CODE2015

3rd INTERNATIONAL CONFERENCE ON COMPUTATIONAL DESIGN IN ENGINEERING

December 14-15, 2015

Tokyo, Japan

COmputational Structural Engineering Institute of Korea

Supported by Institute of Industrial Science (IIS), the University of Tokyo (UTokyo)
Organized by Computational Structural Engineering Institute of Korea (COSEIK)
&
International Center for Urban Engineering (ICUS), IIS, UTokyo

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Welcome Address

It is my great honour and pleasure to invite you to the 3rd International Conference on Computational Design in Engineering (CODE2015) to be held from December 14th to 15th, 2015 at the Institute of Industrial Science, The University of Tokyo, Japan, hosted by the International Center for Urban Safety Engineering (ICUS) and organized by the Local Organizing Committee of CODE2015.

The remarkable development of Computer Science in recent years has contributed greatly to the advancement of research in various fields including the field of engineering. Conducting an actual experiment or survey could be difficult due to limitation in scale or time constraint, material constant, or boundary condition however by utilizing computer simulation, understanding of phenomena and proposal of problem-solving measures are making rapid progress.

Under the theme “Current and Future Directions in Engineering with Computers”, CODE2015 will focus on the Computational Engineering and Mechanics and IT disaster management. CODE2015 will be an excellent learning experience in the field of ‘Computational Design and Engineering’ for all participants. Globally renowned speakers as well as many professionals and experts from around the world have been invited to CODE2015.

CODE2015 will be the third conference following the great success of CODE2009 and CODE2012. Join us to learn and share the most recent advances in the related fields and improve your social network in our ever-smaller global community. The Organizing Committee welcomes all the participants with Japanese Omotenashi (hospitality) spirit and hope to provide full support during the conference.

I am committed to making sure that this conference will be a valuable and enjoyable event. I would like to express my deepest gratitude to all of you for attending CODE2015, to all sponsors for their generous support ensuring the success of this conference, and lastly, to those who made this conference possible with their unwavering dedication.

Once again, all of the members of CODE2015 Organizing Committee welcome you to CODE2015 and Tokyo, Japan.

Prof. K. Meguro
Chairman
Organizing Committee of CODE2015

Organization of CODE2015

Co-Chairman

Waon-Ho Yi, Professor, Kwangwoon Univerity, Korea
Kimiro Meguro, Director, ICUS, IIS, UTokyo, Japan

Steering Committee

Heoung-Jae Chun, Professor, Yonsei University, Korea
Sang-Ho Lee, Professor, Yonsei University, Korea
Chee-Kyeong Kim, Professor, Dankook University, Korea
Maeng-Hyo Cho, Professor, Seoul National University, Korea
Hong Huang, Professor, Tsinghua University, China
Teruo Fujii, Director General, IIS, UTokyo, Japan
Yoshiaki Nakano, Professor, IIS, UTokyo, Japan
Chisachi Kato, Professor, IIS, UTokyo, Japan

Technical Committee

Hyung-Joon Kim, Associate Professor, University of Seoul, Korea
Hyuk-Chun Noh, Associate Professor, Sejong University, Korea
Dae-Jin Kim, Assistant Professor, Kyunghee University, Korea
Sang-Joon Shin, Professor, Seoul National University, Korea
Marie Oshima, Professor, IIS, Utokyo, Japan
Kazuo Kashiyama, Professor, Chuo University, Japan
Kohei Nagai, Associate Professor, ICUS, IIS, UTokyo, Japan

Organizing Committee

Muneyoshi Numada, Lecturer, ICUS, IIS, UTokyo, Japan
Ho Choi, Assistant Professor, IIS, UTokyo, Japan
Hideomi Gokon, Assistant Professor, IUCS, IIS, UTokyo, Japan

Contact

Eiko Yoshimoto

GENERAL INFORMATION

LANGUAGE

The conference will be conducted in English.

SYMPOSIUM VENUE

Convention Hall, Komaba Research Campus

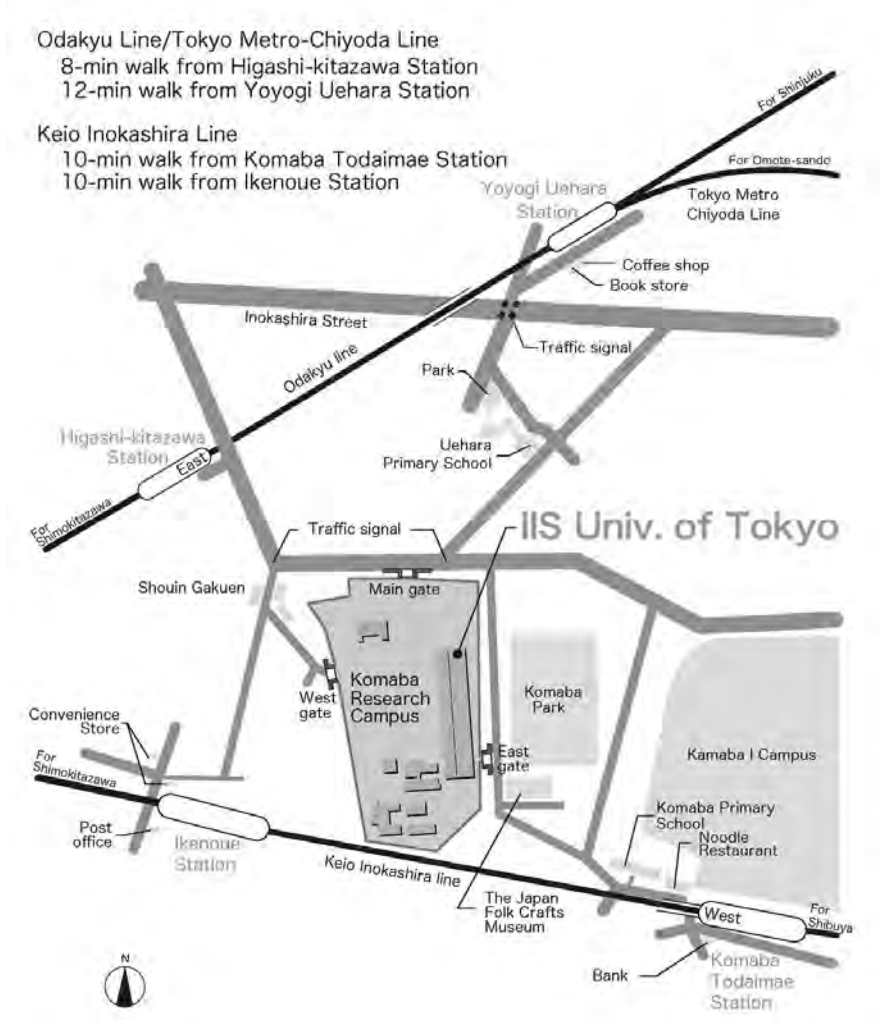
As311,312　As313,314　As303,304

Tel:　+81-3-5452-6472　Fax:　+81-3-5452-6476

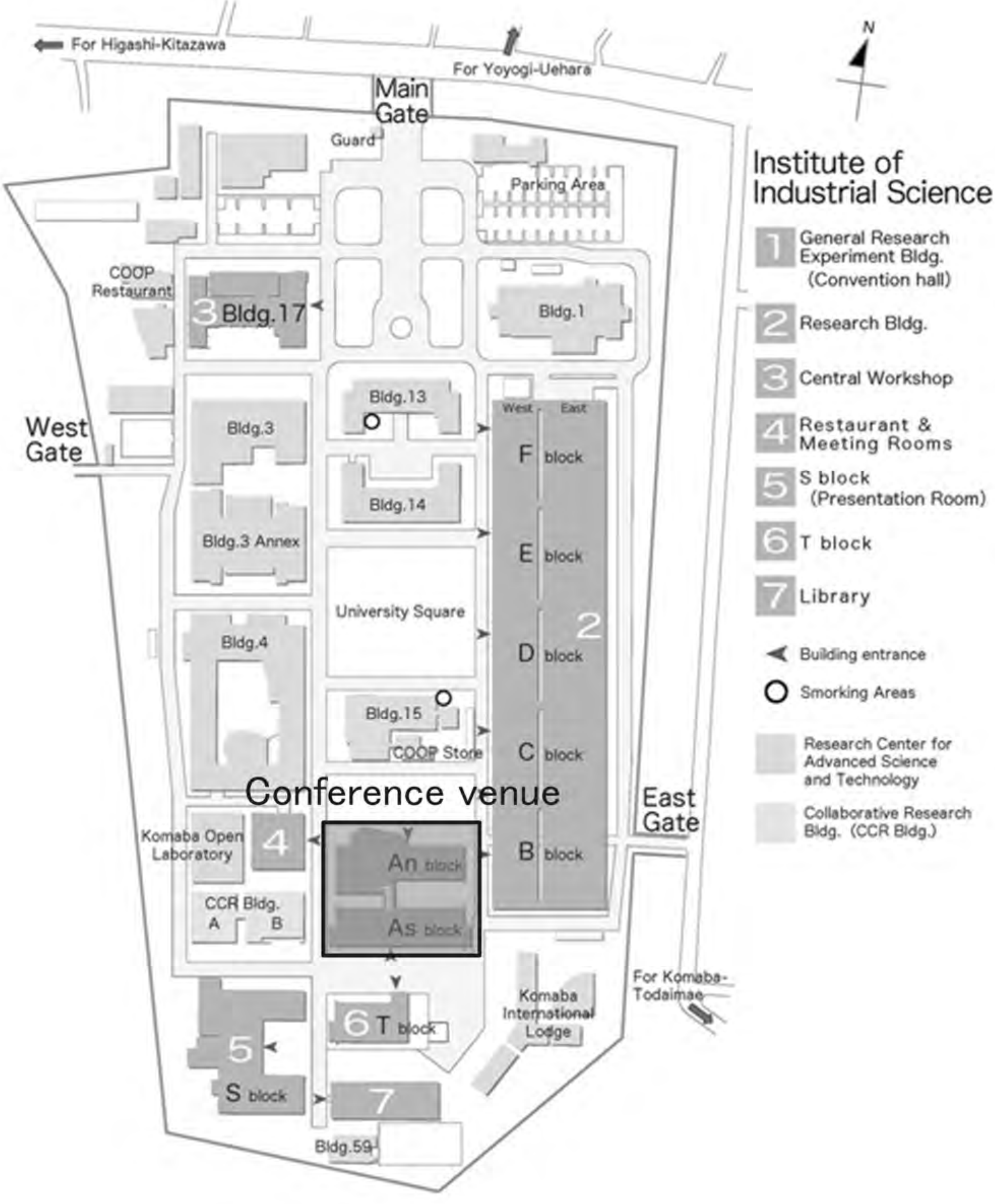
Email:　code2015@iis.u-tokyo.ac.jp

Web: http //icus.iis.u-tokyo.ac.jp/CODE2015.html

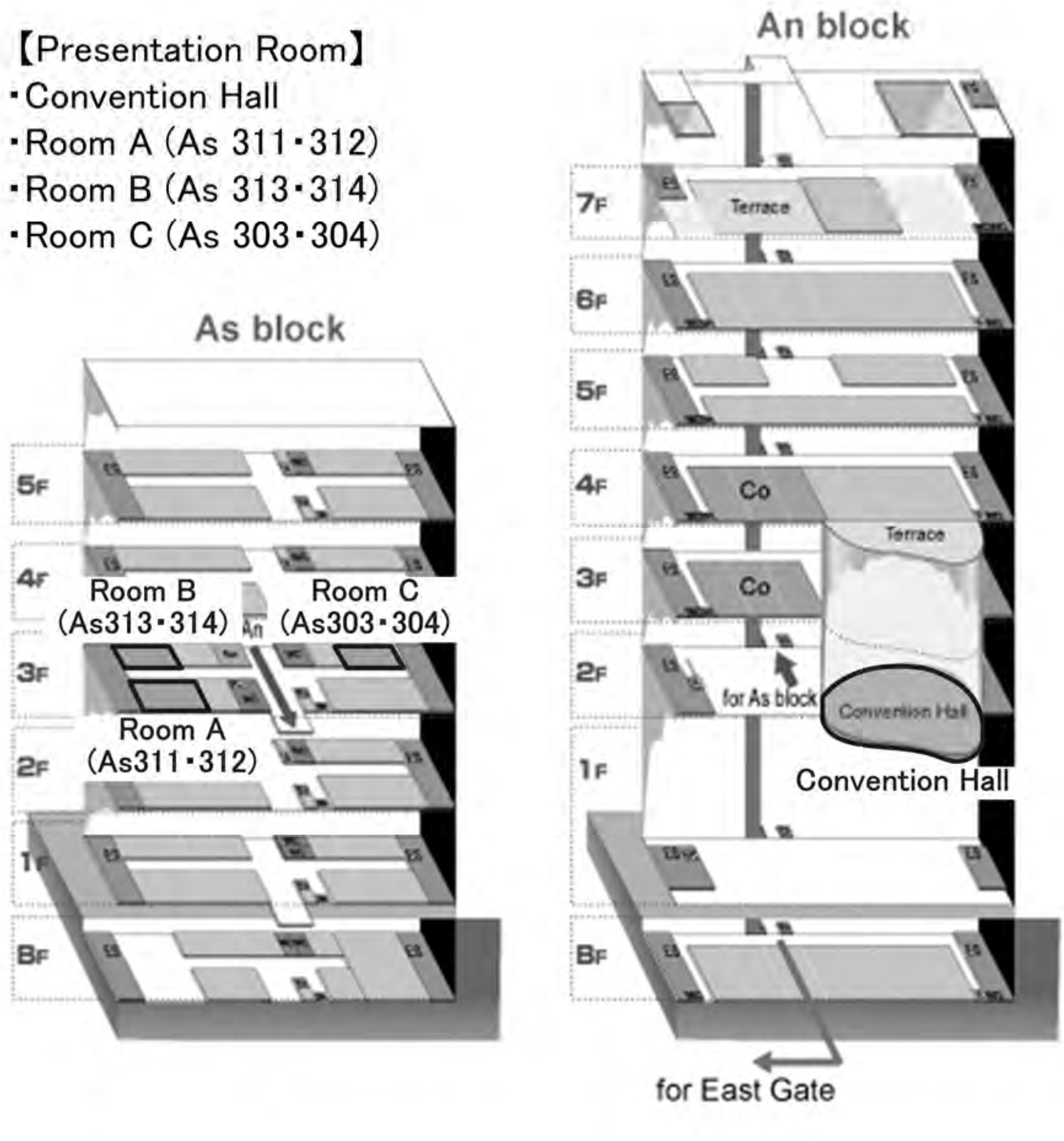
ACCESS to Komaba Research Campus



Map of IIS Campus



Inside map of conference venue



REGISTRATION DESK

The registration desk will be open in front of the Convention Hall for all participants and accompanying guests during the following times:

December 14 12:00 - 13:30

December 15 08:30 - 08:50

The registration fee for participants and students includes one volume of abstract and symposium program, USB proceedings,1 lunch, 3 tea-breaks, and 1 banquet

Foreign Delegates:

USD300 (JPY30,000) Early Bird Registration (Before October 15, 2015)

USD350 (JPY35,000)

Students: (USD100) JPY10,000

WELCOME RECEPTION

The Conference Welcome Reception will be held at Capo Pericano at Komaba campus at 18:00 on Tuesday, December 14, 2015. We will provide the coupon for the welcome reception in your conference bag. Additional tickets for accompanying persons can be purchased from the Registration Desk for USD 40/person.(JPY4500)

LUNCH

The Symposium Lunch will be held at Foyer of Convention Hall on December 14 and 15, 2015. We will provide the coupons for lunch in your conference bag. Additional coupon for accompanying persons can be purchased from the Registration Desk for USD20/person.(JPY2500)

INSTRUCTIONS FOR SPEAKERS

Keynote Speech: 20 minutes presentation

Common Speaker (Presentation):

15 minutes including 12 minutes presentation and 3 minutes discussion

A common computer will be available for speaker presentations if necessary. Because of computer security reasons, we would appreciate it if speakers prepare their own computer.

PROGRAM OVERVIEW

Time	Monday, 14 December		
12:00-13:30	**Registration (Foyer 2nd floor, An block)**		
13:30-13:50	**Opening address (Convention Hall)** **1. Welcome Speech** *(Prof. Teruo Fujii, Director of IIS, The University of Tokyo, Japan)* **2. Welcome Speech** (*Prof. Waonho Yi, Dept. of Architectural Engineering, Kwangwoon Univ., Seoul, Korea*) **3. Opening Remark** (*Prof. Kimiro Meguro, Director of ICUS, IIS, The University of Tokyo, Japan*) Moderators: ***Dr. Hideomi Gokon***		
13:50-14:10 14:10-14:30 14:30-14:50	**Keynote Speech (Convention Hall)** **1. Prof. Waonho Yi** *INTERNATIONAL COLLABORATIVE NETWORK FOR MT. BAEKDU VOLCANIC DISASTER* **2. Prof. Hong Huang** *STUDY ON VULNERABILITY AND COMPREHENSIVE RISK ANALYSIS METHOD AND SYSTEM DEVELOPMENT BASED ON GIS* **3. Prof. Chisachi Kato** *INDUSTRIAL APPLICATIONS OF LARGE-SCALE FLUID FLOW ANALYSIS* Moderators: ***Dr. Ho Choi***		
14:50-15:30	**Group photo – Coffee break**		
	Room As311·312	**Room As313·314**	**Room As303·304**
15:30-17:30	**Session 1:** **Structural Engineering (1)** **Prof. Heecheul Kim**	**Session 2:** **Computer Aided Design** **Prof. Jooho Choi**	**Session 3:** **Biomechanics and Computer supported Collaborative Design** **Dr. Yudai Honma**
18:00-20:00	**Banquet (Capo Pericano)**		

Time	Tuesday, 15 December		
	Room As311·312	**Room As313·314**	**Room As303·304**
09:00-10:30	**Session 4:** **Disaster Risks** **Dr. Takaaki Kato**	**Session 5:** **Computational Mechanics (1)** **Prof. Haengki Lee**	**Session 6:** **Programing and Simulation** **Dr. Muneyoshi Numada**
10:30-11:00	**Coffee break**		
11:00-12:30	**Session 7 :** **Structural Engineering (2)** **Prof. Hong Huang**	**Session 8 :** **Computational Mechanics (2)** **Dr. Kohei Nagai**	
12:30-13:45	**Lunch**		
13:45-15:15	**Session 9:** **Structural Engineering (3)** **Prof. Sangjoon Shin**	**Session 10:** **Computational Mechanics (3)** **Prof. Cheekyeong Kim**	
15:15-15:45	**Coffee break**		
15:45-16:05 16:05-16:25 16:25-16:45	**Keynote Speech (Convention Hall)** **1. Prof. Sangho Lee** *DISASTER INFORMATION MANAGEMENT USING 3D CITY INFORMATION MODEL* **2. Prof. Marie Oshima** *A NEW CHALLENGE: APPLICATIONS OF SIMULATION TO CLINICAL STUDY* **3. Prof. Heoungjae Chun** *BIOMECHANICAL ANALYSIS OF SURGICAL SIMULATION FOR DISC DEGENERATION ON THE ADJACENT SEGMENTS AFTER LUMBAR FUSION AND DECOMPRESSION SURGERY* Moderators: ***Dr. Hideomi Gokon***		
16:45-17:00	**Closing Ceremony (Convention Hall)** **Closing Speech** (*Prof. Waonho Yi, Dept. of Architectural Engineering, Kwangwoon Univ., Seoul, Korea*) **Closing Speech** (*Prof. Kimiro Meguro, Director of ICUS, IIS, The University of Tokyo, Japan*) Moderators: ***Dr. Hideomi Gokon***		

Keynote Speech (Convention Hall)

1. Prof. Waonho Yi

INTERNATIONAL COLLABORATIVE NETWORK FOR MT. BAEKDU VOLCANIC DISASTER

2. Prof. Hong Huang

STUDY ON VULNERABILITY AND COMPREHENSIVE RISK ANALYSIS METHOD AND SYSTEM DEVELOPMENT BASED ON GIS

3. Prof. Chisachi Kato

INDUSTRIAL APPLICATIONS OF LARGE-SCALE FLUID FLOW ANALYSIS - *Present status and future perspectives* -

4. Prof. Sangho Lee

DISASTER INFORMATION MANAGEMENT USING 3D CITY INFORMATION MODEL

5. Prof. Marie Oshima

A NEW CHALLENGE: APPLICATIONS OF SIMULATION TO CLINICAL STUDY

6. Prof. Heongjae Chun

BIOMECHANICAL ANALYSIS OF SURGICAL SIMULATION FOR DISC DEGENERATION ON THE ADJACENT SEGMENTS AFTER LUMBAR FUSION AND DECOMPRESSION SURGERY

TECHNICAL PROGRAMME – DAY 1

PARALLEL SESSION 1:

Structural Engineering (1)

Venue: Room As311·312

Date/Time: 14 December, 2015 MONDAY/ 15:30-17:30
15 minutes including 12 minutes presentation and 3 minutes discussion

Session Chair: Prof. Heecheul Kim

1. **A. KHAN and H.S. KIM**
FREQUENCY RESPONSE ANALYSIS OF SMART COMPOSITE LAMINATES WITH PARTIALLY DEBONDED PIEZOELECTRIC SENSOR

2. **R.NOMURA, S.TAKASE, S. MORIGUCHI and K. TERADA**
MULTISCALE ANARYSISWITH A POROSITY MODEL FOR EVALUATING DAMPING EFFECTSOF COASTALFOREST

3. **S. RAJASEKHARAN, M. NUMADA and K. MEGURO**
SIMPLIFIED NONLINEAR REINFORCED CONCRETE ANALYSIS USING A FINITE ELEMENT MAPPED SPRING NETWORK

4. **Y. YANG, K. MATSUKAWA, H. CHOI and Y. NAKANO**
EVALUATION OF RESIDUAL AXIAL LOAD-CARRYING CAPACITY OF RC COLUMNS AFTER SHEAR FAILURE

5. **P. JIRADILOK and K. NAGAI**
NUMERICAL SIMULATION OF CHLORIDE DIFFUSION IN CRACKED CONCRETE BASED ON TRUSS NETWORK AND RBSM

6. **P.R. DENG and T. MATSUMOTO**
REBAR FORCE ESTIAMTION FROM CRACK MOUTH OPENING DISPLACMENT

7. **C.H. EOM and H.C. KIM**
STRENGTH EVALUATION OF HYDRAULIC CEMENT MORTAR WITH GRAPHENE

PARALLEL SESSION 2:

Computer Aided Design

Venue: Room As313·314

Date/Time: 14 December, 2015 MONDAY/ 15:30-17:30
15 minutes including 12 minutes presentation and 3 minutes discussion

Session Chair: Prof. Jooho Choi

1. **J.C. LEE, J.H. JUNG and C.K. KIM**
REBAR HUB : 3D REBAR AUTO-PLACING SYSTEM BASED ON BIM

2. **J.H. YU and C. KIM**
VIBRATION/SOUND REDUCTION OF AUTOMOTIVE TRANSMISSION HOUSING STRUCTURES

3. **H.S. KIM and J.H. CHOI**
A STUDY ON STATISTICAL VALIDATION OF ELASTO-PLASTIC ANALYSIS OF PISTON INSERTION INTO HOUSING

4. **I. TACHIBANA, S. MORIGUCHI, K. TERADA and S. TAKASE**
A STUDY ON DIRECT PERMEABILITY SIMULATINON OF GEOMATERIALS USING IMMERSED BOUNDARY METHOD

5. **H.H.S. NAGALUR SUBRAVETI, M. IRYO and T. OGUCH**
FEASIBILITY STUDY OF INTERACTIVE PASSING MANEUVER MODEL FOR TWO-WAY TWO-LANE ROADS

6. **J.R. CHO, Y.H. KIM and Y.H. YOON**
μ– MODELING , HOMOGENIZATION AND FATIGUE LIFE EVALUATION OF FABRIC BRAIDED REINFORCED RUBBER HOSE

7. **J. IMANISHI, K. KASHIYAMA and A. KAGEYAMA**
THE 3D MESH MODIFICATION SYSTEM FOR TETRAHEDRON ELEMENTS BASED ON VR TECHNOLOGY

8. **M.G. CHO, H.S. SHIN, J.M. CHOI, S.H. YANG and S.M. CHANG**
MULTISCALE MODELING AND SIMULATION OF POLYMER NANOCOMPOSITES INCLUDING THE AGGLOMERATED FILLERS

PARALLEL SESSION 3:

Biomechanics and Computer supported Collaborative Design

Venue: Room As303·304

Date/Time: 14 December, 2015 MONDAY/ 15:30-17:30
15 minutes including 12 minutes presentation and 3 minutes discussion

Session Chair: Dr. Yudai Honma

1. **M. NUMADA and K. MEGURO**
DISASTER MANAGEMENT SYSTEM "BOSS"
- CASE FOR HUMAN RESOURCES SIMULATION –

2. **H. SONOBE, T. ICHIMURA, P.E.B. QUINAY, K. FUJITA and M. HORI**
THREE DIMENSIONAL FINITE ELEMENT GROUND MOTION ANALYSIS USING GPGPU

3. **T. SHIMURA, T. KATO, T. EDA and D. KOBAYASHI**
MULTI-TIMES SIMULATION ANALYSIS OF HIGH RISK DURING EVACUATION IN A POST-EARTHQUAKE URBAN FIRE

4. **R. YABE, Y. HONMA and S. TORIMITU**
ANALYZING EFFECTIVE ROAD BLOCKING FOR IMPROVING EVACUATION TIME FROM TSUNAMI USING TRFFIC FLOW MODEL

5. **Y. HONMA, Y. MUNEMASA and K. IMAI**
MATHEMATICAL MODEL FOR EQUILIBRIUM AND OPTIMUL LOCATION OF HOUSINGS AND JOBS WITH CONSTRAINED CAPACITY

6. **S. KUBO, R. FUJITA, H. YOSHIDA, M. L. L. WIJERATHNE and M. HORI**
EVACUATION SIMULATION CONSIDERING BUILDING DAMAGES

7. **G. LING, K. KASHIYAMA and J. MATSUMOTO**
A 2D-3D HYBRID MODEL BASED ON STABILIZED FINITE ELEMENT METHOD FOR TSUNAMI RUNUP SIMULATION

8. **X.Z. LU, X. ZENG, T.Y. YANG and Z. XU**
APPLICATION OF THE FEMA P-58 METHOD FOR REGIONAL SEISMIC LOSS PREDICTION

TECHNICAL PROGRAMME – DAY 2

PARALLEL SESSION 4:

Disaster Risks

Venue: Room As311·312

Date/Time: 15 December, 2015 TUESDAY/ 9:00-10:30
15 minutes including 12 minutes presentation and 3 minutes discussion

Session Chair: Dr. Takaaki Kato

1. **Y. BHATTACHARYA and T. KATO**
DEVELOPMENT OF A VOLUNTARY DECISION-MAKING MODEL FOR RESIDENTS DURING POST-DISASTER RECOVERY

2. **M. OTA, G. LING and K. KASHIYAMA**
STABILIZED FINITE ELEMENT METHOD BASED ON VOF METHOD FOR FREE SURFACE FLOW USING LES

3. **J.P. ZHANG, J.G. CHEN and H.Y. YUAN**
PRE-ESTIMATION METHOD FOR LANDSLIDE HAZARD WITH MONITORING AND SIMULATION

4. **T. SRITARAPIPAT and W. TAKEUCHI**
PREPARING SAFE URBAN ROADS FOR FLOOD AND EARTHQUAKE IN YANGON, MYANMAR

5. **T. KOTANI, S. TAKASE, S.MORIGUCHI, K. TERADA,Y. FUKUTANI, Y. Otake, K. NOJIMA and M. SAKURABA**
PROBABILISTICANALYSIS OF TSUNAMI HAZARDUSINGNUMERICAL SIMULATIONSAND RESPONSESURFACE

6. **H. GOKON, S. HAYASHI, S. KOSHIMURA and K. MEGURO**
TOWARDS AN EXPECTATION OF TSUNAMI FEATURES USING SAR DATA

PARALLEL SESSION 5:

Computational Mechanics (1)

Venue: Room As313·314

Date/Time: 15 December, 2015 TUESDAY/ 9:00-10:30
15 minutes including 12 minutes presentation and 3 minutes discussion

Session Chair: Prof. Haengki Lee

1. **J.W. JUNG, H.W. JANG and J.W. HONG**
NUMERICAL SIMULATION OF HIGH VELOCITY IMPACT ON STEEL-PLATE CONCRETE WALL

2. **S. TAKATSU and M. NUMADA**
INFORMATION SYSTEM "COCOA" FOR EFFECTIVE EVACUATION OPERATION BY PERSONAL IDENTITY NUMBER

3. **R.OKAMURA, H. YOSHIKAWA, T. TAKAHASHI and K. KASHIYAMA**
A ROAD TRAFFIC NOISE SIMULATION METHOD BASED ONACOUSTIC WAVE THEORYUSINGTIME DOMAIN FM-BEM

4. **J.M. CHOI, J.H. MOON and M.G. CHO**
A METHOD OF MOLECULAR COMPUTATION OF PHOTO-RESPONSIVE POLYMER REINFORCED WITH NANOPARTICLES

5. **S.HORIIKE and K. KASHIYAMA**
STABILIZED FINITE ELEMENT METHOD FORWIND FLOW ANALYSISWITHPLANT CANOPY

6. **J.Q. HAN, J.G. CHEN, H.Y. YUAN and J.P. ZHANG**
NUMERICAL INVESTIGATION OF NATURAL CONVECTION EFFECTS COUPLED WITH THERMOACOUSTIC OSCILLATING FLOW IN DIFFERENT GRAVITY INCLINATION

PARALLEL SESSION 6:

Programing and Simulation

Venue: Room As303·304

Date/Time: 15 December, 2015 TUESDAY/ 9:00-10:30
15 minutes including 12 minutes presentation and 3 minutes discussion

Session Chair: Muneyoshi Numada

1. **J. LEE and S.W. YOON**
STRUCTURAL TOPOLOGY OPTIMIZATION OF ELECTROMAGNETIC VIBRATION ENERGY HARVESTERS

2. **B. SU, H. HUANG and Y. LI**
OIL SPILL SPREAD SIMULATION MODEL ON COMPLEX TOPOGRAPHY BASED ON HYDRODYNAMICS

3. **H.Y. CHUNG, J.S. PARK, J.M. CHOI, J.H. YUN and M.G. CHO**
A FINITE ELEMENT STUDY ABOUT MECHANICAL FRUSTRATION OF NEMATIC SOLIDS INDUCED BY DISCLINATION DEFECT

4. **M. IRYO and W.K.M. ALHAJYASEEN**
PEDESTRIAN SPEED CHANGE MODEL FOR SAFETY ASSESSMENT AT SIGNALIZED CROSSWALKS

5. **E.Y. KIM and M.G. CHO**
NON-INTRUSIVE REDUCTION METHOD WITH CONNECTED ELEMENTS

6. **G.H. YOON**
STRESS CONSTRAINTS FOR DUCTILE AND BRITTLE MATERIALS IN FLUID-STRUCTURE INTERACTION SYSTEM

PARALLEL SESSION 7:

Structural Engineering (2)

Venue: Room As311·312

Date/Time: 15 December, 2015 TUESDAY/ 11:00-12:30
15 minutes including 12 minutes presentation and 3 minutes discussion

Session Chair: Prof. Hong Huang

1. **H. SATO, M. KOSHIHARA and T. MIYAKE**
OPTIMAL DESIGN OF TIMBER THROUGH COLUMN

2. **Y. PATEL and K.MEGURO**
NUMERICAL ANALYSIS OF 2D-INFILLED FRAME WITH INTERFACE MATERIALS BETWEEN REINFORCED CONCRETE FRAME AND INFILL WALL

3. **B.J. YANG, HAMMAD, R. KHALID and H.K. LEE**
INFLUENCES OF ENTRAPPED AIR VOIDS ON THE MECHANICAL AND STRENGTHENING CHARACTERISTICS OF SPRAYED FIBER-REINFORCED POLYMERIC (SFRP) COMPOSITES: MICROMECHANICS-BASED PARAMETRIC ANALYSIS

4. **D.H. SHIN, S.J. HONG and H.J. KIM**
EQUATION FOR PREDICTIVE HORIZONTAL RESPONSE SPECTARA IN KOREA

5. **M. SAFDAR, T. MATSUMAOTO and K.KAKUMA**
FINITE ELEMENT ANALYSIS OF REINFORCED CONCRETE BEAMS REPAIRED WITH ULTRA-HIGH PERFORMANCE FIBER REINFORCED CONCRETE (UHPFRC)

6. **T. ASAI, K. MATSUKAWA, H. CHOI and Y. NAKANO**
RESPONSE ESTIMATION METHOD OF REINFORCEDCONCRETE BUILDINGS DUE TO WATERBORNE DEBRIS IMPACT LOADS

PARALLEL SESSION 8:

Computational Mechanics (2)

Venue: Room As313·314

Date/Time: 15 December, 2015 TUESDAY/ 11:00-12:30
15 minutes including 12 minutes presentation and 3 minutes discussion

Session Chair: Dr. Kohei Nagai

1. **J.W. KANG, H.D. Lee and B. KIM**
FULL-WAVEFORM INVERSION FOR MATERIAL PROFILE RECONSTRUCTION IN PML-TRUNCATED DOMAINS

2. **S.Y. Tang, X.M. Shu, S.F. Shen and J. Hu**
STUDY ON PORTABLE CELLPHONE DETECTOR FOR EARTHQUAKE

3. **Z.Y. KANG, T.Q. BUI and S. HIROSE**
CRACK PROPAGATION SIMULATION BY THE EXTENDED CONSECUTIVE-INTERPOLATION FINITE ELEMENT METHOD (XCQ4)

4. **L.EDDY and K. NAGAI**
SIMULATION OF FAILURE PROCESS OF REINFORCED CONCRETE BEAM COLUMN JOINT WITH MECHANICAL ANCHORAGES BY 3D RBSM

5. **K.W. KIM, M.K. KIM, W.Y. CHO and K.Y. YEAU**
FINITE ELEMENT ANALYSIS OF BURIED PIPELINE ON FORST REGION CONSIDERING FROST HEAVE

6. **C.K. KIM and S.E. LEE**
STRAUTO: PARAMETRIC STRUCTURAL MODELLING AND OPTIMIZATION SYSTEM

PARALLEL SESSION 9:

Structural Engineering (3)

Venue: Room As311·312

Date/Time: 15 December, 2015 TUESDAY/ 13:45-15:15
15 minutes including 12 minutes presentation and 3 minutes discussion

Session Chairs: Prof. Sangjoon Shin

1. **C.K. GADAGAMMA and K. MEGURO**
NUMERICAL EVALUATION OF DAMAGE STATES AND SEISMIC CAPACITY OF REINFORCED CONCRETE COLUMNS

2. **A.A.M. DRAR and T. MATSUMOTO**
DEVELOPING A NUMERICAL METHOD FOR FATIGUE LIFE PREDICTION OF RC SLABS REINFORCED WITH PLAIN BARS

3. **S. EDALO and T. MATSUMOTO**
FATIGUE ANALYSIS OF FROST DAMAGED RC SLABS SUBJECTED TO MOVING LOAD BASED ON BRIDGING STRESS DEGRADATION CONCEPT

4. **J.S. KIM, T.H. LEE and T.S. HAN**
EFFECT OF THE BASE ISOLATION SYSTEM ON THE LNG STORAGE TANK USING PROBABILISTIC METHOD

5. **T.M. KIM, D.H. KIM, M.K. KIM and Y.M. LIM**
MONITORING OF A FULL SCALE PRESTRESSD CONCRETE GIRDER DURING CONSTRUCTION PROCESS

6. **I.TSUWA, T.NAKAGAWA and M.KOSHIHARA**
3D STRUCTURAL ANALYSIS MODEL AND EARTHQUAKE RESPSONSE ANALYSIS OF WOODEN FIVE-STORIED PAGODA

PARALLEL SESSION 10:

Computational Mechanics (3)

Venue: Room As313·312

Date/Time: 15 December, 2015 TUESDAY/ 13:45-15:15
15 minutes including 12 minutes presentation and 3 minutes discussion

Session Chairs: Prof. Cheekyeong Kim

1. **K. PARK, H. T. KIM and D.J. KIM**
GENERALIZED FINITE ELEMENT FORMULTATION ON FIBER BEAM ELEMENTS FOR DISTRIBUTED PLASTICITY ANALYSIS

2. **K. YOON, P.S. LEE and D.N. KIM**
FINITE ELEMENT FORMULATION FOR FUNCTIONALLY GRADED BEAM STRUCTURES

3. **T. YOSHIMACHI, M. TANIGAWA and K. KASHIYAMA**
ACOUSTIC WAVE SIMULATIONBASED ONPSEUDOIMPULSE RESPONSE

4. **K.T. KANG, S.H. LIM and H.J. CHUN**
EVALUATION OF CONTACT AREA ON KNEE JOINT CARTILAGE USING IN-VIVO SUBJECT-SPECIFIC FINITE ELEMENT MODEL

5. **H. CHO, H.S. JOO, C.W. PARK and S.J. SHIN**
NONLINEAR FLEXIBLE MULTIBODY APPROACHES USING CO-ROTATIONAL FINITE ELEMENTS

6. **H.C. NOH**
APPLICATION OF TRANSFORMED AUTOCORRELATION FOR STRUCTURAL SYSTEMS WITH LOGNORMALLY DISTRIBUTED RANDOM VARIABLES

CODE2015

KEYNOTES

INTERNATIONAL COLLABORATIVE NETWORK FOR MT. BAEKDU VOLCANIC DISASTER

Waon-Ho Yi[1] **and Sungsu Lee**[2]

[1] *Professor, Dept. of Architectural Engineering, Kwangwoon Univ., Seoul, Korea,*
[2] *Professor, School for Civil Engineering, Chungbuk National University, Cheongju, Korea,*
Correspond to Prof. Waon-Ho Yi (whyi@kw.ac.kr)

Keywords*: Volcanic Disasters, Online Networks, International Expert Database, International Collaboration, VDPRC*

1. VOLCANIC DISASTER PREPAREDNESS RESEARCH CENTER

The volcanic eruption in Iceland in 2010 had put air transport throughout Europe on hold for almost two months. Another series of eruptions of Mt. Shinmoedake, in the island of Kyushu, southern Japan, occurred in 2011. In addition, the possibility of Mt. Baekdu eruption again has been presented since 2002 so that national interest in volcanic eruptions has recently been on the rise. With all of these, the demands for volcanic disaster response measures are being discussed.

