GROUND RESPONSE ANALYSIS IN CASE OF LINEAR SOIL

This document describes an example that has been used to verify that the ground response, in case of a linear elastic soil subjected to a seismic motion at its base, is calculated correctly in PLAXIS.

Used version:

- PLAXIS 2D - Version 2015.02
- PLAXIS 3D - Anniversary edition (AE.01)

Geometry: In this validation, dynamic analysis of a linear, drained soil subjected to seismic ground motion is performed. The applied ground motion at the base of the model constitutes the recorded outcrop strong motion at the USGS station 286 (founded on granitic rock), during the Imperial Valley earthquake (15/10/1979). As Figure 1 illustrates, the recorded peak acceleration equals 1.07 $m/s^2 \approx 0.11\ g$.

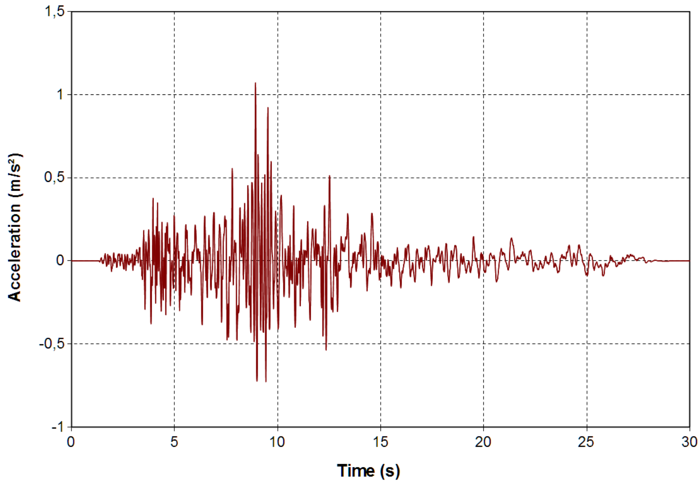

Figure 1 Outcrop strong motion recorded at the USGS station 286 during the Imperial Valley earthquake

In PLAXIS 2D the plane strain model is 50 m wide and 50 m deep and consists of 15-noded triangular elements. The input ground motion is applied horizontally at the base of the model which is assumed to be rigid. All vertical degrees of freedom in the model are restrained with vertically fixed *Line displacements*, placed with 2 m space interval. The PLAXIS 2D model is illustrated in Figure 2.

> **Hint:** In PLAXIS 2D, a ground response analysis can also be performed on a slender soil column using tied degrees of freedom at the vertical model boundaries. In this way the vertical fixities inside the model can be omitted.

In PLAXIS 3D the model is extended by 1 m in y-direction (plane strain conditions). *Surface displacements* are used to restrain all vertical degrees of freedom. Interfaces are used at both vertical boundaries (x_{min}, x_{max}) to enable the use of *Free field* dynamic boundary conditions (see further below). Figure 3 depicts the model geometry in PLAXIS 3D.

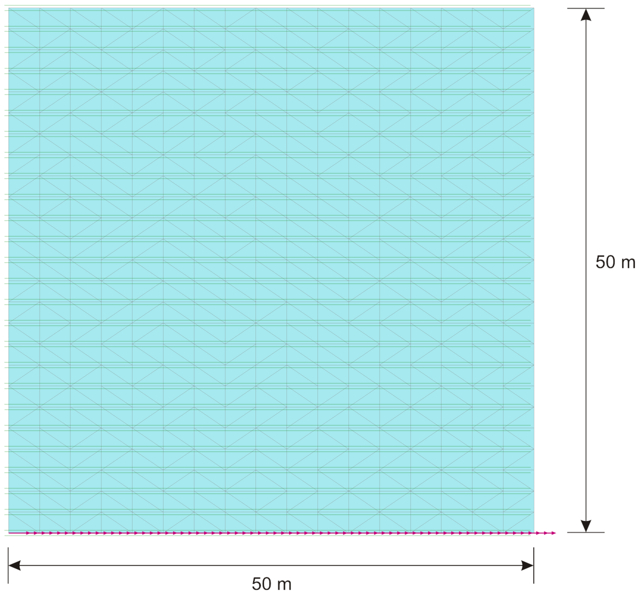

Figure 2 Model geometry and generated mesh (PLAXIS 2D)

