SEISMIC RESPONSE ANALYSIS OF BILLION DEGREE-OF-FREEDOM FAULT-URBAN AREA MODEL ON PARALLEL MULTICORE COMPUTING ENVIRONMENT

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1. INTRODUCTION

For estimating possible response of buildings in an urban area due to ground motion caused by nearby faults, three-dimensional (3D) numerical analysis is one viable option. However, such analysis from fault to building site is computationally expensive due to geologic and engineering length scale processes that require varying spatial resolutions. In this study, we aim to develop efficient simulation tools that combine source (fault) modeling, seismic wave propagation on geologic structures, local site response, and building structure analysis. A key component in this study is the implementation of parallel computing to utilize available multicore computing environments.

2. METHODOLOGY

2.1 Background

For the target problem, we used the finite element method (FEM) to discretize the spatial domains used in wave propagation analysis. For time integration, implicit Newmark-β (β=1/4) method is used. The working equation for the wave propagation solver is given as:

$$\left(\mathbf{K}+\frac{2}{\Delta t}\mathbf{C}+\frac{4}{\Delta t^2}\mathbf{M}\right)\mathbf{u}^{n+1}=\left(\frac{2}{\Delta t}\mathbf{C}+\frac{4}{\Delta t^2}\mathbf{M}\right)\mathbf{u}^{n}+\left(\mathbf{C}+\frac{4}{\Delta t}\mathbf{M}\right)\mathbf{v}^{n}+\mathbf{M}\mathbf{a}^{n}+\mathbf{f}^{n+1} \quad . \quad (1)$$

In the above equation, **K**, **C**, **M** are matrices for stiffness, element damping, and mass, and **u**, **v**, **a**, and **f** are vectors for displacement, velocity, acceleration, and force, respectively. Δt is the time increment and n is the time step. Mesh generation uses tetrahedral and hexahedral elements following the method of Ichimura et al. (2009). Equation (1) is solved by preconditioned conjugate gradient method. Matrix-vector product operation is performed by looping through elements. In the sides and bottom boundaries of the model, viscous absorbing boundary condition is used.

2.2 Implementation of parallel computing

We implemented hybrid parallelization to the wave propagation simulation tool to use parallel multicore computing environment. The 3D domain is partitioned along the horizontal axes (2D domain decomposition). In solving Eq. (1), OpenMP is used to parallelize matrix-vector product operation within each subdomain. Then MPI is used to communicate between subdomains to update the vectors along the partitioning boundary (Quinay et al., 2013).

3. NUMERICAL EXAMPLE

3.1 Performance efficiency test on K computer

In order to test the efficiency of the wave propagation solver, we performed scalability tests using several cases with varying problem size and number of processors used. The model was set with horizontal surface and interface (load balanced subdomains). Table 1 shows sample results of weak scaling tests on matrix vector operation (the most computationally-expensive part of the solver) considering two cases with different number of OpenMP threads and compute nodes of K computer. As shown, good efficiency was achieved for billion DOF problems.

3.2 Scenario earthquake simulation and building response analysis

We conducted a seismic analysis from fault to urban area to test the applicability of the simulation tool to handle realistic problem settings. The fault model is the Kushigata-Sanmyaku Fault Zone (M_w 6.4) and the target urban area is the region around JR Niigata station. The simulation domain has dimensions of 54 km and 46.8 km in E-W and N-S directions, and 45 km in depth. The underground data and fault model data were obtained from Japan Seismic Hazard Information Station (J-SHIS). For the wave propagation analysis, the target maximum frequency is 2.5 Hz. Based from a numerical verification test, we used 12 elements to discretize one shear wavelength. The minimum element size 15 m and time increment is 0.01 second. The total DOF is approximately 4.6 billion. We used 3,120 compute nodes of K computer (24,960 cores). Figure 1 shows the computed ground motions for points close to the fault and target urban area.

We generated the virtual model of a part of Niigata City using the Integrated Earthquake Simulator, or IES (Hori and Ichimura, 2008) based on available GIS data. We selected a 896 m x 896 m region around the target area to refine the computed ground motions up to 3.5 m resolution. The refined solutions at the surface are then used as base input excitations to the present building structures. Using IES, building models in the target area were simultaneously analyzed. Figure 2 shows a sample snapshot of the building responses in the target area using MDOF analysis module of IES.

