Chapter 16

Computational Disaster Mitigation and Reduction Research Unit

16.1 Members

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16.2 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.

The year of 2016 is the final year of the COE project. Our research unit has finalized the core research objectives as well as made preparation of launching a new research objective, as follows:

1) Construction of next generation hazard map for four cities in Hyogo Prefecture. For two scenarios of Nankai Trough Earthquake presumed by National Government, the unit constructed next generation hazard map for four cities in Hyogo Prefecture. Unlike a conventional one, the next generation hazard map is based on large scale numerical simulation of the physical processes of seismic wave propagation and seismic structural responses. The map achieves highest spatial resolution as well as higher rationality. Urban area models of these four cities for man-made structures are used in the physical simulation, and it is these models that determine the quality of the simulation; a more accurate model makes a more reliable estimation of earthquake hazard and disaster. Computational Disaster Mitigation and Reduction Research Unit develops a system called Data Processing Platform that automatically constructs the urban area models using available data resources such as commercial Geographical Information System and governmental data. The system is designed to have high flexibility and expandability so that it can be used for various urban area to which suitable data resources are available.

2) Development of system for real-time estimate of liquefaction occurrence in Hyogo Prefecture. Due to complicated processes, the liquefaction occurrence ought to be estimated by empirical equations that use engineering indices of soil layers of a target site. Computational Disaster Mitigation and Reduction Research Unit constructs a system that enables us to make real-time estimation of liquefaction occurrence; it completes numerical simulation of liquefaction occurrence for 10,000 sites in Hyogo Prefecture for given ground motions. The numerical simulation is made for coupling of soil deformation and underground water flow induced by ground motion, and uses an analysis model for undergrounds that is automatically made by using available boring hole data. Data Processing Platform is used for the automated construction of these underground models.

Figure 16.1: Example of next generation hazard map for Akashi City

3) Study on high fidelity model simulation for natural hazard and disaster. While most advanced numerical simulations are made for the estimation of natural hazard and disaster, it is necessary to increase the accuracy and reliability of the estimation by improving the numerical analysis method that is used for the simulation. To this end, Computational Disaster Mitigation and Reduction Research Unit seeks a high-fidelity model simulation, a massive numerical analysis of a most realistic model of ultra large degree-of-freedom. Such a simulation needs a more advanced numerical analysis method and a better automated model construction. For an exa-scale machine, the analysis method and the construction are being developed.

16.3 Research Results and Achievements

16.3.1 Construction of next generation hazard map for Hyogo Prefecture

National Government issued a possible scenario of Nankai Trough Earthquake. Large and extremely large scenarios were announced for the preparation of earthquake disaster, and a distribution of ground motion index (such as seismic index or peak ground acceleration / velocity) and residential building damage was made by using simple numerical analysis and empirical equations. The distribution is summarized as a hazard map for relatively large "mesh" or "grid" of more than 500 m or town-wise number of damaged houses.

Computational Disaster Mitigation and Reduction Research Unit constructs next generation hazard map for Akashi, Ashiya, Nishinomiya and Amagasaki Cities, using the two presumed scenarios of National Government; see Fig. 16.1 ; the unit has constructed next generation hazard map for Kobe City in 2016. Unlike the conventional hazard map, the next generation hazard map takes advantage of large scale numerical simulation[21-23] of the two physical processes, namely, the seismic wave propagation / amplification and the seismic structural responses. A key issue is the use of Data Processing Platform that constructs analysis models of these two processes for the four cities as shown in Fig. 16.2 . The robustness of the platform is demonstrated as it succeeds to constructs these four models.

Data Processing Platform has a wide range of application since it is able to construct various analysis models for one structure or one city. As an example, we conduct so-called sensitivity analysis of seismic structural response analysis[7], by constructing building analysis models of different structural properties. Data Processing Platform readily constructs normal and week models for each residential building; week models are for the case when the buildings are damaged by previous shaking. The degree and distribution of building damages in an urban area is changed as a consequence; see Fig. 16.3 . As 2016 Kumamoto Earthquake clarified, sequential shakings are surely more hostile to structures, and the numerical simulation that considers the effects of past quakes on structural integrity help to estimate the effects quantitatively.