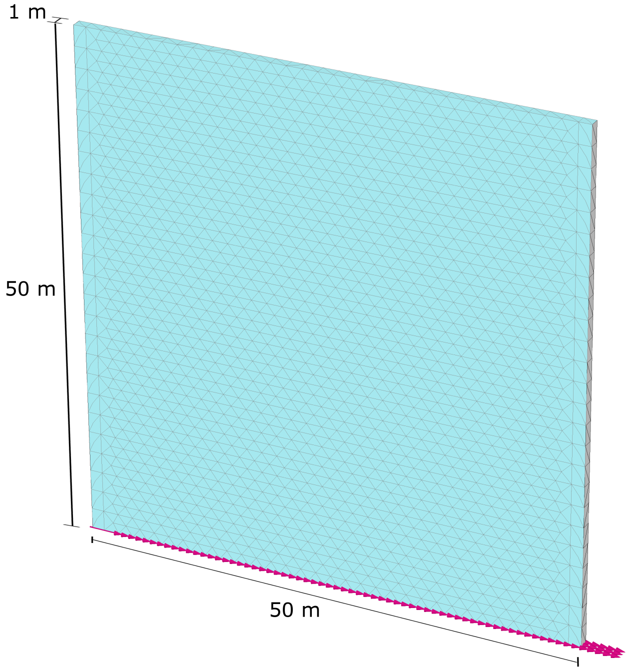

Figure 3 Model geometry and generated mesh (PLAXIS 3D)

Materials: The soil is modeled as *Linear elastic* with V_s = 300 m/s and γ = 20 kN/m^3. The first natural frequency of the soil deposit equals 1.5 Hz (refer to Section 7.8 of the Scientific Manual). Soil damping is taken into account using Rayleigh damping coefficients, with α_R = 1.257 and β_R = 2.829 $\times 10^{-3}$. These values correspond to 8 % of soil damping with first and second natural frequencies equal to 1.5 Hz and 7.5 Hz correspondingly. Poisson's ratio ν' is assumed to be 0.33. The adopted material parameters are:

Soil: Linear elastic Drained γ = 20 kN/m^3 ν' = 0.33 G = 183.5 $\times 10^3$ kN/m^2

Meshing: The line/surface displacements used to restrain the vertical degrees of freedom result in a well-formed structured mesh. In both PLAXIS 2D and PLAXIS 3D models, the *Medium* option is selected for the *Element distribution*. The *Coarseness factor* equals 1. The generated mesh is illustrated in Figure 2 and Figure 3 as well.

Calculations: The self-weight of the soil deposit is not considered for the initial stresses generation in the initial phase ($\sum M_{weight}$ is selected equal to 0). A dynamic analysis is performed in Phase 1. *Time interval* is set equal to 30 s. The *Mass matrix* value is selected equal to 1, considering a consistent mass matrix. The *Maximum steps* of the analysis are manually selected to be 3000. The *Newmark alpha* and *Newmark beta* coefficients for numerical time integration are selected as 0.25 and 0.5 respectively (average acceleration method), to ensure that the model does not have numerical damping.

The line/surface displacements are activated in Phase 1. In both PLAXIS 2D and PLAXIS 3D, the bottom line/surface displacement is set equal to 1 m and its dynamic component is activated. The strong motion time history is assigned to the multiplier in x-direction as acceleration (m/s^2). *Drift correction* is activated.

In PLAXIS 2D, for the left (x_{min}) and right (x_{max}) dynamic boundaries, the *Tied degrees of freedom* option is selected (*Deformations* are deactivated). To simulate the same dynamic boundary conditions in PLAXIS 3D, the interfaces at both sides of the model are activated and the corresponding dynamic boundaries are set to *Free field*. Regarding the bottom dynamic boundary condition, for both PLAXIS 2D and PLAXIS 3D, the *None* option is selected. It is assumed that the base of the model is rigid and the seismic signal is trapped within the soil deposit and cannot escape through the bottom boundary.

Output: The results obtained with PLAXIS 2D and PLAXIS 3D are presented in Figures 4 to 6. For a point *A* located at the mid-surface of the soil deposit (x=25 m, y=50 m), the following output plots are considered:

- the Fourier amplitude spectrum of the surface acceleration obtained at point *A*.
- the pseudo-spectral acceleration (PSA) response of a single-degree-of-freedom (SDOF) system located at the point *A*. Structural damping equal to 5% is assumed.
- the amplification factor (transfer function) between the Fourier amplitude of the output motion (acceleration obtained at point *A*) and the Fourier amplitude of the input strong motion, i.e. the input seismic acceleration at the base of the model.

