Computational Disaster Mitigation and Reduction Research Unit

1. Unit members

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2. Research Activities

Computational disaster mitigation and reduction research unit is aimed at developing advanced large-scale numerical simulation of natural disasters such as an earthquake, tsunami and heavy rain, for Kobe City and other urban areas in Hyogo Prefecture. Besides for the construction of a sophisticated urban area model and the development of new numerical codes, the unit seeks to be a bridge between Science and Local Government for the disaster mitigation and reduction.

Our research unit addressed the following research objects in this fiscal year:

2.1 Development of next-generation urban model for Kobe city

An urban model is used as input data of natural disaster simulation. The reliability of simulations depends largely on the quality of the model. We seek to develop a next-generation urban model for Kobe City; the current model is constructed, based on open-source data of a target area. More detailed data about the urban area, which are managed and maintained by local governments, are to be used to construct the model.

2.2 Numerical simulations for stability analysis of liquefaction

Liquefaction is a kind of disastrous ground failure induced by earthquake. Reliable prediction of liquefaction is of great significance especially for regions near a port where the potential of liquefaction occurrence is high. We develop a finite element method for liquefaction and study the stability of perturbations in the form of plane wave and in the form of spherical wave numerically.

3. Research Results and Achievements

3.1 Development of next-generation urban model for Kobe city

Integrated Earthquake Simulation (IES) requires detailed information about an individual building, such as structure type, construction year and material/structure properties, in order to make a seismic response analysis (SRA) model. External configuration of buildings is stored in commercial GIS (Geographic Information System), but other information is not available unless

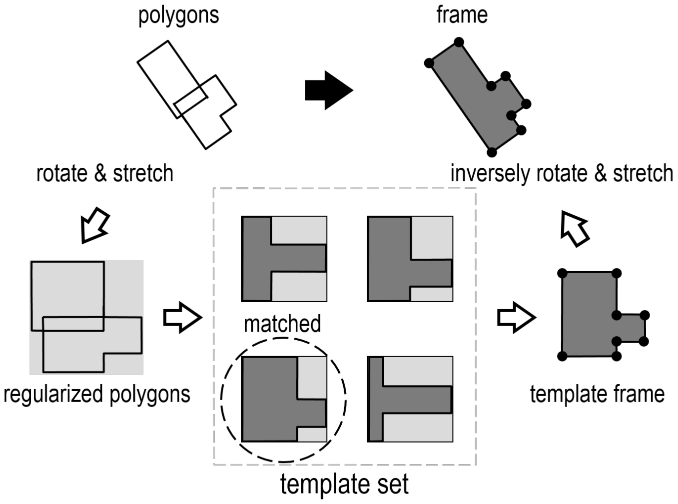


Figure 1. Schematic flow of a template-fitting process.

local government allows us to use their data. With the courtesy of Kobe City Government, we are able to use the data set of some information for registered personal buildings and local government facilities. We are extracting information that is required to make a more sophisticated SRA model from these data sets, and developing a smart program which is capable to handle the data sets to this end. In this fiscal year, we have completed a prototype of such program for the automated construction of an urban area. A new urban area model is made for the city of Kobe, by using this prototype which is applied to multiple data sets of CAD (Computer Aided Design) of structures and building registry of Kobe City.

3.1.1 Template fitting methodology to utilize the CAD data of buildings

In CAD, configuration data of one building are given as a set of polygons. The polygons are independent since it is sufficient for design purpose if they are located at proper positions. No information about connection between polygons is included in CAD. It is a challenging task to utilize CAD data to automatically construct an SRA model, by properly guessing connections of polygons; for instance, a model of finite element method analysis must consist of model elements and those connections.

We have developed a method for automatic construction of a sophisticated SRA model, improving a shape recognition methodology that is based on a template-based floor; see Figure 1. In the developed method, an adequate number of floor arrangements are precomposed as a template set and one of the templates is selected for each floor footprint which is extracted from CAD data; see Figure 2. The advantage of the developed method is that it ensures high robustness in the following two meanings: 1) it can properly convert CAD data to an SRA model;

and 2) it can judge the failure of data conversion due to lack of a proper template.

