquake

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The approach of disaster response and relief efforts has been changing with evolutional development of web-based geospatial technologies. The purpose of this article is to examine how disaster response and relief efforts have been changing along with recent geospatial technological development, mainly from Haiti earthquake response in 2010. This paper outlines how conventional GIS disaster responses by governmental agencies and relief response organizations and the way of geospatial data sharing have been innovatively transforming into more dynamic, opener, and more decentralized way with a wider range of participation. Finally, the paper discusses lessons learned from recent responses and some thoughts for future development.

Keywords: *geospatial technology, data exchange format, API, crowd-sourcing, mash-ups, public involvement*

１．はじめに

地理情報システム（GIS: Geographic Information System) やリモートセンシング，全地球測位システム（GPS: Global Positioning System）などの地理空間情報技術は，今日の自然災害や人的災害における被害軽減，緊急対応，復興計画などの意思決定支援ツールとして欠かせない存在になりつつある．これまでの災害では，主に中央政府や自治体，国連などの救援機関による地理空間情報技術の専門家集団によって，現場の意思決定を支援するためのマップ作成活動が行われてきた．具体的には，被災地に設置された災害対策本部などで，デスクトップやワークステーション型GISシステムを駆使して，集中的な被災情報の収集と意思決定支援マップの作成・編集・印刷などを行い，トップダウンによる情報配信を行うことが主流であった．

しかし，近年のウェブマッピング技術の急速な発展により，従来型の専門家集団による中央集権的な災害対応に加えて，被災地外の公式・非公式な個人・組織によるネットワーク型の災害対応コミュニティによる，より動的でオープンな災害対応支援が展開され始めている．2004年の新潟県中越地震や2005年の米国ハリケーン・カトリーナ災害で出現し始めたその動向は，その後の更なる技術開発や社会意識の変化に伴い，2010年1月のハイチ地震においてその姿が顕著に現れた．

筆者は2010年3月，ハイチ地震においてウェブマッピングによる先進的な緊急対応支援活動を行った，米国ハーバード大学地理解析センターおよびボストン大学リモートセンシングセンターを訪問し，その実情を調査した[1]．本稿では，これらのヒヤリング調査，および参考文献やインターネット上の情報を整理して，ハイチ地震で顕著に見られた新しい災害対応のかたち，すなわちウェブマッピングを活用したネットワーク型コミュニティによる支援活動の全体像を概説する．そして，これらの技術発展が災害対応活動支援にどのような変化を与えているのか，その要因分析を試みる．

はじめに，これまでの災害対応における地理空間情報の活用動向を整理する．つぎに，ハイチ地震でのウェブマッピングを活用した対応支援の代表的な事例，そして災害対応支援がどのように変化したかを概説する．さらに，ウェブマッピング技術の発展が災害対応支援のあり方に与えた影響を分析し，最後にハイチ地震の対応支援活動から得られた教訓と今後の課題を考察する．

２．従来の災害対応における地理空間情報の活用動向

1980 年代後半から，米国では一連の災害対策を支援するためのツールとして，GIS をはじめとする地理空間情報技術が活用されている．1990 年代中ごろからはインターネット上での危険度情報が公開されるようになったり[2]，1994 年のノースリッジ地震では，被災情報が建築物１棟ごとに管理される[3]など先進的な取り組みが行われてきた．

我が国でも 1990 年代初頭から，地理空間情報技術を活用した災害対策支援の先駆的な研究[4)~6)]が始まり，1993年の北海道南西沖地震の際には，被災直後の航空写真か

ら被災域を自動抽出した事例もある[7]．政府も含めた，我が国の GIS に関する本格的な取組が始まったのは，1995 年の阪神・淡路大震災が契機といわれている[8]．震災後，中分解能光学衛星および SAR 衛星によって広域での被害情報収集が行われたが[9) 10]，高分解能衛星はまだ利用できず，詳細な被害状況の把握は主に航空撮影によって行われた[7) 11]．そして，震災時には基図データがなかったにも関わらず，7 市におよぶ町丁目単位での応急危険度判定，悉皆調査などの被災調査を短期間で実施したが，これらのデータの公開は公的機関や一部の研究者など限定的なものであった．

2001 年の米国ニューヨークでのワールドトレードセンター（WTC）災害（同時多発テロ事件）では，衛星画像や航空写真，LIDAR（Light Detection and Ranging）データ，GPS 端末情報入力機器などの地理空間情報技術と，GIS データベースおよびインターネットを組み合わせることで，緊急対応と復興過程において多角的な活動支援が行われた[12)~19]．被災後のグランド・ゼロ（爆心地）を撮影した SPOT 衛星画像は災害当日に web 上で公開され，翌日には IKONOS 衛星による画像が世界中の新聞紙上と web で公開された[18]．恐らく WTC 災害は，被災直後に撮影された衛星画像が多様な対応活動に活用された初めての大規模災害といえる．しかしながら，被災地の規模に対して，当時の Landsat TM，ERS，MODIS などの衛星画像の空間解像度は十分ではなく[18]，また，リモートセンシング画像の取得とその後の解析処理，およびデータの流通に時間を要したため，緊急対応の支援という面で課題を残していた[13]．また，GISMO (Geographic Information Systems and Mapping Operations)という GIS ユーザ・グループがボランティアとして埠頭 92 の Emergency Mapping and Data Center に集結して，緊急対応活動を長期にわたり支援した[19]．

WTC 災害では，被災直後の衛星画像の利用，救助探査活動におけるモバイル機器の利用，インターネットによる情報発信など，地理空間情報技術は災害対応の多様な局面で役立つことを証明した．そして，このような効果的な対応を行う上では，建物や土地区画，道路網などのベースマップの重要性が指摘されるとともに[12) 15) 19]，GIS ボランティア集団の支援が欠かせないことが示された[19]．

2004 年の新潟県中越地震では，被災地外での一元的な情報の集約と発信による被災地内外の活動支援を目的とした，「新潟県中越地震復旧・復興 GIS プロジェクト」のウェブサイトが，発災から 3 週間後に一般公開された[20]．この産官学連携プロジェクトでは，衛星画像や GIS ベースマップなどを一元的に集約・発信するとともに，被災地外に拠点をおく個人や組織的な GIS ボランティアが，WebGIS 上の入力システムから被災状況などのデータ作成を支援するという，インターネット上での先駆的な参加型データ作成の試みが行われた．

2005 年の米国ハリケーン・カトリーナ災害では，FEMA (Federal Emergency Management Agency) をはじめとする米国政府の対応の遅れ[21]が，結果として，寄付サイトやメッセージ・ボード，緊急援助サイトの設立など，インターネット上での多様な対応活動を促進させることになった．地理空間情報の活用という点では，Google Maps や Google Earth が被災地の高解像度衛星画像を迅速に更新し，詳細な被災状況を世界中に発信した[22]．すなわち，従来の災害対応支援の枠組みに入らない，被災地内外の非公式な個人や組織がインターネットやモバイル機器を駆使して，ウェブページや Wiki，ブログなどで災害に関するデータ収集と情報配信を積極的に行った．そして，これらのインターネットを利用した対応支援のあり方を探る中で，災害対応とは一部の専門家集団による特殊な活動ではなく，個人・地域から国家レベルまでが一丸となって取り組むべき，一種のコミュニティ活動であるとの認識が広がりはじめた[23]．ウェブ上でのこれらの自然発生的な動きはとても迅速であり，オープンソースやウェブマッピングの技術開発を模索する試みが促進されると同時に，様々なかたちでのネットワーク型の災害対応コミュニティが形成されはじめた．

３．ウェブマッピングによる災害対応活動支援

(1) ハイチ地震の概要

2010 年 1 月 12 日，カリブ海に浮かぶハイチにおいて首都ポルトープランスの西南西約 15km，深さ 10km を震源とするマグニチュード 7.0 の直下型地震が発生した．国の中心であるポルトープランスでは，大統領府や国会議事堂をはじめとする多くの建物が倒壊し，中央政府機能は壊滅に近い状態に追い込まれた．死者は 22 万人，被災者は総人口の約 1/3 にあたる 300 万人に達し，1976 年の中国・唐山地震以来，最大の死者を出す地震災害となった．水道や電力供給網などのライフラインも壊滅的な被害を受けた．首都の 3/4 の再建が必要であると推測されるなど，莫大な量の復旧・復興活動を必要とされている．ハイチは諸外国から遠隔にある小さな島国であることに加え，被災により幾つかの道路網が封鎖され，国内外を行き来することが難しいという点が特徴である．

(2) ウェブマッピングによる対応支援活動

ハイチ地震は，オープンソース，ウェブマッピングおよび地理空間プラットフォームの潜在能力が最大限に発揮された初めての災害といわれている[24) 25]．具体的には以下に示すような支援活動が行われた．

A. Wiki 型の参加型ベースマップ作成プロジェクト

救援・救助，災害対策センターの設置，緊急物資の分配など，効果的な緊急対応活動を行うためには地理空間情報の活用は不可欠であり，特にベースマップの重要性が指摘されてきた[12) 15) 19]．ハイチ地震では政府機能の壊滅的な崩壊により，震災前の詳細な交通網や重要施設の位置などのベースマップが利用できない状態であった．その状況の中，OpenStreetMap[(1)]がハイチ地震での対応活動において重要な役割を果たした．OpenStreetMap とは，誰もが無料で利用することができる地理空間データセットの作成を目的としたウェブ上のプロジェクトであり，Wikipedia の電子地図版といえる．ハイチ地震では被災から数日以内に，数千ものボランティアが OpenStreetMap コミュニティに加わり，Yahoo の被災直後の衛星画像や他の地理空間データセットをトレースすることで，道路や鉄道網，水路，街の名前標記など，様々なデータセットを短時間で作成するに至った[26]．ポルトープランスでの震災前と震災 2 日後の OpenStreetMap データセットを示した図 1 は，これらのベースマップがいかに短時間に作成されたかを示す．これらのハイチ・プロジェクトで作成されたデータセットは OpenStreetMap source ファイルや Garmin GMAPSUPP.IMG ファイル，ESRI シェープファイル形式でのダウンロードが可能である[27]．また併せて，高解像度衛星画像からの目視による建物や橋梁の

図１　OpenStreetMap での首都ポルトープランス　（左：震災前，右：震災 2 日後の 2010 年 1 月 14 日）出典(4)

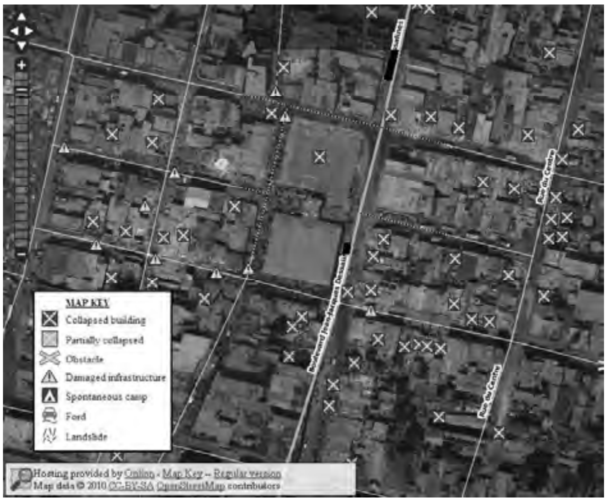

図２　建物およびインフラの被災状況図　出典(5)

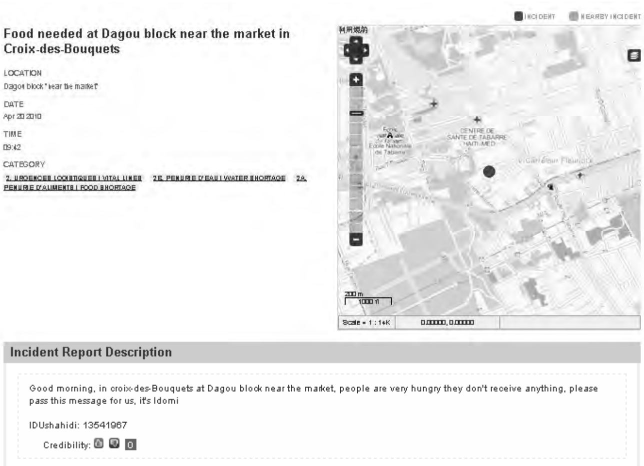

図３　Ushahidi.com の被災状況レポートの一例　出典(2)

被災度判定も行われた（図 2）．

状況が刻一刻と変化する災害対応では，迅速かつ信頼できる地図情報が必要である．従来型モデルであるトップダウン的な GIS データ作成に加えて，OpenStreetMap のような Peer Production（不特定多数によるそれぞれの活動が全体としてまとまることで新しい価値が創出される現象）による地図作成のモデルは，新しい有効な手段であると考えられる．これらの分散型マッピングの最大の利点は，本来であれば限られた技術資源を，被災地外にアウトソーシングすることで，無限にも近いクラウドソース（crowdsourcing：インターネットを活用して，不特定多数の群衆（crowd）から，知的生産力やコンテンツなどを調達・集約し，問題解決を図ること）によって，短時間で大量の地図を生成できることである．これらは従来型の地図データ製作よりも格段に早く実用的であり，もはやクラウドソーシング・データ製作はボランティアやアマチュア以上のものになりつつある．

B.　被災者による地図化された被災情報の発信

首都機能が壊滅的な状態になったハイチの復旧活動においては，主に海外からの救援・援助部隊が被災地の対応活動にあたることになったが，現地の警察，消防からの被害情報の入手が期待できず，被災地の状態が分からない状況であった．そこで，どこにどの程度の救助資源を投入するかなどの意思決定を支援した情報源の一つとして，携帯電話の SMS (Short Message Services)とツイッターの連携による，Ushahidi プロジェクト(2)が挙げられる．スワヒリ語で「証拠，証言」を意味する Ushahidi は，2008 年のケニア大統領選の結果に端を発した暴動の発生状況を報告するため，市民ジャーナリズム・ウェブサイトとして作成された．

Ushahidi は SMS や Email，ウェブなどから，各所に散在するデータを収集して，マップや時系列のかたちへ視覚化するプラットフォームである． SMS とは携帯電話同士で短い文字メッセージを送受信できるサービスである．被災者は，周囲の被災状況や自分自身そして家族の安否情報などをテキストにして，SMS や Email などを通じて Ushahidi へ投稿する．「家族が建物の下敷きになっている」，「近くに死体がある」，「食料が足りない」といった被災者からの投稿情報は，地図上のイベントとして OpenStreetMap の地図プラットフォーム上にタグ付けされ（図 3），更新されるたびにツイッター上でも配信された．

ハリケーン・カトリーナ災害では発災直後から，被災者やその家族，そして臨機応変的に結成された市民グループなどによって，文章やブログ，写真や地図などの多様な被災情報がインターネットを使って発信された．しかし，インターネット普及率はわずか 11%であるハイチ

では，所持率が国民の約 1/3 に及ぶ携帯電話の SMS 機能をつかった情報発信が有効であった [29) 30)]．そのため，発災後約 1 ヵ月間に Ushahidi に届いたメッセージのうち，Email は 770 件であったのに対して，SMS からの発信は 14,137 件であった [31)]．Ushahidi プロジェクトにより，ハイチのようなインターネットの普及率が低い地域でも，多くの被災者が，個人レベルでの地図情報と関連付けされた被災情報を発信することが可能になった．

C. パブリック・ドメイン型地理空間データ共有サイト

ウェブ上の地理空間データの共有プラットフォームとして，GeoCommons[(3)]が利用された．これは地理空間データをアップロードしたり，整理するためのウェブ・サービスである．ハイチ地震においては，Ushahidi による住民からの被災状況レポートなどの情報が GIS データ形式でアップロードされている．GeoCommons は共有された生データを簡易に検索したり，それらのデータを KML ファイルや CSV ファイル，シェープファイルなどの標準的地理空間データフォーマットで，容易にダウンロードできる．これらの機能は，研究者や専門家向けに有効であるが，これに加えて，従来のマッピング・ツールや空間解析などの特別なトレーニングや経験のない一般市民でも，地図情報を視覚的に分析することができる機能も兼ね備えている．GeoCommons はボランティアなどのユーザに限らず，政府・自治体などが自分たちの内部データを公開，クラウドソーシングするための共有プラットフォームとして利用することができた．

４．災害対応支援体制の変化

一般的には，被災地を管轄する政府や自治体，国連などの救援機関が災害対応の主体であり，NGO などが二次的な役割を担うことが多い．しかしながら，ウェブマッピングの発展を通して，従来型の専門家集団による中央集権的な体制から，多様なアマチュアを含んだネットワーク型の災害対応へ体制が拡大するなかで，地図作成や空間解析を通じて災害対応を支援する機会と能力が大きく高まっている．本章は，ハイチ地震で見られたこの現象を整理する．

(1) 民間企業による積極的な航空・衛星画像の提供

衛星や航空のリモートセンシング画像の提供については，複数の国々の宇宙開発機関と同様，もしくはそれ以上に，民間の衛星企業が高解像度の衛星画像を積極的に無償提供する傾向が強まっている（表１）．ハイチ地震では発生翌日から 5 日後の間に，8 カ国 15 以上の衛星が震災直後の高精度衛星画像を，国際災害チャーター（International Charter）や UN-SPIDER（United Nations Platform for Space-based Information for Disaster Management and Emergency Response）などのウェブサイトで公開した．2001 年の WTC ビル災害に比べると，ハイチ地震の対応で使用された衛星画像とそのデータ提供機関の数は，その質と量で格段の違いがあり，その変化は著しい．

衛星とセンサの性能は空間・時間の両面で分解能が向上し続けており，建物や道路の簡易的な被災度判別も可能になってきている．OpenStreetMap のような地図作成活動に対しても，それらの画像を使用したり，配布する権利を付与している．リモートセンシング技術の向上およびデータの交換・共有が容易になったこと，そして，民間企業が積極的に衛星画像を提供することで，地理空間情報を活用した多様な災害対応活動が大きく後押しされたといえる．

表１　リモートセンシング画像の主要な提供機関

データ提供機関	衛星	撮影日	OSM での使用
NOAA (National Oceanic and Atmospheric Administration), USA	Cessna Citiation II (aircraft)	1/18	○
GeoEye, Inc., USA	GeoEye-1	1/13	○
	IKONOS	1/17	○
DigitalGlobe, Inc., USA	QuickBird	1/15	○
	WorldView-1	1/14	
	WorldView-2	1/15	
EROS (Earth Resources Observation Satellite) Corp., US and Israel	EROS B	1/17	○
CNES (Centre National d' Etudes Spatiales) and Spot Image, France	Spot 5	1/14	○
SpotImage	Formosat-2	1/13	
NIED (National Research Institute for Earth Science and Disaster Prevention), and JAXA (Japan Aerospace Exploration Agency), Japan	ALOS	1/23 (Pan-sharpened)	○
		1/23 (PRISM)	
		1/13 (AVNIR-2)	
		1/16 (PALSAR)	
e-GEOS S.p.A., Italy	COSMO-SkyMed	1/15	
MacDonald, Dettwiler and Associates Ltd., Canada	Radarsat-2	1/14	
China	HJ-1-A/B	1/14	
RapidEye AG, Germany	RapidEye	1/13	
Infoterra GmbH, Germany	TerraSAR-X	1/14	
KARI (Korea Aerospace Research Institute, Republic of Korea	KOMPSAT-2	1/15	
NASA, USA	Earth Observing One (EO-1)	1/15	

(2) クラウドソース・マッピングの出現

ハイチ地震の対応活動における最大の変化は，個人や組織，専門家やアマチュアを問わず，被災地内外の各国の人々がインターネットを通じて，ウェブマッピングを活用した災害対応活動に積極的に参加したことにある．

従来，政府・自治体は内部で収集・作成された情報を頼りに災害対応や救援活動を行う傾向があると考えられる．しかし，ハイチ地震では，OpenStreetMap をはじめとする，ボランティアを含めた被災地外のコミュニティが作った外部データセットが，意思決定において重要な役割を担うことになった．これにより政府・自治体，救援・救助機関は，現地で彼らしか行うことができない独自の専門業務に限られた資源を集中することができた．すなわち，被災地の内と外，個人と組織，専門家とアマチュアによる一種の分業体制が構築されたといえる．このネットワーク型の災害対応コミュニティの出現と，それにより生まれた新しいデータセットとの関係を図 4 に示す．

従来の地理空間データセットと専門家集団による災害対応では，通常業務などで使用されている交通網や土地利用，建物，重要施設などの「ベースマップ」，それに加えて，パトロールや住民からの通報，被災直後に撮影された航空や衛星から撮影されたリモートセンシング画像などの災害時に調査で得られた「実被害情報」などを重ね合わせたものが，緊急対応支援の中核的データソースとして使用されてきた [19) 32)]．これらは，主に以下の地理空間情報の専門家集団を含んだ災害対応チームによって作成・使用される．

1) ベクターデータを編集したり，空間解析を実施したり，意思決定のためのマップ作製を行う，「GIS スペシャリスト」

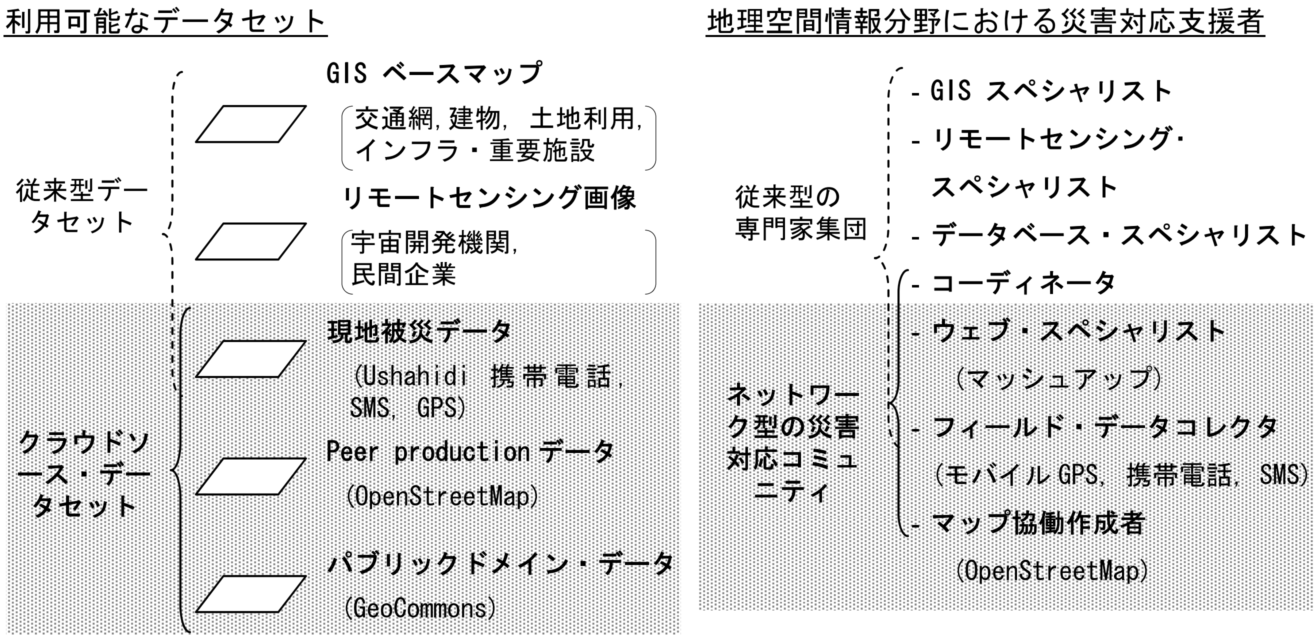

図 4　利用可能な地理空間データセットと災害対応者の変化

2) 衛星や航空から得られた画像をジオレファレンスしたり，解析処理を行う「リモートセンシング・スペシャリスト」
3) 「データベース・スペシャリスト」
4) プロジェクト全体の「コーディネータ」
5) ハンドセット GPS などのモバイル機器による地上での被災情報と災害対応の進捗状況を収集する「フィールド・データコレクタ」
6) ウェブサーバを設置したり，アプリケーションを構築する「ウェブ・スペシャリスト」

これらのチームは，主として，政府・自治体，救援・援助機関，GIS ソフトウェア企業，大学，組織化されたボランティア・グループから構成され，被災地の災害対策本部などで集中的に活動する．

ハイチ地震で見られた災害対応支援の新しいスタイルとして，従来型の専門家集団による災害対応チームに加えて，図 4 のグレー・ゾーンに示したネットワーク型の災害対応コミュニティの存在が大きくなりつつある．

被災地では，住民や市民グループ，災害対応従事者が，SMS による携帯電話やカメラ付きの GPS 携帯電話などを通じて，現地の被災情報の提供に貢献した（「フィールド・データコレクタ」）．前述の Ushahidi プロジェクトでは，市民から発せされたメッセージが，被災状況を把握するセンサのような働きをした．また，被災地外の遠隔地からの支援者が OpenStreetMap などのマップ協働作成プロジェクトに参画して，道路や橋，水路，救援キャンプ地などのマップ・レイヤーの作成に貢献した（「マップ協働作成者」）．また，多くの「ウェブ・スペシャリスト」は，マッシュアップにより災害対応者を支援するためのポータルサイトやアプリケーション・サービスの構築に貢献した．このマッシュアップの技能は，従来型の専門家集団のウェブ・スペシャリストにおいても欠かせないものとなりつつある．

5．ウェブマッピングの発展と災害対応支援の変化の関係

これらの災害対応支援のあり方に変化をもたらした要因は何であったのだろうか？2004 年以降のウェブマッピング技術の発展動向と大規模災害の年譜を図 5 に示す．2005 年の Google Maps と Google Earth などの出現，そして OpenStreetMap や Ushahidi などの新しい技術・サービスの出現により，ウェブマッピング技術は大きく進展し，広く一般市民にも浸透した．それが災害対応における広範な支援者の参入を促し，災害対応コミュニティのあり方を変えることに至った一因であると考えられる．本章では，災害対応支援の中で地理空間情報を活用する上での「閲覧」，「共有」，「独自サイトの構築」という 3 つの段階において，ウェブマッピング技術の発展がどのように災害対応支援と関係しているかを整理し，その背景を探る．

(1) ウェブマッピングによる閲覧

2005 年の Google Maps，Google Earth および Microsoft の Virtual Earth（現在，Bing Maps）の出現，およびその後の度重なるバージョンアップによる機能の向上によって，地理空間データに対する一般市民の意識は，劇的に変化した．これらのウェブ・マッピング・サービスによって，デスクトップ型 GIS ソフトウェアをインストールしなくても，インターネットのブラウザ上で地理空間データを容易に閲覧することが可能になった．これらのサービスでは，行政界や土地区画，道路網，主要な施設などのベースマップと高解像度の衛星画像などのデータセットを無償で利用することができる．これにより GIS を全く知らない一般市民も，世界規模のシームレスな地理空間データを閲覧できるようになった．この背景には，前述した衛星リモートセンシング技術の発展も欠かせない．

(2) ウェブ上での空間データ交換フォーマット

Keyhole Markup Language (KML)という標準データ交換フォーマットの開発によって，地理空間データセット作成の間口は広まった．KML ファイルは，Google Earth や Google Maps に表示するポイント，線，イメージ，ポリゴン，およびモデルなどの地理的特徴をモデリングして保存するための XML 文法および XML ファイル形式である．これにより，従来の GIS ソフトウェアを使わなくても，自在に地理空間データセットを作成し，Google Earth や Google Maps などの既存の地理空間プラットフォーム上に重ね合わせて表示したり，インターネットを通じたデータの共有が容易になった．すなわち，インターネット上のデータ配信が，容易に安価で実現できるようになった．地理空間データの標準フォーマットとしての KML の存在は拡大しており，KML のバージョン 2.2 は，2008 年に OGC（Open Geospatial Consortium）の標準フォーマットとして採択されている[33]．

また，標準プロトコルとしての Web Map Service Interface Standard（WMS）の役割もデータ共有を促進する上で重要であった．これによって，プラットフォームやソフトウェア，データフォーマットの違いに依存しない，データの重ね合わせなどの地理空間情報の相互運用が可能になった．ハイチ地震の際には，DigitalGlobe 社や防災科学技術研究所（NIED）および 宇宙航空研究開発機構（JAXA）など，WMS server を使った衛星画像の配信を行った．現在では，主要な商用およびオープンソースの GIS ソフトウェアはほとんど WMS をサポートしている．WMS という標準プロトコルで画像情報が配信されることで，データフォーマットの変換，流通に要する手間ひまが大幅に削減された．

その後，2007 年 4 月にリリースされた，Google My Maps によって，GIS サーバ・ソフトウェアを使用しなくても，簡易的なウェブマッピング・サイトの作成と共有が可能となった．地図上に自在に印をつけたり，線を引いたり，文字や写真，ビデオを加えた，ユーザのカスタム地図の作成が可能になり，これを他のユーザと共有したり，Google Earth 上で表示することができる．これによって，個人レベルでのウェブ上の地理空間データの共有が容易になった．

(3) マッシュアップによる独自サイトの構築

マッシュアップとは「混ぜ合わせる」という意味であり，ウェブ上の異なる情報源からのコンテンツや技術を複合させて，独自の新しいウェブサービスを構築することである．マッシュアップで作られたウェブサイトは，エンドユーザにはあたかも一つのウェブサービスのように見える．

地理空間情報の分野においては，Google や ESRI 社などが，自社のウェブマッピング・サービスの機能を application programming interface (API)として無償で提供している．これらの Google Maps APIs や ESRI ArcGIS Web Mapping APIs などを利用することで，複合的な機能を持った地理空間情報サービスを容易に開発することが可能となり，ウェブマッピングの可能性が広がった．これにより，地理空間解析についての技能や GIS の経験はなくても，Google Maps などが提供する衛星画像やベースマップと，自らの地域情報などを組み合わせることで，独自のマッピング・サイトを構築できる．これにより，ウ

図 5　近年の大規模災害とウェブマッピングの発展による災害対応支援の変化を表す概念図

ェブ上のリソースを最大限に利用した，新しい災害対応支援サービスの開発の可能性が広がった．前述のUshahidiは，OpenStreetMapとツイッターをマッシュアップして作られた一例である．

６．得られた教訓と今後の課題

(1) クラウドソース・データセットの生産性

迅速な初動活動を支援するために，最初の対応支援地図は数日以内－できれば数時間以内－に作成されるべきである．従来，災害時のデータの作成は，広範なデータセットに熟知していたり，十分なトレーニングを受けた経験を持つ専門家を必要としていた [2) 17) 23)]．実際，研究分野や専門的業務支援における空間解析やモデリングの実施には多くの日数を要するが，災害対応の初期段階においては，これらの熟練したGIS技術は必要としないことが多い．緊急対応で使用する地理空間情報は，複雑な解析処理を必要とするものは少なく，どちらかといえば，信頼性の高いデータをマップに表示する，というシンプルなものである．

新潟県中越地震やハリケーン・カトリーナ以降の災害対応を通して，そして特にハイチ地震において，遠隔地の個人・組織が情報を発信できる力とスピードが示された．ハイチ地震から約1カ月後に発生したチリ地震では，発災翌日の2月28日にUshahidiおよびOpenStreetMapともにチリ地震専用サイトを立ち上げるなど [34)]，より迅速に対応活動支援を開始した．

(2) クラウドソース・データセットの信頼性

災害対応で使用されるデータの信頼性や精度は高ければ高いほどよく，それに応じてより多様な活動に役立つことは明白である．被災者や遠隔地の非専門家により作成・発信されるクラウドソース・データセットは，本節後半で示すように，信頼性という面でその性質に差異がある．しかし，それらの課題を踏まえた上で認識すべきことは，データセットの信頼性にある程度の問題があったとしても，ハイチ地震の現場では多くの活動を支援し，「十分に使えた」という声が多く挙がっている点である．

例えば，Ushahidiのレポートは，赤十字（Red Cross）や米国沿岸警備隊（US Coast Guard），米国海兵隊（US Marine Corp）が救助活動を行う際の情報源として使用された [24) 28)]．OpenStreetMapも，赤十字やコロンビア，米国Fairfax郡の救援・救助活動や資源分配，救援キャンプサイトの設立を支援したり，国連人道問題調整事務所（UNOCHA）や国連衛星プロジェクト（UNOSAT），国際連合食糧農業機関（FAO）などの被害レポート作成や各種意思決定の情報源として使用されたことが報告されている [26)]．

次に，これらのクラウドソース・データセットの課題を整理するため，OpenStreetMapおよびUshahidiプロジェクトで作成されたデータセットの信頼性を検証する．

図1で示した「ベースマップ」は，遠隔地に住むボランティアが，高解像度衛星画像や他の地理空間データセットを目視でトレースすることで作成した地物データセットである．これらの信頼性を定量的に評価することは難しいが，1) 作業自体が地物を目視でトレースするという比較的単純作業であり主観の入る余地が少なく，2) 複数のデータ編集者が同時多発的に作業を行うことで相互チェック機能が働いている，などの理由から比較的高い信頼性を有したデータセットといえる．

しかし，図2で示した建物，道路，橋梁，インフラなどの「被災状況図」は，遠隔地に住むボランティアが2次元の高解像度画像衛星を目視で判別することで作成された．これらのデータセットは，現場での救援・救助活動を支援する上では不確実性を持ったデータといえるが，災害直後の初動期（情報の空白期）に被災状況の全容を把握するためには有効である．

一方，被災者からのメッセージを主な情報源とするUshahidiプロジェクトでは，発災後1ヵ月間にSMSから約14,000件のメッセージを受け取ったが，レポートとしてUshahidiが承認したものは約2,500件に留まった [31)]．位置を特定するのが困難であったり，ミススペルや間違いを含んだメッセージを除外して，住所情報が正確に記載されているもののみを抽出しても，ベースマップの方で詳細な街路名が登録されていないこともあった．また，一つの場所が複数の名前で呼ばれていたり，Bel Airという地名が国内に15か所あるなど，共通の地名が複数箇所に存在していることもあり，Ushahidiのボランティア・スタッフはその選別作業に多くの時間を費やした [35)]．

データセット自体の信頼性の問題に加えて，携帯電話所持率やインターネット普及率などによって，被災地から発信される情報の量に偏りが生じ，それによって，救援活動が優先的に開始されるような地域も出てくるかもしれない．しかし，クラウドソーシングにより迅速に作成されるデータは，従来型の中央集権的に作成されたデータと同様，もしくはそれ以上に役立つ可能性を秘めている [24)]．大規模災害のような未曾有の危機に直面した際には，ある程度の課題があることを認識した上で，限られた情報資源の中から何ができるのかを考え，使える部分は積極的に利用していく，という姿勢が重要である．

(3) リアルタイム被害情報収集の実現可能性

災害対応の現場は刻一刻と状況が変化する．時間経過に伴い，多くのデータセットはその不確実性が増すことになる．これらの問題に対処するためには，モバイルとクラウドリソースの活用が有効である．

例えばOpenStreetMapでは，2次元の高解像度衛星画像と遠隔地のボランティアの視覚判断から得られた第一段階の簡易被災度判定に加えて，Ushahidiに送られてくる被災状況説明の文章や，現場の被災者や対応者によって撮影された写真画像を組み合わせることで，より高い精度の被災度判定をすることが可能であろう．実際，外観目視や非専門家による建物被災度評価手法も検討されている [36) 37)]．これらの知見をもとに，建物や道路，橋梁ごとに，場所や角度，枚数などの写真撮影の指針を作成し，それに基づき撮影された画像を遠隔地の専門家に送ることで，より詳細で信頼できる被災度判定を短時間で行える可能性も十分に考えられる．

また，災害対応の期間は，常に多くのデータが作成されたり更新され続け，これらの情報は時系列データとして記録されることになる．これまでの災害では，日々の衛星画像やリアルタイムの被災報告のような時系列データの取得と管理は難しかった．これらのデータを分析することは災害対応と復興の全体像を分析する上では大いに役立つことが予想される．このような時系列変化を格納するアーカイブ・メカニズムが必要であるが，現在のシステムでは十分に実装されていない．将来の災害対応のためにも，このような時系列分析を可能にするデータ

モデルの検討が GIS 業界や研究開発分野に期待される．

同時に，ハイチ地震をはじめとする昨今の大規模災害では，可視光を観測する光学リモートセンシング画像の分析を中心として地物を認識しているが，観測領域を覆う雲の影響が問われる．降雨などの天候条件によっては光学衛星画像が利用できないケースもあり影響が大きい要素でもある．ハイチ地震では，米国海洋大気圏局（National Oceanic and Atmospheric Administration）による航空写真も利用されている（表１）．航空写真や，天候の影響を受けずに地物認識が可能である SAR 衛星画像の活用・補完も想定した，包括的なリアルタイム被害情報収集の戦略策定も必要である．

(4) ネットワーク型災害対応コミュニティの活用を前提とした，災害対応計画の必要性

災害コミュニケーションは従来，トップダウンで階層的なものであり，権限を持つ公的な職員や専門家が唯一，情報を発信できる主体であった [38]．しかし，これらのアプローチは，災害時のデータ共有という面からは効果的でないことはこれまでの経験から明らかである [2]．

中央政府が崩壊したというハイチの特別な場合を除けば，一般的には，政府・自治体や救援機関が災害対応の中心的役割を担うことになる．近年の大規模災害による対処すべき問題の規模と複雑さを鑑みると，少数の組織の対応に限りがあるのは明らかであり，より規模の大きな災害対応支援体制の構築が必要である．すなわち，政府・自治体や救援機関は，これらのウェブマッピング技術の発展とそれに伴うクラウドソースの出現による新しい動きを理解して，それをどのように充実させるか，そして活用するかを考える必要がある．

来るべき大規模災害に備えて，平常時から位置情報を活用した災害対応業務の標準的な情報処理手法を確立すること [39]に加えて，災害時にクラウドソースの活用を前提とした防災計画を立案することは有効である．これは，世界中から集約される善意と熱意の資源を最大限に有効活用するとともに，大規模災害に対して十分な資源を持ち合わせない政府・自治体が，その対応能力を補強する機会を提供するであろう．

2010 年 5 月，総務省消防庁は，災害時の双方向の情報発信としてツイッターを活用した「災害情報タイムライン」[(6)]をはじめたが，利用者からの情報は他の利用者は見ることができず，消防庁の情報収集のみに利用される．一般的に政府機関は，外部機関のデータを利用したり，外部機関へのデータ提供を好まない傾向がある．しかし，ある程度信頼のおける災害対応コミュニティが作成したデータの利用を試みたり，自分たちの内部データを積極的に外部へ公開することで，新たな災害対応支援が生まれる可能性も秘めている．当然，政府機関として，プライバシー問題などを考慮して，データ共有にある程度の制限をかけることは必要であるが，外部資源と内部データを複合できるような，より高いレベルでの情報共有を検討することが有効と考えられる．

(5) 緊急対応支援と長期的戦略支援

従来，詳細な地理空間データセットを作成するには数カ月から数年を要したが，OpenStreetMap のようなクラウドソースの出現により，わずか数日のうちに詳細なデータセットを作ることが可能になった（図 1）．これらの活動が災害対応の初動活動に大いに役立ったことは確かであるが，データベースの構築は，将来の復興計画なども考慮した長期的なものである必要がある．具体的には，OpenStreetMap で作成されるフィーチャ・データセットはシェープファイルのようなシンプルな GIS フォーマットである．例えば，近年普及しつつある ESRI 社のジオデータベースのようなオブジェクト指向 GIS データモデルは，リレーショナルデータベース管理システムへの格納やデータへの地物間の関連性やネットワークなどの振る舞いの定義づけを実現している．

昨今の国・自治体等での GIS システムの導入に当たっては，データの設計時に現実世界と整合性のとれたモデルを作成することで，GIS アプリケーション開発のコストを減らして総合運用性を容易にすることが求められつつある．ベースマップを持ち合わせていない発展途上国においては，大規模災害後のデータ作成は，新しい地域・国家的地理空間データセットを構築する大きな機会とも捉えられる．この際に，緊急対応だけでなく，長期の地域・国家戦略を考慮した，高度なデータ管理や空間解析に対応できる拡張性の高いデータベースを構築することは，歳入の収集や自然資源の保護，土地利用計画，インフラ計画そして災害対応計画など，多様な分野でのデータセットの利用を可能とする．

災害対応をきっかけとして，世界中の労力を結集して作成されたデータセットを有効活用するためにも，気候変動適応策や地球温暖化緩和策などの地球環境問題を含んだ，長期的かつ包括的利用を考慮した長期戦略とするべきである．

7．おわりに

本稿では，ハイチ地震で顕著に見られた新しい災害対応のかたち，すなわちウェブマッピングを活用したネットワーク型コミュニティによる支援活動の全体像を概説した．そして，ウェブマッピング技術の発展が災害対応支援の在り方に与えた影響を分析し，最後にハイチ地震の対応支援活動から得られた教訓と今後の課題を考察した．今後は，ハイチ地震の災害対応支援から得られた教訓および課題から，我が国やアジア地域での適応可能性を検討する予定である．

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DEVELOPMENT OF A DISCRETE TIME-SERIES MODEL FOR VEGETATION MONITORING

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KEY WORDS: Anomaly detection, Multi-temporal data, Hidden Markov model, Self-organizing map, Phenology, Land cover changes

ABSTRACT:

This paper describes the development of a novel time series modelling and spectrum anomaly-detection method, which takes into consideration wide-area seasonal changes. By taking advantage of both the high temporal resolution and the wide swath mode of multi-temporal satellite data, such as NOAA/AVHRR, MODIS, and SPOT/vegetation, it is possible to perform high-frequency monitoring of wide-area, land cover changes. However, since the multi-temporal satellite data are influenced by clouds and system noise, in many cases, they must be processed in order to accurately represent the actual surface conditions. We engineered a discrete time-series model using a self-organizing map (SOM) and a hidden Markov Model (HMM) to reduce the influence of clouds in order to improve the accuracy of the products. The spectral information of the pixels was first converted to nominal scale values, and the influence of clouds was eliminated through a time-series modelling using HMM. Since the anomaly-detection method requires a clustering of nominal vectors, dedicated software based on SOM algorithm was also developed. The data for anomaly detection is not dependent on the information of neighbouring pixels, and it is possible to detect an anomaly even if there is only one pixel.

1. INTRODUCTION

In order to address the issues arising due to the various environmental problems that are currently attracting attention, it is necessary to devise a method that enables wide-area monitoring of fluctuations in vegetation conditions such as variations in moisture and temperature and land cover changes.
Various research projects on the global environment utilize the characteristics of the cyclic nature of multi-temporal satellite data (Lhermitte et al., 2008). In these research projects, "the n-day composite imagery"(ex. n=8, 10), which is created by selecting the best data in 8 or 10 days for every pixel, is often used for characterised seasonal changes. However, the influence of clouds and haze remain, even in these ten-day composite data, and this complicates the monitoring of phenology with a 10 days interval (Sawada et al., 2005). Monthly composite data are not appropriate to monitor phenology dynamics (Alexandridis et al., 2008) because the seasonal changes of vegetation are phenomena taking place in a few weeks for most of cases.
This paper describes a novel method for time series modelling and spectrum anomaly detection by using SPOT/vegetation and MODIS data. Since this methodology can extract a seasonal change model with pixel by pixel, it is useful to monitoring land-cover change and ecological disasters such as large-scale forest fires.

2. METHOD

In this chapter, the algorithm of discrete time-series model is described. This model consists of four modules. (Figure 1)

2.1 Generating of spectral codebook and encoding

The batch-learning SOM algorithm (Kohonen, 2000 and Yamakawa et al., 2005) was used in order to generate a spectral codebook which encodes multispectral data. In each pixel, "pure components" (endmembers) are extracted throughout the data collection period by OPA (Orthogonal Projection Analysis, Cuesta Sánchez et al., 1996) for removing influence of cloud, haze and other noise. "Pure components" are classified by the batch-learning SOM algorithm. Generated SOM is used as a codebook in spectral encoding step. In addition, SOM node which are assigned as cloud and haze contaminated are masked. Then, mutitemporal and multispectral data such as MODIS band1~7 data (MOD09A1) and SPOT/vegetation S10 produts are encoded by the nearest-neighbour (NN) method. If a pixel was "data missing" and contaminated by cloud, this pixel is assigned "NULL" code. We set size of SOM to 20 × 20 (including "NULL" code, the total number of spectral codes is 401).

2.2 Time-series modelling by HMM

The observation data vector and the state vector of (x,y) pixel are denoted by $\mathbf{o}^{(x,y)}$ and $\mathbf{q}^{(x,y)}$, respectively. Both $\mathbf{o}^{(x,y)}$ and $\mathbf{q}^{(x,y)}$ are nominal scale vectors.

$$\mathbf{o}^{(x,y)}=(o_1^{(x,y)}, o_2^{(x,y)}, \dots, o_T^{(x,y)}) \quad (1)$$

$$\mathbf{q}^{(x,y)}=(q_1^{(x,y)}, q_2^{(x,y)}, \dots, q_T^{(x,y)}) \quad (2)$$

where T = number of scenes
(x,y) = image coordinates

Let assume $\mathbf{q}^{(x,y)}$ follows Markov process, we get the conditional probability of generating $\mathbf{q}^{(x,y)}$ (Rabiner, 1989)

$$P\left(\mathbf{q}^{(x,y)} \middle| \mathbf{o}^{(x,y)}\right) = \pi_{q1} b_{q1}\left(o_1^{(x,y)}\right) \cdot \prod_{t=2}^{T} a_{q(t-1),qt} b_{qt}\left(o_t^{(x,y)}\right) \quad (3)$$

where N = total number of states
N_c = total number of spectral code.

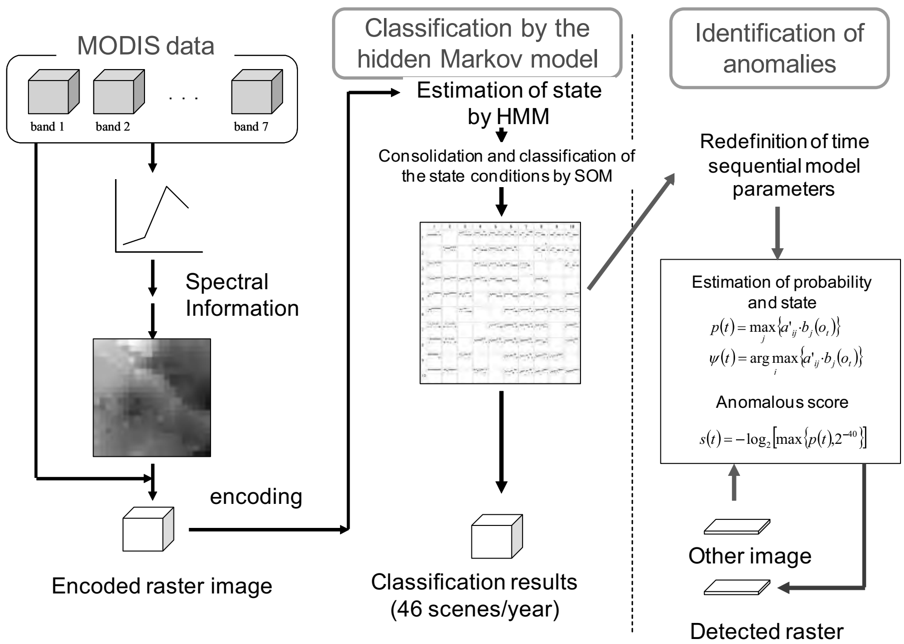

Figure 1. Flow of our discrete time-series model processing

Parameters π, a and b are defined by following formulas

$$\pi_i = \frac{\#(q_1 = i)}{\sum_{i=1}^{N} \#(q_1 = i)}$$
$$a_{ij} = \frac{\sum_{t=2}^{T} \#(q_{t-1} = i, q_t = j)}{\sum_{j=1}^{N}\sum_{t=2}^{T} \#(q_{t-1} = i, q_t = j)} \quad (4)$$
$$b_i(k) = \frac{\sum_{t=1}^{T} \#(q_t = i, o_t = k)}{\sum_{k=1}^{Nc}\sum_{t=1}^{T} \#(q_t = i, o_t = k)}$$

"#()" is a function that returns occurrence frequency of phenomena in parentheses.

If parameters π, a and b are known, $\mathbf{q}^{(x,y)}$ is obtained by Viterbi algorithm. Actually we calculate parameters π, a and b iteratively.

2.3 Classification of seasonal change profile

Since the element of the state vector $\mathbf{q}^{(x,y)}$ is a nominal scale value, we developed nominal scale vectors (and/or strings data) classification method.

Firstly, we define $\mathbf{D}(\mathbf{q}^{(x,y)})$ as a characteristic matrix of the state vector $\mathbf{q}^{(x,y)}$. The (i,j) element of $\mathbf{D}(\mathbf{q}^{(x,y)})$ is one when $q_j^{(x,y)}=i$ and otherwise zero. The size of the matrix $\mathbf{D}(\mathbf{q}^{(x,y)})$ is $N \times T$. For example, when $\mathbf{q}^{(x,y)}$="*124*"

$$\mathbf{D}(\text{"}124\text{"}) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (5)$$

In bioinformatics researches, **D** is called 'Position Specific Scoring Matrix' (Gribskov et al., 1987).

Next, $\mathbf{D}_{\text{cent}}(\mathbf{Q})$, the centroid of **D**, is defined when **Q** is a set that consists of state vectors.

$$\mathbf{D}_{\text{cent}}(\mathbf{Q}) = \frac{\sum_{\mathbf{q}^{(x,y)} \in \mathbf{Q}} \alpha^{(x,y)} \cdot \mathbf{D}(\mathbf{q}^{(x,y)})}{\sum_{\mathbf{q}^{(x,y)} \in \mathbf{Q}} \alpha^{(x,y)}} \quad (6)$$

where $\alpha^{(x,y)}$ = weight for $\mathbf{q}^{(x,y)}$
(x,y) = image coordinates

For instance

$$\begin{aligned} &\mathbf{D}_{\text{cent}}(\text{"}121\text{"},\text{"}314\text{"},\text{"}124\text{"}) \\ &= \frac{1}{3}\{\mathbf{D}(\text{"}121\text{"}) + \mathbf{D}(\text{"}314\text{"}) + \mathbf{D}(\text{"}124\text{"})\} \\ &= \frac{1}{3}\begin{pmatrix} 1+0+1 & 0+1+0 & 1+0+0 \\ 0+0+0 & 1+0+1 & 0+0+0 \\ 1+0+0 & 0+0+0 & 0+0+0 \\ 0+0+0 & 0+0+0 & 0+1+1 \end{pmatrix} \\ &= \frac{1}{3}\begin{pmatrix} 2 & 1 & 1 \\ 0 & 2 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 2 \end{pmatrix} \end{aligned} \quad (7)$$

Then, we define $\mathbf{q}_{\mathrm{cent}}(\mathbf{Q})$, the centroid of $\mathbf{Q}$, and *consensus* function which returns consensus sequence.

$$\mathbf{q}_{\mathrm{cent}}(\mathbf{Q}) = consensus\left(\frac{\sum_{\mathbf{q}^{(x,y)} \in \mathbf{Q}} \alpha^{(x,y)} \cdot \mathbf{D}\left(\mathbf{q}^{(x,y)}\right)}{\sum_{\mathbf{q}^{(x,y)} \in \mathbf{Q}} \alpha^{(x,y)}} \right) \tag{8}$$

For example, from eq. (7)

$$\begin{aligned} &\mathbf{q}_{\mathrm{cent}}(\text{"}121\text{"},\text{"}314\text{"},\text{"}124\text{"}) \\ &= consensus\left(\mathbf{D}_{\mathrm{cent}}(\text{"}121\text{"},\text{"}314\text{"},\text{"}124\text{"})\right) \\ &= consensus\left(\frac{1}{3} \begin{pmatrix} 2 & 1 & 1 \\ 0 & 2 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 2 \end{pmatrix} \right) \\ &= \text{"}124\text{"} \end{aligned} \tag{9}$$

And we define $f_{ij}(\boldsymbol{X})$ as a function that returns (i,j) element of a matrix $\boldsymbol{X}$ for further convenience.
Similarity of $\mathbf{Q}$ and another state vector $\mathbf{q}$' is defined following formula:

$$s_i(\mathbf{Q}, \mathbf{q}') = \frac{1}{L} \sum_{j}^{L} \sum_{i}^{Nc} f_{ij}\left(\mathbf{D}_{cent}(\mathbf{Q})\right) \cdot f_{ij}\left(\mathbf{D}(\mathbf{q}')\right) \tag{10}$$

Consequently, the algorithm of our nominal scale vectors classification method is described below:

i) to initializing weight vectors $\mathbf{w}_{IJ}$
ii) to set iteration counter k_t to zero
iii) to assign $\mathbf{q}^{(x,y)}$ to a node by eq. (11)

$$I', J' \leftarrow \arg\max_{IJ} \left\{ \frac{1}{L} \sum_{j}^{L} \sum_{i}^{Nc} f_{ij}(\mathbf{w}_{IJ}) \cdot f_{ij}\left(\mathbf{D}\left(\mathbf{q}^{(x,y)}\right)\right) \right\} \tag{11}$$

where L = number of scenes
(I,J) and (I',J')= SOM node coordinates
$\mathbf{q}^{(x,y)}$ belongs to the node (I',J')

iv) to calculate coefficient h by eq. (12) and eq. (13)

$$h(I,J,x,y) = \exp\left\{ -\frac{(I-I')^2 + (J-J')^2}{2\sigma(k_t)^2} \right\} \tag{12}$$

$$\sigma(k_t) = \max\left\{ 0.01, \sigma_{\mathrm{init}}\left(1 - \frac{k_t}{K_{\max}}\right) \right\} \tag{13}$$

where $K_{\max}$ = number of maximum iterations
σ_{init} = constant ($\sigma_{\mathrm{init}} > 0$)

v) to update weight vector $\mathbf{w}_{IJ}$

$$\mathbf{w}_{IJ} = \frac{\sum_{x,y} h(I,J,x,y) \cdot \mathbf{D}\left(\mathbf{q}^{(x,y)}\right)}{\sum_{x,y} h(I,J,x,y)} \tag{14}$$

vi) $k_t \leftarrow k_t + 1$
vii) to go to step iii) until $k_t = K_{\max}$
viii) to determine final clustering vector by eq. (11)
ix) to calculate the centroid in each node by eq. (15)

$$\mathbf{q}_{IJ} = consensus(\mathbf{w}_{IJ}) \tag{15}$$

x) to write weight vector $\mathbf{w}_{IJ}$ and final clustering vector (x,y,I',J') to file

2.4 Spectral anomaly detection

In this section, we describe our algorithm about spectral anomaly detection. In general, an anomaly detection methodology is required to clearly distinguish spectral anomaly (i.e. land cover changes) and phenological changes.
If parameters $\mathbf{b}$, seasonal change profile of reference year $\mathbf{q}^{(x,y)}$ and clustering results $\mathbf{Q}$ are known, we can define observation probability of encoded spectrum $p(v_t^{(x,y)})$ in another scene t at (x,y) pixel:

$$p\left(v_t^{(x,y)}\right) = \max_{l} \left\{ a_{kl}^{(t)} b_l\left(v_t^{(x,y)}\right) \right\} \tag{16}$$

where $v_t^{(x,y)}$ = encoded spectrum of another scene
(x,y) = image coordinates
t = scence ID (time)
$a_{kl}^{(t)}$ = $(k \rightarrow l)$ state transition probability at t
$k = q_{t-1}^{(x,y)}$ (the state of reference year at t-1)
l = indices of HMM state

From eq. (16) we get inferential state $\psi_t^{(x,y)}$

$$\psi_t^{(x,y)} = \arg\max_{l} \left\{ a_{kl}^{(t)} b_l\left(v_t^{(x,y)}\right) \right\} \tag{17}$$

$a_{kl}^{(t)}$ is obtained by eq.(18)

$$a_{kl}^{(t)} = \frac{\#\left(q_{t-1} = k, q_t = l, \mathbf{q} \in \mathbf{Q}_{IJ}\right)}{\sum_{l=1}^{N} \#\left(q_{t-1} = k, q_t = l, \mathbf{q} \in \mathbf{Q}_{IJ}\right)} \tag{18}$$

where $\mathbf{Q}_{IJ}$ =a set consists of state vectors which assigned to the SOM node (I,J).
Then, according to hanon's theorem (Shanon, 1948), we define anomaly score s.

$$s = -\log_2 p\left(v_t^{(x,y)}\right) \tag{19}$$

For setting threshold value of s, we assume that encoded spectra are generated by random process. From eq. (16), generating probability p_{random} is

$$p_{random} = \frac{1}{N} \cdot \frac{1}{N_c} \tag{20}$$

where N = total number of states
N_c = total number of spectral code

From eqs. (19) and (20), we get threshold of anomaly score s_{tht}

$$s_{\text{tht}} = -\log_2 \left(p_{random}\right) = -\log_2 \left(\frac{1}{N} \cdot \frac{1}{N_c} \right) \tag{21}$$
$$= \log_2 N + \log_2 N_c$$

We look upon pixels which is anomaly socre s > s_{tht} as occurrence of anomaly phenomena.

3. RESULTS AND DISCUSSION

3.1 Water coverage monitoring

An example of our model processing of MODIS (MOD09A1) data is shown in Figure 2. 414 scenes from the early January 2001 till the end of December 2009 were used. The targeted area is Amazon River basin (10N~20S, 80W~40W, Figure 2). Figure 2a, 2b and 2c are raw composite, time-series modelling results (by HMM) and cluster centroid, respectively. As for the processed data, almost all the influences of cloud and noises disappear. 23 states were obtained and "state 23" is assigned to water spectra which is clearly distinguished from other states in the spectral shape (Figure 3). We obtained the water coverage period map by occurrence frequency of state 23 (Figure 4).

3.2 Burned area detection

In order to detect of burned area with 10 days interval, SPOT/vegetation S10 products were processed. The targeted area is far-east Russia (50N~54N, 127E~133E, Figure 5). The data collection period as reference year is from Apr. 1999 to Mar. 2000 (one year, 36scenes). We set SOM node size to 10×10 for clustering of seasonal change profile.
As results, 15 states were obtained. Figure 6 shows 4bands spectra of each state. There are mainly four categories "vegetation", "soil", "snow" and "water" from visual interpretation (Table 1).
The data collection period for anomaly detection is from Jun. to Aug. 2000 (12scenes). Original data (S10 product), inferred state and anomaly score are shown in Figure 7. For comparison,

(a) (b) (c)

Figure 2. Examples of our discrete time-series processed MOD09A1 data (Jan. 12 2009)
(a) original MODIS data (b) HMM processed image (c) cluster centroid image

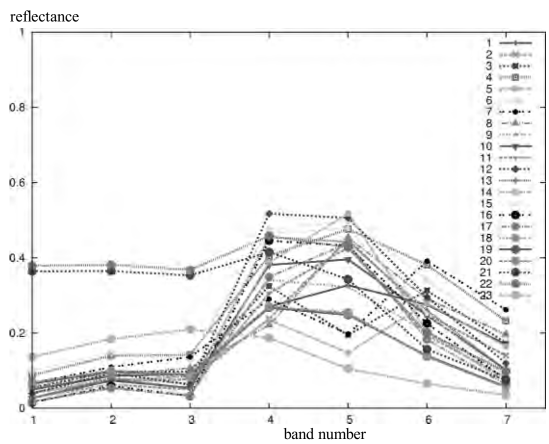

Figure 3. Spectra of states

Figure 4. Water coverage period in 2008

same area of the GBA2000 (Global Burned Area, Grégoire et al., 2006) product is also shown in Figure 7. Our method was found effective to identify burned area with pixel by pixel.

