JST Basic Research Programs

C R E S T

(Core Research for Evolutional Science and Technology)

Annual Report for Research Work in the fiscal year 2006

Research Area :

High Performance Computing for Multi-scale and Multi-physics Phenomena

Research Theme

Integrated Predictive Simulation System for Earthquake and Tsunami Disaster

Name of Research Director, Belonging and Title:

Mitsuhiro Matsu'ura, Graduate School of Science, University of Tokyo, Professor

§1. Outline of Research Work

The aim of our research project is to develop an integrated simulation system for predicting earthquake and tsunami disasters, which covers the entire multi-scale processes related to earthquakes, such as tectonic stress accumulation due to relative plate motion, earthquake generation, seismic wave/tsunami propagation, and building oscillation. For reliable prediction we assimilate observed data from the nation-wide seismic and geodetic networks to the computer simulation. In 2006, integrating correlative basic models, we developed three combined simulation systems for earthquake generation, strong ground motion/tsunami propagation, and building oscillation. In 2007 we develop a platform and data grid that support combined simulations and parallel data management. In 2008-2010 we integrate the three combined simulation systems into a unified system, and make simulations for the prediction of earthquakes and tsunami disasters in realistic scenarios. The integrated simulation system will make a major contribution toward the reduction of earthquake and tsunami disasters.

§2. Content of Research Work

Objects and methods

In the first phase of the project (2005-2007) we develop three combined simulation systems for earthquake generation, strong ground motion/tsunami propagation, and building oscillation. We also develop a platform for combined simulations. The integrated simulation system consists of six basic simulation models (plate motion, tectonic stress accumulation, earthquake rupture propagation, seismic wave propagation, tsunami propagation, and building oscillation), three data analysis programs (geodetic data, seismic data, and strong ground motion data), and a platform that supports combined simulations and parallel data management, as shown in Fig.1.

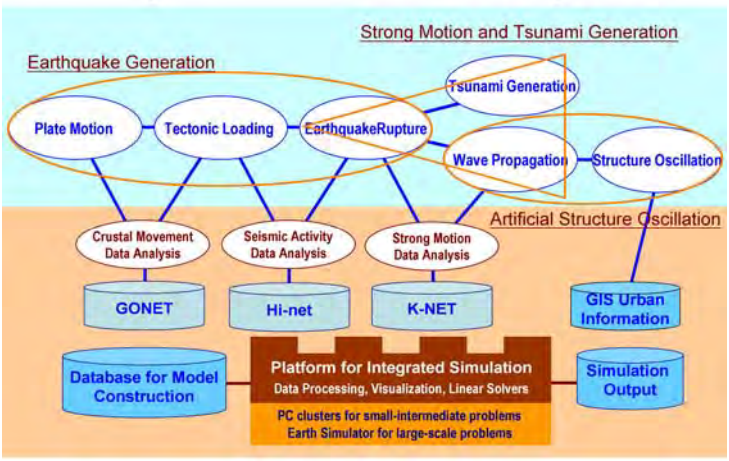


Fig.1. The integrated predictive simulation system for earthquake and tsunami disaster

In the second phase (2008-2010) we will integrate the three combined systems into a unified system, and make simulations for the prediction of earthquakes and tsunami disasters in realistic scenarios.

Our project team has six research groups: 1) Matsu'ura group for the predictive simulation of earthquake generation cycles, 2) Furumura group for the integrated simulation of seismic wave propagation and tsunami generation/propagation, 3) Okuda group for the development of a platform and data grid that support combined simulations and parallel data management, 4) Ichimura group for the coupling simulation of seismic wave propagation and building oscillation, 5) Nagashima group for the coupling simulation of seismic wave propagation and oil-tank sloshing, and 6) Fukuyama group for the combined simulation of earthquake rupture and seismic wave propagation.

Results of the research

In 2006, through the collaborative research between the six research groups, we developed three combined simulation systems for earthquake generation, strong ground motion/tsunami propagation, and building oscillation. We also progressed the development of a platform and data grid that support combined simulations and parallel data management. The details are summarized below.

1) Predictive simulation of earthquake generation cycles

Matsu'ura group and Fukuyama group developed a simulation system for earthquake generation cycles at plate boundaries, and made the combined simulations of quasi-static stress accumulation, dynamic rupture and seismic wave propagation for the 1968 and 2003 Tokachi-oki earthquakes.