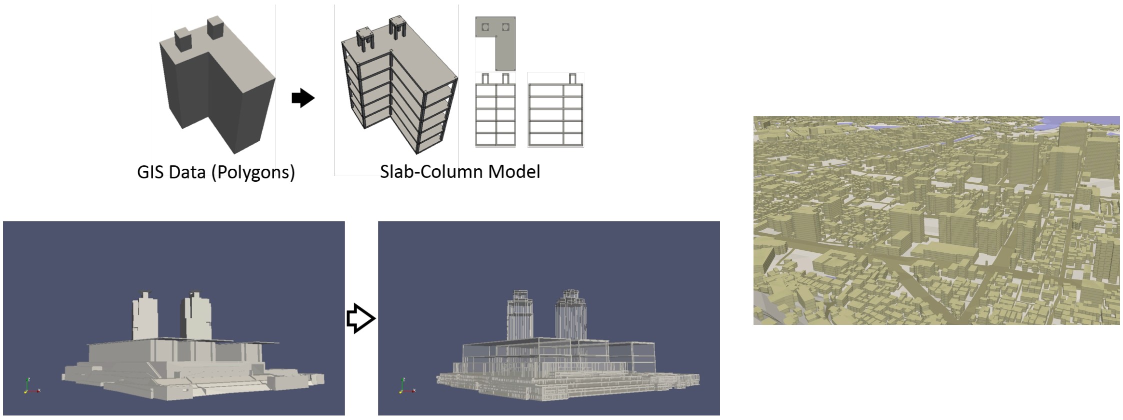
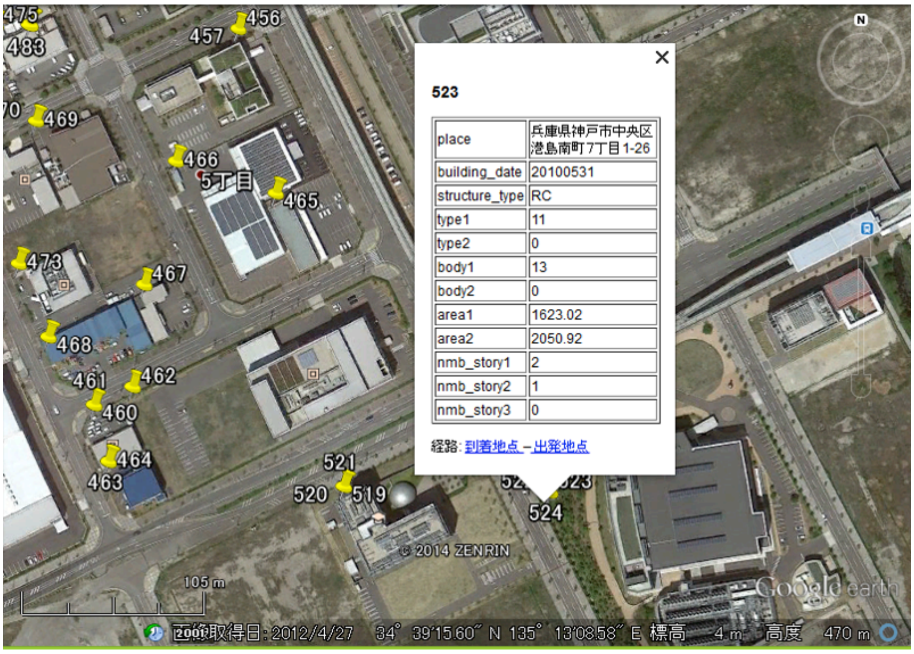


Figure 2. Automatic floor shape recognition against CAD data of buildings.