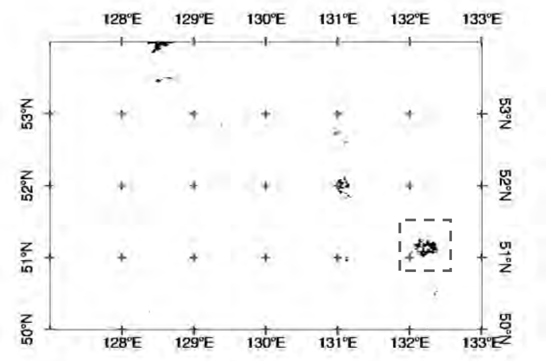

Figure 5. Targeted area of burned area detection

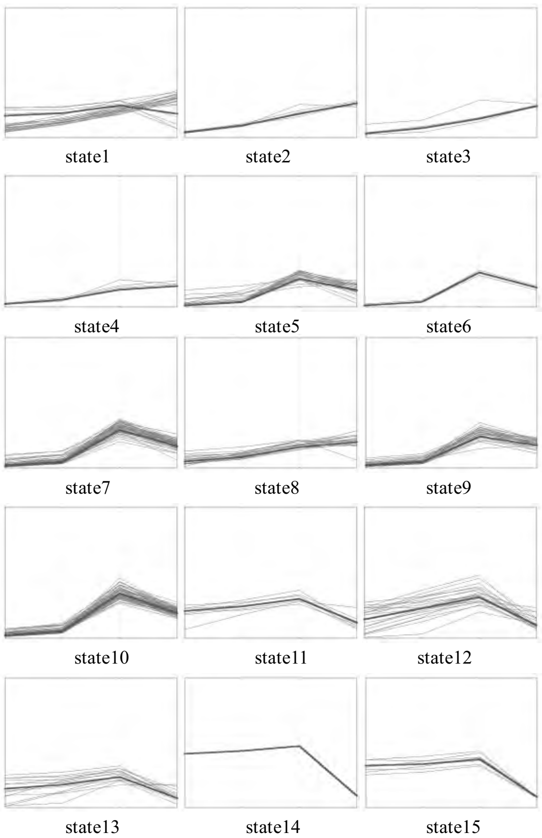

Figure 6. Spectra of each state
(red: averaged spectra)

Table 1. States and Categories

category	state ID
Vegetation	5,6,7,9,10
Soil	1,2,3,4,8
Snow	11,12,13,14,15
Water	1

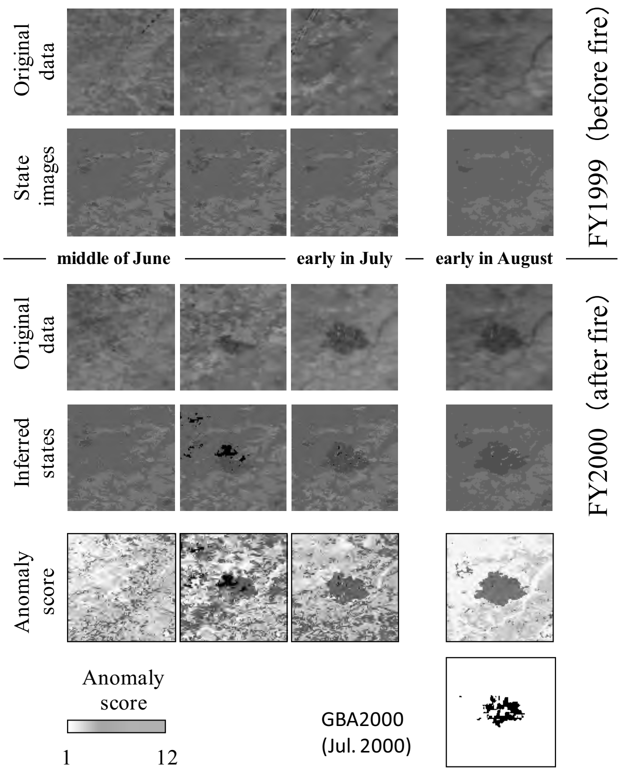

Figure 7. Identification of burned area

3.3 Forest development area detection

In order to identify deforestation trend with 10 days interval, 10-days composite MODIS data were processed. MODIS data were obtained from WebMODIS system (Takeuchi et al., 2005). The result shows to identify deforestation trend with pixel by pixel (Figure 8). ASTER VNIR images are also shown in Figure 9 for comparison.

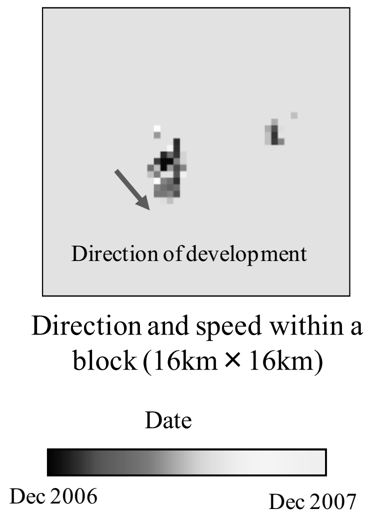

Figure 8. Deforestation direction and trend.
(13.417N, 106.112E)

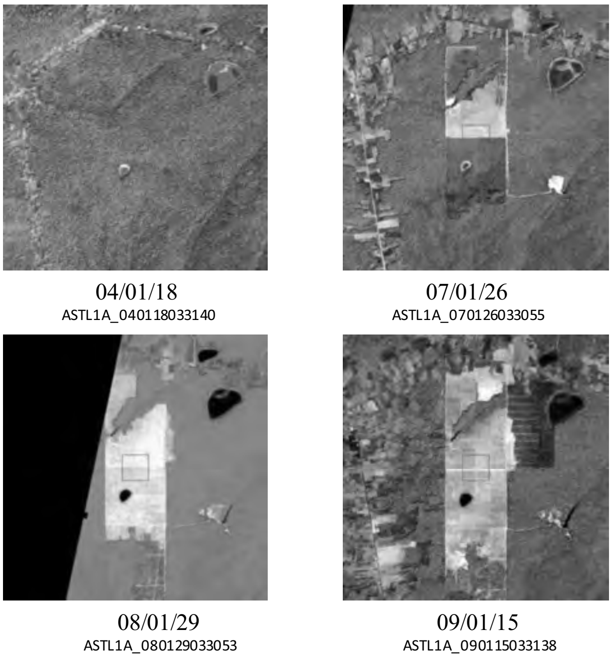

Figure 9. ASTER VNIR image (13.417N, 106.112E, 9km× 9km)

4. CONCLUSIONS

We developed a discrete time-series model using a self-organizing map (SOM) and a hidden Markov Model (HMM) to reduce the influence of clouds in order to improve the accuracy of the products. Our method is able to clearly distinguish spectral anomaly and phenological changes. Our method is found effective to identify land cover changes (i.e. forest fire and deforestation) with pixel by pixel, but further study will be required to clarify its limitation on areas of land cover changes. A small land cover changes will not be identified.

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Optimum design for smoke-control system in buildings considering robustness using CFD and Genetic Algorithms

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ABSTRACT

In fire-prevention designs for buildings, the major concerns are ensuring safe evacuation in the event of a fire and preventing the fire from spreading. Fire inevitably involves many uncertainties, such as the site of the fire source, whether or not a window is open, erroneous operation of prevention systems, and so on, which increases the risk leading to a large disaster. It is very important to consider these uncertainties to design a safe fire-prevention system. In this research, the optimum design method considering the robustness of smoke-control systems in buildings is developed using an approach that couples Computational Fluid Dynamics (CFD) with Genetic Algorithms (GA). The general optimum design and robust design for a vestibule pressurization smoke-control system in an office are conducted. As a result, although the airflow rate through the doorway of the vestibule, intended to ensure that smoke does not escape into the vestibule during evacuation, is a little lower than the general optimum design, the safety performance of the system is more stable in the robust case. The optimum design method proved to be useful in terms of the fire-prevention system design. The approach will be conducted for other urban safety design.

1. Introduction

Due to progressive urbanization, there has been a rapid increase in complex buildings over recent years. As is already well known, buildings are strongly associated with environmental, energy and safety issues. In order to minimize their impact on these issues, sophisticated strategies to control building systems operations must be handled by the designers, planners and engineers. Computer simulation-based control of building systems is recognized as an effective approach. Such simulations can capture a building's dynamic characteristics over time thus providing a more reliable basis for control of its behavior [1,2]. This paper focuses on the safety issue and the use of an optimization program coupled with Computational Fluid Dynamics (CFD) simulations to optimize a smoke-control system, which provides a refined and robust design for the building's safety control.

Preventing smoke from entering a stairwell is very important in smoke-control design. One approach is by pressurizing the stairwell or the vestibule adjacent to the stairwell with outdoor air. Thus, there are basically two types of pressurization smoke-control systems. One is a stair pressurization system, and the other is a vestibule pressurization system. In this study, the well-used vestibule pressurization system will be discussed. At the same time, fire inevitably involves many uncertainties, such as the site of the fire, whether or not a window is open, erroneous operation of prevention systems, and so on. These increase the risk of a major disaster developing. Therefore, the optimum design should give enough consideration to reliability and robustness in cases where such uncertainties exist.

Research into the optimal design in the fields of building construction and building environments has apparently increased. Kato and Lee [3] coupled CFD and Genetic Algorithms (GA) [4] to optimize a hybrid air-conditioning system using natural ventilation in mid-term. Zhou and Haghighat [5,6] developed an optimization approach by using CFD in conjunction with GA and artificial neural network for office environment ventilation system design. For pleasant outdoor thermal environment design, GA and coupled simulation of convection, radiation, and conduction were applied to the optimal arrangement of trees and buildings [7,8]. However, in terms of safety, optimization design has been widely conducted in evacuation processes [9,10], little research is found for smoke-control systems. For smoke-control system designs, three-dimensional distribution of physical characteristics during the fire is necessary. Therefore, it is thought that a similar optimization approach coupling CFD and optimization method could also be applied to build designs for fire prevention. Furthermore, robustness

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of the system has been little considered in previous research. In this research, the optimum design method considering the robustness of smoke-control systems in buildings is developed using an approach that couples CFD with GA, and a vestibule pressurization smoke-control system for offices is optimized using this approach.

2. Method

2.1. Optimization system and GA method

The optimization system coupling GA and CFD for smoke-control design, which is developed based on a feedback system [7,11], is shown in Fig. 1. This system constitutes three parts: (A) Setting of the optimal problem; (B) CFD analysis of fire dynamics, and (C) Evaluation of the smoke-control system and optimal process control. In part A, the design objective and design parameters are determined. Meanwhile, the optimization and evaluation methods for the optimal design are determined. In part B, CFD analysis, which can provide spatial and temporary distribution of the variables of interest in a fire's evolution, is conducted. In part C, if the optimum solution satisfies the design objective, the results are obtained. If it doesn't satisfy the design objective, the design parameters are selected by GA and fed back to the CFD analysis for the next evaluation. The feedback loop will continue until the optimum solution satisfies the design objective.

Genetic algorithms are used to select the optimum solution candidates, and to control the optimum inquiry process. GA is a method that enables optimization problems to be solved by imitating the organic evolutionary process. GA performs the genetic operations such as selection, crossover, and mutations on each individual, and the fitness (objective function) of each individual is calculated for their evaluation. The individual with the highest fitness value among the investigated individuals becomes the optimum individual. GA is an effective means of investigating nonlinear problems, such as turbulent flow and so on.

Moreover, a more efficient genetic algorithm known as "Multi-island Genetic Algorithm" [12] is used in this research. The feature of this method is that the population in one generation is divided into several sub-populations, on which the genetic operations are conducted. The exchange of individual information, a process known as "migration", is generated periodically between sub-populations.

2.2. General optimization and robust optimization

General optimization usually seeks out the optimal combination of design parameters under a fixed environmental condition. However, in practice, environmental conditions usually change or fluctuate. We do not know if this optimum design will function smoothly under these changes. Such uncertainty is very dangerous in a system or product. The objective of robust design is to ensure a robust system under varying environmental conditions and to consider the variability in the system's components.

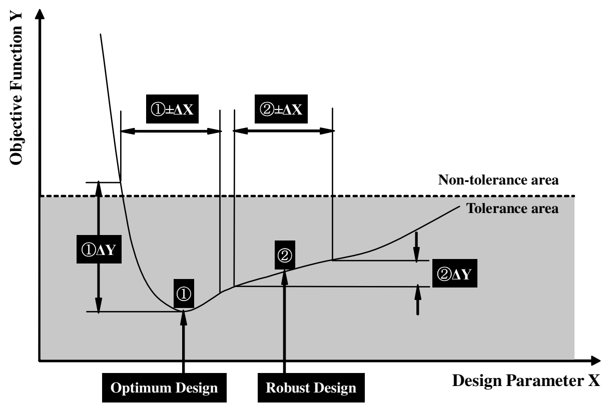

Fig. 2. Difference between general optimum design and robust design.

Fig. 2 shows the difference between the general optimum design and robust design. In the case where fluctuation $\pm\Delta X$ occurs, the fluctuation of the response (ΔY) in the general optimum design ① is large, with a response value far removed from the optimum value. In extreme cases, it may exceed the tolerance area. On the other hand, in the robust design ②, though the same fluctuation $\pm\Delta X$ occurs, the response remains within the tolerance area, due to the small fluctuation in the response (ΔY). Therefore, robustness means system stability within the effects of environmental fluctuations, and is very important for quality design of systems or products. Robust design covers not only the optimum for the objective function, but also minimizing variation in responses arising from any fluctuations. As shown in Fig. 2, the aim of the robust design is to find the point where the variance in response is minimized while at the same time the objective function is optimized when the design parameters and fluctuation factors are entered into the system.

One important point concerning robust design is the robustness evaluation for each candidate solution. This is processed by sampling the environmental fluctuation factors then calculating the response value (objective function). Then the robustness

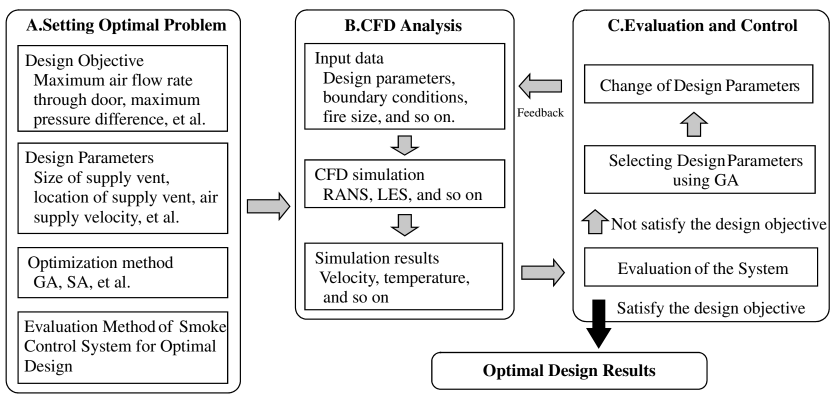

Fig. 1. Optimal design system coupling CFD and GA for smoke-control design.

characteristics are examined. As already mentioned, fire inevitably involves many environmental uncertainties, so a robust design for the smoke-control system is required.

2.3. CFD simulation

The air supply rate required to maintain an adequate pressure differential is usually determined using a zone model [13] or some simplified calculation method [14]. However, in the detailed design of the system, for example, regarding the sizes and locations of air supply vents, it is difficult to factor in these methods. Therefore, the possibility exists that smoke flows into the vestibule or stairwell in the local area even if the required air supply rate is satisfied. CFD can deal with such detailed design issues since it provides detailed 3D dynamic characteristics. CFD modeling has been successfully applied to various fire safety problems, and its role in fire research is steadily increasing as progressively more robust and sophisticated models and validation studies render them more reliable [15]. CFD models are naturally classified in accordance with the methods by which they treat turbulence phenomena. The two major groups may be identified as Reynolds-Averaged Navier–Stokes (RANS) models and Large Eddy Simulation (LES) models. In this study, the fire-driven flow characteristics are simulated by the Fire Dynamics Simulator (FDS), which is based on the fundamental conservation of heat, momentum and mass using an LES method and well validated [16].

3. Application to vestibule pressurization system design

3.1. Design object and design cases

The design object is shown in Fig. 3. This is a simplified office building with 10 stories. The office is of length 10 m, width 10 m and height 2.5 m, and an adjacent corridor is of length 8.0 m, width 3.0 m and height 2.5 m. The office has a doorway of width 1.5 m and height 2.0 m opening into the corridor. A vestibule, which has two doorways opening to the corridor and the stairs, is provided. The heights of the doorways are 2.0 m. The smoke-control system consists of a smoke extractor in the office and a pressurization process through the vestibule. The vestibule is pressurized with outdoor air using a supply fan to prevent smoke from entering the vestibule and the stairwell. In this study, two design cases, the general optimum design and robust design have been conducted. The differences between the two cases will be described in the following sections.

3.2. Design objective function

As mentioned, the possibility exists that smoke may escape into the vestibule or stairs in the local area even if the required air supply rate is satisfied. CO is another important parameter to be analyzed in fire processes too. In this study, smoke (soot) and CO are assumed to be carried on the airflow. Thus the characteristics of the airflow are mainly analyzed. Here, the average airflow rate through the doorway between the vestibule and the corridor during the evacuation time is selected as the design objective. The design parameters are selected using GA to maximize airflow rate during evacuation, which would ensure that the smoke does not escape into the vestibule. At the same time, no back draft exists through the doorway. This means that it would ensure that the smoke and CO does not escape into the vestibule during evacuation.

In the general optimum design, the optimum objective is to maximize the airflow rate through the doorway between the vestibule and the corridor during the evacuation time. In the robust design, the following objective function is used.

$$F = \sum_{i=1}^{l}\left[(\pm)\frac{w_{1_i}}{s_{1_i}}\mu_{Y_i} + \frac{w_{2_i}}{s_{2_i}}\sigma^2_{Y_i}\right] \quad (1)$$

Where, i is the number of the response value. μ_Y is the average of the response value (here, the response value is the maximum airflow rate through the door). It is positive (+) in the case of a minimum problem, and negative (−) in the case of a maximum problem. σ_Y is the standard deviation. Here, the negative (−) is used and the optimum objective is to minimize F. This means to find a design which will provide maximum airflow rate and minimum standard deviation at the same time. w_1 and w_2 are the weight coefficient of the average response value and the standard deviation respectively. s_1 and s_2 are the scale factor of the average and the standard deviation. It is important to set a value for the weight coefficient and scale factor. In this study, before conducting the robust design, the robustness of top candidate of the general optimum design was evaluated, then the weight coefficient and the scale factor were set based on the obtained average response and the variance.

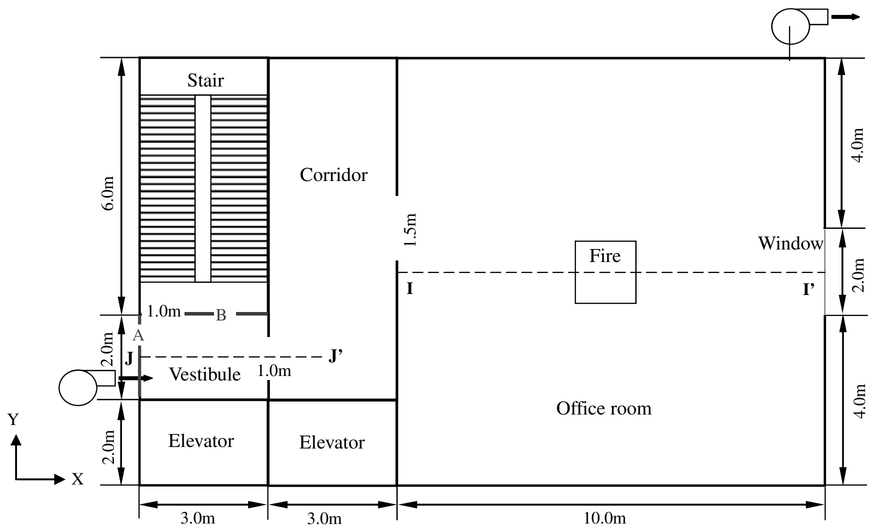

Fig. 3. The design object.

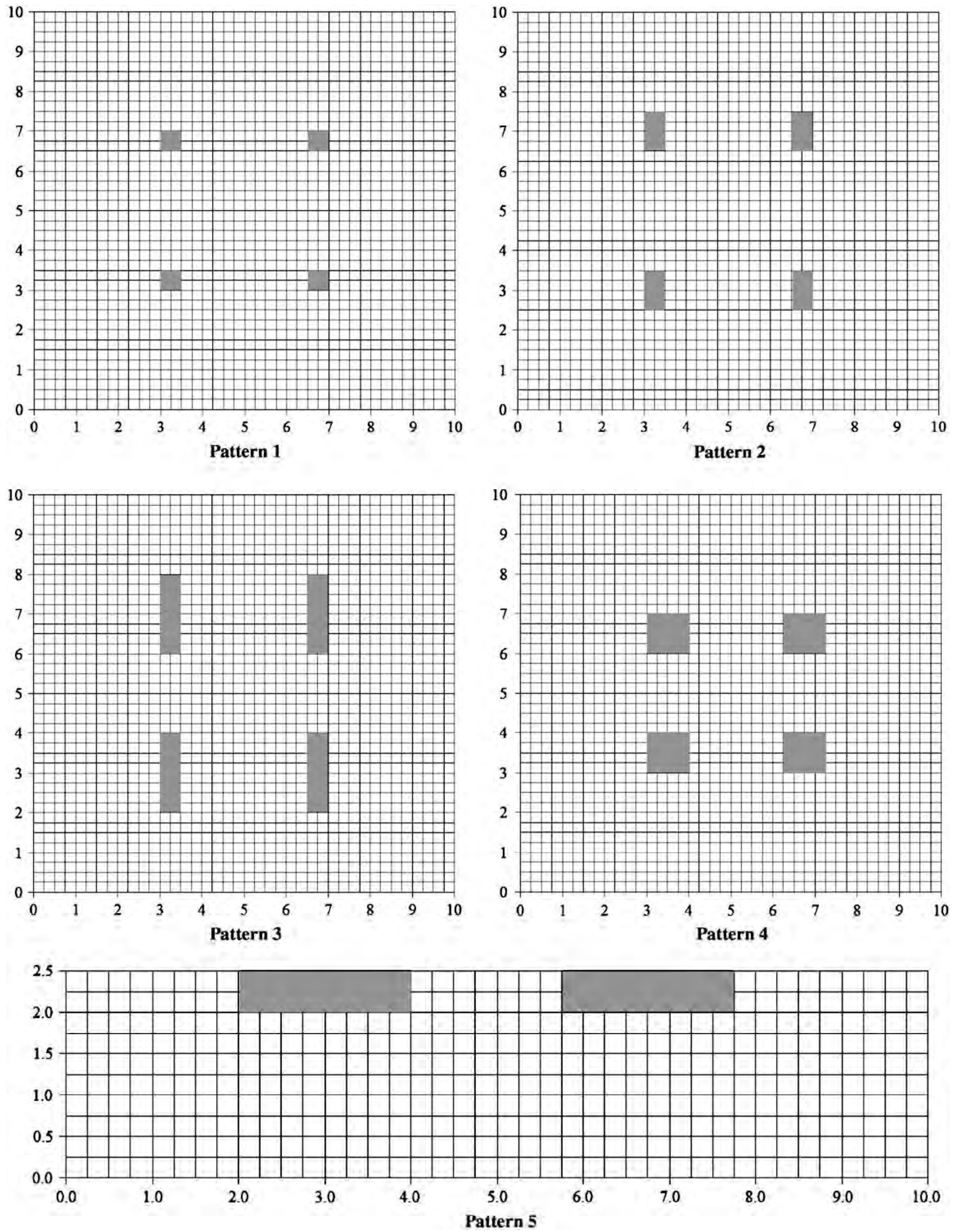

Fig. 4. Patterns of smoke extraction vents (unit: m).

3.3. Design parameters

The required air supply rate from the vestibule is set at 4.17 m^3/s constantly based on the calculations of Matsushita et al. [13] and Kujime et al. [14]. Usually, air is also supplied via the elevator shaft, but here the airflow from the elevator is assumed to be zero for ease of calculation because the air supplied from the elevator is insignificant compared to that from the vestibule. Patterns of smoke extraction vents and air supply vents are shown in Figs. 4–6. The locations and sizes are changed. For the extraction vents, Patterns 1–4 are in the ceiling, Pattern 5 is in the wall with window. In the vestibule, the vents are assumed to be a combination of vents in the ceiling, the wall facing the doorway (Blue part A in Fig. 3) or the sidewall adjacent to the stairs (Red part B in Fig. 3). [For interpretation of the references to colour in this text, the reader is referred to the web version of this article.] Optimum combination of these parameters will be designed to satisfy the optimum objectives.

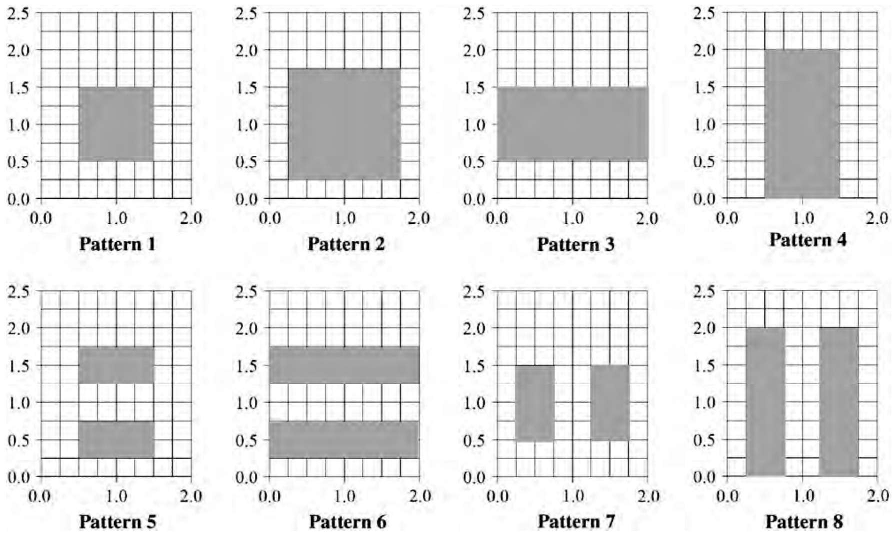

Fig. 5. Patterns of air supply vents (wall facing the doorway and sidewall) (unit: m).

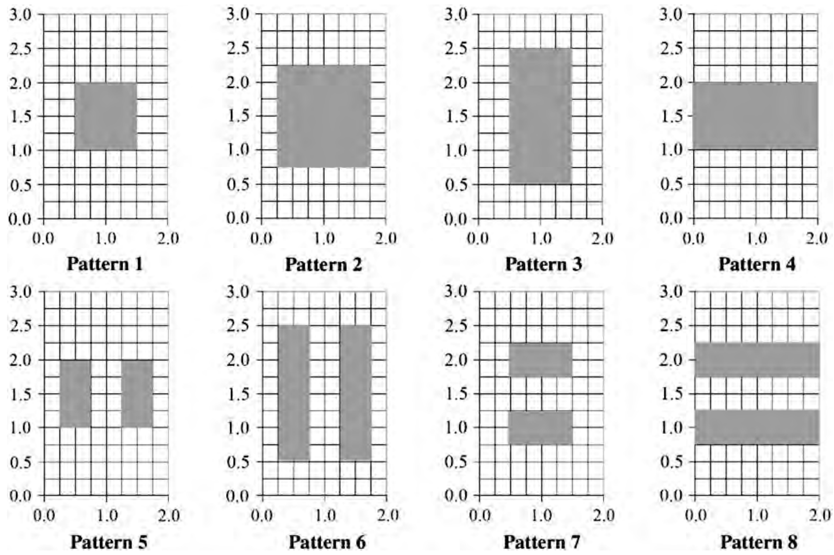

Fig. 6. Patterns of air supply vents (ceiling) (unit: m).

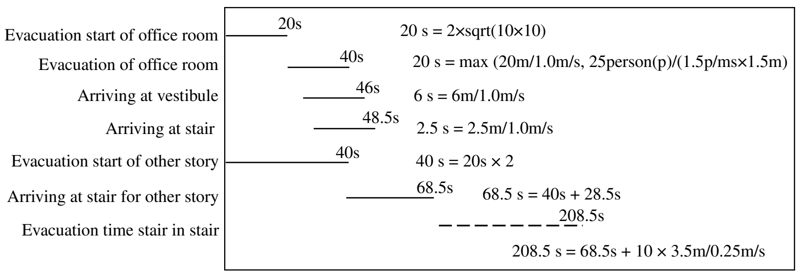

Fig. 7. Calculation of evacuation time.

Table 1
GA parameters.

	General optimum design	Robust design
Size of sub-population	10	8
Number of islands	5	5
Number of generations	20	12
Total individual size	1000 ($10 \times 5 \times 20$)	480 ($8 \times 5 \times 12$)
Rate of crossover	0.5	0.5
Rate of mutation	0.02	0.02
Rate of migration	0.5	0.5
Rate of tournament	0.4	0.4
Interval of migration	4	4

Table 2
Summary of design cases.

Design parameter	General optimum design	Robust design
	Same	
Design objective	Maximum airflow rate	Eq. (1) Maximum airflow rate Minimum variance
Fire source location	Fixed at center	Changed
Fire scenario	Same	
Evacuation time	Same	
GA parameter	Shown in Table 1	
Sampling	Not needed	5 Samplings for every iteration

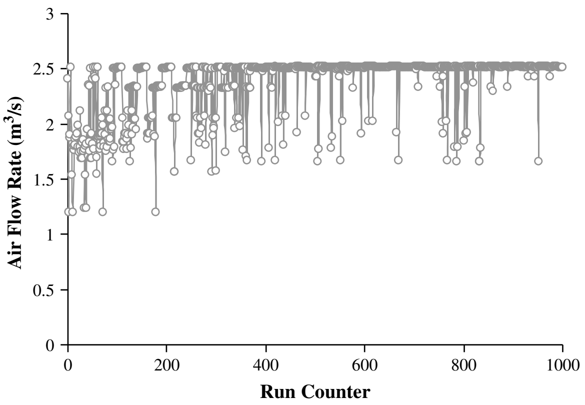

Fig. 8. Curve of GA inquiry in the general optimum design.

3.4. Fire scenario

The fire scenario setting is important in smoke-control system design. The following fire scenario is assumed here. The fire size is set as 1.0×1.0 m^2. The fire was quantified by assuming a fast t^2 fire. That is, $Q = at^2$. This assumption is a reasonable estimate for an office. Parameter a and the maximum heat release rate are set at 0.015 and 500 kW respectively [17]. The smoke-control system is activated 20 s after the fire starts. The window is also assumed to be open 20 s later. Smoke extraction will stop if the temperature of the smoke entering the duct exceeds 280 °C. The doorway adjacent to the stairs in the vestibule is open for evacuation. In the general design, the location of the fire is assumed to be in the center of the office. However, in the robust design, the fire location is set as an uncertainty factor and changing. Therefore, for every iteration, five samples are selected by changing the center of the fire source with 30% every time. Then the μ_Y, σ_Y, and F are calculated for every iteration.

3.5. Evacuation time

An evacuation generally consists of three stages: evacuation first of the actual room containing the fire, then of that story, and finally of the whole building. The evacuation time for this office building is calculated based on the fundamental theory of evacuation [18]. The result is shown in Fig. 7. The evacuation time for the story on fire is 48.5 s, and for the whole building is 208.5 s.

3.6. GA parameters and summary of the design cases

The GA parameters in this study are shown in Table 1 for both the general optimum and robust designs. 20 and 12 generations are processed respectively. Table 2 summarizes the design details for the general optimum and robust designs. The principal differences are the design objectives and location of the fire. For the CFD simulation, the fire is modeled using propane. The yield of soot is set as 0.01. The following FDS default yield of CO is used.

$$y_{CO} = \frac{12x}{M_f v_f} 0.0014 + 0.37 y_s \tag{2}$$

where x is the number of carbon atoms in a fuel molecule, M_f is the molecular weight of the fuel, and v_f is the stoichiometric coefficient of the fuel, assumed to be 1 here [19]. A uniform grid system with a resolution of 0.25 m throughout the simulation domain is used (refer to Section 4.4).

Table 3
Results of the two designs.

	Rank	1	2	3	4	5	6
	Extraction	Pattern 4	Pattern 4	Pattern 2	Pattern 3	Pattern 3	Pattern 1
General Optimum Design	Vestibule ceiling	Pattern 5	–	–	–	Pattern 5	Pattern 5
	Vestibule facing	–	Pattern 4	Pattern 4	Pattern 4	–	–
	Vestibule side	–	–	–	–	–	–
	Total airflow (m^3/s)	2.525	2.516	2.512	2.510	2.508	2.504
Robust design	Extraction	Pattern 4	Pattern 4	Pattern 1	Pattern 1	Pattern 1	Pattern 4
	Vestibule ceiling	Pattern 1	–	–	Pattern 1	Pattern 6	Pattern 5
	Vestibule facing	–	Pattern 3	Pattern 3	–	–	–
	Vestibule side	–	Pattern 7	Pattern 7	–	–	–
	Total airflow (m^3/s)	2.334	2.104	2.097	2.340	1.668	2.519
	Standard deviation	0.00999	0.0108	0.0111	0.0126	0.0091	0.0148
	Objective function F	−0.252	−0.104	−0.082	−0.078	−0.044	−0.001

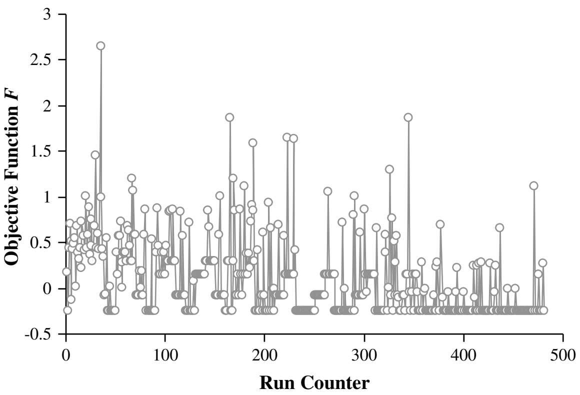

Fig. 9. Curve of GA inquiry in the robust design.

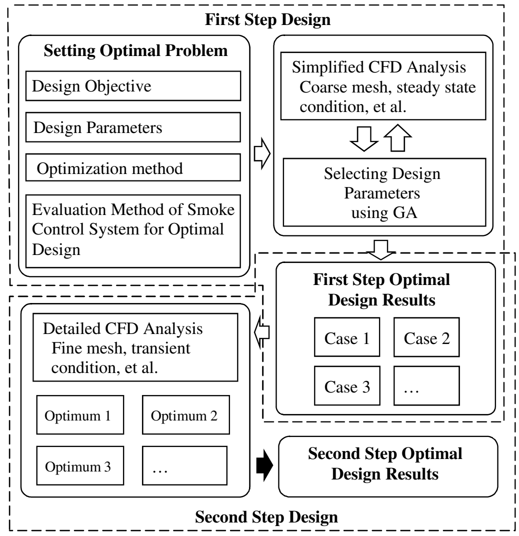

Fig. 10. Two-step optimal design method.

4. Results and discussion

4.1. General optimum design

The curve of the GA inquiry using multi-island GA and CFD is shown in Fig. 8. The horizontal axis shows the Run Counter for the optimum selection process, and the vertical axis shows the objective function (airflow rate). It can be seen that the maximum airflow through the doorway converges at about 2.5 m^3/s. The results of the top six candidates are shown in Table 3. The maximum airflow through the doorway of the vestibule is 2.525 m^3/s. Because the total air supply rate is 4.17 m^3/s, it is clear that some of this air flows into the stairwell through the open doorway adjacent to the stairs. The best result is a combination of Pattern 4 (see Fig. 4) for the smoke extraction vent and Pattern 5 (see Fig. 6) at the vestibule ceiling for the pressurization vent. In terms of the extraction vent in the room, it agrees with the common perception that the extraction vents are best set in the ceiling rather than the sidewalls. Meanwhile, it is worth noting that a square shape is better than rectangular at the same extraction airflow rate. In the vestibule, vents in the ceiling and facing wall are a good choice. In terms of the ceiling, there is a tendency that smaller vents in a uniform arrangement leads to better results. In terms of the facing wall, the shape same as the vestibule door is best.

4.2. Robust optimum design

The curve of the GA inquiry in the robust design using multi-island GA and CFD is shown in Fig. 9. This shows that the objective function decreases, and after 300 runs, converges to its optimal value. The results of the top six candidates are also shown in Table 3. The maximum airflow through the doorway of the vestibule is 2.334 m^3/s. This is a little lower than the optimum design. In terms of extraction vents, Pattern 4 is the best choice too. Pattern 1 is another reasonable choice. This indicates that square vents provide a robust design. The ceiling is still a good choice for the vestibule, and Pattern 1, the square vent, is better too.

Table 4
Robustness of top candidate.

Sampling	Airflow rate (m^3/s)	
	General optimum design	Robust design
1	2.525	2.334
2	2.525	2.321
3	2.477	2.362
4	2.512	2.367
5	2.535	2.326
Standard deviation	0.0226	0.0211

4.3. Evaluation of the robustness

The purpose of conducting robust designs is to achieve a design offering the optimum response for the objective function despite the presence of some uncertainties, while at the same time, minimizing the standard deviation of the response. In order to understand the performance stability of the robust design, robustness evaluations for the top ranked individual in terms of the general optimum design and robust design are conducted. The fire source location is set as an uncertainty and five samplings were selected. The airflow rates are calculated and shown in Table 4 for the five samplings. It is apparent that the airflow rate is lower in the robust design, however, the unevenness is smaller. This means that under the same environmental fluctuations, the change in the general optimum design is larger, demonstrating that the general optimum design is somewhat sensitive. If there is a large fluctuation, this has a greater possibility of failing to operate satisfactorily.

4.4. Limitations and ongoing work

For a fire plume, the characteristic length scale is related to the HRR, Q (kW) [20]. In general, large-scale structures that are controlled by inviscid terms can be completely described when this characteristic length L^* is spanned by roughly ten computational cells [21]. L^* is

$$L^* = \left(\frac{Q}{\rho_\infty c_p T_\infty \sqrt{g}}\right)^{2/5} \tag{3}$$

For the fire plume considered here, the characteristic length, L^*, is in an order of 0.2–0.5 m. This implies that adequate resolution of a large-scale fire plume can be achieved with a spatial resolution of about 0.02–0.05 m.

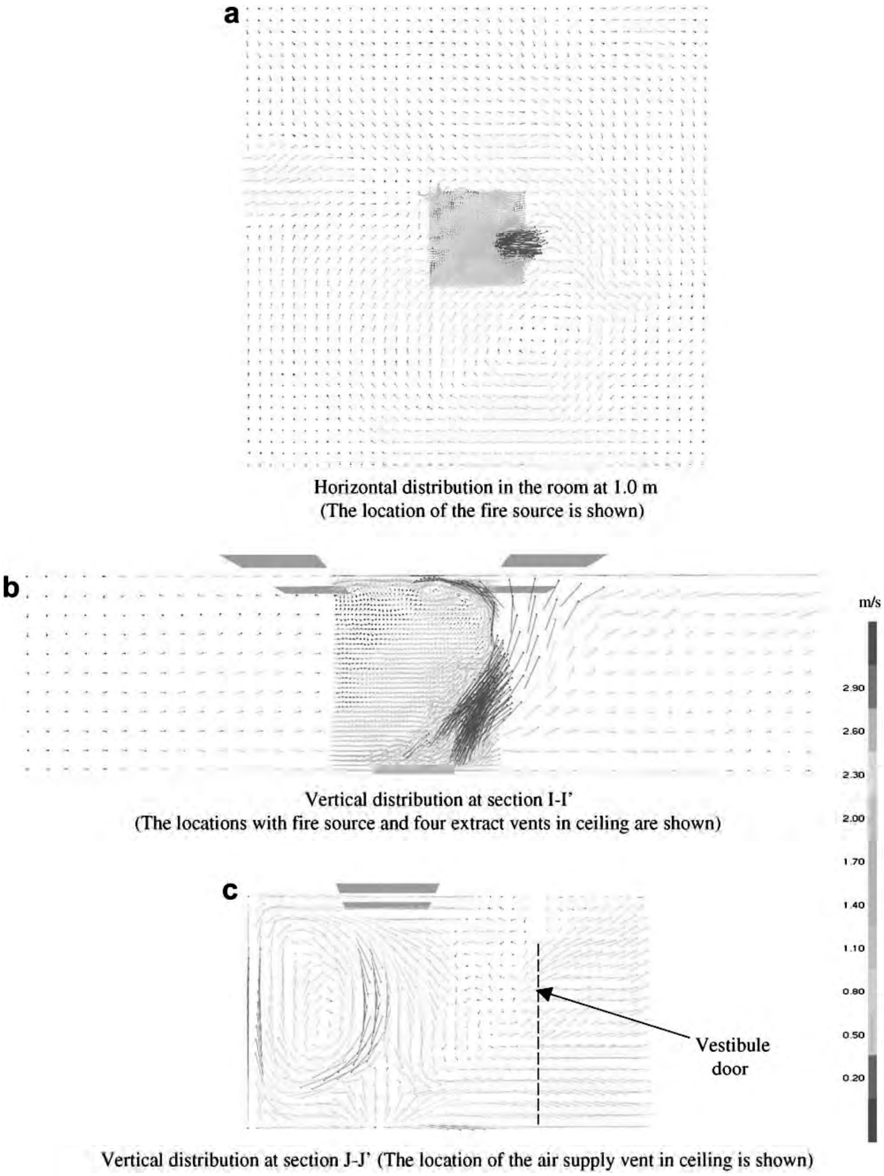

Fig. 11. Wind velocity distributions at three sections (Top candidate in the general optimum design).

The design object is a large office space with an order of 10 m. A uniform grid system with a resolution of 0.25 m throughout the simulation domain is used in the CFD simulation. The CFD can only capture fire structures on a scale which is larger than the grid, which may result in some degree of underestimation. It typically takes about 10 min on a Pentium IV desktop computer with dual-processor (3.0 GHz speed) for one simulation run. On the other hand, the authors also test a finer mesh simulation with a resolution of 0.05 m around the fire source. It typically takes about 20 h for one simulation run. Many pure fire numerical simulation studies using FDS have been performed (e.g. [22–24]). In this study, the main objective is to propose a new optimum approach considering the robustness for smoke-control systems. With the GA setup used here, thousands of runs of the CFD program could have been required for a GA search. In order to apply the developed robust design approach in a practical way, a comparatively coarse mesh was adopted here. The application is used to illustrate the concept of the proposed method and it is not meant to indicate the level of CFD set up for the fire plume calculations. The authors fully recognize this kind of limitation and are now developing a two-step optimization process to reduce the calculation time and increase the design accuracy.

Fig. 10 shows the two-step optimization process. In the first-step design, a rough calculation considering the calculation load is conducted. The highest ranked solutions from the first-step optimal design results will be selected as candidates for the second step design. In the second step design, detailed analysis will be conducted only for the highest ranked solutions. Finally, the optimum solution is obtained. Therefore, if

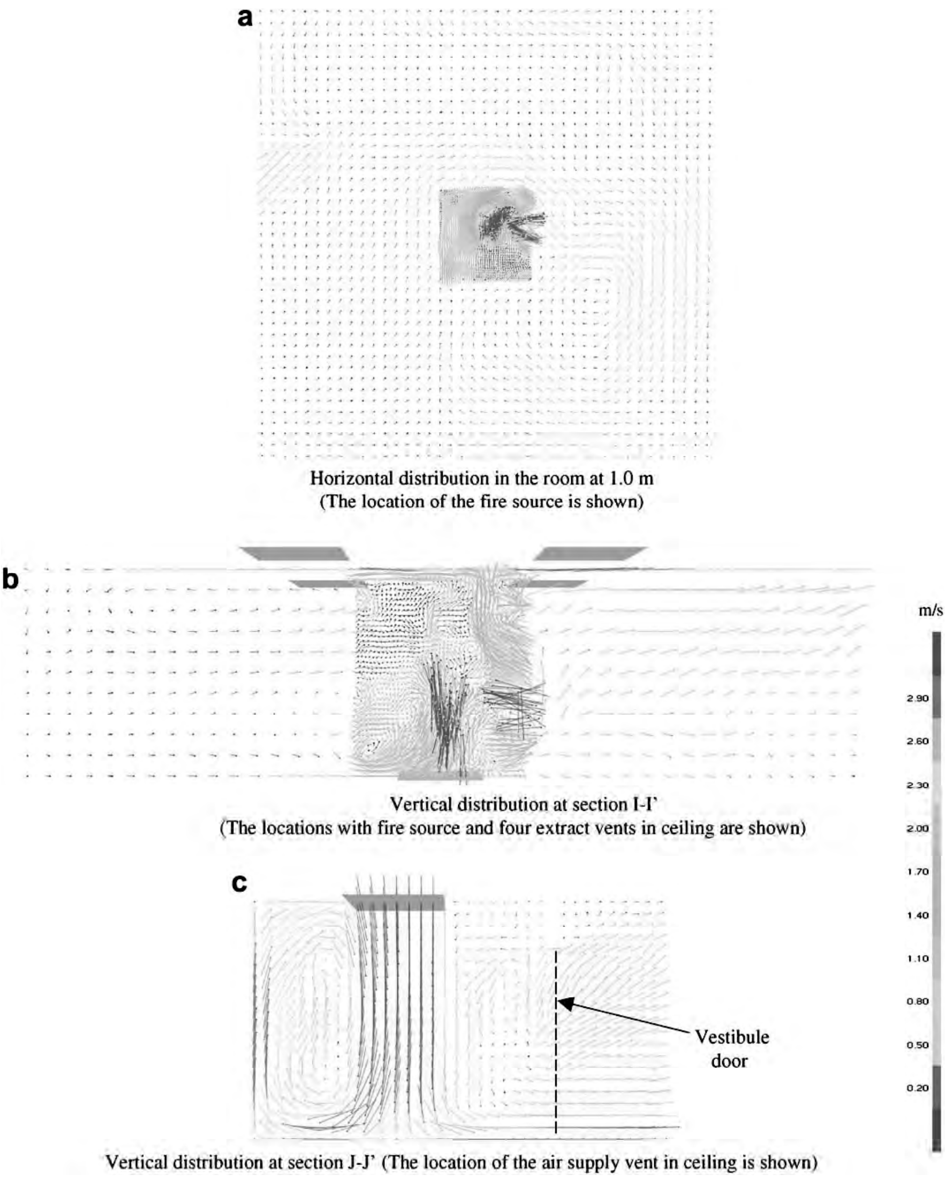

Fig. 12. Wind velocity distributions at three sections (Top candidate in the robust optimum design).

a finer design is required, more detailed CFD analysis using a finer mesh will be conducted on the higher ranked solutions. On the other hand, if the design does not require a detailed environmental simulation, some simplified model, such as a zonal or network model can be used to speed up the design process.

4.5. Wind velocity and temperature characteristics

The wind velocity and temperature characteristics of the top candidates for the general optimum design and the robust optimum design are investigated with a finer mesh with a resolution of 0.05 m locally refined in the fire region. Figs. 11 and 12 show the wind velocity distributions at 200 s when the fire source is in the center of the room. The horizontal distribution at 1.0 m height in the office, the vertical distributions at section I–I′ (refer to "Fig. 3. The center line of the room") and J–J′ (refer to "Fig. 3. The center line of the vestibule") are shown respectively. Fig. 13 shows the vertical temperature distribution at section I–I′. A substantial clockwise horizontal vortex is found to form in both design cases. The air supplied from the upper left door contributes to this vortex formation. A strong fire plume is shown in both design cases. The velocity is over 3 m/s and the temperature is around 1000 °C near the fire source. The fire plume is found to be a little stronger and incline to the window in the general optimum design case than in the robust case. The total air-flow rate through the vestibule door is a little higher in the general design case than in the robust case. This higher air supply rate likely leads to the stronger plume and the inclination in the general optimum design case.

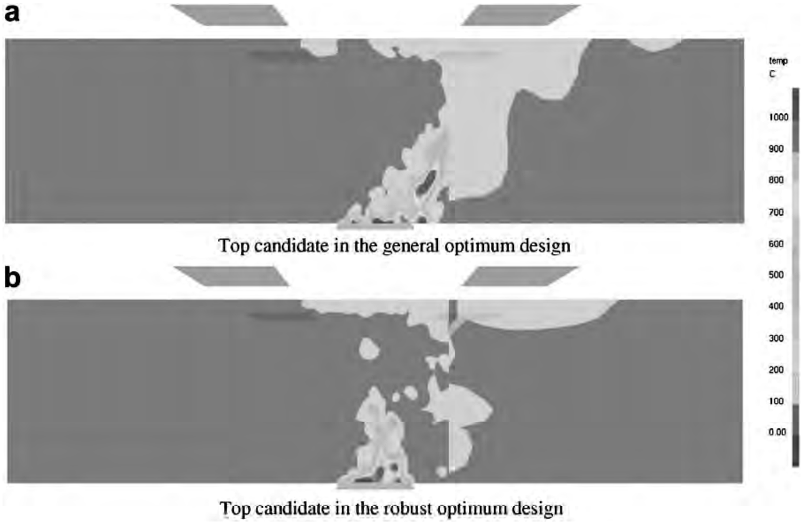

Fig. 13. Vertical temperature distributions at section I–I′ (The locations of the fire source and four extract vents in ceiling are shown).

5. Conclusions

In this research, the optimum design method considering the robustness of smoke-control systems in buildings is developed using a coupled approach combining CFD and GA. General optimum design and robust design for a vestibule pressurization smoke-control system in an office are conducted. As a result, although the airflow rate through the doorway of the vestibule is a little lower than in the general optimum design, the safety performance of the system is considerably more stable in the robust case. The optimum design method has proved to be useful in terms of fire-prevention system design. The effectiveness should be further tested by many other application studies. It is very important to give the convergence of the method after its application to numerous fire scenarios and patterns. In order to maintain the brevity of the paper, a large number of application studies – including convergence, fire scenarios, design parameter and patterns – will be reported in future papers and reports. The approach will be also conducted for other urban safety design, for example, preventing the dispersion of hazardous materials and infectious viruses in the event of terrorism, and so on.

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釘接合部の劣化時せん断性能に関する実験的研究

木造住宅の劣化時構造性能に関する研究（その１）

EXPERIMENTAL STUDY ON THE PERFORMANCE OF THE NAILED JOINT WITH THE RUST

Study on the structural performance of wooden houses when deteriorated (Part 1)

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Hiroki ISHIYAMA and Mikio KOSHIHARA

In this study, nailed joints supposing to be used in the shear walls of wooden houses were exposed in high temperature and humidity in order to accelerate rust development on the nails. The shear tests were conducted on the deteriorated specimens. As the result,

1. As the rust development progressed, the failure mode tended to change from withdrawal to nail-head pull-through.
2. The rating of the nail was adequate to representing the tendency of the shearing performance at the early stage of deterioration, but the later stage, the other parameters were more appropriate.
3. The each factor of the allowable resistance showed different tendencies, as the deterioration advanced.

In addition, the formula of the lateral resistance for the piles was tried to apply to the simplified prediction of the load-deformation relations with characteristic value estimated by simple element tests.

Keywords : *Wooden structure, Bearing wall, Nail connection, Deterioration, Lateral resistance*
木構造，耐力壁，釘接合，劣化，せん断強度

1. はじめに

平成 19 年 5 月に 200 年住宅ビジョンが政策提言され、超長期住宅実現への取り組みが推進されている[1)]。木造住宅の寿命は 1980 年代前半には 30 年程度であったものが 2000 年代前半には 50 年程度になったと言われている[2)]が、これは物理的な寿命に関わらず除却されたものも含む統計であり、材料・工法の選択や維持管理が良い場合にはさらに耐用年数が伸びるとも言われている[3)]。ただし、ここで考慮されているのは木材の生物劣化である。

近年の木造住宅では、面材耐力壁の釘や柱脚金物など、構造耐力要素としての金属接合具の使用が多くなっている。すなわち、金属接合具を用いた接合部の構造特性が建物の構造特性に及ぼす影響が相対的に高くなっていると考えられる。しかしながら、これら構造金物、特に面材耐力壁の釘が劣化した場合の構造耐力に関する詳細かつ体系的な研究は殆ど例がない。例えば、耐震診断の一般診断法における劣化低減係数は、屋根、外壁、バルコニー等の劣化状況から、耐力を一律に低減する考え方をとっている[4)]。また、木造建築物の劣化診断の二次診断では釘を引き抜いて診断するものの、耐震診断の一般診断法と同様、壁倍率を一律に低減する考え方である[5)]。

本研究では、木造住宅における面材耐力壁の釘接合部を想定した試験体を作製し、高温高湿養生によって釘を発錆させた後、せん断実験を行うことによって、釘の劣化度合いが面材耐力壁釘接合部のせん断特性に及ぼす影響を考察する。

２．既往の研究

木造住宅の劣化に関する研究としては、主要な構造材である木材自体の生物劣化に関する研究[例えば6),7),8)]、生物劣化した木材の構造性能に関する研究[例えば9),10),11)]、防火処理木材に打たれた釘の劣化状態に関する研究[例えば12),13),14)]などは比較的多くなされているが、面材耐力壁の釘劣化時の構造性能に関する研究は少ない。また、面材耐力壁の釘接合部の劣化促進実験方法を検討している研究[15)]もあるが、釘の劣化（錆）には言及していない。

Johnson は防火処理木材に合板を釘打ちし、3 種の条件下（低温・常温・高温高湿）に暴露し、せん断実験を行っている[16)]。防火処理木材に打たれた釘は高温高湿下では劣化が著しく、パンチングアウト（釘頭部が合板を貫通する破壊形態）によって耐力低下を示した。

宮村らは製材にパーティクルボードもしくは合板を釘打ちし、高湿環境下に暴露し、釘の引抜試験およびせん断試験を行っている[17)]。引抜耐力は釘の錆に大きく影響を受ける一方、せん断耐力は釘の錆

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に加えて含水率の変化に大きく影響を受けると報告している。

今村らは関東地方を中心とした木造住宅の外壁における釘の劣化状態を調査し、目視による釘の劣化度を定義し[18]（表1)、釘の錆量およびせん断力から求めた釘の有効直径と関連付けている。また、釘の劣化度と釘接合部のせん断耐力についても実験および考察を行い、たとえば劣化度3のCN50釘による合板釘接合部の0.9㎜すべり変位時耐力は、劣化なしの場合の 55%程度であると報告している。なお、劣化度は0.5単位で評価するとしている。

福本らは築 30 年の木造住宅を移築した試験体とそれを新しい材料で再現した試験体の震動台実験を行っている[19]。移築試験体は再現試験体と比べ、剛性、最大耐力、エネルギー吸収性能が小さく、経年劣化によって建物の構造性能が低下する可能性を指摘している。

Johnson は最大耐力による評価のみであり、荷重変形特性にまで言及していない。宮村らは0.4㎜、1.0㎜すべり変位時の耐力を、今村らは0.05㎜～2.0㎜程度の特定変位ごとの耐力を整理しているが、町田らの報告[20]によれば、構造用合板を用いた壁振動台実験において、層間変位1/35rad.時の釘接合部のすべり変位が12.05㎜であり、さらに大きな変位時の耐力も考慮する必要がある。また、福本らの試験体は主な構造耐力要素が筋かいであり、軸材の劣化調査は行っているが[21]、釘などの金属接合具に関する劣化には言及していない。

本研究では、合板耐力壁の釘接合部を想定した試験体に対して高温高湿暴露によって釘を発錆させた後、せん断実験を行い、荷重変形特性を把握、許容耐力を算出する。また、今村らの劣化度や錆量等の指標を用いた釘の劣化状態と許容耐力との関係を分析することにより、釘劣化時の合板耐力壁の許容耐力を推定するための資料とする。さらに、杭の水平抵抗算定式を利用した簡易な荷重変形予測式を提案する。

3．準備調査および準備実験

3．1　解体調査

築21年の木造建物の解体調査を行い、釘･金物類の錆を観察した。主な建物仕様を表2に示す。外壁、小屋裏の釘、柱脚金物等を採取した。外壁木摺を留めつけている釘を写真1に示す。外壁ラス板を留め付けている釘・小屋裏の釘などに赤錆が見られた。これらを今村らの劣化度を用いて評価すると外壁では劣化度1～3.5、小屋裏では1～2であった。これは釘のおかれている環境の違いによると思われる。なお、柱脚金物には亜鉛の腐食生成物と思われる白錆が見られたのに対し､釘には白錆が見られず､赤錆のみであったことから、採取された釘はめっきや塗装などの表面処理を施していない鉄釘であると推測される。

3．2　釘の促進発錆実験

木材を高温高湿環境に暴露すると、ヘミセルロースのアセチル基が加水分解を受け、酢酸となって遊離する[22]。酸性環境下では鉄の腐食速度は増加する[23]。この現象を利用し、試験体を恒温恒湿器内で高温高湿暴露し、促進発錆させることとした。

なお､80℃90%に保った恒温恒湿器内に表面防錆処理を施していない鉄釘N50と木材を24時間共存（木と釘は非接触）させたところ、浮き錆状の赤錆が発生した(写真2)。除錆して重量測定したところ、重量残存率は 93.4%であった。また、釘表面に孔状の腐食が見られた（写真3)。一方、木材と共存させずに表面防錆処理を施していな

表1　今村らの釘の劣化度評価基準[18]

劣化度	基準
1	微小さび
2	表面部分的さび、肉眼的損傷なし
3	表面全面さび、内部健全
4	部分的損傷、原長維持
5	原形不明

表2　解体調査物件建物仕様

建築地	東京都目黒区	木摺	スギ
築年数	21年	防水紙	ｱｽﾌｧﾙﾄﾙｰﾌｨﾝｸﾞ20kg
柱材種	ベイツガ・ヒノキ	外壁	モルタル
壁体内通気	なし	外壁仕上げ	弾性リシン吹付け

写真1　外壁木摺釘（表面処理なしと推測）

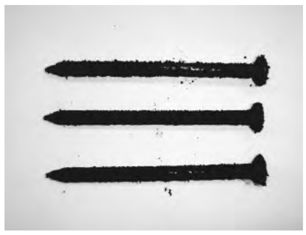


写真2　木材共存・浮き錆発生

写真3　孔状の腐食

写真4　木材共存せず・浮き錆なし

写真5　孔状腐食なし

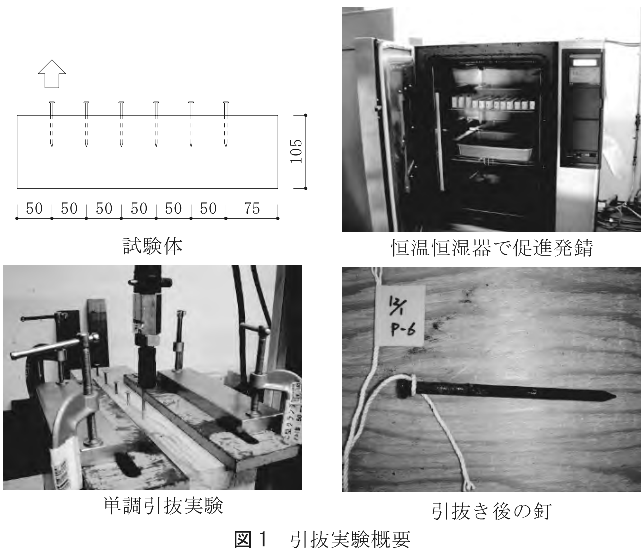


図1　引抜実験概要

い鉄釘N50のみを80℃90%の恒温恒湿器内に24時間暴露したところ、表面に赤錆が発生したが、浮き錆状の赤錆は認められなかった（写真4）。除錆後の表面に孔状の腐食は見られず（写真5）、重量残存率は 99.9%であった。これらのことより、木材内での釘を劣化させる因子として、湿度や結露だけでなく、温湿度によって木材より発生した酢酸の影響が大きいことが確認できた。

３．３　釘の単調引抜実験

釘の引抜抵抗力は木材と釘との摩擦によって生じるので、錆の影響を受けると言われている[24)]。徳田は釘を打ち込んだ木材の含水率条件を変化させ、釘の錆が引抜抵抗力を増加させることを指摘している[25),26)]。これを定量的に確認するため、釘の単調引抜実験を行った。実験概要を図 1 に示す。試験体はスギ製材乙種 3 級（105mm×105mm）に CN65 釘を打ち込み、恒温恒湿器を用いて 80℃90%RH 環境下に 1～9 週間暴露し、釘を促進発錆させた。釘は極力速やかに発錆させるため、表面防錆処理は施さなかった。促進発錆後、4～11 週間 20℃65%で後養生し、釘の単調引抜実験を行った。加力はクロスヘッド変位制御で行い、引抜速度は 2mm/min.とした。それぞれの荷重変形曲線を図 2～5 に示す。引抜実験終了後、釘の錆を除去し、重量を測定した。錆の除去方法は JASO M609-910[27)]に従い、70℃のクエン酸二アンモニウム 20%水溶液に 50 分間浸漬し、乾燥した。実験終了時の木材含水率は 11～12.5%であった。重量残存率と最大引抜耐力の関係を図 6 に示す。