However, little research has been carried out in Korea on volcanic disasters so far. As such, there are only a handful of experts in this field, and the focus of research manpower and capacity of related fields are scattered throughout Korea that the consolidation of the capacity to respond to volcanic disasters as a varying complex catastrophe is pressing.

Accordingly, "Volcanic Disaster Preparedness Research Center" was launched for R&D projects of disaster preparedness technologies since 2012.

These projects of the center is expected to gather prompt information about volcanic activities, enhance the capacity to convey the information nationwide, evaluate national volcanic disaster risks to mitigate damages from the disasters, and consolidate the ability to respond to them. It is also to solve early on the problem of a lack of experience and technology to respond to this new type of disaster, evaluate its risks, and consolidate the technologies to respond to them for a safe society.

2. INTERNATIONAL COLLABORATIVE NETWORKS FOR VOLCANIC DISASTERS

The purpose of the project is to vitalize an online network and an expert group network that specializes in volcanic disaster response as an international collaboration system and help the early introduction of advanced technologies. For this, the project is to build an international expert group network and organize joint research to build a network base for international collaboration.

For online networks, 1) similar networks both in Korea and international communities are investigated and analyzed, 2) an online forum (VDPedia) is established to respond to volcanic disasters with the measures drawn up, 3) the data bank of foreign technologies and materials related to volcanic disasters and a system to convey information, are built.

For building databases, 1) Korean and global technologies specializing in volcanic disasters are investigated, 2) technologies held by related foreign institutes are investigated and databases are built, 3) a database of international experts is built.

For international collaboration, 1) a framework for an international academic congress on how to respond to volcanic disasters is prepared, and 2) developing countries of frequent volcanic disasters was collaborated with.

Fig. 1 Scope of International Collaborative Network

3. CONCLUSIONS

The project produced an online work field, called VDPedia which is a website incorporating cyber forum for experts in volcanic disasters and database showing information on volcanic damage such as area, casualties, and etc. Firstly, VDPedia is providing the online space making experts in volcanic activity, volcanic disaster, and emergency management discuss on the activity and induced disaster. Its goal is establishing the international cooperation system on the volcanic disaster and it makes us quickly response to recover the devastated district. It is also available to secure technical components via various expertise establishments and its sharing.

Furthermore, VDPedia is providing current status on the volcanic disaster with a particular emphasis on Asia. The information is mainly focusing on volcanic activity-induced damages.

At last, VDPedia hopes to be a hub for continuous research and discussion on response to the volcanic disaster.

4. ACKNOWLEDGEMENT

This research was supported by a grant [MPSS-NH-2015-81] through the Natural Hazard Mitigation Research Group funded by Ministry of Public Safety and Security of Korean government.

STUDY ON VULNERABILITY AND COMPREHENSIVE RISK ANALYSIS METHOD AND SYSTEM DEVELOPMENT BASED ON GIS

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***Keywords**: Vulnerability, Integrated risk analysis, Multi-hazard, Disaster chain, GIS*

1. INTRODUCTION

Increasing various risk sources and factors in cities make public incidents complicated and diversified. Multi-hazard and disaster chain are typical characteristics and big challenges. As prevention is the premise for public safety, the vulnerability analysis and comprehensive risk analysis are highly required.

In this study, the method of the combination of stochastic analysis and dynamic simulation were developed to study the vulnerability analysis and comprehensive risk analysis in urban area, especially focusing on the multi-hazard and disaster chain. Then, an integrated system based on GIS was developed which has been applied in the emergency department of several cities.

2. METHODS

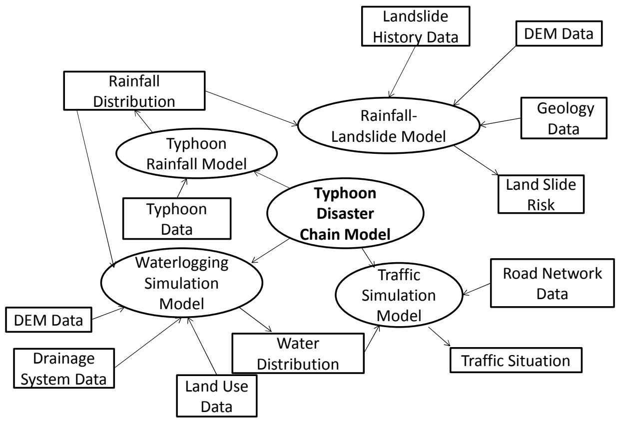
An emergency management concept based on the triangle theory of public safety was proposed by Fan [1]. The theory considers that the whole process of the emergency and its response includes three key aspects: the emergencies, the acceptors, and the emergency management.

In this study, a comprehensive risk assessment model was established based on the triangle theory of public safety. The model considers risk from three aspects: hazardous of emergencies, vulnerability of acceptors, and capacity of emergency management. The system takes all the main factors of public safety into account, and lays a good foundation for the comprehensive risk assessment of urban public safety.

Recently, multi-hazard and disaster chain become typical characteristics and big challenges to urban public safety. The multi-hazard and disaster chain includes typhoon, heavy rain, water-logging, debris, dangerous gas leakage, explosion, fire, traffic congestion and so on. Such emergencies may cause great casualties and economic losses. It is important to improve the quantitative risk analysis method of disaster chains.

In this study, the evolution of disaster chain is simulated and the effect's region and level is analyzed for risk analysis. Take typhoon for example, the structure diagram of disaster chain risk assessment model is shown in Figure 1. Typhoon brings rainstorm, rainstorm cause regional landslide and waterlogging, waterlogging leads to traffic congestion. The disaster chain model integrates multiple disaster simulation models, including typhoon wind field simulation model, typhoon rainfall simulation model, rainfall-runoff simulation model, and traffic simulation model. The intensity and character of different emergency events were simulated using these models. Therefore, spatial-temporal dynamic risk analysis could be achieved.

Figure 1. Structure diagram of disaster chain risk assessment model



An integrated system based on GIS was developed to apply the risk analysis method. The main functions of the system are comprehensive risk map, dynamic risk assessment, emergency response capability analysis, and event risk management. The system has been used in several cities and achieved good results.

3. CONCLUSIONS

In this study, the method of vulnerability analysis and comprehensive risk analysis for multi-hazard and disaster chain was developed. An integrated system based on GIS was developed to apply the risk analysis method to actual cities. The method and system provide a good approach for public safety assurance.

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INDUSTRIAL APPLICATIONS OF LARGE-SCALE FLUID FLOW ANALYSIS

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Keywords: *Large-scale simulation, Industrial Application, Computational Fluid Dynamics, Aeroacoustics*

For the predictions of turbomachinery flows and flow-related phenomena that take place in turbomachinery such as vibrations and noise, the steady and/or unsteady RANS (Reynolds-Averaged Navier-Stokes) equations have been widely used in the industries. Since they model the effects of turbulent eddies in all the scales, simulations based on RANS have an inevitable limitation for their prediction accuracy, which has been preventing them from becoming a complete alternative for testing. Recently, hybrid methods such as DES (Detached-Eddy Simulation) that combines RANS near wall and LES (Large-Eddy Simulation) elsewhere has been proposed and applied to the predictions of industrial flows such as those in turbomachinery and those around an automobile. DES relies on, however, RANS model near the wall and therefore the prediction accuracy for near-wall velocity profiles and/or separation from the wall, which is critically important for turbomachinery flows, does not essentially go beyond that of RANS.

On the other hand, with tremendous increase in performance of supercomputers, the range of applications of computational methods to predict fluid flows and flow-related phenomena are spreading rapidly. In fact, as of November 2014, the theoretical peak performance of high-end supercomputers in the world are in several tens peta-flops and it is expected to reach one exa-flops in around 2020. Fluid-flow computations that use several tens billion grids has already become feasible and the maximum number of the computational grids is expected to reach a trillion even for industrial applications in 2020.

With that number of the computational grids, fully-resolved LES will become feasible for almost all the types of turbomachinery flows. Since fully-resolved LES directly computes smallest but active eddies in the flows, it can provide as accurate results as DNS (Direct Numerical Simulation) does. The only difference between the fully-resolved LES and DNS is that the former models the effects of eddies that are responsible for dissipation while the latter computes them directly with the computational grids.

Our ultimate goal is to provide industrial users with general purpose simulation software, or to be more exact, software system capable of performing fully-resolved LES for industrial flows. To that end, we have been developing FrontFlow/blue system. This presentation will give a brief introduction to the system, and explain numerical methods and particular features of the system. The latest applications that uses several tens billion grids will also be presented. Finally, our perspectives for the computations of the turbomachinery flows for 2020 and afterwards will be given and plans for the near-future projects will also be explained.

DISASTER INFORMATION MANAGEMENT USING 3D CITY INFORMATION MODEL

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Keywords: *Disaster Information Management, City Information Modeling, Information Model*

1. INTRODUCTION

Development of information modeling technology have become an environment in which there are no major difficulties in expressing 3D objects with attributes. The approaches should have a different method in case of city information modeling compared to an individual structure. This study discusses the considerations to utilize the city information model for managing the disaster information.

2. CITY INFORMATION MODELING FOR DISASTER INFORMATION MANAGEMENT

The building and the city information modeling have a similarity in aspects of 3D geometric model implementation and management of semantic meanings by attributes. The strategy for city information modeling, however, should be different from building information modeling by following characteristics; the city information model includes numerous individual models while BIM focuses the only one structure, the city information model have to consider the terrain features, and the objectives of the city and building applications are different.

Level of Development (LoD). Modeling is the process that abstracts required information from the real world. The required information depends on the tasks of applications. The LoD guides the development steps for geometric features and their corresponding semantic attributes. The low level of LoD model guarantees the effective simulation process in case of city information model-based application which contains huge data, while the high level model can provide detailed information.

The relationships between facilities. The city facilities are linked closely. For example, the height of terrain influences skyline of buildings directly, the road conditions are the one of factors to estimate the evacuation route. Therefore, it is indispensable part to consider the relationship between city facilities. The authors were proposed the terrain-centered identifiers to link the information of facilities according to the features that every city facility is located on terrain [1]. Especially, relationship elements in data schema for city information modeling can guarantee the consistency of connection method [2].

Management of dynamic data. City information model-based applications require additional dynamic data such as temperature or water level according to the task of simulation. The dynamic data should be managed through generic elements in data schema [2]. Actual dynamic data stored in external database can be connected with the city information model by generic ones. These features can support the reuse of the city information model in other applications. Figure 1 represents the city information modeling concept based on the CityGML data schema. Figure 2 shows an example of flooding simulation using city information model.

3. CONCLUSIONS

The authors emphasized the LoD of 3D models, the relationship between city facilities, and management of external dynamic data to build the city information model for disaster information management. It is a significant issue to support the disaster information management using 3D city information model. Therefore, concrete application processes based on the city information model are required through future studies.

Figure 1. City information modeling concept

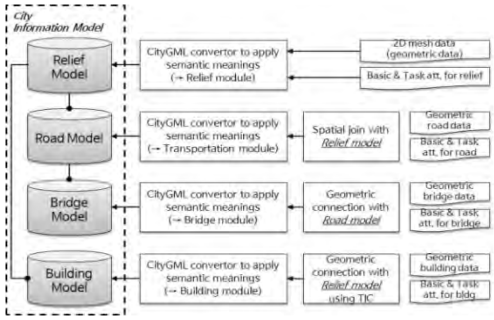

Figure 2. An example of model-based flooding simulation (CityGML LoD1 model with hydraulic data)

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No. 2011-0030040).

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A NEW CHALLENGE: APPLICATIONS OF SIMULATION TO CLINICAL STUDY

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***Keywords**: Multi-Scale Simulation, Medical Image Data, Circulatory System, The Circle of Willis, Carotid Artery Stenting, Carotid Endarterectomy*

1. INTRODUCTION

A technique of simulation has been widely used in various fields of engineering. Nowadays, it has been expanding its horizon to the medical and clinical studies. The authors have been developing an integrated simulation system combined with medical image data to investigate the effects of the surgery such as carotid artery stenting (CAS) or carotid endarterectomy (CEA) on the cerebrovascular circulation for a patient with a serious stenosis due to atherosclerosis. Since widening the stenosis area affects not only the diseased area but also the entire blood circulatory system, it is necessary to consider the entire circulatory system. Diameters of blood vessels in the circulatory system vary in orders of magnitude from mm to μm. In order to simulate the entire circulatory system, the paper developed the multi-scale numerical method based on the one dimension (1D) - zero dimension (0D) [1] or the three dimension (3D) – 1D – 0D model [2]. The present method was applied to the patients with stenosis and the results were compared to the measurement data.

2. NUMERICAL METHOD

Figure 1 shows the schematic illustration of the present multi-scale simulation system.

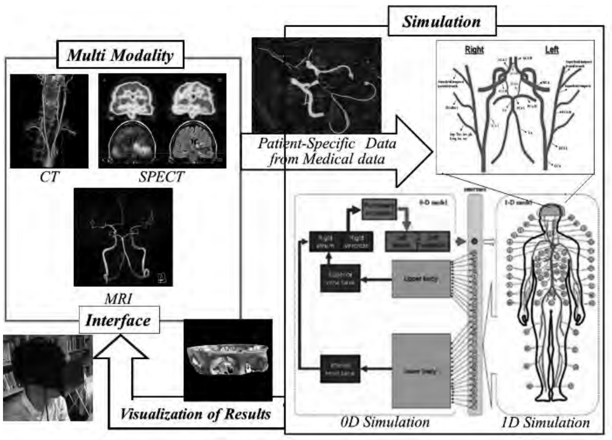

Figure 1: The schematic illustration of the multi-scale simulation system

First of all, the patient vascular geometry of the circle of Wills is extracted from the computer tomography (CT) or the magnetic resonance angiography (MRA) data using our modeling program, V-Modeler [3]. Second of all, the patient-specific geometric model was incorporated into original 1D-0D simulation for the entire circulatory system. The governing equations for the 1D model are the equations of mass conservation, momentum conservation, and the relationship between the pressure and the area while those for the 0D model are the equations of mass and momentums conservation. Finally, the results are visualized in the 3D by remapping the 1D results onto the patient-specific 3D vascular geometry.

When the patient-specific geometry was applied to the 1D-0D simulation, a deviation from the original 1D-0D simulation [1] rises. In order to minimize the deviation, the single photon emission computed tomography (SPECT) data were applied as the reference data to the efferent arteries. Three cases were simulated. The results showed the good agreement with the phase-contrast (PC)-MRA data.

3. CONCLUSIONS

The paper presented an integrated numerical system of the 1D-0D simulation with the entire circulatory system for an individual patient using the patient data from the medical image data. The numerical method was developed to adjust the differences between the original 1D-0D and the resulting flow rates using the SPECT data. The present method was applied to three different patients and the results collated well with the measurement data.

ACKNOWLEDGEMENTS

This study is supported by the Grant-in-Aid for Scientific Research (B) (No.24300158) by Ministry of Education, Culture, Sports, Science and Technology in Japan. The authors would like to thank Dr. Shigeli Yamada (Rakuwakai Otowa Hospital) for the medical image data, and Professor Fuyou Liang (Shanghai Jiao Tong University, China) and Professor Shu Takagi (The University of Tokyo, Japan) for their variable discussion on the 1D-0D simulation.

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BIOMECHANICAL ANALYSIS OF SURGICAL SIMULATION FOR DISC DEGENERATION ON THE ADJACENT SEGMENTS AFTER LUMBAR FUSION AND DECOMPRESSION SURGERY

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***Keywords**: Disc degeneration, Lumbar fusion surgery, Lumbar spinal stenosis, Spinous process osteotomies, Conventional laminectomy, Adjacent segment disease, Finite element analysis*

1. INTRODUCTION

The presence of degeneration alters the stress within that particular degenerated disc [1]. The state of degeneration of the disc adjacent to a single level fusion and after lumbar decompression surgery would influence the rate of subsequent further degeneration of that same adjacent disc. Therefore, the purpose of this study was to investigate the biomechanical effect of the disc degeneration at the adjacent segment on the stress of the corresponding segment after one segment lumbar fusion and two different lumbar decompression surgeries using validated Finite Element (FE) models.

2. MATERIAL AND METHOD

Three validated L2–L5 FE models with different grades of disc degeneration (normal, mild, moderate) at the L2–L5 were simulated. Based on the intact models that represented each grade of disc degeneration, the matched L3–L4 instrumented fusion and decompression using conventional laminectomy (CL) and spinous process osteotomy (SPiO) models were developed. Loading and boundary conditions were referred to our previous study using spine FE model [2].

3. RESULT

One-level lumbar fusion surgery

Disc degeneration led to an increase of maximal von Mises stress of annulus fibrosus at this degenerated disc, related to disc degeneration under flexion, extension, lateral bending and torsion moments. Furthermore, the fusion also increased a maximal von Mises stress of annulus fibrous at both proximal and distal adjacent segments under hybrid protocol. The increases of annular stress were greater at the proximal adjacent segment than those at distal adjacent segment. However, the contribution of the fusion surgery to the increment rate of annulus fibrosus stress at the adjacent segment did not increase in relation with disc degeneration states at the adjacent segment (Fig. 1).

Conventional laminectomy and spinous process osteotomy lumbar decompression surgery

The CL model and moderate disc degeneration model demonstrated a larger annulus stress under all four moments than those in the SPiO model and healthy disc model, respectively. Therefore, the decompression level (L3-L4) in the CL model with moderate disc degeneration showed the highest annulus stress. The percent change at L3-L4 from intact to decompression models was less in the moderate disc degeneration model compared to healthy disc model (Fig 2 and 3).

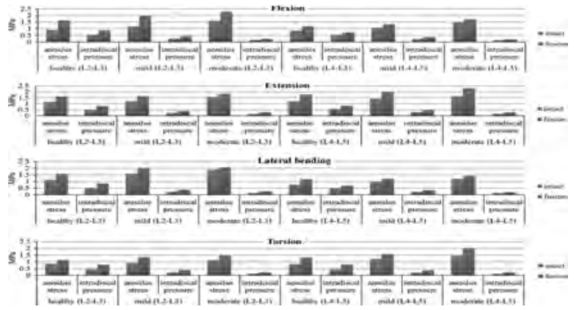

Figure. 1. The effect of disc degeneration and fusion on maximal von Mises stress of AF and intradiscal pressure of NP at L2–L3 and L4–L5 segments under hybrid testing protocol

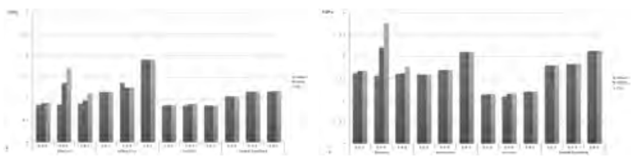

Figure 2. The maximal von Mises stress in the AF of the intact, (a) SiPO and (b) CL models related to disc degeneration under four moments

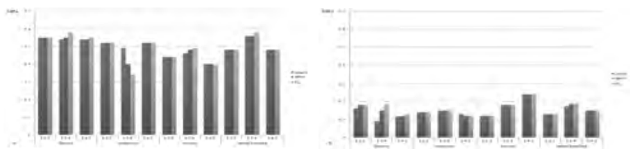

Figure 3. NP in the intact, (a) SiPO and (b) CL models related to disc degeneration

4. CONCLUSIONS

In conclusion, disc degeneration per se and lumbar fusion and decompression can cause the increase of disc stress at the adjacent segment. However, they seem not to act synergistically. In addition, although the CL model in the moderate disc degeneration showed the highest annulus stress, the degenerative models would be less influenced by the decompression technique.

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Technical Program – Day 1

Session 1

FREQUENCY RESPONSE ANALYSIS OF SMART COMPOSITE LAMINATES WITH PARTIALLY DEBONDED PIEZOELECTRIC SENSOR

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Keywords*: composite laminates, piezoelectric sensor, debonding, layerwise theory, frequency response*

1. INTRODUCTION

In the last few decades, composite laminates bonded or embedded with smart materials, named as smart composite laminates, have been developed and widely used in space vehicles, fixed-wing aircraft, rotary-wing aircraft, civil structures, marine systems, automotive systems, robotics systems, machine tools, and medical systems [1]. Piezoelectric material are the most popular smart materials. In smart composite laminates, piezoelectric sensors and actuators are used for active vibration control, delamination detection and classification, structural health monitoring, etc.

Literature review reveals that in most of the applications, the piezoelectric patches are considered to be perfectly bonded to the host structures [2]. However, the debonding failures between the host structures and piezoelectric elements may occur during the service life, due to bonding defects, impact loading or high peeling stress concentration at the bonding edge. Debonded sensor may results in an erroneous sensing signal which may adversely affect the proposed applications. Therefore, it is important to evaluate the effects of partial sensor debonding on the dynamic behavior of the smart structures.

2. MATHEMATICAL FORMULATION

Piezoelectric sensors and actuators are considered as additional layers of the composite laminate. Improved layerwise theory with Heaviside unit step function [3] is employed for the displacement field, while the potential variation through the thickness of piezoelectric patches is modeled using higher order electric potential field. The coupled electro-mechanical field with discontinuities at the debonded interface, is implemented with finite element method. The governing equation is obtained through the Extended Hamilton's principle. The developed model is numerically implemented on a smart composite plate with one piezoelectric actuator and one piezoelectric sensor.

3. FREQUENCY RESPONSE ANALYSIS

To obtain the frequency response of the smart composite plate with partially debonded sensor, the plate is excited by an electric harmonic load with the magnitude of 1V. General mode superposition method is applied to solve the 2^{nd}-order governing differential equation in frequency domain. For partial debonding at the right side edge of the sensor, the decrement in the magnitude of each peak in the frequency response curves, normalized with respect to perfectly bonded sensor case, is shown in the Figure 1. It is observed that the magnitude of sensor output at the resonant frequency has reduced almost linearly with increasing length of debonding.

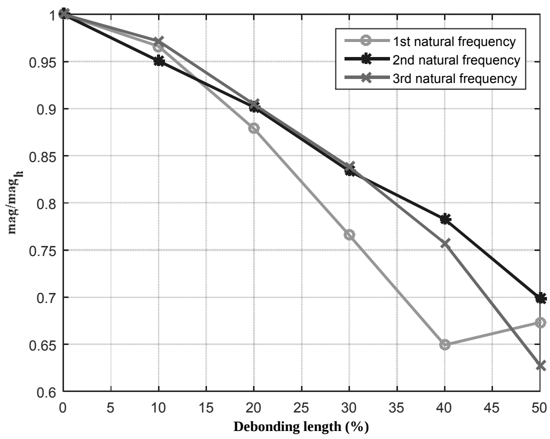

Figure 1. Effect of partial edge debonding in the sensor on the magnitude of peaks in the FRF of sensor output

3. CONCLUSIONS

Partial sensor debonding at the edge of piezoelectric sensor in smart composite laminates results in the decrement of the magnitude of sensor output at the resonant frequencies. The shift in resonant frequencies is subtle.

ACKNOWLEDGEMENT

This work was supported by the Technology Innovation Program (10048305, Launching Plug-in Digital Analysis Framework for Modular system Design) funded by the Ministry of Trade, Industry & Energy (MI, Korea).

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MULTISCALE ANARYSIS WITH A POROSITY MODEL

FOR EVALUATING DAMPING EFFECTS OF COASTAL FOREST

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***Keywords**: Coastal forest, Multiscale analysis, Tsunami run-up, Porous media, Stabilized finite element method*

1. INTORODUCTION

A coastal forest is often built for disaster reduction against tsunami. The quantitative evaluation of its damping effect is required to predict the inundation area and the damages on structures behind the forest. Although several studies have been conducted on this subject of study, most of them are based on the hydraulic experiments. Therefore, it is still difficult to estimate the damping effect quantitatively in real situations. To solve this problem, we propose a multiscale numerical approach that enables us to evaluate the damping effect of the coastal forest in a wide area with relatively low computational costs. The proposed method also allows us to evaluate the influence of the fluid force acting on structures. In this study, a simple numerical example is conducted to demonstrate the performance of the proposed method.

2. NUMERICAL ANARYSIS

The proposed multiscale numerical analysis method is a sort of homogenization methods and designed to characterize the damping effect of coastal forests by performing numerical analyses of the meso- and micro-structures. More specifically, a coastal forest is stratified into three spatial scales as shown in Figure 1; the branch-scale (micro), the tree-scale (meso) and the forest-scale (macro) and the lower-scale analysis is expected to provide the damping effect for the upper-scale analysis. To transmit the lower-scale information about the damping effect to the upper-scale, a porosity model is employed. That is, by regarding the coastal forest as a porous media in the forest-scale, we expect that the overall damping effect can be evaluated by the mechanical behavior at tree-scale.

In numerical analyses, fluid flow is simulated with the stabilized Finite Element Method (FEM) developed to solve the Navier-Stokes equation accompanied by a porosity-related drag term [1], which characterizes the damping effect.

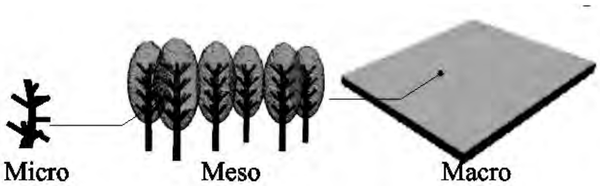

Figure 1. Multiscale analysis: three spatial scales

3. COMPUTATIONAL EXAMPLE

Figure 2 shows the result of the numerical experiment at the forest-scale. Two calculation cases are considered; Cases with (a) low porosity and (b) high porosity. Each case has a porous domain that represent the coastal forest (Length=160m, Width=140m). A building is also set behind the coastal forest. Based on results of the branch-scale and the tree-scale analyses, a coefficient of the porous term is defined as a function of the fluid velocity and depth. As we can see from Figure 2, the fluid for Case (b) reaches 180m longer than that of Case (a). This result indicates that a dense forest is superior to a sparse one in resistance against fluid flow and consistent with the outline of the result obtained from hydraulic experiment. Figure 3 shows the result of the stress distribution on the surface of the building obtained from structural analysis.

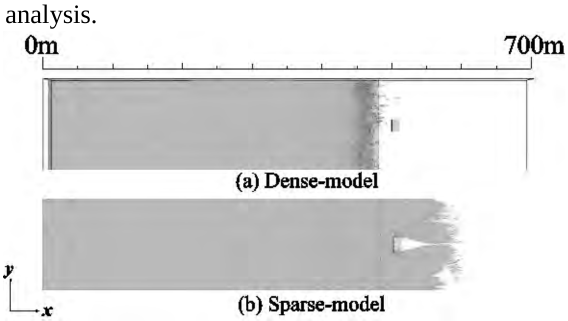

Figure 3. Result of numerical experiment (time=60s)

Figure 4. Stress on the building (time=6.3s)

4. CONCLUSION

We propose the framework of multiscale analyses for evaluating the disaster-reduction effect of coastal forests. The presented multiscale numerical method enables us to evaluate not only the damping effect but also the stresses in structures caused by the fluid force.

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SIMPLIFIED NONLINEAR REINFORCED CONCRETE ANALYSIS USING A FINITE ELEMENT MAPPED SPRING NETWORK

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Keywords: *reinforced concrete, smeared crack model, spring network, secant formulation*

1. INTRODUTION

There are many uncertainties involved in the seismic vulnerability assessment of a large existing building stock, which involves a large number of simulations, to obtain a reliable probabilistic vulnerability estimate. In developing countries, the presence of a large number of non-engineered reinforced concrete (RC) buildings, further adds to the level of uncertainty involved and the computation effort required.

To this effect, a simplified method to analyze the non-linear behavior of RC is proposed in this research. This method involves the usage of a finite element mapped spring network [1], using spatially averaged material models [2]. A secant stiffness based formulation is used [3]. The RC domain is discretized into an assemblage of concrete and steel springs.

2. EXPERIMENTAL VALIDATION

The applicability of the model is checked by comparing the numerical simulation with experimentally tested RC panels [4], RC beams [5], (Figure 1) and RC frames [6] (Figure 2). Good correlation was obtained with the experimental data of the RC beams and RC Frames, using only the concrete compression/tension model. The applicability of concrete shear models is verified through the experimental validation of RC panels subjected to shear loading. Better shear models are required in specimens where excessive shear slippage occours.

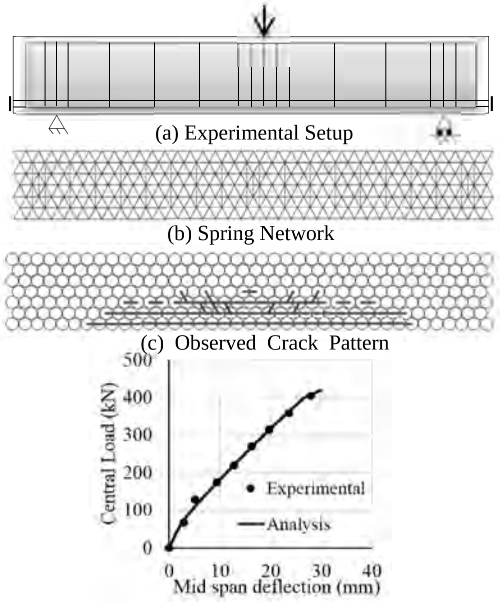

Figure 1. Experimental validation of a RC beam

Through the spring network the crack pattern in an averaged sense can also be obtained.

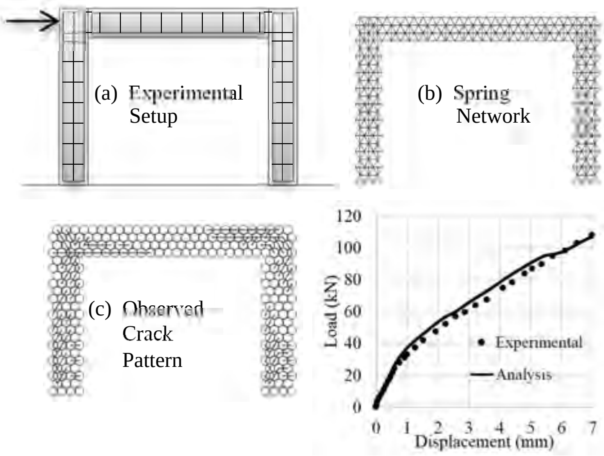

Figure 2. Experimental validation of a RC frame

3. CONCLUSIONS

The results show the capability of the proposed model to follow the nonlinear behavior of simple RC structural members while using a reduced number of degrees of freedom, which also reduces the computation effort required. Simplified spring stiffness formulation and discretization are used, which can be efficiently used to follow the nonlinear behavior of simple structural elements. The advantage of the proposed spring network is that it can be used in tandem with a connected discrete element model, which can be used to perform futher large deformation analysis.

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EVALUATION OF RESIDUAL AXIAL LOAD-CARRYING CAPACITY OF RC COLUMNS AFTER SHEAR FAILURE

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***Keywords**: Shear Failure, Arch Resistance Model, Residual Axial Load Carrying Capacity*

1. INTRODUCTION

From the post-earthquake reconnaissance survey, it is observed that reinforced concrete (RC) short columns and RC columns with poor transverse reinforcement are vulnerable to shear failure. For severely shear-damaged RC columns without adjacent load redistribution members around them, the deterioration of the axial load carrying capacity of these damaged columns can lead to a partial or global building collapse. It can cause a great loss of lives and property. Therefore, it is necessary to evaluate the residual axial load-carrying capacity of them.

Until now, several evaluation models [1]-[3] have been proposed by other researchers to account for the loss of axial load-carrying capacity for such RC columns prone to shear failure. However, it is not easy to obtain an intuitive understanding regarding the loss of axial load carrying capacity through these models.

Hence, in this paper, an arch resistance model is proposed for shear damaged RC columns, which can give a better understanding of the loss of axial load-carrying capacity.

2. ARCH RESISTANT MODEL

In this paper, the state of shear force equal to 0 is defined as the limit state of axial collapse. The model of shear-damaged RC columns can be established as Figure 1. The equilibrium equation of moment of it is shown in Equation 1.

It should be noted that in this model the axial forces acting with an eccentricity e at the end sections of confined concrete part can develop a force couple, which resists the moment induced by the P-Δ effect of longitudinal steel bars. The resistance of the force couple ($N_c e$) acting on the crushed concrete can be considered as the interaction between crushed concrete and longitudinal steel bars and it is called 'arch effect' in this research. It is the big difference compared with other models proposed in the past studies.

Based on the theory of structural mechanics, the evaluation formula of the residual axial load-carrying capacity of shear-damaged RC columns can be deduced.

3. APPLICATION OF THE ARCH RESISTANCE MODEL

To verify the accuracy of the evaluation formula of residual axial load-carrying capacity, a database of test results is compiled from the previous studies. The application results of the shear-friction model [2] and the arch resistant model with the same database are shown in Figure 2. It shows that the arch resistant model can give a better estimate than the shear-friction model for most of specimens.

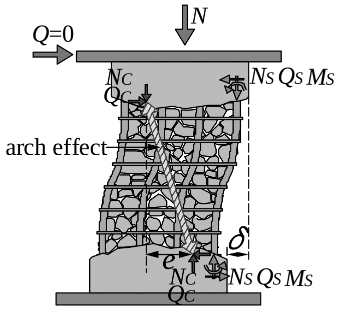
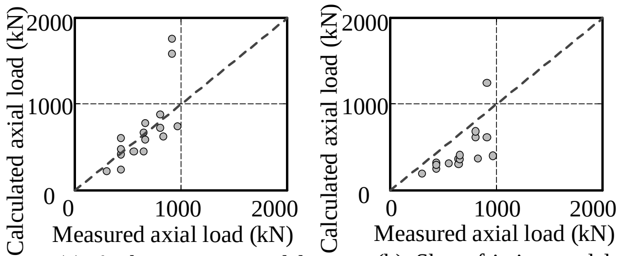


Figure 1 Model of shear-damaged RC columns

$$nN_S\delta = 2nM_S + N_C e \quad (1)$$



(a) Arch resistance model (b) Shear-friction model

Figure 2 Comparison of calculated-to-measured results

4. CONCLUSIONS

For RC columns damaged in shear, the arch resistance model to predict residual axial load-carrying capacity is proposed. For most of the specimens included in the compiled database, the calculated residual axial load-carrying capacity through the arch resistance model has a good agreement with the measured result. Its high accuracy is confirmed by comparing with the application result of the shear-friction model with the same database.

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NUMERICAL SIMULATION OF CHLORIDE DIFFUSION IN CRACKED CONCRETE BASED ON TRUSS NETWORK AND RBSM

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Keywords*: chloride ion penetration, truss network model, RBSM, crack width, Fick's 2nd law*

1. GENERAL AND BACKGROUND

Many reinforced concrete structures are exposed to the marine environments which result in chloride ion penetration; subsequently decreasing in structural capacity due to the corrosion. Therefore, an estimation of chloride ion penetration in concrete with cracking is important for maintenance and predicting service life of the structures. This study aims to develop a three-dimensional numerical simulation system of chloride ion penetration in cracked concrete based on truss network and Rigid Body Spring Model (RBSM).

2. ANALYSIS MODEL

In this study, the truss network system is developed and incorporated into RBSM to simulate the chloride ion penetration in sound and cracked concrete. Truss network model is developed based on Fick's 2nd law for simulating the time dependent chloride ion transportation, while RBSM can simulate cracks from the interaction of each concrete element at meso-scale which calculated by the respond of spring that set on interface between elements.[1] In practice, the chloride ion transport through crack concrete is much faster than that of sound concrete, because of additional flow channel provided by crack space. In RBSM simulation, when concrete is loaded, the crack propagation is directly induced by the spring between elements, and chloride diffusion coefficient through the crack spacing increase according to the crack width which equal to spring elongation [2].

3. GEOMETRY OF NUMERICAL SIMULATION

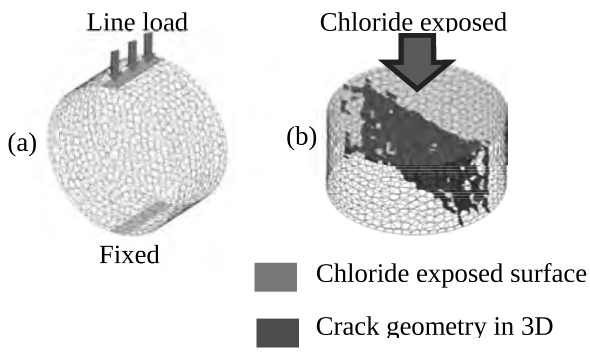

Figure 1. (a) Boundary condition for RBSM numerical loading, (b) Chloride exposed boundary condition.

The indirect tensile loading test model is conducted in order to obtain the uniform crack shape. The short cylinder numerical model size of 100 mm diameter and 50mm thickness are subject to indirect tensile loading. A line of compressive displacement is set at one side of numerical model, while the opposite side is set a line of fixed movement condition. The load was given until the designated crack width passed through specimens (40μm, 80μm, 100μm). Then, the chloride exposure condition is given at one flat surface of cracked concrete models for simulate the chloride penetration in cracked concrete.

