Advanced Disaster Simulation Researches on Earthquakes and Tsunamis using High Performance Computing System ‘Kei’ Part2

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Using ‘Kei’ computer, we are performing the advanced simulation for Disaster mitigation by Earthquakes and Tsunamis. In this simulation research project, we have three part of research fields such as Earthquake simulation research field, Tsunami research filed and Damage estimation research field. In Earthquake simulation research field, we are developing the scenario simulations of earthquake recurrences on the subducting plate around Japan. We are simulating seismic waves based on the scenarios, and the underground structures using seismographs from networks. The second simulation research field on Tsunami hazard, we are developing applications for the simulating tsunami damages at East Japan earthquake 2011. In this research field, not only damage simulations, we are developing the early tsunami detection system using simulation and real time data. Finally, we will applied these research results to the Nankai trough seismogenic zone and etc. The third simulation research field on Damage estimation in cities is the civil engineering research as the adavanced civil engineering structural analyses, seismic response analyses on large scale cities, and advanced agent simulation for more precise and practical evacuations. Finally, in this project, we will integrate these simulation research results in each field as the Earthquake simulator for disaster mitigation. We will present advanced results in each field and propose the new concept of Post Kei project.
‘Kei’ computer is one of the highest computing system in the world. Using ‘Kei’ computer, we are performing the advanced simulation for disaster mitigation by earthquakes and tsunamis in a project ‘Study for Advancement of Prediction Accuracy on Earthquake and Tsunami’. In this research project, we have three research fields as Earthquake simulation research field, Tsunami research filed and Damage estimation research field.
In Earthquake simulation research field, we are developing the scenario simulations of earthquake recurrences on the subduct- ing plate around Japan. As other earthquake simulation researches, we are simulating seismic waves based on the scenarios, and the underground structures using seismographs.
The second research simulation research field on Tsunami hazard, we are developing applications for the simulating tsunami damages at East Japan earthquake 2011. In this research field, not only damage simulations, but also we are developing the early tsunami detection system using simulation and real time data. Finally, we will apply it to the Nankai trough seismogenic zone and etc.
The third research field is the civil engineering research as the adavanced civil engineering structural analyses, seismic re- sponse analyses on large scale cities, and agent simulation for more precise and practical evacuations.
Finally, we will integrate these research fields in this project for the seismic simulator on disaster mitigation.

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Application of High Performance Computing to Earthquake Hazard and Disaster Simulation

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The utilization of high performance computing (HPC) is a key issue for more rational prediction of earthquake hazard and disaster. In principle, all physical processes of the seismic wave propagation and the resulting structural seismic responses are described in terms of sold wave equations, and it is a solution to numerically solve the equations using an analysis model of high fidelity. High performance computing solves uncertainty of material properties that appear in the solid wave equations by considering a suitable stochastic distribution and using ensemble computing.
This presentation explains recent achievement of applying HPC to earthquake hazard and disaster simulation. Explained are two targets, namely, the seismic structural response of an important structure and the urban earthquake disaster simulation. K computer, the supercomputer in Japan, is used to solve the wave equations of these two targets.
As for the seismic structural response analysis, the numerical treatment of non-linear material properties that include the occurrence and propagation of multiple-cracks is a bottleneck of applying HPC. A new discretization scheme is developed for crack which is discontinuity of displacement function. General purpose numerical analysis methods are being developed which are applicable to structures.
Urban disaster simulation is a challenge for HPC, because an analysis model is an urban area of a few kilometer dimension, which requires large-scale computation and automated model construction. In particular, a fast solver is implemented into a finite element method to solve the wave equation for a model of 100,000,000,000 degree-of-freedom, and a robust and flexible system is developed so that various digital data of an urban area are converted to a set of analysis models.

Keywords: high performance computing, earthquake hazard, earthquake disaster

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Multi-scale simulation of damaged transport systems: prospects and tasks of the development