釘が発錆して重量残存率が減少すると最大引抜耐力が上昇し、最大引抜耐力は発錆がある程度進行した後はあまり変化しないことがわかる。また、釘が発錆していないものは引抜け始めると直線的に荷重低下していくが、発錆したものは耐力低下が急激であることがわかる。

鉄は酸化することにより体積が膨張すること、また、発錆により釘表面の凹凸が大きくなることにより見かけ上の摩擦力が上がり、引抜耐力が増加したと思われる。また、発錆がある程度進行して重量残存率が約 95%以下になると最大引抜耐力があまり変化しないことから、最大引抜耐力後の耐力低下は主に錆層の破壊、もしくは錆層と母材との付着破壊によると思われる。釘の発錆と引抜耐力の関係は釘の腐食深さによって変化すると思われ、釘の径、長さが異なっても腐食深さ換算によって推測可能と考えられる。本実験で CN65 釘を用いたのは、N50 よりも引抜耐力の変化を検出しやすい（荷重が大きい）からである。

４．　釘接合部のせん断実験

４．１　実験概要

実験概要を写真 6 に示す。木造住宅における合板耐力壁の釘接合部を想定した試験体を作製し、これを恒温恒湿器内で高温高湿暴露した。暴露条件は目標とする釘の劣化状態によって変化させた。高温高湿暴露によって釘を促進発錆させた試験体に対して単調加力せん断実験を行い、完全弾塑性モデル化によって降伏耐力等を算出した。算出方法は耐力壁の短期基準せん断耐力の算定方法[28)]に従った。また、試験後の釘に対して、発錆状況の観察による劣化度の判定、重量測定、残存径の測定等を行い、劣化状態を定量化した。こうして得られた釘の劣化状態と算出した降伏耐力等とを比較することによって、釘の劣化状態が降伏耐力等に及ぼす影響を考察した。

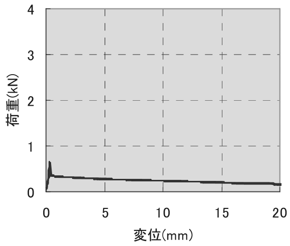


図２　単調引抜試験結果（コントロール）

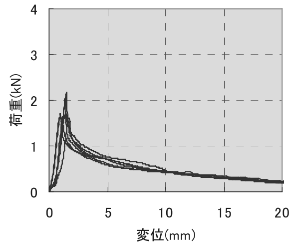


図３　単調引抜試験結果（1 週間促進発錆）

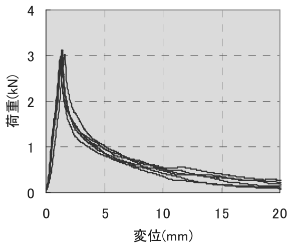


図４　単調引抜試験結果（3 週間促進発錆）

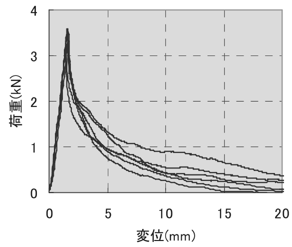


図５　単調引抜試験結果（9 週間促進発錆）

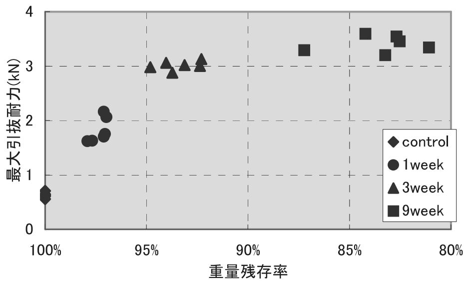
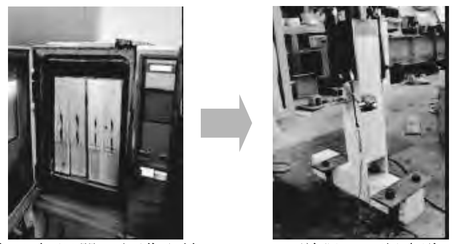


図６　重量残存率と最大引抜耐力の関係



恒温恒湿器で促進発錆　　単調せん断実験

写真６　実験概要

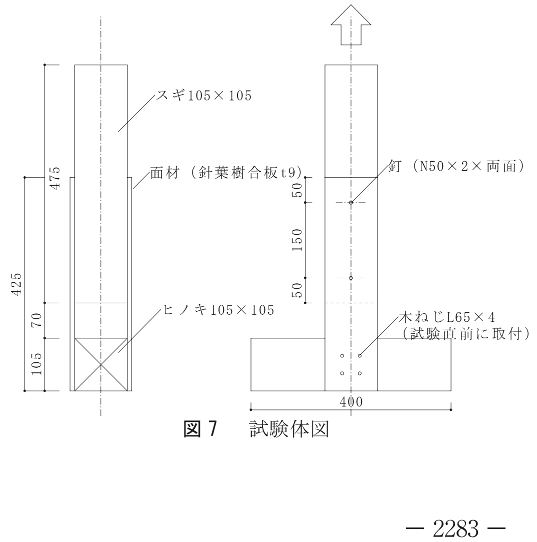


図７　試験体図

４．２　試験体

試験体は合板耐力壁の釘接合部を想定して作製した。合板耐力壁における釘接合部のうち、耐力に寄与する部位としては、柱、梁、土台との接合部が挙げられるが、一般的に釘本数の最も多い柱部分を想定した。試験体図を図７に、試験体仕様を表３に示す。側材は構造用合板 JAS 特類２級（9㎜厚）、主材はスギ製材乙種３級（105㎜×105㎜）、釘は N50 釘とした。釘は極力速やかに発錆させるため、表面防錆処理は施さなかった。釘は先孔を開けずに手打ちとし、主材-側材間の摩擦はコントロールしなかった。

釘接合部のせん断試験方法は、若島の指摘[29)]や山口らの実験[30)]の様に、最終的に合板が浮き上がることを考慮して、側材を長くすることが重要である。本研究では釘の促進発錆を恒温恒湿器で行うため、側材の長さは、恒温恒湿器に設置可能な限り長い寸法とした。

４．３　釘の促進発錆方法

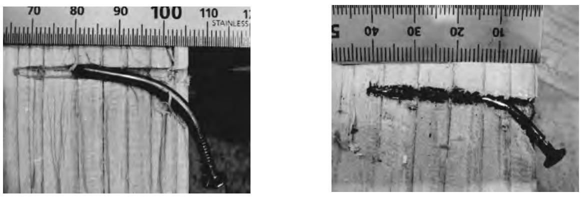
３．２と同様、恒温恒湿器を用いて釘の促進発錆を行った。試験体は予め合板を主材に釘打ちした状態で高温高湿暴露し、促進発錆させた。暴露条件は目標とする釘の発錆状況によって変化させた。すなわち、全試験体を A～D の４グループに分け、A グループ（5 体）：コントロール、B グループ（6 体）：温度 80℃、相対湿度 80%RH、4 週間、C グループ（6 体）：温度 90℃、相対湿度 98%RH、1 週間、D グループ（6 体）：温度 90℃、相対湿度 98%RH、2 週間とし、釘の劣化度合いが異なる 4 グループの試験体を作製した。試験体の含水率による影響を極力抑えるため、試験体重量がほぼ一定となるまで 20℃65%で後養生した。試験時の木材含水率は 10.5～14%であった。試験体の暴露条件を表４に示す。

４．４　単調せん断実験結果および破壊形態

試験体養生後、せん断実験を行った。加力は一方向単調静的加力とし、合板と主材の加力方向相対変位を測定した。試験反力は、フレームに固定した材（ヒノキ集成材 105×105）に試験体の合板をビス留めすることによって確保した。なお、本研究では釘接合部のすべり変形は材軸方向（合板主軸方向）のみ考慮する。

荷重変形曲線を図８～図 11 に示す。A グループは約 5㎜まで荷重上昇後、約 25～30㎜までスティック-スリップを繰り返しながら概ね一定値を示し、その後荷重低下した。B グループは約 20～25㎜まで荷重上昇し、その後荷重低下した。C グループは約 5～10㎜まで荷重上昇し、その後荷重低下した。D グループは約 5㎜まで荷重上昇し、その後荷重低下した。

最終的に釘が引き抜けなかった試験体については、試験終了後、主材を釘施工位置で縦方向に割り、釘の変形状況を観察した。写真 7 に一例を示す。また、破壊形態を引抜け、引抜けを伴うパンチングアウト、パンチングアウト、破断の４つに分類し、グループごとに割合を算出した。破壊形態割合を図 12 に示す。A、B グループは



引抜けを伴うパンチングアウト　　引抜けずにパンチングアウト

写真７　釘の変形状況

表３　試験体仕様

	等級など	寸法
主材	スギ製材乙種3級	105mm×105mm×475mm
側材	構造用合板特類2級（ラーチ）	9mm厚
釘	N50	φ2.75×L50mm

表４　暴露条件

グループ	温湿度	暴露期間
A	−	0
B	80℃80%RH	4週間
C	90℃98%RH	1週間
D	90℃98%RH	2週間

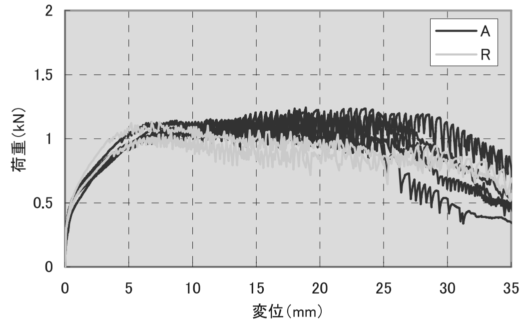


図８　荷重変形曲線（A・R グループ）

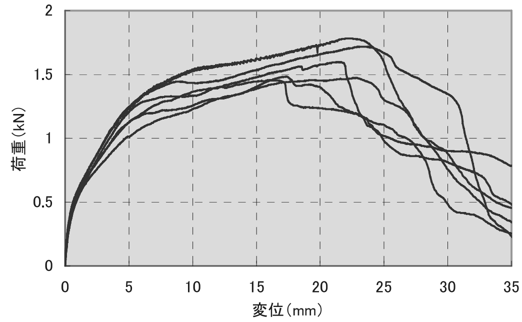


図９　荷重変形曲線（B グループ）

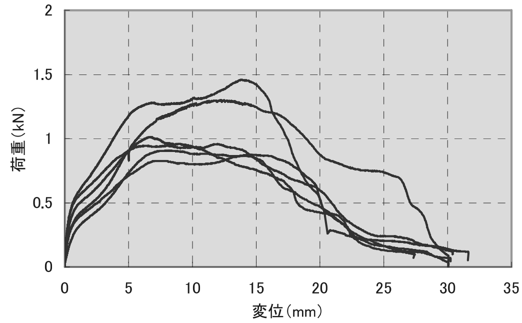


図 10　荷重変形曲線（C グループ）

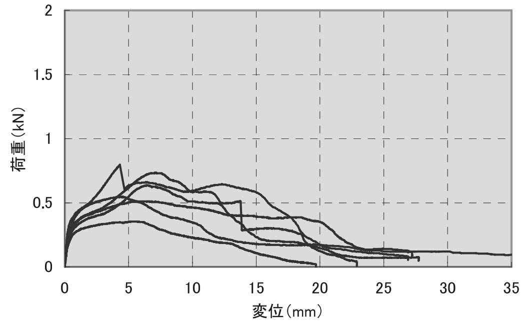


図 11　荷重変形曲線（D グループ）

引抜けあるいは引抜けを伴うパンチングアウトが主であったが、C、Dグループは（引抜けを伴わない）パンチングアウトが主であった。これは、発錆によって釘の引抜耐力が増加し、また、発錆によって釘頭径が減少することによってパンチングアウトに抵抗する耐力（以下、釘頭貫通耐力と呼ぶ）が相対的に低くなり、パンチングアウトしやすくなったことによると思われる。なお、破断は合板と主材の境界面付近で発生した。

さらに、Bグループ、Dグループの実験終了後の試験体1体ずつに対して新品の釘を打ち込み、同様にせん断実験を行った。合板は上下逆にし、主材の未使用面に釘打ちした。これらをRグループとして荷重変形曲線を図8に併せて示す。RグループはAグループとほぼ同じ挙動を示したことから、本研究における促進発錆方法による木材の劣化はほとんどないといえる。

4．5　釘の除錆

実験終了後の釘について、劣化状態の確認を行い、表1に従って

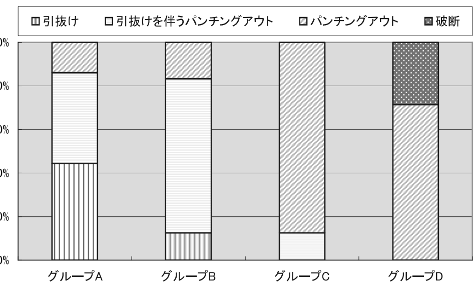


図12　各グループごとの破壊形態

表5　釘の劣化状態一覧

	試験体 No.	釘の劣化度	重量残存率	胴径残存率	頭径残存率
Aグループ	A-1	1.0	100.0%	100.0%	100.0%
	A-2	1.0	100.0%	100.0%	100.0%
	A-3	1.0	100.0%	100.0%	100.0%
	A-4	1.0	100.0%	100.0%	100.0%
	A-5	1.0	100.0%	100.0%	100.0%
	Aave.	1.0	100.0%	100.0%	100.0%
Bグループ	B-1	3.0	95.9%	99.1%	99.3%
	B-2	2.0	99.3%	100.0%	100.0%
	B-3	2.9	98.7%	100.0%	99.5%
	B-4	2.9	98.2%	100.0%	100.0%
	B-5	2.0	98.9%	100.0%	99.9%
	B-6	2.0	99.0%	100.0%	100.0%
	Bave.	2.5	98.4%	99.8%	99.8%
Cグループ	C-1	4.3	67.5%	91.2%	70.4%
	C-2	4.3	72.2%	92.3%	71.1%
	C-3	4.4	73.4%	93.9%	78.2%
	C-4	4.3	82.8%	96.9%	89.4%
	C-5	4.4	73.1%	93.0%	78.0%
	C-6	4.3	73.4%	93.6%	83.7%
	Cave.	4.3	73.7%	93.5%	78.4%
Dグループ	D-1	4.5	59.1%	88.4%	38.6%
	D-2	4.5	64.3%	89.8%	47.9%
	D-3	4.5	76.4%	96.2%	45.3%
	D-4	4.5	61.5%	90.3%	59.7%
	D-5	4.8	46.7%	83.1%	79.1%
	D-6	5.0	59.2%	89.2%	59.2%
	Dave.	4.6	61.2%	89.5%	55.0%

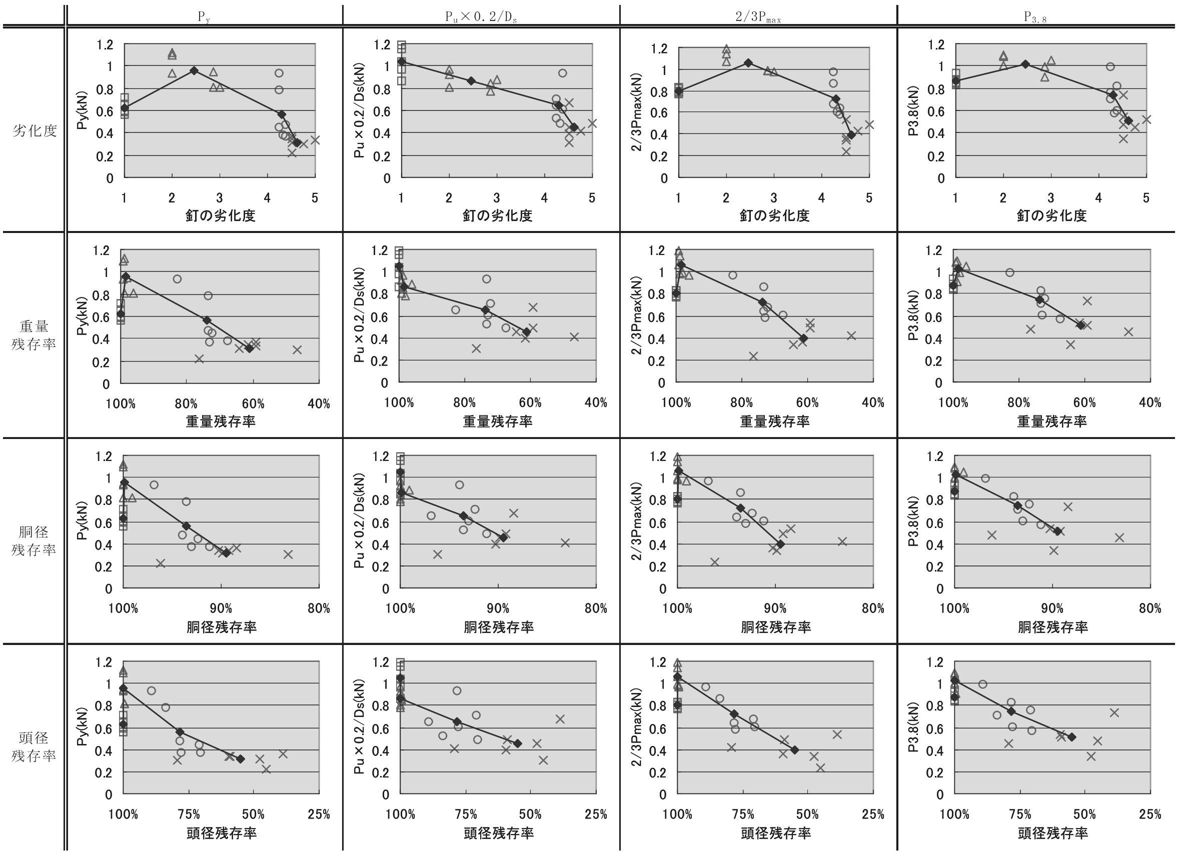


図13　釘の劣化指標と各種性能値　□：Aグループ、△：Bグループ、○：Cグループ、×：Dグループ

劣化度を決定した。劣化度は 0.5 単位で評価し、1 試験体ごとに平均値を算出した。また、釘の錆を除去し、重量、頭径、胴径を計測した。錆の除去方法は3．3と同様とした。頭径については直交 2 方向について計測し、その平均値とした。胴径については、首下、中央、先端のそれぞれの位置で直交 2 方向について計測し、その平均値とした。釘の劣化状態一覧を表 5 に示す。

４．６　考察

得られた荷重変形曲線を完全弾塑性モデル化し、耐力壁の評価方法に準じて、Py、Pu×0.2/Ds、2/3Pmax を算出した。1/120rad.時の荷重については、面材が剛体かつ間柱に完全固定されていると仮定した時の変位（455mm/120=約 3.8mm）時の荷重（$P_{3.8}$と呼ぶ）として対応させた（以下、Py、Pu×0.2/Ds、2/3Pmax、$P_{3.8}$を各性能値と呼ぶ）。釘の劣化度、重量残存率、頭径残存率、胴径残存率を横軸に、各性能値を縦軸にプロットしたものを図 13 に示す。併せて、各グループごとの平均値を折れ線で結んだものを図中に示す。釘接合耐力から耐力壁のせん断耐力を推定する際、耐力壁が 3 次元的に脆性破壊を生じると、靭性が十分に評価できないという指摘がある[31]が、釘劣化時の耐力壁の性状は未知であるため、ここでは Pu×0.2/Ds についても耐力壁の評価方法に準じることとした。

Pu×0.2/Ds は劣化初期から減少傾向を示すが、Py、2/3Pmax、$P_{3.8}$は劣化の進行に伴い、一旦上昇傾向を示した後、減少していく様子がわかる。劣化度は表面状態を詳しく区分できるため、劣化度 4 未満における各性能値の変化傾向をよく捉えられるが、内部損傷を生じると、C、D グループのように劣化度は 4 以上となって差が明確にならず、各性能値の変化傾向を表現しにくい。一方、頭径、胴径は劣化度 4 未満における各性能値の変化傾向をあまり表現できていないが、劣化度 4 以上における各性能値の変化傾向をよく捉えているといえる。すなわち、劣化度 4 未満（表面状態の変化時）においては劣化度を、劣化度 4 以上（内部損傷の変化時）においては重量残存率、胴径残存率、頭径残存率を劣化指標とすれば、釘の劣化による各性能値の変化を表現できるといえる。

このように、釘の劣化に伴う各性能値の変化がそれぞれ異なるということは、耐力壁の許容耐力決定因子が釘の劣化状態によって変化する可能性を示唆する（図 14）。

５　荷重変形特性の予測

５．１　概要

釘の発錆によって合板耐力壁の釘接合部のせん断荷重変形特性が変化するメカニズムは、以下のように考えられる。

1) 発錆によって釘の胴径が減少し、合板面内方向および主材軸方向の反力、釘の曲げ耐力が小さくなる。
2) 発錆によって摩擦力＝引抜抵抗力が増加するので、パンチングアウトしやすくなる。
3) 発錆によって釘の頭径が減少し、パンチングアウトしやすくなる。

これらを考慮して発錆の影響による荷重変形関係の変化を簡易的に予測するため、杭の水平抵抗算定式における一様地盤中の弾性支承梁の解[32]の適用を試みた。2)および 3)を評価するためには、釘の軸力を考慮する必要がある。釘接合部のせん断性状において釘の軸力を考慮するためには、釘の変形を考慮する必要がある。本解は釘接合部の解析手法として一般的である弾性床理論に基づくものであるが、文献32)には杭頭の突出条件と杭頭の固定条件ごとに、荷重に対する杭頭変位、杭頭たわみ角などの解が与えられており、簡易に軸力を考慮する上で都合がよい。ここでは、釘接合部の変形の各段階に応じた杭頭条件を適用することとした。すなわち、合板と主材の境界面を地表面と想定した上で、変形初期は杭頭非突出・固定（図 15）とし、杭頭突出・固定（図 16）を経て、最大荷重時に杭頭突出・自由（図 17）となると仮定した。また、杭頭条件が移行する際のメカニズムを、釘の発錆状況を考慮して想定し、その時点の荷重を導出した。なお、適用にあたり、杭を釘と、水平地盤反力係数を主材軸方向ばね定数と読み替える。

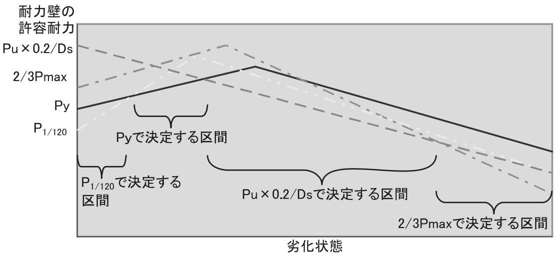


図 14　許容耐力と劣化状態

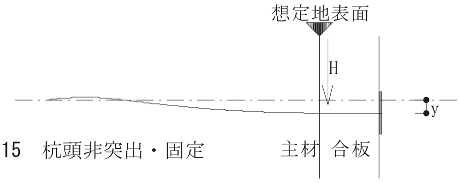


図 15　杭頭非突出・固定

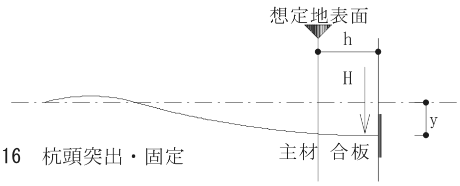


図 16　杭頭突出・固定

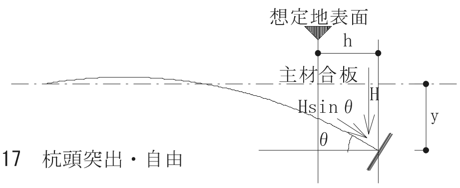


図 17　杭頭突出・自由

５．２　第一折点の決定

前述の通り、変形初期は図 15 のような変形状態であると考える。この状態から荷重が上昇すると、釘が合板面内方向および主材軸方向にめり込むことにより、図 16 のような変形状態に移行する。その際、合板および主材の応力分布は図 18 のようになると考えられる。ここでは簡単のため、応力分布は三角形になると仮定する。釘頭非突出・固定と見なせなくなる点として、合板側の最大応力度 σ_pが合板の釘側面抵抗降伏応力度 σ_{yp}に達する点と主材側の最大応力度 σ_wが主材軸方向降伏応力度 σ_{yw}に達する点との小さい方、すなわち式(1)を満たす荷重および変位を第一折点とする。なお、第一折点変位 y_1の算出においては、合板内での釘の変形を微小であると見なして、釘頭非突出・固定の条件を適用する。

$$H_1 = \min(H_{1p}, H_{1w}) \quad ・・・(1)$$

ただし、

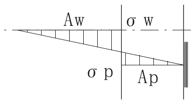


図 18　応力分布

$$H_{1p}=\frac{\sigma_{yp}\times A_p}{2}\quad\cdot\cdot\cdot(2)$$

$$H_{1w}=\frac{\sigma_{yw}\times A_w}{2}\quad\cdot\cdot\cdot(3)$$

H_1:第一折点荷重

σ_{yp}:合板の釘側面抵抗降伏応力度

A_p:合板の釘側面抵抗断面積

σ_{yw}:主材の軸方向降伏応力度

A_w:主材の釘側面抵抗断面積

この時、第一折点変位 y_1 は次式のようになる。

$$y_1=\frac{H_1}{4EI\beta^3}\quad\cdot\cdot\cdot(4)$$

ただし、

$\beta=[K_h\cdot B/(4EI)]^{1/4}$

B:釘幅

K_h:主材軸方向ばね定数

E:釘のヤング係数

I:釘の断面二次モーメント

5．3　第二折点の決定

変位が増加すると、釘の曲げモーメントが増加し、釘が降伏に至ると考えられる。釘の縁応力度が降伏応力度に達する点、すなわち式(5)を満たす荷重および変位を第二折点とする。

$$\frac{M_{\max}}{Z_n}=\sigma_n\quad\cdot\cdot\cdot(5)$$

ただし、

$M_{\max}$：最大曲げモーメント

Z_n:釘の断面係数

σ_n：釘の降伏応力度

釘頭突出・固定の場合、最大曲げモーメント $M_{\max}$ は次式で表される。

$$M_{\max}=-\frac{H_2}{2\beta}\sqrt{1+(\beta h)^2}\exp\left[-\tan^{-1}(1/\beta h)\right]\quad\cdot\cdot\cdot(6)$$

ただし、

H_2：第二折点荷重

h:釘の突出高さ

式(6)を式(5)に代入、変形し、H_2 に関する次式を得る。

$$H_2=\frac{2\beta Z_n\sigma_n}{\sqrt{1+(\beta h)^2}\exp\left[-\tan^{-1}(1/\beta h)\right]}\quad\cdot\cdot\cdot(7)$$

この時、第二折点変位 y_2 は次式のようになる。

$$y_2=\frac{(1+\beta h)^3+2}{12EI\beta^3}H_2\quad\cdot\cdot\cdot(8)$$

5．4　第三折点の決定

さらに変位が増加すると、釘の傾斜が大きくなり、荷重の分力としての軸力が無視できなくなると考えられる（図 17）。釘の軸力が釘の引抜抵抗力 P_d を超えれば釘は引抜け、釘頭貫通耐力 P_h を超えれば釘はパンチングアウトし、釘の引張強さ P_n を越えれば釘は破断すると考えられる。本研究で対象とする接合部では、釘の引抜抵抗力、釘頭貫通耐力、釘の引張強さのうち最も小さい値を N とした時、釘の軸力が N に達する点で破壊モードが決まる。この点、すなわち式(9)を満たす荷重および変位を第三折点とする。

釘が引抜けるモードは靭性が高いため、$N=P_d$ となる場合は第三折点以降荷重一定で 25mm まで変位するものとした。一方、釘がパンチングアウトあるいは破断するモードは脆性的であるため、$N=P_h$ または $N=P_n$ となる場合は、その後の荷重低下を評価せず、第三折点で変位を打ち切ることとした。

なお、ここで用いている評価式は釘の弾性範囲内に適用すべきものであるが、本研究で対象とする釘接合部は急激に塑性化しないと考えられることから、ここでは簡単のため、釘の縁応力度が降伏応力度に達した後にも適用することとする。

$$H_3\sin\theta=\min(P_d,P_h,P_n)\quad\cdot\cdot\cdot(9)$$

ただし、

H_3：第三折点荷重

θ：杭頭たわみ角

P_d:釘の引抜抵抗力

P_h:合板の釘頭貫通耐力

P_n:釘の引張強さ

杭頭突出・自由の場合、杭頭たわみ角は次式で表される。

$$\theta=\frac{(1+\beta h)^2}{2EI\beta^2}H_3\quad\cdot\cdot\cdot(10)$$

ここで、

$$N=\min(P_d,P_h,P_n)\quad\cdot\cdot\cdot(11)$$

$$\alpha=\frac{(1+\beta h)^2}{2EI\beta^2}\quad\cdot\cdot\cdot(12)$$

とし、式(10)、(11)、(12)を式(9)に代入すると、次式を得る。

$$H_3\sin(\alpha H_3)=N\quad\cdot\cdot\cdot(13)$$

式(13)を満たす H_3 が第三折点荷重となる。この時、第三折点変位 y_3 は次式で表される。

$$y_3=\frac{(1+\beta h)^3+1/2}{3EI\beta^3}H_3\quad\cdot\cdot\cdot(14)$$

式(13)を満たす H_3 は収束計算によって求められるが、テイラー展開を利用した近似解を次式に示す。

$$H_3=\sqrt{\frac{6/\alpha^2-\sqrt{36/\alpha^4-24N/\alpha^3}}{2}}\quad\cdot\cdot\cdot(15)$$

5．5　各特性値決定のための要素実験

主材軸方向ばね定数 K_h および降伏応力度 σ_{yw}、釘のヤング係数 E および降伏応力度 σ_n、合板の釘側面抵抗降伏応力度 σ_{yp}、合板の釘頭貫通耐力 P_h（以下、これらを特性値と呼ぶ）を決定するための要素実験を行った。実験概要を図 19 に、実験結果を図 20 に示す。本研究では釘接合部のすべり変形は材軸方向のみ考慮することとし、スギは繊維方向、合板は主軸方向加力とした。グラフ中の太線は平均値、ポイントは特性値算定に用いた点を示す。実験から決定した各特性値および諸定数を表 6 に示す。釘の引張強さは、釘用鉄線（JIS G3532 SWM-N）の引張強さの下限値 690N/mm^2 に釘胴部の断面積を乗

じて算出した。釘の引抜抵抗力 P_d は３．３の重量残存率を平均腐食深さに換算し、N50 に適用して決定した。また、釘幅 B、釘の断面二次モーメント I および釘頭貫通耐力 P_h は４．５で計測した各グループごとの釘の胴径、頭径の平均値に応じて低減した。

５．６　適用結果

得られた特性値を予測式に適用し、実験結果と比較した。実験結果に予測値をプロットしたものを図 21～24 に示す。予測値は実験値に概ね良好な一致を示し、杭の水平抵抗算定式に５．１の仮定 1)～

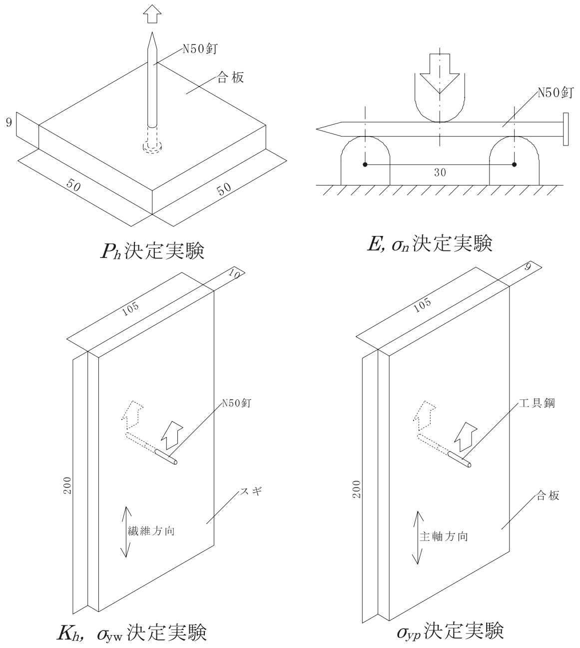


図 19　要素実験概要

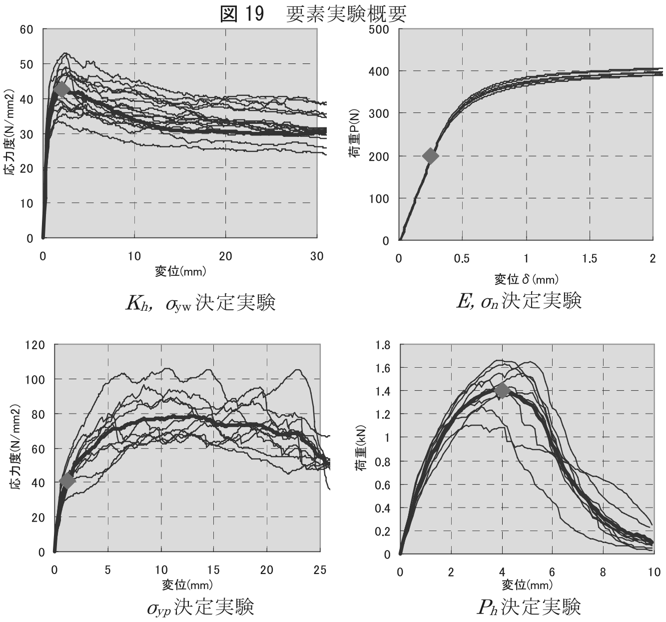


図 20　要素実験結果

表 6　各特性値および一覧

	記号	単位	A グループ	B グループ	C グループ	D グループ
合板厚（釘の突出高さ）	h	mm	9			
釘幅	B	mm	2.75	2.74	2.57	2.46
主材軸方向ばね定数	K_h	N/mm^3	58.04			
釘のヤング係数	E	N/mm^2	1.60E+05			
合板の釘側面抵抗降伏応力度	σ_{yp}	N/mm^2	41.05			
主材の軸方向降伏応力度	σ_{yw}	N/mm^3	29.02			
釘の降伏応力度	σ_n	N/mm^2	734.6			
合板の釘頭貫通耐力	P_h	N	452	762	2327	2494
釘の引抜抵抗力	P_d	N	1404	1398	863	425

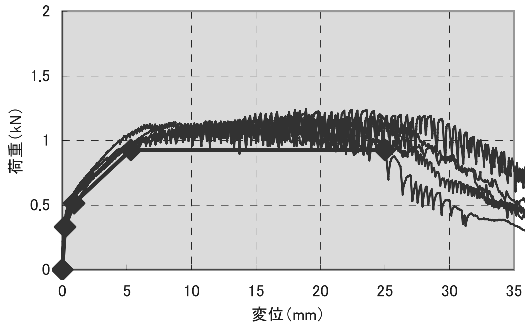


図 21　実験値と予測値（A グループ）

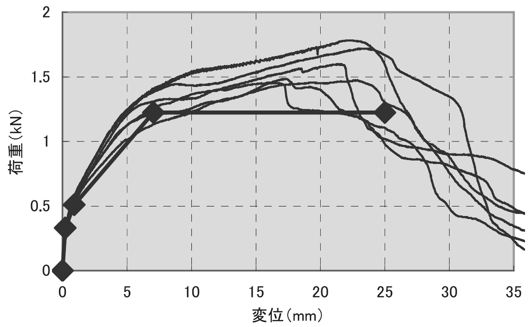


図 22　実験値と予測値（B グループ）

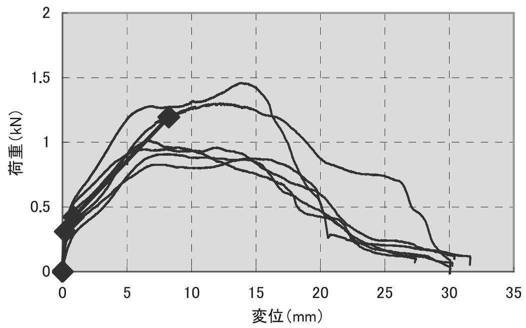


図 23　実験値と予測値（C グループ）

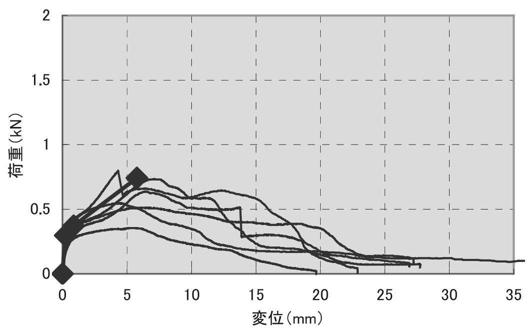


図 24　実験値と予測値（D グループ）

3)を適用する本予測式の有効性を確認することができた。たとえば胴部の発錆に対して頭部の発錆が相対的に小さい（発錆による引抜耐力の増加、胴径の減少に対して釘頭径の減少が相対的に小さい）場合など、様々な劣化状態に対応可能と思われる。

６． まとめ

合板耐力壁の釘接合部試験体を高温高湿養生することにより釘を促進発錆させ、せん断実験を行うことにより、以下の知見を得た。

1)釘の発錆が進むと、破壊形態が釘の引抜けからパンチングアウトへと変化する傾向がある。

2)釘の劣化度は劣化初期の各性能値の変化傾向を、釘の重量、頭径、胴径残存率は劣化後期の変化傾向をよく捉えられる。

3)Pu×0.2/Ds は釘の劣化初期から減少傾向を示すが、Py、2/3Pmax、$P_{3.8}$ は釘の劣化の進行に伴い、一旦増加傾向を示した後、減少していく。

ただし、現段階では釘の劣化状態を予測できるデータが乏しいため、外壁の防水性能を高めたり、壁体内の通気を確保するなど、釘が劣化しにくい環境を確保することが望ましいと考えられる。

さらに、釘の劣化の影響による荷重変形関係の変化を簡易的に予測するため、杭の水平抵抗算定式における、一様地盤中の弾性支承梁の解の適用を試み、以下の知見が得られた。

4)釘の発錆状況を考慮して釘頭条件の移行を仮定し、簡単な要素実験を行って各特性値を決定して適用することにより、合板釘接合部の釘劣化時の荷重変形関係を簡易に予測することができた。これを利用して、 釘の様々な腐食形態を仮定することにより、荷重変形関係を予測できる可能性がある。

７． 今後の課題

本研究では単調加力による実験を行ったが、正負繰返し加力時の性状や動的性状についても確認する必要がある。また、耐力壁としての性状や建物としての性状に展開する必要がある。さらに、実物件の調査および環境計測を数多く行い、建物外壁の防水性能、通気状況などの環境に応じた釘の劣化状態の予測方法を構築する必要がある。

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Feasibility study of peak-hour road shoulder lane utilization in urbanized motorways

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ABSTRACT

There are still a lot of traffic congestions in motorways and the major location of congestion is sag section in Japanese motorways. However, due to the recent socio-economical changes, large investments for road facilities such as new road construction or road widening are getting more difficult, especially on motorways in urban and suburban area because the land acquisition is usually very costly. Therefore, we need less expensive countermeasures to alleviate traffic congestion in such areas.

In this study, we proposed a measure to utilize an additional lane dynamically depending on traffic situations within the existing road width using the road shoulder space. Then the feasibility in the aspects of efficiency and safety of this measure was examined by traffic detector data analyses and driving simulator experiments based on an actual motorway section which had a similar geometric design as our proposal.

The result showed that the capacity of the study section would become increased and it would lead to a shorter duration of the congestion when the road shoulder was utilized. And from the driving simulator experiments, the recorded data showed that there were very few dangerous situations related to the road shoulder lane usage and the testees also had few negative opinions through the questionnaire after driving.

Keywords: Road shoulder utilization, Peak-hour operation, Driving simulator

INTRODUCTION

In spite of a lot of efforts and countermeasures, there are still a lot of traffic congestions on motorways in Japan. The loss by traffic congestion on motorways is estimated about 10 billion USD in one year. The major bottleneck points of congestion are toll gate, sag, merging section, tunnel etc. By the recent dissemination of ETC on-board units, the congestions at toll gates are decreasing, then more emphasis on sag section will be needed from now.

The fundamental cause of traffic congestion can be said that the transportation facility has a limited capacity which is fixed and constant whereas the traffic demand always varies by time or day. Of course, we usually estimate the future traffic demand in the planning stage and construct the transportation facilities to satisfy it, but it is generally very difficult to avoid all traffic congestion in the future due to an extra potential demand or uncertainty. Therefore, to solve such revealed traffic congestions after in service, road improvement measures which enlarge traffic capacity uniformly such as widening or constructing by-pass has been implemented. However by the socio-economic change, the land for road is generally limited and the construction cost is very expensive in urban and suburban area, so it is getting more difficult to construct by-passes or to enlarge the width of existing roads although these measures are effective. Moreover, congestion usually occurs only limited time periods like commuting hours or holidays, so it means the conventional method of uniform improvement provides a kind of waste and sometimes inefficient. Then, if we can implement a dynamic traffic operation which varies the capacity of the transportation facilities depending on the traffic situations while the facilities are as it is, it can provide effective countermeasures and save the road resources. This concept is shown in the Figure 1.

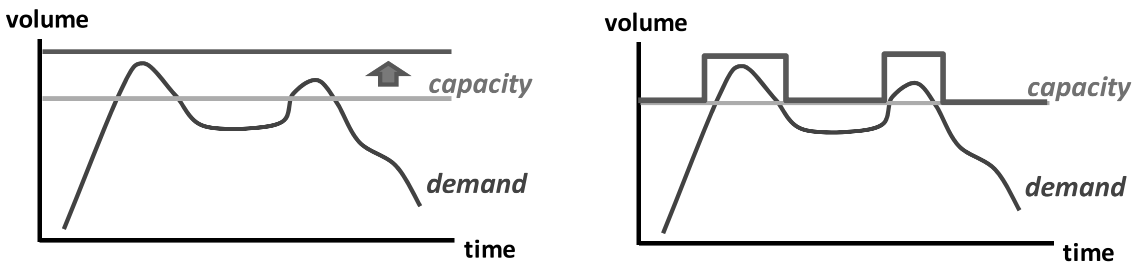

FIGURE 1 Conventional (left) and proposed (right) design of capacity improvement.

Such a dynamic operation of traffic facilities can be realized in various ways. For example, some European countries introduce reversible operation or road shoulder utilization on motorways. The former one alternates the flow direction of one or more lanes and the latter opens road shoulder as a cruising lane depending on the traffic situations. They are operated and effectively used in those countries, but not realized in Japan yet. It is essential to understand the effect or the influence of such a new operation scheme before the implementation since there might be some unknown impact. And such an examination in advance should be useful to reduce the risk and to enhance the operation quality. In this paper, we pick up the road shoulder lane utilization and aim to examine the feasibility to introduce it to a bottleneck sag section in Japanese motorways from the viewpoint of efficiency and safety.

PROPOSAL OF ROAD SHOULDER LANE OPERATION

Considering the experience in other countries, the authors propose the operation scheme of the road shoulder lane utilization as shown in Table 1. The operation image is shown in Figure 3.

TABLE 1 Operation Scheme of Road Shoulder Lane Utilization

Location	Simple section bottleneck (e.g. sag)
Operation Time Period	Peak hours (e.g. commuting hours, holidays) with nearly saturated traffic flow
Structure	Hard paved shoulder with cruising lane marking by narrowing existing main carriageway slightly (see Figure 2) Additional emergency stop bay with a certain interval
Information Provision	By variable signboard in every 500 [m]
Start of Operation	Display "Lane Open" from downstream signboards
End of Operation	Display "Lane Closed" from upstream signboards
Monitoring	Incident monitoring by camera

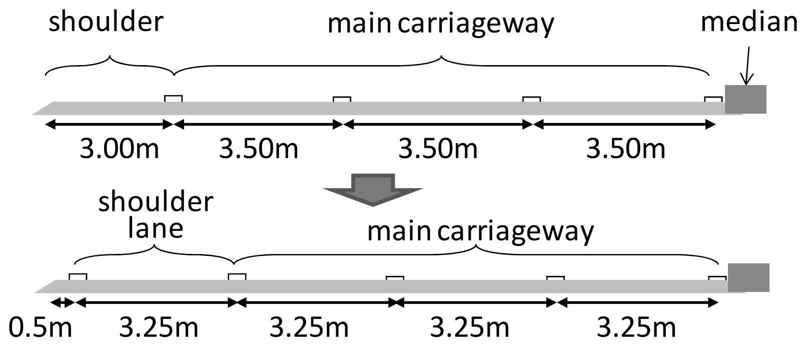

FIGURE 2 Cross section of road shoulder lane.

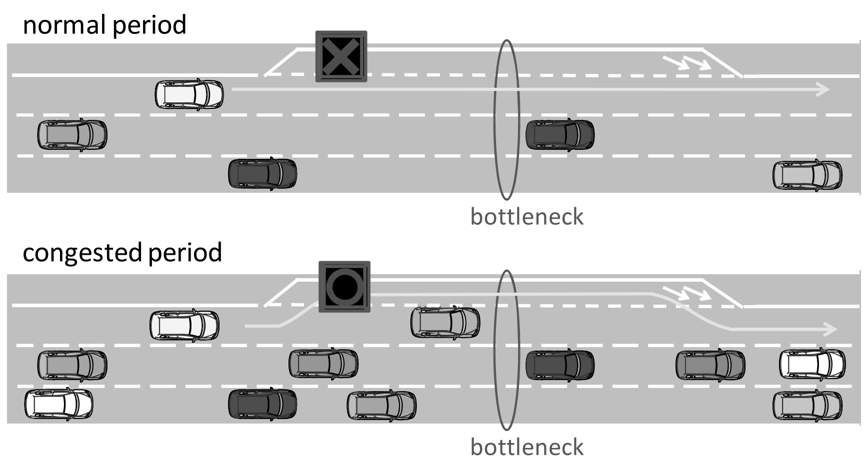

FIGURE 3 Operation image of the road shoulder lane.

Here are some items which should be considered and examined before implementing the proposed operation scheme.

1. Effect of congestion alleviation (e.g. capacity increase)
2. Safety (e.g. risk at the merging point)
3. Information provision method (e.g. easy way to recognize)
4. Emergency function (e.g. refuge in case of incident)
5. Cost (e.g. for construction and maintenance)

This study focuses on the item 1 and 2 as the most important ones. In the following paragraphs, we estimate the effect of congestion alleviation analyzing observed traffic detector data, and examine the safety at the merging point using a driving simulator.

ANALYSIS OF THE EFFECT OF THE CONGESTION ALLEVIATION

There are 3 kinds of expected effects by introducing the shoulder lane operation, that is, capacity improvement, congestion reduction, and accident reduction conducted by congestion reduction. In this paragraph, the former two effects are evaluated through an analysis using traffic detector data. Here, there has been no example of shoulder lane utilization in Japan, so we need to use similar data with some assumption from the existing implementations.

Figure 4 shows the plane view image of the study section. The location is a suburban area of Tokyo where a sag is located at the downstream of rest area on-ramp. As this section was one of the major bottlenecks and previously had held more than 100 times of traffic congestions in one year, an improvement project was completed in 2003 which widened the road shoulder and added a slower traffic lane. As a result, traffic congestion at this section became less drastically as shown in Table 2. Since the road geometry after this improvement is very similar to what we propose as shoulder lane utilization, we analyze the observed traffic detector data before and after this improvement. The analyzed data is 5 minutes traffic count at the sag for one year in the year of 2000 (before) and 2004 (after).

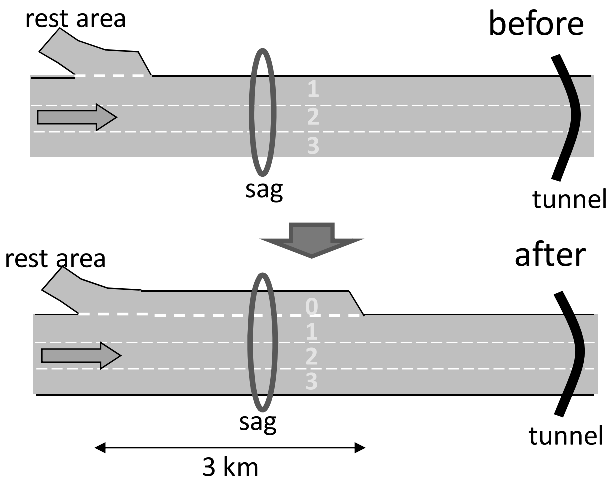

FIGURE 4 Plane view image of the study section.

TABLE 2 Outline of the Congestion Alleviation by the Improvement Project

		2000	2004
Num of Sundays (= analyzed sample population)		53	48
Num of congestions		29	17
Congestion duration:	Average [min]	300	242
	Standard deviation [min]	27.0	20.3
Minimum speed in Congestion:	Average [min]	25	31
	Standard deviation [min]	2.5	3.5

Effect of Capacity Improvement

Figure 5 is the traffic count data at this sag section in 2000 (before) and 2004 (after), showing the section total traffic volume in the horizontal axis and lane traffic volume in the vertical axis. From this figure, we can understand that the capacity of this section is a little bit more than 5,200 [veh/h]. And at this section volume, the volume of Lane 3 is 2,248 [veh/h] (before) and 2063 [veh/h] (after). As congestion starts from the Lane 3 generally, this result means that the beginning of the congestion can be delayed. We can calculate the capacity increase at least (A) 185 (= 2,248 - 2,063) [veh/h], that is 3.5% improvement. And if we assume the same lane usage ratio on the other lane, we can extrapolate the approximated line until the Lane 3 reaches the lane capacity (=2,248 [vhe/h]), and obtain the section capacity approximately (B) 5,560 [veh/h], that is 7% improvement.

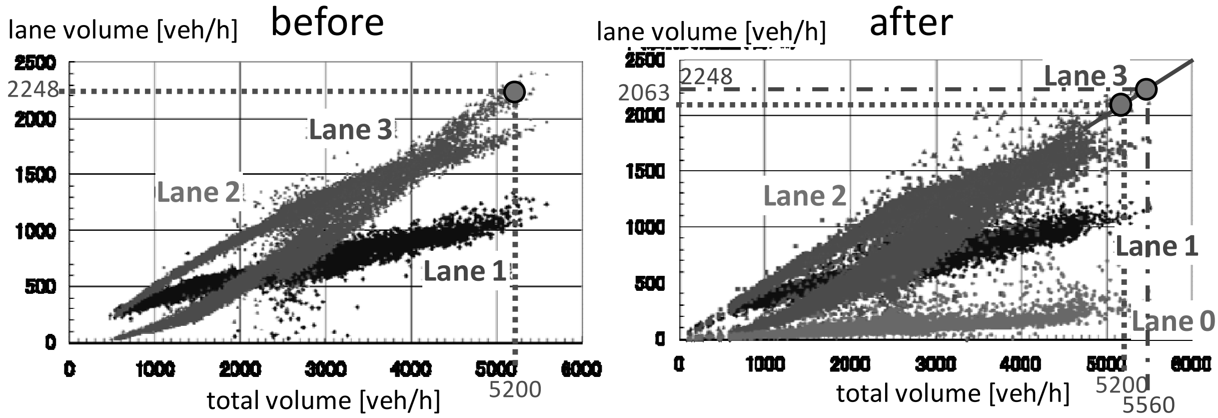

FIGURE 5 Traffic volume of the section total and each lane.

Effect of Congestion Reduction

To understand the effect of the congestion reduction, the congestion duration is estimated using a certain traffic demand profile obtained from one Sunday in 2004. We assume that congestion occurs when this demand exceeds the capacity, that is, 5,200 [vhe/h] (before), 5,385 [veh/h] (after-A) and 5,560 [veh/h] (after-B). Figure 6 shows the cumulative traffic demand profile curve and the slope of each capacity. From this figure, congestion duration is estimated by the intersecting point of these lines. As a result, the estimated durations are 210 [min] (before), 120 [min] (after-A) and 40 [min] (after-B), that is, 42.9% (after-A) and 81.0% (after-B) reduction respectively. And, the total delays are calculated as 4455.8 [veh*h] (before), 536.0 [veh*h] (after-A) and 28.4 [veh*h] (after-B), that is, 88.0% (after-A) and 99.4% (after-B) reduction respectively.

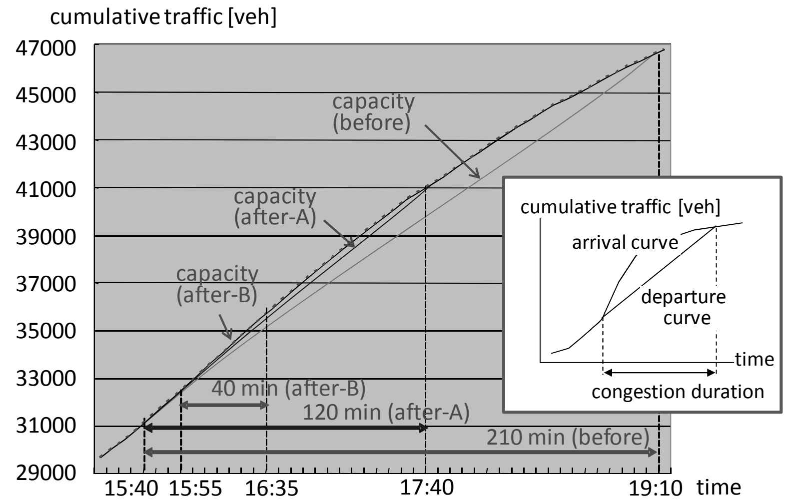

FIGURE 6 Congestion durations before and after improvement.

SAFETY EXAMINATION BY DRIVING SIMULATOR EXPERIMENT

Safety examination is very important when we try to introduce new operation scheme into the actual field. In this stage, the driving simulator (1) is very useful and powerful tool to conduct an experiment for the safety check because it can reproduce the same driving environment for a lot of testee drivers without any risk of real accidents. In this study, we conducted a driving simulator experiment to examine the safety at the merging section of this operation scheme.

Outline of the Experiment

A road segment data of an existing motorway sag bottleneck was prepared with an additional road shoulder lane for the driving simulator experiment. The length of the total segment is 5.5 [km] and the length of road shoulder lane is 2 [km]. In the experiment scenario, a testee driver was asked to drive the simulator 2 times, in different paths as shown in Figure 7. The traffic volume in the simulator was set at 4,000 [veh/h] in order to reproduce the near-congested situation.

The experiment was conducted by 25 testee drivers, and their attributes are shown in Table 3. The testees are relatively less experienced drivers, and it means the testees' reaction might become serious even by a small risk of this shoulder lane operation.

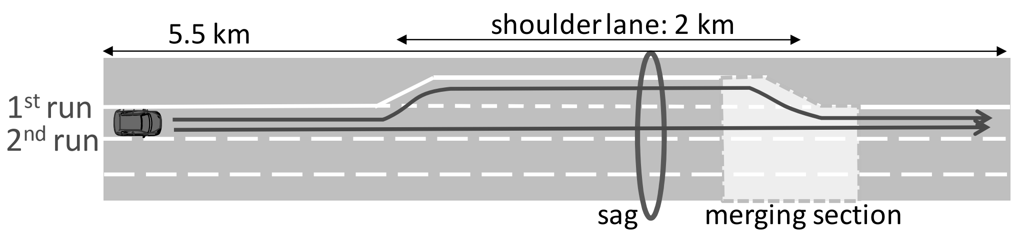

FIGURE 7 Scenarios of driving simulator experiment.

TABLE 3 Attributes of the Testee Drivers

Age	20s (21),	30s (4)
Occupation	Student (21),	Worker (4)
Driving history [years]	Less than 3 (2),	Less than 10 (22),

	10 or more (1)
Driving frequency [hours/week]	No (13), Less than 2 (6), Less than 5 (4), 5 or more (2)
Motorway use frequency [times/month]	No (6), Less than 1(15), 1 or more (4)

Evaluation Method and the Result

The most possible risk by the shoulder lane utilization would be a collision at the merging section where the shoulder lane ends. To evaluate this risk, indices of TTC (Time To Collision) and Minimum Spacing were analyzed, and questionnaire survey was conducted after the testee's driving.

TTC (Time To Collision)

TTC was proposed by Hayward (2) which indicates the time until 2 vehicles collide each other under the condition that they keep moving in their speed without avoidance behavior. Generally, TTC less than 1 second is regarded as dangerous. Since TTC originally considers rear-end collision which is along the same trajectory, this study added some arrangement as follows.

1. Obtain moving speed and direction of the leader and the follower vehicle. If the vehicles are in parallel or getting apart, TTC is regarded the infinity.
2. If their trajectories intersect, calculate the time to the intersection point by each vehicle.
3. Judge whether a collision occurs or not by the calculated time difference.
4. If a collision occurs, this time to approach the intersection point is TTC.
5. Calculate the above in every 1/60 seconds.

Figure 8 shows the result of TTC at the merging section. TTC were more than 10 seconds in most of the case. The lowest value of TTC was 1.87 [sec], which is enough high from the general threshold of 1.0 [sec], so there seems to be no serious conflicts by the shoulder lane utilization in the viewpoint of TTC.

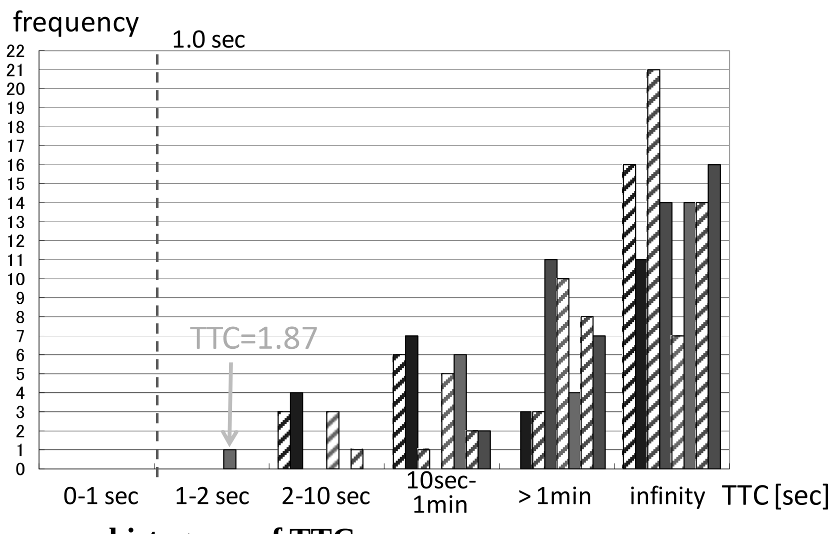

FIGURE 8 Frequency histogram of TTC.

Minimum Spacing

TTC produces an infinite or very large value when 2 vehicles run in parallel or their relative speed is negative even though they run in very close spacing. To cover this risk, another index of the minimum spacing is considered. From the recorded data of 1/60 intervals by the driving simulator, the minimum spacing to the leader vehicle inside the merging section and other section is obtained for 12 cases, that are picked up by the video record as close running cases. Figure 9 shows the result.

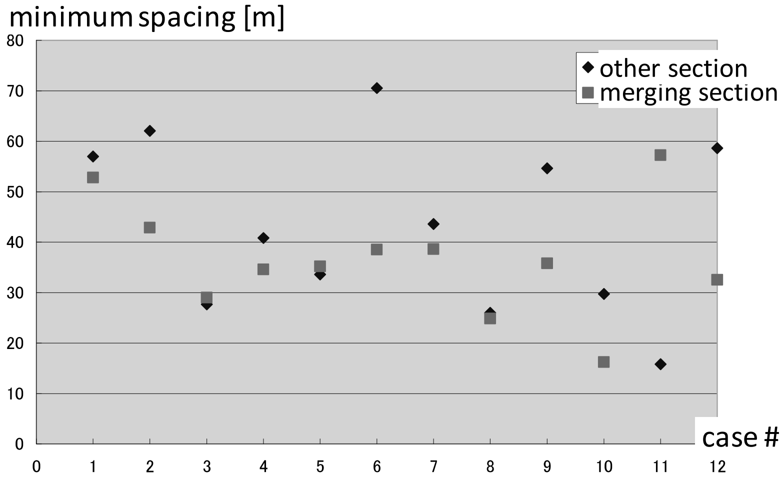

FIGURE 9 Minimum spacing of the merging section and the other section.