Keywords: fault-urban area model, ground motion simulation, parallel computing
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4. CONCLUSIONS

In this study we conducted a fault-urban area seismic response analysis. This analysis combines source modeling, seismic wave propagation, local site response, and building seismic response. To achieve high spatial resolution modeling of the ground motion, we used FEM and implemented parallel computing to the developed simulation tool. For future works, validations of crust and local soil models will be conducted. We will also focus on improving load balancing and memory usage for application to more complicated models and larger simulation domains.

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ACKNOWLEDGEMENT: We used the computing resources of K computer in RIKEN Advanced Institute for Computational Science in Kobe, Japan.

Table 1: Results of weak-scaling test on K computer for two cases

Case	Number of OMP threads	Total no. of DOF: Model 1 (in billions)	Total no. of DOF: Model 2 (in billions)	Set DOF in one subdomain (in million)	No. of K nodes used in Model 1	No. of K nodes used in Model 2	Computed weak-scaling efficiency (%)
1	4	0.463	1.853	7.24	64	256	99
2	8	0.476	1.905	1.86	256	1024	95

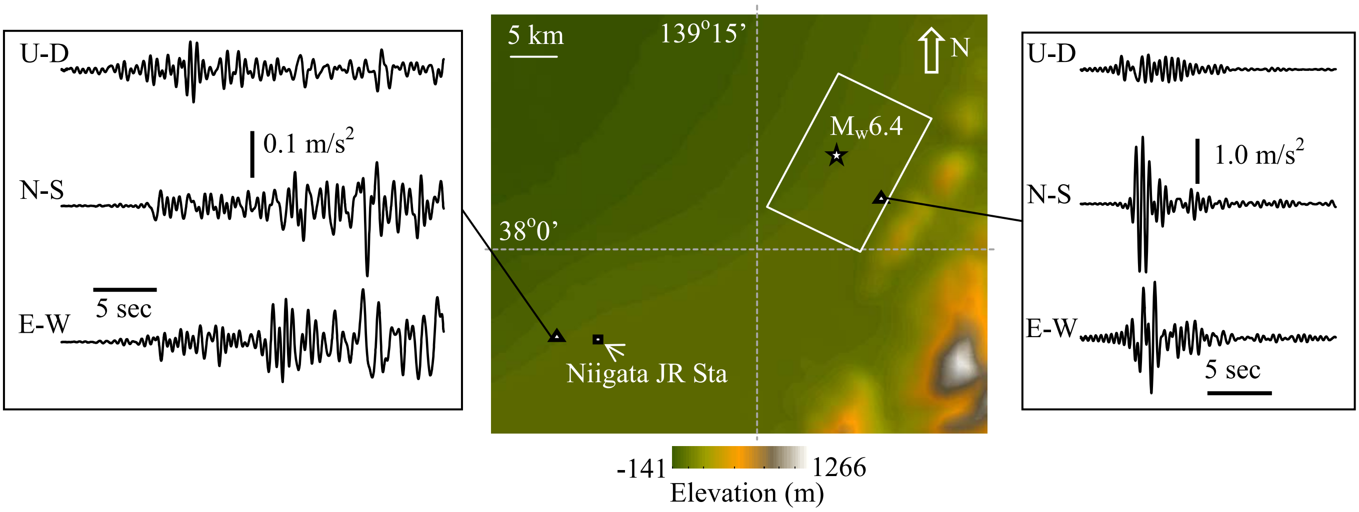

Fig. 1 Computed ground motions of scenario earthquake

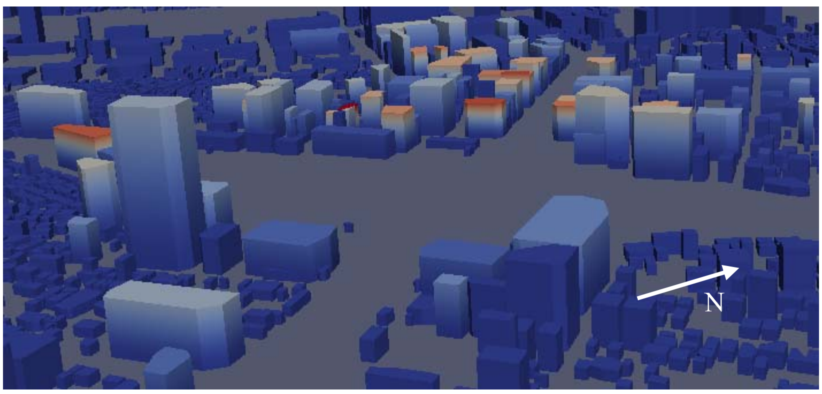

Fig. 2 Sample visualization of response of the analyzed building models in the target area using IES.