18. Computational Disaster Mitigation and Reduction Research Unit

18.1. Team members

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18.2. Research Activities

Computational disaster mitigation and reduction research unit is aimed at advancing large-scale numerical simulation for natural disasters such as an earthquake, tsunami and heavy rain, targeting 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 was launched at October 2012, and addressed the following research objects in this fiscal year:

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 its quality. 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 area managed and maintained by local governments, will be used for the model.

2. Execution of large scale natural disaster simulation and smart visualization

   Utilizing the codes for Integrated Earthquake Simulation (IES) developed in SPIRE Field 3, we make a trial simulation for natural disaster simulation in Kobe City, for a given set of disaster scenarios. Urban area simulations based on the various scenarios generate massive information about possible hazards and disasters. One of the main researches of our unit is to consider smart visualizations of IES outputs so that Local Government can make use of the results of Science.

3. Development of advanced numerical methods for liquefaction and related problems

   Liquefaction is disastrous ground failure induced by earthquake. It refers to the change in ground behavior from solid to fluid. In the past, liquefactions due to strong ground motion have caused severe damages. Reliable predictions of liquefaction is thus of great significance, especially for regions important for human activities.

18.3. Research Results and Achievements

18.3.1 Development of next generation urban area model for Kobe City

In this fiscal year, we have developed an urban model of Kobe City as shown in Figure 1, utilizing the conventional schemes incorporated in codes for Integrated Earthquake Simulation (IES).

In IES, more than 100 thousands of building models are constructed automatically from GIS data, and the highest robustness is required in a methodology of converting GIS data to the building models. We are carrying out a preliminary study of a new methodology for the data conversion which is based on a template fitting operation. Figure 2 shows building models constructed by the