3. RESULTS

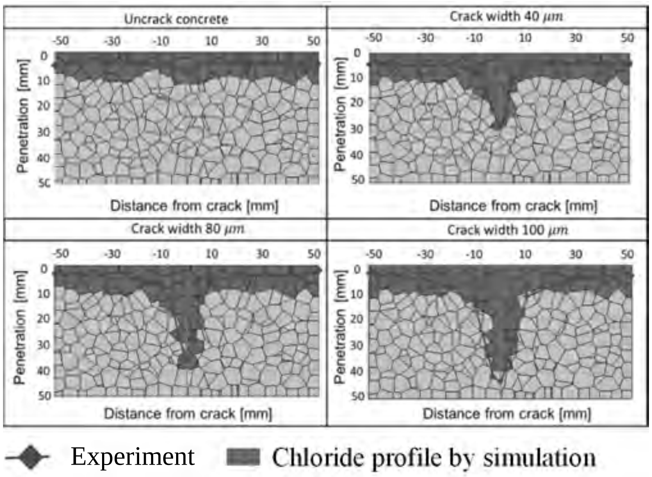

Figure 2. Comparing chloride contamination profile with experiment.

Chloride penetration profiles from simulations were compared with previous experiment by K. Audenaert (2009)[3] and show a good agreement. The chloride transportation through wider crack width is much faster than that of narrow crack width and sound concrete part, the chloride concentration at the perpendicular zone to the crack direction is also higher.

4. CONCLUSION

The coupling simulation can correctly predict the chloride penetration profile and represent the effect of different crack geometry appropriately comparing with the experiment studies.

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REBAR FORCE ESTIAMTION FROM CRACK MOUTH OPENING DISPLACMENT

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Keywords*: Crack mouth opening displacement (CMOD); Fracture mechanics; Reinforced concrete; Bond slip*

1. INTORDUCTION

For reinforced concrete (RC) structures, the state of rebar is an important indicator of structural performance. Fortunately, the rebar force has an inherent relation with concrete cracking process. This relation has been successfully exploited in rebar force estimation by inverse analysis of crack opening displacements (COD profile) in [1]. However, COD profile is difficult to be measured in real existing structures. Therefore, innovation of a reliable and convenient technique deserves attention.

In this paper, the transformation to relate CMOD and rebar forces of RC structures under applied loads is established based on fracture mechanics and bond slip model. Correspondingly, a rebar force estimation method is proposed by using the easily measurable data, CMOD.

2. PROBLEM FORMULATION

According to the concrete crack mechanics, the total CMOD (*um*) of an RC beam is divided into three parts: CMOD due to applied loads (um_a), rebar forces (um_b) and bond slip (um_s). The relation is expressed as:

$$um = um_a + um_b + um_s \qquad (1)$$

among which um_a and um_b can be calculated based on fracture mechanics and are given by:

$$um_a = \frac{4}{E'}\int_0^a \left[\int_0^{a'} G(x', a', b)\sigma(x')dx'\right] G(x, a', b)da' \qquad (2)$$

$$um_a = -\frac{4}{E'}\int_0^a \left[\int_0^{a'} G(x', a', b) f(x')dx'\right] G(x, a', b)da' \qquad (3)$$

where E' is a combination of elastic constants; a is the crack length and a' is the dummy variable of a; G is weight function which can be found in [2]; $\sigma(x)$ and $f(x)$ are stress that would exist on the crack face in the absence of a crack due to applied load and rebar forces per unit length, respectively.

The um_s can be calculated by employing a local bond slip model in [3]. Consequently, the um_s is expressed with a function of rebar force $f(x)$ as:

$$um_s = S(\varepsilon) = S\left(\frac{\int_0^a f(x)dx}{d_b}\right) \qquad (4)$$

where ε and d_b are rebar strain and diameter, respectively.

3. APPLICATION

In this paper, experimental COD data of a tested beam under different load conditions in [1] is employed in estimating the rebar force of that beam. The experimental CMODs are listed in Table 1.

Table 1. Experimental CMOD

Load (kN)	**17.64**	**19.60**	**21.56**	**23.52**	**25.48**
CMOD(mm)	0.132	0.156	0.192	0.221	0.257

Table 2. Experimental CMOD

Load (kN)	**Rebar force (kN/mm²)**			**Estimating error (%)**	
	(1)	**(2)**	**(3)**	**[(3)-(1)]/(3)**	**[(3)-(2)]/(3)**
17.64	304.2	244.6	217.9	-39.59	-12.23
19.60	257.8	278.4	242.1	-6.51	-15.00
21.56	318.3	264.1	266.2	-19.56	0.44
23.52	290.4	278.0	280.4	-3.57	4.26
25.48	314.5	287.3	318.3	1.48	8.66

Table 2. shows the rebar force estimation and the corresponding errors from different approaches: (1) Inverse analysis of COD profile by employing method in [1]; (2) CMOD analysis method proposed in this paper; (3) Standard RC cracked beam transformed section analysis, the results of which can be treated as theoretical rebar force because the bridging effect of concrete is negligible comparing with that of rebar force and the test data is from a newly cured beam under four-point static bending test.

It is found in Table 2 that the rebar force estimating accuracy of CMOD analysis method is generally higher than the accepted method, inverse analysis of COD profile.

4. CONCLUSION

Following the mechanisms of concrete cracking for RC structures, a rebar estimation method from CMOD based on fracture mechanics and bond slip model is proposed in this study. The proposed method is successfully employed in estimating rebar force of the cracked beam in [1]. The better accuracy than the generally accepted rebar force estimation method, inverse analysis of COD profile, verifies the applicability and reliability of this method.

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STRENGTH EVALUATION OF HYDRAULIC CEMENT MORTAR WITH GRAPHENE

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***Keywords**: Carbon Nano Tube Composite material, Graphene, Mortar, Strength enhancement*

1. INTRODUCTION

Graphene's extraordinary properties such as about 200 times stronger than steel by weight shows possibility of excellent role in enhancing the strength of a concrete. Graphene composite was introduced as a strength enhancement material referencing the research on carbon nano tube composite since the material properties of both materials are very similar. Strength improvement effect of graphene composite was observed both on compressive and tensile fields.

2. EXPERIMENTAL PLAN

Strength evaluation experiment was performed according to the ASTM regulation. Mixing ratios of water-cement and nano materials which would affect both the compressive and tensile strength were considered during mixing process of mortar. The quantity of nano material was also considered as one of the important parameters during mixing process.

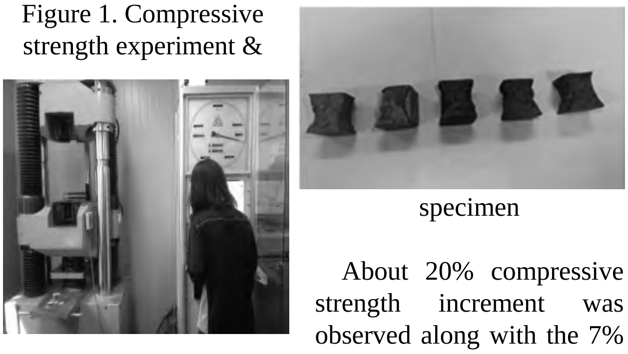
Table 1. Characteristics of Graphene

Test Items	Specification	Analysis Results	Units
C-content	>99.5	99.64	%
Ash	<0.5	0.36	%
Moisture	<0.5	0.23	%
Bulk density	/	145	g/l

3. EXPERIMENT RESULT AND ANALYSIS

The water-cement ratio being kept constant through all specimen. The quantity of graphene was selected as a main parameter for the strength change measurement. The quantity of graphene was 0 to 20% of weighted ratio to the cement.

Figure 1. Compressive strength experiment & specimen



About 20% compressive strength increment was observed along with the 7% graphene composite mortar as shown in table 1. Also the similar percentage of tensile strength was observed along with the 5~7% graphene composite mortar.

Figure 2. Tensile strength experiment & specimen

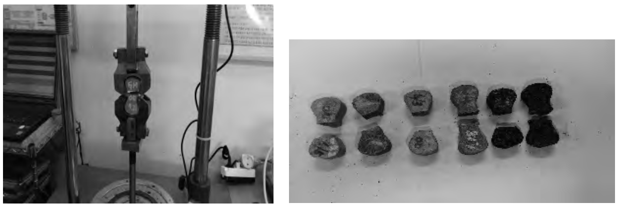


Table 1. Results of test

Specimen	Strength(MPa)	
	Compressive	Tensile
GM00	36.6	2.0
GM01	42.4	2.4
GM02	43.6	2.2
GM03	43.8	1.9
GM04	43.3	2.0
GM05	42.4	2.4
GM06	44.2	2.4
GM07	41.6	2.3
GM08	34.4	1.8
GM09	32.3	2.1
GM10	30.3	1.9
GM15	29.7	2.2
GM20[1)]	29.8	1.2

GM20[1)] : 20 : Amount of Graphene (%)

4. CONCLUSIONS

Graphene contributes to the improvement of both compressive and tensile strength of mortar. The ratio of improvement was 20% in maximum based on the amount of graphene included in mortar.

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CODE2015

Technical Program – Day 1

Session 2

REBAR HUB : 3D REBAR AUTO-PLACING SYSTEM BASED ON BIM

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***Keywords**: BIM, Rebar Detailing, Auto-placing, Structural design*

1. INTRODUCTION

A 3-dimensional rebar auto-placing system, Rebar Hub, has been designed and implemented in this research. Rebar Hub provides an integrated BIM platform from 3D structural modeling of buildings to detailed rebar auto-placing which reflects precise anchorage lengths, lap splices, and order lengths. Rebar Hub executes 3D rebar auto-placing by recognizing 2D drawing CAD files which are auto-converted into 3D structural models. After the auto-placing, each structural member composing the 3D structural model will hold rebar properties data of its own. It means that these rebar properties data can be used for the subsequent works such as quantity-survey, manufacturing, and rebar fabrication.

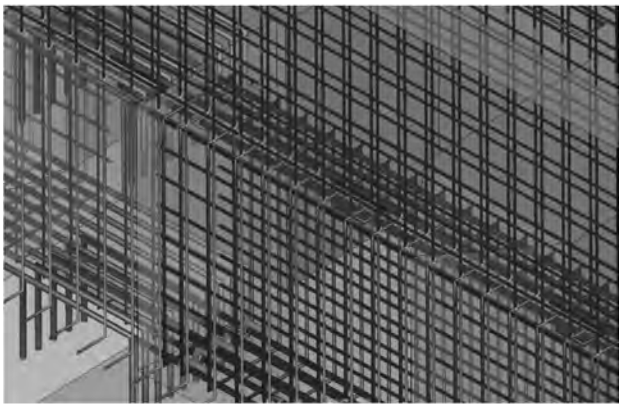


Figure 1. 3D rebar auto-placing by Rebar Hub

2. REBAR AUTO-PLACING

Based on the generated 3D frame model, Rebar Hub auto-generates 3D rebar shapes and placing drawings (Figure 3). Rebar Hub auto-places bars in precise 3D shapes by referring to the relevant rebar detailing code such as KBC or ACI. Precise lap splices and seismic detailing are reflected in the auto-placing, and other various rebar detail options can be set by the user. Unlike other BIM tools where rebar placing is done one element by one element, which can be said to be semi-automatic and time-consuming and all the individual structural members have to be handled by hand, Rebar Hub executes auto-placing for a project by one button-click as all the needed data have been built from 2D recognition. This is the key feature that differentiates Rebar Hub from all the other current BIM tools.

From the generated 3D rebar model, Rebar Hub auto-generates 2D shop and placing drawings required for on-site works (Figure 4). 2D rebar detail drawing works have been the most time-consuming process in the conventional project delivery, but this has been removed in Rebar Hub. Rebar Hub also provides 2D manual editing tools for frequent on-site modifications.

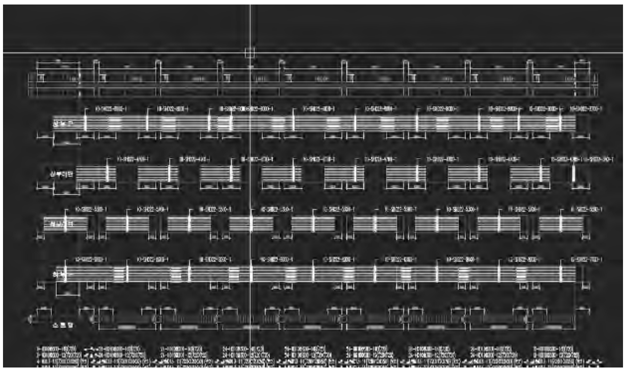
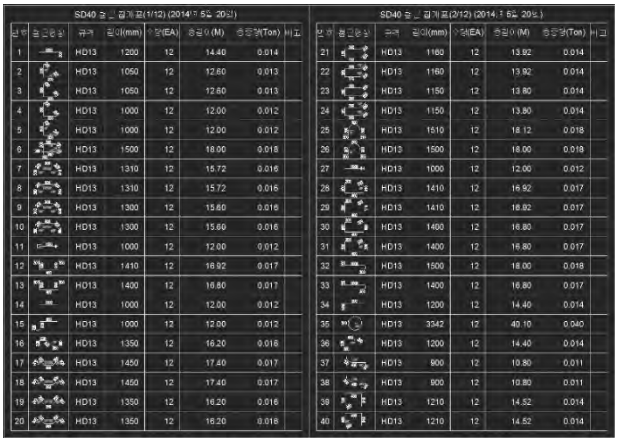


Figure 2. Placing Drawing Auto-generation



SD40 철근 집계표(1/12) (2014년 5월 20일)

번호	철근형상	규격	길이(mm)	수량(EA)	총길이(M)	총중량(Ton)	비고
1		HD13	1200	12	14.40	0.014	
2		HD13	1050	12	12.60	0.013	
3		HD13	1050	12	12.60	0.013	
4		HD13	1000	12	12.00	0.012	
5		HD13	1000	12	12.00	0.012	
6		HD13	1500	12	18.00	0.018	
7		HD13	1310	12	15.72	0.016	
8		HD13	1310	12	15.72	0.016	
9		HD13	1300	12	15.60	0.016	
10		HD13	1300	12	15.60	0.016	
11		HD13	1000	12	12.00	0.012	
12		HD13	1410	12	16.92	0.017	
13		HD13	1400	12	16.80	0.017	
14		HD13	1000	12	12.00	0.012	
15		HD13	1000	12	12.00	0.012	
16		HD13	1350	12	16.20	0.016	
17		HD13	1450	12	17.40	0.017	
18		HD13	1450	12	17.40	0.017	
19		HD13	1350	12	16.20	0.016	
20		HD13	1350	12	16.20	0.016	

SD40 철근 집계표(2/12) (2014년 5월 20일)

번호	철근형상	규격	길이(mm)	수량(EA)	총길이(M)	총중량(Ton)	비고
21		HD13	1160	12	13.92	0.014	
22		HD13	1160	12	13.92	0.014	
23		HD13	1150	12	13.80	0.014	
24		HD13	1150	12	13.80	0.014	
25		HD13	1510	12	18.12	0.018	
26		HD13	1500	12	18.00	0.018	
27		HD13	1000	12	12.00	0.012	
28		HD13	1410	12	16.92	0.017	
29		HD13	1410	12	16.92	0.017	
30		HD13	1400	12	16.80	0.017	
31		HD13	1400	12	16.80	0.017	
32		HD13	1500	12	18.00	0.018	
33		HD13	1400	12	16.80	0.017	
34		HD13	1200	12	14.40	0.014	
35		HD13	3342	12	40.10	0.040	
36		HD13	1200	12	14.40	0.014	
37		HD13	900	12	10.80	0.011	
38		HD13	900	12	10.80	0.011	
39		HD13	1210	12	14.52	0.014	
40		HD13	1210	12	14.52	0.014	

Figure 3. Quantity estimation generated by Rebar Hub

3. CONCLUSION

The development of Rebar Hub started from this very bottom-up approach. Using Rebar Hub, the work can start from conventional 2D drawings, which are converted to 3D, while being able to fully edit 2D figures with the help of familiar 2D authorizing tools. The application of Rebar Hub to a number of pilot projects has proved to be successful so far, to be a feasible BIM tool integrating 2D and 3D modeling.

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VIBRATION/SOUND REDUCTION OF AUTOMOTIVE TRANSMISSION HOUSING STRUCTURES

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Keywords*: Manual Transmission, Vibration Transfer, Transmission Housing, Bracket Noise, BEM*

1. FEM/BEM MODEL

The housing structure of automotive transmission for a passenger car was modeled with many NASTRAN shell finite elements as in Fig. 1, to analyze forced vibration responses caused by fluctuations of an internal combustion engine. The noise is then transmitted from the T/M housing through TGS cables to car interior.

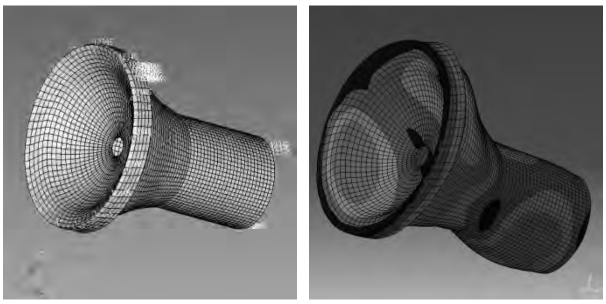
2. ACOUSTIC POWER ANALYSIS

Fig. 2 shows the acoustic field surrounding the transmission housing structure which would be investigated to calculate noise power levels in the car interior. The housing was again modeled with the boundary elements using LMS/Virtual Lab. The forced response results from FE analyses are input to BEM mesh nodes of housing, and the sound pressure at each node is, then, calculated. Finally, SPL can be obtained at the wanted field points on the acoustic field surrounding the housing model. It is known from Fig. 2 that the sound pressure levels are high at the back (driver position) of the housing, up to 136 dB in the car interior.

The acoustic power levels felt from a driver and a passenger positions are shown in Fig. 3. The upper line denotes the acoustic power level at a driver position. Peak dB level was noticed in the frequency of 2300 Hz. The difference was caused by the distance between a driver and a passenger.

3. CONCLUSIONS

Design changes in shapes of brackets and the thickness of supporting rubber washers installed on an automotive transmission housing, that are based on FEM and BEM sound and vibration analyses, can effectively reduce the level of sound and vibration transferred to the vehicle interior.



(a) FE Model of T/M (b) Forced response

Figure 1. A FE model of T/M housing and responses

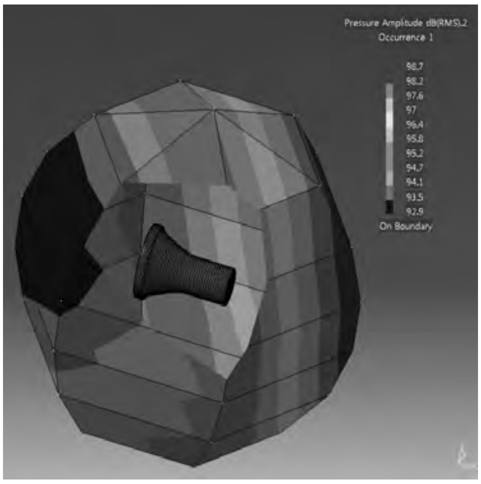


Figure 2. The acoustic field point mesh and results

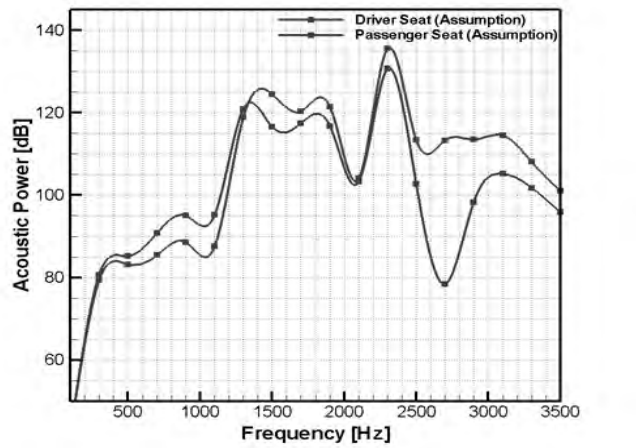


Figure 3. The acoustic power levels in a car interior

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A STUDY ON STATISTICAL VALIDATION OF ELASTO-PLASTIC ANALYSIS OF PISTON INSERTION INTO HOUSING

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Keywords*: Statistical Calibration, Validation, Bayesian Approach, Elasto-Plastic Analysis*

1. INTRODUCTION.

A Pyrotechnically Actuated Device (PAD) is a component that delivers high power in remote environments by the combustion of a self-contained energy source. Once the PAD triggers combustion in a chamber, the expanding gas drives a piston into housing. It usually plays safety-critical role of valve that opens a gas flow in aviation and defense industry such as launching and deployment. Thus the reliability analysis of the PAD is very important.

In this study, statistical calibration and validation procedure is addressed for the elasto-plastic insertion analysis of the piston into the housing by the generated gas pressure. Objective of the study is to develop reliable analysis that agrees closely with the actual test data, and validate the accuracy in probabilistic manner.

2. MODELING & CALIBRATION.

Toward this objective, the actual test data are provided for three types of PAD. The result of test is the resistance force against the piston movement, which is measured by materials testing system under quasi-static condition. In order to evaluate the resistance force via FEA, commercial analysis tool ANSYS is used and elasto-plastic solution is obtained between the piston and housing during the quasi-static piston movement. In the analysis, there are a couple of issues in view of uncertainty. First, the friction coefficient is not clearly identified, which can vary with many factors such as surface condition and contact forces.

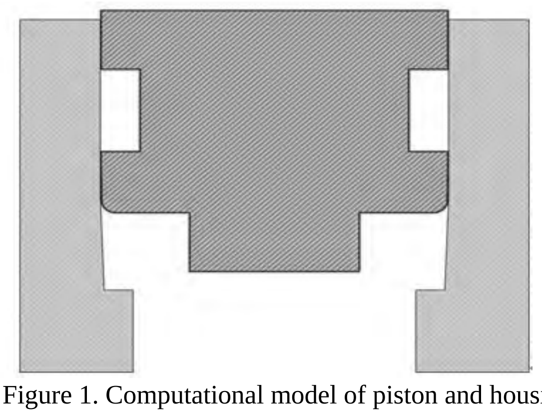

Figure 1. Computational model of piston and housing

Next, the analysis model includes only a part of the device as shown in Figure 1, which is the cutout of the whole device. Then the boundary condition of the model is not clearly specified, but is imposed arbitrarily. All these are the sources of disagreement of the analysis result with the test data. In this case, common practice is to introduce the associated parameters as the unknowns, and carry out calibration to improve the accuracy of the analysis model which is to match the analysis result with the actual test data. In this procedure, however, if the parameters are calibrated without considering uncertainties due to the limited test data, errors of test and modeling, the result can mislead to wrong conclusions.

To solve this problem, a Bayesian approach is proposed to calibrate the parameters of computation model of PAD in a probabilistic way. Markov Chain Monte Carlo technique is employed, which is an efficient computational algorithm to draw samples that satisfies the posterior distribution.

3. VALIDATION & CONCLUSIONS.

Once the calibration is carried out for a baseline model, one obtains the parameters in the form of distribution. The calibrated input parameters are applied to the analysis of other types of PAD. The result of analysis is validated in probabilistic way at each type of PAD. As a means to the probabilistic validation, area metric is introduced between the CDF by actual test data and analysis. The more agreement we get as a result of calibration, the smaller area we get between the two CDF's. Finally, the analysis results enclose the test data completely, which means that the calibration is made successfully.

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A STUDY ON DIRECT PERMEABILITY SIMULATINON OF GEOMATERIALS USING IMMERSED BOUNDARY METHOD

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Keywords*: Permeability, Geomaterials, Immersed Boundary Method*

1. INTRODUCTION

It still has been difficult to predict detailed response of geomaterials theoretically in dynamic interaction problems between geomaterials and pore fluids, such as liquefaction, erosion, and seepage failure of river dikes. In practice, on the other hand, there are certain needs of numerical simulations focused on geohazards with fluid-solid interaction modeling. In this study, we applied Immersed Boundary Method (IBM)[1] to a direct numerical simulation (DNS) on the water passing through saturated geomaterials. Numerical permeability tests were conducted and the effects of soil properties, such as grain size distribution, are discussed.

2. IMMERSED BOUNDARY METHOD

Numerical framework used in this study is composed of Discrete Element Method (DEM), Finite Difference Method (FDM), and IBM. Soil grains are assumed to be rigid spheres and the motion of grains is solved by DEM. On the other hand, flow of pore water is expressed by FDM using fixed calculation grids. Meanwhile, IBM accomplishes a conjunction of those two methods.

Here is the Navier-Stokes equation for incompressive Newtonian fluid with an external force term f;

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}\right) + f_i \quad , \qquad (1)$$

where u is the velocity vector, p is the pressure, ν is the kinematic viscosity coefficient, and ρ is the density. IBM works to evaluate the external force, which emerges from the difference of dynamics on the boundaries between fluid and solid domains, using a smoothed approximation to the Dirac delta function δ_h[1] for quantity translation between fixed grid points and arbitrary moving points. After the original IBM method had been proposed, some modifications of the calculation algorisms have been proposed. In this study, the one proposed by Uhlmann[2] is used to describe interaction between soil grains and pore water.

3. PERMEABILITY TESTS

Numerical permeability tests were conducted using 3D model shown in Fig.1. Soil grains (spheres) are fixed in space. One of the simulated results are shown in Fig.2. Each plots are with critical Reynolds number [3], indicating there be turbulent-like effects in permeability flow when it excesses 1. The plot tells us that original test cases (triangular plots) are getting off the theoretical proportion in laminar flows as the critical Reynolds number increases, while they still keep in line when we modified their pressure conditions to make Reynolds number lower than 1 for study (circle-plotted cases). It can be explained supposing there are turbulent-like effects to diminish flow potential in the soil block.

4. CONCLUSIONS

According to the obtained results, proposed numerical method seems to be enough capable to catch characteristics of micro-scale flow through granular materials. As we hope to describe precise characteristics of geomaterials in future works, further investigation must be done in order to have advanced applications.

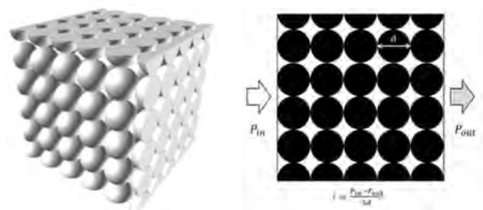

Fig.1 Soil block substituted by uniformed spheres (left) and the sliced part of it (right). Pressure gradient i is evaluated with given pressures P on in/out planes.

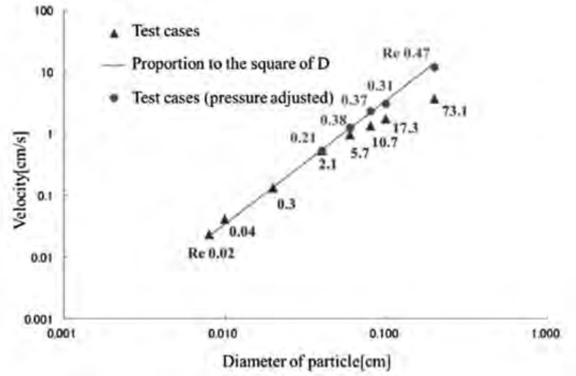

Fig.2 Results of permeability tests with critical Reynolds number proposed by Fancher, et.al.[3]

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FEASIBILITY STUDY OF INTERACTIVE PASSING MANEUVER MODEL FOR TWO-WAY TWO-LANE ROADS

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***Keywords**: Driving Simulator, Conflict Zone, Action Pattern Choice, Vehicle-to-Vehicle Interaction*

1. INTRODUCTION

Vehicular movements on two way two lane roads differ significantly from other facilities due to the high frequency of conflicts between the vehicles in opposing directions of travel. Presence of obstacles like parked vehicles, construction sites etc. increase the frequency of conflicts between the vehicles. These conflicts have a significant impact on the efficiency [1] as well as the safety of road sections.

Fig 1: Representation of the lane with depiction of conflict zone

Driving Simulators (DS) are used for studying various aspects of transportation including driving behavior, road safety, road design and traffic flow. It is very important to model the behavior of surrounding vehicles in the DS realistically. The existing driver behavior model [2] assumes that the opposing vehicles always have priority over the passing vehicles. However in reality, drivers of the passing traffic may adopt aggressive behavior to obtain priority and the opposing vehicles may giveway considering such behavior to avoid any potential conflicts. As it is not possible to deterministically assume the behavior of the subject driver of the DS, the surrounding vehicle model should not consider a fixed priority rule but interactively choose its action. The objective of this study is to propose a framework of an interactive model between the passing and opposing vehicles and evaluate the characteristics of the model by sensitivity analysis using a Monte-Carlo simulation.

2. ACTION PATTERN

Fig 1 represents a scenario where vehicles travelling in opposing directions interact due to the presence of an obstacle. Conflict zone is the area where there is a potential for both cars to collide if both assume that the priority of passing lies with them. Each vehicle has the choice of either 1) giving way to the other vehicle by decelerating, 2) employing aggressive movement by forcing the other vehicle to decelerate to complete the maneuver or 3) move freely without any interaction when there is a sufficient gap between one's exit time of the conflict zone and the other's entering time. The vehicles are modeled as intelligent agents with the individual goal of reaching its destination as soon as possible and having the ability to interact and cooperate with other agents to solve conflicting goals. The flow chart in Fig 2 represents the action pattern choice to be chosen by the driver. The vehicles initially check for the feasibility of free movement and then adopt the aggressive movement in case a collision is expected with the free movement. In the case of the aggressive movement, the vehicle makes an assumption of the maximum speed decrease the other vehicle is willing to use and check for the feasibility of completing the action with these assumed values. If this assumption is feasible, the vehicle will take the aggressive movement by trying to force the other to decelerate, otherwise it gives way.

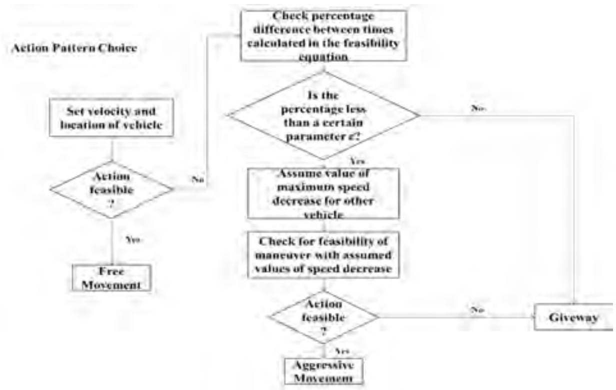

Fig 2: Flow chart representing the action pattern process

3. CONCLUSIONS

The proposed model is implemented to a simulation program. The results of the sensitivity analysis regarding the impact of model parameters upon the traffic performance will be shown in the presentation.

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μ – MODELING , HOMOGENIZATION AND FATIGUE LIFE EVALUATION OF FABRIC BRAIDED REINFORCED RUBBER HOSE

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Keywords: *Fabric braided hose, μ – modeling, Homogenization, Large deformation analysis, Fatigue evaluation*

1. FABRIC BRAIDED BRAKING HOSE IN CYCLIC MOTION

Automotive braking hose is in lamination construction of rubber and fabric braided layers for both oil sealing and preventing the excessive radial expansion. In addition, it exhibits the large deformation during the cyclic motion due to the combination of the steering motion and the up and down motion of vehicle.

Figure 1. Fabric braided braking hose in cyclic motion

The most important function of braking hose is the safe convey of interior working oil without leakage up to the predefined mileage of vehicle. However, its reliable design reliability is not easy because its prediction at the design state requires several considerations, such as the μ -modeling of complex fabric braided layers inserted between rubber layers, an accurate material modeling for the reliable large deformation analysis along the specific cyclic path, and the elaborate fatigue model considering the mean strain.

2. HOMOGENIZATION AND FATIGUE EVALUATION

The mechanical behavior of fabric braided layers is modeled as orthotropic material, and its equivalent material properties were calculated making use of the superposition method and the unit cell finite element analysis [1]. To compute the fatigue life, three fatigue models, standard model without considering the mean stress and strain, Morrow considering the mean strain and SWAT(Smith-Watson-Topper) considering the mean stress are employed [2].

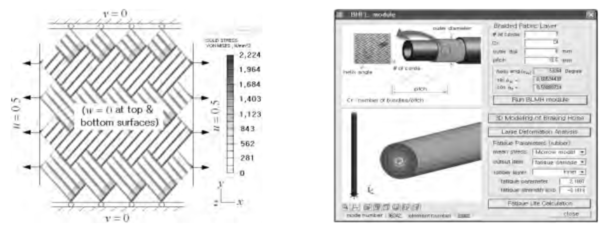

Figure 2. Unit cell finite element analysis and the fatigue life calculation module built in midas NFX.

Meanwhile, the large deformation along the specific cyclic path shown in Figure 1 was carried out by the quadratic interpolation of cyclic path using three known position and rotation data and by updated Lagrangian formulation.

3. FATIGUE LIFE PROFILES ALONG THE SPECIFIC PATH

Figure 3 compares the fatigue life profiles predicted by the proposed homogenization and fatigue evaluation methods. The left profile is by the standard fatigue model without considering the initial hose deformation, while the center and right show the results by Morrow and SWAT(Smith-Watson-Topper) fatigue models. It has found from the detailed numerical data that the remarkable difference in the critical fatigue lives is observed even though the overall fatigue life profiles are almost similar.

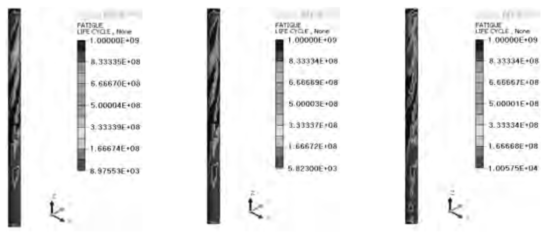

Figure 3. Fatigue life profiles of automotive braking hose for the horizontal cyclic path.

4. CONCLUSIONS

An effective but reliable fatigue life prediction method was proposed by making use of the homogenization method and the modified fatigue evaluation models.

5. ACKNOWLEDGEMENT

The research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (Grant No. NRF-2014R1A1A2055820).

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THE 3D MESH MODIFICATION SYSTEM FOR TETRAHEDRON ELEMENTS

BASED ON VR TECHNOLOGY

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Keywords: *mesh modification, node relocation, mesh refinement*

1. INTRODUCTIONS

The 3D numerical simulations are becoming more powerful and popular tool for various CAE (Computational Aided Engineering) problems. The quality of numerical solution depends on the quality of mesh. If the quality of mesh is extreme worth, we are not often able to obtain the accurate numerical solution. In those cases, it is required to modify the mesh. However, it is difficult to modify the 3D mesh using 2D display.

Therefore, the present authors has been developed a mesh modification system for 3D unstructured mesh using VR technology [1]. Two modification methods are implemented in this system: the node relocation method and the mesh refinement method. The previous system has been shown the efficiency of the method. In order to improve the applicability of the system, we implement several new functions such as the node merge function and the mesh-connectivity modification function.

2. SYSTEM SUMMARY

In order to develop the mesh modification system, we employed the immersive virtual reality device such as CAVE. This device is composed by three 3D projectors, three large screens, position tracking device and active shutter glasses. The Figure 1 shows the scene that user modify the mesh in CAVE (VR space) using the system. User can check the details of 3D mesh and can modify the shape of mesh in VR space interactively by using the controller. This system can be applied to the linear tetrahedron elements and the 2-nd order tetrahedron elements.

Figure 2 shows the flowchart of this system. After the loading the mesh data, the element quality is computed. Then, the value of mesh quality is displayed on the screen. User can perform the mesh modification using the information of mesh quality. This system implements two modification methods: node relocation method and mesh refinement method. For mesh refinment method, this system has two refinment patterns (Figure 4). For the node relocation method, the node control function is implemented to avoid the distruction of the boundary surface by the node relocation. This function control the derection of the node movement. Therefore, the element is modifyed without the destruction of the boundary surface. We also implements node merge function for the overlapping elements and mesh-conectivity modification function for the elements which exist on boundary surface.

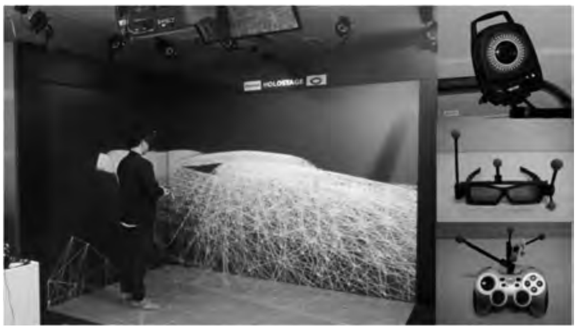

Figure 1. VR environments

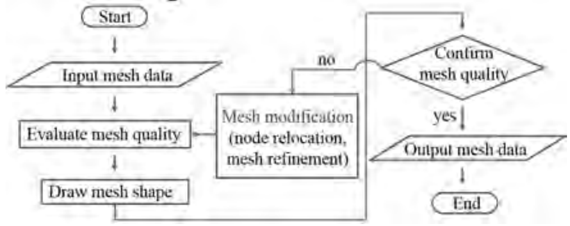

Figure 2. Flow chart of the system

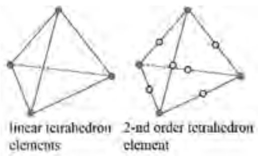

Figure 3.
Applied elements

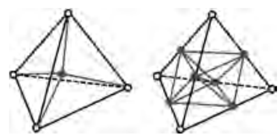

Figure 4.
Mesh refinement patterns

The update of mesh data is performed in realtime. Several application examples will be shown in the presentation.

3. CONCLUSIONS

The 3D unstructured mesh modification system based on VR Technology for tetrahedron elements has been presented. In order to improve the applicability, we have implemented new functions such as the node merge function and the mesh-conectivity modification function. The development of mesh modification for the hexahedron elements is left for the future work.