Verification: The results obtained with PLAXIS 2D and PLAXIS 3D are compared with the corresponding results from the analysis of the same problem in DEEPSOIL (Hashash, Musgrove, Harmon, Groholski, Phillips & Park (2015), http://deepsoil.cee.illinois.edu/Index.html). DEEPSOIL is an one-dimensional site response analysis software that can perform shear wave propagation analysis in linear and non-linear soil both in time domain and frequency domain. The three output plots mentioned above constitute the comparison criteria. However, due to the fact that in PLAXIS only the Power spectrum of the surface acceleration is calculated, SeismoSignal (2004) was used in order to obtain the Fourier amplitude spectrum and compare it with the corresponding one from DEEPSOIL. The surface acceleration obtained with PLAXIS was used as input signal in SeismoSignal.

Results obtained from PLAXIS and DEEPSOIL are illustrated in Figures 4 to 6.

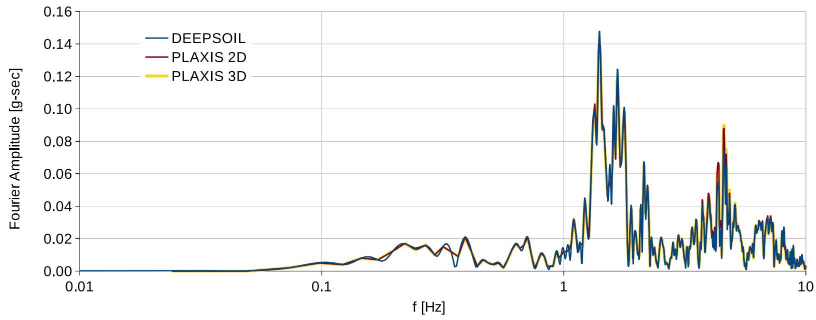

Figure 4 Fourier amplitude spectrum of surface acceleration obtained from PLAXIS and DEEPSOIL

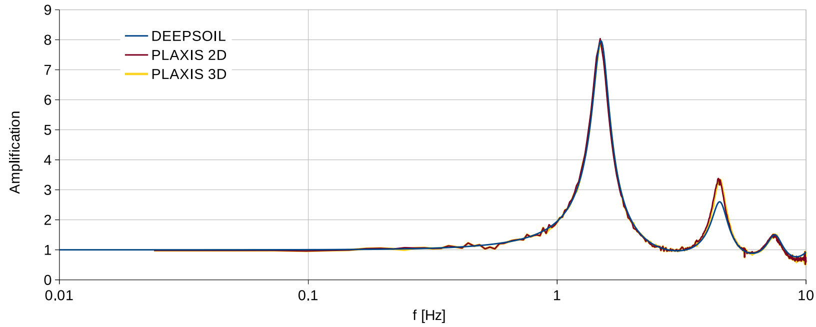

Figure 5 Comparison of amplification ratio obtained from PLAXIS and DEEPSOIL

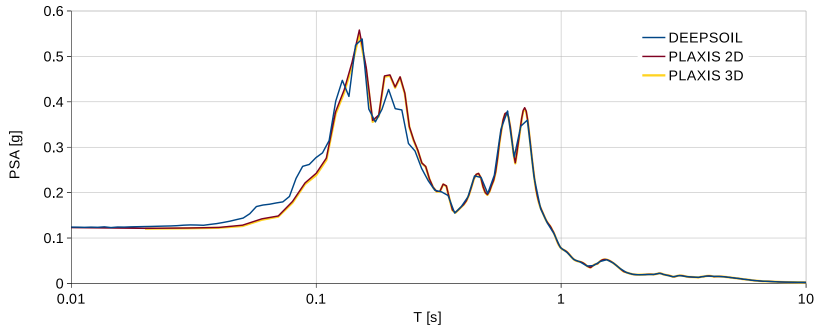

Figure 6 Comparison of PSA response spectra obtained from PLAXIS and DEEPSOIL

It is concluded that the results obtained in PLAXIS are in good agreement with the results obtained in DEEPSOIL. The reliability of PLAXIS for linear ground response analysis is successfully verified.

REFERENCES

[1] Hashash, Y.M.A., Musgrove, M.I., Harmon, J.A., Groholski, D.R., Phillips, C.A., Park, D. (2015). DEEPSOIL 6.1, User Manual. Board of Trustees of University of Illinois at Urbana-Champaign, Urbana, IL.

[2] SeismoSignal (2004). SeismoSignal - A computer program for signal processing of strong-motion data. Version 4.0.0. SeismoSoft, http://www.seismosoft.com/home.