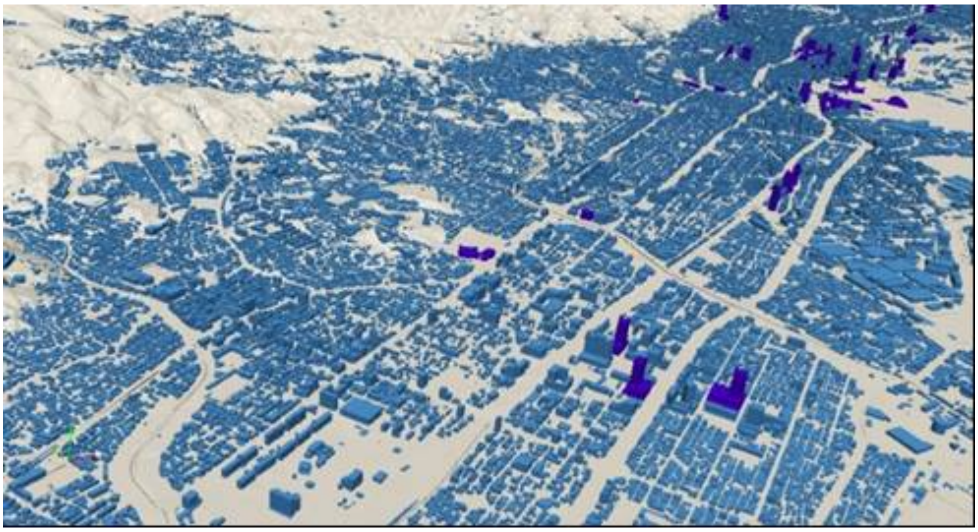

Figure 1: Next-generation urban model of Kobe city

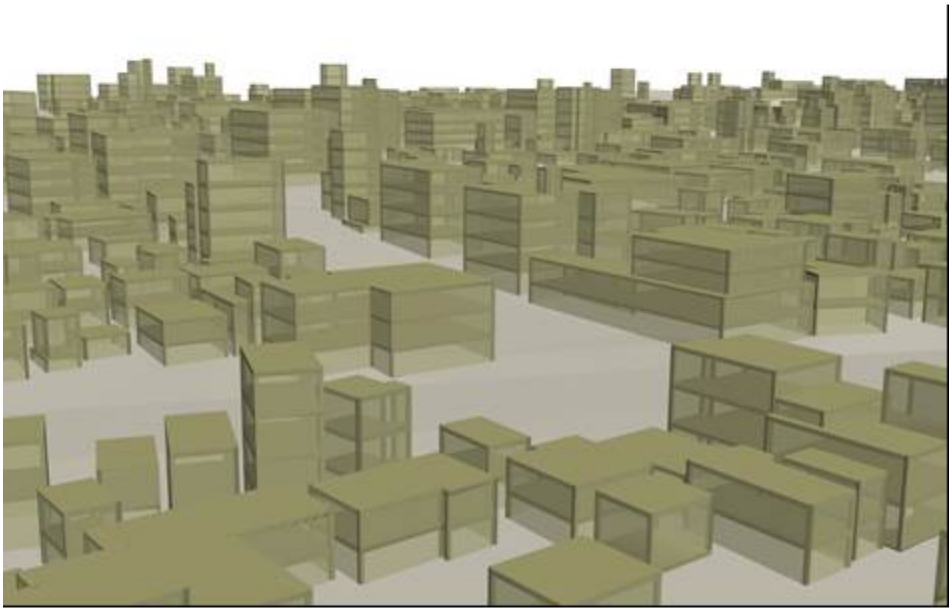

Figure 2: Building models for seismic analysis automatically converted from GIS data.

new methodology; more detailed models are generated, compared with the existing method.

18.3.2 Execution of large scale natural disaster simulation and smart visualization

We made a trial simulation for earthquake and tsunami, using the next-generation urban area model of Kobe City. In the earthquake simulation, more than 100 scenarios are considered. Since

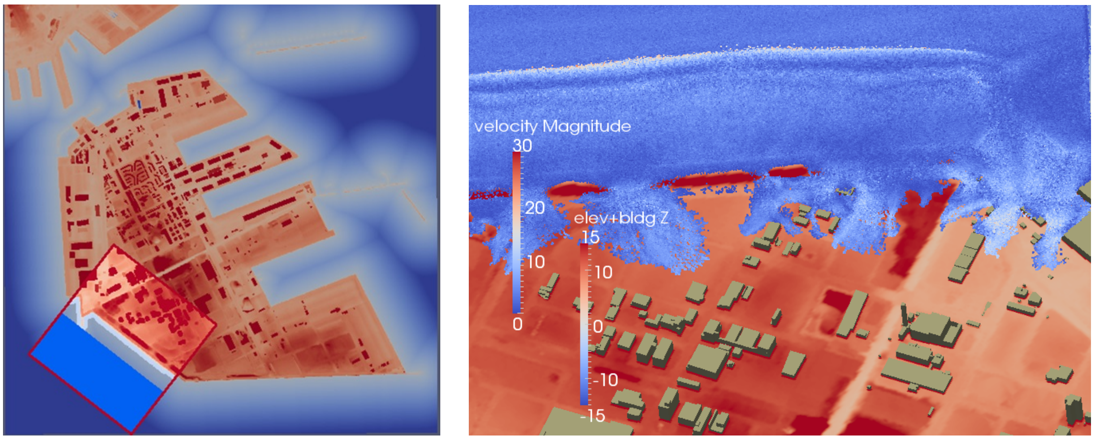

Figure 3: Trial simulation of tsunami attacking Port Island. Left) model of Port Island; elevation data and building data are used, and the model is automatically constructed by using a data conversion module. Right) snapshot of tsunami inundation on Port Island, when an extremely large tsunami height is assumed.

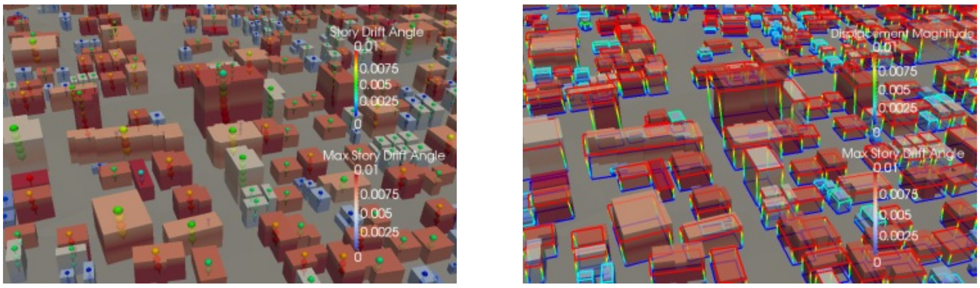

Figure 4: Dual visualizations for animation.