To compare the minimum spacing of the merging section and the other normal section, statistical test of the population mean difference was conducted. As a result, null hypothesis "The population mean of the merging section and the other normal section is the same." was not rejected. It means that the merging section has no special risk compared with the other section.

Questionnaire Survey

After driving the simulator, each testee driver is asked to answer the questionnaire so that the subjective evaluation by drivers can be collected. The result is shown in Table 4. From the result, the testee drivers didn't have negative opinions on the shoulder lane operation scheme even though they were not well-experienced drivers.

TABLE 4 Result of the Questionnaire Survey

	Yes	⟷	No
"Did you feel it dangerous?" (1st run)	0	10	**15**
(2nd run)	2	8	**15**
"Will you use this lane?"	**14**	-	11

CONCLUSIONS

This study advocated the importance to introduce the dynamic traffic operations in order to utilize the existing transportation facilities under the restricted socio-economic conditions. And taking an example of the road shoulder lane utilization, the operation scheme was proposed and the effect and issue to introduce it to Japanese motorway were evaluated. As for the effect, it was revealed through an analysis of traffic detector that the benefit of congestion reduction was very large (88.0 - 99.4 %) even though the capacity increase was small (3.5 - 7 %). The safety issue was evaluated by a driving simulator experiment and no special risk at the merging section of the shoulder lane was found from the recorded data and the questionnaire result.

This study dealt with only fundamental items which are crucial to introduce the shoulder lane operation scheme as a first step. We need deeper and more detailed discussion to implement it in the actual filed, for example, safety evaluation of transition period, operation in case of incident and emergency, etc. Through this kind of comprehensive examination, we'd like to establish the dynamic traffic operation which is flexible and effective depending on the traffic conditions.

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研究速報

森林計測のためのLiDARシミュレーションシステムの開発

Development of a LiDAR simulation system for forest

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Takahiro ENDO and Haruo SAWADA

1. はじめに

LiDAR（Light Detection and Ranging）は，空間情報を計測するリモートセンシング機器の一つであり，計測機器から高頻度のレーザ光線を発射して距離を測定し，GPS（Global Positioning System）とIMU（Inertial Measurement Unit）から得られる情報とを用いて，測量座標系上に対象物の高密度の点群データを取得するシステムである．近年LiDARから得られるDEM（Digital Elevation Model）やDSM（Digital Surface Model）は，航空写真を用いた空中三角測量から得られるデータを補間もしくは独自の利用方法として，河川･砂防，地震防災･土砂災害，火山防災，海岸，都市，道路，森林環境，水資源，エネルギー分野において注目されている[1]．

特に，河川・砂防，防災および森林分野においてLiDARに対する期待が高い．河川・砂防分野では，河川氾濫における浸水想定区域図やハザードマップの作成には，高精度のDEMデータが必要であり，空中写真測量から得られたDEMよりもLiDARから得られるDEMがより高精度であるため，日本国内では主にLiDARから得られたDEMが利用されている．防災分野では，土砂崩れののり面の形状や変化を数センチの高さ精度で計測でき，また，三次元的な現地状況を準実時間で把握することが可能であることから，発災直後の有用な情報となっている．さらに森林分野では，樹木の成長や森林の垂直階層構造の把握は，従来，写真測量の技術を利用し推定していたが，LiDARデータから得られるDEMやDSMおよび発射したレーザ光線からの反射強度を利用することによりそれらの把握が単木単位で評価することができることから，LiDARの利用が近年増加している[2]．

砂防分野や森林分野では，危険箇所の予測や樹高を推定するためには，樹木の下のDEMを正確に計測する必要がある．森林域において高精度のDEMを作成するためには，発射したレーザ光線が樹木間もしくは樹冠をすり抜け地盤面まで到達し，さらに，反射してセンサまで戻ってくる必要がある．

しかしながら，森林域において，どのような計測条件で計測すれば高精度のDEMが作成できるのか分かっていないため，経験則にしたがって計測を行い，場当たり的なDEMが作成されている．そのため，計測場としての森林の状態とLiDARの計測条件とからDEMの精度を客観的に議論することが航測業界として求められている．

そこで，筆者らはこの問題を解決するため森林計測のためのLiDARシミュレーションシステムを開発した．本システムは，森林域における最適な計測条件やDEM精度の限界を推定することを目的としている．したがって，利用者は，DEM計測を業務として行っている航測会社である．本システムは，計測高度，レーザ光線の発射角度および発射頻度などの計測条件とDEM，樹種，林齢，季節，単木間隔などの計測場の条件とから点群をシミュレーションする機能を実装している．

2. ソフトウェアに求められる機能

本章では，森林域におけるLiDARシミュレーションシステムが有すべき要件を議論する．

航空機による森林域のLiDAR計測の条件は，計測高度，レーザ光線の発射角度，レーザ発射頻度，レーザ光線の直径およびレーザ光線の反射強度を記録するI/Oである．このうち，実測において制御可能な変数は，計測高度，レーザ光線の発射角度およびレーザ発射頻度である．レーザ光線の直径は，センサ依存なので，計測高度との関係から対象物に当たる時の直径が決まる．従って，計測高度をシミュレートするためには対象物に当たる時の直径をシミュレートすれば良い．また，レーザ発射頻度は，単位面積当たりの点群密度として利用されているので，本システムでは，単位面積当たりの点群密度で評価することとした．一方，レーザ光線の反射強度を記録するI/Oは，初めに強い反射強度を記録すると次に強い反射強度が記録できるには約3m以上は離れていなければならないという制約が存在する．そのため，同一のレーザ光線の反射から生成される点群は，3m以上は慣れているようにシステムを設計する必要がある．

従って，本システムでは，レーザ光線の発射角度，単位面積当たりの点群密度，レーザ光線が対象物に当たる時の直径および同一レーザ光線から点群の生成数を計測条件と

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して実装する必要がある．

一方，森林域の計測場としての条件は，樹種，林齢，単木分布，樹形，季節およびDEMである．樹種，林齢，樹形および季節の因子により，任意の方向かつ任意直径のレーザ光線が樹冠をすり抜ける可能性が決まる．また，樹形，単木分布およびDEMにより，樹木間をすり抜け地盤面へ到達する可能性が決まる．従って，本システムでは，樹種，林齢，単木分布，樹形，季節およびDEMを計測場の条件として実装する必要がある．

3. システム構成

本システムは，OSにWindows XP x64Edition，シミュレーション環境にAutodesk 3ds max9，樹木の三次元データ作成にnatFXおよびシミュレーション言語にAutodesk 3ds max9付属のMAXScriptを使用した．表1に本システムが使用しているソフトウェア一覧を示す．

表1　システム詳細

OS	Windows XP　x64Edition
シミュレーション環境	Autodesk 3ds max9 64bit version SP2
樹木三次元データの作成	natFX v4.0 for 3ds max
シミュレーション言語	MAXScript

本システムにおける樹木の三次元の作成は，樹木成長モデルであるnatFXを使用した．本ソフトウェアは，樹種，林齢および季節を入力値として樹木の完全な三次元データを作成する．景観CGの分野で樹木を三次元で表現可能なソフトウェアはいくつも存在するが，樹木を種からシミュレーションするソフトウェアは，natFXが唯一であり，フラクタル関数が実装されているため，同一の樹種および林齢であっても個体ごと樹形が異なるという特徴がある．そのため，個体差が存在する自然の樹林をシミュレーションすることに適している．また，樹木の三次元データは，Autodesk 3ds max9内において，一つのオブジェクトとして取り扱うことができるため，枝打ちや樹形の修正のような施業も再現できる．さらに，実際の場のDEMを入力すれば，そのDEMの表面に樹木オブジェクトを配置することが可能である．図1に本ソフトウェアで利用する樹木データの一例として，樹種をヒノキ，林齢を60年，季節を夏および人工林として一般的な施業管理された場合を示す．図1に示すように，幹，枝，個葉まで三次元データとして作成することにより，レーザ光線がどの部位に当たったのか判断することができる．

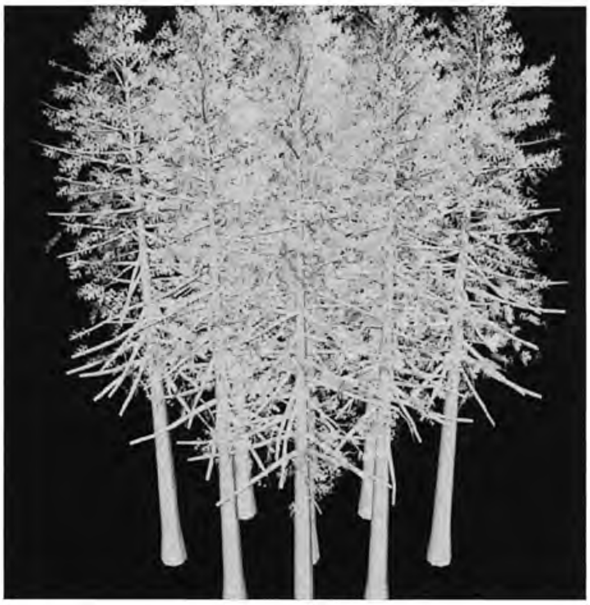


図1　本システムで利用する樹木の三次元データの一例（樹種：ヒノキ，林齢：60年，季節：夏，施業管理：あり）

3. ソフトウェアの特徴

本システムの特徴は，点群を作成する際に，使用するレーザ光線の波長に対する対象物の反射率を計算し，任意の閾値を越えた場合のみ点群を作成する．具体的には，それを実現するために，対象物に当たる時のレーザ光線の直径内に，葉の大きさよりも小さい空間分布になるよう，多数の光線を束として作成し，それぞれの子光線と対象物との交点に対象物固有の反射率を持たせ，任意の領域内の総反射率が閾値を超えた場合に点群を生成させる．これにより，樹種ごとに異なる葉内部の多重散乱特性，湿潤条件により異なる地盤面の分光特性および計測機器メーカごとに異なる使用レーザ波長の違いを考慮することができる．

4. 処 理 の 流 れ

本節では，本システムで行っている処理の流れを説明する．本システムの利用の第一歩は，前処理としての計測場の設計である．

実際にLiDARで計測予定の場の情報として，樹種，おおよその林齢を事前調査により決定し，また，単木間隔を既存の航空写真などから判読することによって，計測場作成のための入力変数とする．計測場の作成後，シミュレーションしたい計測条件を入力する．入力変数は，レーザ光線の発射角度，単位面積当たりの点群密度，レーザ光線が対象物に当たる時の直径，葉の大きさ，葉の反射率，地盤面の反射率，閾値の設定である．入力後，計測場に対して任意の計測条件における点群のシミュレーションを行い点群の分布を得る．最後に，点群の分布からDEMの作成精度等を評価するために点群データを出力する．図2にシステム

処理の流れを示す．

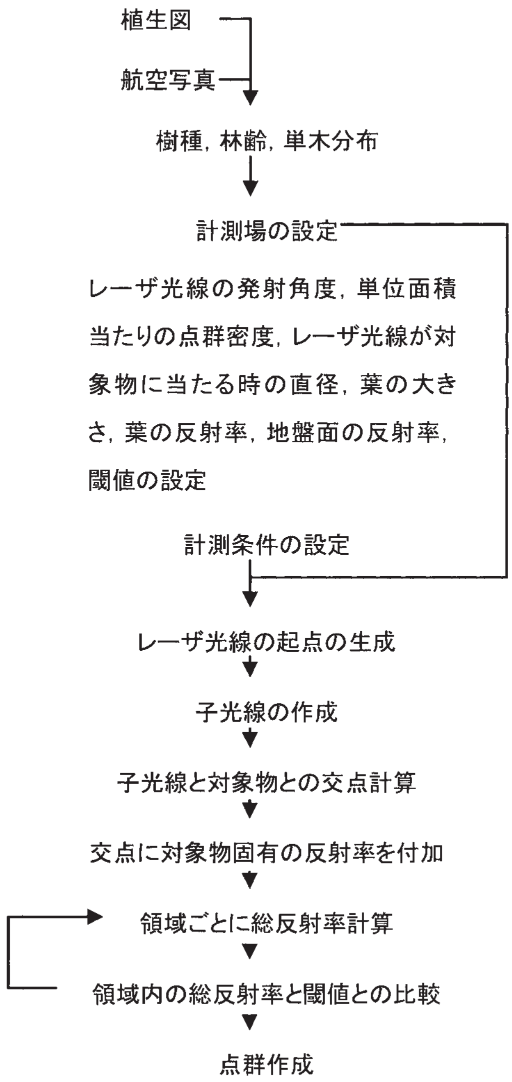


図2　システム処理の流れ

以下，システム内で行っている処理の概要を示す．

4.1　レーザ光線の起点の設定

実際のLiDAR機器は，ミラーを使いレーザ光線を振って対象物を計測しているためアジマス方向に対してジグザグなデータセットとなる．計測視野限界付近のレーザ光線の点密度は直下と比較すると高くなる．このような付近では，斜めからレーザ光線が樹林に当たるため，樹頂点を計測できる可能性が低く，森林域の解析において，そのような領域は基本的に利用されない．実際の計測では，直下視の単位面積当たりの点密度を増加させるため，同一地点を複数回飛行し点密度を増している．そのような現実を考慮し，本システムでは，単位面積当たりの点密度が一定になるような条件下のもと，レーザ光線の起点位置を対象物の上方に設定した面内にランダムに生成させた．また，レーザ光線が発射される面の大きさは，レーザ光線の発射角度と対象物の大きさとから計算している．そのため，斜めからレーザ光線を発射する場合にも対応している．

4.2　LiDAR計測に適したレーザ光線のモデル化

最新のLiDAR機器は，0.2mradの直径でレーザ光線が発射される．一般的な計測高度である1000mからレーザ光線を発射した場合，対象物に当たる時のレーザ光線の直径は20cmとなる．そのため，任意の直径の断面を持つレーザ光線が対象物とどのように当たるのかをモデル化する必要がある．そこで，本システムでは，葉の大きさより狭い空間分布になるような子光線を多数生成させて，面的なレーザ光線を近似することとした．また，レーザ光線の断面のエネルギー分布は，周辺よりも中心が高いガウス分布であることがわかっているため，子光線をレーザ光線の直径の$\pm 2\sigma$以内に分布させることにより，中心付近のレーザ光線から点群を作成するように実装した．

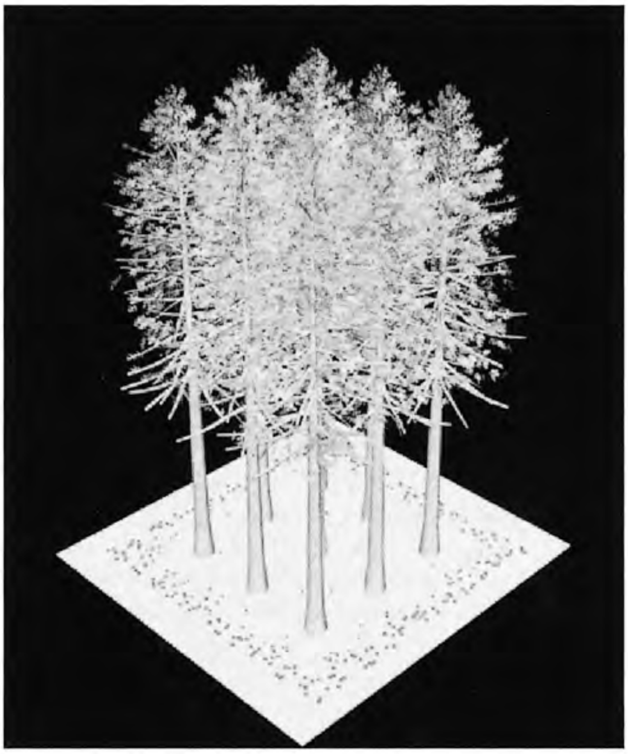
4.3　点群の作成方法

LiDAR計測により点群が作成される原理は，レーザ光線の波長に対する対象物の反射率が計測機器の閾値を越えた場合に点群として記録される．そのため，レーザ光線の波長に対する対象物の反射率を考慮すべきである．一方，計測機器の書き込みI/Oの性能により，記録中は強い反射を受信しても記録されないという制約も存在する．通常，森林域をLiDARにより計測した場合，同一のレーザ光線から4点の点群が生成される場合が多い．

そこで，本システムでは，ハイパースペクトルセンサで計測された対象物の分光特性から，レーザ光線として利用している波長に対する対象物の反射率を利用することにより，反射率の概念を導入した．これにより，水のようにレーザ光線の利用する波長における反射率が低い対象物をシミュレーションした場合でも，点群が生成されないように実装した．また，I/Oの制約を実装するために，4.1で作成した子光線と対象物との交点に対し，対象物に固有の反射室を持たせ，レーザ光線の発射した起点に対して一番近い交点から3 m以内の総反射率が閾値を超えた場合，一番近い交点位置に点群を作成する．一方，閾値を超えない場合，2番目に近い交点から同様の計算を行い点群作成の評価を行うように実装した．閾値は，同一のレーザ光線から最大4点の点群が生成されるように実装した．

5. 点群のシミュレーション結果

シミュレーションした点群は，点群のX,Y,Z座標および同一のレーザ光線の内，何番目に作成されたのかをCSV形式で出力する．計測場として樹種をヒノキ，林齢を60年，季節を夏および人工林として一般的な施業管理された森林，地盤面は水平で乾燥状態，一方，計測条件として，計測高度を1000m，レーザ光線の発射角を真上，点密度8点/m^{2}でシミュレーションした結果を図3 aから3 cに一例とし



(a) 樹林全体としての点群の分布

(b) 樹冠付近の点群の分布

(c) 地盤面付近の点群の分布

図3　本システムのシミュレーション結果の一例

て示す.

シミュレーションした点群を計測場と共に可視化することにより, DEMを作成するための点群がどのように地盤面に分布しているか解析を行うことができる. 図3に示した条件では, 樹冠をすり抜けたレーザ光線はほとんど存在せず, 樹木間の隙間をすり抜けたレーザ光線のみが地盤面に落ちていることが分かる. ヒノキ林のDEMは作成することが難しいと一般的に認識されているが, 本システムから得られた結果は同様な傾向を示した.

6. お わ り に

本研究では, 森林計測のためのLiDARシミュレーションシステムの開発を行った. 本システムを使用することにより, 森林域に対してLiDAR計測を行う前に, おおよそのDEMの精度を評価および論じることができる. また, 本システムは, 反射率とセンサ感度とを考慮して点群を作成しているため, 今までよく分かっていない地盤面の乾湿状態に違いがある樹林下のDEM作成効率も評価できる可能性があると期待している.

今後は, 実際の森林から得られた条件を本システム内で再現させ, 実際のLiDAR計測から得られるDEMとシミュレーションから得られるDEMとを比較検証することにより, 日本に多く存在する人工林を計測する場合に最適なLiDAR計測条件とは何であるのか検討を行う予定である.

(2010年5月13日受理)

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MASSIVELY PARALLEL SIMULATION OF CO_2 GEOLOGIC STORAGE

By

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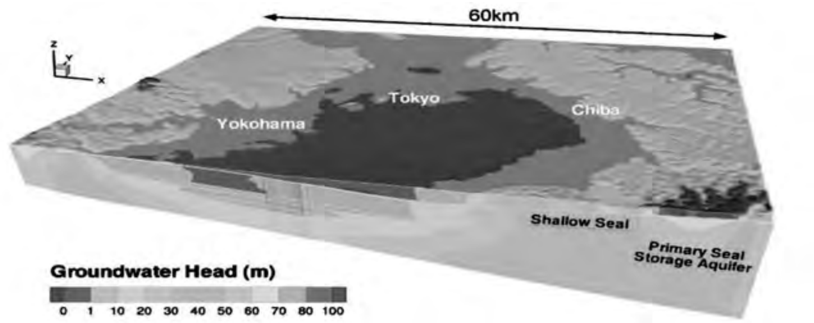
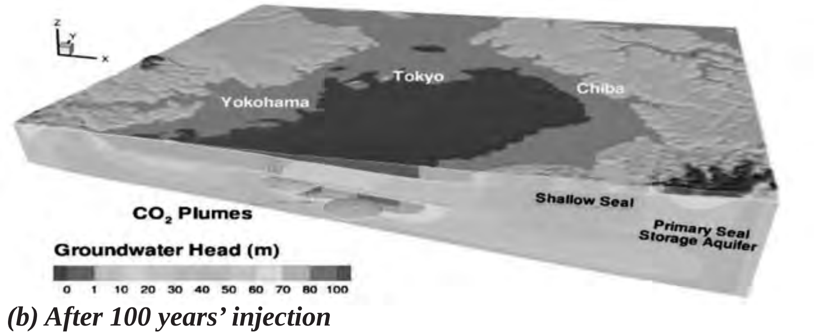
CO_2 capture and storage (CCS) has the potential to significantly reduce the amount of CO_2 released into the atmosphere to mitigate climate change. Technologies are needed to store CO_2 in deep geologic formations safely and permanently. We have developed a high-performance computing system that simulates the long-term fate of injected CO_2, as well as potential impacts and associated risks of CO_2 injection on surrounding regional environment. By combining this system with a world-class super-computer, the Earth Simulator (ES, total 5,120 CPUs) at JAMSTEC, we can now perform high-resolution simulations 100 times finer than previous systems. As a case study, a hypothetical industrial-scale CO_2 injection in Tokyo Bay, which is surrounded by the most heavily industrialized area in Japan, was considered, and the impact of CO_2 injection on near-surface aquifers was investigated, assuming relatively high seal-layer permeability (higher than 10 micro darcy).

However, when a volume of CO_2 is injected into a virgin/native aquifer, it eventually pushes the equivalent volume of water out of the aquifer. In industrial-scale projects of CO_2 geologic storage, it is expected that the amount of CO_2 fluid injected into an aquifer can be several million tons/year for a typical storage site. Continuous long-term injections for more than several decades will buildup groundwater pressures in extensive regions. The Tokyo Bay area is the most populated and industrialized area in Japan, with annual CO_2 emission from large emission sources around Tokyo Bay is about 100 $MtCO_2$/year, comprising roughly 8% of Japan's CO_2 emissions (1.3 $GtCO_2$/ year). Recently, significant efforts have been made to identify the potential for CO_2 geologic storage in the sedimentary basin underlying the Tokyo Bay. It is obvious that a geo-



(a) Steady state groundwater flow at initial condition



(b) After 100 years' injection

Simulated regional groundwater head distribution before and after CO_2 injection

logical CO_2 storage site near large emission sources has an advantage in reducing the transportation costs of captured CO_2 especially in Japan, where the cost of building pipelines is quite expensive.

We conducted a large-scale numerical simulation of CO_2 geologic storage that evaluates CO_2 trapping capacity and its impact on regional groundwater pressure, using parallel computing techniques. The simulation is designed for a preliminary investigation of hypothetical industrial-scale CO_2 injection at Tokyo Bay. To solve the high resolution model efficiently, we used the Earth Simulator. The model will be used to simulate the hypothetical injection activities in the study area.

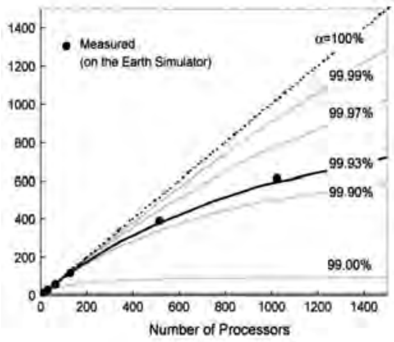
MASSIVELY PARALLEL COMPUTATION

The simulations conducted in this study are computationally demanding, because of the large number of grids and the complex nonlinear processes involved. We adopted the ECO2N module of TOUGH2-MP for the simulations. TOUGH2-MP/ECO2N is an efficient parallel simulator for large scale, long-term CO_2 geologic storage in saline aquifers. It was developed at the Lawrence Berkeley National Laboratory.

ES consists of 640 nodes with eight vector processors and 16 GB of computer memory at each node, for a total of 5,120 processors and 10 TB of main memory. The total peak performance is currently 40 Tflop/s and is increased to 131 Tflop/s by March 2009. In this study, TOUGH2-MP was ported to the Earth Simulator and successfully run on it. The code was specially tuned up to increase its vector operation rati for the efficient use of the ES vector processors.

Amdahl's law states that if a parallelization ratio is the proportion of execution time for a parallelizable part to the total execution time when executed serially, then the speedup that can be achieved by using n processors is: $S_n=1/(1-\alpha+(\alpha/n))$.

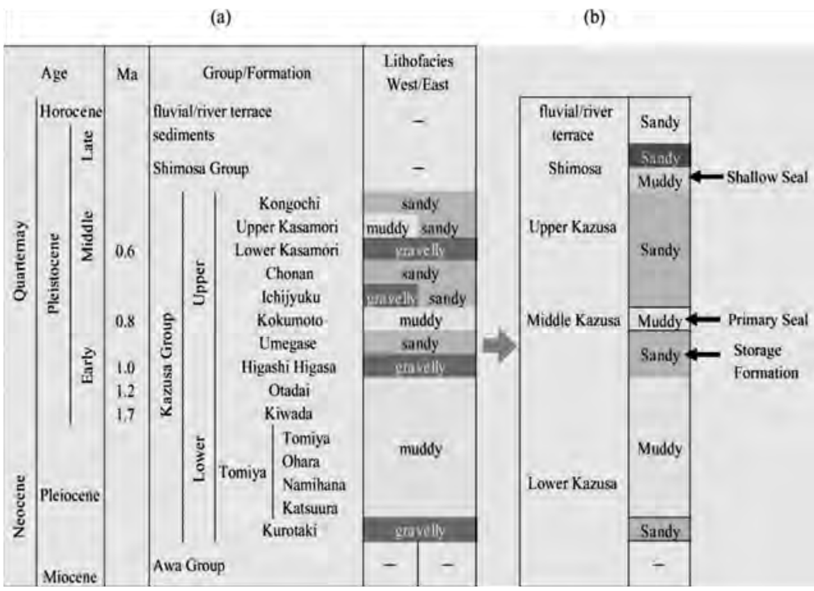
Figure above shows the speedup obtained for TOUGH2-MP on the Earth Simulator. As seen in this figure, the parallelization ratio α is currently 99.93%, with the code benefiting from parallelization on ES with more than 1,000 processors. In this study, the calculation time (CPU time) for the two-phase flow simulations with about 10 million gridblock models was generally 1–2 days for 1,000 years' simulation on 1,024 processors.



Relation between computational speed and number of processors (α: parallelization ratio)

MODEL SETUP

The Kanto Plain is the largest coastal plain in Japan, surrounded by Tokyo Bay, the mountains of Kanto area, the Miura Peninsula, and the Boso Peninsula. Since the 1950s, extensive explorative investigations and production of natural gas (mostly methane gas, dissolved in deep groundwater) have been carried out in the Boso Peninsula. The geologic structure in the plain is well understood through dozens of deep borehole investigations and geophysical explorations for land subsidences and earthquakes. In recent years, a number of hot spring wells (for spa resorts) have been drilled to depths over 1 km. A three-dimensional geological structure model was constructed for the 60 km by 70 km modeling area centered in Tokyo Bay. The surface topography is represented by 50 m grid digital elevation model (DEM) data published by the Geographical Survey Institute, Japan, and the formation boundaries are defined by 200 m grid DEM data. Discretization results in approximately 121,100 grid-blocks on each horizontal layer and 84 layers in the vertical direction, for a total of about 10 million grid-blocks and 40 million connections among them. Figure below lists the geological units/layers for the Kazusa Group and the associated model hydrogeologic layers. These geologic formations have been organized into layered hydrogeologic units, based primarily on the sandy or muddy properties. For this study, it is assumed that CO_2 is injected through 10 wells in the bay, at an annual rate of 1 $MtCO_2$/year for each well



Lithofacies of the Kazusa Group: (a) lithofacies and (b) conceptual hydrogeological model. Arrows indicates storage formation and seal layers.

over 100 years, resulting in a total annual rate of 10 $MtCO_2$/year. The simulation runs cover a time period of 1,000 years, including a post-injection period of 900 years. Given the variations in elevation and thickness of the model layers, the behavior of injected CO_2 will be in turn affected by the variations in ambient temperature, salinity, and pressure, all of which influence the solubility of CO_2 in brine, as well as the density and viscosity of CO_2 and brine.

RESULTS AND DISCUSSION

Results show that the largest lateral plume appears in the injection layer, with the buoyant CO_2 accumulating and spreading under a less-permeable muddy layer. Each plume extends over a range of 4–5 km, which is about half the distance away from the neighboring injection sites. The results indicate that the individual plumes from each injection sites have not merged during 100 years' injection. The circular shapes of the plumes during the injection indicate a pressure-driven feature of the CO_2 migration. Numerically, it is well known that the ‘‘diamond’’ shape of saturation fronts appears when five point finite difference methods with rectangular shaped grids are employed.

In this simulation, by using the Voronoi gridding, the circular shapes of these plumes suggest that the grid orientation effect is comparatively mild. If the injection rate is different for each injection site, the shape of these CO_2 plumes may be distorted, owing to pressure interference between the sites. After the termination of the 100 years' injection, the plumes continue to move mainly due to the buoyancy forces, and eventually a couple of merged plumes are found in the southwest side at 1,000 years. It is found that the directions of the buoyant movement after 100 years are roughly consistent with the maximum gradient directions on the bottom surface of the Kazusa Group, since the primary seal is modeled almost parallel to the bottom elevations of the Kazusa Group. After injection is stopped at 100 years, the plume enters slightly into the seal layer and moves to a shallower region as a result of buoyancy forces, but does not fully penetrate through the seal; it basically continues to be contained under the sealing layer. However, this may also indicate that CO_2 may not be safely trapped over much longer time periods. In reality, the entry pressure of sealing layers should contribute significantly in keeping the CO_2 out. The seal layer in the current model has one-order-of-magnitude higher entry pressure than the sand tentatively, but it is not based on experimental data from the seal layer. In order to discuss the containment of the CO_2, especially over much longer time periods, the effect of the entry pressure must also be investigated in detail. The seal contains alternating beds of sandstone and mudstone that can allow for local leakage of CO_2 through sandy portions. To address this issue, the development of a precise lithofacies model for the seal would be required, which is outside the scope of this article. Initially injected CO_2 is mostly stored as supercritical fluid. However, after the termination of the injection, the contribution of groundwater dissolution gradually increases and finally becomes dominant. The reason for this large contribution of dissolution is attributed to the large surface area of the plumes, which enhance dissolution of CO_2 into surrounding groundwater. However, actual groundwater in this area dissolves methane and has the salinity of 0.2–0.5 mol/L. These two factors should both act to reduce the amount of CO_2 dissolution in groundwater within the storage aquifer, but they are also not accounted for in this current model.

Front page figure shows the simulated spatial distribution of calculated hydraulic heads at pre-injection and 100 years. Our simulations of the hypothetical CO_2 geologic storage suggest the following:

(1) CO_2 plumes from injection can spread over a range of several kilometers within 100 years, using the investigated injection schemes. (2) Buildup of groundwater pressure in shallow confined aquifers on the order of few bars can occur over extensive regions, including urban inlands. (3) Groundwater discharge to the shallow aquifer can increase on the order of tens of millimeters per year as a result of injection activities.

Sensitivity studies indicate, however, that the predictions obtained in this study could be heavily affected by uncertain parameters such as porosity, pore compressibility, and seal permeability. Findings (2) and (3) mostly concern the case in which the permeability of the seal layer is high, so that vertical pressure propagation occurs effectively, as assumed in this study. If the seals were not as permeable, the lateral pressure buildup would reach farther and be higher; then the concern would be that the actual storage aquifer might be updipping to become a shallow groundwater resource at some distance away from the injection site. In this study, it is demonstrated that, for the case in which the permeability of seals overlying a reservoir is insufficiently low (higher than 10 microdarcy), the distribution of low-permeability layers can significantly affect the prediction of near-surface pressure buildup, suggesting the importance of hydrogeological characterizations even in shallow depths. In such a case, modeling studies should fully account for the multilayer characteristics of the storage site when investigating pressure perturbation due to CO_2 geologic storage. The large-scale simulation technique employed in this study could be a very powerful tool in performing site-specific modeling of CO_2 storage candidate sites, with its ability to comprehensively represent hydrogeological features. We plan to refine our preliminary hydro-geological model of Tokyo Bay using a more accurate geological model, when such a model becomes available in the future.

[1]Taisei Corporation Ltd.

RC58 Held Public Forum on BCM

Prof. Meguro released the ICUS report on BCM at the forum.

The Research Committee 58 (RC-58) held a forum to report its results to the general public, at IIS Convention Hall on April 21, 2009. The topic of RC-58 was "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.

Starting in year 2007, 13 companies from various sectors of Japanese society have joined the research committee and studied the topic for two years. There were over 100 participants in this forum, which showed that substantial number of businesses and their departments have a great interest in BCM in Japanese society. In this forum, following the opening address, results from the first year's activity was reported by Prof. K. Meguro, Director of ICUS.

Activities in the first year concentrated on reviewing the existing BCM related literature produced in Japan and abroad. In recent years, BCM systems and Business Continuity Plans (BCP) have become increasingly popular in Japan as well as in US and Europe. Many guidelines to prepare BCPs have been published in Japan. To compare these existing reports, three working groups (WGs) were created. WG1 discussed the differences among the guidelines in Europe and US and those in Japan. WG2 compared the Japanese Cabinet Office Guidelines with those of other Japanese government agencies. WG3 carried its work on a similar line with WG2, but the comparison was done with private sector companies. In these comparisons, "Business Continuity Guidelines 1st edition" (published by Central Disaster Management Council, Cabinet Office, Government of Japan, 2005) was assumed as a standard. Outcomes from each of the three WGs were introduced by Prof. Meguro. Next, activities carried out by the committee in the second year were reported. In the second year, three WGs carried out extensive interactive discussion.

Mr. Y. Kato, Sompo Japan Risk Management and coordinator of WG1a first presented the research outcomes of his group. WG1a discussed suitable BCM systems for private companies. Secondly, Mr. K. Noda, Asia Air Survey Co. Ltd. and coordinator of WG1b, explained the research outcomes of WG1b. WG1b discussed suitable BCM systems for local governments. Finally, Dr. M. Soejima, Obayashi Corporation Technical Research Institute and coordinator of WG2, introduced the research outcome of her group. WG2, discussed suitable methods for evaluating BCP. The final report of these research outcomes written in Japanese was published in April, 2009.

Dr. Nishikawa from MLIT gave a special lecture at the forum.

After the coffee break, a special lecture was given by Dr. S. Nishikawa, Ministry of Land, Infrastructure, Transport and Tourism (MLIT). Dr. Nishikawa talked on "BCP-To maintain the employment and economy in Japan through the international competition". The audience listened very attentively to his lecture. The lecture was followed by a panel discussion. Under chairmanship of Prof. Meguro, Dr. Nishikawa, Mr. Kato, Mr. Noda and Dr. Soejima discussed about BCM Systems Suitable for Japanese Society as panelists. A lively discussion was done with some opinions and questions from the floor.

Prof. H. Sawada delivered the closing speech and introduced the newly proposed Research Committee 67 (RC-67) which focuses on environmental CSR in private corporations. RC-67 has been launched in May.

Working group heads, Prof. Meguro and Dr. Nishikawa joined a panel discussion.

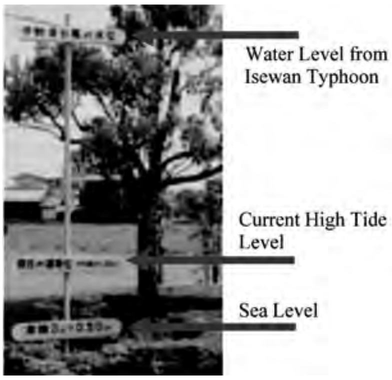
(By M. Soejima, Obayashi Corporation)

50 years since the 1959 ISEWAN Typhoon

Flooding during Isewan landing

The Isewan typhoon landed on Wakayama Prefecture at approximately 6 PM on September 26, 1959. It was a super-huge typhoon with a diameter of 1,500 km and an atmospheric pressure of 929.9 hPa at landing. It was the third biggest typhoon among the recorded typhoons in Japan. About 5,000 lives were lost, which makes it the worst natural disaster in Japan during 20th century before the 1995 Kobe earthquake. The experience of the Isewan typhoon led to the establishment of “Disaster Countermeasure Basic Act” in 1961 that was the first general act for constructing disaster prevention/mitigation system in Japan.

Institute of Social Safety Science held a symposium on June 5-6, 2009 commemorating 50 years of the Isewan typhoon. Professor K. Meguro, Director of ICUS, organized this symposium and participated in the panel discussion as a coordinator. Roles of Disaster Countermeasure Basic Act in past 50 years, its future directions and current issues were discussed.



Water level from the typhoon

After the symposium, the participants visited the damaged area. Although almost all the area was restored during 50 years, we could observe several marks left behind by the typhoon even now. Photo above shows a pole illustrating water level from the Isewan typhoon, average high tide level and sea level. Even now, this region has a high flood risk as the altitude of ground level is lower than the sea level. In order to reduce flood damage, this region has a traditional style of residence called “Mizuya” as shown in the photo below. A Mizuya is built 3m higher than the main residence and is used as an emergency shelter in case of flood occurrence. We could see several Mizuyas in this region.

A Panel discussion moment

This site visit was a valuable experience for knowing the typhoon disaster that changed the disaster prevention system of our country.

(By M. Fujiu, Ph.D. Candidate)

A Mizuya house

Special Talk by Prof. John Burland at IIS

A special talk on “Rescuing the Leaning Tower of Pisa - the inside story” was given by Prof. John Burland of Imperial College, London, on the evening of June 17, at the convention hall in IIS. The event was hosted jointly by Japan Chapter of Imperial College Alumni and IIS, the University of Tokyo, Japan.

The Leaning Tower of Pisa has started to tilt even at the very beginning of its construction in the 11th century. Since then, the tower has kept leaning for 800 years. Professor Burland has notably been involved in the rescuing of the Leaning Tower of Pisa for which he was a member of the Italian Prime Minister’s Commission for stabilizing the tower. Thanks to their considerable effort, the tower has regained its stability and now it is open to general public. Prof Burland talked about the 10-year struggle of engineers and researchers to rescue the tower.

Prof. Yashiro, Director General of IIS, presented letter of appreciation to Prof. Burland (left), Excavation drills were carried out to take out soil beneath the tower for adjustment of its tilt (right) which prevented a possible disaster pictured here (middle).

More than 100 audiences intently listened to the exciting story. Further discussion was continued in the dinner party following the lecture.

(By R. Kuwano)

Ground Cave-in in Golf Course

Opening at the ground (left, courtesy: Hokkaido Shinbun) and location of the collapse (right, courtesy: Asahi Shinbun)

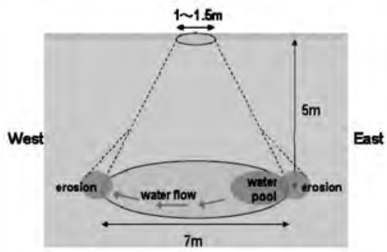
A sudden collapse of the ground occurred in the 8th fairway at the Le Petaw Golf Club in Hokkaido on April 2, 2009, when a woman golfer unfortunately stepped on it. She fell into a hidden hole formed underneath the ground and by the time a rescue team arrived she had passed away.

The hole had a flask shape with a 1 m wide opening at the ground surface, and was 5m deep and 7m wide at the bottom. There was an about 0.6m deep shallow water pool in the east side of the hole. Although the golf course was daily checked by maintenance staff, they could not get any sign of the hidden hole even in the morning of the accident. The ground collapse seemed to have happened all of sudden, as the victim's son who walked just a couple of meters behind her saw her suddenly disappearing into the ground.

The course was originally built more than 15 years ago, by filling a valley with local soil. There used to be a stream along the east-west direction at the location of the collapse. Drain pipes were installed underground to carry away the subterranean water while preventing soil from seeping out.

A detailed investigation took place on May 21 and 22, by Hokkaido prefectural police, assisted by two experts of geotechnical engineering, Prof. Y. Kohata of Muroran Institute of Technology and Dr. R. Kuwano of ICUS, IIS, the University of Tokyo. A large scale excavation was carried out around the hole to understand how and why such a huge underground cavity was created. At the depth of 8m from the ground surface, there was the boundary between original ground and filled soil, where a lateral ground cavity of about 2m wide was discovered in the west side. It seemed to be a path through which soil with water was transported out of the hole. In the excavation on the east side, they found the exact location of the ground where the water flew into the hole. Explanation for the mechanism of ground collapse was tentatively made; soil appeared to be internally eroded by the natural water path at the old stream. The hidden cavity grew silently and eventually caused ground collapse. Further investigation is still underway.

(By R. Kuwano)



Schematic of the opening (top); natural soil pipe from internal erosion at the location of old stream (bottom)

Research Committee 62 Activities

RC-62 Annual Activity Report

Research Committee 62 (RC-62) on "Technologies for Evaluation of Aging Infrastructure Performance Degradation," held its 6th meeting on June 8, 2009. To realize the performance-based maintenance for civil infrastructure, it is necessary to evaluate structural performance using various measuring techniques. However, at present, unfortunately no established techniques are available that can accurately collect quantitative information. In particular, a comprehensive evaluation of an entire structure from the ground to the superstructure is rather difficult. ICUS organized RC-62 in April 2008 to address the challenge of performance evaluation of an entire structure. The first year of our activity focused on the review of current available measuring techniques for concrete or earth structures. Also, we started to seek the future advancement of each technique as well as the merger of several techniques to make it possible to apply to a subsurface concrete structure. The research output of the first year was published as the ICUS committee report 2009-01 in May 2009.

(By Y. Kato)

ICUS Joined the IIS Open House 2009 and Commemoration of 60th Anniversary of IIS

Moments at ICUS display corner as part of the two-day IIS Open House 2009 event; About 300 people from all walks of life visited ICUS during the event.

Every year IIS organizes an Open House for two-day period around May-June to disseminate research activities by all laboratories and research centers. This year IIS Open House was held on May 29 and 30. People from all walks of life including professionals from research organizations, international organizations, industry, non-profit organizations and academic organizations from high-schools to university level take advantage of the unique event to know about latest research and outreach activities of IIS. ICUS has been participating in this event since its inception in 2001.

Since effectively disseminating its research and information collected to society has been one of its core goals, ICUS considers IIS Open House as a valuable opportunity to interact with all members of society to get valuable comments and feedbacks on their activities to realize its vision of a safer urban environment. All 9 laboratories affiliated to ICUS prepared panels on their research and outreach activities as well as planned activities. Themes were "Development of earthquake resilient urban environment" (Meguro Lab.), "Monitoring of environment and disaster risk over Asia" (Sawada & Takeuchi Lab.), "Life-cycle management of civil infrastructure" (Yokota Lab.), "Long term behaviour of earth and undrground structures" (Kuwano Lab.), "Durable and sustainable concrete materials and technology" (Kato Lab.), "Regeneration of modern timber architecture" (Koshihara Lab.), "Improvements of disaster response capacity of hospitals" (Ohara Lab.), "Development of safe, healthy and comfortable urban society"(Huang Lab.) and "Urban traffic management" (Tanaka Lab.). Also international activities by the center and activities by its regional network offices, BNUS in Dhaka and RNUS in Bangkok, were at display. During the event, ICUS Newsletters, Reports and other publications were displayed and presented to interested parties. ICUS staff and students from affiliated laboratories presented live demonstrations of various systems developed by the center and participated in interactive explanations about the research activities to the visitors. ICUS Quiz, which asked visitors to test their general understanding of key ICUS research displayed at the event, was popular among visitors especially among high-school students and families since successful answers were rewarded with symbolic prizes with the ICUS logo on it. About 300 people visited ICUS during the event out of which about 40 were from industry.

This year's event was significant in view of the 60th anniversary of the foundation of IIS. Special events including forums were organized on May 31 at IIS to celebrate the occasion where all laboratories and research institutes displayed their summarized research at a specially designated place. All ICUS laboratories also participated in this special display. On May 28, Prof. J. Hamada, President, the University of Tokyo welcomed all to lectures and celebrations to commemorate the anniversary where several university vice presidents, alumni of the IIS attended. Professor Emeritus Hiroshi Hara, Professor Emeritus Hiroyuki Sakaki, and Executive Vice President Masafumi Maeda made a series of very interesting lectures on the campus, research and organization of the IIS. The anniversary celebrations coincided with the groundbreaking ceremony for the start of the renovation of Building 60 on the Komaba Research Campus, the publication of a book detailing the last ten years of activities at the IIS and a "60 year commemorative special issue" publication.

(By P. J. Baruah)

16th ICUS Open Lecture was held at IIS

Prof. Ikuo Towhata
(the University of Tokyo)

Dr. Hiroshi Dobashi
(Metropolitan Expressway Co. Ltd.)

Dr. Satoshi Imamura
(Taisei Co. Ltd.)

The 16th ICUS Open Lecture was held at IIS on April 3, with approximately 90 participants. Three presentations were given on the broad theme of the lecture, "Contribution of geotechnical engineering to the urban infrastructure environment".

Following the welcome speech by Dr. Kuwano, Prof. Tohata of the University of Tokyo discussed on the factors of prosperity and decay of urban cities. Then he presented how the land constructed by the reclamation of waste materials can be utilized effectively in Tokyo. Dr. Dobashi of Metropolitan Expressway Co. Ltd. Talked on the project of Central Ring Road of Metropolitan Expressway currently constructed between Shinjuku and Shibuya. Various techniques adopted for the safety and environmental consideration were introduced. Dr. Imamura of Taisei Co. Ltd. presented on the technology of Carbon Dioxide Capture and Storage (CCS). The closing remarks were given by Prof. K. Meguro, followed by a small party where further interactive discussions were continued.

(By R. Kuwano)

46th Annual RSSJ Conference Hosts ICUS Special Sessions on "Disaster Prevention and Environment"

The special session was appreciated by participants (left) due its interdisciplinary nature; Dr. Miyazaki (middle) and Prof. Sawada (right) chaired the two sessions.

The annual conference of Remote Sensing Society of Japan (RSSJ) was held on May 21-22, 2009 at Institute of Industrial Science, The University of Tokyo. RSSJ is one of two largest remote sensing societies in Japan and its research fields cover wide range of topics ranging from sensor technologies to terrestrial, oceanic and atmospheric issues. This year's hot topic in RSSJ was early damage detection of disasters by remote sensing technologies such as satellite borne SAR (Synthetic Aperature Radar) and visible sensors and air-borne Laser measurement, because of the recent Iwate-Miyagi Nairiku earthquake that occurred at the northern part of Honshu Island in 2008.

Two ICUS special sessions were successfully organized at the conference: one focused on "Disaster prevention", the other focused on "Environment", respectively. Dr. S. Miyazaki chaired the session on Disaster prevention and four speakers presented on utilization of remote sensing technology for large-scale disasters. The session on Environment was chaired by Prof. H. Sawada and four speakers presented on utilization of remote sensing in forest monitoring and land cover change detection. Prof. K. Meguro, Director of ICUS, gave an invited lecture on disaster information management for improvement of overall disaster prevention.

This was the first time when a ICUS special session was held in a conference of an academic society. After the session, many participants said ICUS activities interested them, and also remarked that information exchange from other research area was useful for them. ICUS expects to hold special sessions like this with relevant academic societies in future.

(By T. Endo)

Visit to Maintenance Demonstration of Metropolitan Expressway Co. Ltd.

Fracture of the weld caused by stress concentration

Portable hammer to detect the sound level with microphone

Magnetic Particle Testing for detection of surface defects

A total of 7 members from ICUS, namely Prof. Sawada, Dr. Endo, Dr. Baruah, Dr. Numada and three students, visited the maintenance demonstration of Metropolitan Expressway Co. Ltd. on Tuesday, June 9, 2009.

They joined several other groups from severeal other universities and organizations in the visit. After an introductory session at the headquarter of Metropolitan Expressway Co. Ltd. all participants were taken to a maintenance site near Kasai junction of the Tokyo Metropolitan Expressway Coastal Line. This junction connects the coastal line of Tokyo Metropolitan Expressway in Edogawa Ward, Tokyo.

During the demonstration, maintenance problems in express-ways were introduced. There are two maintenance problems in steel structures of expressways. There are invasion such as rust and the fatigue fracture by cyclic loading from passing vehicles. Check of the fatigue fracture is especially found to be important in case of Tokyo Metropolitan expressway because of the high frequency of the large-size vehicle traffic. The fracture is often seen at the point of the weld caused by stress concentration.

The maintenance check method is divided into three steps: the car rounding check, the walking check, and the approach check. The visit was focused on the technologies used in the approach check.

Several kinds of checking technologies were demonstrated, e.g. radar technology for searching steel placing inside concrete, thermographing method for detecting air hole inside concrete, magnetic particle testing for detection of defects on the surface of structures and ultrasonic testing for detection of defects inside structures.

Also other methods to detect defects where a human hand cannot reach were shown. These included a portable camera with light pole which can be extended like a fishing rod and portable hummer to detect the sound level with microphones.

The expressway network in Tokyo is important for the efficient functioning of the urban activities. The usual maintenance by Metropolitan Expressway Co. Ltd. can provide us with a continuously functioning expressway that is safe and comfortable.

The visit provided an excellent opportunity to study the real maintenance processes and methodologies.

(By M. Numada)

Research Committee 67 Activities

The first official meeting of the "Research Committee on Evaluation of CSR activities in Environment Conscious Society (RC-67)" was held on 2 July, 2009 following the introductory meeting on May 29. Recently, the Cooperate Social Responsibility (CSR) is considered important and many activities are propagated as CSR activity. However, we found that the effects of the activities were seldom examined by organizations themselves. Therefore, ICUS established this study group (headed by Prof. H. Sawada) to develop an appropriate methodology to evaluate the CSR activities from the point of environmental soundness. At first, the group focuses on the activities related to forestry which more than half of Japanese companies introduced as an CSR activity. The RC-67 is planned to continue for two years.

2nd meeting of RC-67 at IIS on 2 July

(By H. Sawada)

BNUS Activities

BNUS compiled a survey report on cyclone Aila

On the May 25th, 2009, cyclone Aila passed through 14 districts in the coastal area of Bangladesh. According to official sources, about 190 lives were lost and more than 50,000 people became homeless. Other total or partial destructions included about 6.12 million thatched houses, 3.20 million hector harvestable paddies, large number of shrimp ghers and 1.47 million livestocks as well as poultries. At least 7,000 people were injured by the storm and about 48 million people were affected. In Nizum dwip, 20,000 people are homeless, 58,950 animals are killed and 50,000 deer have been missed.

Constructed in 1960s, coastal polders breached by tidal surge during the Cyclone increased the damage. Relief works were hampered due to breached embankments. Storm surge of about 3m height impacted western region of Bangladesh, submerging numerous villages, severely affecting agricultural lands due to intrusion of saline water and isolating more than 400,000 people by severe flooding in coastal regions. In Patuakhali district, a dam broke and submerged five villages.

In Satkhira district the cyclone damaged about 130 km of embankments with an estimated reconstruction and maintenance cost of about $3.80 million. In Khulna district, such costs for 211.24 km of damaged embankment would be about $7.75 million. Other relevant costs, such as repairing and reconstruction of sluice gate/ regulator, other hydraulic structures etc. would require about $6.96 million.

Cyclone Aila damaged embankments at Kapatakha river in Satkhira district.

BNUS conducted a socio-economic survey of households in old Dhaka

To make an effective plan in disaster risk reduction, one of the major goals is to raise awareness level of the local community. In order to assess social vulnerability of individuals due to earthquake within households, BNUS has conducted a socio-economic survey of 200 households in Ward No. 68 in the older part of Dhaka City. The social vulnerability indicators have been selected from the literature and the relevant data needed for the analysis is collected through house to house socio-economic questionnaire survey. Information regarding the level of public awareness about earthquake risk of the community was found through this survey. The sample size is chosen at random basis at 95% confidence level which is 2% of total projected household of 10,942 in the study area in 2009 (according to Bangladesh Bureau of Statistics). Finally the vulnerability of the community has been studied considering the existing socio-economic condition of the locality.

BNUS carried out seismic microzonation study of Cox's Bazar Municipality

Cox's Bazar lies in the south-eastern coastal region of Bangladesh. Being a prime tourist spot, the area has been experiencing rapid urbanization in the last few decades. However, construction of significant number of buildings and other structures has occurred in an unregulated manner and without seismic design considerations. Landslide and related casualties have also become very common in the hilly areas of the locality. In order to assess seismic vulnerability based on ground susceptibility and adopt mitigation strategies for urban areas, seismic microzonation is considered to be the first step. BNUS is carrying out a study on microzonation of the Cox's Bazar Municipality area using geographic information system where reflection of ground shaking and the site attributes of soil amplification, liquefaction and landslide are the salient features. Probable earthquake hazard and expected ground motion calculation, sub-soil investigation, liquefaction potential determination and slope stability analyses were carried out to develop microzonation maps. The study shows that 87% of the study area is highly susceptible to liquefaction. Approximately 8% of the municipality consists of hilly region, 97% of which is found to be very unsafe in view of natural slope stability.

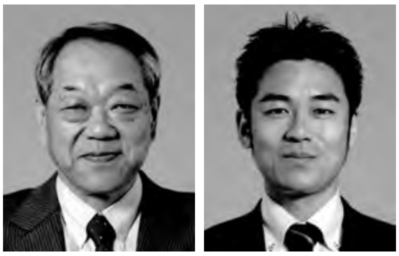
(By M. A. Ansary, BNUS)

RNUS Activities

RNUS is actively participating in a project with colleagues in School of Civil Engineering at AIT and Panya Consultants Co. Ltd., Thailand to develop a Seismic Hazard Map of Thailand and developing Seismic Microzonation Map as well as GIS database of buildings and lifeline systems in 3 major cities in Thailand. Also, a project on Seismic vulnerability and risk assessment of Dhaka, Chitagong and Sylhet city of Bangladesh is ongoing. This project is part of the Comprehensive Disaster Management Program of Bangladesh. RNUS along with AIT is supervising field survey of more than 20,000 buildings in the region.

ICUS Welcomes Visiting Prof. Y. Ichihashi & Dr. M. Numada

ICUS welcomes Mr. Yasuyoshi Ichihashi who joined ICUS on May 1 as Visiting Professor. Mr. Ichihashi has been working in the Ministry of Foreign Affairs, Govt. of Japan, and still currently is a diplomat. He served in Bulgaria and Mongolia as Ambassador to Japanese Embassy, and spent long time in China (Shanghai as Consul-General, Beijing as Minister/ Counselor, Hong Kong as Consul). His other postings include Genève and Bangladesh, and he also served as Deputy Representative of the Government at the World Expo 2005 in Aichi. It is certainly quite exceptional for ICUS to have such an incumbent diplomat as its member. ICUS expects to benefit from his rich diplomatic background in international arena with contributions in the area of



Visiting Professor Y. Ichihashi (left) and Dr. M. Numada (right)

ICUS's international activities/ strategies, as well as their linkages to the Government's external policies related to science and technology. This is a unique challenge for both the Center and the Ambassador himself. Yet his appointment this time shows the ICUS's eagerness to develop broader international strategies and activities.

ICUS would also like to warmly welcome Dr. Muneyoshi Numada to ICUS from April 1, 2009. He received his B.Engg. at Meguro laboratory at Chuo University, Japan in 2000 and carried out his research towards his M.Engg. degree at Konagai Laboratory at the University of Tokyo. He received his Ph.D. from the University of Tokyo for his research on numerical simulation of landslide disaster.

Before joining ICUS, he was a management consultant in a private firm solving various important business problems for clients in industry from 2006 to 2009.

ICUS expects him to contribute to new leadership, use global networks to carry out its activities and to give new insight to ICUS.

(By K. Meguro)

Farewell to Dr. K. Worakanchana

Dr. Kawin Worakanchana retired from ICUS on March 31st, 2009.

Dr. Worakanchana joined ICUS as a Project Researcher in April 2007. During his stay, he continued his research on 3-D Applied Element Method for modeling un-reinforced and retrofitted masonry structures and participated in joint activities between ICUS and RNUS in Thailand. ICUS would like to thank him for all his great contributions during his stay and wish him all the best. Also, ICUS expects to continue professional relationship with him in future.

ICUS Activities

- Prof. K. Meguro visited Incheon, South Korea to attend a meeting on the management of USMCA2009 from April 10 to 12. Prior to that, he visited Chengdu, China from April 7 to 9 to give an invited lecture in a seminar held by Sichuan Provincial Government.
- Dr. M. Koshihara joined other ICUS members to oversee the arrangement of USMCA2009 in Incheon, South Korea from April 10 to 12. From June 24 to 29, he visited Istanbul, Turkey to participate and present at the International Symposium on Timber Structures.
- Dr. K. Worakanchana stayed at RNUS to continue his research and teaching duties till the end of his term at ICUS.

Awards

Dr. P.J. Baruah and Dr. T. Endo received best paper award from Japan Technical Association of Pulp and Paper Industry (TAPPI) for their paper titled "Estimation of Timber Volume in Eucalyptus Plantations using Satellite Images" (in Japanese) published in February 2008 issue of Journal of Japan TAPPI. The research was a result of University-Industry collaboration between IIS and Mitsubishi Paper Mills (MPM) Co. Ltd. Other authors of the paper are Dr. T. Katsura of MPM and Prof. Y. Yasuoka of National Institute of Environmental Studies.

Editor's Note

Last July ten unexpected visitors had come to my laboratory. They were 10 spotbill ducks, called Karugamo in Japanese. This year spring, for the comfort of our laboratory, we made a garden in the veranda of our laboratory using timber from forest-thinning. Eventually, a mother duck flew to our garden and laid eggs from which 9 ducklings were born. The problem was, our laboratory is located on the 4th floor of IIS and there was no food and water for them. We prepared some food and also made a small water pool for them in our veranda. Till now, 3 ducklings have grown up, although 6 had been lost from stealing by crows or other reasons. Recently, the mother duck somehow took these grown-up ducklings and flew away. We yet don't know when exactly this happened.

Our laboratory and ICUS are located in a huge reinforced concrete building. One of my research themes is how to create comfortable office using and incorporating timber within a reinforced concrete building. We think visiting of the ducks is one of the evidences of successful results of our research. We believe that urban safety should take into account comfort of life at the same time.

(By M. Koshihara)

Roof-garden at the veranda (top); Mother duck and the ducklings (bottom)

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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The University of Tokyo

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MODELLING VOLCANIC RISK IN TOKYO

By
Christina Magill[1]

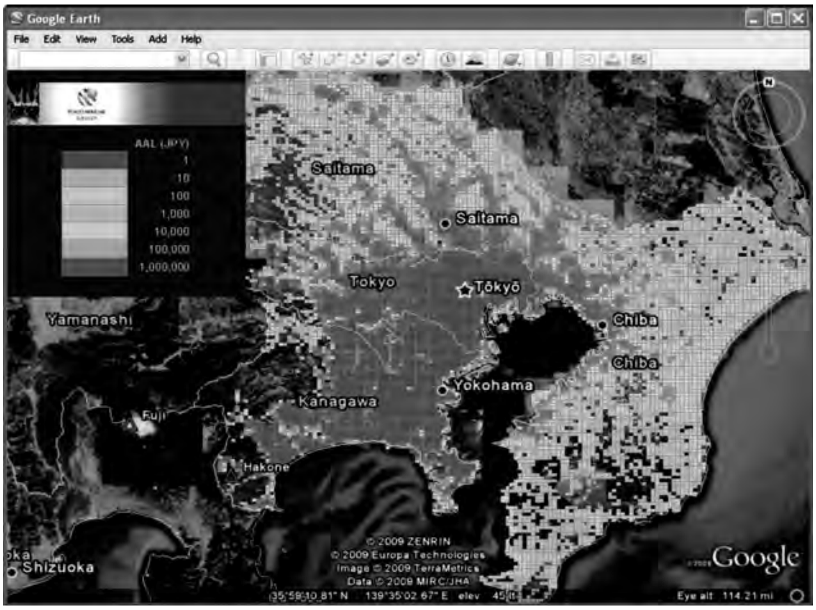
The 1707 Hoei eruption of the Mount Fuji deposited four centimetres of tephra in central Tokyo with much larger thicknesses falling in Western Kanagawa. A repeat of this event would have severe economic consequences for the Greater Tokyo area, causing follow-on effects to Japanese and global economies. But what is the probability of such an event? Should Tokyo prepare for more likely scenarios? And what resources will be required to manage future volcanic crises? Risk Frontiers, in conjunction with the International Center for Urban Safety Engineering, have developed *TokioKazanRisk*, a volcanic hazard and risk model that provides a framework for investigating questions such as these. Support for this project was provided by Tokio Marine & Nichido Risk consulting Co., Ltd.

