Comparison of E-wave FEM and GMS in Calculation of Long-Period Ground Motion in 3D Heterogeneous Underground Structures

*Ryoichiro Agata[1], Yoshihisa Hiyoshi[1], Sayako Hirobe[1], Takahiro Maeda[2], Asako Iwaki[2], Kohei Fujita[3,4], Hiroyuki Fujiwara[2], Tsuyoshi Ichimura[3,4,5], Takane Hori[1]

1. Japan Agency for Marine-Earth Science and Technology, 2. National Research Institute for Earth Science and Disaster Resilience, 3. Earthquake Research Institute, 4. Riken Center for Computational Science, 5. Riken Center for Advance Intelligence Project

Estimation of long-period seismic motions and strong ground motions caused by large subduction zone earthquakes, which are anticipated to occur in the future, is important for advancing measures for earthquake damage in urban areas. For this purpose, it is necessary to calculate seismic ground motions in complex subsurface structures for appropriately set source fault models using numerical methods such as the finite difference method (FDM) and the finite element method (FEM). The advantage of using FDM in such calculations is that discretization using structural grids makes it relatively easy to generate a computational model, to decompose the model domain for parallel computation, and to achieve high computation performance due to efficient memory access. GMS (Aoi & Fujiwara 1999, Aoi & Fujiwara 1998, Aoi et al. 2004), a 3D FDM calculation program using a discontinuous grid, has been packaged and is widely used. Since FEM can handle computation models with unstructured elements, it is suitable for handling complex topography, seismic wave velocity structure, and various source fault models flexibly in seismic ground motion analyses. In combination with an implicit time integration scheme, it is easy to achieve more stable numerical calculations. On the other hand, it has been considered difficult to solve large-scale problems at high speed because of the inefficient memory access when dealing with unstructured elements, and the necessity of solving a large linear equation at every time step when using an implicit time integration scheme. On the other hand, recent development in the field of high-performance computing has led to the development of E-wave FEM (e.g., Ichimura et al. 2014), an implicit FEM simulation program that overcomes the above problems. Seismic ground motion analyses using supercomputers can be performed rapidly for large-scale problems of 10^{10} degrees of freedom or larger. Preparations are now underway to apply E-wave FEM to damage estimations conducted by the government (Agata et al., JpGU-AGU Joint Meeting, 2020). Although comparisons between FEM and FDM in seismic ground motion analyses have been performed already (e.g., Yoshimura et al. 2011, 2012, 2013), it is important to clarify how to use E-wave FEM and widely-used FDM programs such as GMS properly in damage estimations in national agencies, summarizing the differences in the basic features, calculation accuracy, calculation cost, and so on. In this study, long-period earthquake ground motions in 3D heterogeneous velocity structures are calculated using E-wave FEM and GMS, and the results and computational costs are compared and discussed.

We simulated the earthquake near Awaji Island (Mj 6.3) that occurred on April 13, 2013 by using E-wave FEM. Targeting seismic ground motions up to 0.35 Hz, we set up a 3D heterogeneous velocity structure without topography consisting of 33 layers with uniform seismic wave velocity in the region of 900 km, 748 km, and 50 km in the east-west, north-south, and vertical direction, respectively, based on J-SHIS database of NIED. The computational models for the velocity structure were constructed to satisfy the discretization conditions usually used in each program, i.e., at least five elements for E-wave FEM per wavelength for S-wave velocity, respectively. Seismic ground motions for 60 seconds were calculated with a time step size of 0.01 seconds. The resources required to obtain the numerical solution were about 22 minutes using 128 computation nodes of the Oakforest-PACS at The University of Tokyo for the E-wave

FEM. In the conference, we will compare the results and those obtained by using GMS and also show the results of the numerical solution by changing the mesh size, grid size and other settings. In addition, calculations for a larger target domain will be also discussed.

Keywords: High-performance computing, Seismic ground motion analysis, Finite element method, Finite difference method, Long-period ground motion