3.1.2 Utilization of official building registry in urban model

Official building registry provides information about building date, structure type, the number of stories, and so on. Since official building registry is maintained just for taxation in Japan, it often lacks accurate information about the location of individual buildings and cannot be directly utilized for the automatic construction of urban models. We have developed a method to make attribute data of individual buildings with latitudes and longitudes, relating the land identification numbers to the corresponding location on the cadastral map.



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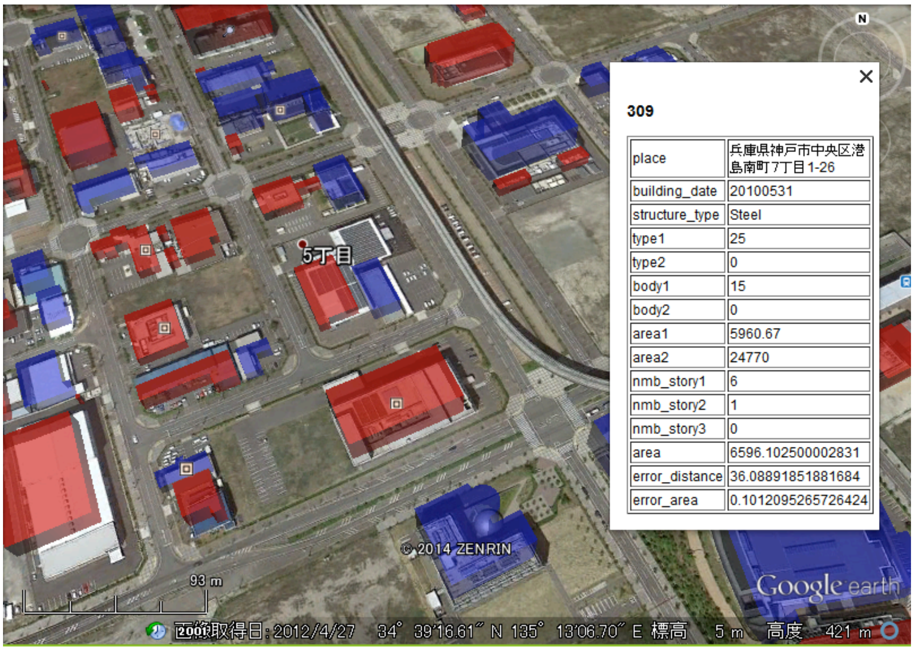
place	兵庫県神戸市中央区 港島南町7丁目1-26
building_date	20100531
structure_type	RC
type1	11
type2	0
body1	13
body2	0
area1	1623.02
area2	2050.92
nmb_story1	2
nmb_story2	1
nmb_story3	0

経路: 到着地点 – 出発地点

Figure 3. Attribute data of individual buildings with latitudes and longitudes.



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place	兵庫県神戸市中央区港島南町7丁目1-26
building_date	20100531
structure_type	Steel
type1	25
type2	0
body1	15
body2	0
area1	5960.67
area2	24770
nmb_story1	6
nmb_story2	1
nmb_story3	0
area	6596.102500002831
error_distance	36.08891851881684
error_area	0.1012095265726424

Figure 4. Combination results of CAD data and official registry of buildings.

3.1.3 Combination of CAD data and official registry of buildings

Different types of GIS data have different accuracy of location information. Hence, it is not an easy task to accurately combine information stored in different GIS data. We perform proper combining of CAD data with official building registry, in order to construct an urban model of Kobe City; see Figures 3 and 4.

3.2 Numerical simulations for stability analysis of liquefaction

Liquefaction could be regarded as an unstable phenomenon in the sense that shaking induces a sudden transition of ground behavior from solid to liquid. It is a result of non-linear coupling between soil and underground water. We develop a numerical analysis method which is able to capture an unstable solution, to analyze the stability of the governing equations of a coupling problem of soil and underground water.