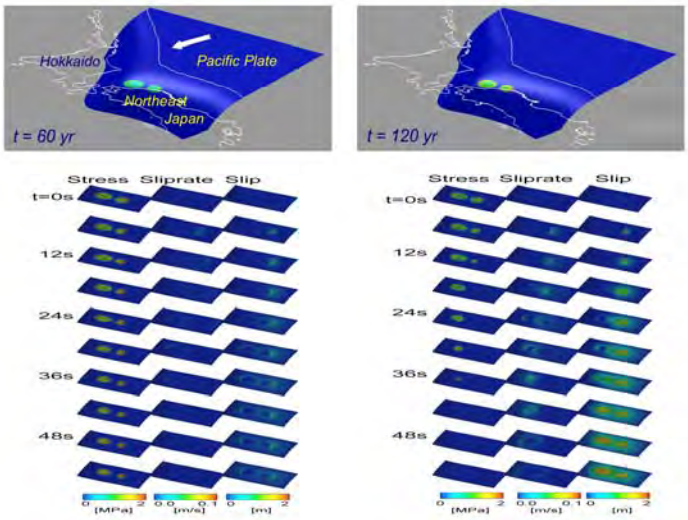


Fig. 2 Combined simulations of quasi-static stress accumulation and dynamic rupture propagation in the source region of the 1968 Tokachi-oki earthquake (Hashimoto, Fukuyama & Matsuura, 2006). Top: States stress accumulation at 60 yr and 120 yr after the 1968 Tokachi-oki earthquake. Bottom: Corresponding dynamic rupture propagation.

2) Integrated simulation for seismic wave and tsunami propagation

Frumura group developed an integrated simulation model for seismic wave propagation and tsunami generation/propagation for accurate prediction of tsunami disasters cause by subductio-zone earthquakes. The integration model for earthquake and tsunami is implemented to the Earth Simulator and a PC cluster for the simulation of strong ground motion and tsunami from the 1944 Tonankai earthquake (Mw8.1).

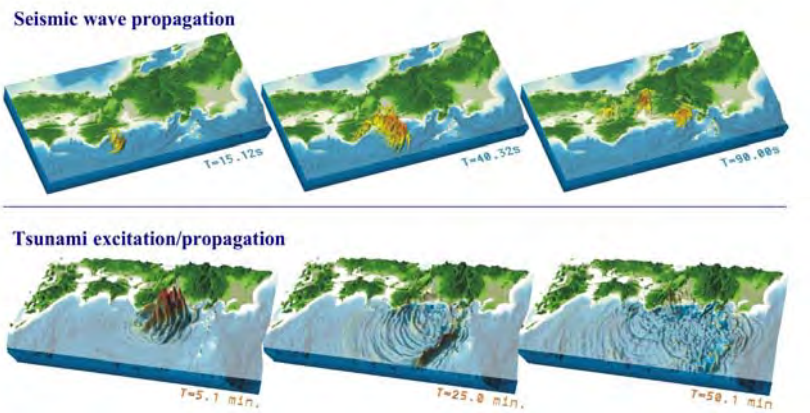
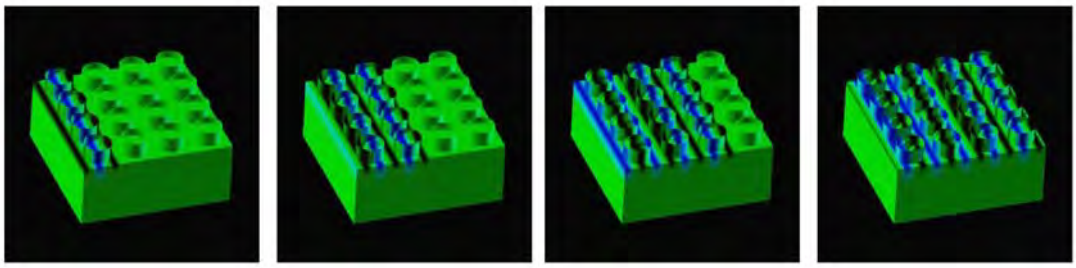


Fig. 3 Integrated simulation for seismic wave (top) and tsunami (bottom) propagation for the 1944 Tonankai earthquake (Frumura and Saito, 2006). The snapshots for seismic wave are at 15, 4o, and 90 sec after the earthquake. The snapshots for tsunami are at 5, 25, and 50 min.

