地震津波の防災減災のための京コンピュータを用いたシミュレーション研究（その２）

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.

高性能計算を使った地震災害・被害シミュレーション

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.

キーワード：高性能計算、地震災害、地震被害
Keywords: high performance computing, earthquake hazard, earthquake disaster

交通障害マルチスケールシミュレーション：開発の展望と課題

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.

キーワード：交通シミュレーション
Keywords: Traffic simulator

余効変動の大規模有限要素シミュレーションを用いた断層すべり量とアセノフェア粘性率同時推定手法の開発

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

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地殻変動データを用いた地震時・余効すべりの推定は，測地逆解析上重要な研究課題である．このような逆解析は，入手可能な高分解能プレート形状データと同分解能の有限要素モデルを用いた，粘弾性変形の有限要素シミュレーションを適用することで高度化することができると考えられる．著者らは，京コンピュータなどの大規模計算機環境上で，このような高分解能有限要素モデル（以下高詳細モデル）を用いた大規模シミュレーションを行うための手法を開発してきた．本研究では，シミュレーションに必要なアセノスフェアの粘性率の設定が自明でないことを踏まえ，高詳細モデルを用いた，粘性率と断層すべり量の同時推定手法を開発した．現在は人工観測データを用いた数値実験により開発した手法の有効性を検証している段階である．Ichimura et al. (2013)の手法に基づき，東北地方および東北地方太平洋沖地震震源域を含む2048x1536x850 kmの領域に高詳細モデルを生成した．プレート形状データとしては，JTOPO30 (2003)，Koketsu et al. (2008)，CAMPモデル(Hashimoto et al. 2004)を用いた．高詳細モデルは現在のところプレート形状分解能2kmで生成され，モデルの自由度は14億程度となっている．入力する断層すべりとして，Suzuki et al. (2011)を基にした地震時すべりと，Yamagiwa et al. (2014)を参考に便宜的に設定した余効すべりを用いた．地震発生から1.5年間の人工観測データをGEONET，GPS/A観測点， S-netの設置地点において生成した．逆解析は有限要素解と観測データの差の二乗和からなる評価関数を，粘性率と断層すべり量について最小化することにより行った．これは非線形最適化問題となるため，準ニュートン法とアジョイント法を組み合わせることにより少ない順解析数で最適化計算を行えるようにした．結果的に，京コンピュータの計算機の1/20を十数時間占有する程度の計算資源で，最適解を得られるようになっている．現在の数値実験設定においては，良好な推定結果を得ている．将来的には本手法の実観測データ解析や，観測点位置の評価などへの適用を考えている．

キーワード：有限要素法、アジョイント法、逆解析、地殻変動、粘性率推定、断層すべり推定
Keywords: finite element method, adjoint method, inverse analysis, crustal deformation, viscosity estimation, fault slip estimation

粒子法計算における動的負荷分散技術の開発：津波等の混相流問題の大規模計算にむけて
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.).

キーワード：粒子法、動的負荷分散、津波
Keywords: SPH, DEM, dynamic load balancing

京コンピュータを用いた釜石の湾口防波堤の被災メカニズムの検討

Failure Mechanism of Breakwaters at Kamaishi Bay by using K computer

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2011年3月11日に生じた東北地方太平洋沖地震津波によって多くの防波堤が被災した．被災形態は様々あるが，今次津波は，その多くが防波堤の天端を超えていたため，津波が越流した際に被災した事例が多かったのではないかと考えられている．釜石湾口防波堤は，今次津波により半分以上の防波堤が被災を受けたが，水理実験などから越流後に破壊されたと推定される．そこで，本研究では，波源域から遡上域までを階層的に解くことのできるSTOC-CADMASシステムを用いた、京コンピュータによる釜石の湾口防波堤の被災時の状況再現を行い、また、構造物との連成計算システムである、CADMAS-STRによって、その被災メカニズムの検討を行うものである。

キーワード：津波、京コンピュータ、防波堤、釜石湾、被災メカニズム
Keywords: Tsunami, K computer, Breakwater, Kamaishi Bay, Failure Mechanism