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Verification and Validation of 3D Nonlinear Physics-based Ground Motion Simulations: Phase II

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Introduction

Significant advances in physics-based earthquake ground motion simulations have allowed us to move towards higher frequencies and finer resolution scales. Some of the most prominent features that higher resolution models are called to account for are the inelastic behavior of geomaterials in the shallow crust, which include hysteresis and permanent or transient ground deformation. These effects span a wide range of scales, affect the amplitude and duration of ground motions over a broad range of frequencies, and are highlighted among the research priorities of SCEC5. This work was the first phase of a verification and validation exercise of prominent ground motion codes developed and optimized for large-scale 3D nonlinear ground motion simulations. These initially included one finite element code (Hercules); one finite differences code (AWP) and a spectral element code (SPECFEM); and were successively limited to Hercules and OPENSEES. The Garner Valley Downhole Array has been identified as benchmark site for the validation exercises, in 1D and in future phases in 3D. Garner Valley was selected because of the wealth of published studies on site characterization and nonlinear properties, key elements of a successful long term validation study. Canonical problems in 3D, both small and large scale computational models, will bridge the reliability gap between idealized 1D models and 3D simulations at Garner Valley. In this report, we show results from comparisons between Hercules and Opensees in 3D canonical problems.

1 Model predictions in large scale simulations

To test the model performance in large scale simulations and quantitatively assess the effects of three dimensional scattering combined with soil nonlinearity on ground motions, we next performed such a simulation using an idealized shape basin with geometry and small-strain soil properties shown in Figure 1. The size of the computational domain is a box with width of 8192m and depth of 2048m. We consider three types of behavior for the basin: (i) elastic, (ii) inelastic with Von-Mises elastic-perfectly plastic model (J2 model); and (iii) inelastic basin with multi-axial bounding surface plasticity model (MCP model). The nonlinear dynamic soil properties assigned to the first and second layers of the basin are depicted in Figure 2. For consistency, we used the same undrained shear strength for both models.

We subjected the model to a vertically propagating SV wave with temporal variation shown in Figure 2. We performed all simulations on Blue Waters supercomputer using 3200 processors for each simulation. Table **??** shows the simulation runtime for each case. As shown, the increase in runtime compared to the elastic model is 1.15 times for the J2 model, and 2.15 times for the case of MCP. Figure 3 and Figure 4

Simulation runtime in an idealized shape basin. max width=

Model	Elastic	J2	MCP
Runtime [s]	1623.25	1864.59	3475.1

show the acceleration and displacement timeseries computed at stations A, B, C, and G shown in Figure 1. In all cases, we also run simulations in a soil column located at the considered stations. This allows us to examine the accuracy of the hybrid 3D-1D methods in computing ground motions taking site effects into account. We notice that the results of J2 model first follow the results of linear model. This is because the model first behaves linearly till it reaches the strain at which it becomes perfectly plastic. Then, in terms of acceleration we notice a decrease in amplitude and in terms of displacement we notice some residual displacement and oscillations around. On the other hand, the results of MCP model start deviating from the linear case even at small strains which is because of the introduced hardening behavior and the model's vanishing elastic region. Moreover, residual deformations tend to decrease by using the MCP model compared to the J2 model. Finally, comparing MCP 1D and MCP 3D results, we notice that the results start to deviate from each other as soon as the scattered waves due to reflection/refraction arrive the station of interest and therefore may under-predict both accelerations and displacements.

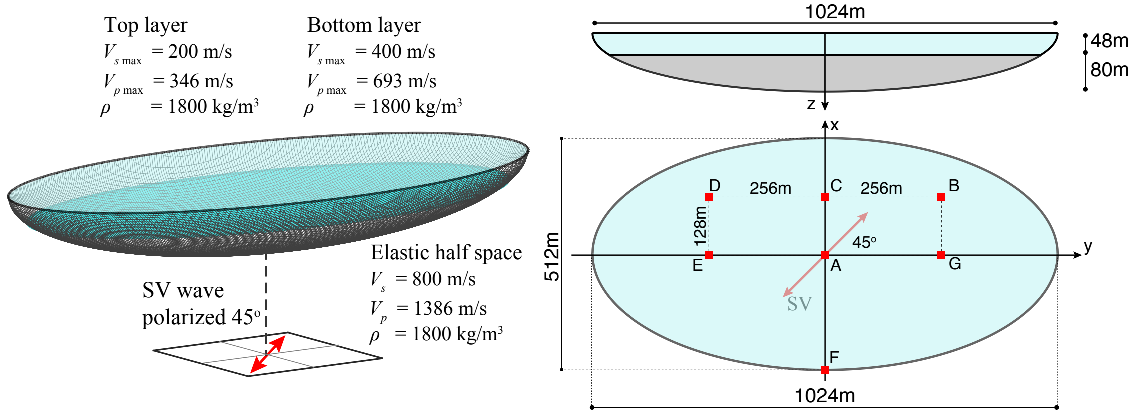


Figure 1: Basin geometry.