3) Large-scale coupling simulation through M×N parallel data redistribution

Ichimura group, Nagashima group and Okuda group developed a prototype of framework for large-scale parallel coupling simulations through M×N parallel data redistribution under SPMD environment. Coupling simulations for seismic response of multi-tanks for oil-strage with fluid-structure interaction have been demonstrated.



T=8 sec T=12 sec T=16 sec T=20 sec

Fig. 4 Coupling finite-element simulations for seismic response of multi-tanks for oil-storage with fluid-structure interaction through framework for coupling simulations with M×N parallel data redistribution (Ichimura, Nagashima, Okuda, and Nakajima, 2006).

4) Development of a platform for combined simulation

Okuda group developed a parallel visualization method for large-scale distributed data sets in numerical simulations with background voxel's. In this method, information of distributed unstructured meshes for FEM has been mapped to background voxel's with adaptive mesh refinement (AMR). Simplification of boundary surface id also applied for reducing data size.

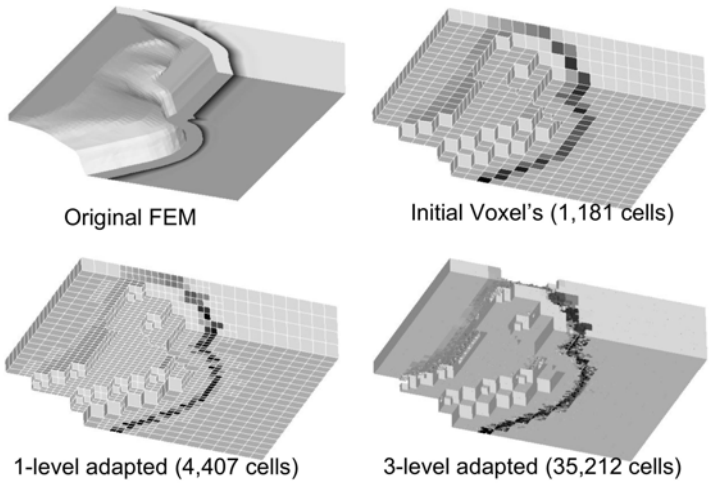


Fig. 5 Temperature distribution of a southwest Japan model with various types of background resolution (Okuda and Nakajima, 2006).

Situation of the progress

In 2006 our project team has developed three combined simulation systems for earthquake generation, strong ground motion/tsunami propagation, and building oscillation. The project is progressing on schedule.

§3. Formation of Research Work

<u>Research Director</u>

Mitsuhiro Matsu'ura, Professor

Graduate School of Science, University of Tokyo

The aim of Matsu'ura group is to develop a predictive simulation system for earthquake generation cycles at plate interfaces in and around Japan, combining a tectonic stress accumulation model, a dynamic rupture propagation model, a geodetic data inversion program, and a CMT data inversion program.

Main Research Collaborators

Takashi FURUMURA, Associate Professor

Earthquake Research Institute, University of Tokyo

The aim of Furumura group is to develop an integrated simulation system for seismic wave propagation and tsunami generation/propagation, and predict strong ground motion and tsunami in and around Japan.

Hiroshi OKUDA, Professor

Research Into Artifacts, Center for Engineering, University of Tokyo

The aim of Okuda group is to develop a hierarchical simulation platform and data grid, which support combined simulations and parallel data management.

Tsuyoshi ICHIMURA, Associate Professor

Graduate School of Science and Engineering, Tokyo Institute of Technology

The aim of Ichimura group is to develop a fast and accurate simulation model for coupling strong ground motion and building oscillation.

Toshio NAGASHIMA, Associate Professor

Faculty of Science and Technology, Sophia University

The aim of Nagashima group is to develop a fast and accurate simulation model for dynamic response of industrial plants such as oil storage tanks against seismic waves.

Eiichi FUKUYAMA, Senior Researcher

Earthquake Research Division, National Research Institute for Earth Science and Disaster Prevention.

The aim of Fukuyama group is to develop a combined simulation code for dynamic rupture and seismic wave propagation, and make realistic earthquake simulations based on earthquake generation physics.