Computational Disaster Mitigation and Reduction Research Unit creates another next generation hazard map for tsunami, using the numerical analysis[1,2] of K computer. The hazard map is fully dynamic rather than static, and provides a video clip which captures tsunami inundation at any site with any viewpoint. Like earthquake, examples of the videoclips are presented in Fig. 16.4 , in which the case that higher and lower seawalls are compared. This next generation hazard map is made with the help of Data Processing Platform, in constructing analysis models of tsunami as well. Two data resources, three-dimensional aerial digital data and two-dimensional Geographic Information System, are used as data resources. Photo-realistic video clips are available for the next generation hazard map, and local government seeks to utilize the map to promote tsunami preparation awareness in resident community.

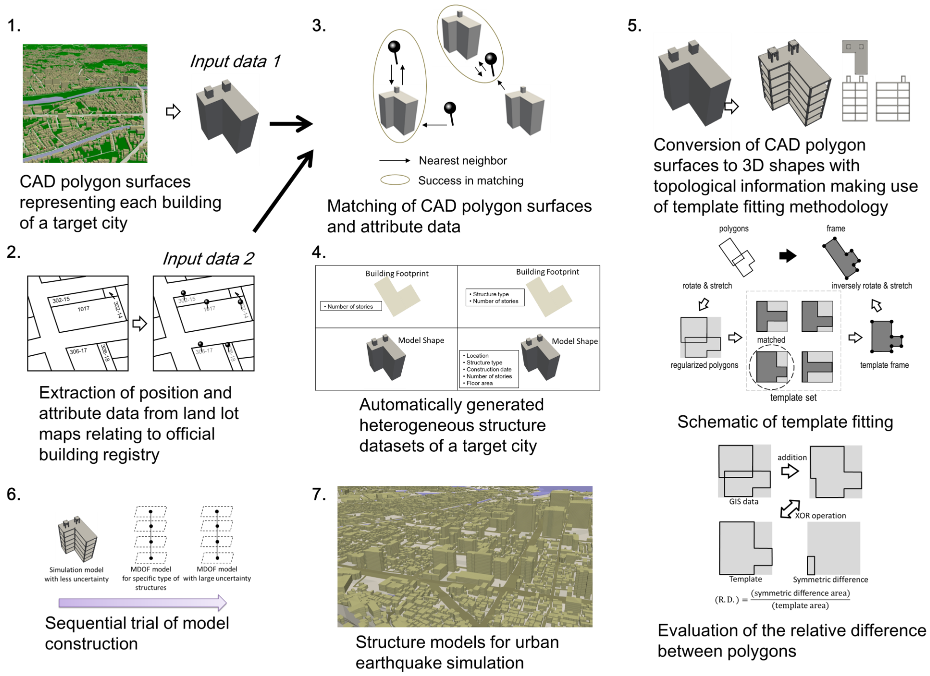

Figure 16.2: Data Processing Platform to generate various urban area models using various data resources

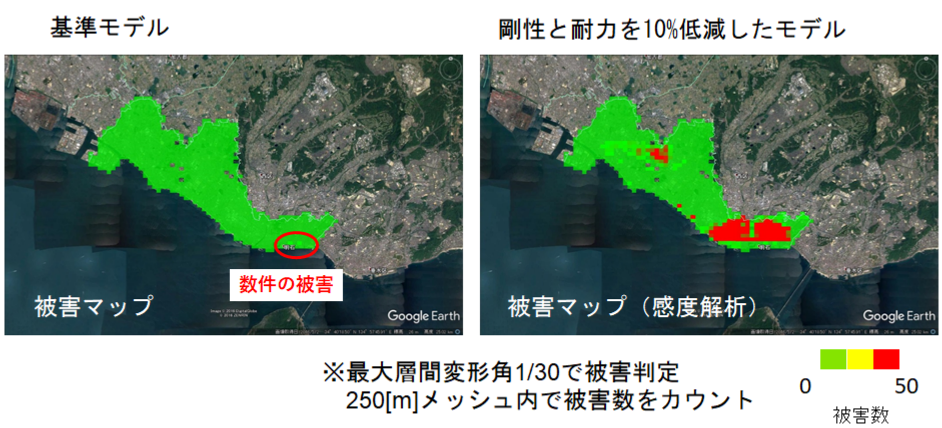

Figure 16.3: Comparison of degree and distribution of earthquake damage of residential buildings by using normal and weak analysis models

