Chapter 17

Computational Disaster Mitigation and Reduction Research Team

17.1 Members

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17.2 Research Activities

Computational Disaster Mitigation and Reduction Research Team is aimed at developing advanced large-scale numerical simulation of natural disasters such as earthquake, tsunami, flood and inundation, 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 team seeks to be a bridge between Science and Local Government for the disaster mitigation and reduction.

From FY2017, Computational Disaster Mitigation and Reduction Research Team started to integrate all kinds of geo hazards, water hazards and related hazards. Demand for natural disaster simulations became increasing because disasters frequently take place. Therefore, we are developing appropriate sets of programs which meet the demand of calculations. Computational Disaster Mitigation and Reduction Research Team is dealing with the following three kinds of research topics.

Urban model development: Research for urban hazards requires urban models which represent structure and shape of cities in numerical form. However, it takes very long time to develop urban models consisting of buildings, foundations and infrastructures like bridges ports and roads. Therefore, it is indispensable to invent methods which automatically construct urban models from exiting data that is basically ill-structured. Computational Disaster Mitigation and Reduction Research Team developed Data Processing Platform (DPP) for

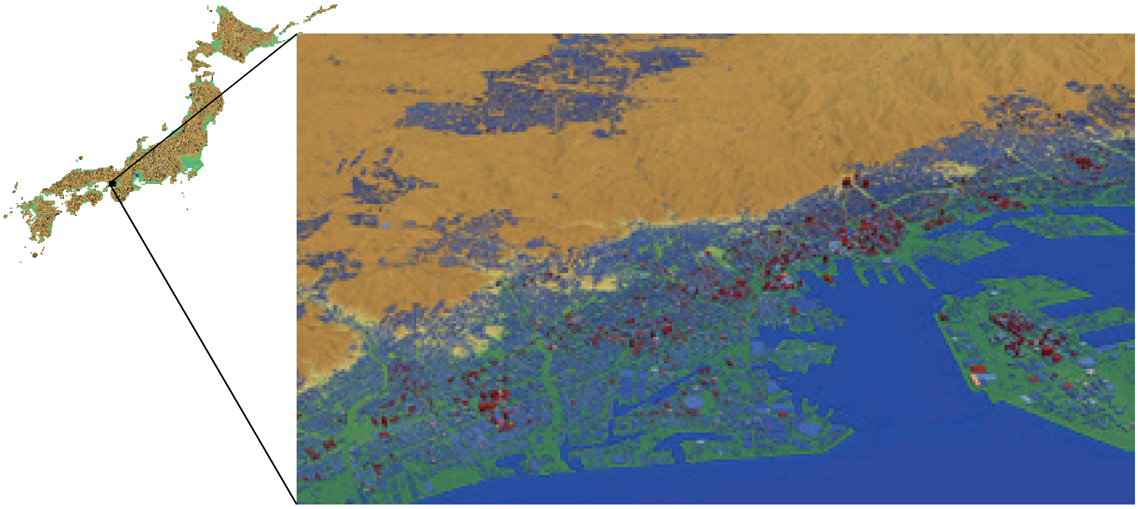

Figure 17.1: The whole Japan model including abount 60,000,000 buildings.

such purpose. By using DPP, construction of a national-wide urban model and 3D model construction from engineering drawings are achieved.

Liquefaction hazard assessment: To rigorously evaluate the quality of liquefaction simulations, and simulations with incremental elasto-plastic models in general, we have developed the method of numerically manufactured solutions (MNMS). This method provides developers and users a quantitative way to examine the accuracy of simulation codes which have implemented elasto-plasticity models for materials. To extend our current liquefaction hazard assessment framework, we have implemented Monte-Carlo (MC) simulations for each single site within a target urban area. This extension allows a prediction with error-bars of liquefaction hazard for urban areas rather than a collection of binary results of deterministic nature. The feasibility of such a prediction for an urban area of target site of the order of 10^4 has been tested.