§4. Publication of Research Results

（4－1） Publication of Thesis (The original Work)

① Number of Publications (4 times-Domestic, 14 times-International)

② Detailed Information of Thesis

[1] Fukahata, Y. and M. Matsu'ura, Quasi-static internal deformation due to a dislocation source in a multilayered elastic/viscoelastic half-space and an equivalence theorem, Geophys. J. Int. 166,

418-434, 2006.

[2] Hashimoto, C. and M. Matsu'ura, 3-D simulation of tectonic loading at convergent plate boundary zones: Internal stress fields in northeast Japan, Pure Appl. Geophys. 163, 1803-1817, 2006.

[3] Takada, Y. and M. Matsu'ura, Geometric evolution of a plate interface-branch fault system: Its effects on tectonic development in Himalaya, J. Asian Earth Sciences 29, 490-503, 2007.

[4] Takada, Y., Y. Fukahata, A. Hashima, T. Terakawa, K. Fukui, T. Yanagisawa, Y. Ikeda, G. Kimura, and M. Matsu'ura, Development of 3-D basement structure in Taiwan deduced from past plate motion: Consistency with the present seismicity, Tectonics, 2007 (in press).

[5] Nakajima, K., The Impact of Parallel Programming Models on the Linear Algebra Performance for Finite Element Simulations, Lecture Notes in Computer Science 4395, 334-348, 2007 (in press).

[6] Nakajima, K., Parallel Preconditioning Methods with Selective Fill-Ins and Selective Overlapping for Ill-Conditioned Problems in Finite-Element Methods, Lecture Notes in Computer Science 4489, 1085-1092, 2007 (in press).

[7] Furumura, T, T. Hayakawa, M. Nakamura, K. Koketsu, and T. Baba, Development of long-period ground motions from earthquakes within the Nankai Trough, Japan: Observations and computer simulation of the 1944 Tonankai (Mw8.1) and 2004 SE Off-Kii Peninsula (Mw7.4) earthquakes, Pure and Applied Geophysics, 2007 (in press).

[8] Furumura, T. and T. Hayakawa, Anomalous propagation of long-period ground motions recorded in Tokyo during the 23 October 2004 Niitgata-ken Chuetsu (Mw6.6) earthquake, Japan, Bull. Seism. Soc. Am., 97, 2007 (in press).

[9] Hori, M., T. Ichimura, H. Nakamura, A. Wakai, T. Ebisawa, and N. Yamaguchi, Integrated Earthquake Simulator for Seismic Response Analysis of Structure Set in City, Structural Eng./Earthquake Eng., Vol.23, No.2, 297-306, DOI: 10.2208/jsceseee.23.297s, 2006.

[10] Hori, M., T. Ichimura, and K. Oguni, Development of Integrated Earthquake Simulation for Estimation of Strong Ground Motion, Structural Responses and Human Actions in Urban Areas, Asian Journal of Civil Engineering (Building and Housing), Vol.7, No.4, 381-392, 2006.

[11] Ichimura, T. and M. Hori, Macro-Micro Analysis Method for Wave Propagation in Stochastic Media, Earthquake Engineering & Structural Dynamics, Vol.35, 419-432, DOI: 10.1002/eqe.533, 2006.

[12] Ichimura, T. and M. Hori, Strong Ground Motion Prediction using Macro-Micro Analysis Method, Earthquake Engineering & Structural Dynamics, Vol.35, 395-417, DOI: 10.1002/eqe.532, 2006.

[13] Ozawa, S. et al., Spatiotemporal evolution of aseismic interplate slip between 1996 and 1998 and between 2002 and 2004, in Bungo channel, southwest Japan, J. Geophys. Res., 2007 (in press).

[14] Matsu'ura, M., C. Hashimoto, A. Noda, K. Nakajima, E. Fukuyama, T. Sagiya, and T. Sato, Development of a predictive simulation system for crustal activities in and around Japan - III, Annual Report of the Earth Simulator Center, April 2005-March 2006, 113-116, 2006.

（4－2） **Patent Application**

① Cumulative Number

1) Patent Applications in the fiscal year 2006 (Domestic- 0 Cases, Oversea- 0 Cases)

2) Cumulative number of Patent Applications for the research period of CREST (Domestic- 0 Cases, Oversea- 0 Cases)