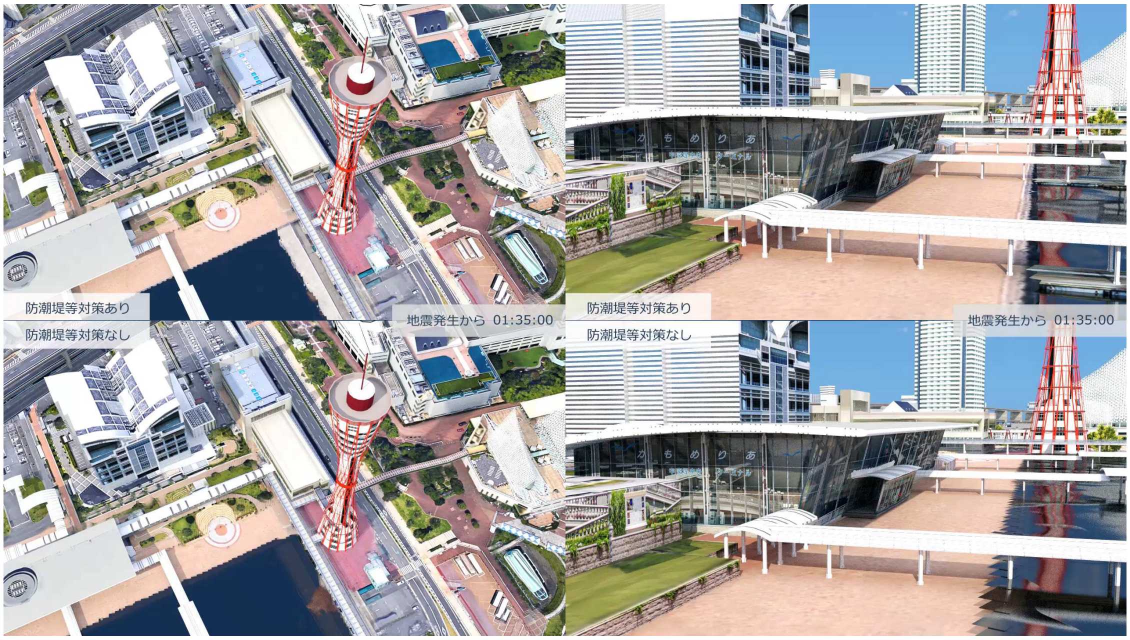

Figure 16.4: Examples of next generation hazard map for tsunami for Kobe City

16.3.2 Development of system for real-time estimate of liquefaction occurrence

Liquefaction is occurred through complicated processes of soil and underground water which are influenced by mechanical properties and permeability of soil and flow of underground water. When underground water pressure increases locally due to the coupling of soil deformation and underground water flow, liquefaction is induced, and it loses ground strength when liquefaction is spread in underground.

Computational Disaster Mitigation and Reduction Research Unit has constructed a system[3-5,11,13-16] that estimates the liquefaction occurrence by using numerical simulation of the above complicated processes of soil and underground water coupling since 2016. The system is now able to make real-time estimate of liquefaction occurrence; for observed ground motion, the system computes 10,000 sites to which analysis models of underground structure are constructed within a few ten minutes, using 1,000 compute node of K computer. A key issue is to improve the performance of numerical analysis method of liquefaction. Figures 16.5 and 16.6 show the speed-up of the method (strong scale) and the break-down of the numerical computation processes. Almost ideal speed-up is observed due to the well tuned numerical analysis processes.

While the numerical analysis method of liquefaction is verified, an analysis model of underground structure which is constructed by using boring hole data is not validated. Material parameters are not fully determined, beside for the applicability of the constitutive relation that is implemented in the analysis method. Uncertainty included in the deterministic numerical analysis ought be estimated; see Fig. 16.7 . To this end, Computational Disaster Mitigation and Reduction Research Unit carries out numerical experiments in which multiple models are constructed for one site or for one boring hole data. The results of the experiment are presented in Fig. 16.8 .