Water related disaster: Frequency of water disaster has increased. Not only water itself but also sediment cause damage to residents and their assets. Understanding possible hazards is necessary for a measure of precaution and making less damage. Therefore, Computational Disaster Mitigation and Reduction Research Team started to deal with water and sediment related disasters by making numerical simulation model for river basins in Kobe city and Hyogo prefecture.

17.3 Research Results and Achievements

17.3.1 Construction of a National-Wide Urban Model

Large-scale disaster simulations for the purpose of comprehensive disaster mitigation and reduction requires an automation tool which can be used to construct the detailed urban models for target cities. We have been developing such an automation tool, named Data Processing Platform (DPP), so that it can deal with multiple numerical simulations including tsunami inundation and evacuation, and seismic response analysis of ground and buildings [1]. In this fiscal year, we have implemented a MPI-based parallelization of DPP, and have constructed an urban models for the whole Japan which includes about 60,000,000 buildings as shown in Figure 1. This is a first step to realize a national-wide real-time disaster simulation. Now, once given a certain appropriate ground property and motion, a simulation-based assessment of disasters can be achieved for the whole Japan. In addition, we have developed an automation functionality of DPP to conduct pre-ordered disaster simulations. This is also important for a national-wide real-time disaster simulation.

17.3.2 Trial of 3D Model Construction from Engineering Drawings

In the collaborative research project with Hanshin Expressway, we seek to develop a module of DPP to automatically construct a certain 3D model from paper-based engineering drawings so that we can simulate the seismic response of the entire network with high fidelity models. Since paper-based engineering drawings include errors and lack of information, it is hopeless to perform a robust model construction by merely extracting information from engineering drawings. To tackle with this problem, we have developed a template-based methodology, where a prescribed template of high fidelity models with appropriate internal structures is to be selected and the selected template is to be modified to fit the input engineering drawings. As a trial, we succeeded to construct a 3D shape from a three-view drawing by selecting an appropriate template and fitting it to the three-view drawing.

17.3.3 Improvement of liquefaction hazard assessment

For predicting earthquake-induced hazards, numerical simulations of physical processes are regarded as promising alternatives for conventional empirical correlation based approaches. However, the trustworthy of numerical simulations relies on an assumption that a simulation code in use solves the target mathematical problems correctly with sufficient accuracy. Objective evaluation of a simulation code in a quantitative manner, the so-called code verification, is thus needed. Such evaluation is seldom performed for simulation of liquefaction, either due to the importance and necessity of code verification not yet well-recognized or due to the lack of suitable methodology for soil simulations in general. For verifying the quality of the code we have been using for liquefaction assessment, we proposed and implemented the method of numerically manufactured solutions (MNMS), see Fig. 17.2. Our MNMS is featured by manufacturing numerically a load term used as an input for code verification, which is difficult for conventional methods. Since the manufactured solutions can be specified arbitrarily, as long as they are smooth enough for the target differential equations, this method enable users to access a large number of "benchmark solutions". More details about MNMS refers to our publication [2]. And we are now preparing a manuscript on the application of MNMS for IES-DACSAR-I, the code we used for simulation of liquefaction.

In recent years, we have been developing and improving a numerical simulation based liquefaction hazard assessment code for urban areas[1]. In FY2016, we started to investigate the effect of uncertainties soil properties on the liquefaction assessment using Monte-Carlo (MC) simulations for a single site [2]. In FY2017, we extended the urban-wide liquefaction assessment framework with MC simulations. With this enhancement, it is possible to predict liquefaction hazard with "error-bars" while conventional predictions are only a collection of binary assessment of deterministic nature. As a trail run, for a target urban region with 11151 sites, we constructed 100 models for each site. These models are with different permeability parameters, k, the orders of the value of which follows a normal distribution, see Fig. 17.3 (a). The statistics of the most and the least occurrence of liquefaction are summarized in Fig. 17.3 (b) from the trial run. From the simulation results, it is clear that the variation is large in the the prediction for liquefaction under the same input earthquake wave when taking into account the uncertainties in one kind of soil property. The research results will be presented in the coming ICCM2018 in Rome, Italy as a keynote speech at one of its mini-symposiums.