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MULTISCALE MODELING AND SIMULATION OF POLYMER NANOCOMPOSITES INCLUDING THE AGGLOMERATED FILLERS

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Keywords: *Agglomeration, Interphase percolation, Molecular dynamics simulation, Finite-element homogenization, Polymer nanocomposites*

1. INTRODUCTION

Filler agglomeration is the most challenging issue in the manufacturing field of polymer nanocomposites **[1]**. Due to the high nonbond interaction such as van der Waals interaction and electrostatic potential, fillers are agglomerated in the polymeric phase. In spite of the importance of filler agglomeration, there is no multiscale framework. In this paper, we propose the multiscale modeling strategy of polymer nanocomposites including the agglomerated fillers. To characterize interphase percolation effect, the molecular dynamics simulations and finite element homogenization models are employed. We verify that the proposed interphase percolation model is applicable to the multiparticulate system.

2. COMPUTATION MODELS AND RESULTS

Figure 1 shows the overview of multiscale modeling strategy to characterize interphase percolation model and verify the propose model **[2]**. Spherical silicon carbide nanoparticles are embedded as the reinforced particle in the polymer phase (polypropylene). In order to identify the interphase percolation effect, six molecular models are used for various interphase particulate distance. Choi *et al*. **[3]** proposed the schematics for characterization of interphase, which is employed in this study.

As shown in **Figure 1**, elastic properties of interphase decreases as the overlapping density increases. The definition of overlapping density is volume of overlapped zone over the volume of interphase. Therefore, overlapped density means how much interphase zone is overlapped. This is key parameter of this study and it reflects degradation mechanism of interphase elastic properties. Interphase percolation model is defined as following form:

$$\delta_{overlap} = \frac{V_{overlap}^{\text{int}}}{V_{total}^{\text{int}}} \leq 1 \tag{1}$$

$$E_{\text{int}} = \alpha e^{\beta(\delta_{overlap} - \gamma)} + E_{mat} \tag{2}$$

To verify the extensibility to the multi-particulate system, additional study is conducted. For same location, volume fraction, and radii of nanoparticles, the homogenized elastic properties are compared between molecular dynamics model and finite element homogenization models. It shows similar results between molecular dynamics model (Young's modulus: 2.55 GPa, and shear modulus: 0.98 GPa), and finite element homogenization model (Young's modulus: 2.83 GPa, and shear modulus: 1.07 GPa).

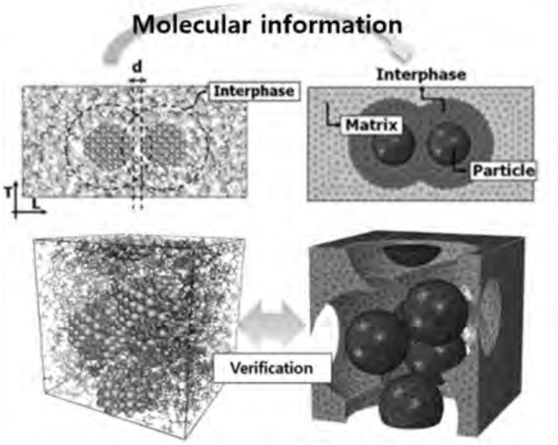

Figure 1. Overview of multiscale modeling strategy to reflect interphase percolation effect

3. CONCLUSIONS

Interphase percolation model is proposed and it is defined by the molecular dynamics models and finite element homogenization models. Extensibility to the multi-particulate system is verified. The proposed model will be extended to the elasto-plastic model and toughness model.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2012R1A3A2048841)

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Technical Program – Day 1

Session 3

DISASTER MANAGEMENT SYSTEM "BOSS"

- CASE FOR HUMAN RESOURCES SIMULATION -

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***Keywords**: disaster response, workload, time chart, schedule, web*

1. INTRODUCTION

This research defined the standard response process for the local governments and developed IT disaster management system based on the standard disaster response process. Developed IT system is named BOSS (Business Operation Support System or BOSai System, Bosai means the disaster management in Japanese). BOSS can show the total disaster process with database of historical disaster knowledge. About 500 processes are defined by the disaster management plan and the experiences of staffs in Yabuki town in Fukushima prefecture and Ishinomaki city in Miyagi prefecture where was heavily damaged by the 2011 Great East Japan Earthquake disaster. The core database of BOSS include people, house, industry, law, land etc. which are defined the relationship to the disaster responses. Before disaster, BOSS can be used to simulate disaster responses according to the level of "scenario disaster". After disaster, BOSS can manage the actual responses and work as a platform of disaster information sharing.

2. Disaster management system "BOSS"

The damage conditions such as number of total collapse houses, number of death, number of injury, etc. are input data set of BOSS. The condition of weather, season, time and week day are also considered.

For each disaster response, the workload is calculated by following to the level of damages. The total amount of wastes by damaged houses, possible total evacuee, necessary toilets for the evacuee and possible temporary houses etc. are also calculated. These calculation is derived from the direct damage such as the number of collapsed houses.

Human resources are assigned to each disaster response following each calculated workload. When the human resources are assigned, the disaster responses are categorize four types. (1) the responses by everyone can work immediately after disasters such as management of the Volunteer Center etc., (2) the responses by government staff at first stage of disasters but gradually shifting to the other people such as food supply, water supply etc. (3) the responses by every government staff such as residents support, issuance of certificate, etc., (4) the responses by government staff with a special skills such as restoration of infrastructure and lifelines, health issues etc.

It is important to make a category for each disaster response according to these kinds of types. Then we can understand what kinds of disaster responses are necessary by staffs with special skills or without those, and manage the limited resources effectively. In this paper, to assign the human resources, three cases can be simulated for different human resources level (Figure 1).

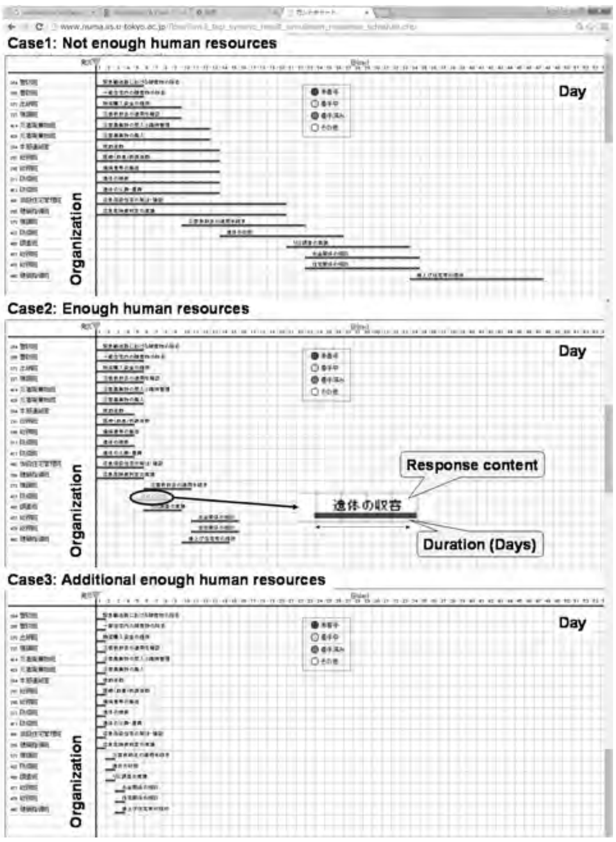

Figure 1: Comparison of different human resources for disaster responses

3. CONCLUSIONS

BOSS can be used the simulation of disaster responses to show the critical path and bottle neck response according to different cases of input conditions. BOSS can show (1) Evaluation of amount of work (work load), (2) Effective distribution of human resources with skill level and work load and (3) Management of response schedule. Then stakeholders can understand all disaster processes with priority, difficulty or level for the effective human resource management.

Small local governments cannot prepare enough budget and knowledge to develop and manage their original IT system. BOSS is usable for local government to prepare the disaster response simulation in Japan.

THREE DIMENSIONAL FINITE ELEMENT GROUND MOTION ANALYSIS USING GPGPU

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***Keywords**: Ground Motion Analysis, Conjugate Gradient Method, GPGPU*

1. INTRODUCTION

Large-magnitude earthquakes can severely damage urban areas, and in order to prepare for seismic hazard of urban structures, a reliable ground motion analysis technique is essential. To gain accuracy, several aspects need to be considered carefully. It is straightforward to consider the physics of these problems and solve the linear or nonlinear solid wave equations. Also, the target domain should be large enough to neglect the boundary effects. Last, structural damage mainly depends on a frequency band of up to 2.5 Hz, and the surface topography is known to affect the response of structures significantly. All of this combined leads to a tremendous amount of computational cost, the degrees of freedom (DOFs) in the order of 100 million to 1 billion, so several research has been conducted to develop sophisticated computational technique. One approach is to use CPU based supercomputers, such as the K computer[1]. Another approach is to use super computers with accelerators, the most popular being GPGPU, general-purpose GPU. Applying GPU acceleration to seismic analysis is recently considered to lead superior performance compared to CPU based computers. [2] uses the finite-different method (FDM), which is capable of gaining high performance due to the structured data sets. When it comes to modeling the surface topography accurately, however, FDM need smaller element sizes, so as a result the DOFs get higher. [3] uses the spectral-element method (SEM) which uses higher ordered elements compared to finite-element method (FEM). In this case, a FE solver would be more suitable, since it can greatly represent the surface topography using lower ordered elements, which is easier to formulize and rather simple to implement. Thus, we have developed a three dimensional finite element ground motion calculation technique using a heterogeneous CPU/GPU platform.

2. METHODOLOGY

For this research, we have enhanced the performance of the pre-conditioner of a finite element based seismic wave amplification CG (conjugate gradient) solver, GAMERA, which was originally developed for CPU based supercomputers. GAMERA uses a CG solver inside the pre-conditioner to calculate the preconditioning matrix of the main CG loop (Figure 1). We have developed a heterogenous computing method for the pre-conditioner, using linear/second ordered tetrahedral mesh and single precision arithmetic. We have conducted numerical experiments to show good weak scaling efficiency, and proved that it is considerably faster compared to using a CPU cluster of the same size. These data will be shown in the presentation. The code was rewritten using OpenACC, a programming standard for parallel computing, and is known to be a relatively user-friendly way to implement on scientific calculation. The rewritten code was merely 5~10% of the original code, showing high portability as well as good performance.

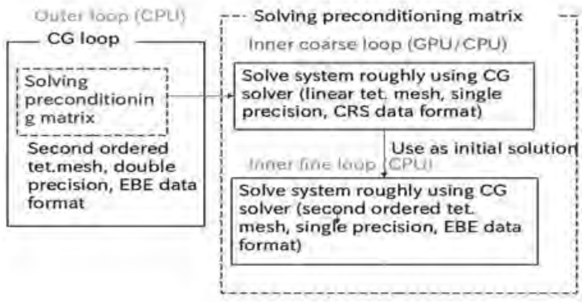

Figure 1. Overview of the CG solver in GAMERA and the proposed method.

3. CONCLUSIONS

This method will be able to enhance forward analysis of seismic response, and treat problems that have higher DOFs using more computational resources. It will also be fairly easy to apply to many-core computing architecture, which is expected to be the mainstream of the next generation's supercomputers.

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MULTI-TIMES SIMULATION ANALYSIS OF
HIGH RISK DURING EVACUATION IN A POST-EARTHQUAKE URBAN FIRE

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Keywords*: Disaster Risks, Urban Fire, Evacuation, Agent-based Simulation*

1. INTRODUCTION

After the Great East Japan Earthquake in 2011, initiatives have focused on eliminating the possibility of an unforeseen disaster situation. In regards to the dangers of urban fire caused by earthquake in Tokyo, according to the earthquake damage assumption by the Tokyo Metropolitan Government in 2012, fatalities are estimated to about 4,100 people in a fire. It can be said that a high risk has been estimated.

However, this estimation was performed with a regression analysis using data of past earthquake-induced fires and peacetime conflagrations all of which occurred in different periods and under different conditions. This method needs to be verified to entail a more scientific approach. It also does not reveal a real image of the damage in the current city which has changed considerably over the years. Therefore, it is necessary to review again the risk of deaths from urban fire due to an earthquake in current Tokyo. Additionally, there is also a need for a better understanding of possible circumstances for mass mortality like in the case of Great Kanto Earthquake in 1923.

Therefore, we attempted to understand whether there is much possibility of mass mortality by urban fire in the modern metropolis. Furthermore, we consider where the cause of the phenomenon lies and how to avoid it[1].

2. METHODOLOGY

By logic, since people walk at faster pace than the rate of fire spread, simple calculation results often estimate that people are able to evacuate in time. However, these calculations do not take into account that there are possibilities of crowd congestions which can slow down the pace of the evacuees thereby entrapping them in fire.

Hence in this research, we developed a simulator which runs the fire-spread simulation and the evacuation simulation simultaneously over a wide area[2].

By performing a large number of trials, we have attempted to clarify the possibilities of mortality due to extreme events and delayed evacuations thereby revealing the structure of the phenomenon.

Accordingly, the calculation target area was concentrated in this range, with the evacuation destinations considered were particular locations that are designated by the Tokyo Metropolitan Government in their wards.

Hamada type sequence formula was used for the calculations of the fire simulation model, due to the fact that it employs a high fire-spread rate and it is considered to be suitable for the evaluation of safety. Occurrence locations of the fire was elected by a random number in accordance with the fire probability that takes into account the differences between the ease of fire occurrence and spread due to applications such as dining options, structure and residential buildings.

Since there is little knowledge about the evacuation in the urban fire, elucidation of the complete behavior is difficult. Therefore, in order to assess the risk with taking into account the variety of actions the evacuees can take, the evacuation simulation model was constructed using the approach of the agent-based modeling. Evacuation routes of evacuees is basically the shortest path on the road network towards the destination. However, evacuees are also able to change their moving path in order to avoid danger, depending on their perception of the.

We have carried out the evacuation simulation with different fire-spread patterns, with several thousand trials for each case.

3. CONCLUSIONS

Possibility for mass death caused by certain conditions has been suggested. Continuing from this, the simulation results further reveal that certain places have higher fatality rates, showing certain characteristics make a place a more dangerous for fire than other places.

Testing with different evacuation decision-making models, consistency is visible among the results attained.

In the future, we hope to construct a more appropriate evacuation model using experimental and questionnaires and the like. We also plan to consider the sensitivity analysis of the model.

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ANALYZING EFFECTIVE ROAD BLOCKING FOR IMPROVING EVACUATION TIME FROM TSUNAMI USING TRFFIC FLOW MODEL

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***Keywords**: Tsunami, Evacuation time, Road Closure, Traffic Jam, Bureau of Public Roads function*

1. Introduction

In the Great East Japan Earthquake Disaster of March 11, 2011, a tsunami of unimaginable proportions assailed the region, costing many lives. In its aftermath, tsunami evacuation procedures came under review.

While there have been many studies of evacuation from tsunamis, few studies have applied mathematical analysis and few have analyzed traffic congestion during an evacuation.

This study attempts to reduce preferential car use in major earthquake disasters by setting road closures. The goal is to reduce the number of car users and detours during emergency periods, leading to a reduction in traffic congestion and evacuation time. The study is aimed at minimizing the total time taken for evacuation by proposing appropriate road closure strategies for a range of evacuation options.

2. EXISTING RESEARCH

Takada et al.[1] identified the impossibility of smooth evacuation using automobiles as one cause of increased human casualties during a tsunami. They discussed the necessity of post-analysis of evacuations by car when planning future tsunami evacuations strategies. Using the urban areas of Kesennuma City as the subject area, they reconstructed the situation of the tsunami evacuation by car during the Great East Japan Earthquake Disaster.

3. DESCRIPTION OF THE STUDY

We take Shizuoka City as our example, where tsunami damage from a Nankai megathrust earthquake is anticipated. We used the basic road data available in the 2005 edition of the National Digital Road Map Database created by Sumitomo Electric as the network in this study.

Figure 1. Road network in the subject area

When a major earthquake strikes, evacuees will start to evacuate from a point in the red-lined area (start of evacuation node) using roads (links) to evacuate to a point in the black-lined area (high ground node). At the same time, some of the roads will be closed to automobile traffic and evacuees are expected to recognize road closures in advance.

If there are no road closures, a large percentage of people will choose car, as that will allow them to evacuate more quickly while fewer people will choose foot. For this reason, road closures were introduced. These change the routes available for car evacuation, producing a (perceived) increase in the time required. Under the road closure scenario, some evacuees who would have previously used a car will evacuate on foot or will take a detour, avoiding the concentration of traffic on certain roads. This avoids major congestion, reducing the average time required to evacuate.

4. CALCULATION RESULTS

In this study, the average time required for evacuation in Shizuoka City improved from 9.41 min prior to applying road closures to 6.62 min after application.

5. FUTURE PLANS AND ANTICIPATED CONCLUSIONS

These trial calculation results still leave some issues unresolved. One is that the results are largely determined by the parameters chosen. In particular, the number of people and traffic capacity settings have a significant impact and have not been appropriately allocated. In this study, the number of vehicles in each link was calculated as the cumulative total when deriving the number of cars passing through a link and calculating the average time required for evacuation. In reality, the flow of car traffic is not even; hence, using a cumulative total will exaggerate traffic congestion. A more accurate per minute calculation will yield more accurate timings.

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MATHEMATICAL MODEL FOR EQUILIBRIUM AND OPTIMUL LOCATION OF HOUSINGS AND JOBS WITH CONSTRAINED CAPACITY

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Keywords: *distribution of housings and jobs, travel cost, discomfort cost*

1. INTRODUCTION

In this paper, we propose a new calculation method of equilibrium and optimum location of housings and jobs theoretically in the urban models with constrained capacities. We show that a problem which incorporates commuting travel cost, working travel cost and discomfort cost caused by the density of the node will be a non-convex quadratic programming problem. By using Reformulation-Linearization Technique, we are able to derive analytically the equilibrium and optimum location of housings and jobs.

2. URBAN MODEL

Let us consider an urban city which contains of working place (*W*) consisting of the building nodes *I* ($1 \leqslant i \leqslant I$) and residence place (*H*) consisting of the building nodes *J* ($1 \leqslant j \leqslant J$), and assume that only two building types exist in the urban city in order to make formulation much more concise. Moreover, proposal urban model is independent; the total number of people moving *W-H* is *T* (= constant number) and there is no inflow and outflow of people between other cities.

Same as the previous model [1], we assume that there is two travel type in urban city, (i)commuting travel of *W-H* and (ii)working travel of *W-W'* and (iii)discomfort due to density of the node. At this time, our purpose of this study is to derive equilibrium and optimum location in the urban city. On that account,

$$T = \sum_{i=1}^{I}\sum_{j=1}^{J} t_{ij}^{\mathrm{h}} \quad (1 \leqslant i \leqslant I,\ 1 \leqslant j \leqslant J), \tag{1}$$

$$w_i = \sum_{j=1}^{J} t_{ij}^{\mathrm{h}} \quad (1 \leqslant j \leqslant J), \tag{2}$$

$$h_j = \sum_{i=1}^{I} t_{ij}^{\mathrm{h}} \quad (1 \leqslant i \leqslant I), \tag{3}$$

where t_{ij}^{h} is a commuting number from i to j, w_i is a working number of people at node i and h_j is a residence number of people at node j. Furthermore, we assume the following inequalities to provide the idea of constrained capacity,

$$0 \le w_i \le W_i, \tag{4}$$

$$0 \le h_j \le H_j, \tag{5}$$

where W_i and H_j is each capacity at the node.

3. EQUILIBRIUM LOCATION

First, we derive the equilibrium distribution of housings and jobs. This problem will be a nonconvex quadratic programming problem stated bellow:

$$\text{min.} \quad F_{\mathrm{UE}} = \sum_{i=1}^{I}\sum_{j=1}^{J} 2d_{ij}^{\mathrm{h}} t_{ij}^{\mathrm{h}} + \frac{\alpha}{T}\sum_{i=1}^{I}\sum_{i'=1}^{I}\frac{1}{2}d_{ii'}^{\mathrm{w}} w_i w_{i'} + \sum_{i=1}^{I}\int_0^{w_i} z_i^{\mathrm{w}}(x)\mathrm{d}x + \sum_{j=1}^{J}\int_0^{h_j} z_j^{\mathrm{h}}(x)\mathrm{d}x \tag{6}$$

$$\text{s.t.} \quad w_i = \sum_{j=1}^{J} t_{ij}^{\mathrm{h}} \quad (1 \leqslant i \leqslant I) \tag{7}$$

$$h_j = \sum_{i=1}^{I} t_{ij}^{\mathrm{h}} \quad (1 \leqslant j \leqslant J) \tag{8}$$

$$T = \sum_{i=1}^{I}\sum_{j=1}^{J} t_{ij}^{\mathrm{h}} \tag{9}$$

$$0 \le w_i \le W_i \quad (1 \leqslant i \leqslant I) \tag{10}$$

$$0 \le h_j \le H_j \quad (1 \leqslant j \leqslant J) \tag{11}$$

$$0 \le t_{ij}^{\mathrm{h}} \quad (1 \leqslant i \leqslant I,\ 1 \leqslant j \leqslant J) \tag{12}$$

By using Reformulation-Linearization Technique [2], we are able to derive analytically the equilibrium location of housings and jobs.

4. OPTIMUM LOCATION

Next, we derive the optimal distribution of housings and jobs. To solve this problem, we only have to change the objective function as follows:

$$F_{\mathrm{SO}} = 2 \times \sum_{i=1}^{I}\sum_{j=1}^{J} t_{ij}^{\mathrm{h}} d_{ij}^{\mathrm{h}} + \sum_{i=1}^{I}\sum_{i'=1}^{I} w_i w_{i'} \frac{\alpha}{T} d_{ii'}^{\mathrm{w}} + \sum_{i=1}^{I} \beta \frac{w_i}{W_i} w_i + \sum_{j=1}^{J} \beta \frac{h_j}{H_j} h_j \tag{13}$$

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EVACUATION SIMULATION CONSIDERING BUILDING DAMAGES

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Keywords*: Integrated Earthquake Simulator, Evacuation simulation, Structure response analysis, Building damages*

1. INTRODUCTION

Serious damages were occurred by the Great East Japan Earthquake in March 11th, 2011. Most victims were engulfed by Tsunami, which were caused by the blindness in the decision of evacuation and the road block by collapsed buildings and stalled vehicles. In order to solve the evacuation problems, 'Integrated Earthquake Simulator' (IES) is developed by the Earthquake Research Institute of the University of Tokyo. The IES enables us to discuss the circumstances or state of city after an earthquake comprehensively through the seamless analyses. In this study, the evacuation analysis is conducted by the IES to discuss the dependency of evacuation on the existence or non-existence of road block collapsed buildings.

2. STUDY FLOW

In this study, first, a structure response to observed earthquake waves (the acceleration waveform at ground level) for the city model of Takamatsu is analyzed by the IES. The numerical result is the time history displacement of every floor of each structure. From the result story drift (θ) is calculated by the following equation.

$$\theta = \delta / H$$

where δ and H are the horizontal displacement and height of each layer, respectively.

Secondary, the city model in which building damages are considered is prepared and evacuation simulations considering building damages caused by the earthquake are carried out. The numerical results show that the evacuation time depends on the existence or non-existence of damages and the difference extent of damages. Thus, the area in which there is no route for evacuation is set up with taking the damage area into account (see Figure 1 and Figure 2). The damage area is determined by the story drift. For example, a damage is assumed to be occuered if the story drift exceed a certain value.

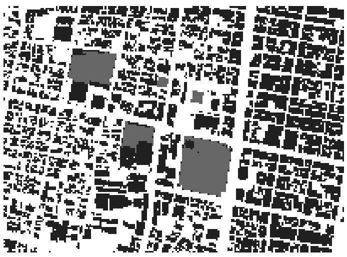

Figure 1. City model ignoring building damage

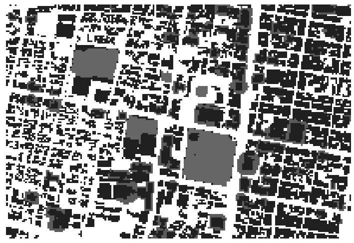

Figure 2. City model concerning building damages

3. ANALYSIS RESULTS

In the-area where low, middle and high-rise buildings are mixed, the building damages concentrate on the middle rise buildings when the Southern Hyogo prefecture earthquake is employed as an incident seismic wave. From the result, it is clarified that the road at the periphery of the damaged buildings can be blocked or narrowed.

Meanwhile, the building damages concentrate on the low-rise buildings when the Great East Japan Earthquake is employed. Since the road around the low-rise buildings is generally narrow, some of the agents go by a roundabout evacuation route or change the evacuation place.

In the area where the low-rise buildings is dominant, the building damages are limited to a portion of middle-rise buildings when the Southern Hyogo prefecture earthquake is employed. Therefore, the road is rarely blocked or narrowed by the building damages.

On the other hand, the road block or narrowing by the building damages is confirmed everywhere when the Great East Japan Earthquake is employed. Due to the road block or narrowing, the agents go by a roundabout evacuation route and head back. At time like this, it is suggested that it may take much time to evacuate.

4. CONCLUSIONS

The analysis results suggest that the evacuation action can depend on the damage situation of buildings, and that the introduction of the visualization of damaged buildings enables us easily to grasp the damage situation. Thus, the proposed scheme is effective to discuss and evaluate the numerical results.

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A 2D-3D HYBRID MODEL BASED ON STABILIZED FINITE ELEMENT METHOD FOR TSUNAMI RUNUP SIMULATION

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***Keywords**: 2D-3D Hybrid Model, Stabilized Finite Element Method, VOF Method, Tsunami*

1. INTRODUCTION

In recent years, a number of destructive tsunamis reveal the importance of making timely predictions of tsunami runup and giving tsunami warnings. Since the traditional 2D tsunami simulations which are based on the hydrostatic approximation may be limited to get the detail information around structures on the coastal area and the 3D tsunami simulations may cost too much, we propose a 2D-3D hybrid model to compute the wave propagation by 2D and the area around structures by 3D. The present method is applied to several benchmark examples to show the validity and efficiency of the method.

2. NUMERICAL METHODS

The 2D-3D hybrid model couples the 2D shallow-water/Boussinesq equation with the 3D Navier-Stokes equation are based on the stabilized finite element method [1]. The advection equation is applied to the interface-capturing approach that based on the VOF method [2] with the 3D analysis. The linear triangular element is employed for the spacial discretization, the Crank-Nicolson method is employed for the temporal discretization, and the Element-by-Element Bi-CGSTAB method is employed for solving the simultaneous linear equations.

A 2D-3D overlapping method which has considered about the conservation of the flow rate is employed. Figure 1 shows the images about the coupling domain. The velocity and the water depth which are computed by the 2D domain will be used as the 3D inflow boundary conditions. As the same, the velocity and the water depth which are computed by the 3D domain will be used as the 2D outflow boundary conditions.

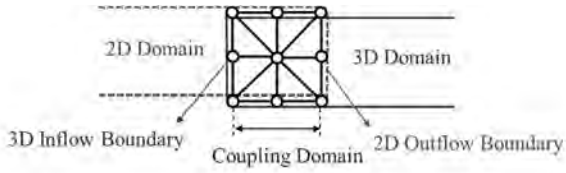

Figure 1. 2D-3D overlapping method

3. NUMEIRCAL EXAMPLES

In order to evaluate the effectiveness of the 2D-3D hybrid model, we applied the runup of solitary waves problem [3] shown in Figure 2. We set the solitary wave with initial amplitude $\zeta_0/h = 0.3$ climbing over the beach with $\cot\beta = 19.85$. Figure 3 is a snapshot of the wave propagation at 0.6s by using the 2D-3D hybrid model. Figure 4 shows a comparison of the 2D-3D hybrid models, 2D models and the experimental results. According to Figure 4, we can see the results of the 2D-3D hybrid model show better agreement with the experimental results.

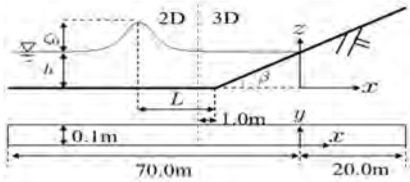

Figure 2. The runup of solitary waves problem

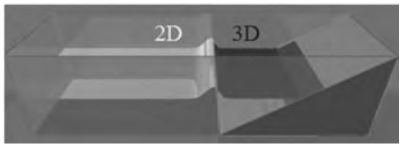

Figure 3. A snapshot of the wave propagation (0.6s)

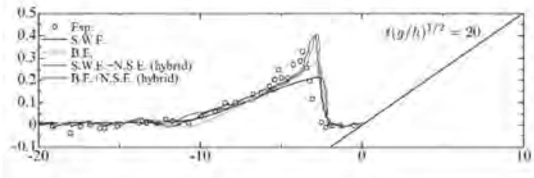

Figure 4. Surface elevation profiles

3. CONCLUSIONS

In this paper, a 2D-3D hybrid model based on the stabilized finite element method for tsunami runup simulation is presented. By comparing the numerical results with the experimental results, it can be concluded that the present method is useful for the tsunami runup simulation. Our future work is the application to real city terrains.

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APPLICATION OF THE FEMA P-58 METHOD FOR REGIONAL SEISMIC LOSS PREDICTION

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Keywords*: earthquake engineering; FEMA P-58; earthquake economic loss; regional seismic damage simulation*

1. INTRODUCTION

FEMA P-58 is the state of the art of seismic loss prediction method[1]. Compared to the existing building-based loss prediction method such as HAZUS, the FEMA P-58 method directly take the fragility of every structural and nonstructural component in a building into account, hence it can generate a more realistic loss result.

The FEMA P-58 method has been successfully applied to individual buildings. However, currently there is no such application for regional predictions. Therefore, a practicable approach for regional seismic loss prediction based on the FEMA P-58 method is proposed in this study. The key challenge when using the FEMA P-58 method for regional seismic loss predictions is the difficulty of obtaining the engineering demand parameters, or EDPs (i.e. building seismic responses, such as inter-story drift ratio or floor acceleration) for a large number of buildings within the region. In this study, the multi-story concentrated-mass shear (MCS) model[2] is adopted for efficient seismic response analysis.

2. LOSS PREDICTION METHODOLOGY

In FEMA P-58 method, the building seismic loss is the sum of the repair cost of all components. The repair cost of each component is calculated through the following procedure: (a) Obtain the EDPs of the building story in which the component is located; (b) Determine the damage state utilizing the fragility curves assigned to the component; (c) Determine the repair cost according to the total quantity and unit repair cost of the component.

The EDPs are obtained through nonlinear time history analysis (THA) using the MCS model. The parameters of MCS models can be conveniently determined for a large number of buildings with different structural types[2]. Moreover, the THA of a region using the MCS model can be very efficient[3]. Hence the adoption of the MCS model overcomes the difficulty of EDP calculation.

3. CASE STUDY

A case study of Tsinghua University campus in Beijing is performed to demonstrate the application of FEMA P-58 method for regional seismic loss prediction. The region consists of 619 buildings. Masonry structure comprise 55%, others are reinforced concrete frame and shear wall structures. The seismic loss prediction is performed at three earthquake hazard levels. Figure 1 shows the result. The total seismic loss ratio is defined as the ratio of total seismic loss to the total replacement value (US$ 7.476 billion) of the region. More details such as the loss results of components can be predicted by the proposed method for each building (Figure 2).

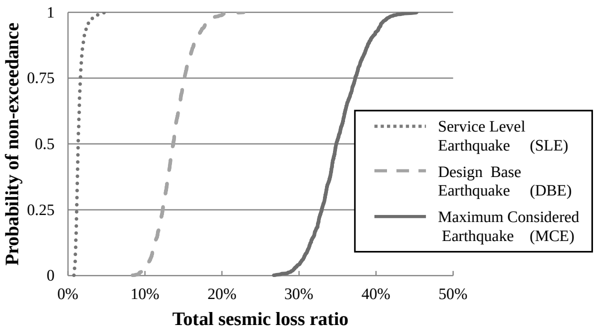

Figure 1. Cumulative probability of the total earthquake loss ratio

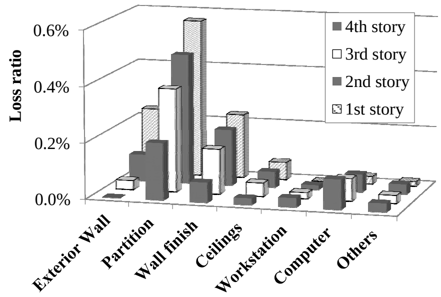

Figure 2. The loss details of nonstructural PGs at each story of an individual building at the MCE hazard level.

4. CONCLUSIONS

A component-based regional seismic loss prediction method is proposed based on the FEMA P-58 method and the MCS model. The outcomes of this work can be used as a reference for urban seismic disaster mitigation or earthquake insurance.

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Session 4

DEVELOPMENT OF A VOLUNTARY DECISION-MAKING MODEL FOR RESIDENTS DURING POST-DISASTER RECOVERY

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Keywords: *Agent-based simulation, disaster recovery, decision-making model*

1. INTRODUCTION

The process of disaster recovery involves the dynamic interaction of multiple factors which often remains hidden from the surface[1]. Furthermore, due to empirical limitations, recovery outcomes are often superficially understood.

One of the major sources of the dynamics in the system is residents' behavioral decisions. The way affected residents make decisions under uncertainty and how these decisions get propagated over space and time to eventually affect the overall recovery in the community is necessary to be understood in order to have an effective recovery policy. Therefore, the objective of this research is to introduce a new methodological approach to capture the dynamics of post-disaster recovery by modeling residents' decision making and interactions within the recovery environment.

2. MODEL COMPONENTS

This paper presents additional enhancement on a multi-agent simulation model for recovery[2], which is developed by taking into consideration the pre-disaster community characteristics of a disaster-hit region; the type of damage; and the recovery policies applied to the situation. In this approach, affected households are modeled as agents with certain requirements and priorities, and a belief structure which is updated as the recovery proceeds. The interaction between their requirements and belief forms the basis for their decision to move away from or stay in the recovery area.

By using a multi-agent model, macro level phenomenon can be understood in terms of micro level decision-making of agents. In this research we have particularly focused on the decision-making in consideration to the voluntary permanent relocation of the household from the temporary housing and not considered the processes involved in the immediate relocation of households from the disaster area to temporary locations.

The decision-making for permanent relocation involves different kinds of characteristics of the agent which can be broadly divided into Primary and Secondary agent characteristics. Primary characteristics relate to the level of attachment to a place; minimum infrastructure threshold; and affordable cost range of an agent. While the Secondary characteristics relates to the preferences of the household regarding the different attributes of an area such as community, employment, and the existence of schools and hospitals etc. which act as weightages when calculating a household's perception of attractiveness for a particular area.

Using this value of attractiveness as a measure, the agents can decide whether to remain in the temporary housing and wait, move to the external area, or return to the disaster area at every one month interval looking at the progress of recovery.

A dynamic component in the model is the decline of the Ideal Attractiveness level which is the total area attractiveness value the agent hopes its final location will have. This ideal begins to declines as the agent continues to be frustrated in the temporary housing unable to find a permanent solution.

Finally, Recovery Policy measures are also represented in the model in terms of short-term and long-term, corresponding to the immediate response measures provided after the disaster and the permanent recovery measures provided, respectively. Short-term measures include temporary housing locations, duration of stay and quality of the area in term of area attributes discussed previously. Long-term measures include the sharing/non-sharing of the reconstruction plan (including the final quality of recovery and the intended date of completion) with the citizens, employment policies and subsidies for rebuilding given to the victims.

3. CONCLUSIONS

Through running the simulation, many of the empirically observed phenomena were validated. Furthermore, it was made apparent that even if a phenomenon seems random at one level of focus, it does not mean that there is no influencing factor on a different level of focus. Since this simulation enables the attainment of a micro-level data in time-sequence it can further reveal the difference in movement patterns between different types of population depending on a recovery policy even when the final outcome is same. Additional simulations may yield insights about the nature of recovery that are not empirically observable.

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STABILIZED FINITE ELEMENT METHOD BASED ON VOF METHOD FOR FREE SURFACE FLOW USING LES

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Keywords: *Stabilized Finite Element Method, VOF Method, LES, Fluid Force, Navier-Stokes Equation*

1. INTRODUCTION

Tsunami causes the serious damage to the structures in coastal area. In order to compute the complicated behavior of tsunami around coastal structure accurately, it is necessary to employ the three-dimensional equations based on Navier-Stokes equation and turbulence model. The finite element method is a useful discretization method for the arbitrary computational domain.

This paper presents a stabilized finite element method for the free surface flow using the LES based on the Smagorinsky model [1]. The present method is applied to the three-dimensional dam break problem with the square pillar.

2. NUMERICAL METHOD

The filtered incompressible Navier-Stokes equation and continuity equation are employed for the governing equations of flow field. The stabilized finite element method based on the SUPG/PSPG method [2] is employed for the discretization in space. The implicit method based on the Crank-Nicolson method is employed for the discretization method in time. The fluid force acting on the structure is evaluated by the weak form of the governing equations.

The VOF method [3], which is one of the interface-capturing methods, is employed as the free surface flow model. The interface function is governed by the time-dependent advection equation. The SUPG method is employed for the discretization in space, and the Crank-Nicolson method is employed for the discretization method in time.

3. NUMERICAL EXAMPLE

The present method is applied to the three-dimensional dam break problem with the square pillar [4]. The computational model and initial condition are shown in Figure 1 (left). The mesh with 7,029,070 tetrahedron elements and 1,224,746 nodes is used in this problem. The minimum mesh size and time increment are 1.27×10^{-3} m and 0.001 s. The Smagorinsky constant is assumed to be 0.10.

Figure 1 (right) shows the profile of free surface and the values of pressure on the structure at t=0.40 s in the case using LES and slip boundary condition. The color denotes the distribution of pressure.