TokioKazanRisk incorporates a catalogue of tephra dispersal simulations from six volcanic centres - Fuji, Asama, Hakone, Haruna, Kusatsu-Shirane and Kita-Yatsugatake - located to the west of Greater Tokyo. To calculate building damage and to estimate clean-up requirements and costs, hazard information is combined with a building, road and land-usage database describing Tokyo, Kanagawa, Saitama and Chiba prefectures. New visualization techniques allow hazard and risk results for these areas to be viewed within mapping applications such as Google Earth.

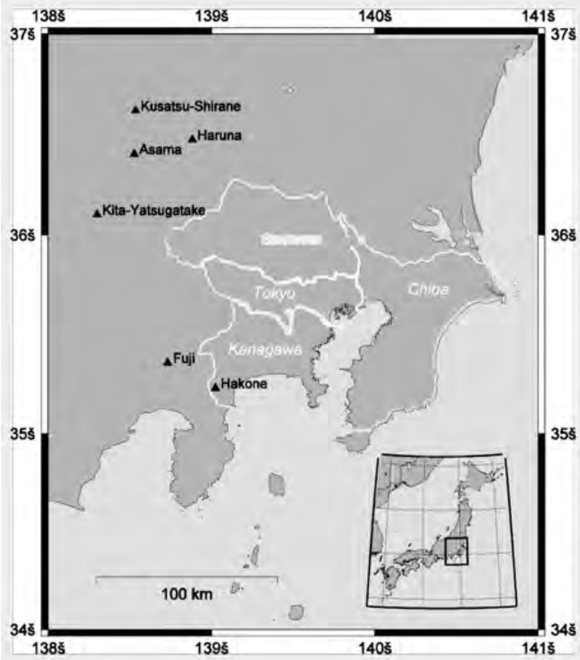
TEPHRA DISPERSAL MODELLING

The tephra dispersal catalogue contained within *TokioKazanRisk* was developed with the use of *TEPHRA2* – an analytical tephra advection diffusion model developed at the University of Southern Florida. Using stratified wind speed and direction information, *TEPHRA2* calculates particle dispersion, transport and sedimentation, and estimates tephra accumulation at specified locations surrounding the source location.

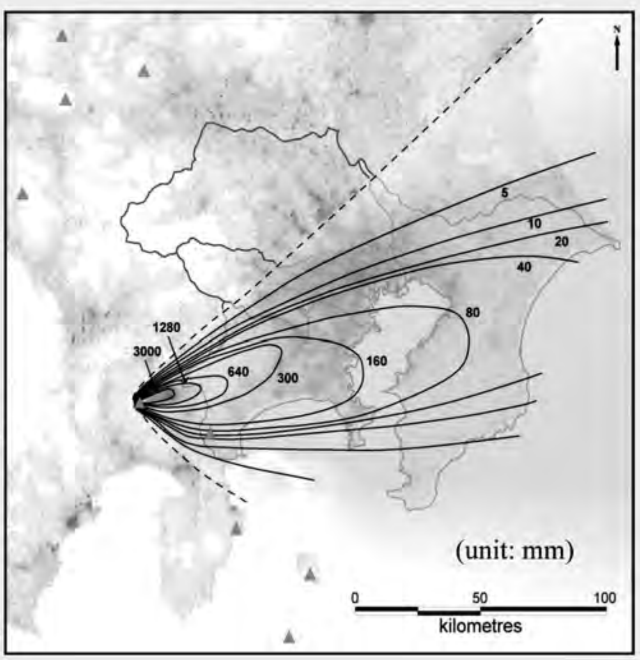
Extensive calibration was carried out to refine the constants used in *TokioKazanRisk*. In particular, the Hoei eruption was intensely studied.



Average Annual Building Loss (AAL) in Japanese yen mapped on a 1 km grid



The six volcanoes and four prefectures considered with TokioKazanRisk



Isopacs of the 1707 Hoei Eruption (depths of air-fall tephra in mm)

Parallel computing techniques were utilised to simulate large numbers of eruptions for each volcanic centre. Wind speed and direction profiles with height were sampled randomly and volcanological parameters selected from magnitude/frequency curves were developed to describe previous activity, current eruption trends and to account for the volcanoes inherent future unpredictability. Hazard results with corresponding probabilities are stored within *TokioKazanRisk* on a 1 km mesh grid.

SAMPLING EXTREME EVENTS

Volcanic centres are capable of producing explosive volcanic events that may vary by more than five orders of magnitude. Traditional hazard modelling samples a fixed time period and simulates the expected events within this period. Using this approach, all events are assigned an equal probability of occurrence and therefore small magnitude events are sampled preferentially.

In developing magnitude/frequency relationships, event magnitude is represented by tephra volume, which we assume has a direct logarithmic relationship to the Volcanic Explosivity Index (VEI) scale. In the modelling carried out to create the *TokioKazanRisk* tephra catalogue, VEI is sampled uniformly with probabilities retained and utilised in later calculations. This methodology is more economic in its storage requirements and provides better sampling of the entire range of eruption possibilities.

RISK CALCULATION

TokioKazanRisk currently focuses on two major outcomes from air-fall tephra – building damage and the necessity for clean-up activities. Exposure information is either a user portfolio or the included database that describes building characteristics, roads and land-usage on a 1 km grid covering the entire Greater Tokyo area. This database incorporates an extensive survey of buildings, where characteristics including building condition and roof construction were collected.

Building damage and associated losses due to three causes are calculated:

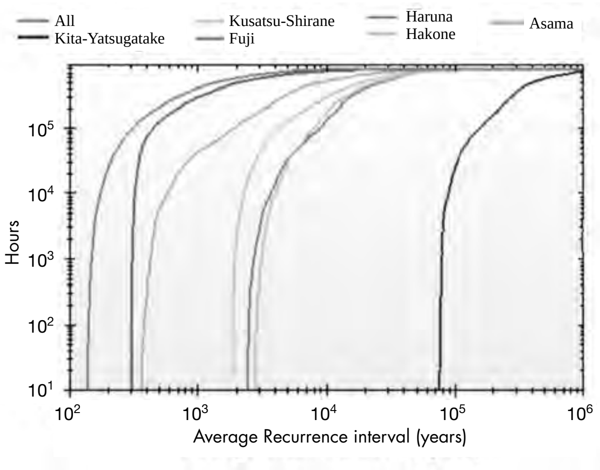
- structural damage - the partial or complete collapse of buildings due to the weight of tephra.
- non-structural damage - the corrosion and abrasion to walls, roof surfaces and exterior fittings caused by tephra particles.
- clean-up costs - the removal, transport and disposal of tephra from properties and the cleaning of building exteriors.

VISUALISING PROBABILISTIC HAZARD AND RISK

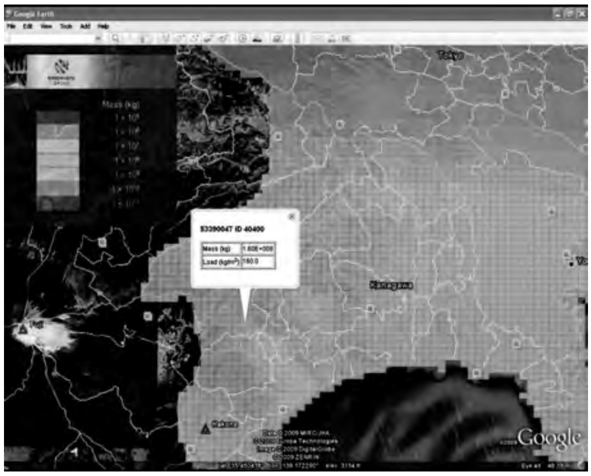
Probabilistic hazard and risk results for particular locations may be plotted against their annual probability of exceedance or average recurrence interval. Statistics, such as average annual loss or expected annual probability for a given volume of tephra, can also be recovered and the output presented in Keyhole Markup Language (KML) allowing easy mapping within applications such as Google Earth.

A PLATFORM FOR HAZARD MANAGEMENT

As well as building damage, *TokioKazanRisk* calculates impacts to various land-usage types, e.g. the built environment, agricultural areas and roads. The probable volumes of tephra to fall on each of these land use categories are calculated and, in the case of roads and the built



Vehicle hours required for cleaning roads against Average Recurrence Interval



Tephra mass mapped on a 1 km grid for a single event from Fuji volcano

environment, the model estimates the personnel, equipment and hours needed for clean-up activities. Data analysed to allow these calculations were provided by the Kagoshima and Tarumizu City Halls who have experienced frequent tephra-fall events from Sakurajima volcano.

To aid in emergency management planning, individual eruption scenarios may be mapped with hazard presented on a mesh grid. This allows for various scenarios to be studied in detail.

The modular nature of *TokioKazanRisk* means that the model will be a useful tool for many future risk applications. By incorporating additional exposure and vulnerability information, probabilistic estimates of impacts to utilities, transport, agriculture, business and health can all be made.

(Support for this project was provided by Tokio Marine & Nichido Risk consulting Co., Ltd)

[1]Risk Frontiers, Macquarie University, Sydney, Australia

Flood Damage in Japan

Strong rain hit the southern part of Japanese island during July 19 and 26. This caused 31 deaths, 55 injured, 48 totally damaged houses and more than 10 thousand flooded houses in the affected area.

Especially, Boufu City in Yamaguchi Prefecture recorded rainfall of 72.5mm per hour around 9:00 A.M. on 21st July. Total rainfall amounted to be almost twice the average monthly rainfall in July. In Manao region of Boufu City, landslide due to the heavy rain hit a special nursing home for the aged and killed 7 people. At that time, 100 aged people were in the middle of their breakfast. Debris flew from mountain side buried dining space on the first floor. The home was located in the red zone of landslide disaster. Yamaguchi Prefecture provided warning information of landslide disaster to Boufu City at 7:40 A.M. in the morning. However, the city didn't announce the warning to a special nursing home and evacuation before the landslide was not achieved.

Recently technologies increased the possibility of early warning before disasters. However, these warning should be conveyed to the proper facilities and persons and used for mitigation of damages. The strong rain in the summer 2009 in Japan reminded the difficulty of successful use of early warning.

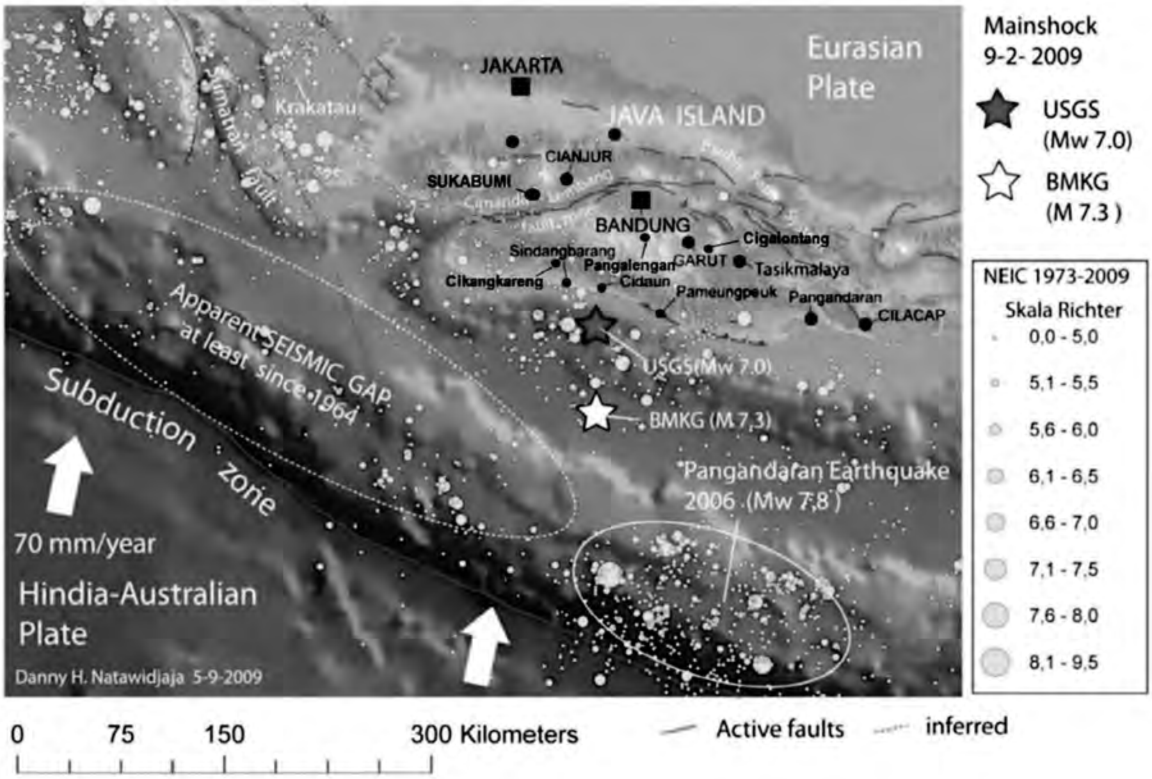
(By M. Ohara)

Landslide hitting a nursing home in Boufu City (© Pasco Co., Kokusai Kogyo Co. Ltd.; Distribution: Pasco Co.)

REPORT ON THE WEST JAVA EARTHQUAKE ON SEPTEMBER 2, 2009

By

Teddy Boen[1] & Danny Hilman Natawidjaja[2]



General seismotectonic map of west Java region. The island sits above the Hindia-Australian plate that is being subducted beneath Java starting from the WNW side trending through deep ocean with a northerly motion of about 70 mm/year relative to the Eurasian plate. Yellow dots are shallow earthquakes (less than 100 km depth) from 1973 to 2009 from National Earthquake Information Center of US Geological Survey (NEIC-USGS) catalog. The red and white stars are main shocks determined by USGS and Badan Meteorologi Klimatologi Dan Geofisika (Indonesian Metereological and Geophysical Agency, BMKG) for the recent large event. Red lines on Java land are preliminary active fault lines mapped from Shuttle Radar Topography Mission (SRTM).

In the afternoon of September 2, 2009 a large earthquake (M7.0) occured about 50 kilometers off the south coast of west Java, Indonesia. According to the NEIC-USGS report, the earthquake source is located at about 7.7 S and 107.32 E at a depth of about 50 kilometer. As a comparison, the BMKG reported the earthquake epicenter further away trenchward with a source depth of about 30 kilometers. The fault mechanisms, given by the USGS Centroid Moment Tensor (CMT) solution, shows that the earthquake fault is a reverse fault striking NNE and dipping steeply about 45 degree. This clearly indicates that the earthquake is an intra-slab event, not on the Java megathrust, which stikes WNW and dips shallow towards the north. The megathrust section in the south of west Java and the Sunda Strait has no history of major earthquakes in the past 100 years, suggesting it is a seismic gap, which may have been acumulating a large amount of strain to produce a giant megathrust event. However, there is not much GPS data to determine or map coupling properties or degree of locking of the subduction interface, so then, one can estimates what portion of the relative plate motion that has been stored as earthquake ammos. Hence, the threats of earthquake shakes and tsunami from the Java megathrust remains unclear.

The news regarding the damage of the September 2, 2009 earthquake in the media was a bit confusing. All media related the magnitude of the earthquake with destruction. The earthquake had a large magnitude (Mw7.0, USGS). However, the distance of the epicenter from several cities/villages where some damage occurred, was more than one hundred kilometer. Also, the epicenter depth was not shallow and was about 50km (according to USGS). Usually, the shaking of an earthquake with Mw7.0 could be felt within a radius of 400 km and might cause damage within a radius of approximately 80 km.

Many houses collapsed in various forms from the earthquake. Pictures show collapsed houses from Pameungpeuk (left), Margamukti Village-Pangalengan (center) and Cigalontang –Tasikmalaya (right).

In fact, such an event should not cause significant damage beyond a 100 km radius. Unfortunately, this earthquake, so far has caused 76 casualties.

The damaged areas are scattered and the damage itself in each area is sporadic. Most of the damaged and /or collapsed buildings are non engineered construction, built with poor quality materials combined with poor workmanship, resulting in very poor quality houses with no resilience to earthquakes. Also, most of the damaged buildings were dilapidated due to lack of maintenance causing deterioration of the materials strength. Non-engineered buildings consist mostly of houses and several one story school buildings.

The nearest damaged areas from the epicenter are Sindangbarang which is approximately 50 km from the epicenter, and Pameungpeuk and Cikelet which are approximately 60 km from the epicenter. In those places the damage was quite substantial, but sporadic.

Approximately 50% of the houses were damaged, ranging from slight to collapse. Rest 50% of the buildings are still intact. The second closest area to the epicenter is Cikangkareng Village (Cibinong, Cianjur), approximately 80 km from the epicenter. The earthquake caused landslides, burying 12 houses, where 30 people died; the biggest human casualties in a single place from the September 2, 2009 earthquake. The earthquake also caused damage in areas far from the epicenter, namely in Pangalengan approximately 125 km from the epicenter, in Tasikmalaya approximately 140 km from the epicenter and in Sukabumi approximately 155 km from the epicenter.

The extent of the destruction by that earthquake deserved careful investigation. Investigation was needed on the cause of the ground motion and the geologic condition to know why that earthquake with an epicenter at a depth of 50 km did cause damage to non-engineered buildings that are relatively rigid in places more than a hundred kilometers away, apart from the fact that the damaged and/or collapsed buildings are poorly built.

In big cities, particularly Jakarta, tall buildings were swaying and caused tremendous panic among the occupants and everybody started rushing to get out of the buildings while the buildings were still swaying. In the course of the escape, some were injured. Subsequently everybody gathered in the streets, causing a chaotic situation and traffic jam. Several of those tall buildings suffered minor non structural damage only.

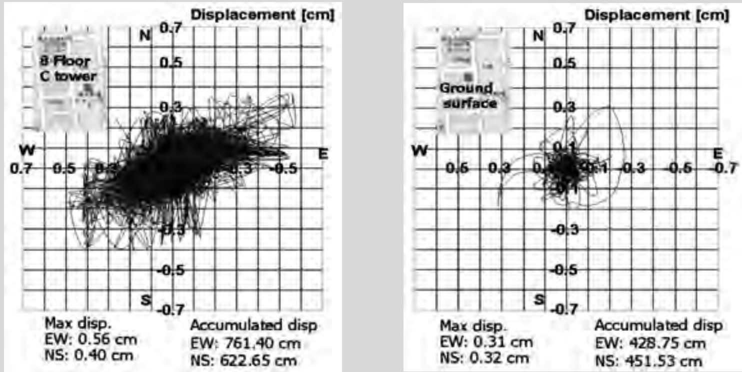
Actually, the damage or collapse of non engineered construction is a repetition of all past occurrences and is a demonstration that not much has been done with regard to non-engineered buildings. All the damage to those non-engineered construction and the casualties could be prevented if the authority has a plan to prepare, prevent or mitigate the effects of earthquakes.

[1]World Seismic Safety Initiative
[2]Indonesian Institute of Sciences

Left: Lanslide at Cikangkareng Village from the earthquake; Right: Panic and chaos in front of Indonesia Stock Exchange after the earthquake (courtesy: kompas.com)

Report on Suruga Bay Earthquake, Japan

Collapsed stone wall due to the earthquake



Displacement at 8th floor in C-block and ground surface at IIS

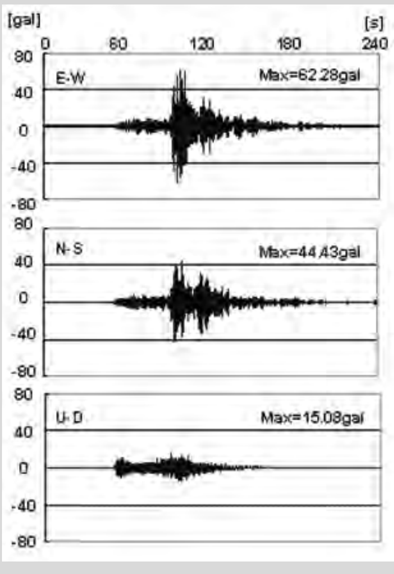
An earthquake with magnitude of 6.5 and centered 23 km below the seabed in Suruga bay in Shizuoka Prefecture occurred on August 11, 2009. After its occurrence, the possibility of the expected Tokai earthquake was examined immediately. However, the results showed that, this earthquake was not the expected Tokai earthquake as the magnitude was smaller than the expected value and it was not a plate boundary type earthquake.

The seismic energy in this earthquake was about 1/180th of that of the expected Tokai earthquake (expected to be of M8 class) and the range of dominant period was smaller than 0.5 seconds or less. Also, damage due to this earthquake was far smaller compared to the damage (the number of casualties, damage to social infrastructures and economic loss) estimated to be caused by the expected Tokai earthquake. In past earthquake disasters, the component of seismic ground motion with about 1 second or more caused large damages to the structures.

Shortly after the earthquake, I visited the site to have a meeting with Mr. Hikoyama, the crisis-management bureau of Shizuoka Prefecture, to enquire about housing damages, governmental action to the damages and the economic loss in industries. Few causalities and extensive damages to housing were caused in Shizuoka Prefecture. The main reason why the structural damage was not so heavy was due to the short-period seismic wave. The damage to the housing roof was predominant. The stone wall of Sunpu castle, situated just in front of a government building, was collapsed by the seismic shaking. The acceleration meter installed by ICUS, observed the seismic response at IIS, University of Tokyo, which is located around 120 km from the earthquake epicenter.

Accelerometer installed at the 8th floor of C-block of IIS building recorded the maximum structural response of 62.28 gal in the east-west (EW) direction due to the earthquake.

The horizontal acceleration record observed at the 8th floor of C-block of IIS building was converted into displacement, and track of displacement was plotted. The maximum displacement was 0.56 cm in the 8th floor of C block on the east side, and the accumulated displacements were 761.40 cm and 622.65 cm in the north and south direction respectively. Therefore, large displacement was caused in the direction of EW. Similarly, the track of displacement at the ground level was obtained. Accumulated displacement in the EW and NS directions were recorded as 428.75 cm and 451.53 cm respectively. The response of the building was dominant in the EW direction.



Seismic wave on 8th floor in C-block of IIS building

The response spectra of the main shaking were calculated and the relationship between the ground motion and structural response are determined. The dominant period in the directions of NS and EW of IIS building were 0.50s and 0.57s respectively due to both the big input motion and lower structural stiffness in the EW direction. The dominant period in the direction of NS and EW of ground response spectrum ratio (ground surface 0m and the 18m depth) were 0.27s for both directions. This can lead to the difference of the predominant period between ground response as input motion to the IIS building.

The damage caused by the expected Tokai Earthquake (M8) is estimated to be about 5,900 human deaths, about 19,000 serious injuries and about 190,000 collapsed buildings. This earthquake on August 11, 2009 should be used as an opportunity to promote and check countermeasures to the future expected Tokai earthquake, which has a 87% probability to occur within coming 30 years.

(By M. Numada)

Robust Optimum Design for Smoke Control System using CFD and Genetic Algorithms

Due to progressive urbanization, there has been a rapid increase in complex buildings over recent years. There is an increasing risk that even a small mistake in operation of disaster management systems may lead to a huge disaster in the event of fire or terrorism activity involving biochemical weapons, because of the complexity of the nonlinear airflow paths in the complex buildings. In order to prevent or minimize such disaster, disaster management systems should be appropriately designed with consideration of their reliability and robustness. In this research, robust optimum design method for smoke control systems in buildings is developed using an approach which couples Computational Fluid Dynamics (CFD) with Genetic Algorithms (GA).

Optimization system and GA method

The optimization system coupling CFD and GA for smoke control design, which is based on a feedback system is shown in the figure below. The system constitutes three parts:
A) Setting of the optimal problem;
B) CFD analysis of fire dynamics;
C) Evaluation of the smoke-control system and optimal process control.

The feedback loop shown in the figure below will continue until the optimum solution satisfies the design objective.

GA is used to select the optimum solution candidates, and to control the optimum inquiry process. GA is a method that enables optimization problems to be solved by imitating the organic evolutionary process. The individual with the highest fitness value among the investigated individuals becomes the optimum individual.

General optimization and robust optimization

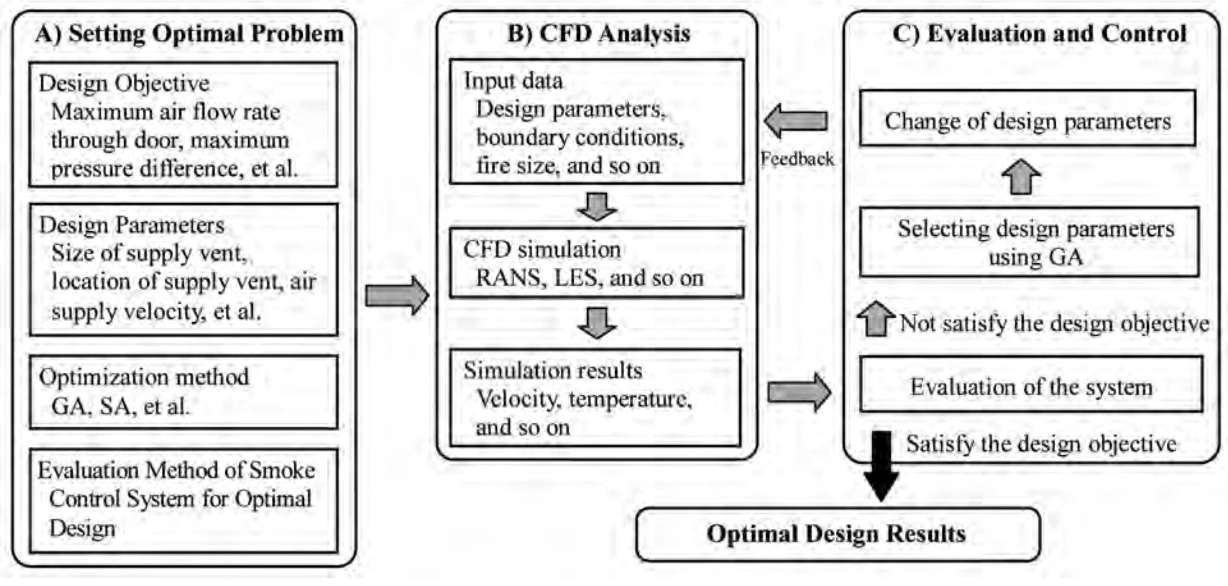
General optimization usually seeks out the optimal combination of design parameters under a fixed environmental condition. However, in practice, environmental conditions usually change or fluctuate. We do not know if this optimum design will function smoothly under these changes. Such uncertainty is very dangerous in a system or product. The objective of robust design is to ensure a robust system under varying environmental conditions and to consider the variability in the system's components. Therefore, robustness means system stability within the effects of environmental fluctuations. Robust design covers not only the optimum for the objective function, but also minimize variation in responses arising from any fluctuations.

Design object

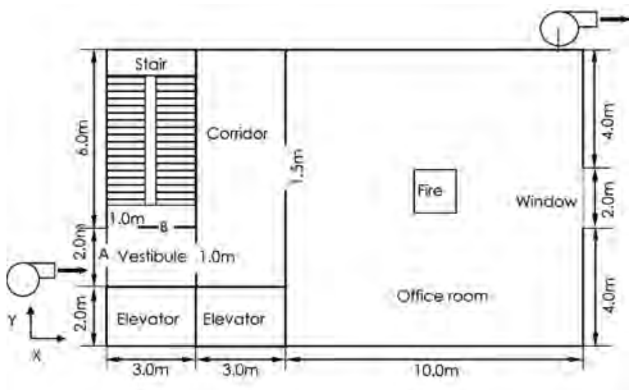
The design object is shown in the top-left figure next page. This is a simplified office building with 10 stories. The smoke control system consists of a smoke extractor in the office and a pressurization process through the vestibule. The vestibule is pressurized with outdoor air using a supply fan to prevent smoke from entering the vestibule and the stairwell.

Design process

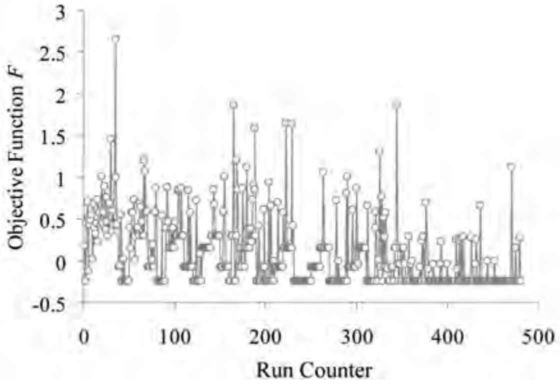
Two design cases, i.e., general optimum design and robust design were conducted. For the general design, maximizing the average airflow rate through the doorway between the vestibule and the corridor during the evacuation time is selected as the design objective. Robust design involves maximizing the above average airflow rate and at the same time minimizing the variation of the airflow rate arising from some uncertainty. Here, the uncertain fire location is set as the uncertainty. Patterns (location, size) of smoke extraction vents and air



Optimal design system coupling CFD and GA for smoke control design



The design object



Curve of GA inquiry in robust design

supply vents are set as design parameter. Optimum combination of these parameters will be designed.

Results

In case of the general design, for the extraction vent in the room, it agrees with the common perception that the extraction vents are best set in the ceiling rather than the sidewalls. In the vestibule, vents in the ceiling and facing wall are a good choice. The curve of the GA inquiry for the robust design is shown in the top-right figure. The horizontal axis shows the Run Counter for the optimum selection process, and the vertical axis shows the objective function (A combination function of airflow rate and the variation). This shows that the objective function converges to its optimal value after 300 runs, The maximum airflow through the doorway of the vestibule is 2.334 m^3/s. This is a little lower than the optimum design. From the result of the best pattern, it is indicated that square vents provide a robust design. Through robust analysis, it is shown that the airflow rate is lower in the robust design, however, the unevenness is smaller. This means that under the same environmental fluctuations, the change in the optimum design is larger, demonstrating that the general optimum design is sensitive. If there is a large fluctuation, this has a greater possibility of failing to operate satisfactorily.

(By H. Huang,
Center for Public Safety Research,
Tsinghua University, China)

Survey on a New Tsunami Disaster Mitigation System

Interview with potential user of TDMS

From September 18 to 24, 2009, Professor K. Meguro, Dr. M. Takashima from Fuji Tokoha University and two graduate students of Meguro lab. visited Phuket and Phang Nga in Thailand. The major purposes of the visit were to investigate recovery situation of the affected sites due to the 2004 Sumatra Earthquake induced Tsunami and to survey potential needs and users' opinions for a new tsunami disaster mitigation system (TDMS) proposed by Prof. Meguro and his research group.

The system proposed by Prof. Meguro combining a reliable but simple warning system and proper evacuation facilities, does not have the practical difficulties of other systems currently proposed elsewhere. The warning system consists of a multi-purpose marine observation buoy network that can be operated by local organizations such as hotels and beach associations. This is a community-based mutual support system and tsunami leading time can be guaranteed by the other network member buoys. Important characteristics of this system are its simplicity, economical efficiency and daily-usability. Information on temperature, current velocity, wave height, moisture, etc. obtained by the buoys can benefit business activities of the users. These information would also help in environmental monitoring and awareness generation, thereby further benefitting the region and the businesses. These factors in turn will motivate the users to play a major role in maintaining the system themselves. Our estimates show that, just by collecting only 1 USD per night above the room rate of the participating hotels, maintenance cost for the system could be adequately raised.

As for evacuation facilities, Prof. Meguro has proposed to use the religious places of worship along the coastal line in the region whose location is carefully selected based on tsunami inundation simulation. This scheme has two main advantages. Because worship centers are frequently used by people, their location is well known for efficient evacuation when a notice is issued. Additionally, as the people feel strong commitment to these facilities, they take active participation in their building and maintenance.

Unlike countermeasures such as landuse control, with the proposed TDMS, people can manage their own businesses and reduce future tsunami disaster without changing their life style. From our interview survey, we could obtain very supportive opinions from users and understand potential needs of multi-purpose marine observation buoy network system.

(By K. Meguro)

Evaluation of ICUS Activities by External Experts

Snapshot of the External Evaluation Committee Meeting

ICUS reports exhibited at the venue

On March 2011, ICUS completes its tenth year of establishment. In order to continue its activities effectively with a vision for a safe urban environment, ICUS carried out an external evaluation of its extensive activities since its establishment till now from a balanced perspective, both of its academic and social contributions. The external reviewers, consisted of six eminent experts inducted from relevant fields from Japan and overseas countries, were namely (1) Dr. Hisashi Tarumi, President, Railway Technical Research Institute, (2) Dr. Kenji Sakata, Professor Emeritus, Okayama University and Chairman of the Japan Concrete Institute, (3) Dr. Haresh C. Shah, Professor Emeritus, Stanford University and founder of Risk Management Solutions (RMS), (4) Dr. Satoru Nishikawa, Director, Water Resources Policy, Ministry of Land, Infrastructure and Transport (MLIT), Japan, and ex-UN Secretariat for International Strategy for Disaster Reduction (UN-ISDR), (5) Dr. Fan Weicheng, Professor, Tsinghua University, Director of the Public Safety Research Center (CPSR), and Member of the China Academy of Engineering, and (6) Dr. Haruhisa Shimoda, Director of Space Information Center, Tokai University and President of Commission VIII (Remote Sensing Applications and Policies), International Society for Photogrammetry and Remote Sensing (ISPRS).

The evaluation committee meeting was hosted at ICUS on 4th and 5th August for evaluation of its activities. The reviewers were presented with reports beforehand describing the overview of the ICUS activities since its establishment to 2008, PowerPoint slides (about 100 sheets each covering approximately 15 selected research topics of each division) describing its activities and track record of its three divisions were sent to them.

At the meeting, ICUS faculties, led by Prof. K. Meguro, Director, ICUS gave explanations on its activities. Detailed explanations were given on key research topics by its three divisions. Also, explanations on the future plans of a post-ICUS center were given. After two days of extensive and rigorous interactive evaluation, reviews were received in writing about a week later.

The reviewers noted that extensive research findings have been made in various topics related to urban safety. Contribution of ICUS was found to be unique and noteworthy despite its limited resources, with 425 peer-reviewed journal papers, 53 books, 486 international conference papers, 832 domestic conference papers, 26 reconnaissance reports and other 396 publications. Also, ICUS activities were in television, newspapers and other media 425 times, ICUS faculty gave invitational lectures 390 times and 65 awards have been received till now for research findings by the ICUS faculty including their students. Reviewers admired the center's international activities- MOUs with domestic and overseas organizations, holding of international symposiums, exchange of researchers and publication of international activity reports. They evaluated that, these activities not only contribute to technology transfer and advanced research, but also build up experiences with different technologies to put these into practical application in developing countries. They found ICUS research findings have been used practically in the society and have contributed significantly in enhancing urban safety of cities.

The reviewers suggested that, though visiting professors and researchers are making up for the limited human resources in ICUS as far as possible, more utilization of graduate students and foreign students in its activities is necessary as implementation of such diversified and energetic activities with inadequate manpower is difficult.

Also, the reviewers suggested that, strengthening of cooperation with administrative bodies and aggressive participation in administrative activities for ICUS to take a leadership role. Overall, they found that, ICUS has achieved its stated objective and "has achieved extremely good results."

On the proposal for a post-ICUS center, the reviewers suggested that, future plans should include organizational cross-cutting research for handling "advanced and core technologies," and should include social science, economics, and public policy along with natural science and engineering. Also, intra-university cooperation and increasing of staff strength is proposed.

ICUS sincerely thanks the distinguished external reviewers for conducting an impartial and critical review of its activities and will strive to carry on its activities aggressively using their valuable suggestions and recommendations.

(By K. Meguro)

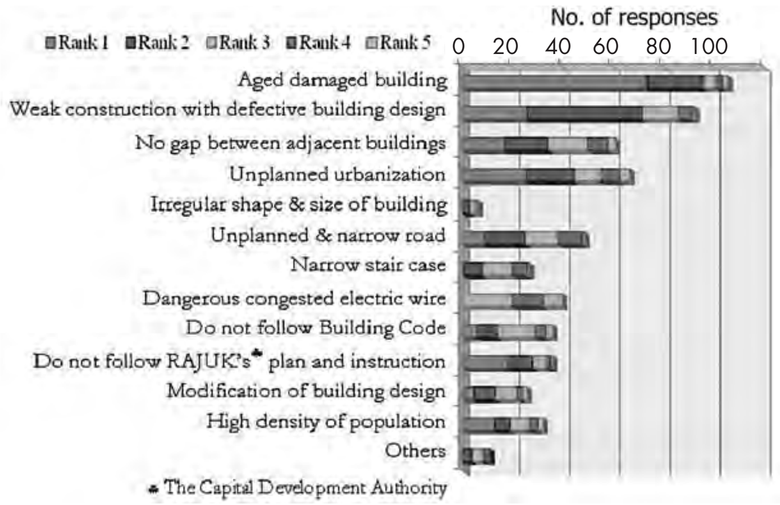
BNUS Activities

BNUS assessed social vulnerability to earthquakes

The major concern in any disaster risk mitigation measures falls on raising awareness level of the local community. BNUS conducted a socio-economic survey of 200 households in ward No. 68 of the older part of Dhaka City. The social vulnerability of individuals due to an earthquake is assessed within the households. The social vulnerability indicators have been selected from the literature and the relevant data needed for the analysis are collected through house to house socio-economic questionnaire survey. Information regarding the level of public awareness about earthquake risk of the community was found through this survey. The sample size of survey is carefully chosen at random basis at 95% confidence level to give a clear view of the whole community. Vulnerability of the community is assessed considering the existing socio-economic condition of the locality.

From the study, it was found that almost 96% literate respondents have earthquake awareness. Also, the literacy rate is more in the age group of 15-29 and 30-44 years and they are more aware about earthquakes than the people of other age groups. The age group 15-29 years is more aware about earthquake because most of them are students. The 30-44 age group is basically engaged in different professions. Professional groups keep themselves informed with day to day information received through professional activities and so they have more experience than others. They also interact with various groups of people which help them to gather information and knowledge. Age group of 0-14 years consists mainly of school going kids and because very few of this group are aware of earthquakes, the number aware members is roughly equal to number of unaware members in this group.

The household heads are important as they make key decisions in a family. In Bangladesh, mostly the male is the head of any family. It is clear from the survey that, most of the household heads are businessmen in the study area and most of them are aware of earthquakes.

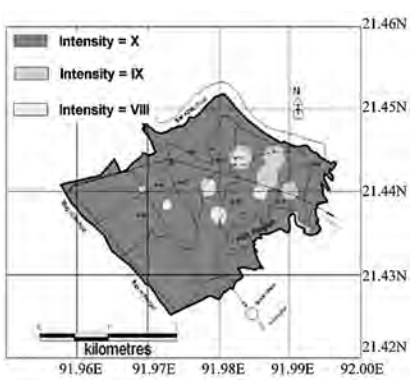


Reasons behind earthquake vulnerability to community

From the study it was found that, overall most of the respondents (74% respondents) in the study area are aware about earthquake. Also, in the study area, most of the respondents (about 75%) think their community to be exposed to earthquake vulnerability. The respondents considered a range of factors for their earthquake vulnerability as shown in the figure above.

BNUS conducted seismic microzonation of Cox's Bazar Municipal Area

Cox's Bazar is in the Southeastern part of Bangladesh, and is a coastal tourist resort. Due to rapid urbanization in past decades, often in an unregulated manner and without seismic design consideration of buildings, seismic microzonation is needed for formulating effective earthquake mitigation measures. Also, common occurrences of landslide and related casualties in the hilly parts of city have increased the necessity of it. BNUS conducted a seismic microzonation study using geographic information system, where reflection of ground shaking and the site attributes of soil amplification, liquefaction and landslide are the salient features. The probable earthquake hazard, expected ground motion and liquefaction potential were assessed using probabilistic approach. The study found that, the rock level Peak Ground Acceleration (PGA) of the area is 0.18g for a 7.5 magnitude earthquake having a return period of 200 years. The surface PGA could be as high as 0.41g for an average 2.3 times amplification factor. Due to ground shaking amplified by 2, 2.5 and 3 times, respectively 47%, 42% and 11% of the municipal area could be affected. About 87% of the study area is highly susceptible to liquefaction. Approximately 8% of the municipality consists of hilly region and 97% of it is found to be very unsafe from the viewpoint of natural slope stability.



Distribution of seismic hazard in Cox's Bazar Area

(By M. A. Ansary, BNUS)

RNUS held the 2nd Joint Student Seminar on Civil Infrastructures

Student seminar participants

A moment from the Seminar

RNUS jointly organized the 2nd Joint Student Seminar on Civil Infrastructure on July 6th, 2009 at AIT Conference Center together with Korean and Thai partners. This seminar is aimed at encouraging students to have an international experience such as making presentations, exchanging opinions and developing good relationship with foreign partners.

We had 34 participants, consisting of faculties and students from Korea University, Chonnam University, Seoul National University, Suranaree University of Technology, Asian Institute of Technology, Khulna University of Engineering & Technology and The University of Tokyo. There were 4 faculty lectures and 18 student presentations in this seminar. The topics were varied from all areas of civil engineering and all students did their best in their own presentation as well as in the discussion. At the end of the seminar, excellent presentation awards were given to 3 students who were selected by votes from all the participants.

On the next day, a field visit was held to see public transportation facilities in Bangkok City. Bangkok is famous for its traffic congestion and there are several ongoing projects to improve the public transportation system. The participants visited 2 construction sites of current public transportation projects, that is, City Air Terminal of Suvarnabhumi Airport Rail Link (SARL) and Bus Rapid Transit (BRT) station. To visit the sites, they experienced various transportation systems on the way, such as MRT (subway), BTS (skytrain), taxi, bus, tuktuk and boat, which were also very impressive for them.

The student participants played a major role by discussing their research topics and communicating with students from other countries. The seminar was successful and fruitful similar to the one last year. We believe this seminar gave not only knowledge and information but also a lot of other stimuli to the students. ICUS hopes to continue to hold this kind of interchange activities also in coming years.

(By S. Tanaka)

ICUS Activities

• Prof. H. Sawada visited Bangkok, Thailand from July 5 to 8, to co-ordinate and participate in the Joint International Student Seminar on Civil Infrastructure. He visited São Paulo and Manaus in Brazil from August 5 to 16 to investigate on changes in carbon budget in Brazilian Amazon. From September 5 to 11, he visited Helsinki and Joensu in Finland to participate in and make a presentation at the Finnish-Japanese Seminar.

• Assoc. Prof. M. Koshihara visited Shizuoka Prefecture on September 26 to do a follow-up survey on Suruga Bay Earthquake.

• Assoc. Prof. R. Kuwano visited Alexandria, Egypt from September 30 to October 9 to attend and make a presentation at the 17th International Conference on Soil Mechanics and Geotechnical Engineering.

• Assoc. Prof. H. Huang visited Beijing, China from July 11 to 20 to conduct research and discuss collaboration between ICUS and Tsinghua University, Beijing, China.

• Dr. S. Tanaka visited Bangkok, Thailand from July 5 to 12 to organize, make a presentation and chair a session at the Joint International Student Seminar on Civil Infrastructure at AIT, Bangkok.

• Dr. M. Numada visited Bangkok, Thailand from July 5 to 9 to make a presentation & chair a session at the Joint International Student Seminar on Civil Infrastructure at AIT.

Awards

Graduate student Mr. K. Sakurai of Meguro Lab. received Excellent Young Researcher Award at USMCA2009, Incheon, Korea.

Three graduate students of Kuwano lab. won best paper and presentation awards by Japanese Society of Civil Engineers (JSCE). They were, Mr. N. Hosoo (at JSCE Annual Meeting in Fukuoka), Mr. A.L. Beltran-Galvis and Mr. B.P.D. Cokorado (both at JSCE International Summer Symposium on Sep. 11 in Tokyo).

Editor's Note

While we edited an article on the West Java Earthquake, news on another big earthquake in Indonesia on September 30 surprised us. It occurred in Padang, West Sumatra Province in Indonesia and its magnitude was 7.6. According to UN Office for the Coordination of Humanitarian Affairs (UNOCHA), about 115,000 houses were severely damaged due to this earthquake. We sincerely extend our condolences to the victims and affected people due to this tragic earthquake and hope prompt restoration in the suffered area.

The main article of this volume was written by Dr. Christina Magill in Macquarie University, Sydney, Australia. She spent two months in our research center in 2007. Her visit was as a part of a joint research project with Tokyo Marine & Nichido risk consulting Co. Ltd. on analysis of volcanic risk in Tokyo. During her stay, she conducted site visits and collected data for modeling reported in this newsletter. ICUS members were very happy to share precious experience with her and hope for continuous collaboration.

During October 15-16, the 8th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia was successfully held in Incheon, Korea. National Institute for Disaster Prevention (NIDP), Disaster Prevention Association (KDPA) and Korean Society of Hazard Mitigation (KOSHAM) in Korea jointly organized it with ICUS. ICUS expresses gratitude from the bottom of our heart to the presenters, participants and all the people who were involved in this symposium. Next symposium will be held in Japan on October 2010.

(M. Ohara)

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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PRESERVATION OF HISTORICAL ARCHITECTURE AND COMPLIANCE WITH TODAY'S SAFETY LAWS

By

Osamu Goto[1]

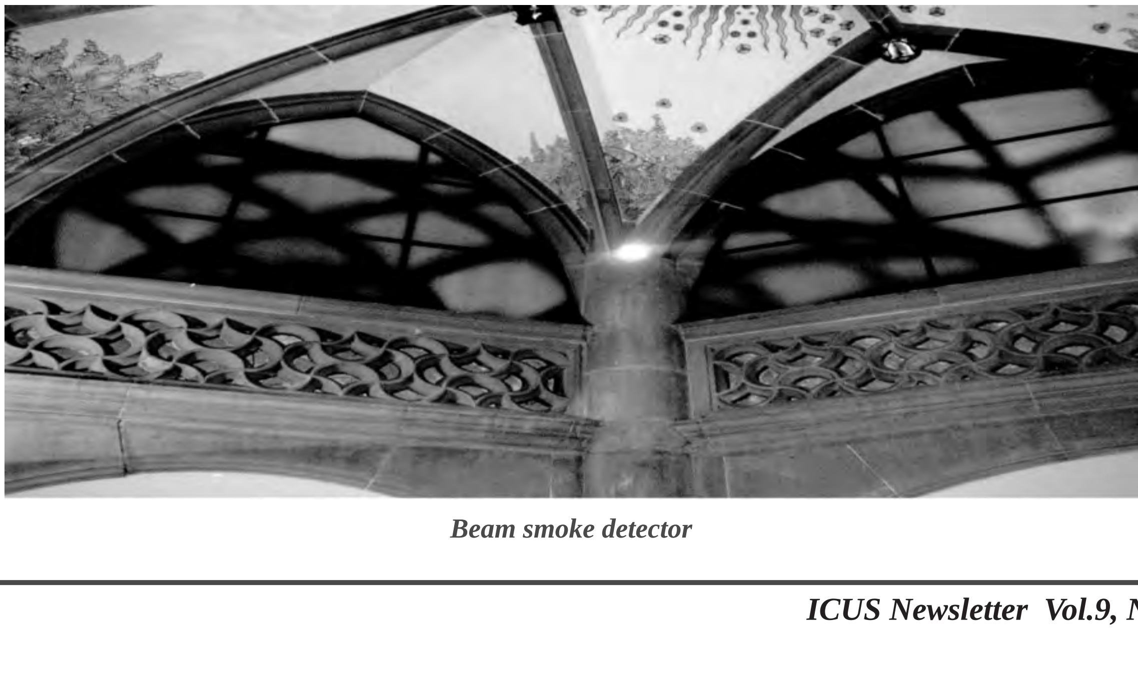
Architecture needs to satisfy various demands, one of which is safety laws. All architecture even existing historical architecture-must comply with these requirements. However, a lot of historical structures do not satisfy modern safety requirements.

There are two main reasons on this issue. The first is that today's standards are higher than those at the time when the historical structures were constructed. The second is that many years have passed since the construction and the structural safety has deteriorated with age.

To bring these historical architectures up to today's safety standards, it is necessary to refurbish their structure. However, the historical value may be lost due to refurbishment. Therefore, a new method is needed. There are laws and regulations that determine the safety. In Japan, building standard law and fire safety law often outline the methods and equipments required. However, these can influence the value of historical structures. For example, even if only the old part of building is refurbished, these laws require improvements to the whole building.

Therefore, special measures are needed within such laws and regulations in order not to lose historical value. Such special measures are seen not only in Japan but also in many other countries. For example, all architecture built before a law or regulation is enacted is covered or exempted by separate special measures for historical architectures.

In Japan, one problem is that



Beam smoke detector

Shakespeare Globe Theater, London, Britain Reconstruction of historical architecture
In general, thatched roof is not permitted in down town area, but this architecture permitted by using fire resistive board and a sprinkler system in the roof.

there is little historical architecture to which special measures can be applied. Another problem is that it is not clear how to apply special measures. However, in the case of historical architectures designated by the national government ("Kokuhou" and "Jyuyo-Bunkazai"), there are national guidelines for seismic diagnosis and earthquake proof reinforcement. However, they give the initiative for diagnosis, reinforcement and fire protection is given to the owners of "Kokuhou" and "Jyuyo-Bunkazai". But most historical architectures won't be able to follow "Kokuhou" and "Jyuyo-Bunkazai" due to high cost and time required. It's a very severe problem in Japan. So it is necessary to quickly propose new special measures that can be applied easily to historical architecture.

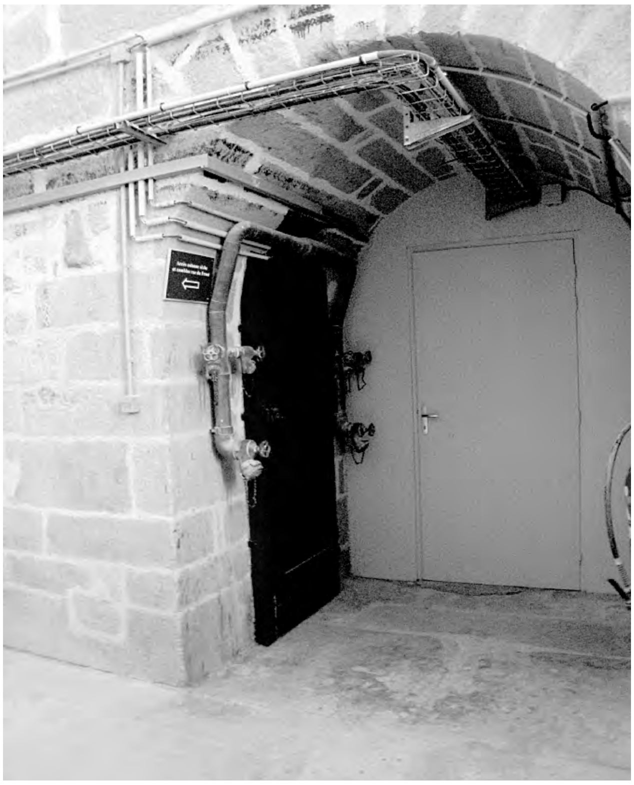
The author has researched the relationship between laws and how they apply to secure the safety of historical structures in Britain, France, Germany, and the United States. This research shows the same problems in these countries. But the solution is different in each country.

In Britain, there are reference standards for refurbishments of historical and cultural architectures, and such standards are included in the "British Standard". British Standard is set by a third party, and the local government or institution for inspection confirms the special measures based on standards, such as in the case of the Shakespeare Globe Theatre.

In the United States, there is the state code for general architectures executed by the International Code Council. But for historic architecture, the local government has set the original codes; for instance, California State has set the 2007 California Historical Building Code.

In France, there is a commission for security under the governments and the commission decides the relevant means for taking special measures in the care of historic architectures. The commission for security is broken down into national, prefectural, and city council levels. Risks are decided by use, scale and accommodation number of the architecture. If the risk is high, a commission of the upper government decides the appropriateness of special measures, as demonstrated by the Cathedral Saint Corentin.

In Germany, first whether architecture has historic value is decided by town planning officers of the local government. Then a safety officer of the local government decides the relevant special measures for the historic architectures under their discretion without affecting the historical

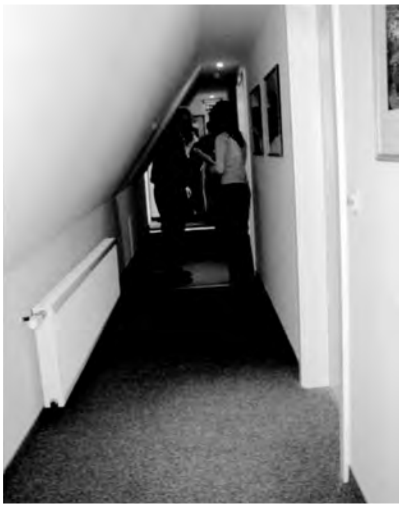


Cathedral Saint Corentin , Quimper, France
This stand pipe is the special fire prevention equipment for the wooden roof frame of this cathedral.

value, such as enhanced escape options to compensate for narrow spaces.

The procedure of the law and how to decide the appropriate methods are different in each country. But practical consistent ways between safety and historic preservation are almost the same in each country. So we can learn many useful facts for how to maintain safety and historical value.

First of all, even if the historical structure doesn't comply with safety. This means that weak points remain in the building, so to compensate for this weakness the other regions and parts are reinforced by appropriate specifications and equipment which have higher quality than the basic ones required by the safety laws and regulations. This method is called the engineering approach.



Hotel converted historic architecture, Goslar, Germany.
In general, such a narrow and low corridor aren't permitted to use as evacuation way. But this corridor was permitted by using doorway and staircase for evacuation wider than standards.

Next, it is possible to restrict the usage or amount of accommodation to ensure safety in the historical which does not meet the safety laws and regulations. In case of new architecture, usage and accommodation are decided by laws and regulations and the same specifications and equipments are applied to each region equally. In the historic architecture different specifications and equipments can be set according to region.

The reason for permitting such an exception is to allow owners and managers to sufficiently ensure the safety of architecture by themselves considering each case individually. In other words, the responsibility of owners and managers to handle risk management for architecture is strictly enforced in Britain, France, Germany, and the United States. Moreover, the usage or accommodation limit are not maintained, violators are severely punished.

This is the difference in philosophy of responsibilities and penalties between Japan and Britain, France, Germany, and the United States. We should follow foreign examples.

One more important point is that the government highly recommends and historic preservation officers permit improvements to historical structures from an engineering approach. In Japan, when the historic architecture is refurbished, it is not clear how to preserve the historic value or how to improve without losing the historic structure.

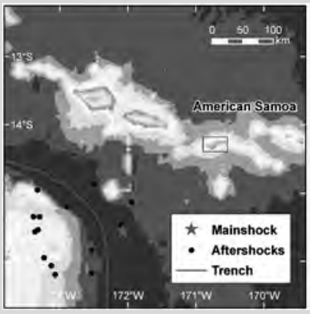
Especially in the case of "Kokuhou" and "Jyuyo-Bunkazai", the owners must apply for permission from the national government in advance by National Preservation Law for Cultural Properties. But the national government doesn't reveal the standards for permission in this law. If the differences between the regions that have historical value and the other regions are clear, it will be ensure for owners to apply for permission. Also, it will be easier for architects and construction engineers to propose new methods and ideas for safety and historic preservation.

I hope that Japan will refer to the examples of other countries and take a positive engineering approach to securing the safety of historical architecture.

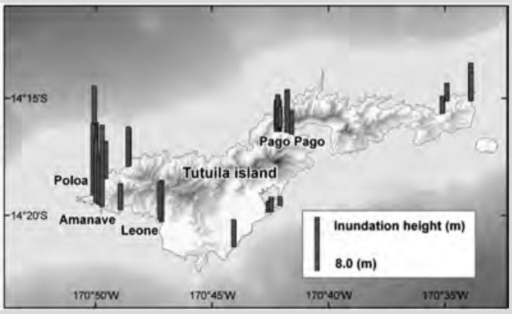
([1] Kogakuin University, Japan)

Residence, Wurzburg, Germany: the large hall of this building is changed using way and accommodation number by the way. So the escape light for emergency is temporary.

The 2009 Samoa Earthquake Induced Tsunami: A Quick Survey from the Field



Samoa island and its vicinity



Tsunami run-up measurement

On 29 September, at 17:48 UTC (06:48 Local time), a major earthquake of magnitude 8.1 occurred off the coast of the Samoa islands. The tsunami generated by this earthquake struck the Samoa islands and killed at least 149 people in Samoa, 34 people in American Samoa, nine people in Tonga, and resulted in the most devastation due to tsunami in the history of the Samoa region. Dr. Shunichi Koshimura, Associate Professor, Tohoku University, and his colleagues conducted a post-tsunami field survey on Tutuila island, American Samoa, from 5 to 8 Oct., 2009, focusing on the measurements of tsunami run-up height, flow depth, extent of inundation zone, structural damage inspection, and collected eyewitness accounts.

Measured tsunami run-up heights are summarized. The tsunami hit more severely along the western coast of Tutuila island. The highest run-up of 16.3m was measured at the village of Poloa which is located on the western coast of the island. The village of Poloa was totally devastated and two people in this village were killed. And 12.4m inundation height was measured at Amanave (southern coast of the island) where the tsunami penetrated roughly 200m inland. Severe damage was also observed at the village of Leone, where 6m tsunami attacked.

The tsunami penetrated more than 200m inland and left extensive amount of debris in the lagoon.

Pago Pago harbor is located in the bottom of the inverse L-shape bay and was hit by 5m tsunami that were penetrated more than 500m inland. We surveyed the structural damage in Pago Pago harbor by on-site inspection with GPS measurement, which leads on the understanding of the relationship between the tsunami hazard and structural vulnerability. As a preliminary result, we found that 35 out of 127 houses within the inundation zone were washed away.

During the survey, we interviewed the survivors to collect eyewitness accounts on the tsunami arrival time, the initial sea surface movement, and the number of tsunami attacks. Along the southern coast of Tutuila island, the tsunami was likely to have started by depression (Leone, Poloa, and Pago Pago) and the second wave was the highest (Leone), which was consistent with the observed tide record at Pago Pago harbor. The most important result of the interviews was that the residents were aware of tsunami and knew that they should move to higher ground as they felt strong ground shaking. In this event, the Pacific Tsunami Warning Center (see the name lists) issued a warning at 07:04 (16 minutes after the earthquake) and the national weather service office of Pago Pago disseminated the guidance of evacuation through the radio at 07:02 (14 minutes after the earthquake). This awareness probably contributed to reducing the number of fatalities in Tutuila island (34 casualties reported). For instance, a school bus driver in Poloa village, who had just left the students in the school, was aware of tsunami after the earthquake and took the children back to the higher ground. This sort of awareness- that strong ground shaking is a sign of tsunami,-is the most important factor for surviving a tsunami disaster.

Tsunami damage in the village of Leone

Tsunami debris left in Leone lagoon

Acknowledgements:

The study was partially supported by Science and Technology Research Partnership for Sustainable Development (SATREPS) of JST and JICA.

Survey team members ;

Shunichi Koshimura (Leader, Associate Professor, Graduate School of Engineering, Tohoku University), Yuichi Namegaya (Researcher, Geological Survey of Japan, AIST, Japan), Yuichi Nishimura (Assistant Professor, Institute of Seismology and Volcanology, Hokkaido University, Japan), Yugo Nakamura (Researcher, Institute of Seismology and Volcanology, Hokkaido University, Japan), Gerard J.Flyer (Geophysicist, Pacific Tsunami Warning Center, NOAA, USA), Akapo Akapo (Director, National Weather Service, NOAA, American Samoa), Laura S. L. Kong (Director, International Tsunami Information Center, UNESCO/IOC-NOAA, USA)

(By S. Koshimura
Tohoku University, Japan)

Japan's Expected Role for Transboundary Collaboration in the Mekong Region

In order to establish a regional cooperative framework in East Asia, namely, creation of Asian free trade regions attention to ASEAN (Association of SouthEast Asian Nations) countries has been increasing. As one of ICUS's focal study regions, this article summaries current interactions between Japan and East Asia, especially in the Mekong area.