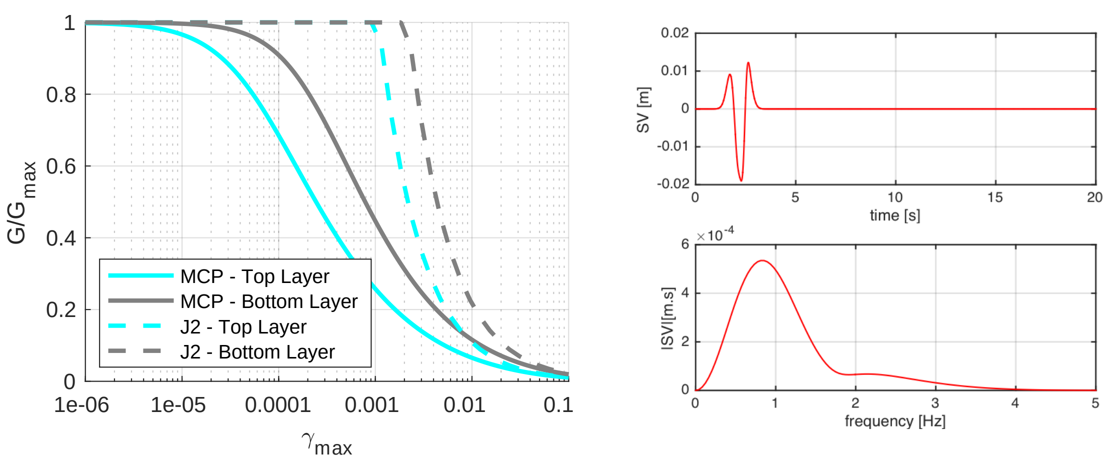
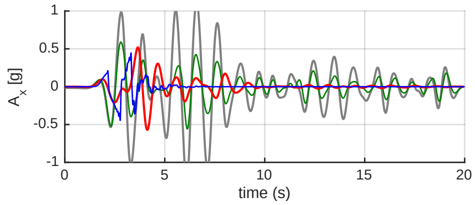
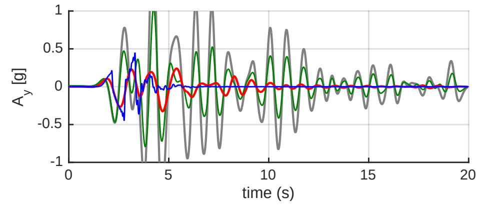


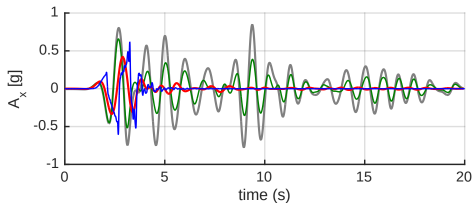
Figure 2: (Left) Modulus reduction curves; (Right) the temporal variation of the imposed SV wave.