Figure 2 shows the time history of the drag force acting on the structure. From this figure, the result using the LES is good agreement with the experimental results. Also, the computed results using the slip boundary condition gives a better solution comparing with the non-slip boundary condition.

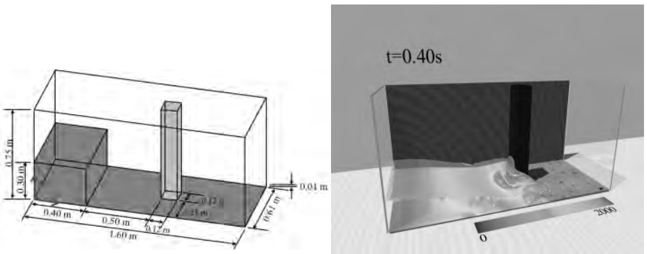

Figure 1. The computational model (left) and the profile of free surface and the values of pressure on the structure at t=0.40 s (right)

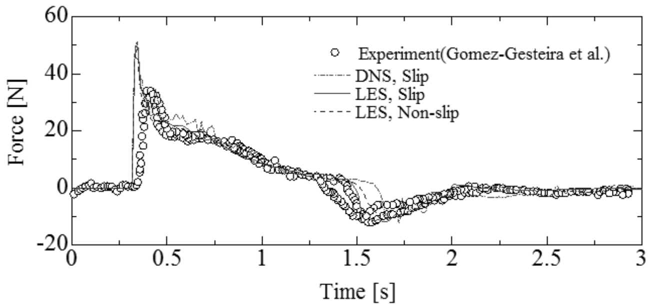

Figure 2. Comparison of the time histories of drag force acting on the structure

4. CONCLUSIONS

The numerical method for the free surface flow using LES based on the stabilized finite element method has been presented. From the results, the present method is useful for the free surface flow analysis.

The development of the fluid-structure interaction method is left for the future work.

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PRE-ESTIMATION METHOD FOR LANDSLIDE HAZARD WITH MONITORING AND SIMULATION

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***Keywords**: Landslide hazard, Pre-estimation, Monitoring, Simulation*

1. INTRODUCTION OF THE PRE-ESTIMATION METHOD

Although it is very difficult to predict the exact time of a landslide hazard, it doesn't mean we can do nothing about it. If one can obtain enough information on what will happen or the impact degree in possible landslide hazards, corresponding protective measures can be taken previously to avoid or reduce losses.

The pre-estimation process can be realized nowadays with the help of the modern information technology. The basic techniques include in-situ monitoring[1] and computer simulation. Monitoring is an important way to get real time data from the slope concerned, with sensors and network transmission. The monitoring data include deformation, displacement, cracks, vibration and the inducing variables of the environment, e.g. rain fall, flood or earthquake. These data are the foundation of the pre-estimation process, which are quite essential for the accumulation of the database, the verification and modification of the analytical model and the evaluation for the current state of the slope. Computer simulation is based on the big data collected through monitoring and high performance computing. Usually, the analysis method is based on empirical models established by analyzing the data collected to build the relationship between the state of the slope and the monitoring data. However, more accurate and effective pre-estimation should combine with numerical simulation[2]. With the development of computer technology and modern computational mechanics[3], the deformation, fracture and movement of the slope under various external loads can be simulated vividly with reasonable and objective results if the right inputs and parameters are given. The monitoring data can be used to validate the computational method and provide information to determine the current state and necessary parameters of the slope for the simulation. Thus, the failure process and damage scale of the landslide hazard under distinct possible conditions can be obtained directly through monitoring data and computer simulation.

2. IMPLEMENTATION SCHEME OF THE PRE-ESTIMATION METHOD

The combination of in-situ monitoring and numerical simulation is the key feature of the pre-estimation method. The implementation scheme is shown in figure 1. The monitoring data provides basic information(e.g., initial and boundary conditions) for simulation and verifies the numerical model. Meanwhile, the numerical model determines the most essential parameters to monitor and optimizes the monitoring scheme specifically. Then, one can preview possible landslide hazards under distinct given conditions and pre-estimate the possible damage degree. Mutual verification and modification of monitoring scheme and numerical model ensures the rationality of this method.

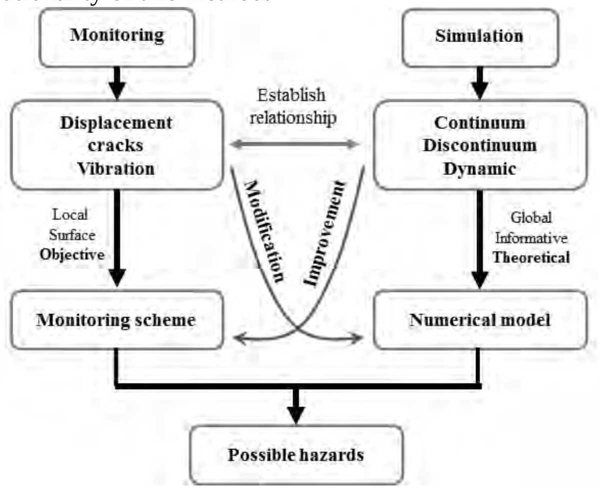

Figure 1. Scheme of the pre-estimation method

3. CONCLUSIONS

The pre-estimation method for landslide hazards with in-situ monitoring and numerical simulation can make full use of the monitoring data and the latest computing technology. Preview of possible landslide hazards in given conditions can be called "condition prediction". It can provide suggestions for the design of the anti-landslide structures and help government to make proper plans and decisions in landslide-prone regions.

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PREPARING SAFE URBAN ROADS FOR FLOOD AND EARTHQUAKE IN YANGON, MYANMAR

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***Keywords**: Road, Flood, Earthquake, Traffic Congestion*

1. INTRODUCTION AND METHODOLOGY

Around the word, disaster is the serious problem that negatively impacts to humanity. Especially, it happens in an urban area that has the high density of population and a number of human activities. Road network plays an important role in transportation for people, goods, objects and etc.. Also, the urban road system is rather crucial as a media to link all the human activities. When roads are rapidly damaged by the disaster and not able to commonly use, it has a serious effect on transportation and possibly breaks down some related activities. In order to reduce effects of disasters such as flood and earthquake in the urban area, it is necessary to prepare safe roads which are not damaged by the disaster to securely evacuate or to normally operate when disaster occurring.

Estimating hazard roads for the flood was introduced by Kalantari [1]. They used the factors from soil wetness index, road density, soil properties and channel slope to evaluate the hazard roads. Preparing pedestrians to evacuate in case of the earthquake was proposed by Bernardini [2]. They applied previous databases on human evacuation behaviours to find safe pedestrians. Moreover, traffic state estimation was introduced by Shan [3]. They employed local camera with big GPS data to detect traffic congestion.

This work proposed a methodology to extract safe roads for flood and earthquake in Yangon, Myanmar. In this research, Stereo GeoEye Images and Landsat time-series were used to provide flood and earthquake maps [4]. While roads were manually extracted by ICUS (International Center for Urban Safety Engineering). The roads with disaster risk were computed by integrating between road products and disaster risk map.

For the factors to indicate flood risk, there are two factors; (1) land elevation, (2) floodway. For the factors to indicate earthquake risk, there are three factors; (1) land slope, (2) indirect old building, (3) distance from faultine. Moreover, traffic congestion can be indirectly estimated by observing land value area. There are two factors; (1) urban expansion (2) the height of building to indicate land value. After processing for disaster risk map, we integrated the roads with a buffer zone and disaster risk map to produce the map of the roads with flood and earthquake risks.

2. EXPERIMENTAL RESULT

In our experimental results, there are two safe road maps for flood and earthquake in figure 1 and 2. Also, indirect traffic congestion map was illustrated in figure 3.

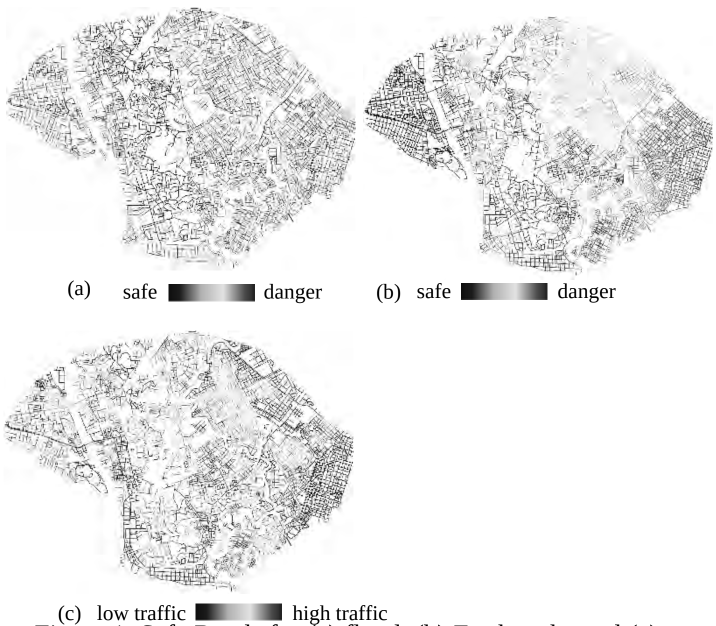

Figure 1. Safe Roads for (a) flood, (b) Earthquake and (c) traffic state

According to the resultant maps, the roads, which are located in high elevations and non-floodway, are secure for the flood. The roads which are located in high elevations and non-floodway are secure when earthquake occurring. Additionally, the roads, which are near the commercial building and are the center of the urban area, are high traffic state. Combining dangerous roads from disaster with traffic state, the huge impact from disaster in transportation can be detected.

3. CONCLUSIONS

This research introduced a method to estimate safe roads for flood and earthquake in Yangon, Myanmar. Satellite images from GeoEye and Landsat were employed to provide flood and earthquake maps. Integrating between roads with a buffer zone and disaster map, safe road maps for flood and earthquake were proposed. These maps can be used to prepare and mitigate the effect of the disaster in transportation.

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PROBABILISTIC ANALYSIS OF TSUNAMI HAZARD USING NUMERICAL SIMULATIONS AND RESPONSE SURFACE

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Keywords: *Tsunami Hazard analysis, Numerical Simulation, Response Surface*

1. INTRODUCTION

A method of probabilistic tsunami hazard analysis had been proposed by the Japan Society of Civil Engineering (JSCE) [1], and the method have been widely used in subsequent studies. In the method, however, numerical simulations are only partly used to evaluate the probability density function. By using numerical simulations more efficiently, more accurate method can be potentially established. The purpose of this study is to propose a new approach which can enable us to use numerical simulations properly in the probabilistic tsunami hazard analysis.

2. OUTLINE OF THE PROPOSED METHOD

A framework of the reliability based design for geostructures had been proposed by Honjo [2]. In this study, the basic concept of the framework is applied to tsunami hazard evaluation. Fig.1 shows a flow of the proposed method. As shown in the figure, evaluation procedures are separated into three parts; (i) numerical simulation, (ii) uncertainty analysis, and (iii) reliability assessment. In the part of the numerical simulation, a series of simulations are performed under the different calculation conditions to obtain the response surface (RS) which is a relation between evaluation target and basic variables. Then, in the part of the uncertainty analysis, the uncertainty of the basic variables are quantified based on the database and engineering knowledge. The Monte Carlo simulation (MCS) is finally performed using RS and quantified uncertainty of the basic variables to obtain the probability density distribution of evaluation target.

3. APPLICATION EXAMPLE

The proposed method was applied to evaluate the tsunami that had been induced by the great east Japan earthquake. Fig.2 shows obtained probability density distribution of maximum tsunami height at Sendai and Ishinomaki. Observed maximum tsunami heights at each point obtained from the results of the field survey are also shown in the figure. In addition, the exceedance probability against the observed maximum tsunami heights were calculated. Consequently, we infer that the result is consistent against observed data.

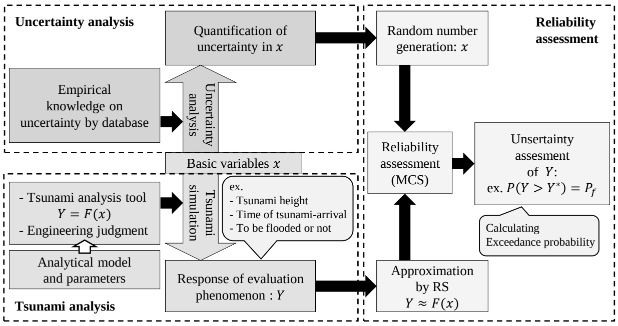

Figure 1. A flow of proposed method

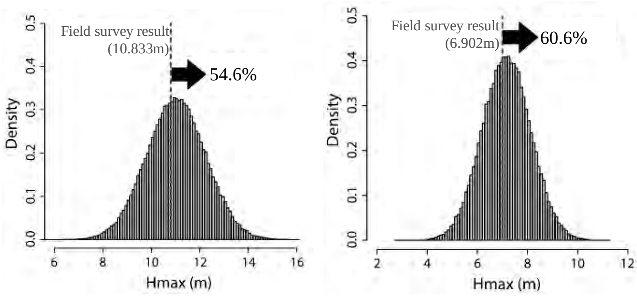

Figure 2. Probability density distribution of maximum tsunami height at Sendai (left) and Ishinomaki (right)

4. CONCLUSION

The new method of probabilistic tsunami hazard analysis was proposed, and the method was applied to evaluation of the tsunami in the great east Japan earthquake. Although consistent result was obtained, it is necessary to perform more detailed validation to clarify the capability and the advantage of the proposed method.

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TOWARDS AN EXPECTATION OF TSUNAMI FEATURES USING SAR DATA

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Keywords*: Tsunami Feature, Remote Sensing, Synthetic Aperture Radar, Tsunami Fragility Function*

1. Introduction

Field survey after an extensive tsunami disaster needs a large amount of effort and times. Furthermore, the delay of the field survey might cause the lost of the evidence of tsunami features. To solve this problem, this study aims at developing a technology to expect the tsunami features in a tsunami affected area using remote sensing technology.

1. Study area and data set

The study area encompassed Arahama, Sendai ciy in Miyagi prefecture, which was devastated by the 2011 Tohoku earthquake and tsunami event. Pre- and post-event high-resolution Synthetic Aperture Radar (TerraSAR-X) data, that observed affected areas on 20 October 2010 (UTC) and 12 March 2011 (UTC), were used. Built-up areas were identified by a GIS data with building footprint published by Zenrin company. The result of the expectation of tsunami features was verified by the spatial distribution of tsunami in- undation with maximum inundation depth and the maximum flow velocity, that were calculated by Hayashi et al.(2013)[2].

2. METHOD

Expectation of tsunami features consists of 1) Building damage estimation with TerraSAR-X data, 2) Conversion of the estimated building damage to the features of tsunami inundation using tsunami fragility function.

2.1.BUILDING DAMAGE ESTIMATION

First, damage estimation of washed-away buildings is conducted by applying the following 6 procedures to pre- and post-event TerraSAR-X data ([1]); 1) Pre-processing, 2) Change detection, 3) Extraction of built-up areas, 4) Object-based image processing, 5) Estimating damage ratio of washed-away buildings.

2.2.Conversion of damage ratio to tsunami features

Based on the fragility function proposed by Hayashi et al.(2013)[3], the damage ratio estimated by the damage function was changed into maximum inundation depth and maximum flow velocity. The fragility functions for wooden buildings, that were used for estimating tsunami features, are shown in. Finally, the expected values of the

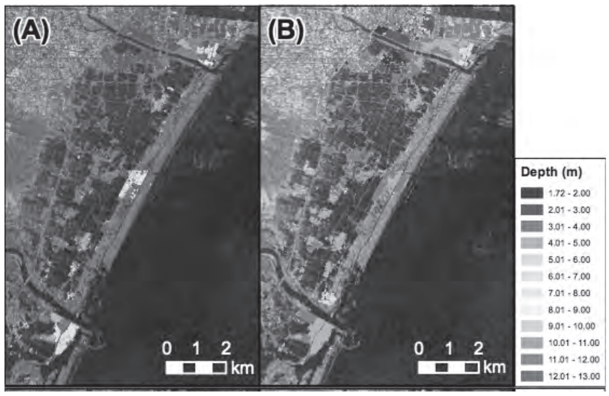

Fig1. An example of expecting flow depth using SAR data (A) Expected, (B) Calculated

flow depth and flow velocity was verified by the results proposed by Hayashi et al.(2013)[2].

3. RESULTS AND CONCLUSIONS

The summary of this study is shown as follow; (1) A new method was proposed to expect the maximum inundation depth and maximum flow velocity, by using pre- and post- event TerraSAR-X data, and the feasibility was tested. (2) It could be found that, as the damage ratio is close to one, the overestimation was easy to be caused. (3) On the other area, the tsunami features could be estimated almost well.

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Session 5

NUMERICAL SIMULATION OF HIGH VELOCITY IMPACT ON STEEL-PLATE CONCRETE WALL

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***Keywords**: SC wall, High velocity impact, Finite element analysis, Failure mode*

1. INTRODUCTION

The SC walls are composed of several components such as infill concrete slab, steel plates, and headed steel studs that anchor the steel plate to the concrete slab. Those structures have many advantages compared with conventional RC structure in terms of construction efficiency and performance for the safety [1], [2], [3]. For example, the SC walls have much higher shear strength and resistance than the RC structure [4]. Many researchers still elaborate in order to investigate the performance of SC walls in different kinds of structures including nuclear facilities as well as conventional structures [4].

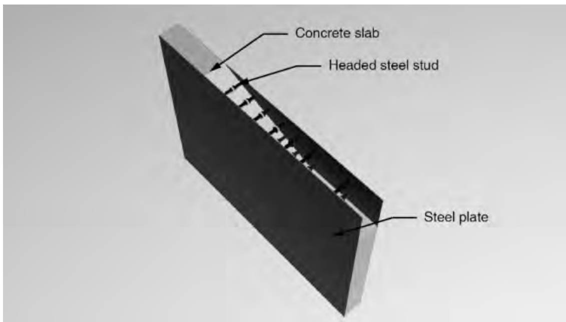
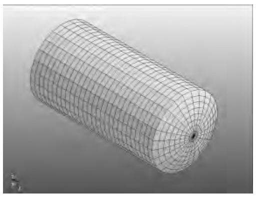
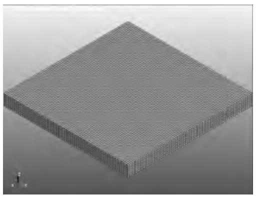


Figure 1. Schematic of SC wall.

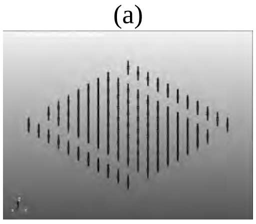
2. NUMERICAL SIMULATION



(a)



(b)



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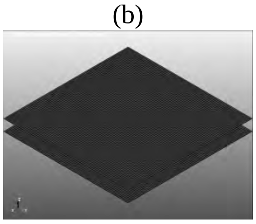

(d)

Figure 2. Simulation models of (a) projectile, (b) concrete slab, (c) headed steel studs, and (d) steel plates.

High speed impact analyses are performed using a commercial finite element code LS-Dyna, and the plastic behavior due to the large deformation and strain rate effect are considered. As shown in Figure 2, the projectile, the concrete slab, and steel plates are constructed using 3D solid elements while the steel studs are modeled with beam elements. In order to describe the large deformation of steel and concrete materials, the plastic kinematic material model and the CSCM concrete model are employed. Contact conditions should be taken into consideration in order to describe the interaction between projectiles and targets as well as the contact between the components of SC walls. The deformation, penetration, and perforation of the SC plates are studied by changing the initial projectile velocity, and the critical velocity is investigated parametrically.

3. CONCLUSIONS

The simulation model is constructed, and the critical impact velocity is calculated by increasing the velocity of the impact projectile. The result is compared with the criterion derived from the available analytical equation [5].

ACKOWLEDGEMENT

This work is financially supported by Korea Minister of Ministry of Land, Infrastructure and Transport (MOLIT) as「U-City Master and Doctor Course Grant Program」.

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INFORMATION SYSTEM "COCOA" FOR EFFECTIVE EVACUATION OPERATION BY PERSONAL IDENTITY NUMBER

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Keywords*: information sharing, evacuation facility, evacuee, headquarter, development of IT system, personal identity number*

1. INTRODUCTION

Information sharing among disaster headquarters and sites of evacuation facilities is important to operate effective evacuation facility management. But, it was difficult to obtain and share the information during earthquake disasters. It is difficult to get even the number of evacuees in each evacuation facility under the condition of a concentration of a lot of evacuees.

One of the possible reason is that no effective information sharing tools is developed. Although some IT system have been developed, most systems cannot manage the condition of evacuation facilities (For example [1]). And, the developed IT system by the municipality is difficult to maintain it without the necessary budget.

It is necessary to achieve effective and smooth operations of the evacuation facilities by sharing the information environments among headquarters and evacuation facilities for the national standard system.

2. COCOA

In this study, we have developed the IT evacuation facility system “COCOA” that can manage and support in accordance with conditions of each evacuation facilities by sharing the information such as the needs and demands, the number of evacuees and those personal information. COCOA can serve and collect the various personal conditions and manage the information of all evacuation facilities.

The personal identity number service (PIN service) will start in Japan. COCOA can be used in many cases (during staying the evacuation facility, moving to the temporary house, condition of received administrative services, etc.) by applying PIN service (Figure 1). For the next huge disaster, COCOA can provide the environments for sharing the information among the evacuation facilities and support appropriate decision-making for the person in charge of the evacuation facility (Figure 2). Figure 3 shows the age number matrix of evacuee for each facility on the web browser.

COCOA can manage the schedule of assigned staffs and calculate optimum assignment schedule. The volunteer is necessary by optimum assignment and manage the schedule. COCOA can also manage the volunteer staffs not only government staffs.

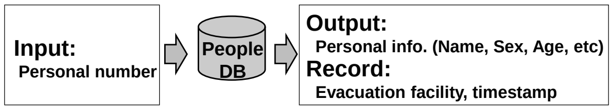

Figure 1: Information structure in COCOA

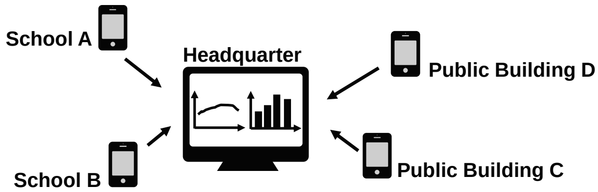

Figure 2: Information structure in COCOA

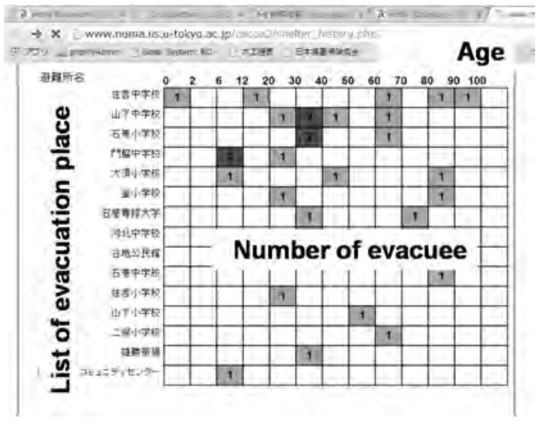

Figure 3: Age number matrix of evacuee for each facility

3. CONCLUSIONS

It is necessary to achieve smooth information sharing at the time of the disaster. But obtaining and sharing information was difficult during the past disasters. And the lessons learn from the past disasters are also difficult to update or apply to next disaster by a system. But, COCOA is effective information tools for the evacuation management as a Japan standard system. Japan have experienced for many kinds of disasters, the experiences can be applied to other places by COCOA.

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A ROAD TRAFFIC NOISE SIMULATION METHOD BASED ON ACOUSTIC WAVE THEORY USING TIME DOMAIN FM-BEM

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Keywords*: boundary element method, acoustic wave theory, fast multipole method, road traffic noise, auralization*

1. INTRODUCTION

As road traffic noise problems are to be serious social problem in urban area, it is very important to evaluate traffic noise for the planning and designing of highway. The numerical simulation for traffic noise can be classified into two approaches; wave acoustic theory and geometrical acoustic theory.

This paper presents a simulation method for road traffic noise based on acoustic wave theory. The wave scattering problem for road traffic noise is solved by the time-domain fast multipole boundary element method (FM-BEM) [1]. The auralization is realized with the computed sound pressure.

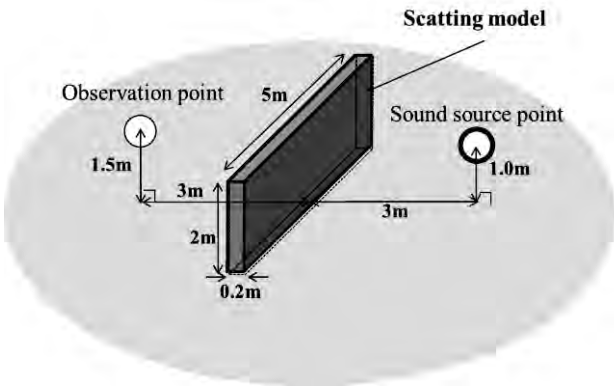

Figure 1. The computational model.

2. GOVERNINGE EQUATION AND NUMERICAL METHOD

The unsteady wave equation is employed for the governing equation. The governing equation is discretized by the time-domain interpolation based FM-BEM proposed by Takahashi [1], which is based on an approximation of the integral kernels of the boundary integral equation with interpolation functions. For the spatial discretization, the piecewise-constant interpolation based on triangular element is employed. On the other hand, the piecewise-linear interpolation is employed for the temporal discretization. The computational results are obtained by the convolution using the impulse response and the actual road traffic noise.

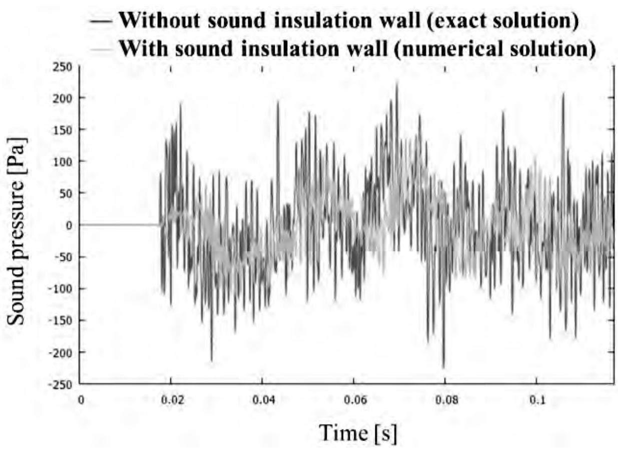

Figure 2. Sound pressure at observation point.

3. NUMERICAL EXAMPLE

To comfirm the validity of road traffic noise analysis using the FM−BEM, we calculate the three-dimensional acoustic problem with the sound insulation wall as shown in Figure 1. The number of the boundary elements is 250840, the time increment Δt is assumed to be 0.0585 ms. The input data at the sound source point is given by the actual road traffic noise which is obtained from the observation at the driving test course of Ministry of Land, Infrastructure and Transport.

Figure 2 shows the comparison of sound pressure at the observation point with or without the sound insulation wall. The attenuation of the comparison of sound pressure by the sound insulation wall can be clearly shown in Figure 2. The auralization is also performed using the computed sound pressure. We can understand the effect of sound insulation wall by the change of sound pressure and tone.

4. CONCLUSIONS

In this paper, we have developed a numerical simulation method based on FM-BEM for the three-dimensional transient acoustic field analysis. The attenuation of sound pressure with the sound insulation wall can be verified.

The application of the present method to the actual road traffic problem is left for the future work.

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A METHOD OF MOLECULAR COMPUTATION OF PHOTO-RESPONSIVE POLYMER REINFORCED WITH NANOPARTICLES

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Keywords: *Molecular dynamics simulation, Photo-responsive polymer, Nanocomposites, Nano-mechanical modeling, Gold nanoparticle, Carbon nanotube*

1. INTRODUCTION

In this paper, we introduce the molecular-level computational modeling method, which for the opto-mechanical design and analysis of photo-responsive polymer (PRP) and polymer nanocomposites. PRPs have their unique characteristics in that the material reversibly deforms up to centimeter-scale by irradiation of specific wavelength of light **[1]**. The main cause of such photo-responsibility of the material is that the photo-reactive mesogen molecules inside of the polymer networks directly modulate the alignment of the polymer microstructures under light/thermal exposure. In the present work the effective photostrain and the corresponding thermal and mechanical stability of the material are quantitatively derived according to the photo-isomerization ratio of the reactive mesogen molecules **[2]**, by adapting photo-reactive potential to the classical molecular dynamics (MD) simulations.

Together with the molecular computation model for bulk responsibilities of PRP structure, the present work also covers the improvement of the thermal and mechanical properties of the material by inserting nano-sized gold particles or carbon nanotubes. Due to the strong filler-matrix interaction and its extremely high surface-to-volume ratio **[3]**, one can expect the extraordinary properties as well as multi-functionalities of the nano-sized filler embedded composite system.

2. COMPUTATION MODELS

To simulate the photo-responsibility of PRP structure and its nanocomposites, azobenzene-contained liquid crystalline polymer molecules are generated *in silico* and allocate along nematic direction. Regarding the nanocomposites system, silicon carbide (zero-dimensional) and single-walled carbon nanotube (one-dimensional) filler are positioned in the center of the unit cell as shown in **Figure 1**. The polymer matrix are tightly crosslinked and thermodynamically equilibrated using MD. The photoactive potential is selectively applied in the unit cell to estimate the photostrain and other thermo-mechanical properties of the material according to the photo-isomerization ratio of azobenzene molecules. The elastic stiffness and the thermal stability of the considered unit cells are derived through uniaxial tensile loading simulation under NVT and heating-up simulation under NPT ensembles, respectively.

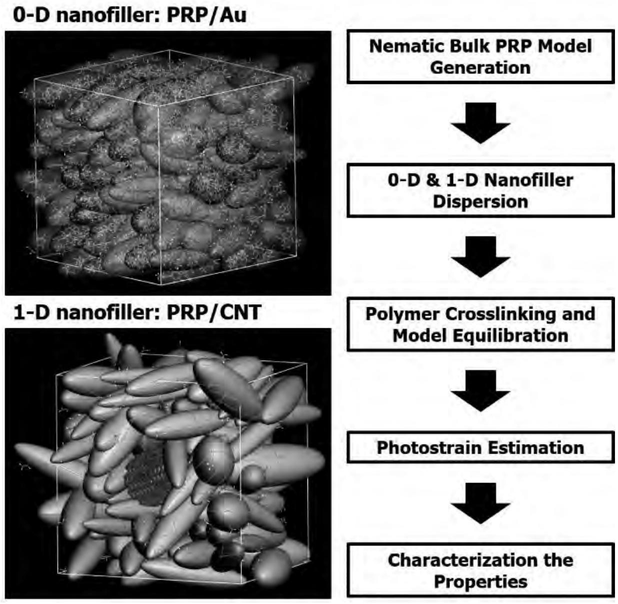

Figure 1. Equilibrated molecular configurations of the PRP/nanoparticle composite structures constructed in the MD simulation (left) and their modeling process (right).

3. CONCLUSIONS

It is verified that the considered 0-D and 1-D nanocomposite models show significantly enhanced mechanical and thermal properties without loss of photo-deformation characteristics of polymer domain. The effect of interfacial region between the nanofiller and the surrounding matrix and the nanoparticle particle size effect also be characterized.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2012R1A3A2048841)

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STABILIZED FINITE ELEMENT METHOD FOR WIND FLOW ANALYSIS WITH PLANT CANOPY

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***Keywords** : LES, plant canopy model*

1. INTRODUCTION

In recent years, the heat-island phenomenon is becoming serious problems in the urban area by the effect of rapid urbanization. The major cause of the heat-island phenomenon is based on the decrease of vegetation, and thermal storage effect by alteration of ground and structures. In order to estimate the extent of the environmental issues quantitatively, it is develop an accurate numerical method. The finite element method is suitable method for the thermal environment in urban area, since the finite element method can easily treat the geography and buildings.

This paper presents a numerical method for the evaluation of environmental flow with plant canopy by a stabilized finite element method. The one-equation model of LES [1] is employed for the turbulence model.

2. NUMERICAL METHODS

In this study, we deal with the compressible viscous fluid. The incompressible Navier-Stokes equation and equation of continuity are employed for the basic equation of flow field. For the turbulent model, the one-equation model based on LES [1] is employed. In order to consider the effect of plant canopy, the plant canopy model [2] is employed.

For the discretization in space, we employed the stabilized finite element method based on the SUPG/PSPG method. The Crank -Nicolson method is employed for the discretization in time. The parallel computing based on MPI is performed. The element-by-element Bi-CGSTAB2 method is employed for solving the discretized simultaneous equations.

3. NUMERICAL EXAMPLE

The present method is applied to a numerical example containing a plant canopy to investigate the validity and efficiency of this method. The computed results are compared with existing experimental results [3].

Figure 1. shows the computed domain. The inlet velocity is assumed to the values obtained from the experimental data [3], and the outlet velocity is free outflow boundary condition. The upper and side is slip boundary condition. The parameter for plant canopy model are assumed as; the drag coefficient of tree crown $C_f = 0.8$, the leaf area density $a = 17.93$ [m^2/m^3] . The minimum mesh size and the time increment are assumed to be $\Delta x = 0.06$ and $\Delta t = 1.0 \times 10^{-3}$. Figure 2. shows the velocity distribution at y=0.6, y=0.8. The computed result obtained by the present method is good agreement with the experimental value.

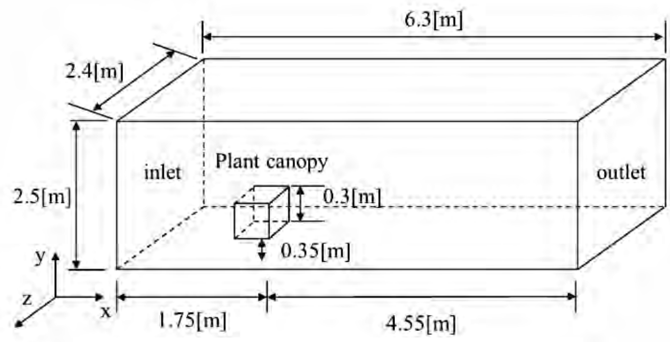

Figure 1. Numerical Example

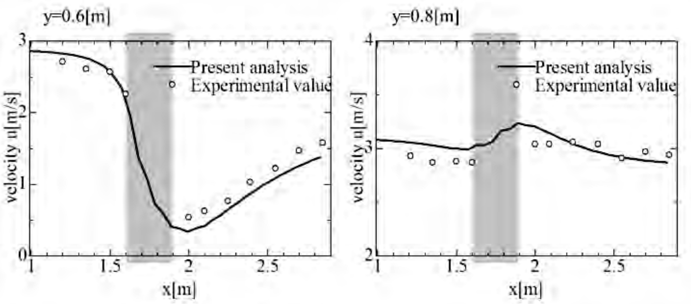

Figure 2. Velocity distribution(y=0.6[m], y=0.8[m])

3. CONCLUSIONS

This paper presents a numerical method based on the stabilized finite element method for the wind flow considering the plant canopy model. From the results obtained in this paper, it can be concluded that the present method is an useful tool for the wind flow analysis. The consideration of the radiation damping by the plant canopy is left for the future work.

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NUMERICAL INVESTIGATION OF NATURAL CONVECTION EFFECTS COUPLED WITH THERMOACOUSTIC OSCILLATING FLOW IN DIFFERENT GRAVITY INCLINATION

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***Keywords**: thermoacoustic, natural convection, gravity effects, oscillating flow*

1. INTRODUCTION

Pulse tube refrigerator has many advantages over conventional refrigerators, such as no moving part, low cost, high reliability and less mechanical vibration. Therefore, it is recognized as one of the most promising refrigerators in the future. There exists gravity property in pulse tube refrigerators, as shown in figure 1, which incarnates that the gravity affects thermoacoustic engines efficiency when the hot side of the pulse tube is placed in the lower than the cold side. This problem attracts many researchers, including Fujimoto, Johnson, Thummes, Kasthurirengan and others. Previous research results are almost experiments. Quantitative results and mechanism knowledge which need theoretical analysis and numerical simulation are seldom. There are many factors that affect the efficiency pulse tube refrigerator, including the gravity angle, the oscillating flow frequency, the temperature difference between the hot and cold side, the pressure amplitude of oscillating flow, and so on. This article researches the coupling mechanism between oscillating flow and natural convection in pulse tube with the change of angle by numerical simulation.

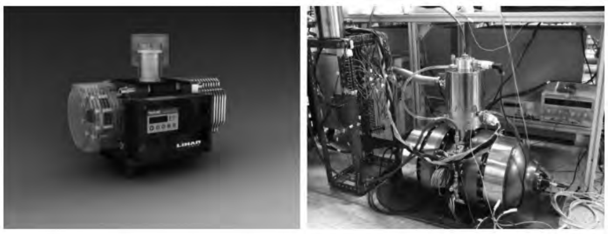

Figure 1. Thermoacoustic pulse tube refrigerator

2. RESULTS AND DISCUSSIONS

We study numerically oscillating flow coupled with natural convection in different inclination angle by the finite volume method with the SIMPLE algorithm. Boundary layer mesh is used to get accurate details of the flow field. α is the angle between gravity inclination and temperature gradient. ΔT is the temperature difference between cold side and hot side. Nu number characterizes convective heat transfer intensity. The development of natural convection is governed by the Navier-Stokes equations for compressible fluid.

Figure 2 is the comparison of oscillating flow Nu and natural convection Nu in different gravity angles at $\Delta T = 200K$. $Nu_{natural}$ is the Nu number for natural convection and $Nu_{oscillating}$ is the Nu number for oscillating flow coupled with natural convection. In these two cases, the temperature difference, geometry of structure and other conditions are same.

