GROUND RESPONSE ANALYSIS IN CASE OF LINEAR SOIL

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

Used version:

- PLAXIS 2D - Version 2018.0
- PLAXIS 3D - Version 2018.0

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 $m/s^2 \approx 0.11\ g$.

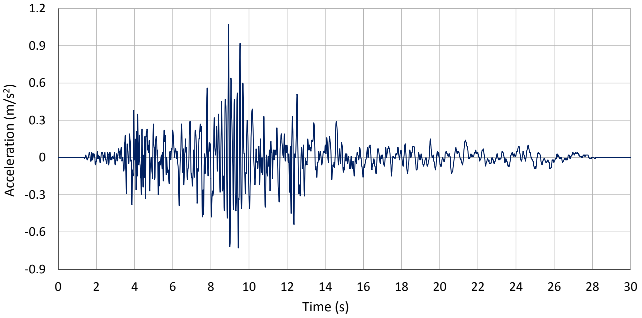

Figure 1 Outcrop strong motion recorded at the USGS station 286 during the Imperial Valley earthquake

In PLAXIS 2D, one-dimensional wave propagation is performed by using a soil column 2.0 m wide and 50.0 m deep. 15-noded triangular elements are employed. The input ground motion is applied horizontally at the base of the model, which is assumed to be rigid. The *Tied degrees of freedom* option is used for the dynamic boundary conditions of the vertical boundaries. The PLAXIS 2D model is illustrated in Figure 2.

The width of the soil column is determined based on Eq. (1) (Kuhlemeyer & Lysmer, 1973), in which f_{max} is the maximum frequency component of the input seismic signal (about 15 Hz in this example) and $v_{s,min}$ the lowest wave velocity of the adopted soil profile. Assuming a homogeneous and constant shear stiffness profile (G) and soil density profile (ρ), $v_{s,min}$ is calculated by Eq. (2) (about 300 m/s in this example).

$$\text{Average Element Size} \leq \frac{1}{8}\lambda = \frac{1}{8}\frac{v_{s,min}}{f_{max}} \tag{1}$$

$$v_{s,min} = \sqrt{\frac{G}{\rho}} \tag{2}$$

In PLAXIS 3D the model is 50.0 m wide, 50.0 m deep and extended by 1.0 m in y-direction (plane strain conditions). *Surface displacements* with 2.0 m space interval are used to restrain all vertical degrees of freedom within the model. 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 2 depicts the model geometry in PLAXIS 3D.

> **Hint:** In PLAXIS 2D, a ground response analysis can also be performed on a wider soil deposit, e.g. 50.0 m by 50.0 m. In this case all vertical degrees of freedom within the model should be restrained vertically, by setting the *All nodes fixities* option to *Fixed in y-direction*.
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> » The *Tied degrees of freedom* dynamic boundary condition are not available in PLAXIS 3D.

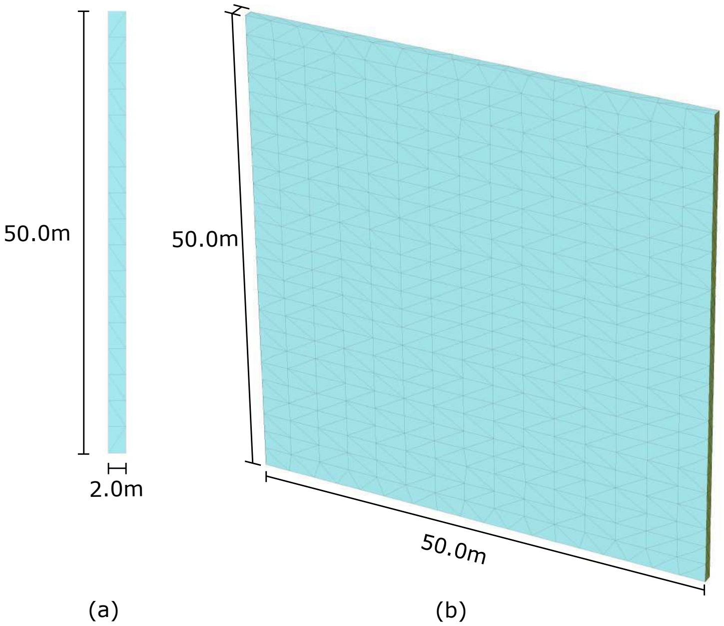

Figure 2 Model geometry and generated mesh in PLAXIS 2D (a) and PLAXIS 3D (b)