16.3.3 Study on high fidelity model simulation for natural hazard and disaster

High fidelity model simulation is a primary target of capability computing, as it needs a large-scale model and short time to solution. Taking advantage of world top class (or world number one) finite element method[9,10,12,14-16,24-28] enhanced with high performance computing, Computational Disaster Mitigation and Reduction Research Unit studies the following three target: 1) the crust deformation analysis for the prediction of earthquake occurrence processes; 2) the highway network analysis for the estimation of seismic safety against large scale

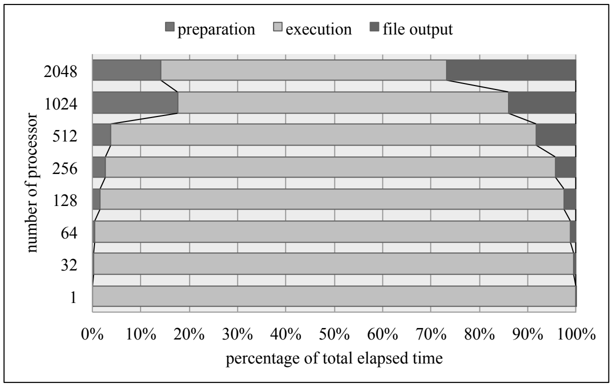

Figure 16.5: Speed-up of the numerical analysis method for liquefaction

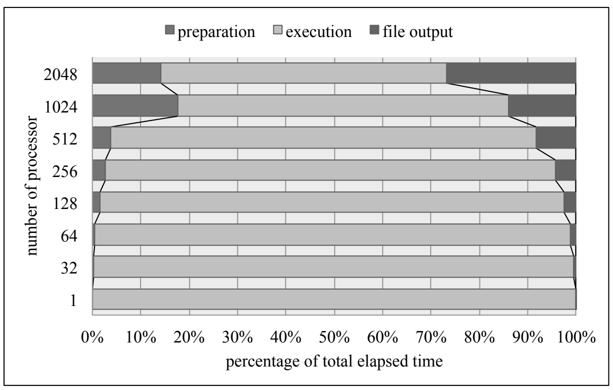

Figure 16.6: Figure 16.6: Break-down of the numerical analysis method for liquefaction

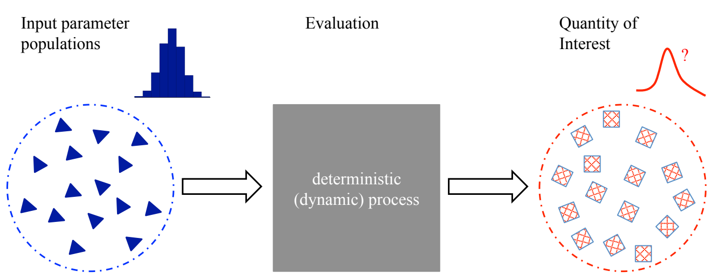

Figure 16.7: Uncertainity estimation for deterministic numerical analysis of liquefaction

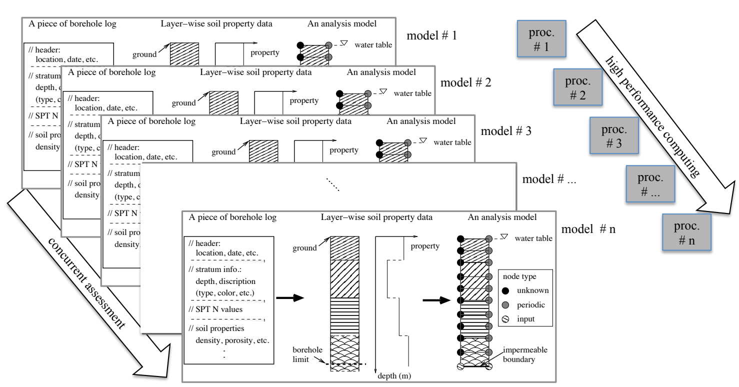

Figure 16.8: Multiple models constructed for numerical experiment of uncertainty estimation of liquefaction