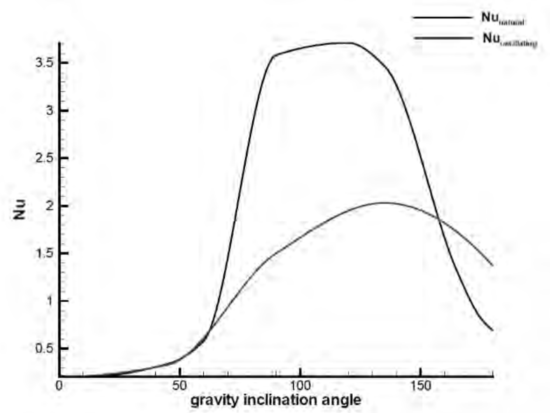

Figure 2. Oscillating flow Nu and natural convection Nu in different gravity angles at $\Delta T = 200K$.

3. CONCLUSIONS

We find there is the intersection of two Nu curves, which is corresponding to a critical angle. When it is less than the critical angle, the oscillating flow Nu is smaller than natural convection Nu and oscillating flow weakens natural convection; and when it is greater than the critical angle, oscillating flow Nu is larger than natural convection Nu, and oscillating flow is enhanced by natural convection.

In this article, for the first time, the coupling mechanism of the oscillating flow and the natural convection with the change of inclination angle is revealed. For the latter part of the study, this part work provides a reference basis.

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STRUCTURAL TOPOLOGY OPTIMIZATION OF ELECTROMAGNETIC VIBRATION ENERGY HARVESTERS

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***Keywords**: Topology optimization, Energy harvesters, Permanent Magnet*

1. INTRODUCTION

This work presents topology optimization of electromagnetic vibration energy harvesters [1]-[2]. The harvester transduces the mechanical vibration into electric energy through the magnetic field based on the electromagnetic induction. The harvester is composed of a mechanical coil spring, wires and permanent magnets (PMs) with or without a magnetic back iron. In this work, the configuration and geometries of the permanent magnet with or without back irons are designed using the topology optimization approach. For both problems with and without back irons, the magnetization direction of the permanent magnet is also designed. The optimization objective is the maximization of the root-mean-square (RMS) value of the harvested output voltage, which will determine the amount of the harvested energy. The output voltage is calculated using the Lagrange polynomial interpolation of the flux linkages, which can be calculated from the magnetic field distribution. For calculating the magnetic field distribution, the Maxwell's equation is solved using the finite element analysis for the given mechanical vibration. The sensitivity of the objective function is derived using the adjoint variable method. The volume of the permanent magnet and back irons are constrained as the given values. For the topology optimization the conventional nodal-density based topology optimization is applied using the commercial software COMSOL.

2. OPTIMIZATION RESULT

The proposed topology optimization approach successfully finds the optimal design of the harvester with or without back iron structure. The haversters are modeled as axi-symmetric two dimentional one. The design result with and without back iron is obtained. Fig. 1 shows the design result with back iron when the volume of permanent magnet is 25% and the back iron volume is also 25% of the whole design domain. The optimal design result is compared with the initial benchmark design. The comparison results shows the huge increase of the output voltage. This enhancement comes from the optimal location and shape of the harvester components, which maximize the time variation of the flux linkages. In addition, the effect of the volume constraint for the permanent magnet and/or back iron is also investigated.

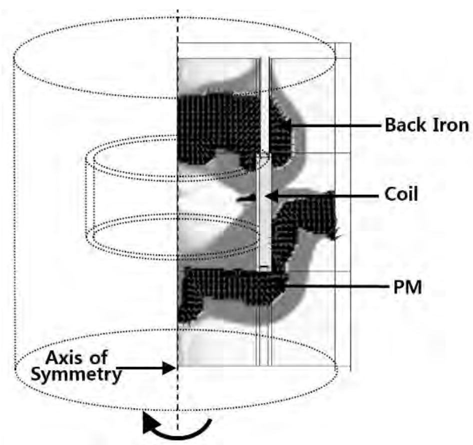

Fig. 1. Topology optimization result of electromagnetic vibration energy harvesters.

3. CONCLUSIONS

This work presents the topology optimization of electromagnetic vibration energy harvesters. The permanent magnet with or without back iron is successfully optimization to maximize the harvester performances. In the future, the optimal design will be fabricated, and the performance enhancement will be validated by the experiment.

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OIL SPILL SPREAD SIMULATION MODEL ON COMPLEX TOPOGRAPHY BASED ON HYDRODYNAMICS

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***Keywords**: Oil spill, Simulation Model, Complex Topography, Hydrodynamics*

1. INTRODUCTION

Accidents of oil leakage occur frequently during transport and storage. Such accidents waste oil resources, pollute environment, and may cause serious fire. Numerical simulation of oil spill spread is helpful for risk analysis and accident prevention.

Most of studies on oil spill spread paid attention to water surface or flat ground [1]. However, experiments showed that ground slope influence the spread significantly [2], indicating that topography is an important factor in fuel spread. Therefore, it is almost impossible to simulate oil spill spread accurately under real accident scenarios due to the lack of simulation model on complex topography.

In this paper, an oil spill spread simulation model on complex topography is established based on hydrodynamics. The model is applied to an actual oil tank area for oil leakage simulation.

2. METHODS

SWEs (Shallow Water Equations) are widely used for flood simulation in hydraulics. In this paper, oil spill spread simulation model is established based on a diffusive wave approximation model, LISFLOOD-FP [3]. Many details were improved to make the model suitable for oil spill spread simulation. Firstly, the calculation formula of flow velocity is modified from Manning Formula to Darcy-Weisbach Equation. Reynolds number in oil spill spread is usually small (due to high viscosity and low velocity) and maybe not in turbulence regime. Darcy-Weisbach Equation is suitable for all flow regimes, while Manning Formula is only applicable in complete turbulence regime. In this paper, Darcy friction factor was determined based on formulas in reference [4]. Secondly, additional limit condition at spread border is introduced to obtain correct spread area. Flow is allowed to flow out a grid cell only when depth is greater than a threshold [5].

3. RESULTS AND DISCUSSIONS

An oil tank area is selected as the study area. Figure 1(a) shows the region of study area, and Figure 1(b) shows the GIS (Geographic Information System) data.

An accident scenario is simulated. In this scenario, oil tanks #9, #10, #11, and #12 leak at the same time due to external damage. The tanks contain crude oil. Figure 2 shows the simulation results, which are the spatial-temporal distributions of oil depth.

Oil gradually filled the pool, which is designed to stop fuel spread. Due to the limit of pool volume, oil overflowed form the pool and started spread to low-lying areas. The spread area covered most of the area, large scale fire may occur if oil is ignited, which is very dangerous.

(a) Region (b) GIS Data

Figure 1. Study area

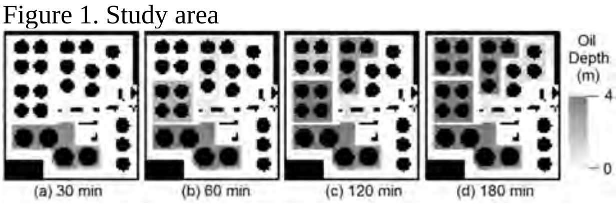

Figure 2. Simulation results

4. CONCLUSIONS

In this paper, an oil spill spread simulation model on complex topography is established based on hydrodynamics. Many details were improved to make the model suitable for oil spill spread simulation. The model is applied to an actual oil tank area for oil leakage simulation, and the spatial-temporal distributions of oil depth were obtained. The simulation model is helpful for risk analysis of overland oil spill.

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A FINITE ELEMENT STUDY ABOUT MECHANICAL FRUSTRATION OF NEMATIC SOLIDS INDUCED BY DISCLINATION DEFECT

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Keywords*: Nemati solid, Disclination defect, Finite element, Geometric nonlinearity*

1. INTRODUCTION

A nematic solid, wherein a uniaxial long-range order is incorporated into a polymer via crosslinking of rigid rod and flexible chain, has been envisaged as a multi-physical smart material as macroscopic shape change is induced by either mechanical load or order-changing stimuli such as light and temperature [1]; upon exposure to stimuli that change alignment condition of liquid crystalline chromophores, the structure either shrinks/expands following the principal direction and the of the shape of the microstate. Nematic director n, which terms an ensemble average of the rigid rods, is thus determines the deformed shape of the structure. For instance, when the director is deviated from the longitudinal direction of the cantilevered thin strip, the structure twists, and even bend away from light.

Accordingly, nontrivial distribution of the director over the structure generates corresponding stress field that oftens induces mechanical frustration. A disclination defect, by which a arbitrary Schileren texture found in the liquid crystal is parameterized, is therefore pivotal to understand order-induced deformation.

In this work, we numerically investigate the deformation and the mechanical frustration of the nematic solid generated by disclination-like texture. A core position and the strength of the defect is blueprinted arbitrarily; a corresponding stress field generated by photomechanical constitutive relation and its effect on the structure is analyzed by facilitating nonlinear finite element method incorporating photomechancal discussions [2].

2. METHODS

A nematic solids with liquid crystal chromophore deforms as the uniaxial order of rigid constituents either increases or decreases. Such mechanical phase behavior of projecting microscopic conformation to macroscopic structure is well explained by reference [2]

The constitutive equation is incorporated into geometric nonlinearity with corotational consideration. Element Independent Corotational (EICR) formulation, which utilizes displaced element to extract in/out rigid body displacement and rotation. Discrete Kirchhoff Triangle (DKT) and Optimal membrane triangle (OPT) elements are used to construct linear 18-dof element.

Distribution of the nematic director *n(x)* is assumed to known *a priori* and be blueprinted before the change of order. Some examples of disclinations are tested in the present work; the positions of the core and strength are altered arbitrarily, where the distributions at the vicinal of the core are computed by 1st order Fredericks distortion energy whenever required.

3. RESULTS

A light-induced deformation topographies of circular nematic solids with disclination strength *m* and center core position are illustrated in Fig. 1. Monopole (*m*=1) and quadpole (*m*=-1) geometry are exhibited, and both agree well with the experimental results. Geometric nonlinearity is found to be crucial to correctly figure out such topology evolution, as linear counterpart does not relax mechanical frustration imposed by disclination, and thus possesses overestimated membrane strain energy.

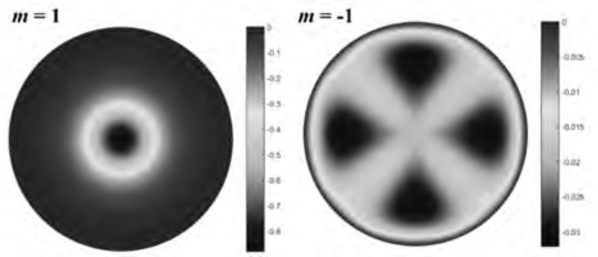

Figure 1. Deformed pattern of photo-responsive nematic liquid crystal with texture marked by *m.*

3. CONCLUSION

In this work, we simulate deformation of nematic solid induced by mechanical frustration with blueprinted disclination; by facilitating finite element formulation that combines nematic constitutive relation with geometric nonlinearity, effects from arbitrary texture are fairly simulated when compared to experiments.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No. 2012R1A3A2048841)

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PEDESTRIAN SPEED CHANGE MODEL FOR SAFETY ASSESSMENT AT SIGNALIZED CROSSWALKS

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Keywords: *Traffic Safety, Pedestrian Behavior, Empirical Data Analysis, Traffic Simulation*

1. INTRODUCTION

Pedestrians are vulnerable road users. In Japan, more than one-third of the fatalities in traffic crashes are pedestrians. To evaluate alternative countermeasures effectively, recently traffic simulation is considered as one of the powerful decision support tools. So far, most of the existing simulations assume that pedestrians walk at a constant speed and follow the traffic rules when they cross roads. In reality, the pedestrians may suddenly start rushing in order to complete the crossing or for other reasons. These behaviors are critical for collision avoidance.

The objective of this study is to integrate a detailed pedestrian maneuver model at signalized crosswalks into the traffic simulation model for assessing traffic safety.

2. PEDESTRIAN SPEED CHANGE EVENTS AS CRITICAL MANEUVERS

Pedestrians' sudden speed change is an important factor for safety assessment. Figure 1 shows an example of pedestrian trajectory. If there is a turning vehicle approaching to the conflict area, the driver may behave based on the expected arrival time of pedestrian at the area. As he/she suddenly changed the speed in the middle of crosswalk, the difference between the expected and actual pedestrian arrival time, T_{dif}, becomes approx. 2 seconds, which is significantly large in terms of conflict avoidance.

Empirical observation data show that pedestrians tend to change their speed when they are approaching the conflict area and when there is a large gap between current speed of the subject pedestrian and the necessary speed to complete the crossing. Further in-depth analysis is conducted to quantitatively explain the probability of speed change considering location, timing and other related variables.

3. SIMULATION INTEGRATION FOR SAFETY ASSESSMENT

The developed model is applied in a simulation model that contains a comprehensive turning vehicle maneuver model [3]. Pedestrian-vehicle conflicts are generated by the traffic simulation.

The traffic simulation model can derive surrogate safety measures such as Post Encroachment Time and vehicle speed at a conflict point, in order to indirectly evaluate the probability and the severity of pedestrian-vehicle conflicts. Sensitivity of the pedestrian maneuver upon surrogate safety measure is analyzed through the simulation.

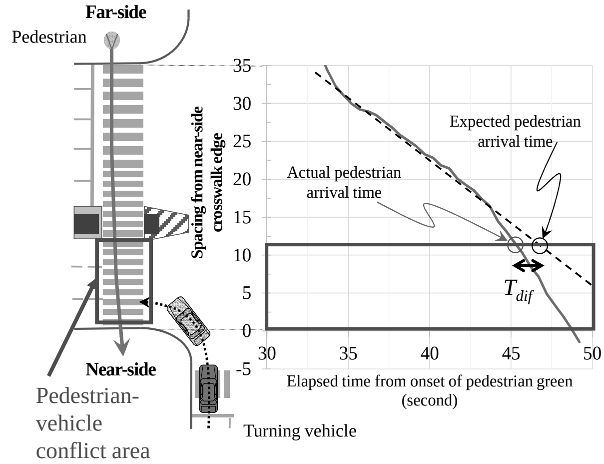

Figure 1. Example of a pedestrian speed change event and a possible pedestrian-vehicle conflict

4. CONCLUSIONS

This presentation demonstrated the impact of pedestrian speed change maneuver on traffic safety. The proposed model can be used for safer crosswalk/traffic signal design and the development of vehicle safety assistance systems.

ACKNOWLEDGEMENTS

This research is supported by the Deanship of Scientific Research (DSR) at King Fahd University of Petroleum & Minerals (KFUPM) through project No. IN141020 as well as JSPS KAKENHI Grant No. 15H05534. The authors are grateful to Prof. Hideki Nakamura for providing video survey data.

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NON-INTRUSIVE REDUCTION METHOD WITH CONNECTED ELEMENTS

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***Keywords**: Maximum Reduced Order Model, Structural dynamics, Optimization, Nonlinear transient analysis, Geometrical nonlinearities, Multibody Dynamics, Absolute Nodal Coordinate Formulation*

1. NON-INTRUSIVE REDUCED ORDER MODELING

Various reduced order modeling techniques have been studied to solve the geometrically non-linear transient response analysis. The nonlinearities cause the iterative evaluations of the internal force, which makes the reduction process difficult. If we reduce the internal force itself, the equivalence of the system suffers. If we reduce the system without the internal force reduction, the efficiency does not rise much.

As shown in the eq.(1), a non-intrusive reduction modelling technique uses the polynomial formulation to describe non-linear internal force terms. With the equation, the construction time of the reduced model increases with cubic order of the system size.[1,2]

$$M_{ij}\ddot{q}_j + C_{ij}\dot{q}_j + \Gamma_i(\mathbf{q}) = F_i \qquad (1)$$
$$\Gamma_i(\mathbf{q}) = K_{ij}^{(1)} q_j + K_{ijl}^{(2)} q_j q_l + K_{ijlp}^{(3)} q_j q_l q_p$$

In this work, a Non-Intrusive reduction method with Connected Element (NICE reduction method) is proposed. The element connectivity is used to construct the non-intrusive models. Then, the system equation is reduced to eq.(2) with proper orthogonal modes Φ .

$$\Phi^T M\ \Phi\ \ddot{a} + \Phi^T C\ \Phi\ \dot{a} + \Phi^T \Gamma(\mathbf{q}) = \Phi^T F \qquad (2)$$
$$q_i = \Phi_{ij} a_j$$

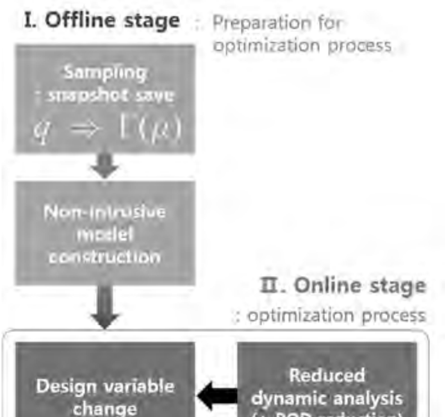

Figure 1. Flow chart for the optimization of transient dynamic system based on NICE reduction method.

This reduced order model can be effectively included in the optimization process. See Fig. 1.

2. NUMERICAL EXAMPLE

A cantilever beam is subjected to the dynamic loading at the tip. A 9-node nonlinear shell element with 6-DOF per node is used. The length and width of the beam are 0.5m and 0.05m, respectively. The number of elements is varied from 8(270 DOFs) to 48(1,350 DOFs). The NICE reduced model is established and the transient analysis is conducted under the perturbed loading condition. Fig. 2. shows the effectiveness of the proposed method. The reduced model is 29 times faster for 8-elements case and 37 times faster for 48-elements case.

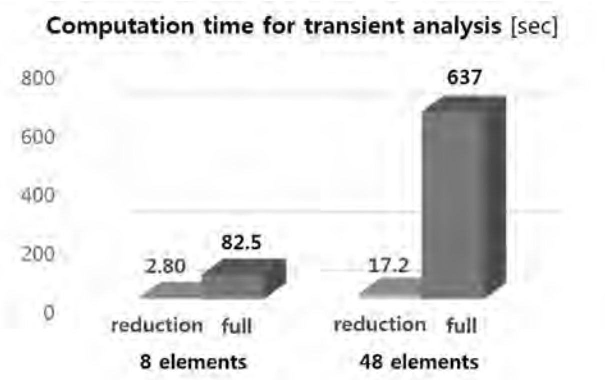

Figure 2. The computation time for the transient analysis

3. CONCLUSIONS

A new reduced modelling technique (NICE reduction) for the geometrically nonlinear transient analysis is proposed. Non-intrusive modelling technique was modified using the information on the element connectivity. The NICE reduction method is useful for the design optimization of the nonlinear transient system. The larger the system, the more effective the method becomes.

AKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No. 2012R1A3A2048841).

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STRESS CONSTRAINTS FOR DUCTILE AND BRITTLE MATERIALS IN FLUID-STRUCTURE INTERACTION SYSTEM

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Keywords: *Stress-based topology optimization, fluid-structure interaction, monolithic approach*

1. INTRODUCTION

This study developed a new stress-based topology optimization method (STOM) for a steady state fluid-structure interaction (FSI) structure minimizing the volume, subject to the local stress constraints for brittle and ductile materials. Despite some researches on the subject of STOM, perplexing optimization issues related to stress-based topology optimization for FSI multiphysics systems still are. Serious issues when creating a effective topology optimization for an FSI structure include: the interpolation method between the fluid equation and the structure equation with respect to locally defined design variables; the mutual multiphysics coupling boundary conditions at dramatically evolving interfacing boundaries; and a clear clarification of the governing equations and the interaction boundary conditions for varying intermediate design variables as shown in Figure 1. Along with these three issues, which are related to multiphysics equations, there are three important considerations related to the STOM: the stress singularity issue, the issues of multiple constraints and the highly nonlinear behavior of the stress constraints. Particularly this problem becomes serious when the failure constraints for ductile and brittle materials are considered. To resolve all of the aforementioned issues, we applied a monolithic analysis, integrating the *qp*-relaxation method and the global *p*-norm approach. And we employ the differentiable max and min operators. In our present method, we were able to create optimal layouts that minimize the volume constraining local stress values for a steady state fluid and structural interaction system for brittle and ductile materials.

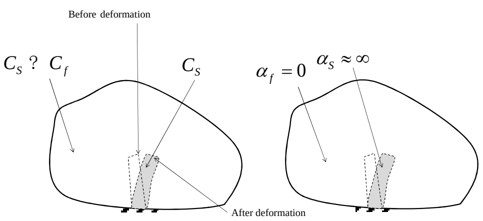

Figure 1. The monolithic analysis and design method for a steady-state fluid-structure interaction problem without explicit interaction boundaries: material values for structural and fluid domains[1].

2. MONOLITHIC APPROACH FOR FSI AND FAILURE THEOREIS

In the present approach, the following monolithic approach is employed (See [1] for more details).

$$-\int_{{}^{0}\Omega} \delta\mathbf{v}^{\mathrm{T}} \left\{\rho(\mathbf{v}\cdot\mathbf{F}^{-\mathrm{T}}\nabla_{\mathbf{x}}\mathbf{v})\right\}\left\|\mathbf{F}\right\| d\Omega = \int_{{}^{0}\Omega} \mathbf{F}^{-\mathrm{T}}\nabla_{\mathbf{x}}\delta\mathbf{v}^{\mathrm{T}}\mathbf{T}_f \left\|\mathbf{F}\right\| d\Omega + \int_{{}^{0}\Omega} \alpha\delta\mathbf{v}^{\mathrm{T}}\mathbf{v}\left\|\mathbf{F}\right\| d\Omega - \int_{{}^{0}\Gamma_{p^*}} p_{p^*}\mathbf{n}d\Gamma \quad (1)$$

$$-\int_{{}^{0}\Omega} \delta p^{\mathrm{T}} \left\{(\nabla_{\mathbf{x}}\cdot\mathbf{v})\right\}\left\|\mathbf{F}\right\| d\Omega = 0 \quad (2)$$

$$\int_{{}^{0}\Omega} \delta\mathbf{S}^{\mathrm{T}}\cdot\mathbf{T}_s d\Omega = \int_{{}^{0}\Omega} \Psi\cdot\mathbf{F}^{-\mathrm{T}}\delta\mathbf{S}(\mathbf{u},\delta\mathbf{u})^{\mathrm{T}}\cdot p\left\|\mathbf{F}\right\| d\Omega + \int_{{}^{0}\Omega} \Psi\cdot\mathbf{F}^{-\mathrm{T}}\delta\mathbf{u}\cdot\nabla_{\mathbf{x}}p\left\|\mathbf{F}\right\| d\Omega \quad (3)$$

All the notations are explained in the reference [1].

There are many failure theories for brittle and ductile materials such as Tresca failure theory, Columb-Mohr theory, Mohr theory and Drucker-Prager yield theory. In order to consider these failure theories in topology optimization, the differentiable max and min operators should be developed.

3. CONCLUSIONS

The present research adopts the monolithic approach for FSI analysis for topology optimization and develops some differentiable failure theories for ductile and brittle materials. With the developed approach, the failure constraints for various materials can be considered.

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CODE2015

Technical Program – Day 2

Session 7

OPTIMAL DESIGN OF TIMBER THROUGH COLUMN

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***Keywords**: Traditional Timber Construction, Traditional Townhouse, Seismic Analysis, Parametric Study*

1. INTRODUCTION

This paper presents the study of analytical evaluation of timber frame with through column for the optimal design of timber through column.

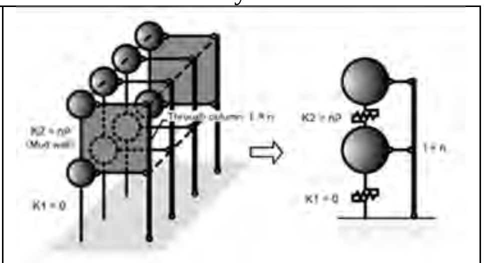
Japan has a long history of earthquakes. The old timber structures in Japan have suffered great damage caused by strong earthquakes, because many of the traditional structures often have insufficient earthquake-proof performance. Besides, many of traditional timber townhouses in each area have same construction system or same structural elements. If the structural performance of their system and elements is clarified, the technique of earthquake-proofing suitable for those buildings can be examined. Therefor it is important to clarify structural performance of their elements in each historical area.

2. SEISMIC ANALYSIS

To evaluate the structural performance of through columns, the analyses were performed using the mass system model added the through columns, as shown in table 1 [1]. The structural elements in this analysis were mud walls at the second floor and through columns.

The input waves of the analysis were five simulated earthquake motions equivalent to design earthquake ground motion based on the Japanese Code. They were modulated to the standard level using coefficient 0.85.

Table 1. Parameter of mass system model

Model	
Structural elements	K1 = 0 (Mud walls at 1st floor) K2 = n_w×P (Mud walls at 2nd floor) I×n_c (Through columns)
n_c	14
Weight (tf)	M_{1F}: 2, M_{2F}: 5, M_{RF}: 5
n_w (P)	1 – 20 (1 P = 0.91 m)
Column Section (mm)	135×135, ×150, ×180, ×210 150×150, ×180, ×210 180×180, 240×240, 300×300
Species	Japanese cedar fb: 70 kgf/cm^2, E: 70 tf/cm^2
Input level	Japanese Code×1.0

The stiffness at the second floor and the column dimensions were used for parameters. To verify the optimally design, the failure mode was established two case as follows; (1) the collapse caused by few quantities of walls and (2) the bending fracture of through column caused by much quantities of walls.

As results, the optimal design of timber through column considering the wall quantity at the second floor was verified, as shown in figure 1.

When the limit of collapse was established at the 1/10 rad., the optimal wall quantity was approximately 2.5 P or more. When the limit of collapse was established at the 1/30 rad., which was the safe limit for new construction, the optimal wall quantity did not exist without through column more than 210 mm. In addition, the column dimension and the failure mode by bending fracture of through column have correlation.

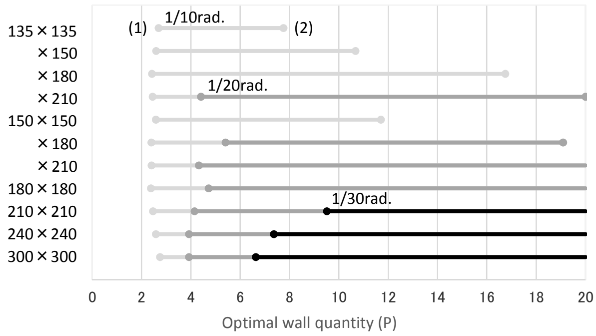


Figure 1. Optimal wall quantity at the second floor

3. CONCLUSIONS

In this model with actual situation of townhouse, the optimal design of timber through column considering the wall quantity at the second floor was verified.

1) When the limit of collapse was established at the 1/10 rad., the optimal wall quantity at the second floor was 2.5 P or more independently of the column dimension.
2) When the limit of collapse was established at the 1/30 rad., the optimal wall quantity did not exist with through columns of small dimension.
3) The column dimension and the failure mode by bending fracture of through column have correlation.

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NUMERICAL ANALYSIS OF 2D-INFILLED FRAME WITH INTERFACE MATERIALS BETWEEN REINFORCED CONCRETE FRAME AND INFILL WALL

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Keywords*: Infilled Frame, Monotonic Loading, Interface Material, Applied Element Method*

1. ABSTRACT

Infilled structures are widely used for construction in many parts of the world due to social acceptability and ease in availability of construction materials. Observation from last major earthquakes and previous studies have demonstrated that infill wall in reinforced concrete frame causes an increase in initial stiffness and strength. However, it has been also observed that infill walls are the first element to be damaged due to brittle nature and increase of attracted force during earthquake (increase of attracted forces often associated with the change in dynamic properties due to increase in stiffness). Infill wall has four types of damage; crushing at the corner, diagonal tension failure, shear slide failure and out-of-plane failure. Current study is focused on the in-plane characteristic of infilled frame. The current aim of the study is to propose a simplified method for modification in infilled frame to reduce in-plane damage in masonry wall by the use of a soft material at the side interface (column and infill wall) and weak mortar at the top interface (beam and infill wall). Effect of proposed method were understood on non-engineered and engineered infilled frame. And, under displacement controlled loading their shear resistant, storey drift and displacement ductility of non-engineered and engineered frames were observed.

2. INTRODUCTION

During an earthquake disaster, loss of non-structural component in a building may easily surpass the replacement cost of building [1], due to loss of business, downtime and inventory. In addition, many constructions in developing countries are not regularized and done without proper monitoring, which increases the risk of life safety as well as economic losses, especially in the non-engineered frames. There has been many research focusing on strengthening of reinforced concrete infilled frames but very few interest has been shown in the reduction of damage to infill walls and harnessing that intact infill wall strength. With the introduction of interface material in the infilled frame, even if reinforced concrete structural member suffers damages, infill wall can support the upper storey load and could effectively mitigate the partial or full collapse.

Numerical simulation of engineered and non-engineered frames were analyzed using Applied Element Method (AEM) [2]. AEM divides the infilled frame in a finite number of discrete elements. And, these elements were connected using multiple normal and shear springs.

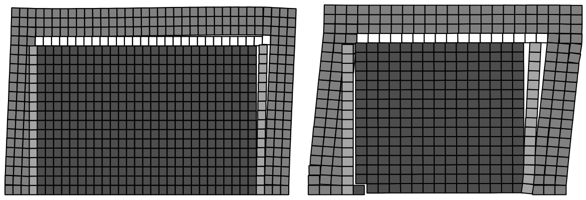

Figure 1 Introduction of proposed method to the engineered (left) and non-engineered infilled frames. (Right) (Colour code:
Grey = Reinforced Concrete, Pink = Soft Material, White = Weak Mortar and Red = Masonry Wall)

Table 1 Reduction in lateral drift of infill wall at 10mm lateral load

Frame Type	%drift reduction in infill wall
Engineered Frame	84%
Non Engineered Frame	86%

3. CONCLUSION

The introduction of interface material reduces the transfer of lateral forces on infill wall. The above Table 1 and Figure 1 demonstrate a significant reduction in lateral displacement and damage in infill wall, respectively. This reduction prevents in-plane damages and renders deformability to RC frame. The mitigation of in-plane damages will intact infill wall strength and allow it to carry the vertical load during failure of the reinforced concrete structural members.

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INFLUENCES OF ENTRAPPED AIR VOIDS ON THE MECHANICAL AND STRENGTHENING CHARACTERISTICS OF SPRAYED FIBER-REINFORCED POLYMERIC (SFRP) COMPOSITES: MICROMECHANICS-BASED PARAMETRIC ANALYSIS

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***Keywords**: Micromechanics-based damage model, air voids, strengthening and mechanical characteristics, SFRP composites*

1. INTRODUCTION

In this study, the structural behavior of reinforced concrete strengthened by the sprayed fiber-reinforced polymeric composites (SFRP) composites considering the influences of entrapped air voids is computationally investigated.

A micromechanical constitutive damage model, which accounts for the entrapped air void [1,2], is implemented into finite element (FE) code ABAQUS [3], and the overall strengthening performance of the system is predicted based on the method proposed by [4].

2. NUMERICAL RESULTS

A numerical study considering the initial air voids is performed to estimate the mechanical properties of SFRP composites [4,5]. It shows that increase in the volume fraction of initial air voids weakens the overall properties of SFRP composites. In addition, the simulation result reveals that higher volume fraction and aspect ratio of fiber lead to stiffer stress-strain responses of the composite.

A comparison between the present numerical simulations and experimental results from four-point loading tests is also discussed in this paper [4,5]. The predicted results are shown to be similar to the experimental results, showing applicability of the model to simulate the behavior of concrete beams strengthened by SFRP composites (See, Figure 1). Details on the influences of entrapped air voids on the mechanical and strengthening characteristics of SFRP composites will be discussed.

Figure 1. The von-Mises stress of a reinforced concrete (RC) beam strengthen with SFRP composites

3. CONCLUSIONS

In this study, a parametric analysis based on micromechanics and FEM is conducted to evaluate the influences of entrapped air voids on the effective behavior of SFRP composites. In the future, the proposed approach would be further compared with additional experimental data for the validation purpose.

ACKNOWLEDGEMENT

This research was supported by a grant (13SCIPA01) from Smart Civil Infrastructure Research Program funded by Ministry of Land, Infrastructure and Transport (MOLIT) of Korea government and Korea Agency for Infrastructure Technology Advancement (KAIA).

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EQUATION FOR PREDICTIVE HORIZONTAL RESPONSE SPECTARA IN KOREA

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Keywords: *response spectra, nonlinear optimization, regression analysis, predictive equation*

1. INTRODUCTION

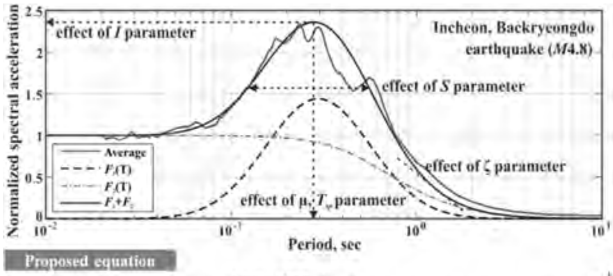
Considering the characteristics of earthquake records measured at Korea, this study empirically proposes a predictive equation for horizontal response spectra that can be applicable to structural seismic design.

2. DERIVIATION OF THE ESTIMATING EQUATION FOR RESPONSE SPECTRA

Total 1,404 ground motion records from 20 earthquakes in Korea are organized from 120 nationwide earthquake stations of Korea institute of geoscience and mineral resources (KIGAM) and Korea meteorological administration (KMA). Using this database, the characteristics of spectral shapes are investigated and describe in terms of shape parameters such as peak intensity (*I*), predominant period (T_{sp}), and width of spectral shape (*S*) with respect to three independent parameters such as magnitude (*M*), distance (*R*), and the average shear wave velocity in upper 30m (V_{S30}).

As shown in Figure 1, the shapes of response spectra are formulized as an approximate spectral shape function ($SA_{norm}(T)$) which is empirically determined from the combination of the function F_1(T) and F_2(T) (Graizer and Kalkan, 2009). Using the function, $SA_{norm}(T)$, the approximate spectral shapes of individual ground motions can be accurately estimated by adjustment procedure of shape parameters. In this study, the parameters representing the effects of basin depth, D_{sp} and ζ are 1.75 and 1.25 from best fit.

This study aims to fit into the 3D response spectra plotted in increasing order of distances using a single continuous equation which can be used for all possible earthquakes. To do this, the correlations of dependent shape parameters are expressed as the sub-functions with respect to three independent variables (*M*, *R*, V_{S30}). In order to find the best representative sub-function for shape parameters, this study performs the nonlinear optimization coupled with regression analyses. This procedure is repeatedly carried out for entire earthquake data sets. From this result, estimator coefficients (m_1~m_4, t_1~t_4 and s_1~s_3) minimizing difference between prediction results and measured data are obtained. Finally, sub-functions of shapes parameters are substituted to baseline equation, and response spectra are then predicted by anchoring the approximate spectral shape function to peak ground acceleration (PGA). Figure 2 comparatively presents measured and predicted average response spectra of several earthquake records.



Proposed equation

$$SA_{norm}(T/M,R,V_{S30}) = \underbrace{I(M,R)e^{-\frac{1}{2}\left(\frac{\ln(T)-\mu(M,R,V_{S30})}{S(M,R)}\right)^2}}_{F_1(T)} + \underbrace{\left[\left(1-\left(T/T_{sp,0}\right)^{\zeta}\right)^2+4D_{sp}^{2}\left(T/T_{sp,0}\right)^{\zeta}\right]^{-\frac{1}{2}}}_{F_2(T)}$$

Sub-functions

$$\mu(M,R,V_{S30}) = m_1R + m_2M + m_3V_{S30} + m_4 \qquad I(M,R) = (a_1M + a_2)e^{a_3R}$$

$$T_{sp}(M,R,V_{S30}) = t_1R + t_2M + t_3V_{S30} + t_4 \qquad S(M,R) = s_1R + s_2M + s_3$$

Estimator coefficients

m_1	m_2	m_3	m_4	a_1	a_2	a_3
-0.001372	-0.28777	-0.0002026	3.6138	1.7816	-3.9698	-0.0014

t_1	T_2	t_3	t_4	s_1	s_2	s_3
-0.000042	0.07973	-0.0000027	-0.0489	0.000259	0.088772	0.2763

Figure 1. Predictive equation for estimating response spectra in Korea

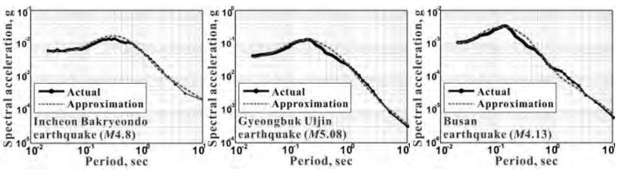


Figure 2. Application of the predictive equation comparison with major earthquake events in Korea

3. CONCLUSIONS

This paper makes an effort to propose empirical equation for predicting response spectra in Korea. Based on the proposed equation, predicted response spectra of major earthquake events are well-matched with measured response spectra. Especially, peak spectral acceleration, predominant period and slope of post-peak decay are approximately corresponded to those of measure response spectra.

ACKNOWLEDGEMENT

This research was supported by a grant from the Research for improvement plan of existing public structures in Korea funded by the Ministry of Public Safety and Security.

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FINITE ELEMENT ANALYSIS OF REINFORCED CONCRETE BEAMS REPAIRED WITH ULTRA-HIGH PERFORMANCE FIBER REINFORCED CONCRETE (UHPFRC)

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Keywords: *ultra-high performance fiber reinforced concrete, finite element analysis, flexural strength, strengthening*

1. INTRODUCTION

Over the past few decades, premature deterioration of reinforced concrete structures exposed to severe environmental conditions and mechanical loading has become a serious problem. Previous studies have shown that the use of ultra-high performance fiber reinforced concrete (UHPFRC) improves the structural response and extends the durability of concrete structures.