In January 2010, China and Korea largely reduced trade tariffs with six major ASEAN countries, including Singapore and Thailand, and Free Trade Agreement (FTA) between ASEAN and India, Australia and New Zealand went into effect. Japan has already completed FTA and Economic Partnership Agreement (EPA) with ASEAN countries, and Prime Minister, Yukio Hatoyama has recently reintroduced the concept of the East Asian Community (EAC).

Through a series of these moves, Mekong-Japan Exchange Year was promoted in 2009 under the catchphrase of "Together toward the future, Mekong and Japan." The Mekong-Japan Summit Meeting, which included Cambodia, Thailand, Vietnam, Myanmar, and Laos, was held in Tokyo in November 2009 and the Tokyo Declaration of the First Meeting among the Heads of the Governments of Japan and the Mekong region countries and the Mekong-Japan Action Plan 63 were announced. Many visions are shared among these countries, such as becoming mutually important partners in political, economic and social perspectives, and cooperating with various regional frameworks. In addition, it was recognized that the Mekong region still confronts regional and global challenges including climate change, natural disasters and infectious diseases, which are threats to human security.

To realize the Green Mekong, Japan committed to important actions on climate change and environmental and disaster management in the region. Japan committed to promote technology and knowledge transfer to the Mekong region for improving environmental management, especially for water resources management and flood control. Many technical and financial assistance strategies were declared but, as the Mekong is the longest "international river" in Asia, more support is required to realize the Green Mekong through facilitating cooperation and collaboration among riparian countries in cross-boundary environment. This means that many of the proposed actions, such as strengthening capacity to tackle rapidly-spreading infectious disease and reducing flooding damage by extreme climate change, expand beyond national borders.

In the Mekong, upstream and downstream issues interlace hierarchically in both mainstream and tributary systems. Economic discrepancy, political conflicts and cultural differences lie hidden across national borders. Therefore, in order to promote effective regional actions, especially from an environmental management perspective, solving or facilitating cross-boundary issues becomes a very challenging but unavoidable problem. By collaborating with riparian and stakeholder countries, international organizations and Mekong River Commission, Japan is expected to take leadership in coordinating cross-boundary issues from a neutral position with Yuai (友愛: Prime Minister Hatoyama's principle, the spirit of friendship). Considering current ASEAN situations, there is still a long way to go until East Asian Community (EAC) can be realized, but this starting point is one of many important and enduring tests of Japan's commitment.

(by A. Kawasaki)

A dam construction in the upstream of a river tributary in Vietnam

Nonaligned upstream development affects the life of downstream residents in tributary systems in Cambodia

Survey of September 30, 2009 Sumatra Earthquake

On September 30, 2009 at 17:16, an intense earthquake (M7.6) occurred just off the western Sumatra coast in Indonesia (Location: 0.789°S, 99.961°E). The focal depth was 80 km (USGS). The epicenter was 45 kilometers from the port city of Padang, Sumatra. An after shock (M6.2) occurred 22 minutes later, followed by a third quake (M6.8), which struck 225 km southeast of Padang. This continuous shaking caused widespread destruction in the area of Padang Pariaman District. Most inhabitants in the affected areas have lost their houses due to collapse by seismic motion or landslide. The official death toll confirmed was 739, with another 296 people missing and presumed dead, primarily in Padang Pariaman District. A total of 863 people were seriously injured, and 1,356 people slightly injured. Damage to houses was widespread with 121,679 houses severely damaged, 52,206 moderately damaged, and another 57,510 lightly damaged, rendering homeless estimated was 250,000 families, many people were too frightened to return home (UN OCHA). We conducted a survey of the damaged area from Oct. 16 to 18.

There were many damaged buildings in both Pariaman and Padang. Over 300 building were observed quickly during this survey.

Structures affected by this earthquake were low-rise residential masonry, hotel buildings, government offices and industrial facilities. Low-rise residential masonry buildings are generally constructed with bricks and they are either one story or two story buildings. In the structural type, engineered and non-engineered structures in the seismic affected areas may be classified into three general categories; namely, wooden structure, unreinforced-masonry structure and masonry structure with frame.

There were much typical damage to wooden houses and masonry houses constructed with bricks. Compared to brick masonry houses with or without RC slabs and/or columns, they performed better; however, there were instances of total collapse due to intense ground shaking. Pancake-type collapse was observed in the buildings of China Town. These buildings are probably the most vulnerable to seismic motion and may collapse during the next strong earthquake.

Totally collapse of wooden house

Pan-cake type collapse in China town

From an assessment of 15 bridges, no significant damage was observed from this earthquake. Bridges in the epicentral area are mainly truss or simple beam bridges. The damage to bridges were mainly caused by the failure of approach embankments and uneven settlement of piers.

During the survey, roads were available to traffic. The damage to roadways was also observed in this study. Surface ruptures and failures of embankment along the river and slope cut caused damage to roadways at several places in Padang and Pariaman. In particular, slope failures occured in places with volcanic sediments and volcanic soft rocks, such as in Pariaman. Extensive slope failures were observed along the moutainous road. Some of these roadways were constructed on the thin ridge with soil surface along the river. The failure points occurred at the attacking side of river, where the foot of the slope loses stability because of erosion due to water flow. Typically, the slope at the attack side may be unstable due to erosion of the foot.

There was a large slope failure of volcanic sediment. Since the volcanic sediment is a type of pumice soil, under water supply it can easily fail on the sliding surface of the clay layers. When the earthquake occurred, a wedding ceremony was being held on the sliding soil mass. This failure shown the photo above caused the deaths of 200 people attending the party.

Slope failure along mountain road

Large slope failure of volcanic sediment

The railway is normally used for leisure on the weekends. The railway was available on the first weekend after the earthquake. Slight failure of railway embankments was observed, however they were completely recovered after the first leisure day.

The most remarkable geotechnical damage was caused by liquefaction and accompanying lateral movement.

The liquefaction sites are located between the coastal line and a small river with ground layers of sand and a shallow ground water level in the marine deposit. Settlement of buildings and foundation damage due to liquefaction-induced ground failure and lateral spreading resulted in the collapse of masonry houses and/or severe cracking walls.

Most industrial facilities are located in Southern Padang City. Inspection of some industrial plants in Padang and Pariaman showed that the earthquake did not cause any major damage to industrial facilites except some small scale damage.

Two ceramic isolators in electric power station were damaged, but were repaired two days later. However, seven to ten days were needed to restore electric power in Padang city. Electricity was fully recovered by ten days.

Two port facilities in Padang were surveyed. The cement plant and coal storage did not suffer considerable damage and the economic loss due to the subsidence or lateral movement of coastal line was little. Liquefaction and slight damage at the ferry crossing were observed. No damage was found in the petroleum tank yard.

(by M. Numada)

Project on Amazonian Carbon Dynamics

"CArbon Dynamics of Amazonian Forests" (CADAF) project is a science technology and research partnership for sustainable development project under the framework of both the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA), and will start from January 2010. CADAF is a giant project spanning 4 years with a budget of approximately 1.5 million USD per year. Prof. Sawada and Dr. Endo are participating in the project with the Forestry and Forest Products Research Institute (FFPRI), Japan; Instituto Nacional de Pesquisas da Amazônia (INPA) and National Institute for Space Research (NPE), Brazil. The objective of the project is the development of quantitative evaluation technology for assessing the carbon dynamic of Amazonian forests, including methodologies for Reduced Emissions from Deforestation and forest Degradation (REDD). We are in charge of mapping the carbon dynamic of the whole Amazonian forest using satellite data in the project. From 20th November to 1st December, we went to Sao Paulo and Manaus in Brazil for discussion with the project participants, and then stayed at a test site inside the Amazonian forest near Manaus for a day and discussed the common goals of the participating parties. We will inform you of some of the highlights of this project by newsletter over the next year.

(by T. Endo)

Overview of field survey at Amazonian forest

Disaster Drill held at the University of Tokyo Hospital

Disaster drill was held at the University of Tokyo Hospital from 13:30 on October 1st, 2009. Prof. Meguro and Dr. Ohara are studying disaster management manual system for University of Tokyo Hospital with the University of Tokyo Hospital and the Division for Environment, health and Safety. The disaster drill was planed based on the disaster management manual.

In the drill, occurrence of the Tokyo Metropolitan Earthquake with magnitude 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. Based on the reports from each ward and sections, the disaster command center decided that the hospital has the capability to accommodate disaster victims transported from outside. 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.

Lessons learnt from these drills will be included to brash up the contents of disaster management manuals.

(by M.Ohara)

Disaster command center

Triage of mimic patient

USMCA 2009 was held in Incheon, Korea

Experts from 7 countries delivered 82 presentations at USMCA 2009, Incheon

The National Institute for Disaster Prevention (NIDP), Seoul, Korea; the Korea Disaster Prevention Association (KDPA), Seoul, Korea; the Korean Society of Hazard Mitigation (KOSHAM), Seoul, Korea; and ICUS organized the Eighth International Symposium on New Technologies for Urban Safety of Mega Cities in Asia, (USMCA2009), at Incheon, Korea on October 15-16, 2009. This symposium were supported by the Incheon Metropolitan City Government (Korea); Incheon Urban Development Corporation (Korea); The Foundation for the Promotion of Industrial Science (Japan); and Global Center of Excellence for Sustainable Urban Regeneration (Japan).

The two-day symposium program was arranged in three keynotes, two plenaries and 12 technical parallel sessions.

The symposium was inaugurated by Dr. Byung-Ha, President of KDPA, Dr. Wook Kwon, President of KOSHAM, Mr. Sang-Soo Ahn, Mayor of Incheon City and Prof. Kimiro Meguro, Director of ICUS. Keynote lectures were given by Dr. Yeon-Soo Park, Adminsitrator of National Emergency Management Agency, Mr. Yasuyoshi Ichikawa, ICUS Visiting Prof. and Prof. Haruhisa Shimada, Tokai University. Plenary speakers were Prof. Sudhir Misra, IIT Kanpur and Prof. Waon-Ho Yi, Director of NIDP.

About 260 people participated in the symposium, and 82 papers were presented in technical sessions covering a wide range of issues in the area of urban safety, including green growth technology for urban safety; urban risk and response strategy against climate change; safety assessment of existing infrastructure; decision-making technologies for dealing with urban disasters; advanced technologies for monitoring and assessment of urban safety; rehabilitation an retrofitting of urban structures against disasters; emergency management for urban disasters; risk assessment, prediction and early-warming of urban disasters; and application of GIS,GPS and RS to enhance the urban safety. 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. Tae-Ho Ahn, Mr. Kotaro Sakurai and Ms. Risa Kuwahara (IIS, The Univ. of Tokyo).

Young researcher award recipients

Post-Conference Field Study Trip

USMCA 2009 participants visited the inside of the Northeast Asia Trade Tower (NEATT), the supertall skyscraper standing 305 meters (70 floors); which is under construction in New Songdo City, on 17th October. This post-conference field study trip to Incheon Bridge and 2009 Incheon Global Fair & Festival was specially arranged by with the help of the Incheon Metropolitan City Government.

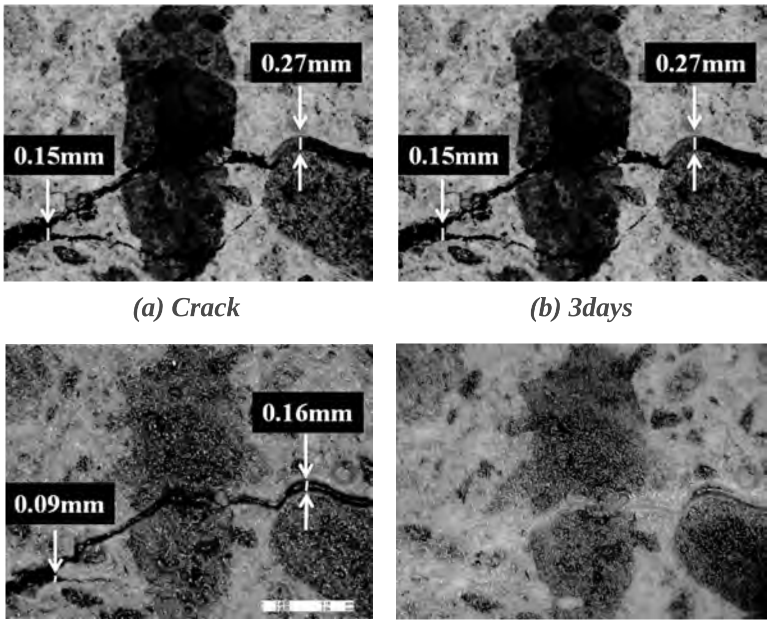
New commercial and residential construction in Songdo New City

At the USMCA2009 in Incheon, Korea, three researchers were selected as winners of the Young Researcher Award. One winner briefly introduces his award-winning research below.

Design of Crack Self-Healing on Concrete Structures

This study aims to develop and apply self-healing concrete as a new method for crack control and enhanced service life in concrete structures. This concept is one of the maintenance-free methods which, apart from saving direct costs for maintenance and repair, reduces the indirect costs – a saving generally welcomed by contractors. In this research, the self-healing phenomenon of autogenous healing concrete using geo-materials for practical industrial application was investigated. Moreover, in order to apply this concept to the field, a self-healing concrete, designed by the author, was fabricated by ready-mixed car in a ready-mixed concrete factory, then used for the construction of artificial water-retaining structures and actual tunnel structures. The results show that the concrete cracks were significantly self-healed after 28 days re-curing. Crack width of 0.15mm was self-healed after re-curing for 3 days and the crack width decreased from 0.22 mm to 0.16 mm after re-curing for 7 days. Furthermore, it was almost completely self-healed at 33 days. It was founded that this phenomenon occurred mainly due to the swelling effect, expansion effect and re-crystallization. From these results, it is considered that the utilization of appropriate dosages of geo-materials has a high potential for a new repair method for cracked concrete under the water leakage of underground civil infrastructure such as tunnels.

(By T. H. Ahn, IIS, The University of Tokyo)



(a) Crack *(b) 3days*

(c) 7days *(d) 33days*

Process of self-healing on self-healing concrete at water/binder ratio of 0.47

RNUS Activities

Regional Network Office for Urban Safety (RNUS) played an important part in the Outreach International Program between Universiti Technologi Malaysia (UTM) and Asian Institute of Technology (AIT) on December 18, 2009. AIT and UTM committed to send studStudents in the Department of Remote Sensing and Geoinformatics visited AIT accompanied by senior lecturers and pursued collaborated academic activities from December 14 to 20. On December 18, as a part of the activities, Prof. Haruo Sawada of ICUS gave an hour' lecture with the title "Introduction of ICUS Activities and Remote Sensing Study in Regional Scale," which included the role of RNUS. Twenty-one students and two lecturers from the department of remote sensing, UTM, attended the lecture and listened intently to it, and asked vigorous questions after the lecture.

(By A. Kodaka, RNUS)

Commemorative photo

BNUS Activities

"Release of pressure model" for reducing earthquake vulnerability

Most earthquake-related deaths are due to structural collapse or lack of awareness among the inhabitants, so for disaster mitigation, both construction and planning play a vital role in reducing casualties and minimizing damage in the affected areas. To promote disaster mitigation, BNUS has prepared a "release of pressure model" as a guideline intended for use in disaster-vulnerable areas.

To make this model, different factors were selected from a literature study considering ward No. 68 in Dhaka city and from a socio-economic survey of 200 households in the ward. Major aspects of the model include:

Root causes:
- Prejudice towards ethnic minorities and social groups
- Unequal distribution of economic power
- Belief in modernization and science

Dynamic pressures

Lack of:
- Awareness of earthquake risk
- Awareness that Old Dhaka is more vulnerable than other areas

Macro forces:
- Economic strength creating work opportunities
- Aging population for both genders

Unsafe conditions

Physical environment:
- Unsafe, non-engineered dwellings due to design faults
- Aged and damaged buildings
- Narrow staircases in buildings
- Severe overcrowding in high-density urban areas in Dhaka
- Unsafe infrastructure due to lack of knowledge on seismic design

Impact of local economy:
- Businesses run on the ground floor or front of building with upper levels used for residential purposes
- Unsafe conditions in factories or industrial areas

Social relationship:
- Lack of mobility for the elderly, such as escape routes during disasters
- Sub-standard living conditions

Public actions and institutions:
- Lack of proper implementation of disaster management planning in older and more-vulnerable areas
- Lack of coordinated action
- Lack of disaster preparedness at all levels

Hazards

Primary impact:
- Earthquake ground shaking

Secondary impact:
- Fire, ground displacement

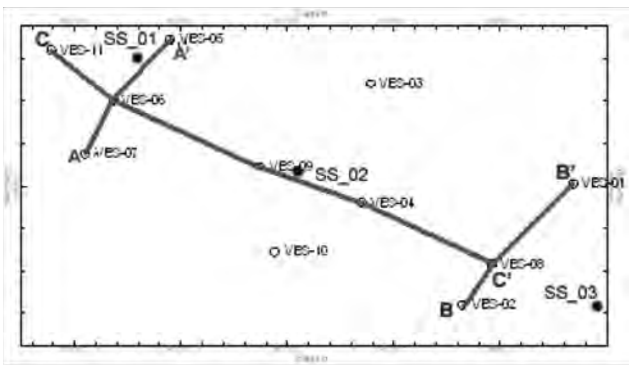
Shallow seismic survey at Muchai Site, Rashidpur

A shallow seismic survey was carried out to evaluate shear wave velocity to a depth of around 30 meters. Hammer source was used to generate the energy and a 12-channel seismograph was used to record the data. Geophone spacing was 3 meters. Data were recorded when the ambient noise was at a minimum. The collected data were processed using Pickwin software. The survey was conducted at three locations, as shown in the figure below, with an example of the shear wave velocity observed at Station 1. These shear wave velocities can be used for site categorization used in the national earthquake hazard reduction program.

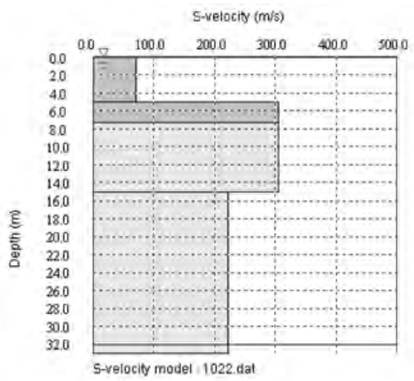
Dr. Tanaka visits BNUS

Dr. Shinji Tanaka from the Transportation Engineering division AIT, Bangkok, visited BNUS, BUET, Dhaka on December 7, 2009. During this visit, Prof. M.A. Ansary of BNUS briefly introduced the Earthquake Evacuation Plan for Old Dhaka, the microzonation map of Cox's bazaar city, earthquake recording instruments used in Bangladesh, the effects of cyclones Sidr and Aila, climate change scenarios for Bangladesh, and other BNUS research activities. Finally, Prof. Ansary presented a gift to Dr. Tanaka for visiting the BNUS office.

(By M. A. Ansary, BNUS)



Shallow seismic (SS) and vertical electrical sounding (VES) locations and the direction of electrical profiles in the survey area



Shear wave velocity at Station 1

Order of the Rising Sun to Dr. Suvit Vibulsresth

Dr. Suvit with Dr. Yasuoka and Prof. Meguro

Dr. Suvit Vibulsresth received the honor of the order of the Rising Sun (Gold Rays with Neck Ribbon) from the Japanese Government. He graduated University of Osaka in 1964 and received his Ph.D from the University of Tokyo in 1989 after studying at the Institute of Industrial Science (IIS). He was a director of the Department of Remote Sensing on the National Research Council of Thailand and became the first Director General of the Geo-Informatics and Space Technology Development Agency (GISTDA) in Thailand. This honor is the result of his continuous contribution to establishing friendship and scientific cooperation between Japan and Thailand, particularly in the field of remote sensing. He often attended ICUS's international workshops and is a collaborator of IIS, and is also working the president of IIS Alumni Thailand chapter. We congratulate him on this prestigious decoration.

(by Prof. H. Sawda)

17th ICUS Open Lecture was held at IIS

The 17th ICUS Open Lecture was held at IIS on November 4 with approximately 150 participants. Three presentations were given on the lecture' theme, "town planning with all safety, cityscape and cultural properties," and forcused on the preservation of houses in the Important Traditional Building Preservation Area. Dr. Kariya of Oyama National College of Technology discussed the houses from the view point of preservation as cultural properties. Dr. Kawai of the Building Research Institute discussed them from the view point of safety against the earthquake. Prof. Goto of Kogakuin University discussed the practical preservation with diverse values after three presentations, panel discussion was held by the speakers and the importance of considering various value systems for traditional houses was recognized.

(By M. Koshihara)

Dr. Y. Kariya

Dr. N. Kawai

Prof. O. Goto

ICUS Activities

- Prof. Meguro, Prof. Sawada, Visiting Prof. Ichihashi, Assoc. Prof. Kuwano, Assoc. Prof. Kato, Assoc. Prof. Hong, Dr. Tanaka, Dr. Endo, Dr. Numada, and Dr. Baruah attended the 8th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia (USMCA 2009) in Incheon, Korea.
- Prof. Sawada visited Soul, Korea from Oct. 12th to 13th to make a presentation at the Korea Forest Research Institute.
- Prof Sawada visited Beijing, China from Oct. 17th to 21st to attend the Asian Conference for Remote Sensing.
- Prof. Sawada and Dr. Endo visited São Paulo and Manus in Brazil from Nov. 20th to Dec. 1st to attend CADAF project.
- Dr. Endo visited Busan, Korea from Oct. 11th to 13th to make a presentation at the Dept. of Geoinformatic Engineering, Pukyong University.
- Dr. Numada visited Padang, Indonesia from Oct. 15th to 20th to investigate earthquake damage.
- Dr. Tanaka visited Dhaka, Bangladesh from Dec. 3rd to 8th to participate in and make a presentation at the GCOE Seminar.

Awards

Graduate students Masamitsu Suzuki and German Alberto Pardo Rios of Kato Laboratory received Excellent Presentation Awards at the Japan Society of Civil Engineers Annual Conference 2009.

Editor's Note

In the main article, Prof. Goto of Kogakuin University reported difficulties and problems associated with the preservation of historical architecture. The historical value is as precious as safety and how to refurbish aged valuable architectures in order to secure the safety without damaging their historical characteristics is one of the most important issues. Currently, our mission – the search for urban safety – is in a similar situation. Everyone would agree that the safety of the urban system is a very important matter, but other factors – including economic, environmental, aesthetic, cultural and historical issues – should also be taken into account. Such difficult tasks can only be overcome by the development of social strategies as well as engineering technologies. We, ICUS, need to continue making efforts with colleagues in many countries to contribute to the safety of urban systems.

During the period covered by this volume, USMCA 2009 was successfully held at Incheon, Korea, thanks to our Korean colleagues at NIDP, KDPA, and KOSHAM. I would like to deeply express our appreciation to all the participants who contributed to USMCA 2009. At the post-conference tour, we visited the Northeast Asia Trade Tower to view the newly-constructed Incheon Bridge and New Songdo City. Both of these works made us feel the rapid growth, prosperity and future possibility of urban cities as a result of the application of modern advanced technologies.

(By R. Kuwano)

Call for Paper of USMCA2010

The 9th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia (USMCA2010) will be held in Kobe, Japan on October 13th and 14th, 2010. The symposium is co-organized by ICUS and the United Nations International Strategy for Disaster Reduction (UNISDR), and marks the 15th anniversary of the Kobe Earthquake of 1995 and International Day for Disaster Reduction on October 13th. The deadline for abstract submission is June 30, 2010. Please visit the ICUS website for more information. The symposium brochure will be sent to you soon.

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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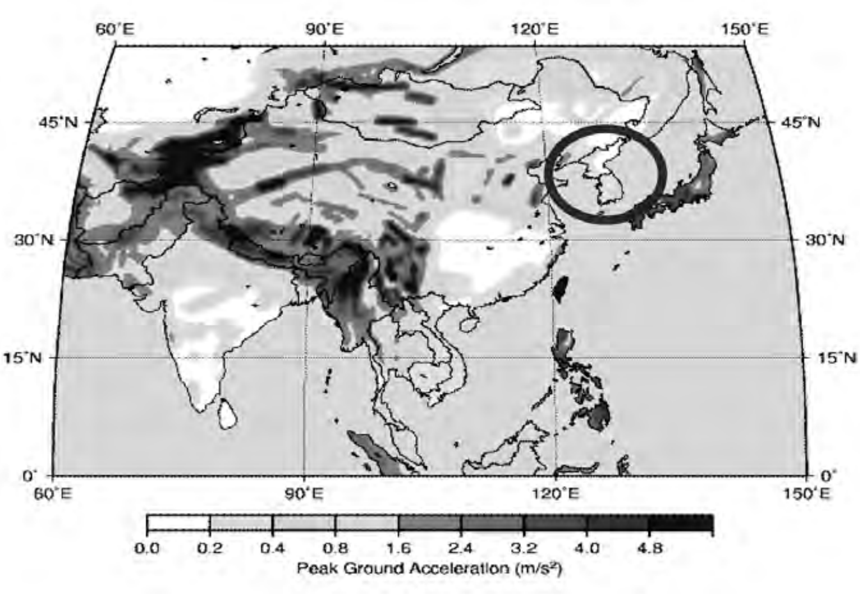
EARTHQUAKE COUNTERMEASURES FOR SAFER FUTURE IN KOREA

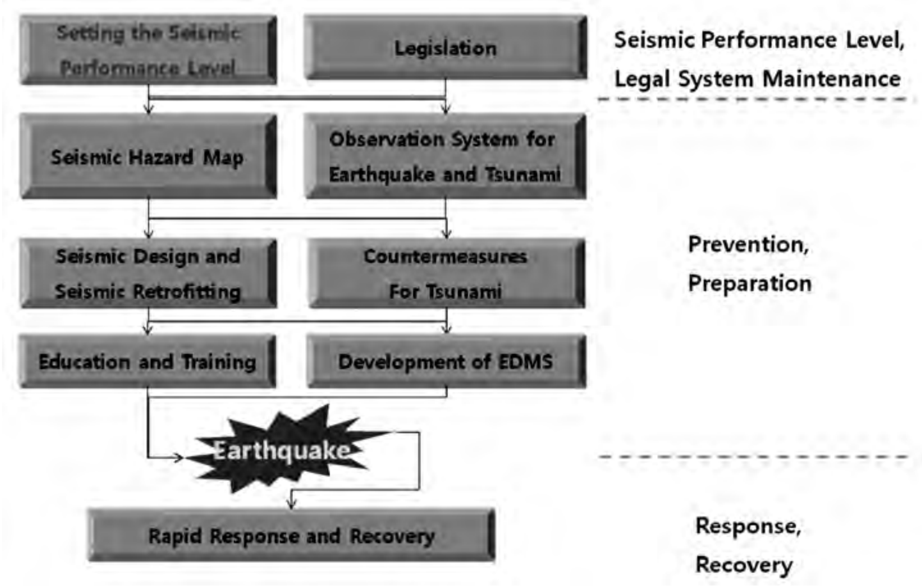
By

Waon-Ho Yi[1]

The devastating 1995 Kobe (Hyogoken-Nambu) Earthquake in Japan with more than 6,400 fatalities, the 1999 Chichi Earthquake in Taiwan with about 2,500 fatalities and the 2008 Sichuan Earthquake recently in China with more than 69,000 confirmed fatalities have awakened the public to a possible earthquake disaster in Korea. After the Kobe Earthquake in 1995, the Korean government added "earthquake" as a disaster item in the revised "National Disaster Countermeasures Act" and established the 1st Earthquake Disaster Countermeasures Plan. Continued effort has been made for earthquake hazard mitigation with the 1st to 3rd Earthquake Disaster Countermeasures Plans and Earthquake Disaster Countermeasures Act enacted on Mar. 28, 2008. A comprehensive plan was drawn up in 1998 to establish the mitigation countermeasures, emergency response, and rehabili-



Seismic hazard map for Asia showing the seismicity of Korea (http://www.seismo.ethz.ch/gshap/eastasia)



2nd Phase of Earthquake Disaster Countermeasures Plan

tation for related agencies. In this article, historical and recent earthquakes in Korea and 1st to 3rd phases of the Earthquake Disaster Countermeasures Plan are introduced along with research related to the Earthquake Disaster Countermeasures Plan.

As shown on the seismic hazard map on the previous page, Korea is relatively safer than neighboring countries located on the Pacific Rim such as Japan and China. However, Korea is not free from earthquakes according to historical records, which indicate that the number of earthquakes increased from the 15th to the 18th century. In addition, frequency steadily rose in the 20th century. Therefore, it is necessary to prepare for future earthquake events.

1ST PHASE OF COUNTER-MEASURES PLAN

The 1st Earthquake Disaster Countermeasures Plan of the Korean government was established on January 27, 1995, with the participation of relevant ministries and experts. In this plan, seismic performance level, maintenance of the legal system, and the Earthquake Disaster Countermeasures Act were mainly focused on, with the following goals:

- Promotion of the Act for Earthquake Countermeasures
- Establishment of a practical plan for the earthquake disaster mitigation
- Reduction of casualties by maintenance of rescue and relief system
- Strengthening the relationship between ministry and experts
- Enhancing consciousness of earthquake disasters through public relations
- Strengthening and developing the seismic design code and provision
- Encouraging research and development for earthquake damage mitigation

From the 1st phase, adaptation of the seismic design was widened for 20 kinds of facilities, and seismic design provisions were re-established and applied. Through the evaluation of the 1st phase, the 2nd phase was established and completed in December of 2005.

2ND PHASE OF COUNTER-MEASURES PLAN

After the earthquake in Fukuoka, Japan, on March 20, 2005, the 2nd phase of Earthquake Disaster Countermeasures Plan, shown above, was established and reported on April 12, 2005. After building a research and development (R&D) and policy plan over five years, the 2nd phase was started. The direction and goals were planned as follows:

- Enactment and maintenance of the Act for earthquake disaster mitigation
- Support of early response by improving the observation and alert system for the earthquake and tsunami
- Developing and strengthening the education and training program for rapid response to the earthquake disasters
- Improving mitigation by strengthening the seismic provisions and developing an earthquake hazard map

From the 2nd phase, the earthquake/tsunami alert system and the Earthquake Disaster

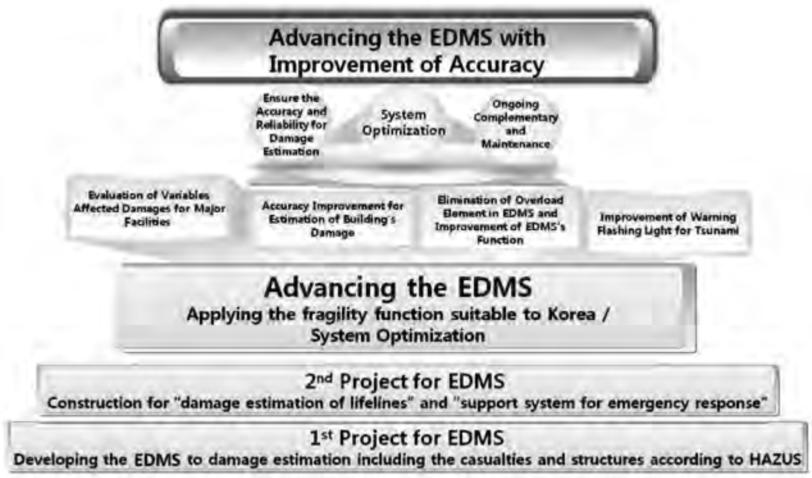
Management System (EDMS) were successfully developed. Through the development of EDMS, a national intensity map and estimation of casualties and structural damage were created.

The Earthquake Disaster Countermeasures Act (Act No. 9001) was enacted on March 28, 2008 and enforced from March 25, 2009, a related enforcement decree (Presidential Decree No. 21362) was enacted and enforced from March 25, 2009, and an enforcement ordinance (Ordinance of Ministry Public Administration and Security No. 72) was enacted and enforced from March 26, 2009.

3RD PHASE OF COUNTER-MEASURES PLAN

To make and keep Korea safe against future earthquakes, the 3rd Earthquake Disaster Countermeasures Plan is under development from 2009. This 3rd phase, from 2009 to 2013, focuses mainly on six subjects, including (1) seismic retrofitting of existing structures which used non-seismic design, (2) development and application of seismic hazard map, (3) development of earthquake notification and response system, (4) development of tsunami countermeasures, (5) improving public education and training related to earthquake disaster prevention and (6) strengthening and maintaining the legislation and organization dedicated to earthquakes. This plan will be established with three main tasks and eight subsidiary tasks, shown to the right, and the subsidiary tasks will be divided into a total of 24 tasks. From the eight subsidiary tasks, R&D projects are being partially implemented in 2009 with 58 detailed projects.

Precedence and Advanced Research on EDMS



Advancing the EDMS

(1) Seismic Performance Level and Legal System Maintenance
- Establishment of integrated seismic performance level
- Maintenance of organizations for promoting the Earthquake Disaster Countermeasures Plan

(2) Prevention and Preparation
- Advancement of earthquake/ tsunami observation system
- Development and utilization of the earthquake hazard map and active faults map
- Re-establishment of seismic design provision and promotion of retrofitting for existing facilities
- Establishment of tsunami disaster countermeasures
- Strengthening public education and training program for earthquake disaster prevention

(3) Response and Recovery
- Development of earthquake rapid response system

In conclusion, it is urgently necessary to prepare for future earthquakes. Lessons from past disastrous earthquakes as well as efforts for earthquake disaster mitigation will be devoted to developing the Earthquake Disaster Countermeasures Plan.

[1]*Director, National Institute for Disaster Prevention / Professor, Kwangwoon University, Korea*

Integration of advanced technologies for construction, environmental protection, and safety in the Yamate Tunnel

The 4.3 kilometer section of the Central Circular Shinjuku Route "Yamate Tunnel" between Shibuya and Shinjuku was opened on March 28th, 2010. This section followed the completion of the 6.7 kilometer section between Shinjuku and Ikebukuro, which was finished in December of 2007. The Yamate Tunnel is intended to transfer traffic which is not bound for the Tokyo city center to the Central Circular Route, thus greatly reducing traffic congestion and enhancing usage of the Tokyo Metropolitan Expressway network.

YAMATE TUNNEL OUTLINE

The Central Circular Route is 47 kilometers long with a radius of about 8 kilometers from the Tokyo city center, as shown to the right, with roughly 37 kilometers currently in service. The Yamate Tunnel is an 11 kilometer expressway located in the western part and runs underground beneath circular Route No. 6 in order to preserve the environment and make effective use of limited urban space. The alignment of the tunnel, structural types and con-struction methods have to consider various constraints such as river crossings, subways, trunk roads and railways, and major existing public utilities.

INNOVATIVE TUNNEL TECHNOLOGIES

The recently developed shield tunnel construction technique was utilized for roughly 80% of the tunnel section. In response to the application of shield tunnel with such a large diameter, numerous innovative construction technologies were developed such as the "shield tunnel expansion methods" (STEMS) to construct underground junctions and the connection of ramp tunnels; "u-turn tunneling operations" which rotates a shield by 180 degrees in a shaft; and so on.

ENVIRONMENTAL PRE-SERVATION MEASURES

In addition to environmental improvement due to the allevia-tion of traffic congestion, an NO_2 removal system for extracting low concentrations of NO_2 was installed in nine ventilation stations. The system is composed of an electric precipitator and NO_2 removal equipment. The removal performance such as removal ratio for suspended particulate matter (SPM) and NO_2 is more than 80% and 90%, respectively, on a daily average.

SAFETY AND DISASTER PREVENTION SYSTEM

In order to secure safety and prevent disasters such as fire or other accidents, various equip-ment to achieve AA grading such as emergency phones, fire detection systems, water

Central circular route

Shield tunnel expansion method

sprinklers, foam hydrants, and so forth were installed. In addition, several advanced technologies were employed due to the tunnel's length. The tunnel is monitored 24 hours a day from a traffic control room by CCTV cameras which can immediately detect unusual traffic incidents using image processing, and a loud speaker system can provide evacuation information. Furthermore, the Metropolitan Expressway motorcycle patrol corps, the first emergency-designated motorcycle squad operated by a private company in Japan, was founded to ensure rapid initial response to accidents.

FUTURE PERSPECTIVE

Early completion of the entire Central Circular Route is highly desired to provide an effective expressway network in the Tokyo Metropolitan area which can reduce traffic congestion as well as provide significant socio-economic benefits and improve environmental preservation. The last section, the Shinagawa Route, is under construction and scheduled for completion in 2013.

In the meantime, the innovative construction and safety technologies and disaster prevention systems developed by the Metropolitan Expressway Co., Ltd. will be expected to contribute further to effective utilization and development of underground spaces in urban areas.

(by H. Dobashi, Metropolitan Expressway Co., Ltd.)

Tour of the Uemachi Terrace, a potential disaster area

The Uemachi fault belt runs 42 kilometers from Toyonaka City to Osaka City, passing through Kishikawa City. It is a reverse fault, running primarily south to north, with the west side rising up at an average velocity of roughly 0.4 meters per 1,000 years. The estimated average activity interval is around 8,000 years. According to an estimation by the Central Disaster Prevention Council, the potential loss of life due to Uemachi fault belt move may be up to 42,000 people.

The Karahori area, which is located on the Uemachi Terrace, is an unusual area where the scenery, such as old tenement houses (nagaya), and machiya utilize the geographical features to create alleys. I participated in a walking tour of this area on January 19, 2010 with Mr. Hayakawa, a member of the Karahori Club. This area is located near the moat on the southern side of Osaka Castle, which was originally built at the end of the 15th century. The slope and cliff existed even at that time, and the Karahori shopping street still slopes downward.

The primary feature of this area is neighborhoods with old tenement houses built closely together. However, modern apartment houses have also been recently built here and the population is rapidly increasing.

Although there is the potential for earthquake disaster from the Uemachi fault belt, effort is made to preserve the historical value of the tenement houses through maintanence. When considering disaster prevention, however, there exists significant risk such as collapse of the tenement houses, poor space utilization, fire disaster, and so forth, which need to be solved before a future earthquake strikes.

This area is a good example of the dual problems of how to preserve historical architecture and neighborhood atmosphere while protecting against earthquake damage.

(by M. Numada)

Old tenement houses

Coexistence of old and modern construction

15 years after the Kobe Earthquake: Basic steps for earthquake disaster reduction and the necessity for an integrated disaster management strategy

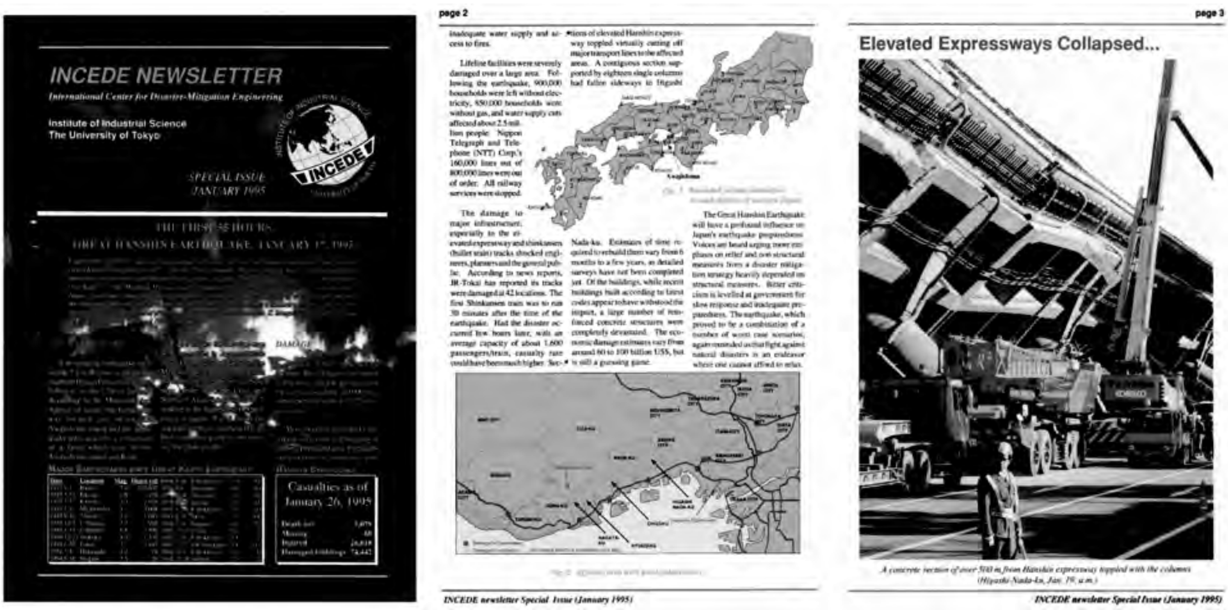
UNFORGETTABLE JANUARY 17, 1995

Even now, I can still remember clearly the morning of that day. I was awakened in my hotel room in Osaka at 5:46 am by strong shaking. This shaking was due to the 1995 Kobe (Hyogo-ken Nanbu) Earthquake, with a magnitude of 7.3 which lead to the deaths of over 6,400 people, damaged 650,000 structures, and caused over US$ 100 million in direct economic loss. The US-Japan direct International Symposium for earthquake disaster mitigation was scheduled to be held in Osaka, just 30 kilometers east of Kobe City, to commemorate the one-year anniversary of the Northridge Earthquake which struck the Los Angeles area on January 17, 1994. But unfortunately, three hours before the opening of the symposium, the Kobe Earthquake occurred.

I took a taxi to Kobe and wandered around the affected areas of Kobe for a couple of days and nights, surveying the damage from building collapse and fires. I was shocked to see the large gap between what I had learned and reality, and that experience became an unforgettable and formative part of my career as a researcher in the field of disaster mitigation.

WITH STRONG SHOCK AND COMPLICATED FEELINGS

After coming back to Tokyo, I was gripped by complicated and strong feelings of responsibility, powerlessness, apology, and more. I felt that I had to do something, so I worked with my research center, INCEDE (International Center for Disaster-Mitigation Engineering) on a full-color newsletter, as shown below. This special-issue newsletter was delivered to over 140 countries, and was the first English report on the damage survey conducted by Japanese specialists. Other activities included the establishment of KOBEnet, a researcher network for supporting restoration and reconstruction after the Kobe earthquake, with colleagues at the Institute of Industrial Science, the University of Tokyo, and publication of damage reconnaissance reports in cooperation with many earthquake disaster-related associations national and local governments. The importance of seismic retrofitting of existing structures was apparent from these activities, but I felt that focusing only on technical problems was not enough to solve this issue – research on the policy



Cover page and contents of INCEDE Newsletter Special Issue reporting on the Kobe Earthquake disaster and social systems was also necessary, so I proposed social incentive systems to promote seismic retrofitting activities. Also, I worked to promote disaster education through programs and materials for children and the general public, utilizing picture books, comics, maps, manuals, and more.

CURRENT EARTHQUAKE DISASTER RISK IN JAPAN

Fifteen years after the Kobe Earthquake, what is the most important issue for minimizing earthquake disasters in Japan in this high-seismicity period? In the coming 30 to 50 years, four to five earthquakes of magnitude 8 or higher, and 40 to 50 magnitude 7 events (similar to The Kobe Earthquake) may occur. The total economic loss due to these events is estimated by the national government at roughly 40 percent of GDP, with the number of collapsed and burnt-out structures between one and two million.

KEY FOR EARTHQUAKE DISASTER REDUCTION

It's common knowledge that the final goal of earthquake disaster countermeasures is to minimize the negative impact due to earthquakes. Based on the current situation, how many people have been working towards this goal? Are the people in this field satisfied with only considering their own field – for example, are scientists satisfied focusing only on scientific mechanism; the engineer satisfied with only tackling technical issues; do the administrators only discuss issues in their own section? What is the gap between their purpose and society's expectations? Do they believe that if they solve a problem in their field, they can achieve the final goal? If the problem is due to a lack of political power, they should make efforts to have political power; if it is due to economic or social regulation problems, they should tackle them, and try to find their own solution and implement measures to apply that solution. It is necessary for people to change their mindset. We are not only engineers or researchers, but also citizens and taxpayers, so whatever we do, we should always keep in mind the viewpoint of the citizens and taxpayers. It is important to conduct research and disseminate information to the public keeping in mind this viewpoint, by using basic terminology and clear explanations for the public.

IMPORTANT RESEARCH TOPICS TO BE TACKLED

Considering the above-mentioned points, I believe that the following research topics are important for implementing efficient earthquake disaster countermeasures.

- Record data of the Kobe Earthquake disaster as much as possible in order to fully imagine the whole disaster (the record must have data structure that enables us to analyze the data from various viewpoints)
- Continuous promotion of conventional, individual, and fundamental research (the topics described below can be implemented based on these research works)
- Shift from research focusing on mechanisms to research on developing measures (from focusing on mechanisms based on disaster experience to developing countermeasures and predicting phenomenon which have not yet been observed in past disasters)
- Promote research on quantitative evaluation of the usefulness, social impact, and long-term effect of the social system and regulation related to disaster reduction (without this, it is impossible to implement systems and regulations that can truly contribute to reducing disasters in the whole country and maintain accountability with the taxpayers)
- Establish a promotion system, research promotion, and implementation system for countermeasures on huge, longterm, and complex disasters which haven't been experienced yet, such as large, multi-event disasters
- Establish a cooperation system among universities and academic associations working on disaster research and implement a system for coordinating activities through research organizations, mass media, administrative organizations, and politicians
- Develop a disaster education program and materials for all generations, from infants to adults
- Create and promote the attractive business of disaster reduction
- Establish a system for getting support from other countries in case a large earthquake disaster occurs during the 21st century (this is necessary due to the shortage of human resources, construction labor and engineers necessary for recovery and reconstruction)

(by K. Meguro)

Visit to Ohashi junction before the public opening

Prof. Meguro, Dr. Kuwano, Dr. Miyazaki, and other ICUS members visited the Ohashi Junction site in the Central Circular Route of the Metropolitan Expressway in Tokyo on January 29, 2010, just before opening of the expressway to the public.

The junction is located between the Shinjuku route and Shinagawa route (which is still under construction), as explained in Dr. Dobashi's article on page 4, and has a double loop structure between the Central Circular Route and the connecting route. The latest technology was fully used to reduce environmental impact, and the roof of the junction structure will be utilized as a garden. It will soon become part of a new urban landscape.

(by R. Kuwano)

Group photo taken on the roof-top of Ohashi Junction

Schematic of Ohashi Junction (http://www.c2info.jp/ohashi-summary.php)

15th anniversary forum of the Kobe Earthquake

Fifteen years have passed since the Hyogo-ken Nambu (Kobe) Earthquake, which oc-curred on January 17, 1995, at 05:46 JST in the southern part of Hyōgo Prefecture, Japan. To mark the 15th anniversary, 14 academic groups organized a commemoration forum at the international congress center in Kobe. Its purpose was to look back on past activities, clarify the role of the academic groups, and determine future courses of actions, including research and communication with society.

In the keynote speech, Prof. Kenzo Toki (Ritsumeikan University) gave a lecture on the fire seismic hazard and also on cultural heritage; following that, Prof. Masanori Hamada (Waseda University) gave a presentation on the role of research institutes after the Kobe Earthquake and reducing future seismic risk.

During the panel discussion, topics such as the problems before and after the disaster, ideal disaster prevention education, and the means for announcing research results to the public were discussed. The director of ICUS, Prof. Meguro, was a member of the panelists.

In Kobe, around 20 percent of the current population did not experience the Kobe Earthquake. Therefore, problems related to disaster prevention education including its implementation were discussed. Another discussion pointed out that the researcher's activities may not be easily understood or distributed to the society, yet it is important to get social feedback regarding the research and the effectiveness of the education methods.

(by M. Numada)

During the panel discussion

Ground-breaking ceremony of BUET-JIDPUS

Unveiling of the foundation stone of BUET-JIDPUS

Dignitaries at the opening ceremony

The ground breaking ceremony of the Bangladesh University of Engineering and Technology (BUET) and the Japan Institute of Disaster Prevention and Urban Safety (JIDPUS) was held on March 20, 2010 in the seminar room of the Information Access Center at BUET. The welcome speech was given by Dr. Raquib Ahsan, Deputy Project Director of BUET-JIDPUS. First, Dr. Ahsan introduced BUET to the invited guests, then gave a brief description and overview of the objectives of the institution: to strengthen the capacity of engineering professionals in the fields of infrastructure management and structural health monitoring, disaster management and prevention, and urban safety by developing research infrastructure, library and computational facilities; to strengthen other local agencies through training and dissemination of knowledge; to promote collaboration with other national and international universities and research organizations; and to provide testing and consultancy in the field of disaster prevention and urban safety.

In the opening ceremony, Air Vice-Marshal (Rtd.) Mr. A.K. Khandaker, Honorable Minister, Ministry of Planning, Govt. of People's Republic of Bangladesh was the chief guest. He said that Bangladesh is a developing country with a large budget deficiency for infrastructural development. At the same time, Bangladesh is highly disaster-prone, but there is no institution to monitor infrastructure development. The chief guest claimed that BUET-JIDPUS will strengthen the capacity of infrastructure development and disaster prevention.

The Japanese ambassador, his Excellency Mr. Tamotsu Shinotsuka, was also invited as a special guest. He discussed the relationship between disaster management and infrastructure development. He believes that this new institution will help improve the infrastructure in Bangladesh through research and practical experience. Prof. Taketo Uomoto, Professor Emeritus, the University of Tokyo and Mr. Takao Toda, Chief Representative, JICA were other Guests of Honor.

Prof. A.M.M. Safiullah, Vice-Chancellor of BUET was the chair for the ground-breaking ceremony. He said that Dhaka is a megacity for which urban safety is a necessity, and it is of great importance to give more priority to this sector. He addressed this institution as the first-ever capable of monitoring urban safety issues in Bangladesh. The chair of the ceremony also added that BUET-JIDPUS will boost the capacity of people in construction, disaster prevention and mitigation, and that this institution will carry out research activities for assuring quality infrastructure development. Finally, the chief guests unveiled the foundation stone of BUET-JIDPUS.

(by M.A. Ansary, BNUS)

Workshop on urban safety held at BUET

BUET-JIDPUS, in collaboration with ICUS, the University of Tokyo, organized the Workshop on Urban Safety from March 20 to 21, 2010, at the BUET Information Access Center. This was the first such workshop organized by BUET. Fifty five participants from several institutions attended this workshop, mainly from the civil engineering, architectural, and urban planning fields. Four researchers from BNUS (Md. Kamruzzaman, Md. Saidur Rahman, Ripon Hore, Sharmin Ara) also participated.

The workshop was divided into six sessions with lectures given by experts on the subjects of urban safety issues and disaster management. Prof. Kimiro Meguro, Director of ICUS, presented “Towards Implementation of Disaster Safer Built Environment.” This lecture consisted of two issues: “implementation of earthquake safer housing by combination of technological and social approaches” and “integrated disaster information system and information management.”

Mr. Yasuyoshi Ichihashi, visiting professor of ICUS, presented “Framework/Mechanism of International Cooperation for Disaster Risk Reduction and Japan’s Contribution.” This lecture briefly reviewed the process and accomplishments so far in the title areas, focusing on Japan’s contribution.

Prof. Haruo Sawada, professor of ICUS, presented “Global Changes and Disaster Events Observed by Satellite Remote Sensing.” Primary knowledge on remote sensing, its application in the field of land use change detection, disaster management and global climate change were covered in this lecture.

Prof. Taketo Uomoto, Professor Emeritus, the University of Tokyo also delivered a lecture on “The Importance of Overall Evaluation of Civil Structures to Maintain Safety.” The lecture explained what sort of problems are faced by structures such as buildings, tunnels, and roads and what kind of maintenance is required for reinforced concrete structures. Different practical examples were also given to show the overall situation in Japan. This lecture was intended to help the concrete engineers who are trying to design, construct, and maintain concrete structures.

Another lecture was given by A.S.M. Woobaid Ullah, Professor, Department of Geology, University of Dhaka, on “Geophysical Survey.” In this lecture, he gave different information on geophysics, methods of geophysical survey, techniques of geophysics, and implementation in the field.

Prof. Mehedi Ahmed Ansary, Project Director of BNUS, presented a lecture on “Recent Earthquake-Related Activities in Bangladesh (1996-2008).” This was the last session of the workshop and, in this lecture, he discussed activities and research undertaken in recent years in Bangladesh related to the title topics. He also gave a short description of the ongoing and completed research activities conducted by BUET.

Finally, certificates were given to the participants of the workshop by Prof. A.M.M. Safiullah, Vice-Chancellor of BUET.

(by M.A. Ansary, BNUS)

Group photo of workshop participants

BNUS Activities

BNUS has been busy with several research projects. The first is evaluation of the seismic vulnerability of buildings in Dhaka using non-destructive tests such as FERROSCAN and Microtremor. These methods were applied to establish the configuration and response behavior of the investigation's target structures.

Another investigation is being conducted to evaluate the fire-fighting system in high-rise buildings in Dhaka in cooperation with the Department of Fire Service and Civil Defense. The purpose of this investigation is to check the existing fire systems as well as raise awareness about fire hazards and earthquake-related issues among people.

Research activities funded by the Ministry of Science and Information Technology include a project focusing on urban vulnerability to earthquakes in unplanned areas in old Dhaka and structural health monitoring of reinforced-concrete bridges in Bangladesh.

(by M.A. Ansary, BNUS)

Order of the Rising Sun to Dr. Tsuneo Katayama

Dr. Tsuneo Katayama received the honor of the Order of the Rising Sun (gold rays with neck ribbon) from the Japanese government. He graduated from the University of Tokyo in 1962, received his Ph.D. from the University of New South Wales, and served as director of INCEDE (predecessor to ICUS). This honor is the result of his continuous contribution to establishing friendship and scientific communities around the world. His research field is very wide, spanning the fields of social and safety systems engineering considering materials, disasters, maintenance, and more. He often attended international workshops held by ICUS and is a collaborator with IIS. He is now working for the Tokyo Denki University in the Department of Architecture. We congratulate him on this prestigious decoration.

(by K. Meguro)

Prof. Katayama (third from right)

ICUS Activities

- *Prof. Meguro, Prof. Sawada, and Visiting Prof. Ichihashi vi-sited Bangladesh from March 17th to 22nd for a ground-breaking ceremony and workshop on urban safety at BUET.*
- *Prof. Meguro went to Indonesia from March 12th to 16th to promote low-cost retrofitting methods.*
- *Prof. Sawada had a meeting with the Cambodian Forestry Administration, a research meeting at AIT, and conducted field research in last December and February.*
- *Prof. Sawada also attended an international workshop in Beijing from February 26th to 28th, and also visited RNUS and GISTDA from March 22nd to 25th.*

Awards

- Mr. Makoto Hosoo, graduate student of Kuwano Laboratory, received the Best Presentation Award at the 44th annual conference of the Japanese Geotechnical Society.
- Mr. Kotaro Sakurai, graduate student of Meguro Laboratory, received the Best Presentation Award at the 7th annual international conference on Urban Earthquake Engineering.

Editor's Note

During the period of this volume, there were many events held to commemorate the 15th anniversary of the 1995 Kobe Earthquake. As reported on pages 6 and 7, I was in Kobe from the morning of the day of the earthquake and had a formative experience as disaster researcher. I was 32 years old at that time and I gave the name 'Nozomi' to my first daughter who was born one month after the Kobe Earthquake. Her name "Nozomi" means hope in Japanese and I chose it because I wanted her to live a life of hope and give hope to others. I strongly recognized the importance of hope for life as I saw many people who couldn't find hope in the affected areas.

Soon after coming back from Kobe, I prepared INCEDE Newsletter, Special Issue, and distributed it all over the world. Also we established KOBEnet and KOBEnet room to support recovery activities through information sharing, and many people from Japan and more than 500 people from 34 countries visited it. We received many thank-you letters from those countries who improved their disaster systems using the information collected from KOBEnet. Korea, reported in the main article of this volume, is one of the typical examples.

Fifteen years is a relatively long period, but the time since the Kobe Earthquake has passed quickly, and my working period left at the University of Tokyo before retirement is less than that. Now Japan has entered a high seismicity period, and we may have many big earthquakes in the near future. Considering the current situation and the time remaining to me at this university, I keenly feel the importance of efficient use of time and selection of research topics and activities for disaster reduction to let people have lives with hopes, 'Nozomi'.

(By K. Meguro)

Call for papers: USMCA 2010 (Kobe, Japan)

The 9th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia (USMCA 2010) will be held in Kobe, Japan, on October 13th and 14th, 2010. The symposium is co-organized by ICUS and the United Nations International Strategy for Disaster Reduction (UNISDR), and marks the 15th anniversary of the Kobe Earthquake of 1995 and International Day for Disaster Reduction on October 13th. The deadline for abstract submission is June 30, 2010. Please visit the ICUS website for more information.

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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EXPECTATIONS FOR ITS BASED ON TRAFFIC ACCIDENT ANALYSIS

By
***Yasushi Nishida*[1]**

TRANSITION OF TRAFFIC ACCIDENTS

The number of fatalities due to traffic accidents has been decreasing since 1992. In 2009, there were only 4,914 fatalities, the lowest number in the last 50 years, and the number of accidents and injuries is also decreasing. This appears to be a desirable situation.

With these conditions, the government set a new goal to reduce the number of fatalities to less than 2,500 by 2018. The new goal is ambitious and seems difficult to achieve by only conventional countermeasures. Some innovative counter-measures are needed to achieve this goal. Therefore, the expectations for ITS (Intelligent Transport Systems) as a promising new technology are high, as without ITS it may be difficult to achieve this new goal.

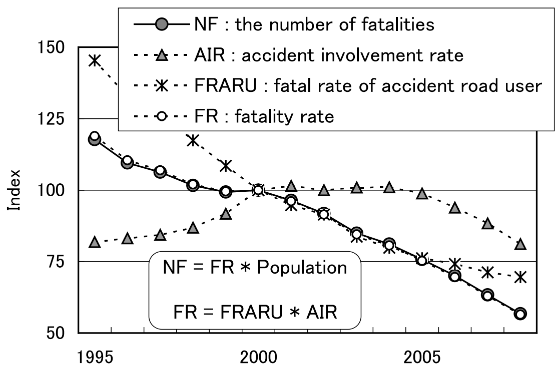
In this article, the potential for ITS to reduce traffic accidents is explained from several viewpoints and the need for ITS is introduced based on traffic accident analyses.

TO REDUCE THE NUMBER OF FATALITIES

There are two ways to reduce the number of fatalities: (1) to reduce the number of accidents or (2) to prevent an accident from becoming a fatal one. The former is called preventive safety measures, and the latter is called protective safety measures.

Before 2005, the reduction in fatal accidents was mainly due to the effectiveness of protective safety measures, but the effect of

Scene of traffic accident survey
(source: Institute for Traffic Accident Research and Data Analysis)



Transition of traffic fatalities and related rates preventive safety measures and less road usage became relatively large after 2005. Therefore, it is essential to improve preventive measures to achieve the above-mentioned goal considering the amount of possibilities. ITS is expected to greatly contribute for preventive measures.

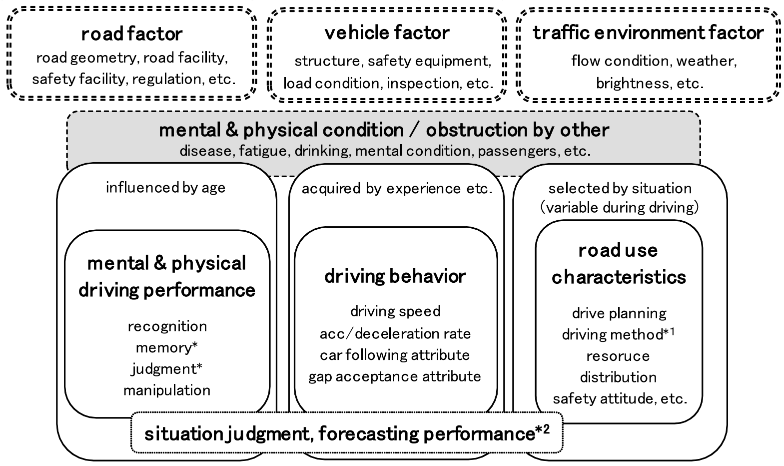
TRAFFIC ACCIDENT PREVENTION BY ITS TECHNOLOGY

From traffic accident analysis, various levels of human factors causing traffic accidents have been identified. A lot of researches and analyses show that people's ability of mental and physical performance for driving declines as they get older. A basic function of ITS is to make up for the decline in driving performance and many technologies have already been put into practical use. ITS also assists road users at the level of driving behavior and road use characteristics.