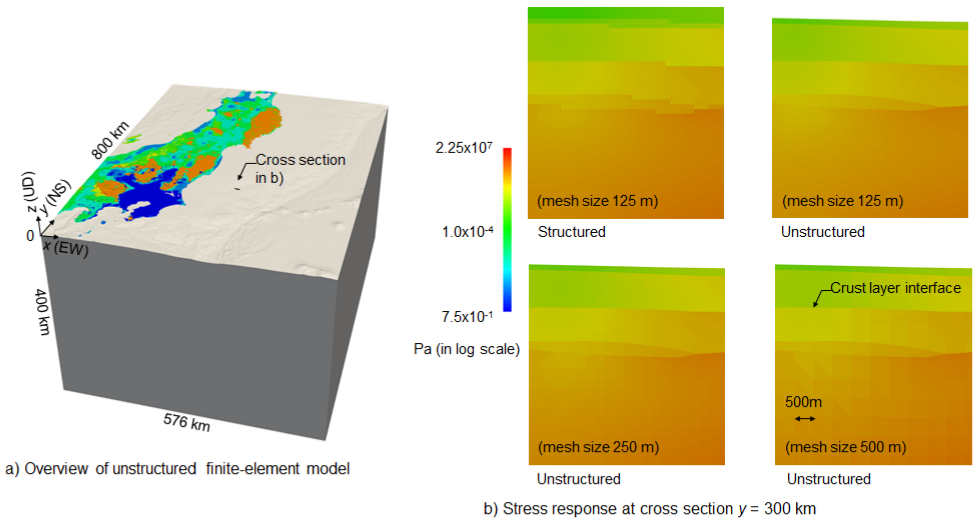

Figure 16.9: Crust deformation analysis

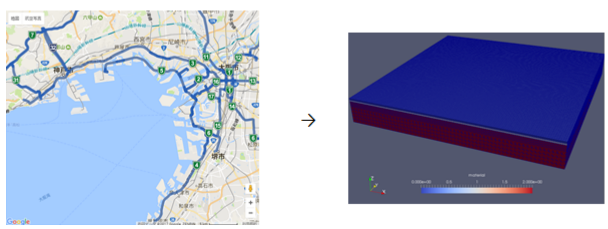

Figure 16.10: High fidelity model of subsurface for highway network seismic response analysis

earthquake[8,21]; and 3) the nuclear power plant building analysis that accounts for non-linear material properties of reinforced concrete[6,16].

The crust deformation analysis uses a large-scale crust model, the construction of which is a challenging subject in the model construction; 10 m resolution is achieved for the inter-plate boundary of complicated configuration. The finite element analysis of this model needs a fast solver, and a pre-conditioner that reduces memory usage drastically is being developed. Figure 16.9 presents the overview of the analysis model and the result of the analysis in which stress accumulation on the inter-plate boundary is computed.

In the collaborative research project with Kobe University and Hanshin Expressway, the unit is constructing a high fidelity model of subsurface (or surface ground layer) in order to compute ground motion distribution which is input to a highway network of a few 10 km or longer; see Fig. 16.10 . While only a small portion (or one span of the network) is studied in ordinary numerical computation, this models enables us to study a more realistic input to the network; the amplitude and phase of the ground motion differ from place to place.

Imitating an international collaborative research project with CAE in France, the unit starts the nuclear power plant building analysis that accounts for non-linear material properties of reinforced concrete. While a multiple mass spring model is often used for a nuclear power plant building for practice, its limitation of evaluating the seismic safety is obvious, especially for large ground motion which induce considerable non-linear responses of local structure components or the overall structure. A high-fidelity model of the building is a more reliable model. The non-linear material properties of concrete or reinforced concrete ought to be accurately computed for such a model; see Fig. 16.11 .

16.4 Schedule and Future Plan

As mentioned, the year of 2016 is the final year of the first phase of the unit. The unit is moving towards more extensive and exclusive research on natural disasters, and the current concern of primary importance is heavy rain in an urban area.

The objectives of the unit research are summarized as follows:

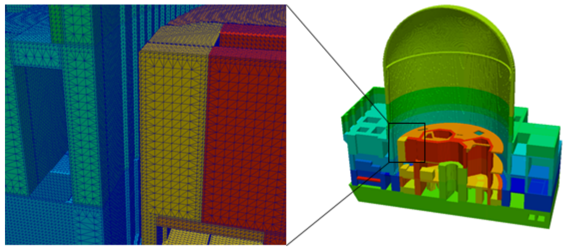

Figure 16.11: Example of a high fidelity model of a nuclear power plant building

Developing Data Processing Platform: Data Processing Platform automatically constructs the urban area models. The development consists of automatic urban model constructer and conceptual representation of components of urban model. These are highly related with Artificial Intelligence research field and Computational Disaster Mitigation and Reduction Research Unit is trying to collaborate with AIP center of RIKEN.