In this study, the flexural behavior of reinforced concrete beams retrofitted with UHPFRC is investigated, and experimental results are compared with 3-D finite element analysis. The experiments were performed on reinforced concrete beams repaired in tension and compression zone, with UHPFRC of varying thicknesses. The flexural strength of repaired beams was investigated using four-point bending test and compared with that of reference beam without repair. After that, three dimensional analysis was carried out by using a computer software i.e. MSC/Marc to investigate the flexural capacity and failure modes of all beams.

2. NUMERICAL ANALYSIS

In finite element analysis, ordinary concrete is modeled as an isotropic material capable of cracking in tension and crushing in compression using Buyukozturk concrete model. UHPFRC is also modeled as an isotropic material with parabolic constitutive relation for compression and bilinear constitutive relation in tension. Truss elements are used for modeling of steel reinforcement (rebars and stirrups) with the common node points defined for each rebar element and concrete solids. A bilinear constitutive relation and von Mises failure criteria are employed for steel modeling.

3. RESULTS

Figure 1 shows the load-deflection curves of repaired beams and a reference beam (B-0) obtained by experiment and finite element analysis. Experimental and analytical results indicate that the ultimate flexural strength of RC beams repaired with UHPFRC in flexural tension and compression zone increased, with the increase of UHPFRC thickness. This is attributed to the high tensile strength and strain hardening of UPHFRC. Thicker UHPFRC layer leads to increase in stiffness and cracking load, thus, delaying the formation of localized macro-cracks results in improving the protection function under service conditions.

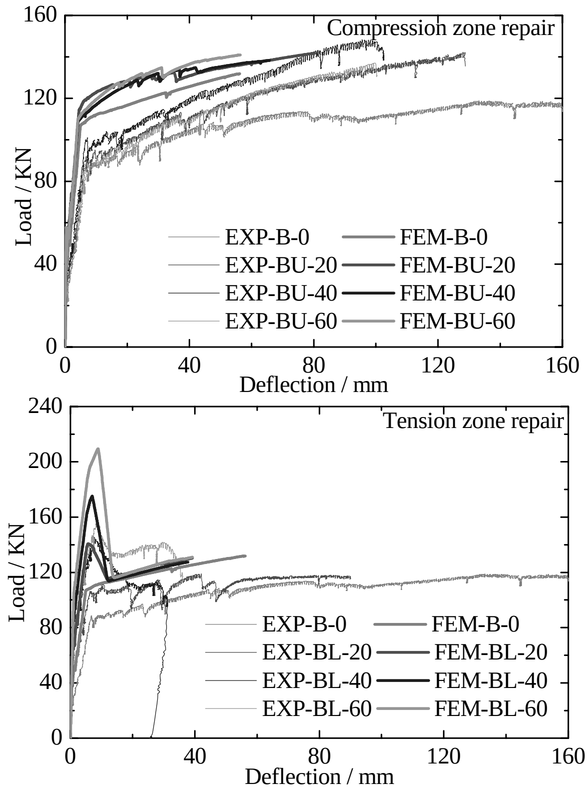

Figure 1. Comparison between the repaired beams and the reference beam

4. CONCLUSIONS

In this study, the use of UHPFRC as restorative material cross-section leads to higher stiffness and increased bending capacity compared to previously repaired thickness. In future based on the results of this study and additional experiments, the structure performance of UHPFRC as a strengthening material can be utilized.

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RESPONSE ESTIMATION METHOD OF REINFORCED CONCRETE BUILDINGS DUE TO WATERBORNE DEBRIS IMPACT LOADS

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Keywords*: Impact Load, Tsunami, Tsunami Evacuation Building, Elastic Response Estimation*

After the 2011 Great East Japan Earthquake, tsunami loads were evaluated based on the damage observations [1], and a structural design code for tsunami evacuation buildings was established [2]. However, impact loads due to waterborne debris were not considered quantitatively in the code. Waterborne debris were reported to cause damage to buildings [3] (Figs. 1 and 2), and design methods against the debris impact loads are therefore currently in urgent need for designing safe tsunami evacuation buildings.

Figure 1. Building collapsed by ship collision (Kamaishi city, 2011) [3]

Figure 2. Stranded cargo ship collided with building (Kamaishi city, 2011)

In the previous researches, impact loads due to waterborne debris have been examined through experiments [4], but the building responses were not focused in the discussions. To understand the building responses due to the debris impact loads, in this paper, impact loads due to ships and shipping containers are firstly defined as a rectangular pulse, based on the studies to evaluate collision strength of a ship's bow [5] and those to obtain a time history of an impact load due to a shipping container [6].

The defined loads are secondly imposed to a particular six story reinforced concrete building designed to an expected tsunami wave load, and its elastic responses are computed by applying modal analyses. Because the building response due to an impact load is significantly affected by the impact duration, the response characteristics are parametrically analyzed to different impact durations. It is then found that the time, either before or after the termination of the loading, when the story drift reaches its maximum value depends on the impact duration. Two simplified approaches are therefore proposed considering impact duration to roughly estimate the maximum story drifts due to the impact loads.

As a result, the estimated maximum story drifts are found in a good agreement with those computed by modal analyses (Fig. 3).

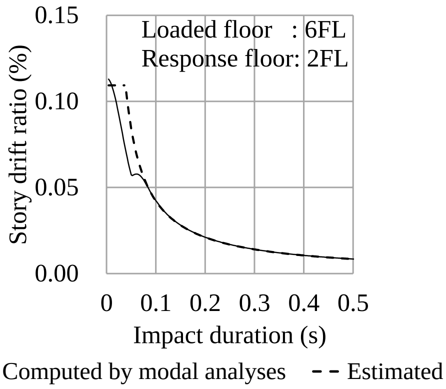

Figure 3. Example of estimated maximum story drifts

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Session 8

FULL-WAVEFORM INVERSION FOR MATERIAL PROFILE RECONSTRUCTION IN PML-TRUNCATED DOMAINS

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***Keywords**: Full-waveform inversion, Shear wave velocity, Perfectly matched layers (PMLs), PDE-constrained optimization, KKT conditions, Regularization, Source frequency continuation*

1. ELASTODYNAMIC FULL-WAVEFORM INVERSION

In this study, a full-waveform inversion method for material profile reconstruction in heterogeneous semi-infinite domains was developed. In particular, the method aims at imaging the spatial variation of shear wave velocities, directly in the time-domain, from scant surficial measurements of the domain's response to prescribed dynamic excitation.

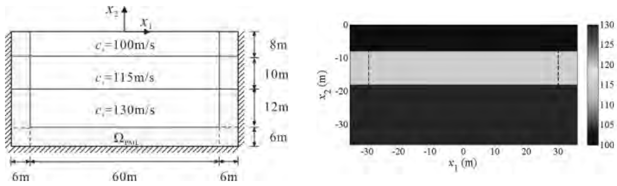
To truncate the semi-infinite extent of the physical domains in numerical analysis, perfectly-matched-layer (PML) wave-absorbing boundaries were introduced. Within this framework, a mixed displacement-stress formulation based on unsplit-field PML was developed for transient elastic wave simulations in heterogeneous semi-infinite solid domains. The developed PML method can be implemented by a mixed finite element method, and is relatively straightforward when compared with split-field PML methods. It also bypasses the need for complicated convolutional time integration which arises when recent displacement-based formulations are used [1].

To formulate the full-waveform inversion of elastic waves, a PDE-constrained optimization approach was used, which lead to a classic KKT (Karush-Kuhn-Tucker) conditions comprising an initial-value state, a final-value adjoint, and a time-invariant control problem. The shear wave velocity profile of medium was iteratively updated by solving the KKT conditions with a reduced space approach. To narrow the feasibility space and mitigate the inherent solution multiplicity of the inverse problem, Tikhonov (TN) and Total Variation (TV) regularization schemes were used with a regularization factor continuation algorithm. A source frequency continuation scheme was also utilized to make successive iterates remain within the basin of attraction of the global minimum.

2. NUMERICAL RESULTS

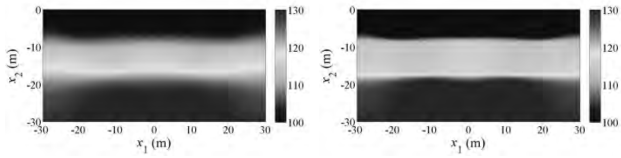
Consider a 60m×30m truncated heterogeneous half-plane, where PMLs are introduced on the sides and bottom of the truncated domain, as shown in Figure 1(a). The domain has 3 horizontal layers of shear wave velocities 100 m/s, 115 m/s, and 130 m/s from surface to bottom. The density is 2000 $\mathrm{kg/m^3}$ for all three layers. Figure 1(b) exhibits the target velocity profile.

Figure 2 shows the reconstructed shear wave velocity profiles using both TN and TV regularization schemes. As shown in the figure, TV regularization captured the sharp interfaces of medium better than TN scheme.



(a) (b)

Figure 1 (a) Configuration of a PML-truncated heterogeneous domain; (b) Target shear wave velocity profile



(a) TN regularization (b) TV regularization

Figure 2 Inverted shear wave velocity profiles

In Figure 3, the variation of misfit, which is the difference between calculated and measured responses, is plotted versus the number of iterations. The misfit decreases monotonically as the iteration progresses.

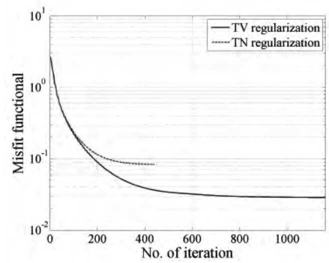


Figure 3 Misfit versus number of inversion iterations

3. CONCLUSIONS

A full-waveform inversion method for reconstructing the material profile of heterogeneous semi-infinite elastic media was developed based on a PDE-constrained optimization approach. Using the developed method, a layered shear wave velocity profile could be reconstructed with the aid of regularization schemes.

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STUDY ON PORTABLE CELLPHONE DETECTOR FOR EARTHQUAKE

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Keywords: *Fake base station, Cellphone detection, earthquake, Disaster relief.*

1. INTRODUCTION

Mobile phone is one of the best beacon for detecting survivor in disaster situation. A survey form project "I-LOV" shows that there are about 80% victims carry their mobile phone with them [1]. For the rescue in earthquake, a cellphone detecting and positioning system is proposed in this paper. This system is designed for searching survivors indirectly by detecting and positioning cellphones.

2. SYSTEM ARCHITECTURE

The cellphone detector is based on software defined radio (SDR) technology and the open software OpenBTS.

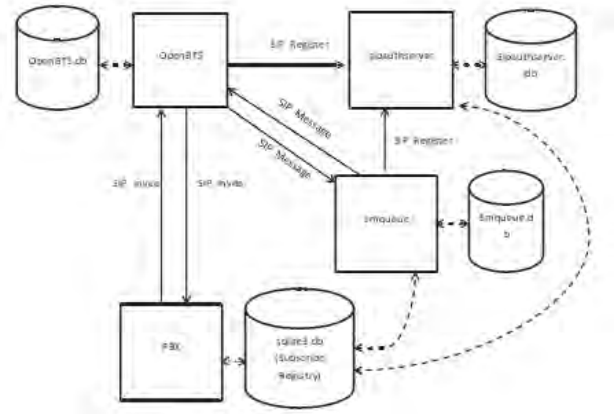

Figure 1. OpenBTS system diagram [2]

OpenBTS builds Global System for Mobile Communication (GSM) cellphone network, allow cellphone to register in it and get International Mobile Subscriber Identification number (IMSI) for individual recognition. By initiate a voice call procedure, OpenBTS can get transmit power of a cellphone and Receive Signal Strength (RSS) of the system. By working with different types of antenna, the system can get cellphone's position with triangulation algorithm of RSS and Angle of Arrival (AOA).

Hardware of the system include an integrated backpack and an antenna. Figure 2 is the whole hardware system. A series of component include Universal Software Radio Peripheral (USRP), power amplifier, low noise amplifier and duplexer are in the backpack. The laptop run OpenBTS and positioning algorithm. An omnidirectional antenna, Yagi-Uda antenna or sector antenna can be applied in this system.

The max rate of transmit power is 20W. With sector antenna plugged into backpack, the system can detect cellphones in extremely wide rage in disaster situation and run AOA positioning algorithm. Omnidirectional antenna is used to detect cellphone in all direction and run RSS positioning algorithm. Yagi-Uda antenna is used for poximity sensing.

Figure 2. Hardware system

3. CONCLUSIONS

With several experiments, some key features of this system are proven. (1) The system allow all cellphone which support GSM protocol to register in, and accept IMSI in the same time; (2) By start a voice call procedure with a specific cellphone, the system can continuously accept cellphone transmit power and RSS; (3) When the system is running with directional antenna, the angle of signal arrival can be reached by the correlation between antenna direction and RSS; (4) Working with sector antenna in full transmit power, cellphones in 1.2km away are able to register in.

The results shown above, indicate that the system is suitable to work in huge disaster situation, especially effective in no mobile service network case. The cellphone detecting and positioning system can detect mobile phones in more than 4km^2 range in short time, acquire rough number of victims and evaluate the demand of rescue resource.

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CRACK PROPAGATION SIMULATION BY THE EXTENDED CONSECUTIVE-INTERPOLATION FINITE ELEMENT METHOD (XCQ4)

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Keywords*: Fracture, XFEM, consecutive-interpolation, crack growth, stress intensity factor*

1. INSTRCUTIONS

The extended finite element method [1] is originally developed for crack growth without remeshing in terms of the partition of unity method. Currently, Bui et al. [2] developed a new consecutive-interpolation 4-node quadrilateral finite element (CQ4) initially applied to stress analysis of 2D solids. Based on the CQ4 scheme the extended consecutive-interpolation finite element is later developed, named as XCQ4, for stationary cracks in 2D solids [3]. The numerical results indicate that the XCQ4 offers a better accuracy and higher convergence rate compared with those derived from the classical XFEM using 4-node quadrilateral element (XQ4). The underlying idea behind the proposed XCQ4 is that the approximation functions constructed based on the CIP contain both nodal values and averaged nodal gradients as interpolation conditions.

In this work, the new element (XCQ4) is further extended to predict the crack growth paths in 2D linear elastic solids. We integrate the interaction integral in terms of J-domain to estimate the fracture parameters.

2. FORMULATION OF THE XCQ4 ELEMENT

The enriched displacement approximation using the new XCQ4 is executed in a similar way with XQ4 as

$$\mathbf{u}^h(\mathbf{x}) = \sum_{i\in I^s} \tilde{N}_i(\mathbf{x})\mathbf{u}_i + \sum_{j\in J^{cut}} \tilde{N}_j(\mathbf{x})\left[H(\mathbf{x}) - H(\mathbf{x}_j)\right]\mathbf{a}_j + \sum_{k\in K^{tip}} \tilde{N}_k(\mathbf{x})\sum_{\alpha=1}^{4}\left[F^\alpha(\mathbf{x}) - F^\alpha(\mathbf{x}_k)\right]\mathbf{b}_k^\alpha \quad (1)$$

where I^s, J^{cut}, K^{tip} denotes the total set, Heaviside enriched set and asymptotic enriched set respectively. In addition the XCQ4 shape function is defined as Eq. (2). node$_x$ ($x=i,j,k,m$) denotes the surrounding nodes of considered quadrilateral element.

$$\tilde{N}_f = \underbrace{\phi_i N_f^{[i]} + \phi_{ix}\bar{N}_{f,x}^{[i]} + \phi_{iy}\bar{N}_{f,y}^{[i]}}_{\text{node } i} + \underbrace{\phi_j N_f^{[j]} + \phi_{jx}\bar{N}_{f,x}^{[j]} + \phi_{jy}\bar{N}_{f,y}^{[j]}}_{\text{node } j} + \underbrace{\phi_k N_f^{[k]} + \phi_{kx}\bar{N}_{f,x}^{[k]} + \phi_{ky}\bar{N}_{f,y}^{[k]}}_{\text{node } k} + \underbrace{\phi_m N_f^{[m]} + \phi_{mx}\bar{N}_{f,x}^{[m]} + \phi_{my}\bar{N}_{f,y}^{[m]}}_{\text{node } m} \quad (2)$$

In terms of the maximum hoop stress criterion the crack should initiate in a direction defined as Eq. (3) when the circumferential stress is maximum.

$$\theta_c = 2\tan^{-1}\frac{1}{4}\left(\frac{K_I}{K_{II}} \pm \sqrt{\left(\frac{K_I}{K_{II}}\right)^2 + 8}\right) \quad (3)$$

3. NUMERICAL RESULTS

A cracked beam with three holes is adopted to assess the robustness of XCQ4. Two test cases having different values of a and b is computed as case I $a=1.5$ $b=5.0$; case II $a=1.0$ $b=4.0$. In both cases the numerical results show a desirable agreement with experimental solutions reported by Bittencourt et al. [4].

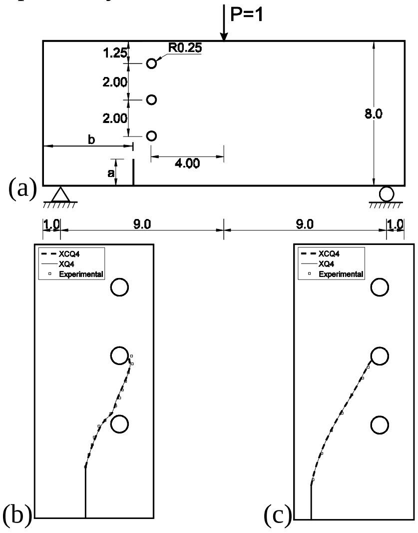

Figure 1. (a) Configuration of cracked beam with three holes; Comparison of predicted crack paths with experimental solution (b) case I; (c) case II

4. CONCLUSIONS

A novel approach for modelling crack propagation was proposed. The XCQ4 method is successfully validated as the predicted crack growth paths agree well with reliable experimental solutions.

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SIMULATION OF FAILURE PROCESS OF REINFORCED CONCRETE BEAM COLUMN JOINT WITH MECHANICAL ANCHORAGES BY 3D RBSM

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***Keywords**: Mechanical Anchorages, 3D RBSM, Knee Beam Column Joint, Failure Process*

1. BACKGROUND

The use of mechanical anchorages is still limited when they are placed near the surface of the beam column joint since the internal stress and cracking pattern have not been well understood. A meso-scale analysis by 3D discrete method, called 3D RBSM, is conducted, because the 3D shape of a reinforcement bar is modeled directly including ribs of a reinforcement bar, cracks occur as the results of discontinuous of concrete and interaction between concrete and a reinforcement bar at meso-scale level, and cracks can be simulated directly. In this study, by investigating the internal stress and cracking pattern of simulation results, the failure process of the beam column joint with mechanical anchorages is revealed through the comparison with the experimental results.

In RBSM, proposed by Kawai *et al.* (1978), a 3D reinforced concrete member is meshed into rigid bodies. The simulation system, developed by Nagai *et al.* (2005), is used.

2. NUMERICAL MODEL

Simulation is conducted for the experiment of beam column joint with mechanical anchorages done by Yoshimura *et al.* (2012). 756642 elements are used to model the beam column joint (Figure 1). The same dimension and material properties as experiment are modeled.

3. SIMULATION RESULTS

Figure 2 shows the load displacement relationship of simulation result which is roughly the same as that of experimental result with 10% difference of capacity, i.e.

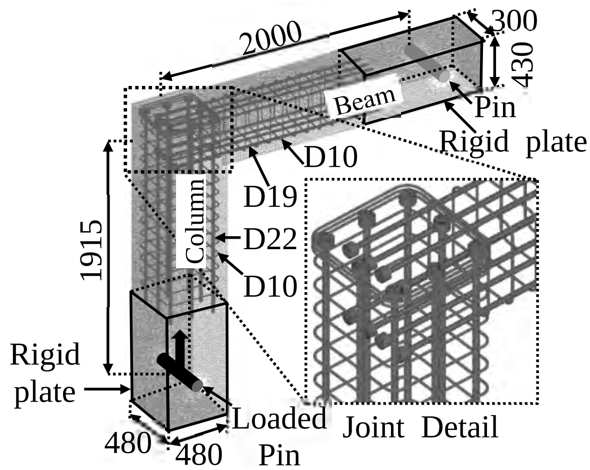

Figure 1. Detail of numerical model (Units: mm)

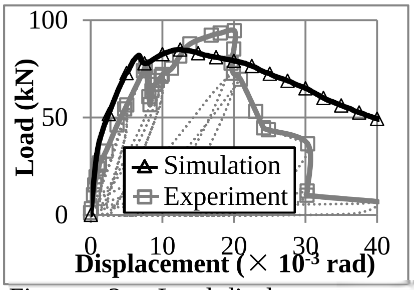

Figure 2. Load-displacement relationships

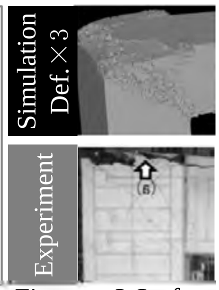

Figure 3.Surface cracks

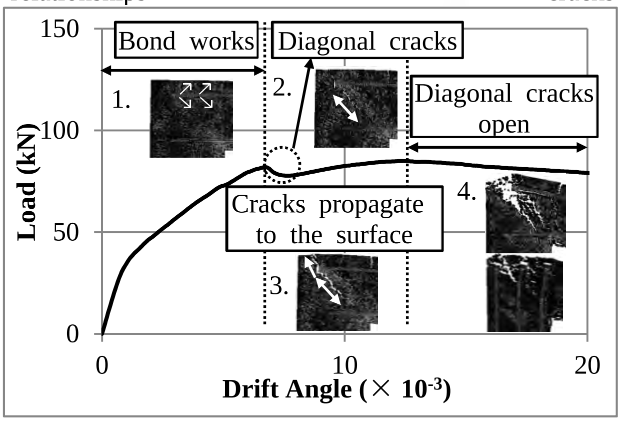

Figure 4. Failure process based on the simulation result

85 kN and 94.5 kN in case of simulation and experiment, respectively. Figure 3 shows the surface cracks of the numerical model which are also roughly the same as those of experimental specimen. Based on the study of the internal stress and cracking pattern of simulation result, the failure process is revealed, shown on Figure 4.

4. CONCLUSIONS

The failure process of the beam column joint with mechanical anchorages has been revealed through the study of internal stress and cracking pattern of 3D RBSM.

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FINITE ELEMENT ANALYSIS OF BURIED PIPELINE ON FORST REGION CONSIDERING FROST HEAVE

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***Keywords**: frost heave, soil freezing, porosity rate, buried pipeline*

1. INTRODUCTION

Due to the growing demand for oil and gas in the world, there is an increasing interest to explore new areas for petroleum production. The Arctic Circle has 13% of the undiscovered oil in the world. Oil and gas are transported over long distances in pipelines, and the pipeline crosses regions of permafrost or seasonal frost. Ground-induced actions due to frost heaving and thawing in regions of seasonal frost are responsible for the majority of damages in oil and gas buried steel pipelines. Therefore, researches of pipelines crossing frozen soils have been performed and several models describing the heaving process have been developed in the past.

The porosity rate model is indicative of ice growth. Ice growth is dependent on the temperature gradient and the stress state in the freezing soil. The porosity rate model was introduced by Michalowski and Zhu [1], and the model was implemented in a 2-D Problems. When soils are frozen by air or inner pipeline temperature, ices made the adhesive force between the pipeline and the soil. The 3-D numerical model is necessary to consider this phenomenon. Therefore, this study performs numerical analysis for the 3-D pipeline using the porosity rate model. We compared the numerical results between the 1-D model [1] and the 3-D model.

2. NUMERICAL ANALYSIS

The numerical computations are performed using the commercial program ABAQUS. Some assumptions are applied in this study. The heat transfer takes place by conduction only. The soil is fully saturated. The thermal conductivity of soil is isotropic. The behavior of the soil to loads is elastic, but the elastic properties depend on the temperature. The total strain increment consists of both the elastic strain increment and the growth increment due to the change in porosity. The thermal constitutive behavior of the soil and the porosity rate model are defined and integrated into ABAQUS using the user subroutines UMATHT and UEXPAN, respectively.

Two types of problems are performed in this study: 1-D freezing (1-D heat flow) for validation of the model, and 3-D pipeline analysis. The analysis is a fully coupled thermal-displacement analysis.

The pipeline is buried 1.72m below the top surface (Figure 1). Pipeline is composed of steel. The diameter of the pipe is 0.9m, and the thickness of the pipe is 8.5mm. The pipeline is not insulated. The width of the model is 12.0m and the height is 8.0m. The size of the analysis model was formed large enough to determine the temperature distribution due to the change of air and inner pipeline temperature. Soil skeleton, water, ice thermal properties that used in this study are represented in Table 1. The total simulation time was 60days.

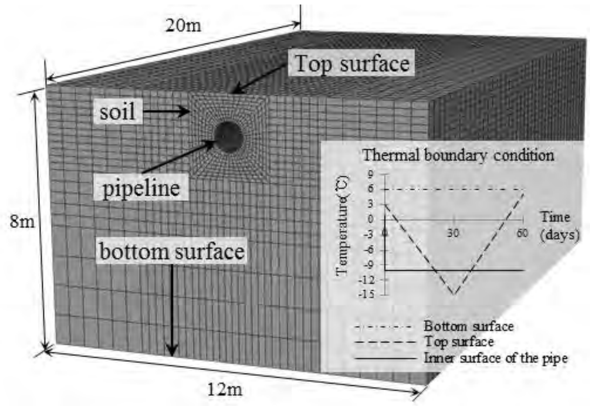

Figure 1. Finite element modelling

Table 1. Thermal properties of soil constituents

	Density (kg/m^3)	Mass heat capacity (J/kg℃)	Thermal conductivity (W/m^3℃)
Soil skeleton	2620	900	2.92
Water	100	4180	0.56
Ice	917	2100	2.24

3. CONCLUSIONS

This study was extended to 3-D model from 2-D porosity rate model to consider the effect between the pipeline and ground. As a result of numerical analysis, the presented model in this study confirmed that indicated the 3-D behavior of the frozen ground. But many experiments and data of field are still needed to indicate the realistic behavior of the frozen ground. The model of this study is expected that be able to consider the behavior of discontinuous frozen ground or the pipe-soil interaction.

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STRAUTO : PARAMETRIC STRUCTURAL MODELLING AND OPTIMIZATION SYSTEM

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***Keywords**: StrAuto, Parametric Design, Computational Optimization, Distributed Parallel Solver System*

1. INTRODUCTION OF STRAUTO

StrAuto is a parametric structural optimization tool developed by our team, a plug-in for Grasshopper running on Rhinoceros. It uses SAP2000 and ETABS APIs for operating real-time iterative analysis, controlling the external solvers and bringing back the results in real-time for evaluation. Thus, selecting an optimum design is enabled by utilizing StrAuto's iterative analysis function, which checks a number of automatically generated alternatives and brings back their analysis results in real time for evaluation.

A key feature of StrAuto's design optimization function lies in the iterative data exchange between auto-generated geometric models and external analysis solvers. It is the APIs that interconnect parametric analysis models, geometries of which can change in real time, with external analysis solvers. StrAuto interacts with the solvers to change the model structure's geometry or properties, manages analysis, and evaluates alternatives by processing analysis results. Until the evaluated results reach a specific goal, StrAuto creates new combinations of parameters to develop the analysis model. By such features, thousands of design alternatives, which can take over a week for modelling a single alternative if using existing engineering platforms, can be created, analyzed, and compared in just a few hours for locating optimal solution.

In order to achieve the lowest cost possible, multiple simulation runs should be performed and project-specific process should be built for finding the fittest structural system or member section. Material strengths and the sizes of vertical structural members (columns and walls) are usually examined for tall building cases.

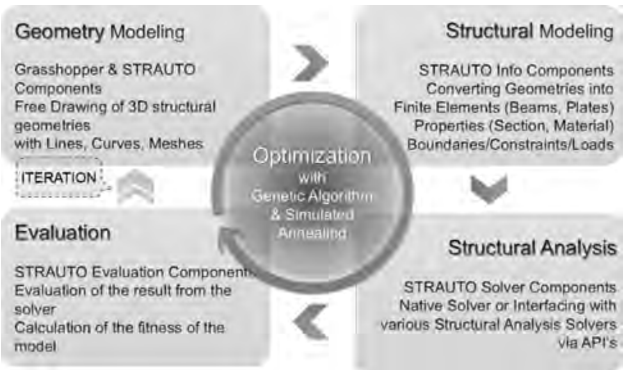

Figure 1. 4 StrAuto's Design Optimization Process

2. APPLICATIONS

The Blade reaches 300 meters with the total gross floor area of 101,700 square meters. It is diamond-shaped in plan with its sharpest edges at the north-east and south-west corners of the site.

We examined alternative structural systems for the tower, mega brace and tube wall system to replace the original structure. We tested multiple steel sections with multiple vertical zonings for each of the three structural systems to determine an optimal system for the tower. Not only did we provide the comparative data for material quantities for each system, but we also provided optimized design results for each of them. The tube wall system was proved to satisfy the minimum cost.

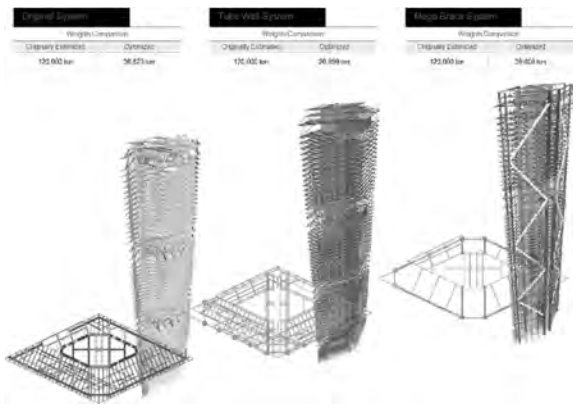

Figure 2. Comparative Optimization for The Blade

3. CONCLUSIONS

StrAuto's functionality is clear and powerful and can be effectively adapted to custom projects. StrAuto's capability to check numerous alternative cases based on the design development plans can be greatly utilized to suggest guidelines for the subsequent construction design phase. We expect to expand StrAuto's functionality to support multiple types of project cases based on our track record of delivering diverse major projects.

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Session 9

NUMERICAL EVALUATION OF DAMAGE STATES AND SEISMIC CAPACITY OF REINFORCED CONCRETE COLUMNS

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Keywords: *AEM, Reinforced Concrete Columns, PEER, Seismic Capacity*

1. INTRODUCTION

To assess the seismic vulnerability of reinforced concrete buildings, a damage database is being developed, which requires an accurate and sophisticated numerical tool. In this study, a discrete element approach based numerical tool called Applied Element Method (AEM) [1] is used. To verify the capability of AEM to carry out inelastic analysis and study the properties of plastic hinges corresponding to different damage states, validation of rectangular RC columns was required. Pacific Earthquake Engineering Research (PEER) experimental database for structural performance, which is a compilation of various experiments conducted on rectangular reinforced columns against monotonic cyclic loading was selected. This paper evaluates visual damage states as provided in the database with respect to measurable parameters using numerical simulation.

2. MODELLING OF RC COLUMNS USING AEM

In this study, test results were studied from the literature [2], [3] and the most suitable ones have been shortlisted for numerical validation. Figure 1 shows a typical AEM model of test specimen.

3. VALIDATION

Using AEM, the experimental results have been numerically simulated and the corresponding results are as shown in Figure 2. The necessity of further investigation into the results for accuracy was desired. This led to the examination of material models being used in the existing AEM. The uniaxial compression material model being used in AEM is based on Maekawa's Elasto-Plastic Fracture (EPF) model [4], which considers single post peak behaviour of concrete in compression. Observing this, authors have considered the possibility of size effects in concrete during post peak softening of concrete under uniaxial compression. The brittle nature of concrete as seen in Figure 2, is mainly due to size effects, which were initially witnessed and experimentally verified the existence in 1990s [5]. Further, the constitutive models for concrete were modified based on parameters from fracture mechanics and validated and the detailed analysis is being communicated as a part of another study. These combined models have been used to revaluate RC columns from PEER experimental database.

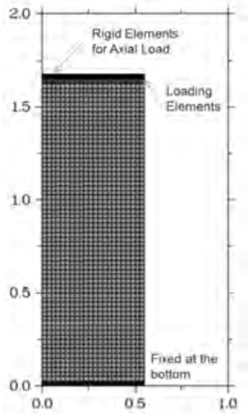

Figure 1 AEM Model of RC column by [1]

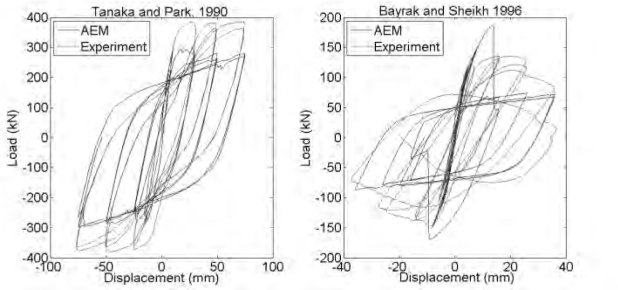

Figure 2 Preliminary Results of [1] and [2]

3. CONCLUSIONS

The results obtained from the simulations are in agreement with experimental results and with improved accuracy due to the modification in the constitutive material model of concrete subjected to uniaxial compression. The visual damage states were evaluated using crack initiation and propagation. The changes in plastic hinge properties are evaluated by studying the spring properties for different damage states. Further, the seismic capacity of the columns has been discussed by assessing energy dissipation, stiffness and strength.

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DEVELOPING A NUMERICAL METHOD FOR FATIGUE LIFE PREDICTION OF RC SLABS REINFORCED WITH PLAIN BARS

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Keywords: *Fatigue, RC slabs, Bridging degradation, Moving load, Plain bars*

1. INTRODUCTION

Recently, there is an increasing request to estimate the fatigue behaviors of RC bridge slabs under a moving load. Most of the previous studies focused on the modeling of fatigue behaviors of RC slabs reinforced with deformed bars. However, many RC slabs in use today are reinforced with plain bars, and they are suffering from fatigue damages. This study presents a numerical method to simulate the fatigue behaviors of RC slabs reinforced with plain bars under a moving load.

2. METHOD

An RC slab model of smeared crack elements is solved using finite element method. A moving load was simulated by moving a constant load level along the longitudinal direction as shown in Figure 1. The cracked elements are modified according to the bridging stress degradation concept [1, 2]. This concept can be defined as the reduction of transferred stress between crack surfaces through aggregates under repetitive loading. The bond-slip effect between a plain reinforcing bar and its surrounding concrete is taken into consideration by adding equivalent bond strain to plain bar strain [3]. The numerical model is verified using the experimental data by Shakushiro et al. [4]. The details of the tested slabs are shown in Table 1.

3. RESULTS AND DISCUSSION

Applying moving load leads to the cracked elements propagation. By increasing the number of cycles, the bridging stress degradation of these cracked elements lead to a decrease in slab stiffness and an increase in slab deformations. The center displacement evolution versus the number of cycles for all slabs is compared with the experimental results in Figure 2. The slab under a higher moving load level shows a larger slab center displacement than that under a lower moving load level due to the initial displacement at first cycle. In addition, at a higher moving load level, the center displacement evolution shows a larger slope than that at a lower moving load level. The reason is that the slab under a higher moving load level deteriorated more quickly than that at lower moving load level. The RC slab subjected to a higher moving load shows a shorter fatigue life than that at a lower moving load. The experimental and numerical results reveal similar values for fatigue life and center displacement, indicating an acceptable agreement between them.

Table 1. RC slabs details [4]

Slab ID	Moving load (kN)	Rebar type	Concrete strength (MPa)
P110	110	Plain bar SR235	43.0
P150	150		41.7
P190	190		36.6

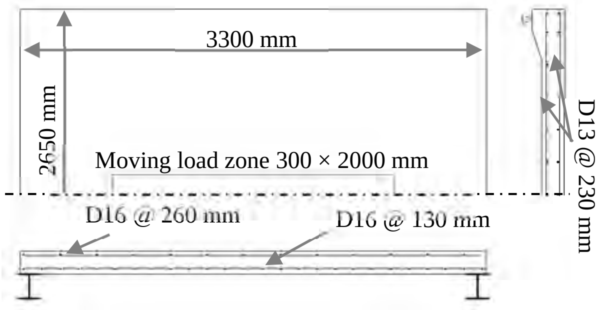

Figure 1. RC slab geometry

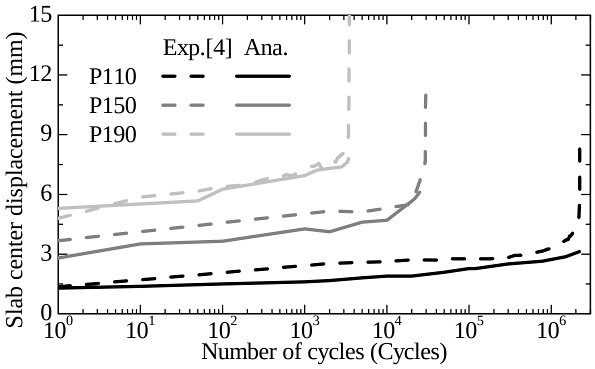

Figure 2. Center displacement evolutions

4. CONCLUSIONS

The fatigue analysis of RC slabs reinforced with plain bars under moving load was conducted using this numerical method, and it shows a good agreement with the experimental results. Bond-slip effect of plain bars shall be taken into consideration for accurate fatigue life prediction.