17.3.4 Development of Distributed Rainfall-Sediment Runoff/Inundation Simulator

In order to evaluate a risk of flood disaster under the influence of sediment production/supply due to landslide disaster, integrated simulator considering both water and sediment runoff and their inundation is required. However, existing 2D rainfall runoff and inundation simulators do not basically consider the sediment transport. On the contrary, existing sediment runoff simulators mainly focus on the small-scale sediment transport such as soil erosion and fine particle transport. Therefore, these simulators are not suitable for evaluating the flood risk under the large scale sediment supply due to landslide. For this reason, we have been started to develop Distributed Rainfall and Sediment Runoff/Inundation Simulator (DRSRIS).

DRSRIS can be characterized as an integrated simulator considering the series of phenomena which occurs in a river catchment related to rainfall runoff and sediment transport shown in Fig. 17.4. In this calculation, 2D underground flow, 2D overland flow, and 2D sediment transport are calculated employing Finite Volume method on orthogonal staggered grid from rainfall distribution, DEM, land use, distribution of sediment supply volumes, and sediment characteristics (e.g. porosity, grain size distribution). To take the different flow characteristics depending on the land use into account, land use is divided into 3 categories (i.e. forest, channel, and city).

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[1] Chen, J., Takeyama, T., O-tani, H., Fujita, K. and Hori, M. (2016). "Framework for Assessing Liquefaction Hazard for Urban Areas Based on Soil Dynamics", International Journal of Computational Methods, 13(4), 1641011.

[2] Chen, J., Takeyama, T., O-tani, H., Fujita, K., Motoyama, H. and Hori, M. (2018). "Using High Performance Computing for Liquefaction Hazard Assessment with Statistical Soil Models", International Journal of Computational Methods, Online, 15(2),1840005.