3.2.1 Mathematical model

As the first step, we study an idealized mathematical model to analyze the stability of a coupling problem solution of soil deformation and water pressure. Denoting by $\boldsymbol{u}$ and p the perturbations of the increments of soil displacement and water pressure, the governing equations of the coupling problem are expressed as

$$\begin{aligned} \rho \mathrm{D}^2 \boldsymbol{u} - \boldsymbol{\nabla} \cdot (\boldsymbol{c} : \boldsymbol{\nabla} \boldsymbol{u}) + \boldsymbol{\nabla} p &= \boldsymbol{0}, \\ \boldsymbol{\nabla} \cdot \mathrm{D} \boldsymbol{u} - \boldsymbol{\nabla} \cdot (k \boldsymbol{\nabla} p) &= 0, \end{aligned} \tag{1}$$

where ρ, $\boldsymbol{c}$, and k are density, elasto-plasticity and permeability; $\boldsymbol{\nabla}$ and D are spatial and temporal differentiation; and $\cdot$ and : stand for the first and second-order contraction.

Table 1. Material properties for code verification.

	Young's modulus E (MPa)	Poisson's ratio v	Density $\boldsymbol{\rho}$ (kg/m^3)	Permeability $\boldsymbol{k}$ (m^{3}s/kg)
Case 1	50	0.4	2000	1.02e-8
Case 2	32	0.4	2000	1.28e-8
Case 3	12.5	0.4	2000	2.04e-8

3.2.2 Numerical analysis

In the fiscal year of 2012, via theoretical analysis, we show that perturbations in the form of plane wave are always stable if dilatancy is ignored, while, as the degree of dilatancy increases, perturbations in the form of plane wave could propagate in an unstable manner. In this fiscal year, a finite element code for the coupling problem has been fully developed. A key feature of this code is that it is able to model the detaching effect of soil particles, which results in sharp drops in the stiffness of elasticity observed in liquefaction phenomenon. Table 1 summarizes the material parameters which are used in the present numerical analysis.

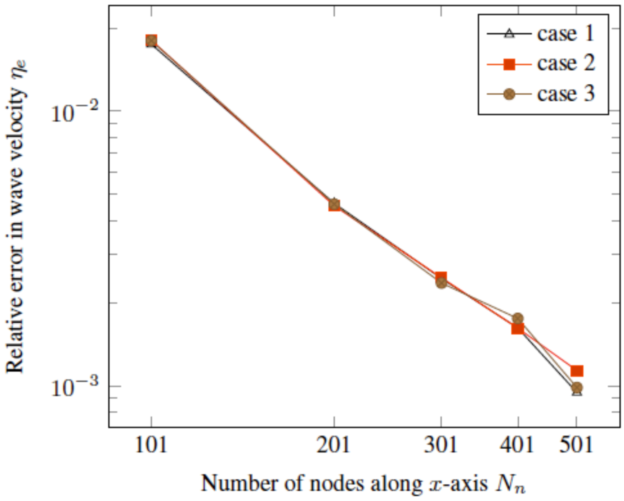

Figure 5. Convergence of wave velocity.

(1) Code verification: Convergence of wave velocity

A closed form expression of the wave velocity is derived for plane wave without dilatancy. We design three test cases of different wave velocities to verify our code. The wave velocities that are computed by using the developed code are in good agreement with the closed form solutions; the relative error in computing the wave velocity converges 0 as the degree-of-freedom of the model increase; see Figure 5.

(2) Effect of dilatancy in plane wave case

An initial perturbation in the displacement field is prescribed symmetrically at the center of a cubic domain. When the degree of dilatancy is small, the initial perturbation propagates stably from the center to the boundaries of the domain. As the degree increases, unstable solutions are found for the displacement increment and the pressure increment; see Figure 6. The numerical code succeeds to capture this unstable solution of the coupling problem, which we think corresponds to the occurrence of liquefaction.