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FATIGUE ANALYSIS OF FROST DAMAGED RC SLABS SUBJECTED TO MOVING LOAD BASED ON BRIDGING STRESS DEGRADATION CONCEPT

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Keywords: *Fatigue, Frost Damage, RCSlab, Bridging Stress Degradation*

1. INTRODUCTION

Freeze-thaw cycling is one of the main causes of reinforced concrete (RC) deck slab deterioration in cold regions. This deterioration stems from water freezing in concrete upon cooling, and its thawing upon subsequent heating. This process is accompanied by dimensional change and internal stress change, and leads to a progressive accumulated physical damage in concrete. Freeze-thaw cycling can result in severe damage.

Therefore, it is necessary to quantitatively evaluate the relationship between the level of frost damage and the remaining lifespan of RC deck slabs. This study aims to propose an experimentally verified numerical model for predicting the fatigue life of frost damaged RC deck slabs.

2. METHOD

Finite element method is used to solve a slab model of smeared crack elements. The cracked elements are modified according to the bridging stress degradation concept by Li and Matsumoto [1]. Frost damaged concrete stress-strain model by Hasan et al [2] is used to take into account the frost damage. Giuffré-Menegotto-Pinto model [3] is employed to represent the stress-strain behaviour of a rebar under repetitive load.

3. RC SLAB MODELING

The studied slab is of dimension 2300 ×3000 × 180 mm and is supported by steel I-beams along its width. Frost damage is simulated in experimental study by reducing the slab thickness by 10 mm rather than freezing-thawing the slab [4].

On the other hand, in the present proposed finite element method, the slab is divided into 5 layers, and the top layer of 10 mm thickness is frost damaged. The concrete and reinforcement properties of the slab are the same as those used in the experimental study. A moving fatigue load is applied along the slab length centerline as indicated in table 1.

Table 1. Applied load

Number of cycle N	Load (kN)
1 ≤ N ≤ 100000	130
100000 < N ≤ 200000	140
200000 < N ≤ 300000	170
300000 < N ≤ 400000	200
400000 < N	230

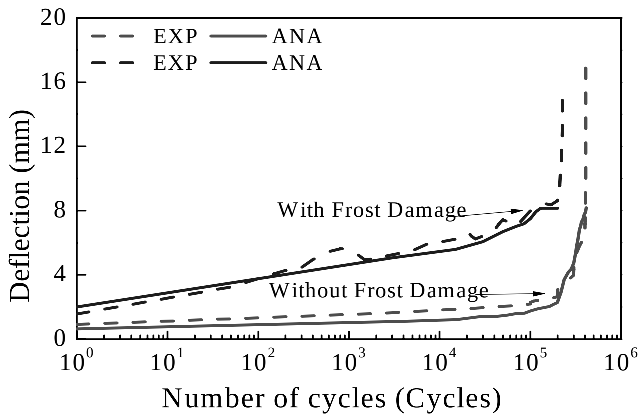

Figure 1. Midspan displacement evolutions

4. RESULT

Figure 1 shows the midspan displacement evolutions obtained by experiment and numerical analysis for the slab without frost damage and that with 10 mm frost damage.

It comes out that the midspan displacement evolution for the RC slab with frost damage shows a larger slope than that without frost damage. A possible explanation for this is the reduction of the slab flexural stiffness due to the concrete stiffness deterioration caused by the frost damage.

The fatigue life of the RC slab with frost damage is shorter than that without frost damage consideration. This is due to the degradation of the concrete initial strength and stiffness by the frost damage.

Numerical results show a good agreement with experimental ones.

5. CONCLUSION

The good correlation between the experimental and numerical result confirms the applicability of the proposed model to predict fatigue behaviour of frost damaged slab under moving load.

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EFFECT OF THE BASE ISOLATION SYSTEM ON THE LNG STORAGE TANK USING PROBABILISTIC METHOD

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***Keywords**: Base Isolation System, LNG Storage Tank, Probabilistic Method, First-order Second-moment Method, OpenSees, Finite Element Method*

1. INTRODUCTION

As the natural gas demand has been steadily increased, the interest in liquefied natural gas storage tank is also increased. When the LNG storage tank is designed, the large safety factor will be considered for earthquake load. It is very hazardous that the liquefied natural gas is accidentally spilled out or leaked by the earthquake. Therefore, LNG storage tank will be protected from random ground motions by seismic design. Among various seismic design methods, using base isolation system is one of the effective methods to reduce the lateral force from earthquake. There are several uncertain mechanical properties which affect the seismically performance. To provide more accurate seismic analysis, the probabilistic approach such as the first-order second-moment (FOSM) method can be used. The objective of this study is to investigate the effect of the base isolation system on the LNG storage tank considering the distributed properties of base isolation system.

2. PROBABILITY APPROACH FOR BASE ISOLATION SYSTEM

The behavior of the base isolation system depends on the mechanical and geometrical properties. Because each property involves uncertainty and error, probability approach would be beneficial to provide accurate seismic analysis. The first-order second-moment (FOSM) method is one of the most popular methods to determine the stochastic moments of a function with random input variables [1]. In previous studies, random variables are selected as structural properties such as concrete strength

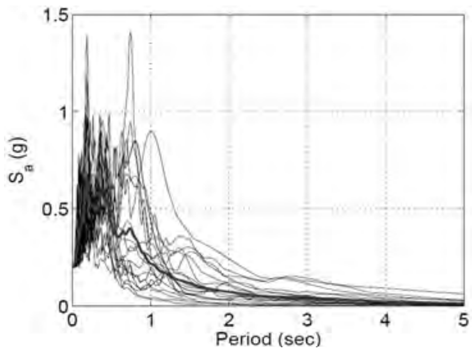

Figure 1. Acceleration response spectra of the 20 different earthquakes. Bold line is average response

and initial stiffness or earthquake input profiles. The property of base isolation device is one of the key factors to seismic performance, and the FOSM method is applied to analyze the seismic effect of the LNG storage tanks.

3. MODELING PROCESS

The LNG storage tank (Lee et al., 2013) and the base isolation system are modeled by OpenSees, a finite element analysis software framework for earthquake engineering simulations [2]. It is simply assumed that the LNG storage tank consists of concrete outer tank, steel inner tank, and liquid part as shown in Fig, 2. The '*Tuning-fork model*' is used to model the LNG storage tank. The base isolation system is located at the bottom of the tank, which is modeled using the '*elastomericBearing*' element provided by OpenSees. Using this model, nonlinear time history analyses are conducted.

4. CONCLUSIONS

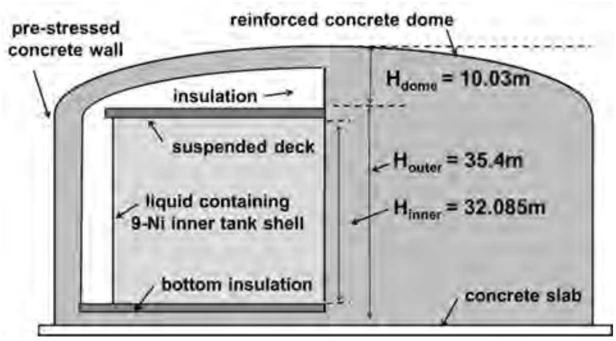

Figure 2. Schematic of the LNG storage tank.

The effect of seismic isolation system is investigated from nonlinear time history analyses when the properties of base isolator are considered as probabilistic variables. Using the FOSM method, more accurate seismic analysis can be provided and this result can be utilized to design the optimal base isolation system.

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MONITORING OF A FULL SCALE PRESTRESSD CONCRETE GIRDER DURING CONSTRUCTION PROCESS

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***Keywords**: Monitoring, Full Scale, Prestressed Concrete (PSC), Construction Process*

1. INTRODUCTION

Many other studies already have tried to measure the behavior of girder using the fiber bragg grating (FBG) sensors. However, it was hard to measure the behavior of prestressed concrete (PSC) girder in the course of being lifted and carried. During the construction process of PSC girder, the structural system of it changes due to the changes of loading and boundary conditions, so that the monitoring of these changes is important. Thus, this paper deals with the method to monitor a full scale PSC girder during construction process.

2. SENSOR INSTALLATION AND MEASUREMENT

In order to monitor the deflection and strain, long length FBG sensor was fabricated and applied to the PSC girder. Full scale PSC girder of 60 m span was also fabricated and three FBG sensors were attached at the bottom fiber of mid-span and both 1/4-spans. In the mid-span, additional FBG senor was attached at the top fiber to measure the neutral axis. In order ot install the long gauge FBG sensors, iron support devices were embedded to the girder. Figure 1 shows the sensor attachment locations and Figure 2 shows the actual installation of FBG sensors.

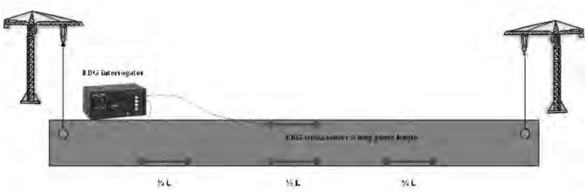

Figure 1. Attachment Locations of FBG Sensors

Figure 2. Sensor installation.

After installation of sensors, the fabricated PSC girder was lifted by crane and carried by trailer from the casting bed to the structural laboratory. Figure 3 shows the actual process of lifting girder. In order to verify the effect of changed structural system in these process, occurred strain and displacement were measured. The way to estimate of deflection was based on Euler–Bernoulli beam theory.

Figure 3. Lifting Girder.

The girder was carried to laboratory and then four point bending test was conducted. In this process, the way to estimation of deflection was verified by measuring of deflection using LVDT. Estimated deflection from FBG sensors and measured deflection from LVDT were compared.

3. CONCLUSIONS

This paper presents the way to estimate the strain of the PSC girder using FBG sensors during the construction process. This method using long gauge FBG sensor was able to measure the behaviors of girder effectively.

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3D STRUCTURAL ANALYSIS MODEL AND EARTHQUAKE RESPSONSE ANALYSIS OF WOODEN FIVE-STORIED PAGODA

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Keywords*: traditional timber structure, five-storied pagoda, non-linear dynamic behavior, Kumimono, seismic performance, rocking motion,*

1. INTRODUCTIONS

The conservation and utilization of traditional wooden buildings have been conducted actively in Japan. Even existing such buildings need sufficient seismic performances because many general people visit and use them. Therefore the quantitative evaluation of seismic capacity for traditional timber structures is indispensable. However most of them are built based on the knowledge and experience of carpenters. We need more experimental and analytical data when we evaluate the seismic performance of such buildings quantitatively.

This study focused on the five-storied pagoda in traditional wooden buildings. It is said that no pagoda have collapsed against large earthquakes and they have a good seismic performances. Studies on wooden five-storied pagoda have been increasing. However it is not clarified how a wooden pagoda can be modeled with theories or the formularization of restoring force characteristics proposed previously.

An early research [1] pointed the effect of the bending deformation of a whole building on the vibration characteristics of a pagoda. It said that a bending deformation was caused by the rocking behavior of each floor, and compressive strain inclined to the grain will happen at the parts of *Kumimono* etc., when each floor moved rocking motion. *Kumimono* is called bracket complexes in English and is between columns and roof.

In this study, we focused on the vertical stiffness of *Kumimono* and roof truss as the structural elements causing rocking motion and developed the three dimensional analysis model of a five-storied pagoda considering rocking motion. In addition earthquake response analysis was conducted.

2. ANALYSIS METHO

We developed a three dimensional analysis model like Figure 1 and analyzed with the analysis soft, *wallstat*, developed by BRI in Japan. An analysis model was 1/5 scale model of wooden five-storied pagoda used for shaking table tests in an earlier research [2]. The evaluation method of vertical stiffness of *Kumimono* was developed based on the compression tests. We applied the method to the evaluation of roof truss. Analysis results were compared with shaking table tests ones.

3. RESULTS

The analysis results almost agreed with experimental ones on the time history of horizontal displacement in each floor shown in Figure 2. However there are some differences in the largest deformation upper the 4th floor between the experiment and analysis. It was seen that the uplift of a plate under columns upper the 4th floor was small in the analysis result compared to the experimental one.

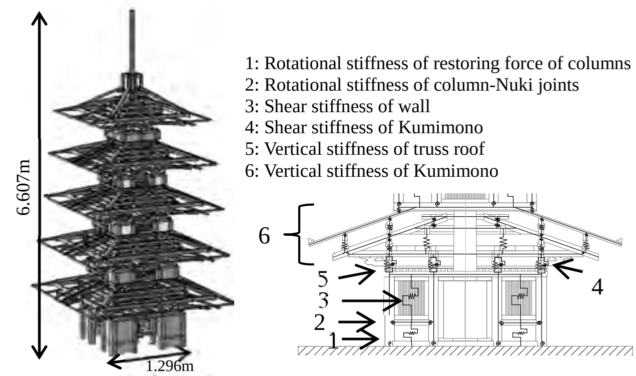

Figure 1. Analysis model

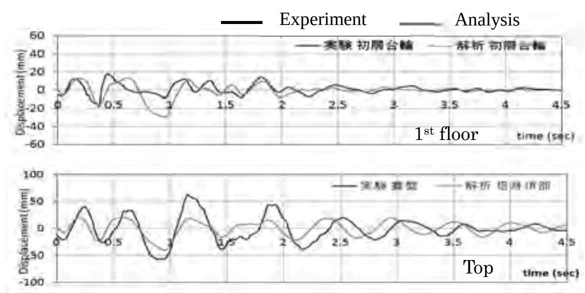

Figure 2. The time history of horizontal displacement

4. CONCLUSIONS

The analysis model could almost estimate an experimental result. In order to increase the accuracy of analysis model, we need to reconsider the setting method of the spring under the plate furthermore and to make a lot of parametric studies.

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Technical Program – Day 2

Session 10

GENERALIZED FINITE ELEMENT FORMULTATION ON FIBER BEAM ELEMENTS FOR DISTRIBUTED PLASTICITY ANALYSIS

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***Keywords**: Fiber beam element, Plastic hinge analysis, Generalized finite element method, Enrichment function.*

1. INTRODUCTION

In the nonlinear finite element analysis of fiber beam members, plastic hinges start to form at the locations where extreme fibers reach the yield strength. As load increases, the number of fibers that yield also increases, thus the region of the yielded cross-sections exist over a certain length of the member. As a result, the overall stiffness of the cross-section abruptly decreases in that region and the deformed shape of the structure shows a strong gradient. If the standard finite element is used, this effect can be accurately captured only by using a fine mesh, which may lead to a large computational cost. Furthermore, the progressive collapse analysis of a frame structure requires the modeling of plastic hinges, and, in general, a large number of plastic hinges are formed before the collapse of the structure. Consequently, the standard finite element method is not an ideal choice to perform this kind of analysis. In this study, we propose a generalized finite element technique that can accurately capture the deformed shape of fiber beam members with plastic hinges. This methodology enables us to obtain accurate solutions with a relatively small computational cost, if compare to the standard finite element method.

2. GENERALIZED FINITE ELEMENT FORMULTAION FOR PLASTIC HINGE MODELING

The deformed shape and its derivative of the classical Euler-Bernoulli beam with a plastic hinge are presented in Figure 1, as discussed in [1]. In this case, the plastic hinge modeling is based on the distributed plasticity. The generalized finite element method can model an internal hinge by adding new degrees of freedom to the element with the plastic hinge, instead of using a more refined mesh for the member with plastic hinges. As a result, the displacement of the element with a plastic hinge can be represented by the addition of a smooth approximation (v^0) and a plastic hinge approximation (v^E), i.e.

$$v(x) = v^0(x) + v^E(x) = \sum_{\alpha=1}^{2}\varphi_\alpha(x)\sum_{i=1}^{D_L}\left[L_{\alpha i}(x)\underline{u}_{\alpha i}^0 + BL_{\alpha i}(x)\underline{u}_{\alpha i}^E \right] \quad (1)$$

where φ_α is a partition of unity function, $L_{\alpha i}$ a polynomial enrichment function, and B an enrichment function describing strong gradient in the yield region due to the formation of the plastic hinge. Since the formulation of the Euler-Bernoulli beam requires the approximated displacement field to retain the C_1 feature, the Hermite cubic shape functions associated with displacement are used as the partition of unity function in Eq. (1). Figure 2 shows the partition of unity and enrichment functions in Eq. (1). Several numerical examples demonstrate the effectiveness of this approach.

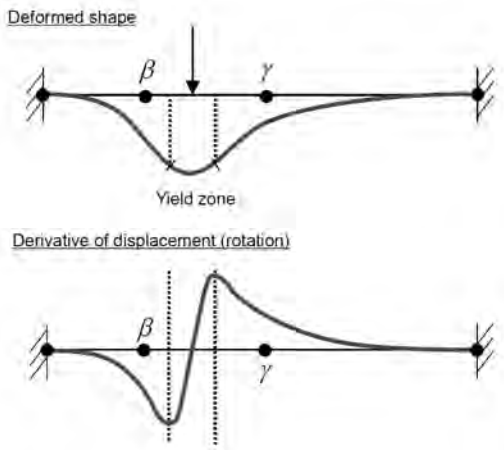

Figure 1. Deformed shape and its derivative of a fiber beam member with a plastic hinge

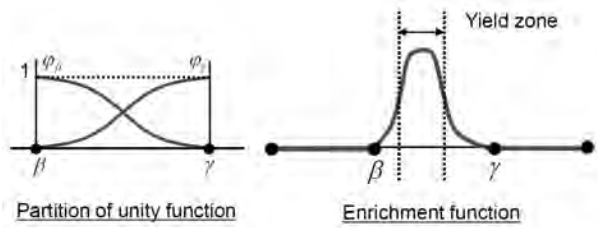

Figure 2. Partition of unity and enrichment functions for plastic hinge modeling

3. CONCLUSION

In this study, we briefly present a generalized finite element formulation for the modeling of fiber beam elements with plastic hinges. Proper enrichment functions are also proposed to accurately capture the deformed shape of the beam with plastic hinges.

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FINITE ELEMENT FORMULATION FOR FUNCTIONALLY GRADED BEAM STRUCTURES

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Keywords*: Finite element method; Beam; Functionally graded material; Torsion; Warping*

1. INTRODUCTION

Functionally graded materials (FGMs) have received great interest from engineers and researchers as a potential structural material for future engineering applications. So far, a large number of investigations concerned with the analysis of FG beams has been reported. However, most research work has been limited to analysis on 2D plane.

In this study, we present a formulation of three dimensional FG beam finite element for predicting structural responses. Here we briefly introduce the formulation of beam element and warping effects for functionally graded material.

2. FORMULATIONS

The geometric interpolation of the continuum mechanics based beam finite element including warping displacements are written as,

$$ {}^t\mathbf{x}^{(m)} = \sum_{k=1}^{q} h_k(r)\,{}^t\mathbf{x}_k + \sum_{k=1}^{q} h_k(r)\bar{y}_k^{(m)}\,{}^t\mathbf{V}_{\bar{y}}^k + \sum_{k=1}^{q} h_k(r)\bar{z}_k^{(m)}\,{}^t\mathbf{V}_{\bar{z}}^k + \sum_{k=1}^{q} h_k(r)\,f_k^{(m)}\,{}^t\alpha_k\,{}^t\mathbf{V}_{\bar{x}}^k \,, \qquad (1) $$

in which $h_k(r)$ is a longitudinal directional interpolation function, ${}^t\mathbf{x}_k$ is a position vector for beam node k, ${}^t\mathbf{V}_{\bar{x}}^k$, ${}^t\mathbf{V}_{\bar{y}}^k$ and ${}^t\mathbf{V}_{\bar{z}}^k$ are directors, $\bar{y}_k^{(m)}$ and $\bar{z}_k^{(m)}$ are discretized cross-sectional position function, and $f_k^{(m)}$ and ${}^t\alpha_k$ are warping function and warping degree of freedom, respectively.

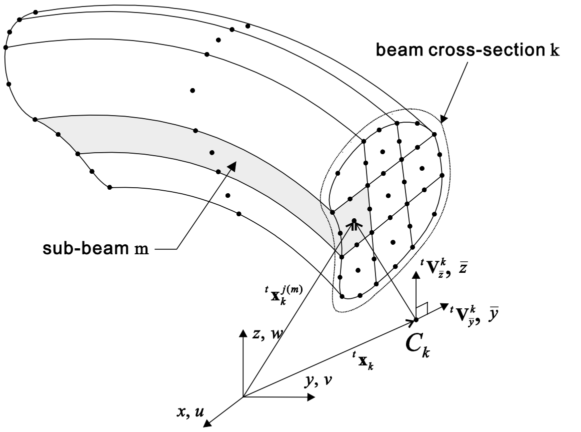

Figure 1. Concept of the continuum mechanics based beam element.

The governing equation of the warping function for FG beams are given by

$$ G^{(m)}\left(\frac{\partial^2 f_k^{(m)}}{\partial \hat{y}^2} + \frac{\partial^2 f_k^{(m)}}{\partial \hat{z}^2}\right) + \frac{\partial G^{(m)}}{\partial \hat{y}}\left(\frac{\partial f_k^{(m)}}{\partial \hat{y}} - \hat{z}^{(m)}\right) + \frac{\partial G^{(m)}}{\partial \hat{z}}\left(\frac{\partial f_k^{(m)}}{\partial \hat{z}} + \hat{y}^{(m)}\right) = 0 \,, \qquad (2) $$

where $G^{(m)}$ is a functionally graded shear modulus.

Applying some algebraic manipulation to Eq. (2), the finite element formulation of the warping function for FG beams are derived as

$$ \sum_{m=1}^{n}\left[\int_{\Omega^{(m)}} G^{(m)}\left(\frac{\partial \delta f_k^{(m)}}{\partial \bar{y}}\frac{\partial f_k^{(m)}}{\partial \bar{y}} + \frac{\partial \delta f_k^{(m)}}{\partial \bar{z}}\frac{\partial f_k^{(m)}}{\partial \bar{z}}\right) d\Omega^{(m)}\right] = \sum_{m=1}^{n}\left[\int_{\Gamma^{(m)}} \delta f_k^{(m)} G^{(m)}\left(n_{\bar{y}}^{(m)}\bar{z}^{(m)} - n_{\bar{z}}^{(m)}\bar{y}^{(m)}\right) d\Gamma^{(m)}\right] - \sum_{m=1}^{n}\left[\int_{\Omega^{(m)}} \delta f_k^{(m)} \frac{\partial G^{(m)}}{\partial \bar{y}}\bar{z}^{(m)} d\Omega^{(m)}\right] + \sum_{m=1}^{n}\left[\int_{\Omega^{(m)}} \delta f_k^{(m)} \frac{\partial G^{(m)}}{\partial \bar{z}}\bar{y}^{(m)} d\Omega^{(m)}\right] . \qquad (3) $$

By using the numerical warping function obtained from Eq. (3), the accurate and reliable twisting response can be predicted. The detailed derivation is well described in Ref. [1, 2, 3, 4].

3. CONCLUSIONS

In this paper, we presented a finite element formulation of FG beams. Since the warping function appropriately calculated by using newly derived equations, the element can accurately predict twisting actions.

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ACOUSTIC WAVE SIMULATION BASED ON PSEUDO IMPULSE RESPONSE

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Keywords*: Noise, Impulse response, CIP Method, AMR, Convolution*

1. INTRODUCTION

The evaluation of noise is important for the planning and designing of traffic facility, construction work and so on. The acoustic wave theory is a suitable method to obtain the accurate numerical solutions because it is easy to treat the complicated geometry and boundary conditions. However, the method based on the acoustic wave theory require a lot of CPU time. The convolution of impulse response and input sound is a suitable method to obtain the output for various type of sound source.

This paper presents a method for acoustic wave simulation. The CIP method using adaptive mesh refinement [1] is employed for solving the impulse response. The present method is applied to a three-dimensional wave propagation problem in order to investigate the validity of the method.

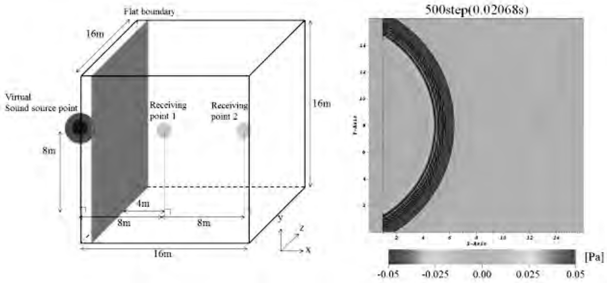

Figure 1. Sound wave propagation

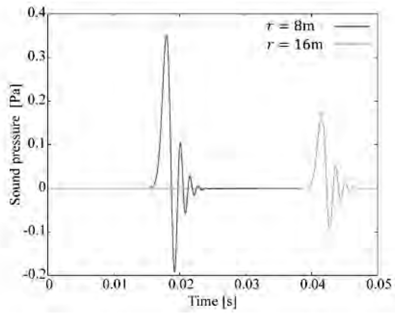

Figure 2. The sound pressure at the receiving point

2. GOVERNING EQUATIONS AND NUMERICAL METHOD

The equation of motion and the equation of continuity in an acoustic medium are employed for the governing equations. The CIP method, which is a highly accurate method for solving advection equations, is employed for the discretization.

The adaptive mesh refinement method is employed to realize the efficient simulation. The convolution quadrature developed by Lubich [2] is employed for the pseudo-impulse response. The pseudo-impulse generated by this method has smooth waveforms and almost flat frequency characteristics.

3. NUMERICAL EXAMPLE

The present method is applied to the three-dimensional wave propagation problem to investigate the validity and efficiency. The computational model is shown in Figure 1(left). The virtual sound source is arranged at the point which is 4 m away from the flat boundary. The receiving points are arranged at the points which are 8 m and 16m away from the virtual sound source.

Figure 1(right). shows the sound propagation at 500step. From this figure, it can be seen that the pseudo impulse from the flat boundary propagate in the three-dimensional space. Figure 2. shows the sound pressure at the receiving points 1 and 2. The maximum sound pressure at receiving point 1 is 0.3514Pa, and at point 2 is 0.1757Pa. The distance attenuation of sound pressure between the receiving points 1 and points 2 is to be 0.1753⁄0.3514=0.498, and which is good agreement with the theoretical values of spherical sound wave propagation in free space.

4. CONCLUSIONS

A acoustic wave simulation method based on pseudo impulse analysis has been presented in this paper. The convolution quadrature method developed by Lubich has been employed for the pseudo-impulse response. The CIP method using adaptive mesh refinement has been usefully employed for solving the impulse response. The solution of present method was good agreement with theoretical values. The verification of the present method to the actual noise problem is left for the future work.

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EVALUATION OF CONTACT AREA ON KNEE JOINT CARTILAGE USING IN-VIVO SUBJECT-SPECIFIC FINITE ELEMENT MODEL

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Keywords*: Finite element analysis, in-vivo validation, Subject-specific knee model, Weight-bearing MRI*

1. INTRODUCTION

Contact pressure increases or alterations in knee joint structure and contact area are critical causes of knee pain and osteoarthritis [1]. This is an active area of research, the exact mechanical behavior of the knee joint and the causes of knee joint injury have not been completely elucidated. Carey et al. have developed a technique to validate the Finite Element(FE) model in-vivo using dynamic stereo-radiography data [2]. However, it requires a dual-fluoroscopy apparatus or weight-bearing MRI. The present FE study is cost effective and efficient and allows us to resolve problems as they develop, which is not generally the case in experimental studies.

2. MATERIAL AND METHOD

The subject was positioned supine with his right knee at full extension in an axial loading device. Images were acquired using a 3.0 Tesla Magnetic Resonance Imaging(MRI) scanner and a custom designed knee joint cadio coil. A 3D FE model of a healthy lower extremity was developed from Computed Tomography(CT) images obtained with a light-speed volume CT scanner. An Iterative Closet Point(ICP) algorithm was used for alignment of X-ray and supine MRI(XSM).

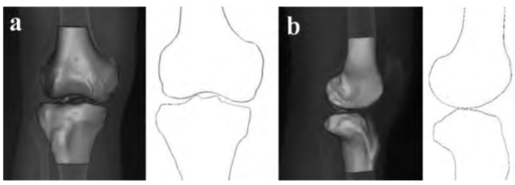

Figure 1. Alignment of X-ray and supine MRI using an ICP algorithm

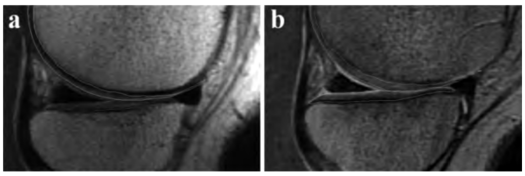

Figure 2. Interaction volume between non-deformed tibiofemoral cartilage: (a) X-ray and supine MRI (XSM); (b) Weight-bearing MRI(WBM)

3. RESULT

The XSM and WBM methods were employed for verification of the subject-specific FE model. Table 1 shows the values of contact area and contact deformation for subject specific XSM method, WBM method and FE model.

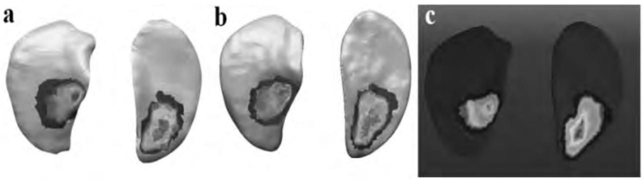

Figure 3. Results of cartilage contact area and contact deformation distribution: (a) X-ray and supine MRI (XSM); (b) Weight-bearing MRI(WBM); (c) FE model

Table 1. Result of cartilage contact area and contact deformation

	Contact area (mm^2)		**Contact deformation (mm)**	
	Medial	Lateral	Medial	Lateral
X-ray and supine MRI	224.1	198.9	0.51	0.43
Weight-bearing MRI	228.8	193.4	0.49	0.41
FE model	246.8	188.5	0.53	0.39

4. CONCLUSIONS

Verification was conducted by comparing the results from the model with either literature data or in vitro cadaveric data. Our study reduced the error in six degrees of freedom in alignments of 2D and 3D images. The errors between the two images were 0.043 ± 0.011 and 0.021 ± 0.005 in coronal and sagittal views, respectively. The XSM method used in this study is an acceptable validation method in general situations and showed very similar results to the WBM validation method for the in vivo model. In conclusion, the XSM method proposed in this study represents a step forward in subject-specific in vivo validation of original subjects in biomechanics.

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NONLINEAR FLEXIBLE MULTIBODY APPROACHES USING CO-ROTATIONAL FINITE ELEMENTS

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***Keywords**: Flexible multibody analysis, Co-rotational finite elements, Lagrange multiplier*

1. INTRODUCTION

Flexible multibody analysis is generally required with growing demands in the mechanical engineering field. It combines concepts and solution techniques from both flexible structural mechanics and the rigid body mechanics. During the last few decades, the researchers established existence and uniqueness of solutions and benign numerical methods related with the multibody analyses. The Lagrange multiplier technique plays a major role in modeling the multibody analysis with constraints [1]. In this paper, an improved and more versatile structural analysis applicable for nonlinear flexible multibody system is developed. In more detail, nonlinear finite element based on co-rotational (CR) framework is developed. Then, interconnecting methods using the Lagrange multipliers are implemented to constrain the kinematic relationship among the flexible components. Moreover, parallelized algorithm of the analysis will be suggested.

2. CO-ROTATIONAL FINITE ELEMENTS

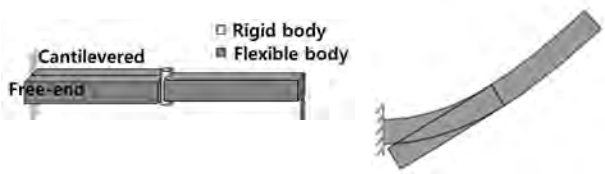
The CR framework is independent of the specific local element formulation. Thus, a number of existing robust and accurate geometrically linear plane elements can be reused and extended to geometrically non-linear analyses. A basic idea of this approach is to extract pure elastic deformation from the total motion using the CR frame which translates and rotates along the element. Accordingly, three kinds of coordinates are to be defined to deal with such decomposition of the behavior. By following the transformation between the coordinates, the global stiffness matrix and internal force vector of the element can be defined. Details of its derivations are presented in Ref. [2].

3. MULTIBODY APPROCHES

In this section, both serial and parallel versions of multibody analysis are presented. Classical Lagrange multiplier method is employed to enforce the kinematic constraint among the components. This method yields a straightforward formulation, in which addition of the virtual work of individual bodies is performed to obtain the total virtual work of entire bodies, considering each of the kinematic constraints between any two bodies or two adjacent nodes by the Lagrange multiplier vector. To ensure computational robustness and efficiency, the parallelized algorithm based on the improved finite element domain decomposition method using local Lagrange multipliers is also developed [3]. And it is applied for the present analysis. Currently, static algorithm regarding nonlinear analysis is developed. Thus, it will be extended to nonlinear transient analysis.

4. NUMERICAL RESULTS

To examine the present analysis, interconnected three-beam structure under a tip load is considered (Fig. 1(a)). The CR planar element is employed and both serial and parallel analyses are conducted. The deflected configuration is illustrated in Fig. 1(b). To verify an efficiency of the present parallel analysis, scalability test is conducted (Fig. 2).



(a) Configuration of multibody analysis (b) Deformed configuration

Fig 1. Interconnected beam structures under tip load

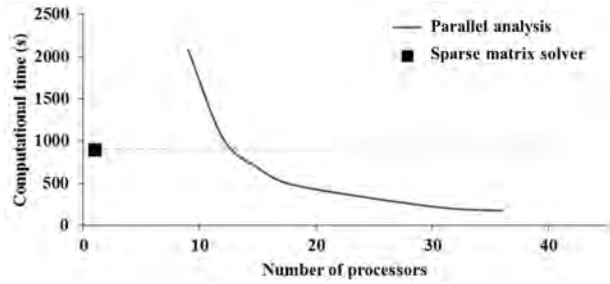


Fig 2. Scalability test of the present parallel analysis

5. CONCLUSIONS

In this paper, flexible multibody analysis using the CR elements is developed. Extension of the present analysis in order for transient analysis will be conducted.

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APPLICATION OF TRANSFORMED AUTOCORRELATION FOR STRUCTURAL SYSTEMS WITH LOGNORMALLY DISTRIBUTED RANDOM VARIABLES

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Keywords: *Response variability, Lognormal random variable, Weighted integral method, Uncertainty, Correlation*

1. STRUCTURAL UNCERTAINTIES

The uncertainties or randomness in structural systems are caused by a variety of reasons. Probabilistic assumption on the systems is the first source of uncertainties from the perspective of uncertain responses. However, this source is intrinsically unpredictable and is bound to have errors. The uncertainty which is natural, influential and conceptually easy to implement is the material randomness spread out over the domain of the system. The other one is categorized as geometrical parameter which characterize the shape of the system.

In order to deal with the randomness in the structural systems, we have two types of methods. One is the MCS(Monte Carlo Simulation) which can be called a statistical method and the other is indirect method which uses indirect function of autocorrelation which implies the statistical characteristics of the given random fields. The MCS is easy to implement if we see this method from the viewpoint of analysis itself since the essence of this method is repetitive application of finite element analysis. MCS, however, is based on the actual (theoretically) random fields which are numerically generated relying on the various random field generation schemes. We can use, for example, spectral representation and/or statistical preconditioning etc. In the case of indirect method, it has a relative advantage to the MCS in the computation time since it deals only with the autocorrelation (or spectral density) functions which represent the random field in an indirect way. The further advantage of the indirect method to the MCS is that we can obtain a regular results which is not random. With this, we mean the results of MCS is irregular depending on the condition of analysis.

Whatever the scheme of analyses, almost all the random parameters have been assumed to be distributed in a Gaussian way [1]. (Not all, but almost.) It is natural to think that a random parameter is to have probability density of Gaussian, and the central limit theorem is giving us legitimacy for this assumption. The several practical random parameters, however, show probability density other than Gaussian, e.g. lognormal distribution, beta distribution etc. To assess the uncertain response due to random parameters other than Gaussian, the random fields need to be numerically generated. For this purpose, the so-called translation theory can be employed, with which the Gaussian random fields (and/or processes) can be transformed into the fields distributed in the other way. Accordingly, we need to follow the following procedure: the generation of Gaussian fields, and then transform them into the target fields distributed in a nonGaussian way, and then perform N repetitive analyses.

In the case of indirect method, however, direct application of nonGaussian random parameter is not easily achieved since the autocorrelation (or spectral density) function is not easy to get. Fortunately, we can derive the corresponding autocorrelation function for the lognormally distributed random parameters.

In this study, by using the autocorrelation function transformed from that for Gaussian random variable is adopted to apply to the stochastic weighted integral formulation.

2. FORMULATION

The form of autocorrelation function for lognormal variable is as follows [2]:

$$C_{LN} = \gamma_{LN} \exp\left(\left(C_N \sqrt{\alpha\beta}\right) - 1\right) \quad (1)$$

Where, three parameters of α, β, γ are determined based on the statistics of lognormal variable, and C_N denotes the correlation structure of Gaussian variable.

If we employ Eq. (1) to be the correlation structure for the lognormal variable, we can get the weighted integral formulation as follows:

$$Cov[\mathbf{U}] = \bar{\mathbf{K}}_{LN}^{-1} \sum_{e1}^{N_e} \sum_{e2}^{N_e} E\left[C_{e1e2}\right] \bar{\mathbf{K}}_{LN}^{-T} \quad (2)$$

$$E\left[C_{e1e2}\right] = \int_{V_2} \int_{V_1} \left(\sigma_{LN}^2 C_{LN}(\xi)\right) \bar{\mathbf{k}}^{(e1)} \bar{\mathbf{U}} \bar{\mathbf{U}}^T \bar{\mathbf{k}}^{(e2)T} dV_2 dV_1 \quad (3)$$

Finally, with Eqs. (1-3) we can get the variability of the response for the given system [1].

3. CONCLUSIONS

How to evaluate the response variability of structural systems with lognormal random parameters is addressed. By comparison with the results obtained for the Gaussian random variable, we can get the characteristics of practical variability caused by the lognormal random variable. Furthermore, by employing the translation theory, this method is expected to have more broad application to the practical structures.

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