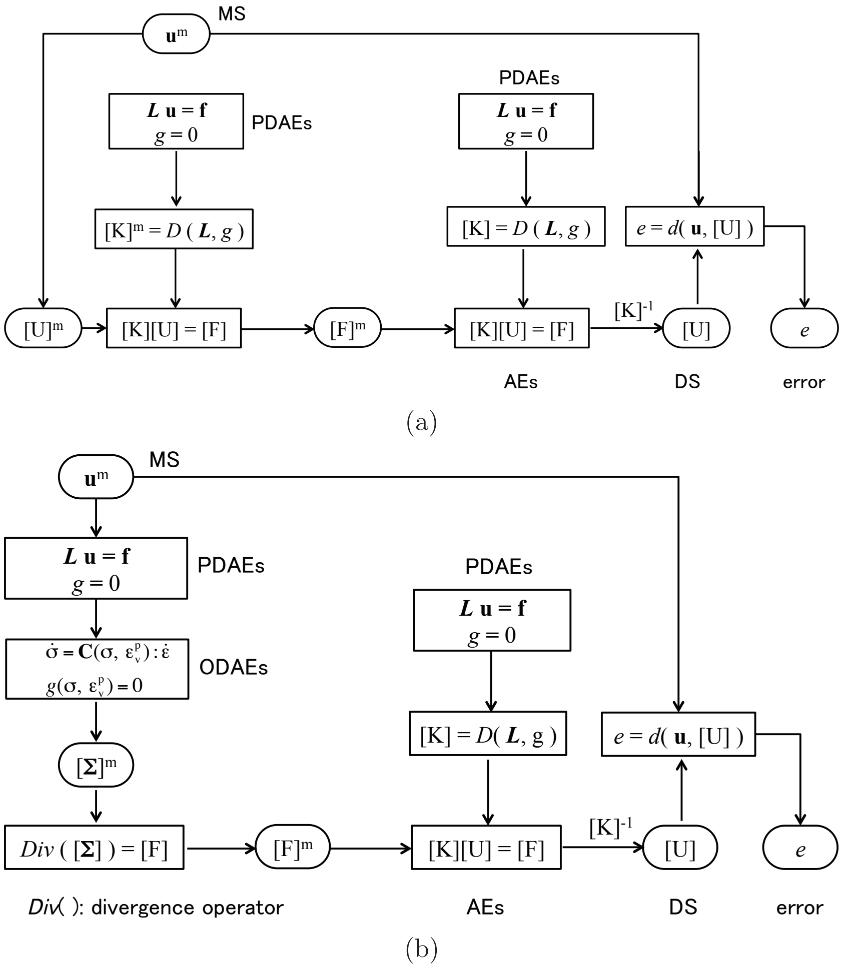

Figure 17.2: The flowcharts of two alternatives of the Method of Numerically Manufacture Solutions (MNMS) we proposed [2]: (a) For a target set of partial differential algebraic equations (PDAEs), MNMS-I manufactures a load term numerically based on the discretized algebraic equations (AEs) from a given manufactured solution (MS), which is compared with the discrete solution (DS) for error measurement. (b) With a given MS, the target PDAEs is converted to a set of ordinary differential algebraic equations (ODAE) which is solved numerically to manufacture a load term for code verification.

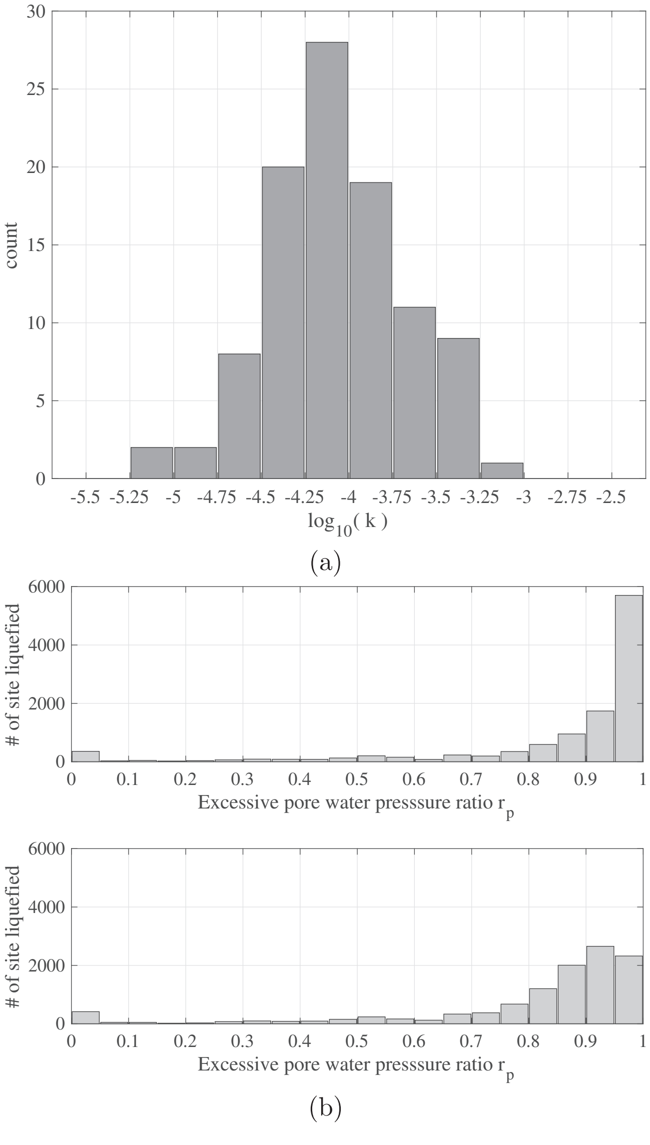

Figure 17.3: Monte-Carlo simulations for liquefaction hazard assessment of an urban area: (a) A normal distribution for the order of the value of soil permeability parameter, $k = 1 \times 10^n$ m/s where n follows $f(n| -4, 0.5^2)$. (b) The number of sites assessed as liquefied in the most occurrence of liquefaction is more than twice of the number in the least case when considering statistical soil models (liquefaction criterion $r_\mathrm{p} > 0.95$).

