Large-scale finite element simulation of earthquake ground motion and its numerical verification aiming for enhanced earthquake damage estimation

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Estimation of long-period ground motions caused by a giant subduction-zone earthquake that is likely to occur in the future is important for promoting earthquake disaster countermeasures in urban areas. For this purpose, it is necessary to carry out numerical simulations of seismic wave propagation in a complex underground structure for an appropriate source fault model. Earthquake ground motion has been estimated by using the finite difference method (FDM) in the damage estimations conducted by the government (e.g. Cabinet Office, 2015). On the other hand, detailed databases of underground seismic velocity structures have been developed (Koketsu et al. 2012). In performing numerical simulations that reflect complex topography and seismic velocity structures based on these databases, the advantage of the finite element method (FEM) using unstructured elements over structured-grid-based methods such as FDM has been pointed out (Ichimura et al. 2007). FEM is also superior in handling various source fault models flexibly. A barrier for introducing FEM in the ground motion prediction was the associated high computational cost. FDM calculation is based on a structured grid, which is highly efficient in memory access. By contrast, FEM generally incorporates unstructured elements, with which the memory access becomes less efficient and it is difficult to solve large-scale problems with a practically enough speed. It has also been known that the calculation cost for constructing the computation mesh using unstructured elements possibly becomes a bottleneck rather than the calculation of the ground motion itself. However, recent developments in the field of high-performance computing have enabled us to perform both constructions of unstructured mesh and calculations of earthquake ground motion in enough short time even for very large-scale problems of the order of 10^{10}-10^{11} degrees of freedom using a world-class supercomputer (e.g. Ichimura et al. 2018). Therefore, we expect that it will be possible to conduct a more accurate prediction of earthquake ground motion in a wider range of problems by replacing FDM with FEM in the damage estimation by the government. Aiming for such a goal, we here carry out numerical verifications of the calculation of earthquake ground motion based on FEM, comparing the results with those obtained by using FDM that has been conventionally used for damage estimation by the government.

We first considered the earthquake motion in a stratified layer model due to a point source for benchmarking, which has a quasi-analytical solution and is known to be accurately handled by FDM. The problem setting was the same as one of the benchmark tests for strong motion prediction by Yoshimura et al. (2012). We obtained the results that are in good agreement with the semi-analytical solutions and FDM codes that are used in national research laboratories and construction companies. At present, we are further considering problem settings that demonstrate the advantages of FEM, such as the so-called “Moon-basin” problem (Sánchez-Sesma and Luzón 1995), in which a soft sedimentary layer is installed in the basin structure. In the conference, we will discuss the convergence of the numerical solution calculated by using FEM, while comparing it with FDM calculations.

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