(3) Spherically symmetric perturbations

For spherically symmetric perturbations, it is difficult to obtain analytical solution for the stability problem. This problem is tackled by the numerical code we developed. For simplicity and to preserve symmetry, initially a perturbation of water pressure is prescribed. When the dilatancy is small, the amplitude of the perturbation decays as it propagates. The solutions of displacement and water pressure are stable. When the dilatancy is large, the perturbation grows exponentially. Unstable solutions of displacement and water pressure are captured; see Figure 7.

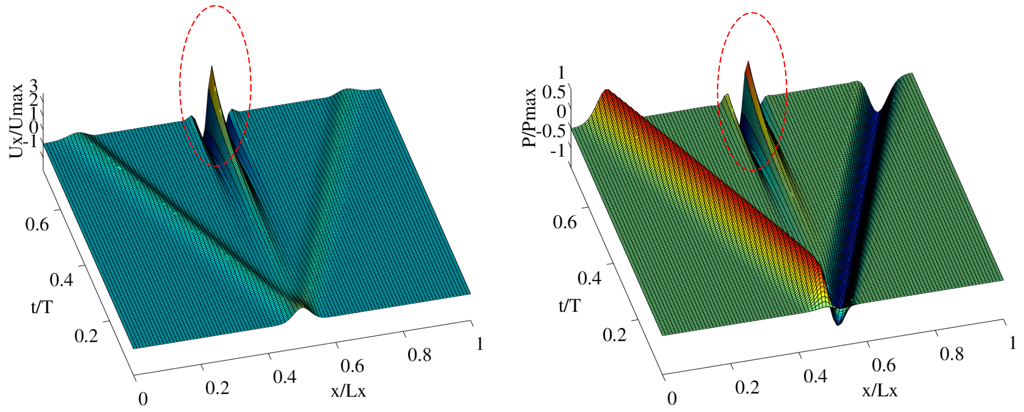

Figure 6. Large dilatancy. Perturbations in the form of plane wave propagate unstably; left) evolution of displacement increment; right) evolution of displacement increment.

(4) Detaching effect:

With the developed numerical code, the detaching of soil particle during liquefaction can be analyzed. Unstable solutions of displacement are suppressed by implementation of detaching. The influence of detaching on pressure changes, whether a detaching criterion is for tensile or compressional stress. As for compression stress, the *loss* in compression stress due to detaching is compensated by an increase of water pressure with respect to the normal (non-detaching) case. As for tensile stress, the stress loss is due to the weakening of tensile stress, which is compensated by the decrease of water pressure. Figure 8 shows the results of the both cases.

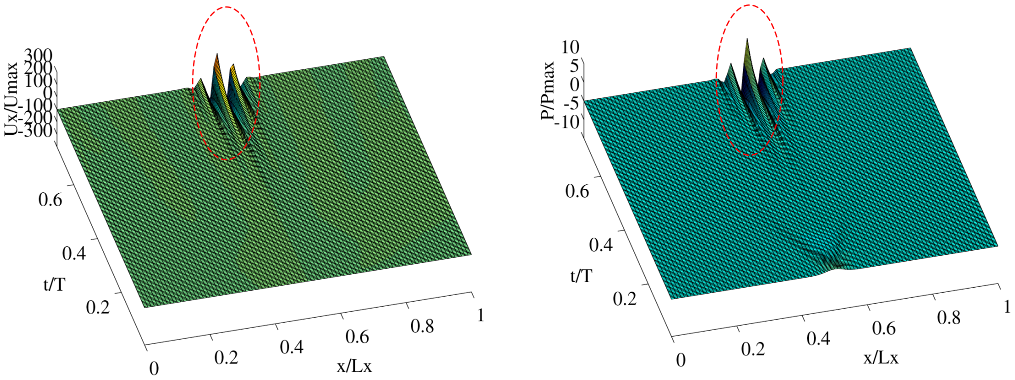

Figure 7. Large dilatancy. Perturbations in the form of spherical wave propagate unstably: left) evolution of displacement increment; right) evolution of displacement increment.