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This presentation proposes an outline of the multi-scale simulation of damaged transport systems and discusses its prospects and tasks of the development. Damages on buildings and infrastructure by a major disaster will influence both performances and demand patterns of transport systems in a damaged area. The combination of degraded performances and a demand pattern that is significantly different from a normal demand can cause severe congestion, creating a major impact on the social systems of a damaged area. The multi-scale simulation of damaged transport systems aims to reproduce such situations using a traffic flow simulator and a transport demand model for a disaster situation combined with an estimated physical damages on buildings and infrastructure. Two issues should be mentioned to develop the simulation system. First, in a major disaster, an affected area should be substantially large and hence the scale of the problem (i.e. the number of links of a network and agents moving in it) must be very large. Second, the demand pattern after a disaster should be completely different from that of normal days and cannot be precisely estimated beforehand, implying that a huge number of demand patterns needs to be evaluated in the simulation. These two issues certainly arise computation burden that is very huge compared to typical problems that have been dealt with in past transport studies. The high-performance computing is useful to overcome these issues. In this presentation, the following technical topics will be introduced with a few tentative result: (1) How a traffic flow simulator is to be parallelised, (2) How travellers' behaviour in a post-disaster network can be mathematically modelled, (3) How numerous patterns of the demands are to be sampled so that practically important cases are effectively evaluated.

Keywords: Traffic simulator

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Simultaneous Estimation of Fault Slip and Asthenosphere Viscosity Using Large Scale Finite Element Simulation of Postseismic Deformation

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In the field of geodetic inversion, estimation of the coseismic/postseismic slip using postseismic deformation observation data is an important topic. Such estimation is expected to be improved by an inverse analysis method using numerical simulation (e.g. finite element (FE) method) of viscoelastic deformation, whose model is of high-fidelity to the available high-resolution crustal data. The authors had been developing a large-scale simulation method using such FE high-fidelity models (HFM), assuming use of a large scale computation environment such as the K computer in Japan. In this study, we developed an inverse analysis method incorporating HFM, in which fault slip and asthenosphere viscosity are estimated simultaneously, since the value of viscosity in the simulation is not trivial.We carried out numerical experiments using synthetic crustal deformation data. We constructed an HFM in the domain of 2048x1536x850 km, which includes the Tohoku region in northeast Japan based on Ichimura et al. (2013). We used the model geometry data set of JTOPO30 (2003), Koketsu et al. (2008) and CAMP standard model (Hashimoto et al. 2004). The HFM is currently in 2km resolution, resulting in 1.4 billion degrees-of-freedom. Coseimic slip based on Suzuki et al. (2011) and afterslips originally set by the authors based on Yamagiwa et al. (2014) were used as the inputted fault slips. Synthetic crustal deformation data of one and a half years after an earthquake in the location of GEONET, GPS/A observation points, and S-net were used. Inverse analysis was formulated as minimization of L2 norm of the difference between the FE simulation results and the observation data with respect to viscosity and fault slip, combining the quasi-Newton algorithm with the adjoint method. Use of this combination decreases the necessary number of forward analyses in the optimization calculation. As a result, we are now able to finish the estimation using 1/20 of entire resource of the K computer for 10 hours and a few. In the future, we would like to apply the method to the actual data.

Keywords: finite element method, adjoint method, inverse analysis, crustal deformation, viscosity estimation, fault slip estimation

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Parallel implementation of the particle simulation method with dynamic load balancing: Toward large scale simulation of geophysical system of mutiphase flow

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Fully Lagrangian methods such as Smoothed Particle Hydrodynamics (SPH) and Discrete Element Method (DEM) have been widely used to solve the continuum and particles motions in the computational geodynamics field. These mesh-free methods are suitable for the problems with the complex geometry and boundary. Moreover, their Lagrangian nature allows non-diffusive advection useful for tracking history dependent properties (e.g. chemical evolution) of the material. These potential advantages over the mesh-based methods offer effective numerical applications to the geophysical flow and tectonic processes, which are for example, tsunami with free surface and entrainment of sand, magma intrusion within a fracture of rock with crystals, and shear zone pattern generation of granular deformation.
In order to investigate such geodynamical problems with the particle based methods, over millions to billion particles are required for the realistic simulation. Parallel computing is therefore important for handling their huge computational cost. An efficient parallel implementation of SPH and DEM methods is however known to be difficult especially for the distributed-memory architecture. Lagrangian methods inherently have workload imbalance problem for parallelization with the fixed domain in space, because particles move around and change workloads during the simulation run. Therefore, dynamic load balance is key technique to perform the large scale SPH or DEM simulation.
In this presentation, we introduce the parallel implementation technique of SPH and DEM method utilizing dynamic load balancing algorithms toward the high resolution simulation over large domain using the massively parallel super computer system. Our method utilizes the imbalances of the executed time of each MPI process as the nonlinear term of parallel domain decomposition and minimizes them with the Newton like iteration. In order to perform flexible domain decomposition in space, the slice-grid algorithm is used. Numerical tests show that our approach is suitable for solving the particles with different calculation costs (e.g. boundary particles) as well as the heterogeneous computer architecture. We analyze the parallel efficiency and scalability on the super computer systems (K-computer, Earth simulator 3, etc.).

