On large-scale numerical simulation of earthquake generation, wave propagation and soil amplification aiming for comprehensive earthquake damage estimation

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The operation of the supercomputer "Fugaku" has started in FY2020. The Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) has established “Program for Promoting Researches on the Supercomputer Fugaku” (FY2020-2022). "Large-scale numerical simulation of earthquake generation, wave propagation and soil amplification," which the authors have applied for the project, has been adopted as one of the subjects. In this task, we have been developing finite element (FE) analysis methods targeting earthquake generation, wave propagation and soil amplification, which can make the most of the computational performance of “Fugaku”. “E-wave FEM” and “STRIKE” are programs for seismic wave propagation and soil amplification analysis that combine an implicit time integration scheme, unstructured tetrahedral quadratic elements, and an iterative solver using a high-performance preconditioner. By using these applications, seismic wave propagation and soil amplification analysis in complex ground can be performed accurately, stably, and rapidly.

In this project, we aim to lay a foundation for using numerical simulations with computational applications that utilize high-performance computation in policy making and practice uses. First, there is a need for more sophisticated methods in the evaluation of long-period ground motions in the national damage estimation. E-wave FEM, which meets this need, has been included in the committee's investigation for application to the national damage estimation. This project aims for ensuring the accuracy of the method based on calculations that can only be done at “Fugaku”, and then to actually use the method in the national damage estimation. Using “Fugaku”, we improved the program by using the most advanced technology of computational science and computer science to bring out the performance of “Fugaku” in the FE analyses (Ichimura et al., SC20, 2020). In addition, by comparing the numerical solutions of E-wave FEM and a finite difference method conventionally used in the national damage estimation through benchmark tests, we summarized the merits of adopting E-wave FEM as a tool for damage estimation. Then, preparations are made for the implementation of seismic wave propagation analysis using E-wave FEM in the national damage estimation. We also developed a platform for constructions and civil engineering companies to use a system that can perform calculations equivalent to those applied in the government. In order to provide the tools that is easy to use, we developed a computing environment, including manuals, pre-post processing computers, and tools. In addition, tutorials on calculations using E-wave FEM were held for companies participating in this project. We have already received feedback on the functions implemented in the tool set, and we will improve the environment based on the feedback. As for STRIKE, we are preparing for conducting soil amplification analyses at “Fugaku” based on the needs of each company, aiming for application to more practically relevant problems.

In this project, we have developed a large-scale simulation program for elastic and viscoelastic crustal deformation, E-cycle FEM, using a FE analysis solver that is essentially the same as E-wave FEM. Main applications of this program is to estimate the initial water level of tsunamis and the spatio-temporal evolution of fault slips in the Nankai Trough. In this project we mainly target to obtaining reference

solutions based on elastic and viscoelastic crustal deformation calculations that can only be done at Fugaku, such as those in 3D heterogeneous structures in a large area or very detailed structures in a limited area. Such a reference solution will be important for creating Green's functions with high accuracy, which can be provided to those applications mentioned above.

Keywords: High-performance computing, Finite element method, Supercomputer "Fugaku", Seismic wave propagation analysis, Nonlinear soil amplification, Crustal deformation