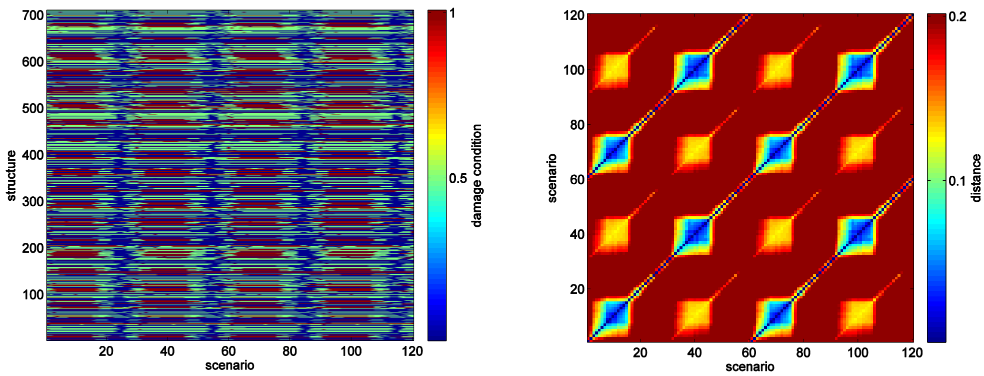

Figure 5: Pixel matrices for direct visualization of many earthquake scenarios. Left) damage conditions of all computed scenarios. Right) a trial clustering of many earthquake scenarios.

simulation for one scenario generates results of 10TB, smart visualization methods are being studied. An input of the urban area hazard and disaster simulation is an output of hazard simulation that is made in the Japanese Island scale.

18.3.3 Development of advanced numerical methods for liquefaction and related problems

Key mechanism of liquefaction is non-linear coupling between soil and underground water, and it could be regarded as an instable phenomenon in the sense that shaking induces sudden transition from solid to liquid. A most advanced numerical method is required to analyze this phenomenon, which is able to chase the unstable solution.

18.3.3.1 Mathematical model

As the first step, we consider idealized mathematical model to analyze the stability of soil deformation and water pressure coupling problem. Denoting by $\boldsymbol{u}$ and p the perturbation of the soil displacement and water pressure, a mathematical model which describes liquefaction is 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 ・ and : stands for the first and second-order contraction.

Applying Fourier transform with kernel of $\exp(\iota(\boldsymbol{\xi} \cdot \boldsymbol{x} - \omega t))$, Eq. (1) becomes

$$\begin{aligned} -\rho \omega^2 \boldsymbol{u} + (\boldsymbol{\xi} \cdot \boldsymbol{c} \cdot \boldsymbol{\xi}) \cdot \boldsymbol{u} + \iota \boldsymbol{\xi} p = \boldsymbol{0}, \\ \omega \boldsymbol{\xi} \cdot \boldsymbol{u} - k(\boldsymbol{\xi} \cdot \boldsymbol{\xi}) p = 0. \end{aligned} \tag{2}$$

Here, for simplicity, the same symbols $\boldsymbol{u}$ and p are used for the transformed functions.

18.3.2.2 Theoretical and numerical analysis

For the isotropic case, it is readily shown that for any real-valued $\boldsymbol{\xi}$, ω becomes complex number but its imaginary part is always negative. This means that, due to coupling of soil deformation and water pressure, plane waves such as P- or S-wave decays. For the anisotropic case, however, the imaginary part of ω becomes positive for large anisotropy. Dilatancy, volume expansion due to shear stress, is a unique mechanical characteristic of soil, and can be regarded as anisotropy. Hence, this result suggests that as the degree of dilatancy increases, plane wave which accompany water pressure change could propagate in an unstable manner.

A numerical code which is able to analyze these two cases as well as the case of spherically propagating waves is being developed. The unique feature of this code is that it is able to model detachment of soil particles, which appears sharp drops in stiffness or elasticity.

18.4. Schedule and Future Plan

The unit has 5 years plan (2012-2016), and the first two years (2012-2013) are for the establishment of the unit. In this period, we seek to develop a prototype of a next-generation urban area model and its simulation methodology for multiple natural disaster scenarios, and to develop a prototype of an analysis method for liquefaction.

According to this schedule, in the fiscal year of 2013, we are going to construct a prototype of the next-generation urban area for Kobe City to carry out several natural disaster simulations using K computer. The results will be shared by local government as well as regional researchers. We are going to develop a prototype of liquefaction analysis, and examine the nature of instability of liquefaction by using large-scale numerical computation.

18.5. 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) Conference Papers

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(3) Invited Talks

1. M. Hori, Application of large scale numerical computation to earthquake simulation, Seventh Gulf Seismic Forum 2012, Jeddah, Saudi Arabia 22-25 January

(4) Posters and presentations

1. Hideyuki O-TANI, Jian CHEN and Muneo HORI (2012): Smart Visualization of Urban Simulation, 32nd JSCE Earthquake Engineering Symposium.
2. Hideyuki O-TANI, Jian CHEN and Muneo HORI (2012): Smart Visualization of Urban Simulation, The 3rd AICS International Symposium.

(5) Patents and Deliverables

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