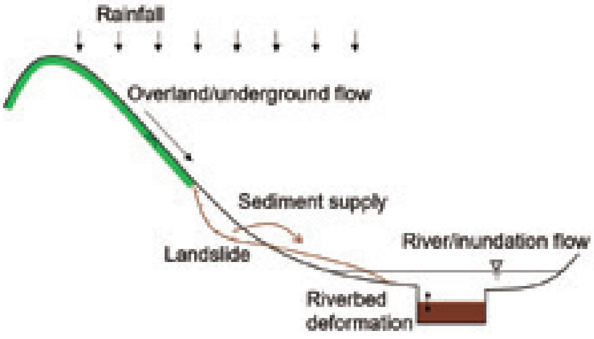

Figure 17.4: Overview of the phenomena simulated in DRSRIS

DRSRIS calculates underground flow only in the forest area considering lateral saturated flow based on Darcy's law and overland/inundation flow in all of land use employing Saint-Venant equations. Also, 2D sediment transport calculation is contained in the DRSRIS considering bed load and suspended load transportation. Currently, DRSRIS requires the assumed distribution data of sediment deposition, which means that it is difficult to apply besides already-happened landslide disaster. To solve this problem, we will combine DRSRIS and a landslide simulator to consider the dynamic movement of landslide mass and its deposition and improve the applicability and validity of the DRSRIS in the next fiscal year.

As a trial, we applied the DRSRIS to simulate Akatani river watershed in Asakura city, Fukuoka prefecture, where actually damaged by the heavy rainfall event occurred in Northern Kyushu Island in July, 2017. In this calculation, input condition of sediment supply volume was estimated by actual landslide distribution data and topography assuming that the deposition angle of sediment is constant. Figure 17.5 shows the one of the trial results of the water level during the heavy rainfall event, which roughly agreed with the observed inundated area.

17.4 Schedule and Future Plan

[1] Developing a national-wide real-time disaster simulation: We will enhance the automation of DPP to collect real-time seismic information and to perform an automated disaster simulation in a certain target area. This will reveal the extent to which speeding up is required for real-time characteristics.

[2] Construction of templates for high fidelity models of highway network: In the template-based methodology, we need to ready the templates in beforehand, and the quality and quantity of templates will be critical to the output model.

[3] Extend current Monte-Carlo simulations for multiple types of soil properties with uncertainties: it is clear that not only the permeability parameter, which is currently studied with statically models, but also other types of soil property, such as the so called N values, has significant effect on liquefaction occurrence. The current code will be extended for Monte-Carlo simulations with multivariate statistical models.

[4] Introduce the "big data" and AI techniques for fast liquefaction prediction: From our numerical simulations, a large number of samples are ready for AIs as training data. We will look for further opportunities to take advantage of the simulation data accumulated for fast liquefaction prediction.

[5] Extend soil dynamics-based simulations for liquefaction assessment to the other type of geo-disaster, landslides: we will start to develop simulation based assessment code for landslide hazards.

[6] Quantitative verification of DRSRIS: We will continue application to an actual flood disaster and evaluate the validity of the calculation. Also, we will apply it to the well-gauged catchment in Rokko mountain area, Hyogo, Japan to make a quantitative verification of sediment transport.

[7] Establishing a method of evaluating flood risk change due to the earthquake-induced landslide disaster by connecting the landslide simulator and DRSRIS: By connecting them, sediment supply volume, one of the required data of DRSRIS, will be obtained directly from the ground condition.