Improving Numerical Analysis Method of Liquefaction: Numerical Analysis Method of Liquefaction will be improved in terms of uncertainty and downscaling. Both of the improvement has been started in 2016, then the improvement will be kept undertaking in the second phase of the unit. Computational Disaster Mitigation and Reduction Research Unit undertake the above two research items with Hanshin Expressway and Kobe University.

Development of Comprehensive Numerical Simulation Method for Natural Disaster: Computational Disaster Mitigation and Reduction Research Unit starts to deal with multiple hazard including geotechnic hazard, flood and sediment related hazard as well as seismic hazard and tsunami hazard. After big earthquake would happen, slope becomes unstable and hazard potential of geotechnic hazard like land slide and mudflow become increase followed by sediment transportation into river bed raising flood risk. Computational Disaster Mitigation and Reduction Research Unit develops comprehensive numerical hazard assessment method consisting of landslide simulation using Smoothed Particle Hydrodynamic Method, hydrological simulation with inundation by shallow water equation and sediment transportation simulation as well as seismic propagation simulation and liquefaction.

Design of Integrated Engineering System (IES): Integrated Engineering System is a platform to assess the risk of natural disaster of all kinds. Risk of natural disaster will take social aspect into account, for example, transportation congestion during evacuation and recovery, risk finance using insurance and reasonable redundancy of lifelines like water supply, sewage water drainage, electric / gas supply and public transportation. By using comprehensive numerical hazard assessment method, Computational Disaster Mitigation and Reduction Research Unit will design the IES with many research partners.

16.5 Publications

16.5.1 Articles

[1] Eguchi, S., Asai, M., O-tani, H., Isshiki, M., "3D Tsunami Run-Up Simulation by Using Particle Method with Geography Analysis Model Including Building Information", Journal of Japan Society of Civil Engineers, A1 (2016)

[2] Isshiki, M., Asai, M., Eguchi, S., O-tani, H., "3D tsunami run-up simulation and visualization using particle method with GIS-based geography model", Journal of Earthquake & Tsunami (2016)

[3] Chen, J., Takeyama T., O-tani, H., Fujita, K., Hori, M., "Using High Performance Computing for Liquefaction Hazard Assessment with Statistical Soil Models", International Journal of Computational Methods (accepted) (2017)

[4] Chen, J., O-tani, H., Fujita, K., Hori, M.,"On elastic waves in granular assemblies: from a continuumnization viewpoint", Mechanics of Materials, 109 (2017)

[5] Supprasert, S., Chen, J.,Maddegedara, L. and Hori, M., "Application of continuumnization and PDS-FEM for the analysis of wave propagation in brick structures", Journal of Japan Society of Civil Engineers, Ser. A2, 72(2) (2016)

[6] Miyamura, T., Tanaka, S. and Hori, M., "Large-Scale Seismic Response Analysis of a Super-High-Rise-Building Fully Considering the Soil?Structure Interaction Using a High-Fidelity 3D Solid Element Model", Journal of Earthquake and Tsunami 10 5 (2016)

[7] Sahin, A., Sisman, R., Askan, A. and Hori, M., "Development of integrated earthquake simulation system for Istanbul", Earth Planets Space 68 115 (2016)

[8] Hori, M., Wijerathen, L., Ichimura, T., and Tanaka, S., "Meta-Modeling for Constructing Model Consistent with Continuum Mechanics, Journal of Japan Society of Civil Engineers, A2 71(1) I_133-I_142 (2016)

[9] Kohei Fujita, Tsuyoshi Ichimura, "evelopment Of Large-Scale Three-Dimensional Seismic Ground Strain Response Analysis Method and Its Application to Tokyo using Full K Computer, Journal of Earthquake and Tsunami", Journal of Earthquake and Tsunami 10(4) (2016)

[10] Kohei Fujita, Keisuke Katsushima, Tsuyoshi Ichimura, Muneo Hori, Lalith Maddegedara, "Octree-based Multiple-material Parallel Unstructured Mesh Generation Method for Seismic Response Analysis of Soil-Structure Systems", Procedia Computer Science, 80, 1624-1634 (2016)

16.5.2 Conference Papers

[11] Chen, J., O-tani, H., Fujita, K., Hori, M., "High performance computing for liquefaction hazard assessment with statistical soil models", The 7th International Conference on Computational Methods (ICCM2016) 51, 1483-1493 (2016)