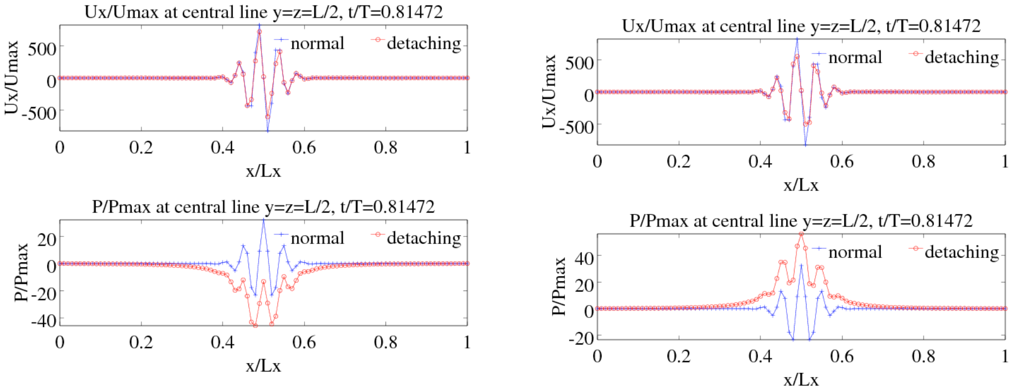

Figure 8. Trial of detaching simulation, solutions along the central line parallel to the x-axis: left) Detaching with respect to tensile criterion; right) Detaching with respect to compression criterion.

4. Schedule and Future Plan

Improvement of the next-generation urban models for Kobe:

In the fiscal year of 2014, we are going to improve the prototype of the next-generation urban model for Kobe City, developing more accurate combination method between different GIS data.

Liquefaction hazards assessment:

In the fiscal year of 2014, we are going to incorporate into IES an advanced finite element code for soil dynamics simulation. Methods to generate ground models and input files from borehole data will be established. Trail run for a target site of Kobe City will be conducted to assess liquefaction hazards.

5. Publication, Presentation and Deliverables

(1) Journal Papers

[1] Hideyuki O-TANI, Jian CHEN and Muneo HORI (2013): Smart Visualization of Urban Earthquake Simulation, *Journal of Japan Society of Civil Engineers, Ser. A1 (Structural Engineering & Earthquake Engineering (SE/EE))*, Vol. 69, No. 4.

[2] Hideyuki O-TANI, Jian CHEN and Muneo HORI (2014): A template-based floor recognition applied to 3D building shapes of GIS data, *Journal of Japan Society of Civil Engineers, Ser. A1 (Structural Engineering & Earthquake Engineering (SE/EE))*, Vol. 70, No. 4, accepted.

(2) Conference Papers

[3] Cheng Weishen, Jian CHEN, Hans-Georg Matuttis (2013), Granular Acoustics of Polyhedral Particles, *AIP Conf. Proc.* Vol. 1542, 567-570.

(3) Posters and Presentations

[4] Jian CHEN, Hideyuki O-TANI and Muneo HORI (2013): Stability analysis of liquefaction for plane wave propagation, 68th JSCE Annual Conference.

[5] Jian CHEN, Hideyuki O-TANI and Muneo HORI (2013): Stability analysis of plane wave propagation for investigation of liquefaction triggering condition, The 4th AICS International Symposium.

[6] Hideyuki O-TANI, Jian Chen and Muneo HORI (2013): Template-based automatic construction of building models from GIS data, The 4th AICS International Symposium.

[7] Hideyuki O-TANI, Jian CHEN and Muneo HORI (2013): A template-based construction of seismic response analysis model from GIS data, 33nd JSCE Earthquake Engineering Symposium.

[8] Cheng Weishen, Jian CHEN, Hans-Georg Matuttis (2013), Granular Acoustics of Polyhedral

Particles, Powders and Grains 2013 (The 7th International Conference on Micromechanics of Granular Media).