Keywords: SPH, DEM, dynamic load balancing

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Failure Mechanism of Breakwaters at Kamaishi Bay by using K computer

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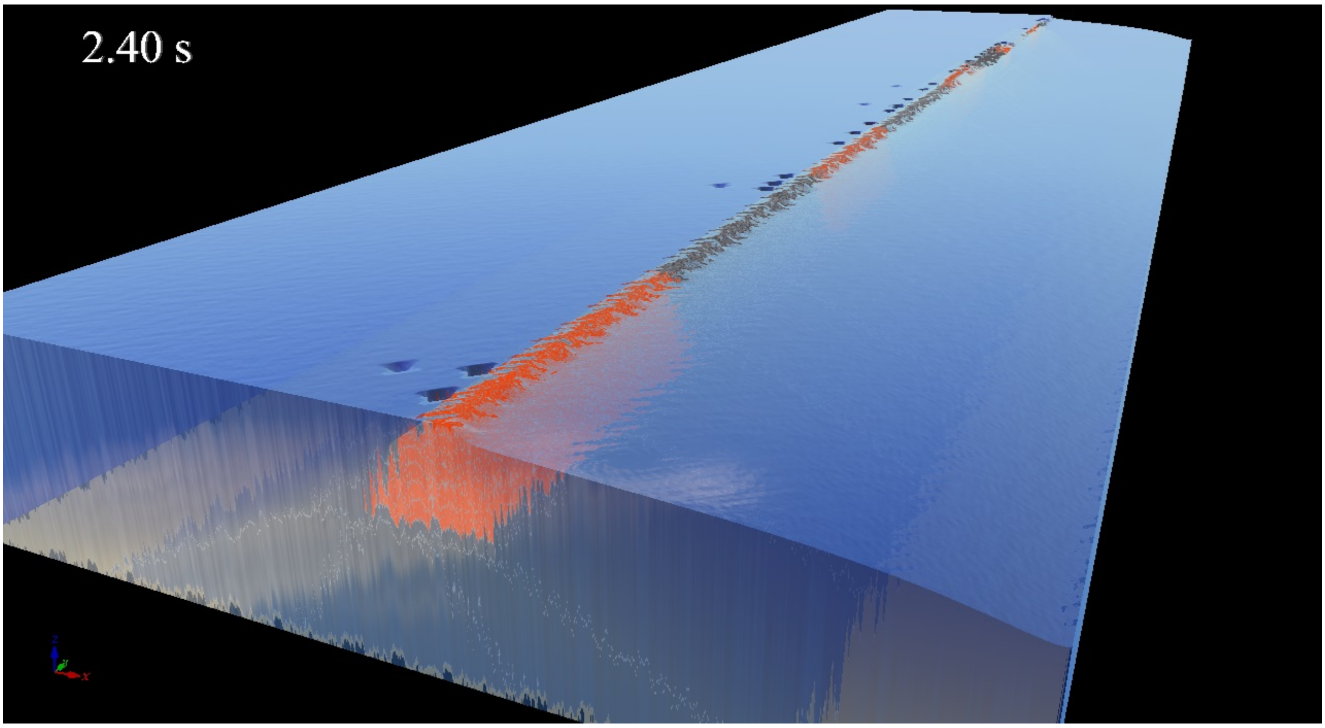
A lot of breakwaters were damaged by the 2011 off the Pacific coast of Tohoku Earthquake Tsunami that had been caused on March 11, 2011. Because a lot of tsunami exceeded the crown of the breakwater, there were a lot of cases where a breakwater was damaged when the tsunami overflowed it. The stability in the breakwater under the tsunami overflow has not been researched up to now, and the mechanism is not clear. The Kamaishi bay mouth breakwaters were presumed to have been destroyed when the tsunami overflowed from the physical experimental analysis.In the present study, the tsunami situation around the Kamaishi breakwaters was calculated by K computer based on STOC-CADMAS system, which is the Multi scale simulator, and verify the failure mechanism of breakwaters by using CADMAS-STR system, which is the coupling system with the structure analysis.

Keywords: Tsunami, K computer, Breakwater, Kamaishi Bay, Failure Mechanism



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