[12] Kohei Fujita, Takuma Yamaguchi, Tsuyoshi Ichimura, Muneo Hori, Lalith Maddegedara, "Acceleration of Element-by-Element Kernel in Unstructured Implicit Low-order Finite-element Earthquake Simulation using OpenACC on Pascal GPUs", Proceedings of Third Workshop on Accelerator Programming Using Directives (WACCPD), Best Paper Award (2016)

16.5.3 Posters and Presentations

[13] Chen, J., O-tani, H., Fujita, K., Hori, M., "Application of High Performance Computing for Assessing Hazard of Earthquake induced Liquefaction in Urban Regions", The 2nd Huixian International Forum on Earthquake Engineering for Young Researchers (2016)

[14] Chen, J., O-tani, H., Hori, M., "High Performance Computing for Assessing Hazard of Earthquake induced Liquefaction in Urban Regions", WCCM XII & APCOM VI (2016)

[15] Chen, J., O-tani, H., Hori, M., "Application of High Performance Computing for Liquefaction Assessment Based on Soil Dynamics Analysis", JAEE Annual Meeting (2016)

[16] Hori, M., "Continuumnization of regularly arranged rigid bodies to estimate overall properties", Symposium on The Application of Mechanics to Geophysics (2015)

[17] Hori, M., "Uncertainty and Predictability - Utilization of High Performance Computing for Uncertain Problem", Fukushima Session, Enhancement of Risk-Informed Decision Making against External Natural Events Toward Practical Implementations 2016 ANS Winter Meeting and Nuclear Technology Expo (2016)

[18] Hori, M., "Uncertainty and Predictability - Utilization of High Performance Computing for Uncertain Problem", Expert Meeting on IAEA/ISSC/WA3-2 (2016)

[19] Hori, M., "Earthquake hazard and disaster simulation using urban are model of 10.7x109 degree-of-freedom", Exascale Computing, XXIV ICTAM (2016)

[20] Hori, M., "Regional Scale Modeling in Japan - Integrated Earthquake Simulation", Regional Scale Earthquake Hazard and Risk Assessments (2016)

[21] Hori, M., Riaz, M., Motoyama, H., Akiba, H., and Ohtsuka, Y., "Consistent Modeling for SSI Analysis Using High Performance Computing", 10th Nuclear Plants Current Issues Symposium Assuring Safety against Natural Hazards through Innovation & Cost Control (20169

[22] Hori, M., "Application of High Performance Computing to Earthquake Hazard and Disaster Assessment", 1st International Symposium on Research and Education of Computational Science (RECS) (2016)

[23] Hori, M., "Application of High Performance Computing to Earthquake Hazard and Disaster Assessment", UK- Japan Disaster Research Workshop: Cascading Risk and Uncertainty Assessment of Earthquake Shaking and Tsunami (2016)

[24] Kohei Fujita, Tsuyoshi Ichimura, Kentaro Koyama, Masashi Horikoshi, Hikaru Inoue, Larry Meadows, Seizo Tanaka, Muneo Hori, Maddegedara Lalith, Takane Hori, "A Fast Implicit Solver with Low Memory Footprint and High Scalability for Comprehensive Earthquake Simulation System", SC16 (The International Conference for High Performance Computing, Networking, Storage and Analysis), Best Poster Award (2016)

[25] Kohei Fujita, Tsuyoshi Ichimura, Muneo Hori, "Urban earthquake simulation of Tokyo metropolis using full K computer", European Geosciences Union General Assembly (2016)

[26] Kohei Fujita, Tsuyoshi Ichimura, Muneo Hori, "Integrated earthquake simulation enhanced with fast wave propagation analysis using full K computer", WCCM XII & APCOM VI (The 12th World Congress on Computational Mechanics and 6th Asia-Pacific Congress on Computational Mechanics) (2016)

[27] Keisuke Katsushima, Kohei Fujita, Tsuyoshi Ichimura, Muneo Hori, Lalith Wijerathne, "Parallel and Robust Tetrahedral Mesh Generation Method for Seismic Response Analysis of Structures", WCCM XII & APCOM VI (The 12th World Congress on Computational Mechanics and 6th Asia-Pacific Congress on Computational Mechanics) (2016)

[28] Kohei Fujita, Tsuyoshi Ichimura, Muneo Hori, "Development of High-Performance Finite-Element Solver and Application to Seismic Ground Strain Analysis of Tokyo", Techno-Ocean 2016 (2016)