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

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, while the *Time step determination* is set to *Semi-automatic*. 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 surface displacements in PLAXIS 3D 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). In PLAXIS 3D, the left (x_{min}) and right (x_{max}) dynamic boundaries are set to *Free field*, while the front (y_{min}) and rear (y_{max}) dynamic boundaries are set to *None*. Regarding the bottom dynamic boundary condition, for both PLAXIS 2D and PLAXIS 3D, the *None* option is selected. In this way 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 3 to 4. For a point *A* located at the mid-surface of the soil deposit (2D: x=1.0 m, y=50.0 m and 3D: x=25.0 m, y=0.5 m, z=50.0 m), the following output plots are considered:

- the Fourier amplitude spectrum of the surface acceleration obtained at point *A* (Figure 3)
- 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 (Figure 4)
- 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 (Figure 5)

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, DEEPSOIL was used in order to compute the Fourier amplitude spectrum. For this purpose, the surface acceleration obtained with PLAXIS was used as input signal in DEEPSOIL

Results obtained from PLAXIS and DEEPSOIL are illustrated in Figures 3 to 5.

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.

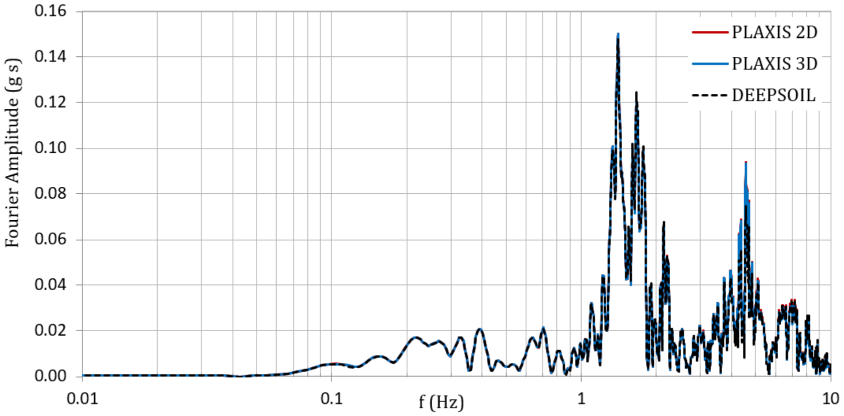

Figure 3 Fourier amplitude spectrum of surface acceleration obtained from PLAXIS and DEEPSOIL

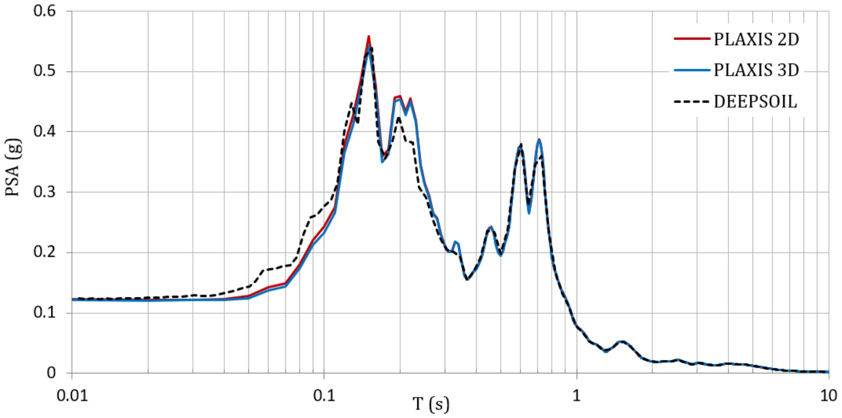

Figure 4 Comparison of PSA response spectra obtained from PLAXIS and DEEPSOIL

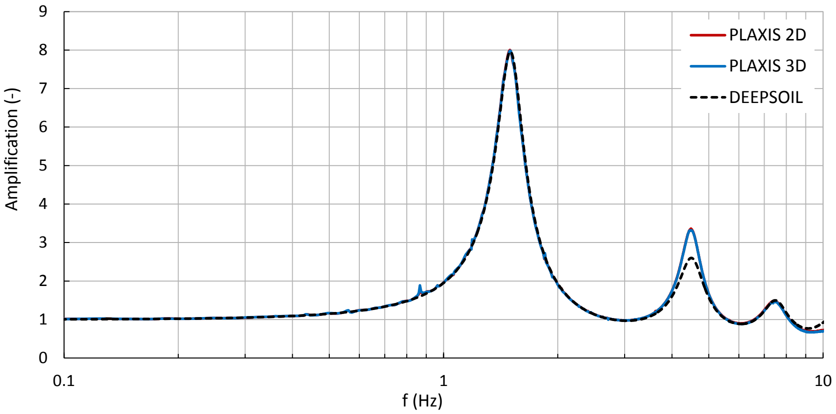

Figure 5 Comparison of amplification ratio obtained from PLAXIS and DEEPSOIL

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] Kuhlemeyer, R.L., Lysmer, J. (1973). Finite element method accuracy for wave propagation problems. Journal of soil mechanics and foundation devision, 99(5), 421–427.