EFFECT OF PASSENGERS – FROM ASSISTANCE TO COOPERATION

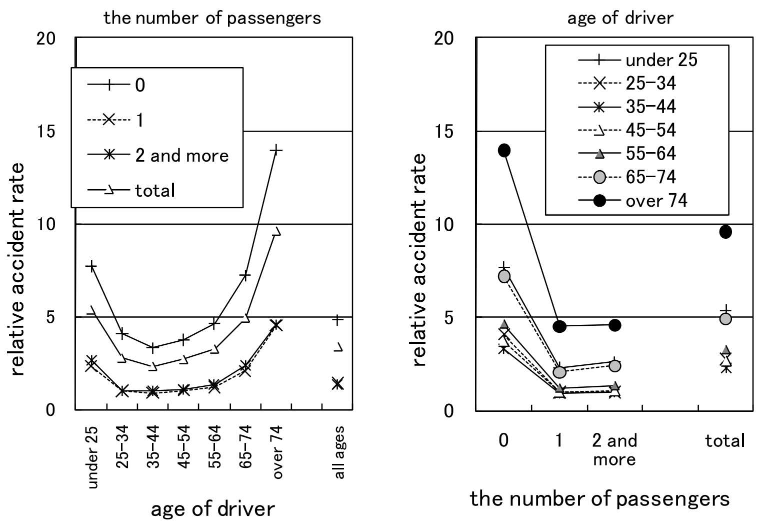
Only considering ITS as an assistance system for declining driving performance may limit its full potential. The potential for ITS could expand by considering other ways to support drivers, as will be illustrated in the following example.

The accident rate per unit exposure to road traffic (estimated by the number of collisions from behind while standing) is estimated to become less than half in all age groups, including elderly people, when they have other passengers in their car compared to the case with no passengers. Similarly, the accident rate for drivers aged 65 to 74 with passengers appears less than that of younger drivers without passengers. It can also be seen that the effect of passengers (a kind of assistance) is different by age of driver.



*1: As driving behaviors acquired by experience have some variation to meet various conditions, road use characteristics are selected from them depending on the situation.
*2: Situation judgment and forcasting performance are classified into mental & physical performance and driving behavior depnding on the level.

Human factors affecting traffic accident occurrence



Relative accident rate by age of driver and the number of passengers (2004-2006, belted male driver of passenger car for private purpose)

Just as research on artificial intelligence not only developed computer technologies but also revealed the nature of human mental characteristics, so too can research on ITS contribute to revealing the nature of driving performance, driving behavior and road user characteristics.

PREVENTIVE SAFETY MEASURES CONSIDERING INDIVIDUAL DRIVER CHARACTERISTICS

The accident rate per vehicle kilometer for elderly and young people is significantly higher than that of middle ages (30s – 50s). However, looking at the accident rate over one year, elderly people's value is not significantly high.

The probability of being involved in an accident in a year depends on not only the driver's accident rate per vehicle kilometer but also how much he/she is exposed to road traffic. To evaluate this effect, the relative accident rate, which corresponds to the accident rate per vehicle kilometer, is calculated along with the number of collisions from behind while stationary as an index of exposure to road traffic. The result shows that as the number of accident experiences in the last 5 years increases, both the relative accident rate and the accident involvement rate increases. This means that drivers with accident experience may have both poor performance and high road usage.

Frequent drivers have reasons to drive, so it is not easy to reduce the driving frequency. Therefore ITS measures, which can provide the most effective safety support system corresponding to each individual driver, are expected to reduce the accident rate per unit exposure to road traffic.

FEASIBILITY OF VISION ZERO IN JAPAN

The "vision zero" policy in Sweden aims to reduce fatalities by traffic accident to zero, but does not aim to completely reduce traffic accidents to zero. As long as the road transportation system involves people, it is impossible to completely eliminate human errors. Therefore, since we cannot completely prevent accidents from occurring, we need to focus on preventing fatalities from those accidents that do happen.

In the vision zero policy, it is described that pedestrians should not be killed in accidents when collision speed is less than 30 kilometers per hour. However, looking at pedestrian accident records in Japan, only 15% of pedestrian fatalities can be saved by this standard. That means that protective measures only are not enough to reduce pedestrian fatalities drastically, and preventive measures which prevent collision between vehicles and pedestrians are essential .

EXPECTATION FOR ITS

Some key points to consider for countermeasures towards reducing traffic accidents were shown with examples of specific accident analyses. However, ITS is expected to support not only accident prevention systems but also evaluation systems.

When we consider counter-measures to reduce traffic accidents, it is necessary to evaluate the risk of traffic accidents objectively. ITS, which can automatically collect exposure data to road traffic considering driver's attributes, could provide useful data towards this purpose.

Moreover, discussion on what ITS should be leads to discussion on what road traffic systems – which consist of people, vehicles and roads – should be. Achieving safety and efficiency through flexible systems which give drivers multiple options would make road traffic systems more human-friendly.

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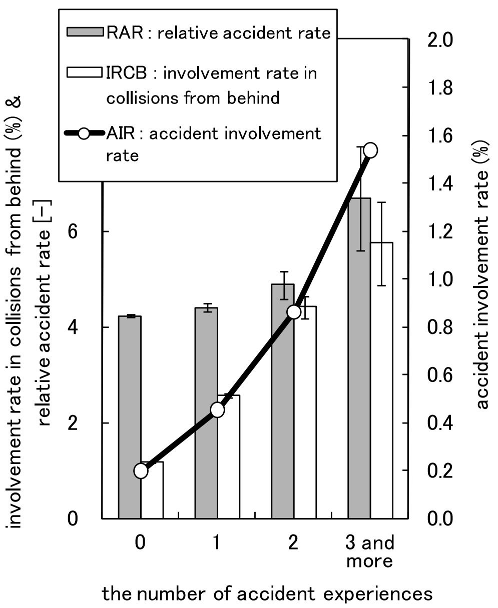
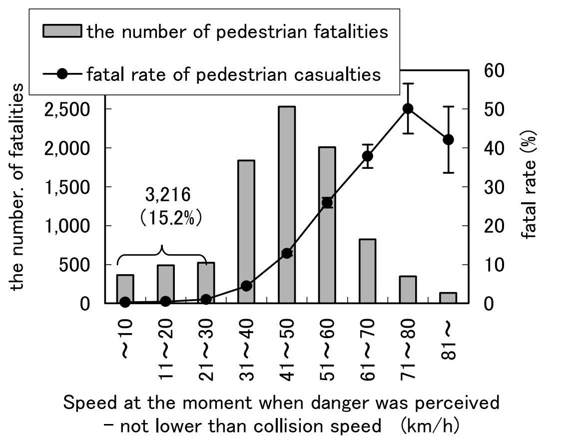




Pedestrian fatalities and fatality rate by vehicle speed (2001-2007)

Statistics for collisions from behind while stationary by the number of accident experiences over the last 5 years

Tsinghua Week at Todai – International Forum on Public Safety and Disaster Emergency Management

The University of Tokyo (Todai) and Tsinghua University have been jointly organizing Todai-Tsinghua Week for the purpose of deepening mutual exchange of research and activities. This program was first hosted by Tsinghua University in 2008, and the University of Tokyo hosted the second event, Tsinghua Week at Todai, on May 12 to 14, 2010.

ICUS and the Center for Public Safety Research (CPSR), Tsinghua University, organized the International Forum on Public Safety and Disaster Emergency Management on May 12 and 13 as part of Tsinghua Week at Todai. The forum included three parts: a keynote speech at the week's opening ceremony and International Forum for Doctoral Candidates on Public Safety on May 12 and the International Forum on Public Safety and Disaster Emergency Management on May 13.

Following the opening speeches by both universities' presidents, Prof. O. Hamada and Prof. B. Gu, two keynote speeches were provided. In the first keynote speech, Prof. W. Fan (Director of CPSR) presented "Emergency Management and Public Safety Science and Technology in China," in which the framework, methodology, application, and recent progress were introduced. Following that, Prof. K. Meguro (Director of ICUS) presented his keynote speech "Integrated Information System for Total Disaster Management," in which a new-generation disaster manual based on user, time and purposes was introduced.

In the International Forum for Doctoral Candidates on Public Safety, eighteen doctoral students presented their studies covering a wide range of issues in the areas of urban safety, including emergency management for urban disasters, advanced technologies for monitoring and management of urban safety, risk assessment, prediction, early-warning of urban disasters, and so on. Many interesting and fruitful discussions were held during this time.

In the International Forum on Public Safety and Disaster Management, Prof. T. Yashiro (Director General of the Institute of Industrial Science, the University of Tokyo), Prof. Fan, and Prof. Meguro provided the opening speeches.

Group photo of forum participants

The forum then began with Prof. H. Zhang, who introduced the emergency management system and standardization in China, followed by Prof. A. Tanaka's presentation about information management for efficient emergency disaster response. Next, Prof. Q. Zhang presented energy and environmental safety issues within the context of global change. The relationship between climate change and hydrological disaster were presented by Prof. M. Kimoto, then Prof. Meguro delivered a lecture about disaster simulation tools. Risk analysis integrating uncertainties was presented by Prof. Y. Liu, and topics on urban planning for earthquake disaster mitigation and studies on urban safety problems using multi-scale and multi-physics models were introduced by Prof. T. Kato and Prof. H. Huang, respectively. Finally, in the last session, Prof. S. Kato gave a lecture about countermeasures for air-infectious disease and bioterrorism and Prof. H. Zhang made a speech on the methodology for integrated risk assessment of multi-hazard events.

This event provided an opportunity to share the latest technologies and information and discuss possible means for joint research with the overall purpose of raising the level of public safety-related science and technology in both countries.

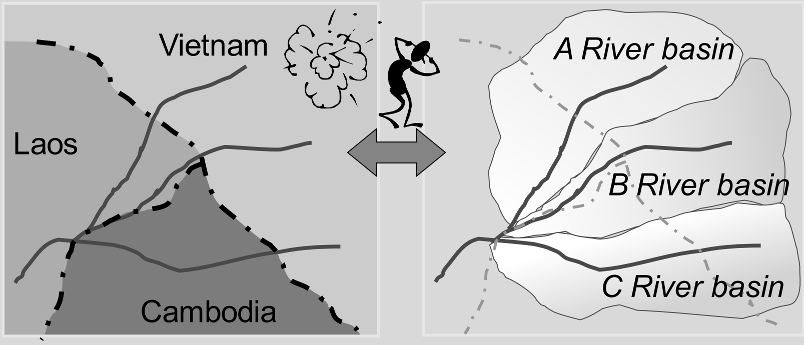
(by H. Huang, CPSR, Tsinghua University)

Exploring environmental change adaptation covering disaster management aspects using watershed as a unit

My name is Akiyuki Kawasaki, and I joined ICUS from this April as a project researcher. I'm also acting as coordinator for the Regional Network Office for Urban Safety (RNUS), as well as visiting faculty of the Water Engineering Management field at the School of Engineering and Technology, Asian Institute of Technology, Thailand.

After getting my doctoral degree and working at Yokohama National University, I conducted research at United Nations University, Harvard University, and at the Institute of Industrial Science, the University of Tokyo. I have over 13 years of experience utilizing GIS (Geographic Information Systems) for multidisciplinary environmental research while developing systematic approaches for integrating a wide range of data models, data formats, and research methodologies into a common GIS computing environment. Using GIS as the main tool, I have been conducting research on both disaster management such as landslide and earthquake response, and environmental management such as an integrated approach to evaluate the potential impact of precipitation and land-use change on stream flow.

By combining my career and ICUS's and RNUS's splendid research resources and networks, I would like to explore comprehensive environmental research which involves disaster management – for example, waster resources management as a strategy for disaster risk reduction.



Political boundary (national border) approach vs. natural boundary (watershed/basin) approach

Let me introduce my current study in the Mekong River Basin, the longest international river in Asia. The concept of water security is becoming more common because many of the large river basins of the world are shared among several nations. Developing a scientific framework for cross-boundary water resources adaptation is urgently required as water becomes scarcer, and thus conflicts over water more common, due to economic development, population growth and climate change. To contribute to solving this issue, I'm investigating how water and its benefits can be fairly shared among riparian countries using the Mekong River Basin as a study area.

Conventionally, river basin policy is divided by "man-made" boundaries such as national and provincial borders. However, "natural boundaries" such as watersheds, the area of land in which all of the water which is under it or drains off of it goes into the same place, is considered as a promising way for promoting better environmental management. Therefore, I'm examining the utility of the two approaches – a "watershed" approach and a "political unit" (national boundary) approach – for water resources adaptation in cross-boundary river basins by comparing a range of climate adaptation strategies for cooperation among the riparian nations. GIS is among the best tools for analyzing this kind of regional issue.

Although environmental aspects such as climate change and socio-economic factors such as population increase have been considered, disaster management aspects such as food risk reduction should also be incorporated, thus supporting decision making on global change adaptation strategy. This is an across-the-board, complex and challenging theme, but I would like to address this issue by collaborating with ICUS researchers and beyond using GIS as a multidisciplinary collaboration tool among fields. I always appreciate suggestions and support towards my research.

(by A. Kawasaki)

Development of IT triage system

Slightly-injured patients after the first and the second triage (left) and system utilizing FeliCa reader (right)

Prof. K. Meguro, Prof. M. Ohara, and Dr. M. Numada have developed an IT triage system for collecting disaster medical information in real time. FeliCa cards and card readers are used to obtain the number and condition of patients.

The system is composed of two elements. First, the number of patients for each triage level and the accepted number of patients in each diagnosis and treatment department are obtained in real time, including response for changing triage level. Second, this information can be shared among hospitals, the administration, and residents in real time who are searching for their family.

A disaster drill utilizing this system was held at the University of Yamanashi Hospital with 450 participants from 9:30 on May 22nd, 2010. During this drill, the system displayed the number of patients in real time according to triage level, the number of consultation patients of each diagnosis and treatment department, and easily showed the change in triage level.

This system can upgrade the current triage and also support sharing of this information across an entire region, including other hospitals, administrators, and residents, to facilitate quick transfer of patients and support response to patients' families.

(by M. Numada)

Project on Amazonian Carbon Dynamics (Part II)

Following our first article in the ICUS Newsletter Vol. 9, No. 3 on the "CArbon Dynamics of Amazonian Forests" (CADAF) project, we can announce that the project has officially begun from the end of May 2010. From May 19th to June 2nd, Prof. H. Sawada, Dr. T. Endo, and Mr. Y. Sawada (project researcher) visited São Paulo and Manaus in Brazil to meet the Forestry and Forest Products Research Institute (FFPRI) and Japan International Cooperation Agency (JICA), Japan, and the Instituto Nacional de Pesquisas da Amazônia (INPA) and the National Institute for Space Research (INPE), Brazil. In this project, we will survey the Amazonian forest using an airborne fullwaveform LiDAR instrument to evaluate forest inventory such as terrain under the trees, dominant tree height and geographical position. The fullwaveform LiDAR instrument is the latest LiDAR sensor and can receive the returned laser pulses from objects as a continuous signal. We believe this instrument will work well in the Amazonian forest.

During our stay in São Paulo, we discussed how to measure the Amazonian forest using the LiDAR instrument with the local survey company, and established plans to begin the first LiDAR measurement in September.

After that, Dr. Endo and Mr. Sawada moved to Manaus to confirm the measurement methods for terrain and tree height using the laser distance meter and trained the local staff in the measurement protocol.

We will visit Manaus again this September to evaluate the preliminary results derived from the LiDAR data, and will introduce and discuss some of the highlights of the project in part III of this article.

(by T. Endo)

Airplane used for LiDAR measurement

Joint research on PP-band technology in China

Prof. K. Meguro (Director, ICUS) Dr. M. Numada (Research Associate, ICUS), and Mr. F. Ito (Senior Researcher, Infrastructure Development Institute, Japan) visited China from April 14th to 23rd, 2010, for joint research on the application of PP-band method to masonry structures in China.

We first exchanged views on how to use the PP-band technology locally in China with the China Development Research Foundation and China Earthquake Administration, then conducted a site survey on masonry houses in the suburban area of Lhasa City (altitude: roughly 4,700 meters). Finally, we gave a lecture and demonstrated the installation of PP-band method to Chinese engineers using 1/3-scale models.

The PP-band retrofitting method was conceived and developed so that it can be implemented even by low-income people in developing countries using strong and durable but very cheap polypropylene bands as a new, simple, and efficient seismic retrofitting technique. Mesh made of PP-bands, as a seismic reinforcement material, can be easily and inexpensively fabricated at the site with locally-available materials.

During the discussion with the China Development Research Foundation and China Earthquake Administration, the research background and purpose of the PP-band technology was explained by Prof. Meguro, including experimental results carried out in Japan. Afterwards, there were questions about applicability to Chinese structures, and the discussion became a positive skills session.

In the site survey of Lhasa City, characteristics such as strong ultraviolet rays, large temperature fluctuations, and strong wind exposure were all identified. The house roofs in this region are therefore heavy with wood and clay layers and are neither connected nor fixed to the walls. This may contribute to collapse during an earthquake.

Eleven Chinese engineers from Lhasa City came to the China Earthquake Administration in Harbin City to participate in practicing the PP-band retrofitting method. The necessary supplies and tools, such as PP-band, welding machine for making PP-band mesh, drills for creating holes in the walls of existing houses, and so forth were prepared locally. The practice itself consisted of making PP-band mesh, wrapping, and installing the mesh to the masonry model under the guidance of the Japanese members. During this collaborative activity, the effects of PP-band technology, practical points for its installation at the actual site, and more were covered, with particularly positive discussion on the method for fixing the roof and the PP-band mesh due to the high importance of roof fixation for earthquake resistance.

The Yushu Earthquake in China occurred on April 14th, just after we arrived in China. More than 90% of the buildings in the affected area were heavily damaged, and the number of victims reached as high as 2,000 people. The importance of this joint research can be recognized in light of this devastating disaster.

Discussion on PP-band technology

Demonstration of PP-band technology in Harbin City

Site survey in Lhasa City

(by M. Numada)

Institute of Industrial Science Open House 2010

A busy day at ICUS during the IIS Open House 2010

The Institute of Industrial Science (IIS) organized and held the IIS Open House on June 3rd, 4th, and 5th. This event provides an opportunity for people of all ages and professions to explore the IIS campus and learn about the research activities being conducted at IIS, the University of Tokyo. ICUS has been participating in the Open House since its inception in 2001, taking the opportunity to educate people about ICUS activities on the different aspects of urban safety issues.

This year, over 300 people visited ICUS, with nearly 200 of them participating in the ICUS quiz and receiving ICUS goods such as towels, key chains, and more. Research works on display included disaster simulation and education, seismic retrofitting and evaluation, remote sensing and geospatial technologies, maintenance and deterioration of infrastructure, traffic engineering and urban planning, with increasing consideration of environmental disaster such as climate change. BNUS and RNUS activities over the past year were also summarized.

(by M. Henry)

18th ICUS Open Lecture held at IIS

The 18th ICUS Open Lecture was jointly organized with the Advanced Mobility Research Center (ITS Center) and held at IIS on April 27th, 2010, with approximately 110 participants. Four lectures were given on the theme "Traffic Safety and ITS," focusing on how traffic safety can be improved and how ITS (Intelligent Transport Systems) can contribute towards such improvement.

Prof. M. Kuwahara (ITS center, IIS, and Tohoku University) introduced ITS Center's research activities regarding traffic safety. Mr. Y. Nishida of the National Research Institute of Police Science discussed the expectations for ITS based on traffic accident analysis. Prof. H. Akahane of the Chiba Institute of Technology presented how ITS can be used to enhance people's awareness of traffic safety, followed by Mr. K. Yamada of Nissan Motor Co., Ltd., who presented state-of-the-art technologies to prevent traffic accidents. Finally, after these presentations, a panel discussion was held and the potential for ITS to enhance traffic safety was explored.

(by S. Tanaka)

Prof. M. Kuwahara

Mr. Y. Nishida

Prof. H. Akahane

Mr. K. Yamada

BNUS coverage of urban disasters in Dhaka, Bangladesh

Over the last three months there have been several urban disasters in Bangladesh. The first was the collapse of a five-story building in Dhaka's Begunbari area on June 2nd, which killed at least 25 people, including 11 women and children. Originally, the owner had permission to construct a three story structure, but it was later changed to five stories. Rescue work was difficult due to narrow access routes, gas leaks, and damaged electricity lines. Most residents of the collapsed structure escaped harm whereas people living in the surrounding tin houses were trapped under the rubble. Similar incidents have occurred before in Dhaka, particularly in older areas, so the developmental authority is taking measures to inventory buildings with vulnerable foundations and structures and buildings without proper authorization and arrange their demolition or reinforcement.

Aftermath of building collapse

Five buildings burning in Nimtoli in Old Dhaka

On June 3rd, a large fire broke out in the densely-populated Nimtoli area in Dhaka. At least 117 people were killed and hundreds injured. Investigations found that the fire originated at an oil stove and spread to nearby chemical warehouses. Such factories for chemicals, plastics, rubber, etc. are commonly located on the lower levels of residential buildings. In addition, houses in Dhaka are not equipped with fire-fighting equipment such as extinguishers, hose pipes, and so forth, nor do they have sufficient space for emergency exits in the stairwells. This incident greatly exposes the vulnerability to fire in densely-populated areas due to unplanned urbanization, narrow roadways, and lack of awareness. Proper land-use patterns need to be established following development plans and strict building enforcement in order to prevent such events from occurring in the future. Currently, BNUS is conducting a field survey to evaluate current fire-fighting systems and develop an evacuation plan for residents of Dhaka.

(by M.A. Ansary, BNUS)

Commendation for Science and Technology to Prof. Meguro

Prof. Kimiro Meguro, Director of ICUS, and Dr. Fumiaki Uehan, Railway Technical Research Institute, received the Commendation for Science and Technology from the Minister of Education, Culture, Sports, Science, and Technology, Prizes for Science and Technology, Development category, 2010. Their award-winning research was on the development of a method to remotely measure microtremors for vibration diagnosis of railway structural systems using Laser Doppler Velocimeter (LDV) which can accurately estimate the dynamic characteristics of an existing reinforced-concrete rigid-frame structure. We congratulate Prof. Meguro on this prestigious award.

(by H. Sawada)

Prof. Meguro and Dr. Uehan after receiving their award

RNUS seminar on fiber reinforced concrete

Seminar participants

On June 30th, RNUS (Regional Network Office for Urban Safety) organized a seminar on "Fiber Reinforced Cement Composites (FRCC) and Concrete (FRC)" at Milton Bender Auditorium, Asian Institute of Technology (AIT), Thailand.

Two speakers delivered presentations. First, Dr. Praveen Chompreda, Program Director of the Department of Civil Engineering, Mahidol University, gave a lecture on "Strength and shrinkage properties of fiber reinforced cement composite." Following that, Dr. Withit Pansuk, Lecturer in the Department of Civil Engineering, Chulalongkorn University, delivered a presentation on "Shear capacity of ultra high strength fiber reinforced concrete beams."

About 25 participants joined the seminar, including undergraduate and graduate students from the structural engineering field at AIT and the Department of Civil Engineering and Technology at Sirindhorn International Institute of Technology (SIIT), Thammasat University, as well as researchers from ready-mixed concrete companies. There were many fruitful discussions regarding the challenges and future of FRCC and FRC, and the seminar was considered successful.

(by A. Kodaka)

Seminar with Nanyang Technological University at ICUS

On April 26th, 2010, a delegation of five representatives from Nanyang Technological University (NTU), Singapore, visited ICUS and IIS. The delegation, led by Prof. T.C. Pan, attended a seminar at ICUS on topics related to disaster and disaster management.

During the morning, Prof. T. Oki, a former member of ICUS, introduced research works related to hydrological processes, modeling, and flooding. After lunch, both ICUS and NTU members visited Prof. T. Yashiro, Director General of IIS, for the renewal of a joint research protocol between the College of Engineering, NTU, and IIS. In the afternoon, Prof. K. Meguro and Prof. H. Sawada presented ICUS research works covering remote sensing technologies and GIS for urban disaster mitigation, integrated seismic and tsunami hazard assessment, evacuation simulation, earthquake loss modeling, vulnerability and strengthening, and more.

From this exchange of knowledge, it is hoped that ICUS can support disaster mitigation and management in Singapore and Asia through cooperation and collaboration with colleagues at NTU.

(by M. Henry)

Discussion between NTU delegation and ICUS members

ICUS Activities

- Prof. K. Meguro and Dr. M. Numada traveled to Lhasa and Harbin cities in China from April 14^{th} to 23^{rd} for site survey and teaching of the PP-band retrofitting method.
- Prof. H. Sawada and Dr. T. Endo visited Brazil from May 19^{th} to May 26^{th} to oversee the start of the project on carbon dynamics of the Amazonian forest. Dr. Endo remained in Brazil until June 2^{nd} to conduct equipment training.
- Prof. R. Kuwano attended the 7^{th} International Symposium on Physical Modeling in Geotechnics in Zurich, Switzerland, from June 26^{th} to July 3^{rd}.
- Dr. A. Kawasaki traveled to AIT in Bangkok, Thailand, from May 16^{th} to 23^{rd} for overseeing RNUS activities.

Awards

- *Prof. R. Kuwano received the Best Paper Award from the Japanese Geotechnical Society for her paper entitled "Aging effects on small strain shear moduli and liquefaction properties of in-situ frozen and reconstituted sandy soils."*

New ICUS members

Prof. T. Kato

Dr. A. Kawasaki

Dr. S. Kondo

Dr. M. Henry

ICUS would like to welcome four new additions to our center as of April 1^{st}, 2010. Associate Professor Takaaki Kato joined the Urban Safety and Disaster Mitigation Division, and Dr. Akiyuki Kawasaki, Dr. Shinya Kondo, and Dr. Michael Henry joined as ICUS project staff.

Prof. T. Kato moved to ICUS from the Department of Urban Engineering. His research field is "urban planning and engineering for social safety systems," focusing on the safety of cities and regions considering spatial structure and composition of urban areas and utilizing social and technical systems.

Dr. A. Kawasaki joined ICUS after serving as a JSPS research fellow in Meguro Laboratory. He received his Doctor of Engineering from Yokohama National University, and has also conducted research at United Nations University and Harvard University. He is highly experienced in utilizing GIS for multi-disciplinary research covering both disaster and environmental management.

Dr. S. Kondo came to ICUS from the Disaster Reduction and Human Renovation Institute in Kobe, Japan, where he was a research scientist. He earned his Ph.D. in Meguro Laboratory in ICUS while researching a new-style disaster management manual. His research topics also include disaster information management and simulation and support programs for areas isolated after disasters.

Dr. M. Henry entered ICUS after graduating from Kato Yoshitaka Laboratory in ICUS. His Ph.D. research proposed a framework for developing and assessing sustainable concrete materials considering social perspectives. During that study, he focused on the Japanese concrete industry, but will continue his research by extending the scope to include other Asian countries.

Please see either this volume or the next volume of the ICUS Newsletter for more detailed information about the new members' research topics.

(by K. Meguro)

Editor's Note

During the period of this issue, the FIFA World Cup was held in South Africa, and a lot of people spent many sleepless nights cheering for their favorite teams. Japan got through the group stage and proceeded to the elimination round, which was a very exciting event for Japanese people – particularly because there had been very little expectation before the games began. From this, we could learn a couple of things. One is of course that believing in one's own way regardless of others' evaluation is important. Another is that people's attitudes and behaviors may change very easily depending on the situation.

In the main article, Mr. Nishida showed the importance of considering human factors leading to traffic accidents based on analyses from practice. The panelists, including Mr. Nishida, in the ICUS Open lecture held in April also discussed the possibility of ITS to prevent accidents, but it is subject to how people use ITS. As our society is an aggregation of people's activities, we always have to keep in mind that any technologies or countermeasures to improve urban safety must be developed considering the existence of people – that is, how people are involved in the system, how they think of it, and how they use it.

(by S. Tanaka)

Announcement of Joint Symposium on Geospatial Technologies and 4th IIS Alumni Party

We would like to announce that RNUS (Regional Network for Urban Safety) will organize the 4th IIS Alumni Party in downtown Bangkok on Saturday, November 27th, following a joint symposium on the "Forefront and challenges of geospatial technologies for environmental and disaster management in Southeast Asia". IIS alumni includes not only graduates but also those who had any relationship with IIS (as staff, post-doc, etc). Alumni from the Department of Civil Engineering, RCAST, Hongo campus and other Todai alumni are also warmly welcomed. Some IIS professors will join it and the party is free of charge. For more detail, please check the RNUS website.
<http://www.set.ait.ac.th/rnus/rnusnew/>.

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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RESTRUCTURING OF URBAN AREAS AND MODERNIZATION OF RURAL AREAS DURING POST-EARTHQUAKE RECONSTRUCTION

By
Takaaki Kato[1]

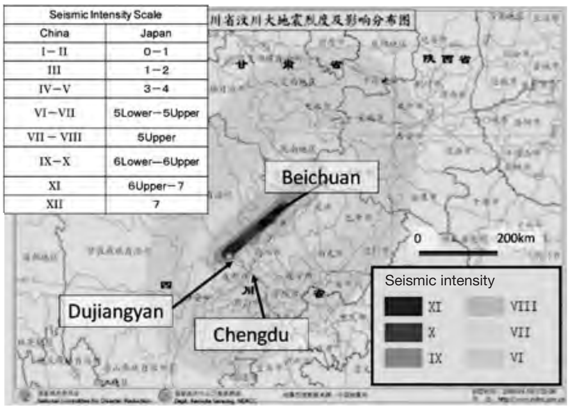
INTRODUCTION

The Wenchuan earthquake, which occurred on May 12, 2008 in Suchuan, China, was one of the largest disasters in the past hundred years. It measured 7.9 on the moment-magnitude scale (USGS) and is the largest class of inland earthquake. The epicenter was located in a mountain-ringed region and the focal area of the earthquake spanned three hundred kilometers in the north-south direction; therefore, a huge number of villages suffered from devastating damage, but urban areas (except Dujiangyan City and Qushan Town in Beichuan) avoided serious damage. The fatalities, however, were reported to be more than 90,000 and the number of collapsed buildings approximately 8 million. If the earthquake had hit at Chengdu City – the closest mega-city to the epicenter with a population of more than 10 million – the disaster could have been the worst in the world.

Presently, more than two years have passed since the earthquake occurred. During this period, the post-disaster reconstruction has been progressing at a steady but remarkable speed.

Post-disaster urban reconstruction and rehabilitation have become important themes in the academic field of urban planning as a shift towards disaster preparedness after the Great Hanshin-Awaji earthquake disaster. The situation of post-disaster urban reconstruction

Post-disaster reconstruction plans shown at reconstruction exhibition in Chengdu City in October 2009



Location of Wenchuan Earthquake affected area and distribution of seismic intensity (http://www.ndrcc.gov.cn)

varies depending on specific factors of the affected areas such as urban planning institution, government system, and historical factors such as economic development. However, it is important to share the experiences and learn the lessons beyond these differences, as this can contribute to fruitful ideas and concepts for forth-coming post-disaster urban reconstruction in Japan.

This article reports the current situation of urban reconstruction, and introduces the results of investigations on the reconstruction plan of rural areas and Dujiangyan City.

PRESENT SITUATION OF AREA AFFECTED BY WENCHUAN EQ

The first step for urban reconstruction was early and dynamic. The reconstruction plan envisioned a rosy future, as demonstrated at an exhibition for urban reconstruction held at Chengdu City five months after the earthquake. Presently, this dream is being put into reality. Post-earthquake reconstruction has been implemented at an amazingly high pace, as the national government declared that reconstruction should be completed within three years, and it was finished a year ahead of schedule. Sixty kilometers of high-speed railway connecting Chengdu and Dujiangyan was also completed and started commercial service in May 2010.

Post-disaster reconstruction has two meanings – relief of the affected people and development for the coming future – and the balance between these two factors is said to be an important key for success in post-disaster reconstruction. Considering the images of reconstruction it would appear that Dujiangyan focused more on the latter. However, remarkable relief policies such as house-space exchange systems for the affected households were implemented in the background of the high-speed economic period, so we can understand that the government intended to balance these two factors.

The earthquake mainly hit the rural areas, except for Dujiangyan City, which has world heritage sites, and Qushan Town, which is the central town in Beichuan. During the planning process, housing supply for the affected households was given high priority. New houses were supplied by “new farm village construction” in rural areas and development of new urban areas in the cities. Urban redevelopment of the inner city was planned after settling.

FARM RECONSTRUCTION IN RURAL AREAS

Various kinds of “new village constructions” were implemented with the objectives of modernizing life and industrialization in China during the early 2000s. Sichuan has a large amount of farmers, so it experienced many trial models of “new village construction.” The reconstruction in rural areas was based on the new village construction plans which were already in place.

The reconstruction was conducted at a high pace and large scale beyond what is possible in Japan. Planning and design drawings were given to thousands of villages in the affected areas and each village was reconstructed just as shown in the drawings. By March 2010, new life had already begun in many villages and, at the present, the situation in rural areas appears like an exhibition for new village models.

RECONSTRUCTION IN URBAN AREAS

Dujiangyan City developed new residential areas and restructured inner city areas, and residential apartments for affected households were nearly completed in May 2010. These houses, however, are not public housing for affected people but for general sale, following a Chinese-specific characteristic policy. The house-space exchange system was a new institution published by the government one month after the earthquake. All households which lost houses were to be given a new house of 70 square meters and, in exchange, they would give up their rights to their original house and land. Most people chose this institution and received new houses, except for a few people who rebuilt on the original site.

This institution aims to quickly handle disposition rights and accelerate housing acquisition for affected households, while also moving those households from the inner city to the suburbs. This strategy thus made redevelopment of the inner city easier and, in fact, the inner city redevelopment plan was published as soon as the affected households signed the contract to relocate. Currently, the inner city redevelopment is being fully carried out and, next year, Dujiangyan City will present a new, redeveloped face to the world.

Qushan Town in Beichuan, which was devastated by huge landslides, was moved to a flat site more than 20 kilometers away from its original location. The new town has been constructed but the original town will be preserved without change as a "museum of earthquake disaster," and will serve as an important tourism resource for the region.

CONCLUSION

Dynamic reconstruction has been performed in area affected by the Wenchuan earthquake. Perhaps it can be said that the disaster accelerated the modernization of the rural area and redevelopment of urban areas. This situation is in contrast to recent cases in Japan, where the focus is on the protection of individual lives and there is little consideration of future reconstruction of cities or regions. There is a large difference in conditions, as Japan is facing low economic growth and a decreasing population, whereas China is in a high economic growth period. Clearly, many more lessons may be learned from these reconstruction activities.

[1]*Associate Professor, ICUS, IIS, The University of Tokyo*

A typical reconstruction model for "new village construction" in Pengzhou (top) and Dujiangyan (bottom), March 2010

Original Qushan Town in Beichuan

Flooding of the Indus River in Pakistan

The Indus River is a major and historical river which runs through Pakistan, starting from the northern areas of Pakistan adjacent to China and India. Its main source is from the melting of snow and monsoon rains. In the hilly area where the Indus River starts, the temperature is below zero degrees most of the winter, and heavy snowfall occurs in these areas. In summer, this snow melts and, at the same time, monsoon rains occur. The melting of snow coupled with heavy rains produces severe flooding. The Indus River passes through the whole length of Pakistan and is joined by many other tributary rivers, such as the Kabul River, Jhelum River, Chenab River, Ravi River, and Sutlej River, etc. Ultimately, the Indus River discharges into the Arabian Sea at Tatta near Karachi.

In 2010, the melt was higher than the average due to wildfires in Russia and higher-than-average temperatures; at the same time, monsoons produced a heavier rainfall than the average yearly precipitation value, and NASA and the Pakistan Meteorological Department cautioned that the risk of flooding was high from July to September 2010.

This water caused heavy flooding in northern Pakistan. Since these areas are hilly, the flood area was small but the water velocity was high, which led to the collapse of waterway structures such as bridges. Further downstream more water entered the Indus River from the tributaries and this accumulated water flooded the area between the Jhelum and the Indus Rivers. Discharge from other rivers into the Indus combined at Panjnad in Punjab and submerged the city of Sukkur. Areas along the 2,200 kilometer-length of the Indus were severely affected by the flood and most infrastructure such as bridges, roads, villages and recreational places on river banks were completely flushed.

Many reasons for this flooding have been pointed out:

- *In 2010, the monsoon rains were above average compared to previous years*
- *The melting of snow was above average due to wildfires in Russia*
- *Lack of water storage reservoirs*
- *Global warming*

The disaster caused by this flood was the severest in the history of Pakistan. Damage statistics include:

- *Flooding submerged 17 million acres of land, caused scarcity of food in the near future.*
- *Communications facilities were damaged due to flooding, and the damage estimated was 131 million US$.*
- *In most flood areas, many residential structures were damaged; in some areas, whole villages were destroyed.*
- *1,961 deaths and 2,995 injuries were reported; overall, more than 20 million people were affected.*

Areas in Pakistan affected by flooding of the Indus River (source: United Nations Office for the Coordination of Humanitarian Affairs)

(by Mr. S. Nazir, former Meguro Lab student)

2010 Darfield (Canterbury) Earthquake – initial report

The magnitude 7.1 Darfield (Canterbury) earthquake occurred at 4:35am 4 September 2010 (NZST) on the previously unknown Greendale fault. The surface rupture was a dextral strike-slip extending about 30km. The maximum surface ground movement was approximately 4.6m and the rupture zone was 30 to 300 m along the fault. The focus was approximately 11km deep and was located about 8km southeast of Darfield and about 37km west of the centre of New Zealand's second largest city, Christchurch. This area is considered to be in a zone of moderate seismicity. In the weeks subsequent to the main shock, a number of aftershocks rocked the region and caused strong localized shaking and further damage and liquefaction.

Possibly one of the most significant effects of the earthquake was the extensive damage to lifelines and residential houses resulting from liquefaction and lateral spreading. This occurred primarily in areas close to major streams, rivers and wetlands throughout Christchurch as well as Kaiapoi, approximately 19km north of Christchurch. Ejection of silt causing a blanket over 200mm thick occurred in many regions. Lateral spreading of up to 3m caused large cracks and damaged houses severely. Houses settled unevenly, and many kilometres of water pipe and wastewater pipe were damaged. Empty sumps floated and roads had up to 0.5m vertical offsets.

Older residential houses suffered collapse of brick chimneys. Older houses often had vertical and horizontal cracks around the interior gypsum board. Many houses on good soil, especially those with lighter roofs built on a slab-on-grade foundation suffered no damage at all. A number of older unretrofitted unreinforced masonry (URM) structures in the central business district partially collapsed, and many unreinforced brick parapets collapsed onto the footpath below.

33 cm vertical offset observed at St. Paul's Church, Dallington (Cubrinovski et al.)

Damage to ceilings and contents (photo: Giacomo Paganotti)

Newer multi-storey structures generally seemed to behave well. One structure made from concrete indicated beam plastic hinge rotations; in others, damage was evident in gravity columns or at the ends of simply supported precast beams. Most structures showed no distress, and the base-isolated hospital performed well.

Non-structural damage caused the majority of business interruption in both older and newer structures. This resulted from ceiling tiles falling, cracking in internal linings and contents falling to the ground. The University of Canterbury was closed for 2 weeks while ceiling tiles were replaced over some lecture theatres. Damage to water supply systems and leaked water from broken pipes led to falling wall tiles. Damage to tiles and carpet occurred at internal building separation joints.

While the Darfield Earthquake was similar in magnitude to the 2010 Mw 7.0 Haiti earthquake, there was no loss of life and only 2 injuries. One of the major reasons for this difference is the time of day the earthquake occurred. Nevertheless, it shows that a system of building construction controls, while never perfectly followed, can be very effective in limiting life and other losses.

The initial estimate of losses is NZ $4 billion. All residential houses are insured by the NZ Earthquake Commission to NZ $100,000 before private insurance takes over. These insurances are bringing a lot of money into the region and mitigate long term losses.

Acknowledgement

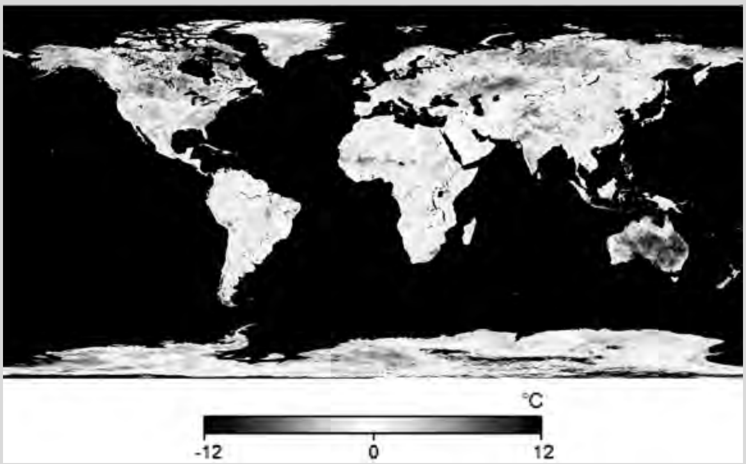
This report, was made possible by information provided by many researchers from around the world. Much of this is recorded in the Bulletin of the New Zealand Society for Earthquake Engineering, 43(4), Dec. 2010.

(by Prof. G. MacRae,
University of Canterbury)

Project on Amazonian Carbon Dynamics (Part II)

Hundreds of forest fires were reported this summer in Russia. According to the Russian News and Information Agency, RIA Novosti (http://en.rian.ru), the fires killed over 50 people, burned out more than 2,000 homes, making thousands homeless, and affected 11 million hectares of crops. Pilots from neighboring countries, such as Ukraine, Belarus, Kazakhstan, Azerbaijan, Italy, France, and Turkey fought to smother the wildfires, while many other countries contributed rescue works. Russian Prime Minister Vladimir Putin said on 15 September, 2010, "Next year we will allocate 2.5 billion rubles (US$ 81 million) for forest rehabilitation and 5 billion rubles (US$ 161.5 million) for preventing wildfires." In line with Russian law, the Russian Emergencies Ministry is in charge of extinguishing fires only in residential areas, not in forests, so new amendments are necessary. In the end of September, satellite images started to show us a sequence of forest fires in east Siberia. The smokes from east Siberia sometimes cover northern Japan and we cannot stop watching the wildfires in Russia.

(by H. Sawada)



Land surface temperature anomaly in September 2010 (NASA)

RC67 Committee Activities

Recently in Japan, forest management and education using actual forests have been implemented as CSR (Corporate Social Responsibility) activities by many private companies. However, no one is sure whether these activities are environmentally-friendly or not, so from April 2009 ICUS started RC67 (Research Committee 67) with several private companies to evaluate the CSR activities currently being implemented.

Lecture on CSR activities in the forest

Forest visit

Over the last year, we have investigated more than 200 CSR reports in all types of industries and then reported on the re-forestation or educational activities using actual forests as CSR activities. These reports are available from ICUS in Japanese.

This year, we are investigating how CSR activities are implemented. As part of our investigation, we visited the forest owned by Mitsubishi Paper Mills Ltd. on August 3, 2010. Implemented CSR activities included forest education on the industrial method for producing paper and forest management methods such as thinning and re-forestation, and the importance of forest conservation. These activities are implemented for both the company employees and the community.

The purpose of CSR activity is to develop a younger generation who doesn't purchase products from illegal logging and who thinks sustainable logging and utilization of trees is importance. When the younger generation with these values grows up, it may help to reduce illegal logging – or so we hope.

(by T. Endo)

Development of a new-style simulation exercise

Disaster Reduction and Human Renovation Institute (DRI), established in Kobe City after the Kobe earthquake disaster, developed a Simulation Exercise for emergency response headquarters, Management by Objectives (SEMO), based on the result of several years of experience. The purpose of SEMO is to perform and learn how to manage an emergency response headquarters based on management by objectives.

Management by objectives is one type of management method. DRI researchers adapted this method to the style of disaster response as an organization based on past disaster experiences. Management by objectives consists of three principles: “sharing the common operational picture with all concerned,” “developing action plan with strong objectives,” and “conducting strategic public relations.”

The basic model of SEMO consists of five stages: “orientation,” “team meeting,” “exercise,” “simulated press conference,” and “evaluation.” To design a real exercise, the basic model is customized based on the constrained conditions, the object of the exercise, and time for exercise. “Exercise” means the field participants practice management of emergency headquarters according to management by objectives.

The training course based on SEMO was conducted at DRI. The main target of this course was the disaster response officer of local government. Participants repeated the sequence “team meeting,” “exercise,” “simulated press conference,” and “evaluation” twice after the first orientation. In the training course, participants learned the purpose of the course and rules of the exercise with concentration through orientation and team meeting. In the exercise, participants responded according to management by objectives based on this sequence. For example, participants shared common operational pictures such as writing a situation on a map. They organized action policies according to problems in the affected area for making action plan with objectives, and they conducted strategic public relations using maps with journalists. If some participants had not yet understood the purpose of this training course, then the exercise designers coached them. During the simulated press conference, participants announced their own action plan with objectives one week after the earthquake occurred to the journalists. After the simulated press conference, each group looked back at their response and made a presentation summarizing the content of their self-view according to the three principles of management by objectives. Finally, the roles of journalist and designers of exercise evaluated and commented on the response and presentation of the participants.

Through this training course, almost all participants answered that they benefited greatly from this training course. Some participants replied that they understood the importance of management by objectives and would try to apply SEMO to their disaster training course of the local government.

(by S. Kondo)

Training course curriculum

Sharing common operational picture

Strategic public relations

BNUS activities

Seminar on "Urban building fire disaster mitigation focusing on Bangladesh building fire issues"

Participants of fire disaster mitigation seminar

On August 17, 2010, BNUS and Bangladesh Fire Service and Civil Defense members organized a seminar on "Urban building fire disaster mitigation focusing on Bangladesh building fire issues." It was held at BUET, and Prof. M.A. Ansary of BNUS moderated the seminar. In this seminar, renowned fire expert Prof. Shinichi Sugahara of Tokyo University of Science and his visiting team presented their experiences on fire hazard.

An official of the Bangladesh Fire Service and Civil Defense also gave a lecture on "Practical observation of Bashundhara City fire to Nimtoli fire." In his lecture, he presented very practical facts and issues behind the fire hazard in Bangladesh. He also gave emphasis on the additional rules and regulations which should be incorporated in the upcoming National Building Code.

Dr. Sanjib Barua showed the "The academic observation of Bashundhara City fire to Nimtoli fire in light with Bangladesh Building Design Code," followed by Prof. Sugahara who delivered a lecture on "The simple and affordable fire protection for buildings in Bangladesh referring to experience in Japan." Finally, Dr. Hideki Yoshioka, research engineer of the Building Research Institute of Japan, presented a lecture on "The academic evaluation of Bashundhara City fire with respect to Japan building fire technology."

Evaluation of fire fighting system at high-rise buildings in Dhaka

Recently some serious fire incidents have occurred and fire has affected many lives and properties. The main causes behind the large losses were inadequate firefighting equipment in buildings and lack of awareness about fire safety. These stimulate the researchers of BNUS to conduct detailed studies on fire fighting systems of high-rise buildings in Dhaka City. To get an idea about the fire fighting system in Dhaka, 2.5% of 2,150 high-rise buildings have been surveyed (with the assistance of the Bangladesh Fire Service and Civil Defense) from 9 zones (Dhaka City was divided into 12 zones total). Most of the survey buildings are taller than 8 stories, or high-rise.

In this study, researchers examined the existing condition of fire fighting systems including fire protection and detection systems, precautionary arrangement in and around high-rise buildings, occupants' awareness level and evacuation plan during fire break out and assessment of these systems with the Bangladesh National Building Code (BNBC) rules in terms of Total Score (TS).

(by M.A. Ansary, BNUS)

Educational institution with inadequate fire fighting system

Blocked emergency exit of commercial building

RNUS – ICUS's Regional Network Office for Urban Safety in Bangkok, Thailand

About six months have passed since I became Coordinator of the Regional Network Office for Urban Safety (RNUS), ICUS's regional research body in Bangkok, Thailand. In this article, I would like to describe my role and activities in Thailand as RNUS coordinator.

RNUS was founded in 2002 as a collaborative center jointly operated by the School of Engineering and Technology (SET), Asian Institute of Technology (AIT), and ICUS. RNUS's missions are: establishing regional research network for sharing information and technology in the field of urban safety engineering; conducting collaborative research with various research institutes, governmental and international organizations in Asia; and developing and disseminating innovative urban safety technology by considering sustainability and unique regional characteristics.

RNUS is now operated by three staff: a coordinator (myself) and a secretary, Ms. Aphisorn Suwannasuk, with supervision by Dr. Pennung Warnitchai, Associate Professor of SET, AIT. As coordinator, I have three main roles as follows.

First: enhancing RNUS activities by organizing seminars and events inside AIT campus and in Bangkok. For example, this year at AIT we organized the RNUS seminar on Fiber Reinforced Concrete in June, and the 3rd International Joint Student Seminar on Civil Infrastructures in July. In November we will organize a Symposium on Geospatial Technologies for Disaster and Environmental Management, and the 4th IIS Thailand Alumni party in downtown Bangkok.

Second: providing regular lectures at SET, AIT as a visiting faculty. I will teach a course on "EIA (environmental impact assessment) and GIS (geographic information systems) for water resource management" at the Water Engineering and Management (WEM) field of study at SET, AIT, in the semester starting from 2011 January. In addition, I have been supervising three Master course students from Afghanistan, Myanmar, and Pakistan at AIT's WEM and Disaster Preparedness and Mitigation Management program.

Third: conducting my own research on sustainable watershed management in the Mekong River basin. Luckily, AIT is the best location for conducting my research because of the convenient access to the Mekong region.

For further details on RNUS activities, please visit our recently-renewed website. Also, you are welcome to stop by the RNUS office when you have the opportunity to come to Bangkok.

(by A. Kawasaki)

RNUS staff picture, from left to right: Ms. Aphisorn, Dr. Pennung, Dr. Kawasaki

RNUS website: <http://www.set.ait.ac.th/rnus/>

3rd Joint Student Seminar on Civil Infrastructures at AIT

The 3rd Joint Student Seminar on Civil Infrastructures was held at the Asian Institute of Technology (AIT) in Bangkok, Thailand, on July 29 and 30.

The participants joined two main activities. First, the presentation session was held at AIT on July 29. In this session, three professors gave us lectures and then 16 students presented their research works in various fields such as transportation, geotechnical, concrete structure, disaster mitigation, and applied remote sensing engineering.

The next day, a field trip to Pattaya was organized by RNUS. We visited the Petroleum Authority of Thailand (PTT), Sea Turtle Conservation Center, Thai Island and Natural History Museum and Pattaya Floating Market.

This seminar provided us with many great experiences. First, the presentation session was very exciting and we could enjoy lots of good discussion on our research topics and exchange communication with different students and researchers. Second, the field tour was an unforgettable trip. We had many new experiences with the other participants. In particular, a lecture by Mr. Chatchai Subin, staff at PTT, gave us a good understanding of the history of gas transmission and its network in Thailand. Finally, the best part of this seminar was making many new friends with the civil infrastructure students from Thailand, Korea, and Bangladesh. We really appreciate the work of the organizers, Dr. Tanaka, Dr. Kawasaki, Dr. Park, and Ms. Aphisorn in AIT, and also the participation of all members who joined the seminar. We hope next year's seminar will also be very good.

(by H. Kishi, PhD student, Sawada-Takeuchi laboratory)

Group photo of seminar participants

Severe heat wave in Japan

Japan experienced an extremely hot summer in 2010. From June to September, the monthly mean temperatures were higher than normal (based on 1971-2000 average). The difference in Japan between the monthly mean temperatures and normal was higher than the global difference. In particular, the monthly mean temperature in August was the highest recorded in 113 years, since statistics began being taken 1898.

In Tokyo in August, the monthly mean temperature was 29.6°C (+2.9°C above normal); 30 days with maximum temperatures over 30°C (+8.6 days above normal); 6 days with maximum temperatures over 35°C (+4.8 days above normal); and there were 30 days with minimum temperature higher than 25°C.

Under this severe heat, many people suffered from heat stroke. In the four months from June to September, 56,119 people were taken to hospital by ambulance for heat stroke in Japan, and 171 people died and 1,848 people were in serious condition. Senior citizens over the age of 65 made up 46.3% of those hospital visitors.

Overall, residents in Japan were unable to sleep well at night and had to endure the heavy heat during the day.

(by S. Kondo)

RC62 Committee Activities

ICUS Research Committee on the performance degradation due to ageing infrastructure (RC62) has conducted quantitative evaluation of the performance of concrete and soil structures towards evaluating the performance of an entire structure from the ground up. This committee is targeted at real structures and, for infrastructure facilities, there are many different types of structures. This particular study looked at a type of underground reinforced concrete box culvert structure. In order to determine the condition of the structure, the committee members visited an actual structure on-site and conducted a general inspection to check the deformation and cracking and diagnose repair and reinforcement based on the degree of deterioration. However, at this time there is no evaluation method for change of performance due to ground factors, so in the future the committee needs to organize the information necessary for this evaluation using inspection results of actual structures.

(by K. Hayakawa, Tokyu Construction Corporation)

View inside box culvert structure

Observed deterioration inside box culvert structure

ICUS Activities

- *Prof. K. Meguro traveled to Jakarta, Indonesia, from Sept. 25 to Oct. 4 for a survey on the development of PP-band method.*
- *Dr. S. Tanaka traveled to Lisbon, Portugal, from July 10 to 15 for the World Conference on Transportation Research 2010. He then also visited Bangkok, Thailand, for the Joint Student Seminar on Civil Infrastructure.*
- *Dr. T. Kato traveled to Suchuan, China, for an investigation on the post-disaster reconstruction after the 2008 Wenchuan Earthquake from Aug. 13 to 18.*

Awards

- Dr. T. Endo received the Best Paper Award at the International Society for Photogrammetry and Remote Sensing (ISPRS) Commission VIII on Aug. 12.
- Mr. K. Makinodan, master course student in Ohara Laboratory, received the Best Presentation Award from the Japan Society for Natural Disaster Science on Sept. 17.
- Mr. K. Hayakawa, researcher in Y. Kato Laboratory, received the Excellent Presentation Prize at the Japan Concrete Institute Annual Conference on July 8.
- Dr. M. Henry, ICUS project researcher, Mr. K. Makinodan, master student in Ohara Laboratory, and Mr. T. Takaishi, master student in Meguro Laboratory, all received the Excellent Presentation Prize at the Japan Society of Civil Engineers Annual Conference from Sept. 1-3.

Editor's Note

During the period covered by this volume, many disasters and accidents happened in the world. Some of them were reported in our newsletter, such as flooding of the Indus River in Pakistan, the Canterbury Earthquake, forest fires in Russia, and a severe heat wave in Japan.

The most notable accident for me, however, was the Copiapó mining accident. On August 5, 2010, a cave-in occurred at the San José copper-gold mine in the Atacama Desert near Copiapó, Chile. The accident left 33 men trapped 700 meters below ground. All trapped men were rescued on October 13, 2010, after 69 days of rescue works. We could see many miracles such as none of the men died – even though it was such a large-scale accident – and the period to rescue was far shorter than expected. We could also see many advanced technologies for supporting their life underground and for the rescue works, and it taught us the importance of technological development. However, "hope" is an extremely important factor for surviving under such severe conditions (Prof. Meguro wrote about "hope," or "nozomi" in Japanese, in ICUS Newsletter Vol. 9 No. 4).

In the main article of this newsletter, Prof. Takaaki Kato of ICUS reported on reconstruction of urban and rural after the 2008 Wenchuan Earthquake. A good reconstruction plan helps to keep the victims' "hope" alive for a long time.

(by Y.Kato)

Announcement of USMCA 2011 (Chiangmai, Thailand)

We would like to announce that the 10th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia (USMCA2011) will be held in Chiangmai, Thailand on October 12-14, 2011. Further information will be available on the ICUS and RNUS websites as details of the symposium are decided.

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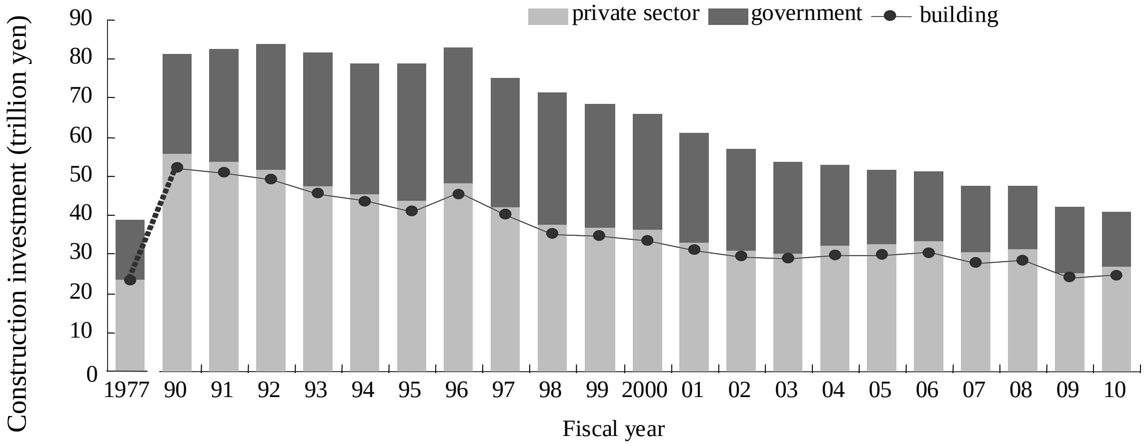
THE ROLE OF THE CONSTRUCTION INDUSTRY IN THE 21ST CENTURY CONSIDERING GLOBAL ENVIRONMENTAL ISSUES

By
Koji Sakai[1]

INTRODUCTION

The world population has increased 34 times its size since the Roman period and eight times its size since the industrial revolution. The supply of resources, energy and food has thus become the most serious problem facing the planet, along with the grave issue of global warming brought about by the enormous consumption of fossil fuels and increase in CO_2 concentration in the atmosphere.

In addition to the increase in food production, infrastructure construction has played a significant role in human population growth. In that sense, human history can also be regarded as a history of infrastructure development. History has shown that the development of a nation is driven by infrastructure construction. Public works have weakened in value in Japan in recent years with decreasing construction investment, and those



Decreasing construction investment in Japan with a peak in 1992
(data source: Ministry of Land, Infrastructure, Transport, and Tourism)

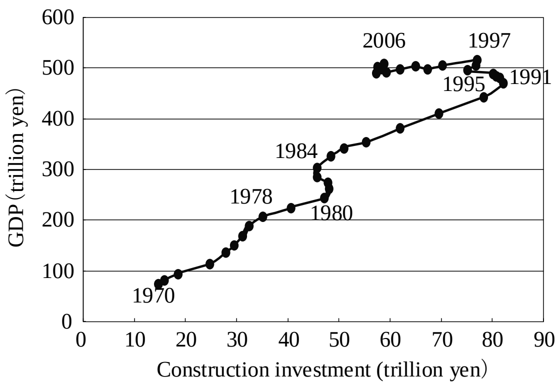
involved in public works do not have an optimistic outlook on the future.

Globally, there are many countries either developing or waiting to develop their infrastructure, and there is some possibility for Japan's construction industry to expand its operations overseas in the future. This article will discuss the path the construction industry should follow into the 21st century, with greatly different conditions compared to the centuries which came before.