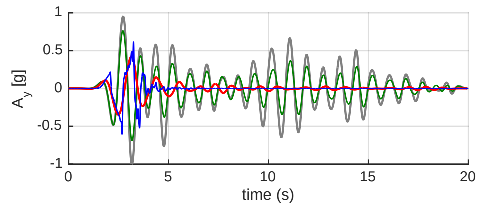
(a) X component at station A



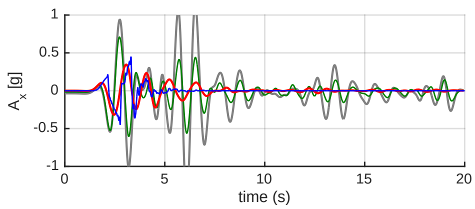
(b) Y component at station A



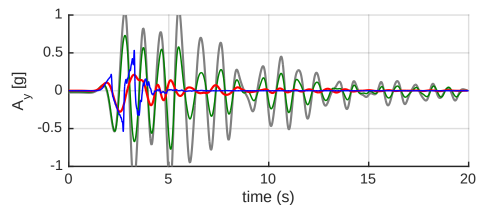
(c) X component at station B



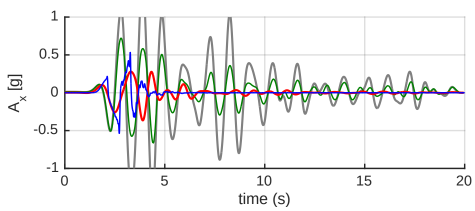
(d) Y component at station B



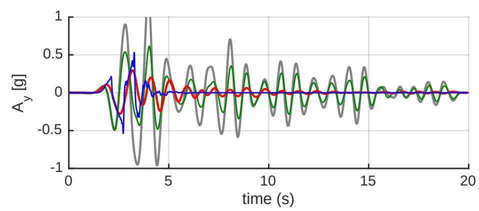
(e) X component at station C



(f) Y component at station C

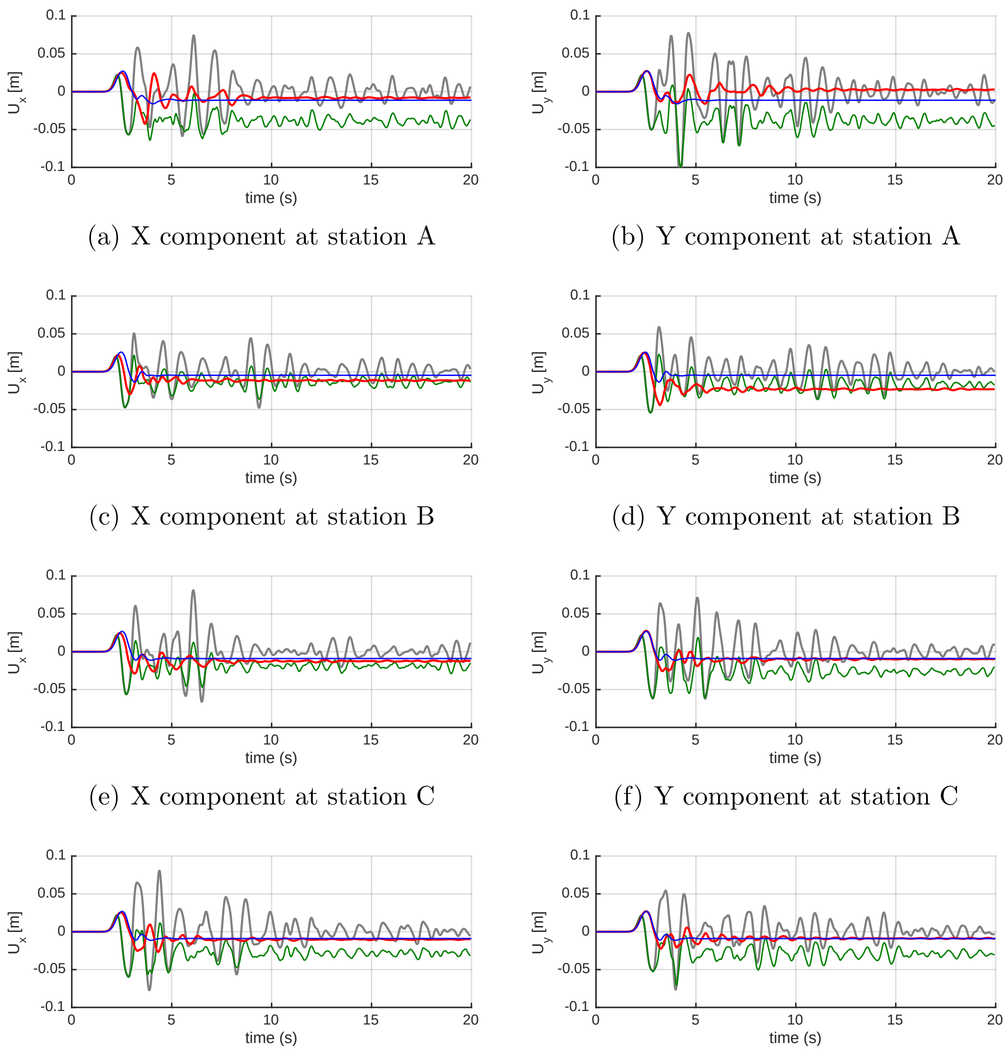


(g) X component at station G



(h) Y component at station G

Figure 3: Acceleration responses in the basin; (——) elastic-3D, (——) J2 model-3D, (——) MCP model-3D, (——) MCP-model-1D.



(a) X component at station A (b) Y component at station A

(c) X component at station B (d) Y component at station B

(e) X component at station C (f) Y component at station C

(g) X component at station G (h) Y component at station G

Figure 4: Displacement responses in the basin; (——) elastic-3D, (——) J2 model-3D, (——) MCP model-3D, (——) MCP-model-1D.