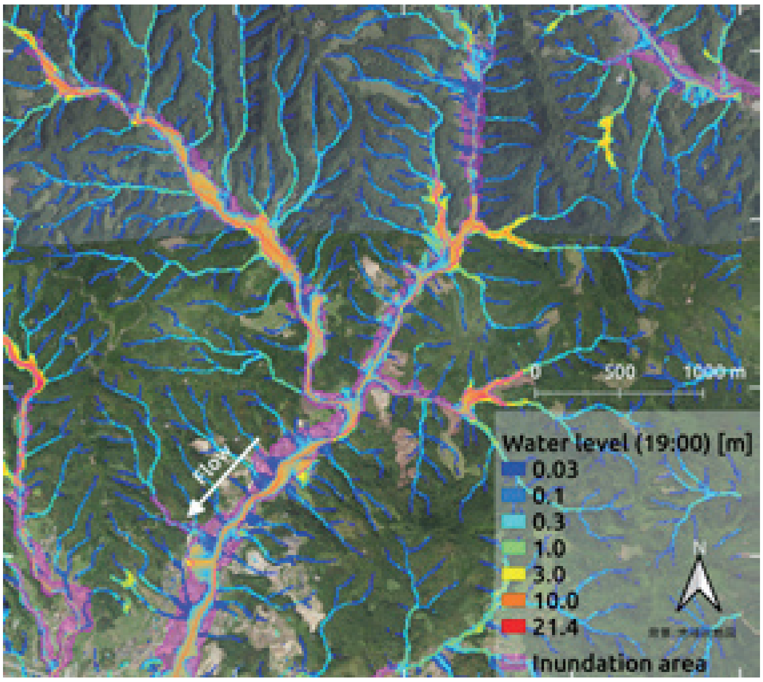

Figure 17.5: A trial results of the comparison between calculated water level (19:00) and the observed inundated area during the sediment-related disaster happened in northern Kyushu island. Note that this result is only for testing the simulator under development.

[8] Applying to a larger river catchment: Urban area is often located in a great river catchment. To estimate the flood risk change due to sediment supply in such areas, we will challenge to expand a calculation area to $100 - 1000\text{km}^2$ in order. To establish it, parallelization rate will be improved by introducing 2D domain decomposition.

[9] Developing FDPS based landslide simulation: Landslide simulation is one of the difficult target for numerical simulation because sediment particles consisting a slope move largely when land slide takes place. By using FDPS framework made by Makino Team, large scale land slide simulation can be developed. We are developing FDPS based landslide simulation program that simulates a slope with size of original scale rather than laboratory scale.

17.5 Publications

17.5.1 Articles

[1] Hori, M., Ichimura, T., Lalith, M., Ohtani, H., Chen, J., Fujita, K., Motoyama, H. (2018). ”Application of High Performance Computing to Earthquake Hazard and Disaster Estimation in Urban Area.” Frontiers in Built Environment. 4. 1. 10.3389/fbuil.2018.00001.

[2] Chen, J., Hori, M., O-tani, H., Oishi, S., Fujita, K. and Motoyama, H. (2017). “Proposal of Method of Numerically Manufactured Solutions for Code Verification of Elasto-Plastic Problems”, Journal of Japan Society of Civil Engineers, Ser. A2 (Applied Mechanics), Vol.73(2).

17.5.2 Oral Talks

[3] O-tani, H., Chen, J., Fujita, K. and Hori, M. (2017). ”A Data Integration Framework for Urban Area Disaster Simulations.” 6th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN2017), Rhodes Island, Greece, June 2017. (KEYNOTE)

[4] Chen, J., O-tani, H., Fujita, K., Motoyama, H., Takeyama, T. and Hori, M. (2017). “High Performance Computing for Hazard Assessment of Soil Liquefaction in Urban Regions”, 15th International Conference of

the International Association for Computer Methods and Advances in Geomechanics (IACMAG), Wuhan, Oct. 2017
[5] Chen, J., O-tani, H., Oishi, S. and Hori, M. (2017). “Application of HPC boosted liquefaction assessment for urban regions”, 2nd International Conference on Computational Engineering and Science for Safety and Environmental Problems (CompSafe), Chengdu, Oct. 2017.