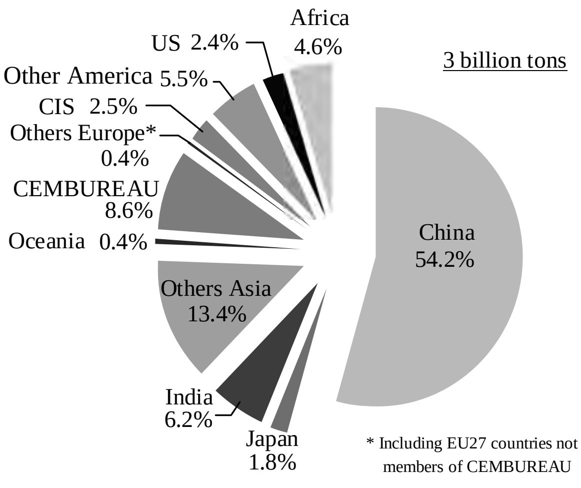
INFRASTRUCTURE DEVELOPMENT IN JAPAN

After the Meiji Restoration, which took place in 1868 (about a century after the industrial revolution in the UK), Japan implement implemented catch-up policies to increase its national strength. Unfortunately, after World War II this plan had to be restarted again from zero, and in 1962 a comprehensive national development plan was formulated for well-balanced development, thus boosting the social and economic development of Japan.

However, although there was a significant increase in construction investment in the 1970s, the decrease investment and its relationship with an un-changing GDP cannot be easily understood. One theory is that the maturity of infrastructure construction reduces its effect on the GDP. This is not to say that construction investment is no longer needed, but rather that the quality should be maintained and renewed. It is thus necessary to ensure construction investment in Japan in the future. In addition, Japanese contractors are expected to enter construction markets in developing countries, so the construction industry needs to globalize into the future.



Relationship between construction investment and GDP



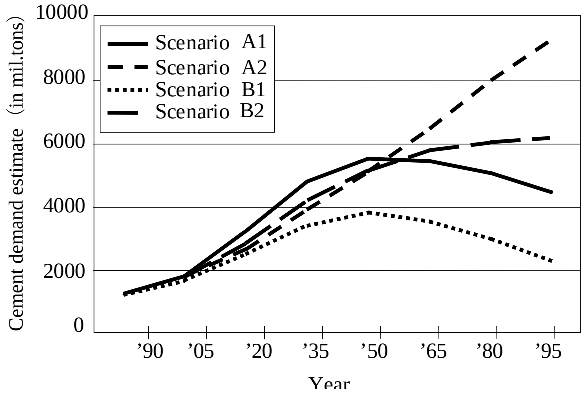
World cement production in 2009
(data source: CEMBUREAU)

ENVIRONMENTAL ISSUES FOR THE CONSTRUCTION INDUSTRY

The challenges facing humanity are resources, energy, and food issues. The world will inevitably collapse if resource efficiency is not improved. Demand for fossil fuels is also surging, which means that CO_2 emissions will increase. The only option for humans is to strive towards reducing their CO_2 emissions, and there is no reason why the construction industry should be excused from this effort, so Japan needs to consider how to tackle these global problems.

The construction sector carries out its activities using cement and steel as primary materials, almost half of which is produced in China. Though it is difficult to determine precise data of CO_2 emission from the concrete sector worldwide, a figure of roughly 5 billion tons can be reached given some assumptions and existing data. This makes up 17% of the total CO_2 emissions of fossil fuel origin in 2007. CO_2 emissions from the construction industry worldwide can be roughly calculated at 6.3 billion tons, or 21.7% of total CO_2 emissions from fossil fuels.

Current global demand for cement is already exceeding even the most conservative estimates of future demand; furthermore, global cement production is expected to double in the future. Even if emissions were halved in the future, the total contribution of the construction industry is still huge, and so pressure on the construction industry to reduce its CO_2 emissions is expected to become more and more intense.



Cement demand estimation by Humphreys et al. (data source: WBCSD)

ROLE OF CONSTRUCTION INDUSTRY IN THE 21ST CENTURY

The role of infrastructure development in the history of mankind is clear: in order to stabilize a country or the world, it is necessary to construct infrastructure so that the social and economic activities of people can run smoothly. During the period of rapid economic growth in the 1960s in Japan, hasty infrastructure construction led to low quality and shortened service life. This was due to the low technological level during development. Although many lessons have been learned, many unsolved problems still remain.

In addition to technical problems, it has become necessary to also consider how to solve the problems related to the global environment. Conventionally, environmental problems in the construction field may be seen as disruption of nature by construction works. Of course, water and soil contamination and the vibration and noise associated with construction are environmental issues, but these do not grow into a serious environmental problem – at least in the case of Japan. Disruption of the environment is unavoidable when securing the land necessary for an increased population. The only option available then is to increase the efficiency of the land use as much as possible. Rather, what is more serious for humankind in relation to population growth is the increase in the consumption of resources and energy.

Minimizing resource usage is of paramount importance. Fortunately, concrete is mostly composed of the most abundantly-available resource on Earth – aggregate. Although its production does not have a heavy environmental load, it is still used in large quantities. With some basic assumptions regarding concrete composition the amount of basic resources for concrete can be calculated to exceed 16 billion tons.

In the meantime, CO_2 emissions from the construction industry are estimated at roughly 6.3 billion tons. If this figure were to double in the near future the effects could be enormous. However, the author has shown that a reduction of 40% is possible by combining several reduction tools, but there is a natural limit to such a reduction due to the use of materials and fossil fuels for producing cement and steel.

Recycling is one option for enabling the cement industry to achieve carbon neutrality through artificial recycling of calcium ions and captured CO_2. On the other hand, hardened cement paste absorbs CO_2 during carbonation, so if CO_2 can be forcibly absorbed in fine powder of demolished concrete, the resulting powder with absorbed CO_2 can be used as a substitute for limestone. This is another option for contributing to carbon-neutrality of cement production.

With regards to the machinery used for construction, hybrid systems combining electric motors and gasoline engines have recently appeared, and full-electric systems are expected in the future.

CONCLUSION

Considering these examples, the dream of carbon-neutrality in the concrete sector may not be unobtainable after all. Many technical difficulties lie in the way, however, but setting targets over the next few decades can help drive the challenge. The direction the construction industry should take in the 21st century is to minimize resource usage and improve infrastructure using a low- or carbon-neutral approach. To achieve this and construct high-quality socio-economic foundations on a global scale is the most important role the construction industry should assume.

[1]*Professor,*
Kagawa University,
Takamatsu, Japan

Volcanic eruption in Merapi, Indonesia, on October 26, 2010

Merapi is the most active of 129 active volcanoes in Indonesia. Located in between the Yogyakarta special region and the center of Java, Merapi has a height of 2978 meters and diameter of 28 kilometers. It is a strato-volcano which produces basaltic andesitic magma, and was formed by the subduction meeting of the Indo-Australian plate with the Asian plate. Frequent eruptions have been observed from 1768 to 2006, but the eruption which occurred in 2010 is said to be the largest in the last hundred years.

On October 26, 2010 at 5:02 pm Merapi began erupting, spreading hot clouds with a radius of four to six kilometers over the southern slope of mountains. Further eruptions followed five days later, then once again three more days later. After the largest explosion the vertical smoke column reached five kilometers and vibrations were felt up to 25 kilometers away. Pyroclastic flows were observed on the mountain slopes and hot clouds reached more than 15 kilometers above the top of the mountain, spreading a rain of ash and sand which covered all of Yogyakarta. Even though more than 320 thousand people were evacuated to a safe distance of 20 kilometers from Merapi, the eruption still destroyed more than 26 villages and left more than 150 people dead.


Grey ash and lava flow before the 2010 Merapi eruption (courtesy of BPPTK)

By December 3, activity on Merapi decreased and the hazard zone was reduced to a 2.5 kilometer radius around the volcano, but other disasters followed. Heavy rainfall on top of Merapi caused the cooled lava to overflow through nine river channels around the base of the volcano. Accumulated mounds of mud and sand reached more than 1.5 meters in height.

Researchers and government officials were surprised by the nature of the Merapi eruption. Generally, past eruptions were preceded by a glowing dome of lava, but the 2010 eruption was characterized by a direct blast which broke apart the lava dome formed in the 2006 eruption.

The dense population living on the slopes of Merapi and the river running from the mountain are the primary hazards related to the Merapi eruption. It is difficult for people to leave the Merapi area because most people's livelihood is related to agriculture; the people rely on the fertility of the volcanic soil, and just two months after the eruption the land again became green. This natural beauty also attracts tourists, who contribute to the local economy. After the eruption, the people who lived in the Merapi area began trying to rebuild their homes using whatever building materials were available, but they returned to the evacuation centers at night.

This volcanic disaster demonstrated the need to apply disaster mitigation practices such as settlement planning, microzoning of volcano hazards, strengthening dikes around rivers, and improving all equipment monitoring the volcanic activity and behavior.

(by Silvia F. Herina, Research Institute for Human Settlements, Agency for Research, Indonesia Ministry of Public Works)

Village destroyed by the eruption

River filled with cooled lava

Sustainable concrete considering the Japanese context

Sustainability remains difficult to implement due to the variety of perspectives on what constitutes sustainability. This may be attributed to a critical aspect of the sustainability concept: that it is a human vision with human values. What may be sustainable in one region of the world for one set of social, economic, and environmental conditions may not be sustainable in a different region under different conditions. In a similar fashion, it is also difficult to establish a global strategy for sustainable concrete practice.

General principles such as limited CO_2 emissions, recycling, resource consumption reduction, and enhanced durability have been proposed, but how to achieve these goals depends on available resources, construction industry culture and stakeholders, institutional systems, technology level, and more. These factors are affected by regional or local socio-economic conditions and in turn affect the potential for sustainable concrete.

To better understand this relationship, results from an investigation in Japan will be briefly discussed here to illustrate some of the challenges facing a developed country with unique socio-economic issues.

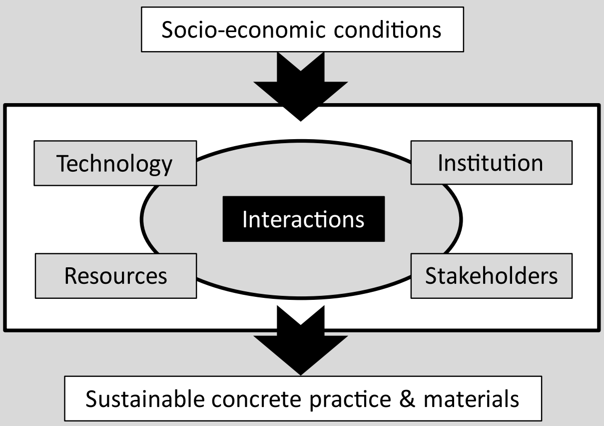
Japan is facing several long-term social and economic problems which strongly affect the potential for sustainable concrete. In the future, Japan will have to maintain an increasing number of ageing infrastructure but do so with less financial and human resources. Durability towards sustainability was given high importance in interviews and surveys with Japanese concrete industry members, which can be seen to reflect the conditions under which infrastructure will be required to serve a longer service life with little maintenance. In addition, since the industrial level of the Japan is already high, reducing CO_2 emissions through reduced transportation and construction may be one possibility for mitigating climate change.

The limited availability of habitable land in Japan increases the importance of reducing waste disposal, but Japan already has a 96% recycling rate for waste concrete. This material is, however, generally used as backfill for road construction and doesn't contribute to reducing the consumption of raw materials in concrete, which are growing very scarce domestically. Therefore, the importance of recycling in Japan is better attributed to the need to reduce resource consumption than waste disposal.

Perhaps the clearest difference when considering sustainable concrete in Japan compared to other developed countries can be seen in the barriers to implementation. Institutional, social, and organization barriers in particular are most likely specific to Japan, as these vary the most between different countries; for example, sustainability in Japan is more driven by government forces, as opposed to the USA where the private sector carries more of the weight. In addition, less importance was given to social indicators such as health, welfare, and so forth in the investigations, suggesting that the standard of living in Japan is already sufficiently high that sustainable concrete should focus on other sustainability aspects.

The Japanese situation highlights some important issues underlying sustainable concrete in a developed country. However, the majority of concrete construction is going to occur in developing nations, particularly in Asia where growth is expected to increase greatly in the coming future. Understanding the challenges for sustainable concrete considering the conditions of other countries in the Asian region will be an important step in improving the sustainability of the concrete industry as a whole.

(by M. Henry)



Relating socio-economic conditions to sustainable concrete

USMCA 2010 was held in Kobe, Japan

Experts from 21 countries delivered 80 presentations at USMCA 2010, Kobe

ICUS, along with the United Nations International Strategy for Disaster Reduction (UNISDR), Asian Disaster Reduction Center (ADRC), Disaster Reduction and Human Renovation Institution, Graduate School of Global Environmental Studies at Kyoto University, Research Center for Urban Safety and Security at Kobe University, United Nations Center for Regional Development, and United Nations University Institute for Sustainability and Peace (UNU-SP), jointly organized the 9th International Symposium on Urban Safety of Mega Cities in Asia (USMCA 2010) in Kobe, Japan, on October 13 to 15, 2010. More than 125 people from 21 countries participated in the two-day symposium, which included twelve parallel sessions and six keynote and plenary speakers.

The symposium was inaugurated by Ms. Yuki Matsuoka (UNISDR), Mr. Atsushi Koresawa (ADRC), and Prof. Kimiro Meguro (director of ICUS).

Keynote speeches were given by Dr. Kenzo Toki (Director and professor, Research Center for Disaster Mitigation of Urban Cultural Heritage, Ritsumeikan University, Japan), Dr. Yasuo Tanaka (Director, Research Center for Urban Safety and Security, Kobe University, Japan), Dr. Taketo Uomoto (Chief executive, Public Works Research Institute, Japan), and Dr. Yoshiaki Kawata (Director and professor, Kansai University, Japan). Plenary speeches were given by Dr. Tsuneo Katayama (Professor, Tokyo Denki University, Japan) and Dr. Srikantha Herath (Senior academic program officer, UNU-SP, Japan).

Eighty papers were presented in twelve parallel sessions, covering topics including disaster response and recovery; risk assessment, prediction, and early warning; decision-making technologies; planning and development of urban infrastructure systems; life-cycle management of infrastructure systems; climate change mitigation and adaptation; development and application of sustainable technologies; and application of geospatial technologies.

Recipients of the Excellent Young Researcher award

The Excellent Young Researcher Award, prepared by ICUS to encourage the activities of young researchers, was presented to Ms. Mari Sato (The University of Tokyo, Japan) and Mr. Md. Faiz Shah (University of Tsukuba, Japan). Their research works are introduced briefly in this newsletter.

USMCA 2011 will be held in Chiangmai, Thailand, on October 12-14, 2011. Please check this issue of the ICUS newsletter for more information and follow the RNUS and ICUS websites for future updates.

(by M. Henry)

The two winners of the Young Research Award at USMCA 2010 present their research works below.

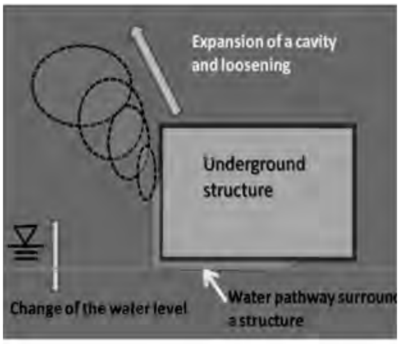
People's seismic risk recognition in Dhaka and Bangladesh National Building Code (BNBC) 1993

Dhaka is one of the fastest growing megacities in Asia, but it is prone to natural disasters including earthquakes. The current generation has never experienced a large earthquake, as the last one occurred in 1897 and caused widespread destruction and casualties. A similar earthquake may occur at any time, so good knowledge and strong infrastructure is necessary to mitigate loss. However, the rapid urbanization of Dhaka did not consider earthquake risk; buildings are constructed in an unregulated manner without earthquake consideration, which questions people's risk recognition. In order to examine inhabitants' risk recognition and intention for residential safety measures, a questionnaire survey was conducted in eighteen selected wards of Dhaka. Based on the obtained data, the major results show that inhabitants anticipate an earthquake as the most catastrophic disaster for Dhaka, which may occur in 5-10 years; and cost cutting, lack of information, and not following the proper design will be the main cause of house collapse. Results show only 2.4% of respondents have heard about the BNBC but they do not know it in detail. The authors checked the present status of BNBC with construction practice and conducted interviews with BRAC University, Bangladesh University of Science and Technology, Rajdhani Unnayan Kartipakkha, and the Housing and Building Research Institute. The paper described the following results: inhabitants construct buildings without following approved design; BNBC is included under law, but no buildings legally follow it; a large number of buildings, constructed before and after 1993, may perform poorly in a big earthquake. The paper concluded that inhabitants recognized risk and acceptable damage for their residential buildings and intended to pay for safety measures.

(by Md. F. Shah, Doctoral Student, University of Tsukuba)

Fundamental study of permeability change around buried structures in sandy ground

This research focused on cave-in accidents, which are caused by expansion of an underground cavity and loosening. The mechanism of cavity formation and loosening generation, however, is not clear, and it is difficult to prevent cave-in accidents before the cavity and loosening expand to the ground surface. Recent research shows that the boundary between underground structures and the ground may be an important factor in cave-in accidents. It is supposed that the water pathway expands through gaps between a buried structure and the ground due to changing water level. The water pathway causes soil drainage which results in expansion of the cavity and soil loosening. In order to study the effect of permeability at the boundary, constant head permeability test with a contact plane between the ground and the acrylic cylinder was conducted. As a result, permeability with a cylinder is often higher than normal permeability especially in loose sand. This result suggested that loose sand has larger gaps and makes water pathway formation easier than dense sand. The direction of unevenness is also important for making the water pathway. This research suggests the existence of water pathway between buried structures and the ground may occur in particular conditions.



Expansion of water pathway around buried structure

(by M. Sato, Master student, Kuwano Lab)

USMCA 2010 post-symposium tour

Group photo at the Akashi Kaikyo Bridge

After the conclusion of USMCA 2010 in Kobe, participants joined a post-symposium tour on October 15 to various notable landmarks in the Kobe area. The first stop on this tour was the Nojima Fault Preservation Museum, where people can view part of the exposed fault line which caused the Kobe (Hyogo-ken Nanbu) Earthquake. The second stop was at the Akashi Kaikyo Bridge exhibition center, which offers the opportunity to learn about the technologies used to construct the Honshu-Shikoku bridges. Lastly, participants visited the Disaster Reduction and Human Renovation Institution (DRI). This institute was established after the Kobe Earthquake to preserve and pass down the experiences and lessons learned from that disaster to future generations.

(by M. Henry)

19th ICUS Open Lecture held at IIS

ICUS hosted the 19th ICUS Open Lecture at the Institute of Industrial Science on November 10, 2010 with approximately 100 participants. The theme of the lecture was "The construction industry's vision of the future: overseas projects, environmental strategies, and industry structure," and covered topics related to the future role of the Japanese construction industry considering the reduction in public investment and declining and ageing population, with particular focus on social, economic, environmental, and institutional issues.

Dr. Koji Sakai (Professor, Kagawa University), a global leader on environmental issues in the concrete industry, spoke first on the role of the construction industry in the 21st century from the perspective of global environmental issues. Next, Mr. Toshihiro Chiba (Future Planning), a well-published journalist on the construction industry, proposed his thoughts and ideas for how the construction industry should move forward into the future. Finally, Dr. Kazumasa Ozawa (Professor, The University of Tokyo), chair of the Japan Society of Civil Engineers Construction Management Committee and one of Japan's leaders in the construction management field, discussed how the Japanese construction industry should take its experience with infrastructure construction overseas.

(by Y. Kato)

Dr. K. Sakai

Mr. T. Chiba

Dr. K. Ozawa

BNUS Activities

Training course on GIS

A training course on "Application of GIS for Natural Hazard and Risk Assessment" was held on Sept. 25-29, 2010, at Dhaka. It was organized by the Asian Disaster Prevention Center (ADPC), and Sharmin Ara, a research planner from BNUS, participated. The training course's objective was to develop basic skills on GIS analysis and application of GIS and Remote Sensing Techniques for Disaster Risk Reduction.

Risk resilient infrastructure workshop

BNUS members participated in a two-day workshop on "Risk Resilient Infrastructures: Role of Education and Training" on Nov. 13-14, 2010. This workshop was jointly organized by BUET-JIDPUS, the Comprehensive Disaster Management Programme (CDMP), UNDP, and the Ministry of Food and Disaster Management, Bangladesh. The chief guest was the honorable minister of Food and Disaster Management, Dr. Muhammad Abdur Razzaque, and Prof. M.A. Ansary gave the keynote speech. The different sessions of the workshop focused on a variety of issues covering environment, architecture, civil engineering, water resources, planning, and other fields.

Lecture course and seminar on urban building fire and safety

BNUS also participated in the lecture course and seminar on "Urban Building Fire Mitigation and Safety Issues in Asian Mega Cities: Bangladesh Chapter" on Dec. 21-23, 2010 at the Public Works Department, Dhaka. This event was a collaborative research study between the Tokyo University of Science (TUS), the Building Research Institute, Japan, the Bangladesh University of Engineering and Technology, American International University Bangladesh, Fire Service and Civil Defense (FSCD), and the Ministry of Housing and Public Works, Bangladesh. The lecture course was designed for students of architecture and engineering, fire professionals, and other concerned officials. Experts placed emphasis on urban building fire issues, and included several speakers from Japan.

Prof. Ansary receiving a certificate at the seminar on urban building fire and safety

(by M.A. Ansary, BNUS)

RC67 Committee Activities

The "Research Committee on Evaluation of CSR Activities in Environmental Conscious Society" (RC67) was started in May 2009 and, over the past year, we have interviewed five companies from various industries. After these interviews, it has become clear that these companies are not aware of the importance of domestic timber, so we developed evaluation documents to help increase the effectiveness of the interviews. This has helped increase awareness among the interviewed companies towards forest-related CSR activities. One company whose business is not related to forest management promotes CSR activities such as collecting and planting acorns with regional volunteers in order to reforest areas which were deforested by construction of their factories. On the other hand, companies related to forest management or water resources enable large-scale forest management and put their effort into environment education or human resource development.

From the interviews we have also identified important elements for ensuring forest-related CSR activities, such as the importance of activity continuity, promoting the use of domestic biomass to support forestry, and cooperation with local organizations and regional volunteers. From these elements we have put together evaluation points and are working on an objective evaluation system for CSR activity.

(by K. Tokunaga, Sawada-Takeuchi Lab)

Environmental and disaster management symposium and IIS alumni party were held in Bangkok, Thailand

On Nov. 27, 2010, a half-day symposium on the "Forefront and Challenges of Geospatial Technologies for Environmental and Disaster Management in Southeast Asia" was held at the Patumwan Princess Hotel, Bangkok. The symposium was organized by RNUS, AIT, and Chula Unisearch, Chulalongkom University.

Eight distinguished speakers in this field from both Japan and Thailand gave excellent presentations as follows:

- *Dr. Suvit Vibulsresth (National Research Council of Thailand)*
- *Prof. Yoshifumi Yasuoka (Executive Director, National Institute of Environmental Studies)*
- *Dr. Anond Snidvongs (Acting Executive Director, Geoinformatics and Space Technology Development Agency GISTDA)*
- *Mr. Shinichi Mizumoto (Director, Japan Aerospace Exploration Agency JAXA)*
- *Dr. Wataru Takeuchi (Director, JSPS Bangkok Office; IIS, The University of Tokyo)*
- *Dr. Nitin Kumar Tripathi (Director, UNIGIS, AIT)*
- *Prof. Kimiro Meguro (Director, ICUS, IIS)*
- *Dr. Charat Mongkolsawat (President, Remote Sensing and GIS Association of Thailand RESGAT; Khon Kaen University)*

Approximately 140 participants joined the symposium, with 40% coming from universities, 40% from government agencies, and 20% from the private sector or other organizations. Due to such

Participants at the symposium

Presentation by Dr. Suvit (Rep. of IIS Alumni Thailand Chapter)

Toast at the alumni party

Toast by Dr. Yasukoa (NIES)

large participation the venue had to be changed from the initial, smaller venue to a much larger one. This positively demonstrated the high degree of interest in this field of research in Thailand.

Following the symposium, the 4th IIS Thai alumni party was held at the same hotel. Many IIS alumni from governmental organizations, universities, and companies in Thailand joined the party. The meeting was wonderfully filled with a friendly atmosphere and the participants reminisced about their lives at IIS and caught up on each others' recent news.

In the coming year, many ICUS-related activities will be held in Thailand. First is the 10th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia (USMCA2011), which will be held in Chiangmai on Oct. 12-14, 2011. The second even is the next all-Todai (University of Tokyo) alumni party, which will be held on Oct. 15 in Bangkok. Please check the ICUS and RNUS websites in the future for more information and announcements regarding these and other events.

(by A. Kawasaki)

ICUS Activities

- All ICUS members (excluding Prof. Yokota and Prof. Ohara) joined USMCA2010 held in Kobe, Japan, on Oct. 13-15.
- Prof. K. Meguro attended a half-day symposium and IIS alumni party on Nov. 27 in Bangkok, Thailand.
- Prof. H. Sawada visited Hanoi, Vietnam, from Oct. 30 to Nov. 3 for the 31st Asian Conference on Remote Sensing.
- Prof. H. Sawada also visited Tsinghua University in Beijing, China, from Dec. 19-21 for a research meeting on disaster protocol.
- Dr. T. Endo left for Pusan, South Korea, on Dec. 1 for a 2-month investigation on the existing conditions of LiDAR research in South Korea.
- Prof. Y. Kato visited Delft (Aula), The Netherlands, from Oct. 4-6 for the 2nd International Symposium on Service Life Design for Infrastructure.
- Prof. Y. Kato also attended the 4th Asian Concrete Federation International Conference from Nov. 28 to Dec. 1 in Taipei, Taiwan.
- Dr. A. Kawasaki went back to AIT in Bangkok, Thailand, from Nov. 15 to Dec. 14 and again from Dec. 23.

Awards

- *Dr. A. Kawasaki won the GIS Award for Young Researcher from the GIS Association of Japan in October for his active submission of publications to the association.*
- *Ms. M. Sato, master student in Kuwano Lab, received the Excellent Young Researcher Award in October at USMCA2010 in Kobe, Japan.*

Editor's Note

Last November I experienced a personal disaster: I had to be taken to the hospital in an ambulance to have my gall bladder removed. Afterwards, I thought that the ambulance is not a comfortable vehicle at all and I remembered we were often stopped by other cars even though traffic was not so heavy.

Globally, many disasters occurred before the beginning of the New Year. Monsoon rains continued for five months in Pakistan. More than 200,000 Australians were affected by floods in Queensland at the end of December caused by Tropical Storm Tasha. High waters washed out roads, isolated entire towns, and forced thousands to flee. Conversely, temperatures in some areas rose to more than 40 degrees Celsius and the hot and dry conditions contributed to large wildfires along the coast. After facing these disastrous events, we always recognize that we need to continually improve our efforts towards mitigating natural disasters.

It is the tenth fiscal year of ICUS and we were able to successfully hold the 9th USMCA in Kobe with the support of many agencies and institutions, along with the friendly participants. It really is an honor that we could continue our activities with many colleagues and supporting parties. However, our objective is not just to hold such meetings but to decrease the number of disaster victims who must ride in uncomfortable ambulances. We strongly wish to expand our activities.

(by H. Sawada)

Announcement of USMCA 2011 (Chiangmai, Thailand)

We would like to announce that the 10th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia (USMCA2011) will be held in Chiangmai, Thailand on October 12-14, 2011. Further information will be available on the ICUS and RNUS websites as details of the symposium are decided.

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The University of Tokyo

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EASTERN JAPAN STRUCK BY MAGNITUDE 9.0 EARTHQUAKE AND MASSIVE TSUNAMI

By

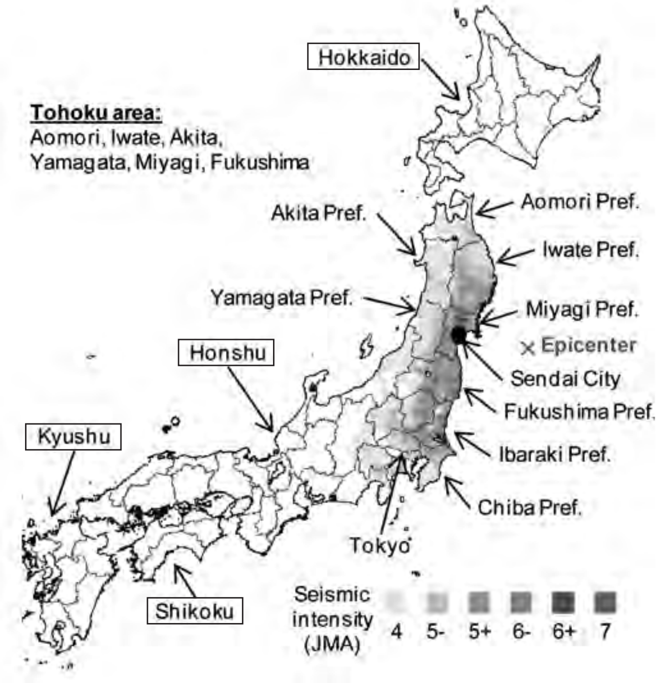
Kimiro Meguro[1]

On March 11, 2011, at 2:46 pm Japan standard time, a magnitude 9.0 earthquake struck off the eastern coast of Honshu, Japan's main island, approximately 129 kilometers east of Sendai. This earthquake triggered a massive tsunami, which inundated the eastern Pacific seaboard of Japan with waves up to tens of meters high. The Tohoku region was hit the hardest, particularly the coastal areas of Iwate, Tochigi, Fukushima, and Ibaraki prefectures. As of the time of this newsletter's publication, more than 23,000 people are confirmed dead or missing.

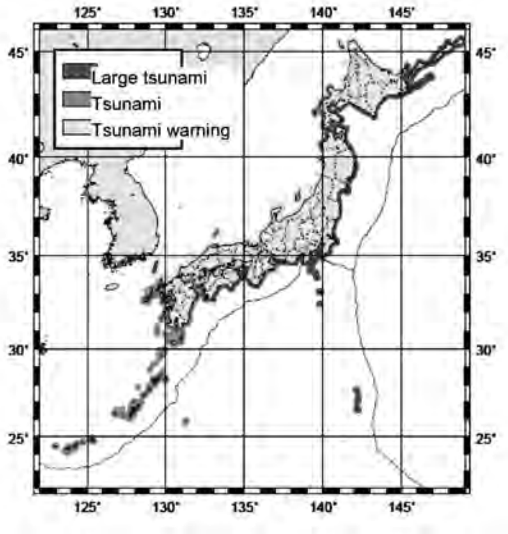
At this time, ICUS is preparing a special-edition ICUS Newsletter to help disseminate important data about the earthquake, tsunami, and its aftermath, along with reconstruction efforts, and we hope to publish it soon.

[1]Director, Professor, ICUS

Scenes of damage from the Tohoku area



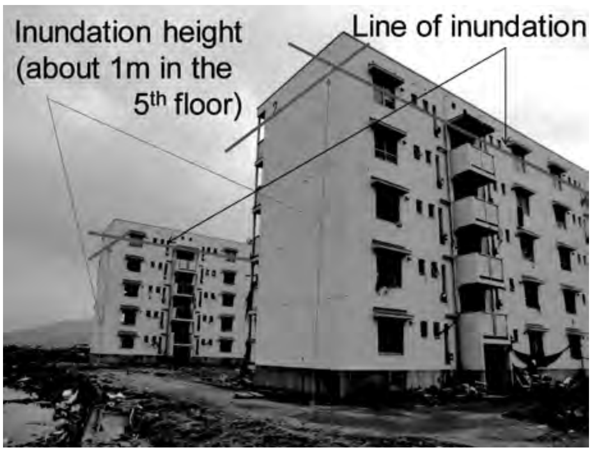
Distribution of seismic intensity
(source: Japan Meteorological Agency)



Distribution of tsunami danger
(source: Japan Meteorological Agency)

4-story steel building toppled by the tsunami
in Onagawa City, Miyagi Prefecture

Concrete bridge swept away by the
tsunami in Rikuzentakada City,
Iwate Prefecture



Tsunami damage to 5-story concrete RC apartment
building in Rikuzentakada City, Iwate Prefecture

Fire-damaged structures in the waterfront area
of Minami-sanriku, Miyagi Prefecture

Pancake-type failure of a building in Sendai City, Miyagi Prefecture

Tsunami damage and debris at Sendai Airport, Miyagi Prefecture

Convenience stores in Tokyo were sold out of food the night of the earthquake

Huge traffic jams filled the streets of Tokyo as stranded people tried to get home

ICUS and IIS researchers establish 3.11net Tokyo for disaster-related information collection and dissemination

The Great East Japan Earthquake had a devastating impact on both the public and research community in Japan. In order to support recovery and reconstruction in disaster-affected areas from the perspective of university researchers, several researchers at the Institute of Industrial Science (IIS), the University of Tokyo have built a voluntary group called "3.11net Tokyo." The main activities of this group are to collect and transfer information on various activities related to the academic society, to distribute information on the earthquake, its aftermath, and recovery and reconstruction activities, and to take care of foreign researchers. Meetings are regularly held three times a week in the ICUS Lecture Room for sharing information about support activities, field surveys, briefing sessions and so on.

"3.11net Tokyo" collects documents on this earthquake and its aftermath, and manages an environment for browsing documents and report activities at the clearing house and through a webpage, especially academic survey findings, newspapers and books. The URL is: http://icus.iis.u-tokyo.ac.jp/rnet_edr/

Gathering of ICUS and IIS researchers at a morning meeting

(by S. Kondo)

Risk management of cultural heritage in Kyoto

A FORGOTTEN POINT OF VIEW

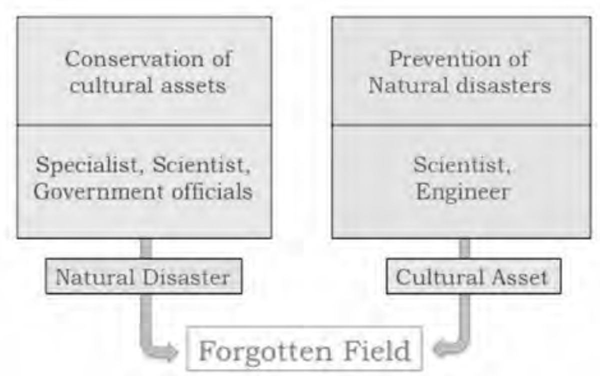
The Cultural Assets Preservation Act was established in 1950, one year after the Kondo Mural Painting at Horyuji Temple was destroyed by fire. Since then, thanks to continuous effect by the central and local government and the cultural heritage community, Japan has achieved significant and brilliant results in cultural heritage preservation. These wide-ranging results include the prevention and mitigation of age-induced changes to cultural heritage, the excavation and examination of buried cultural assets, and protecting cultural heritage from fire.

This is not to say, however, that there has been enough done in preparing for natural disaster. Many treasures have been lost due to natural disasters – for example the damage of the stage on the sea at Itsukushima Shinto Shrine during Typhoon No. 18 in September 2004, or the damage to the five-story pagoda at Murouji Temple from a fallen tree in September 1998.

The field of cultural property protection is wide and varied, with the problem of natural disaster alone having been overlooked. Experts in the field of cultural property preservation recognize the need to focus on this problem in the future, but have not worked together to tackle the problems inherent in protecting cultural properties from disaster. Safeguarding against natural disaster has also been neglected among cultural property preservationists. Since cultural properties and assets are irreplaceable, they should be viewed from a different perspective than other assets.

WHAT'S THE PROBLEM?

In the Great Hanshin-Awaji Earthquake of 1995 Kyoto was shaken by seismic intensity 5, but damage was relatively slight. Kyoto is located some 50 to 60 kilometers away from Kobe, so if an earthquake were to strike closer to Kyoto, it is not hard to imagine that many more temples and shrines would be damaged. There is not only a lack of equipment and facilities to combat earthquake-induced fires, but also a shortage of reserve water. Without enough water reserves, fires in surrounding areas will not be prevented from spreading to the precincts of temples and shrines. This is exacerbated by such problems as the lack of quake-resistant water cannon pumps and power-generating equipment at temples and shrines. The biggest problem is that these measures for containing the spread of fire are not considered.



Protection of cultural heritage from natural disaster

INCREASE IN FIRE RISK

Kyoto has one of the lowest rates of fire outbreak among large cities in Japan. This is probably due to the visceral sense of potential danger among the citizenry of Kyoto, which contains many old wooden buildings. However, a low rate of fire outbreak and high resistance to fire are two different things. Since there are many old buildings, if a fire were to break out, it would be very difficult to extinguish.

Just one hundred years ago Kyoto's population lived in a smaller area, with most of the city as farmland. Today the entire Kyoto basin is covered with residential buildings from every corner to corner, and the populated area expanded about five-fold in one century. Since this densely-populated area is covered with flammable material, if multiple fires were to break out there simultaneously, many national treasures would definitely be lost.

Furthermore, reconstruction of such treasures is very difficult in current times due to the loss of political power and reduced support from private individuals. If many properties were lost to a fire, they would not be rebuilt as they were in the past.

ACTIVE SEISMIC PERIOD

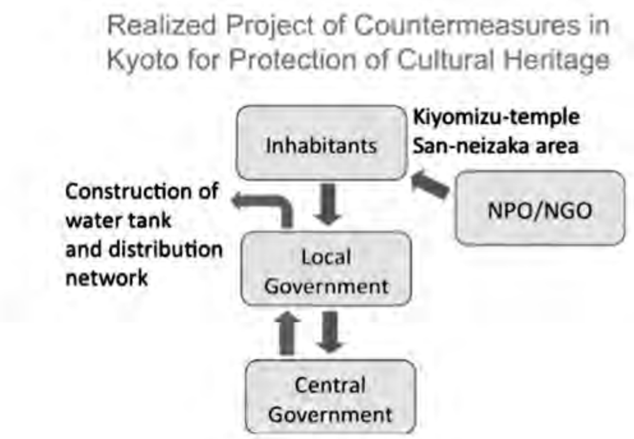
There were only two earthquakes of magnitude 6 or greater in the Kinki Region during the forty years between the Fukui and Great Hanshin-Awaji Earthquakes. However, during the fifty years between 1900 and the Nankai Earthquake of 1949, there were more than thirteen earthquakes of a magnitude of 6 or greater in the Kinki region alone, with all of them coming during the short period between 1925 and 1943. History shows that the Tokai, Tohnankai, and Nankai Earthquakes along the Nankai Trough recur over cycles of 100 to 120 years, so earthquakes in these regions should be looked at in terms of a hundred years. From this point of view, it can be said that we are in an active period like the one that began in 1925, this time starting with the 1995 South Hyogo Prefecture (Kobe) Earthquake.

"LIFE INSURANCE" FOR KYOTO

Some 47 million tourists flock to Kyoto each year. Since they come to see the historic buildings and cultural properties at the temples and shrines, the loss of these assets would hurt Kyoto terribly, and the number of people who visit would drop drastically. If cultural assets determine the fate of Kyoto, shouldn't it have an insurance policy to protect itself? Such insurance is to be found in disaster prevention measures. At the present time, however, Kyoto's cultural assets do not seem to be sufficiently insured.

WHAT MUST BE DONE

The importance of cultural heritage disaster mitigation is recognized by the national government and some local governments. The city of Kyoto, with its wealth of cultural properties, has for the past several years expressed concern over these issues. Determined to maintain its historical ambience, the city has set up a committee to find a way to create a water supply system for use in disaster prevention efforts. Meanwhile, the Society for Protecting Cultural Assets from Disaster, an NPO, has been active for thirteen or fourteen years, though formerly as a different organization. At the request of the national government, the society, Kiyomizu Temple and local citizens have collaborated to formulate specific disaster prevention measures for Kiyomizu Temple, Sanneizaka, and the surrounding area. The implementation of cultural heritage disaster mitigation measures requires not only the cooperation of custodians of cultural properties but also a specific plan that is acceptable to local citizens.



Cycle of collaboration towards disaster countermeasures

THE WORK HAS BEGUN

While paying due attention to historical ambience, the Society for Protecting Cultural Assets from Disaster has also explored the particulars of a water supply system for use in disaster mitigation efforts. The NPO formed a Study Group for Maintaining a Disaster Mitigation Water Supply System, and crafted a plan thereof with cooperation from the temples, local government, and Kyoto City Fire Department. Through workshops and discussions they developed a proposal to dig a tunnel (to avoid blemishing the landscape) through the mountains of Higashiyama for storing water, and to install fire hydrants and a water sprinkler system. Funding for the first phase of this project was approved in 2006, and is the first national project for protecting cultural assets against natural disaster. The focus of the project is a 1,500-ton underground water storage tank beneath the "disaster-prevention park" which will be used not only for fighting fires during after big earthquakes but also as easy-to-operate fire hydrants for other fires as well.

(by Kenzo Toki,
Professor and Director,
Research Center
for Disaster Mitigation
of Urban Cultural Heritage,
Ritsumeikan University)

2011 Christchurch Earthquake – quick report from the field

An earthquake of magnitude 6.3 centered some 10 kilometers from downtown Christchurch occurred at 12:51 on Feb. 22, 2011. The shallow earthquake occurred at a depth of 5 kilometers and caused more damage in the Christchurch CBD (Central Business District) than the 2010 Darfield (Canterbury) earthquake of magnitude 7.1, which occurred 5 months prior to this event. As of March 18, the death toll reportedly reached around 180.

Some earthquake records show that buildings may have experienced severe shaking more than double the current code requirements in New Zealand. The buildings designed according to the current seismic codes, however, performed well, with a few exceptions such as a 17-story modern RC building, in which its staircases collapsed.

In New Zealand, ductility was not explicitly required for non-residential buildings designed before 1976, and much improvement was made in the design standard for RC buildings in the early 1980's to eliminate brittle behaviors and to ensure the strong column and weak beam system. It should be noted that many buildings designed before the early 1980's may have experienced shaking exceeding the code requirements but many of them had minimal structural damage.

The most serious building damage was found in pre-1970's RC buildings which had survived the 2010 Darfield earthquake. Some of them had total collapse and/or severe shear failure in columns.

URM (unreinforced masonry) buildings within the CBD were significantly damaged, just as they had been during the 2010 Darfield earthquake. Several buildings recently seismically upgraded also collapsed, including the Christchurch Cathedral. URM buildings that were temporarily shored or retrofitted after the 2010 Darfield earthquake showed a wide variety of responses: some performed successfully but some others partially or totally collapsed.

In addition to the shaking-induced damage, much damage due to soil liquefaction was found. The suburbs had more significant soil liquefaction than the downtown district, and the northern and eastern suburbs along or close to the Avon River had the most serious damage.

Building safety evaluation according to the Civil Defense/ City Council Building Safety Evaluation Operations was made by structural engineers to assess the buildings' safety for re-occupation or temporary re-entry. As of March 18, 826 buildings (23%) were red tagged, 862 buildings (24%) yellow tagged, and 1933 buildings (53%) green tagged [1].

[1] W. Y. Kam, U. Akguzel, and S. Pampanin: "4 Weeks on: Preliminary Reconnaissance Report from the Christchurch 22 Feb. 2011 6.3 Mw Earthquake," WEB at NZSEE Clearinghouse.

Acknowledgement: This field survey was made under the AIJ-JAEE joint reconnaissance led by Prof. S. Kono of Kyoto University with cooperation from Prof. S. Pampanin, Dr. W. Y. Kam, and Dr. U Akguzel of the University of Canterbury. The author gratefully appreciates their support.

(by Yoshiaki Nakano,
Prpf. IIS, The University of Tokyo)

Massive liquefaction at Bexley

Severely damaged pre-1970's RC building

A URM building with temporary shoring survived

Briefing of structural engineers for building evaluation

Seminar on "Current Seismology and Related Urban Safety Engineering Researches in Mongolia"

At the invitation of Prof. K. Meguro, Director of ICUS, three scholars from Mongolia visited ICUS on 20 January and held a seminar on "Current Seismology and Related Urban Safety Engineering Researches in Mongolia." The visitors were: Prof. Dr. S. Demberel, Scientific Secretary, Research Center of Astronomy & Geophysics (RCAG), Mongolian Academy of Sciences (MAS), Dr. M. Ulziibat, Head of Seismological Department, RCAG, MAS, and Dr. E. Ninjgarav, Associate professor of Geotechnical Engineering, Vice Director of the School of Civil Engineering and Architecture, Mongolian University of Science and Technology (MUST).

In recent years, seismic activities have been increasingly observed near and within Ulaanbaatar area, the capital city of Mongolia where nearly one-third of the total population is concentrated. Two times as many earthquakes were recorded during the last five years (2005-2010) as between 1970 and 2004, and more than 1600 events, having a magnitude between 0.5 to 4.2 are caused mainly due to two major active structures: NS Emeelt and EW Hustai active faults. Also, with the mining boom, there are increasing numbers of newly built high rise buildings in the city, thereby creating an amount of new concerns among the society on the safety of old and new buildings against seismic hazard.

Against these backgrounds, urban disaster reduction has become one of the priority policy areas of the government of Mongolia, and the government has been showing its willingness to cooperate with foreign governments, including Japan. In November 2010, when the President of Mongolia paid an official visit to Japan, the two governments issued a joint statement that touched upon, among others, importance of enhanced bilateral cooperation in the area of disaster prevention/ reduction. The seminar, held at ICUS this time, therefore, was quite timely to follow up these recent moves.

Dr. Demberel talked about historical development of seismology in Mongolia since the Soviet time, introduced current activities of RCAG, MAS, and touched upon lots of tasks ahead from now on. Dr. Ulziibat introduced recent research results in the context of seismic hazard assessment of Ulaanbaatar area. Dr. Ninjgarav presented geotechnical features of Mongolian soil properties, and said that 61 % of the ground surface is within the semi permafrost region. Dr. Demberel also expressed his hopes for the strengthened cooperation between Mongolia and Japan.

The seminar was also attended by Prof. Y. Nakano, who presented some salient features of earth quake engineering researches in Japan, as well as Prof. K. Meguro, who introduced ways of improving seismic performance of weak brick and masonry structures using PP-band method.

Prior to the seminar, three scholars also paid a visit to relevant Japanese institutions such as Disasters Reduction and Human Renovation Institution, Asian Disaster Reduction Center (both in Kobe), Nojima Faults Preservation Musium (in Awaji-shima), National Research Institute for Earth Science and Disaster Prevention, Public Works Research Institute (both in Tsukuba), Earthquake Research Institute of the University of Tokyo, Life Safety Learning Center of Tokyo Fire Department, and Tokyo Metropolitan Gov. Disaster Prevention Center.

(by Y. Ichihashi)

Visiting the Public Works Research Institute

The Mongolian delegation with Prof. Meguro

Symposium on forefront and challenges of water resources management in Bangkok, Thailand

On January 29, 2011, a half-day symposium on the "Forefront and Challenges of Water Resources Management in Southeast Asia," organized by ICUS, the Regional Network Office for Urban Safety (RNUS), Asian Institute of Technology (AIT), and Chula Uniseach, Chulalongkorn University, was held at the Novotel Bangkok Fenix Ploenchit Hotel.

Six distinguished speakers in the field of water resources management from the academic field and government in Thailand and the USA gave excellent presentations as follows (order of presentation):

- *Mekong sub-regional framework: opportunities and challenges (Ms. Manitkul, Thai Ministry of Foreign Affairs)*
- *Vulnerability assessment of freshwater resources in the Mekong River basin (Dr. Babel, AIT)*
- *Integrating community water planning with provincial development plan by area based information system (Dr. Koontanakulvong, Chulalongkorn University)*
- *Water resources management in MRC & Thailand's perspectives on MRC's role (Mr. Siripornpibul, Thai Ministry of Natural Resources and Environment)*
- *Who's river is it anyhow? Some issues regarding transboundary development on the Mekong River basin (Prof. Rogers, Harvard University)*
- *Challenges to benefit sharing in the Mekong River basin (Prof. Ogden, Northeastern University)*

Following the presentation session, a panel discussion with the six presenters was chaired by Dr. A. Kawasaki. Many interesting and sharp questions came from the floor, especially about the impact of upstream Chinese dams on lower Mekong River basins. Because historical drought and flood happened recent years in the Lower Mekong, some people blame China for causing such problems in the Mekong. The reply from the panel member was as follows: "Upstream Chinese dams might have actually affected draught and flooding in the Lower Mekong, but nobody knows because Chinese dam operation information is not open. At the same time, however, rapid changes in human activities such as population increase, deforestation, and land development in Laos, Thailand, Cambodia and Vietnam also largely affected the water flow in the Lower Mekong basin." Many questions and comments were raised during the panel discussion, but discussion had to close due to running out of time.

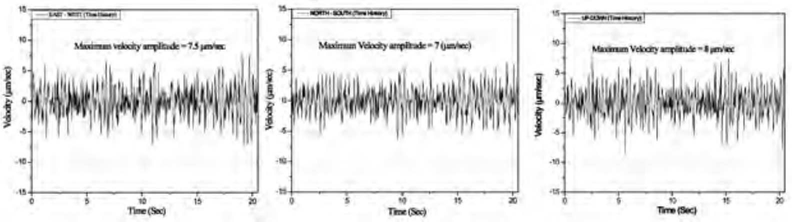
About 180 participants joined the symposium: 53% from university; 27% from government; and 20% from private sector and other. Although the announcement of this symposium was just two weeks before the symposium, the application exceeded 200 in just 10 days, so we had to decline applications starting several days before the symposium. This demonstrates Thailand's high degree of interest in water resources management.

(by A. Kawasaki)

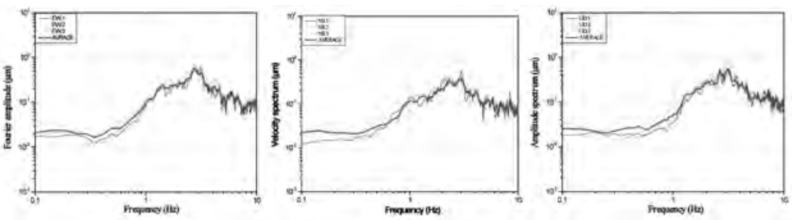
Panel discussion with the six presenters

Participants at the symposium

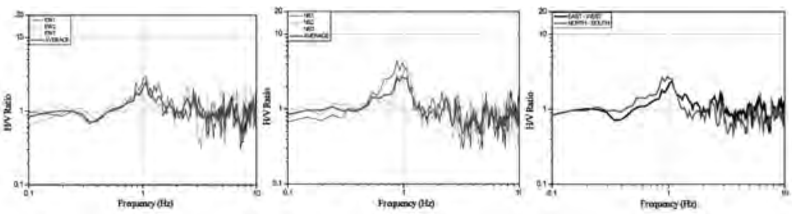
BNUS Activities



Velocity time history along three directions



Three segments of Fourier amplitude and average values



H/V spectral ratio

FIRE FIGHTING AND HAZARDOUS FIRE LEGISLATION WORKSHOP

A workshop on "Fundamental Concepts of Fire Fighting and Formulation of Legislation Regarding Hazardous Fire" was held on January 20, 2011, at the ITN Center, Bangladesh University of Engineering and Technology. This day-long workshop was organized by BUET-JIDPUS (Japan Institute of Disaster Prevention and Urban Safety). The workshop was divided into two sessions with two experts who gave lectures on different issues regarding the basic concepts of fire hazard, fire fighting systems, design standards, standard rules, and regulation and law practiced in Bangladesh. The main lecturer was architect Tajuddin Ahmed Chowdhury and Dr. Md. Maksud Helali, professor of the Mechanical Engineering Department, BUET. Forty participants took part in this workshop from different professional groups, including a research planner from BNUS, Sharmin Ara. The contents of the workshop were particularly helpful for the fire fighters of the Fire Service and Civil Defense (FSCD).

MICROTREMOR H/V TECHNIQUE FOR SITE RESPONSE ANALYSIS

The amplitude ratio (H/V) of horizontal to vertical spectra has become popular to determine the predominant period and amplification of a site. It is well known that the degree of damage during earthquakes strongly depends on dynamic characteristics of buildings as well as amplification of seismic waves. Among the other time consuming and expensive approaches, microtremor is the easiest and cheapest way to understand the dynamic characteristics of soil as well as structural element. In a short period of time it provides several information including natural frequency and amplification and vibration characteristics of soil and structure at different frequencies.

Microtremor data recordings have been carried ouat in 132 locations in Dhaka City. Each record comprises three components: east-west, north-south, and up-down. For spectral analysis three noise-free portions of 20.48 seconds have been taken at 100 hertz instrumental sampling. For checking the stability of soil response using microtremor at each point of sensor location microtremor data recordings have been executed at different times of the day.

The results show that the ranges of predominant frequency in BUET area are between 0.30 and 6.5 Hz, and Horizontal to Vertical spectral Ratio (H/V) ranges between 1.0 and 6.5. In some locations of the observation point the H/V ratio obtained was very flat. In other locations the result was very clear predominant peaks. For the stability analysis of microtremor thirteen selected points show that H/V ratios are very stable. In general, the long period or low frequency zone corresponds to the soft soil zone, with shorter period or high frequency in the hard and middle soil zones. In some places, long periods or low frequency have been detected in the hard soil zone, this being due to local artificial deposits caused by compacting the soil.

(by M.A. Ansary, BNUS)

RC62 Committee Activities

The performance of infrastructures necessary to support our lives deteriorates due to changes in required features and aging. Traditionally, evaluation of structures has been tried utilizing various measuring techniques. However, technology which can appropriately evaluate structural performance has not been established. In addition, techniques for evaluating the performance of the entire structure considering both the structure and the ground have not been studied.

From this background, the "Research committee on evaluation technology of the performance degradation due to aging infrastructure" (RC-62) started over three years ago in April 2008, and we have conducted quantitative techniques to evaluate the performance of concrete and soil structures and technical investigations to evaluate the performance of the entire structure to encompass the structure from the ground.

In the first year, we organized existing technologies of the measurement and evaluation on each field such as concrete and soil structures, etc., and discussed the direction of future technologies. Next, as a concrete example, we selected a box culvert structure in the earth with reinforced soil walls (Terre Armee) and we examined structural deformation due to changes in ground conditions. Based on these results, we proposed a technique for monitoring or measuring the deformation expected. For the reinforced earth wall, we tried to assess the soundness of reinforcement in the ground using field tests with acoustic shockwave. This series of study results are summarized in a final report published in March 2011. Although this study is limited, continued work is required for effective and efficient maintenance of infrastructures.

(by Kenji Hayakawa,
Tokyu Construction Co., Ltd.

RC67 Committee Activities

The "Research Committee on Evaluation of CSR Activities in Environmental Conscious Society" (RC67) has continued to work for two years in order to create a guideline for CSR activity about forests. Specifically, over the first year we investigated and analyzed the CSR activities of private Japanese companies which have responsibilities related to environmental issues. Then, during the second year we focused on hearing from the voices of those actually in charge of CSR activities through hearings and interviews with leading companies.

At the end of March 2011, we published our conclusions as the "ICUS Committee Report 2010-02." In this report, we proposed the guidelines and an evaluation form for improving the quality of current CSR activities. Following is a brief summary of the reported guideline and evaluation form.

The results of the interview indicate that the scale, continuity, PDCA (plan-do-check-act), environmental educations, contributions to local community, support of forest management, soil and water conservation and biodiversity are all needed for evaluation of CSR activities. The evaluation form was created based on this result. Moreover, we concluded that four functions of CSR activities are needed to improve the quality of CSR activities through analysis of the evaluation forms. Important functions are: 1) CSR activities should support sustainable forest industry, 2) CSR activities should be close to the core business, 3) experts should contribute to private CSR activities, and 4) CSR activities should collaborate with other CSR activities. We would also like to add that sustainable use of wood is one type of CSR activity. Finally, RC67 hopes that the report will contribute positively to CSR activities. If you want to know more about these results, please refer to the "ICUS Committee Report 2010-02" (available in Japanese language only).

(by T. Endo)

Report on LiDAR research in Korea

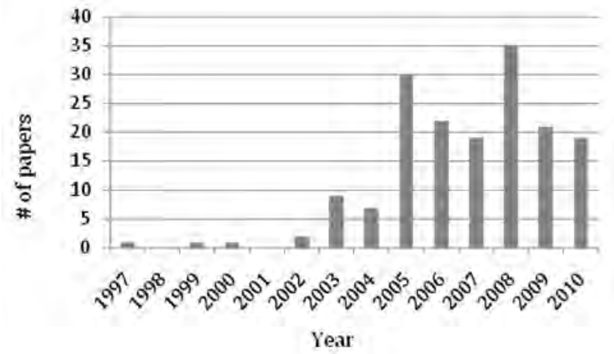
LiDAR (Light detection and ranging) is one type of remote sensing instrument which measures terrain surface and 3-dimensional structures. South Korea actually has more LiDAR instruments than Japan despite the area of Korea being roughly just one-quarter the size of Japan.

To investigate the status of current LiDAR research in South Korea, I stayed in Pusan for two months from December 1, 2010 to January 31, 2011. The research counterparts during my stay were Prof. Yong Cheol Suh, Prof. Chul Uong Choi, and Dr. Yang Won Lee in the geoinformatic engineering group at the Pukyong National University, who helped me collect domestic papers on LiDAR research written in Korea.

I found that the amount of LiDAR research increased rapidly from 2005, and has continued to increase until now. The major research field in LiDAR application was related to civil engineering applications, such as extraction of building and terrain shapes. There was little environment-related research, however, in contrast to Japan. Environmental research using LiDAR may become more popular in the future in South Korea, and I hope that Japan and South Korea will tackle these issues together in the future.

Acknowledgement: Funding for this research was provided by the "Global Center of Excellence for Sustainable Urban Regeneration."

(by T. Endo)



Number of Korean domestic LiDAR research papers

ICUS Activities

- *Prof. K. Meguro traveled to Bangkok, Thailand, from Feb. 4 to 7 for a lecture on earthquake preparedness.*
- *Prof. Sawada visited Thailand from Jan. 5 to 11 for a meeting and investigation on forests in the Mekong region.*
- *Prof. Sawada also attended a meeting in Laos from Feb. 3 to 9 for a meeting related to forest management and natural disasters.*
- *Dr. R. Kuwano attended the 5th International Conference on Earthquake Geotechnical Engineering from Jan. 8 to 17 in Santiago, Chile.*
- *Dr. T. Kato visited Chengdu, Sichuan, China from March 7 to 12 for an investigation.*
- *Dr. A. Kawasaki traveled to Kunming and Jinghong, China, Vientiane, Laos, and Phnom Penh, Cambodia, from Jan. 1 to 13 for research investigation.*
- *Dr. A. Kawasaki also visited Amsterdam, Holland, and London, England, from March 10 to 19 to share his research works.*

Awards

- Mr. M. Hosoo, master student in Kuwano Laboratory, won the Furuichi Award from the Dept. of Civil Engineering, the University of Tokyo, for his excellent master research entitled "Study on healing capability of bio-cemented sandy soil."
- Ms. M. Sato, master student in Kuwano Laboratory, also won the Furuichi Award from the Dept. of Civil Engineering, the University of Tokyo, for her excellent master research entitled "Effects of underground structures on expansion of subsurface cavaties."

Editor's Note

On March 11th, at 2:46 pm a massive earthquake occurred off the eastern coast of Japan and caused a huge tsunami. In the Sanriku area, which has a history of tsunami damage and was also directly affected by this recent earthquake, there are many countermeasures against tsunami in place, such as large seawall, education about tsunamis and tsunami drills due. But even with these countermeasures the damage and casualties are larger than those which resulted from the 1896 Sanriku earthquake.

What countermeasures should we take? Should all people live in high ground or another area far from the sea for safety? Should higher seawalls be built? Should all buildings be built by reinforced concrete structure and designed to withstand tsunami forces?

There is not only disaster safety to think of, but also many other problems related to communities, industries, landscapes, and so forth – all of which need to be solved. Unfortunately, these problems cannot be solved easily, but gathering all the knowledge and techniques in Japan as well as around the world is a good place to start. Researchers all over Japan, including those in ICUS and also in the University of Tokyo are working towards solving these problems and helping move towards reconstruction.

(by M. Koshihara)

Announcement of abstract due date for USMCA 2011 (Chiangmai, Thailand)

We would like to announce that the due date for submitting abstracts for the 10th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia (USMCA 2011), to be held in Chiangmai, Thailand from October 12 to 14, has been extended to the middle of July, 2011. Further information such as the abstract format is available at the USMCA 2011 official website:

http://www.set.ait.ac.th/rnus/USMCA2011/index.html

International Center for Urban Safety Engineering

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