CIRCULAR PIPE LOADED LATERALLY IN COHESIVE SOIL

This document describes an example that has been used to verify the correct implementation of 3D isoparametric interface elements in PLAXIS 3D. For that purpose, the response of a pipe subjected to horizontal loading under undrained soil conditions is studied.

Used version:

- PLAXIS 3D - Version 2018.0

Geometry: Figure 1 illustrates the model considered for a circular pipe embedded in soil. The soil layer thickness has been set to 1 m (unit length is selected for matter of comparison with analytical solutions). The circular pipe diameter D equals 5 m and it is embedded in a uniform soil layer 45 m wide (x-direction) and 35 m long (y-direction). Due to symmetry, only half of the geometry is modelled in PLAXIS 3D.

The circular pipe is modelled as half cylinder and the *Rigid body* feature is used. The *Translation condition* in x-direction is set to *Force* and the parameter F_x is set equal to 250.0 kN (which is equivalent to F_{eq} = 500 kN/m for the entire geometry). The *Translation conditions* in y and z directions are set to *Displacement*. Zero values are assigned to u_y and u_z. The *Rotation condition* in all directions is set to *Rotation* and zero values are assigned to the rotation angles ϕ_x, ϕ_y and ϕ_z. An outer interface is used to model the interaction between the pipe and the surrounding soil (outside the pipe).

A rectangular region (15 m $\times$ 8.5 m) is designed around the pipe to be used for mesh refinement. Figure 1 illustrates the model geometry in PLAXIS 3D.

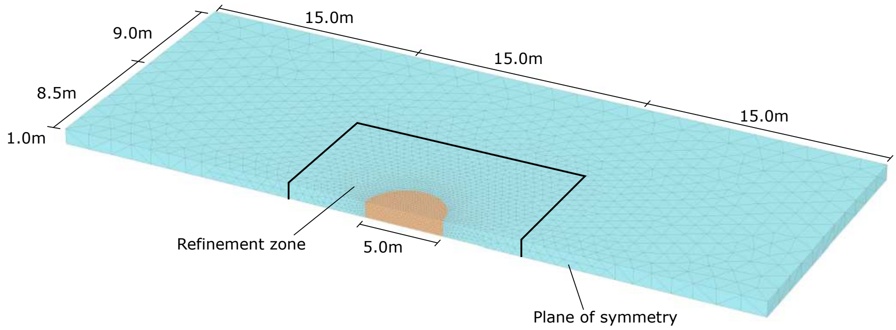

Figure 1 Model geometry (PLAXIS 3D)

Materials: The selected material parameters of the plug (material inside the pile) and the surrounded soil are:

Soil:	Mohr-Coulomb	Undrained (C)	E' = 30000 kN/m^2	ν' = 0.495	S_u = 5 kN/m^2
Plug:	Linear elastic	Drained	E' = 30$\times$10^6 kN/m^2	ν' = 0.495	

Meshing: The rectangular soil cluster surrounding the pipe outside is refined with a *Coarseness factor* of 0.4. The pipe is refined with a *Coarseness factor* of 0.1. The *Fine* option is selected for the *Element distribution*. The resulting mesh is illustrated in Figure 1.

Calculations: The project is calculated for different values of the interface strength R_{inter}. The considered values are presented in Table 1. The *Rigid body* and the *interface* are activated for all plastic calculation phases. All boundary conditions are set to *Normally fixed* via the *Model explorer* window. For advanced calculation settings, a *Tolerated error* of 0.001 is selected and the *Max load fraction per step* is set to 0.1. The *Solver type* for all phases is set to *Pardiso (multicore direct)* for faster calculation.

Output: Total displacements at failure for R_{inter} equal to 1.0 are depicted in Figure 2.

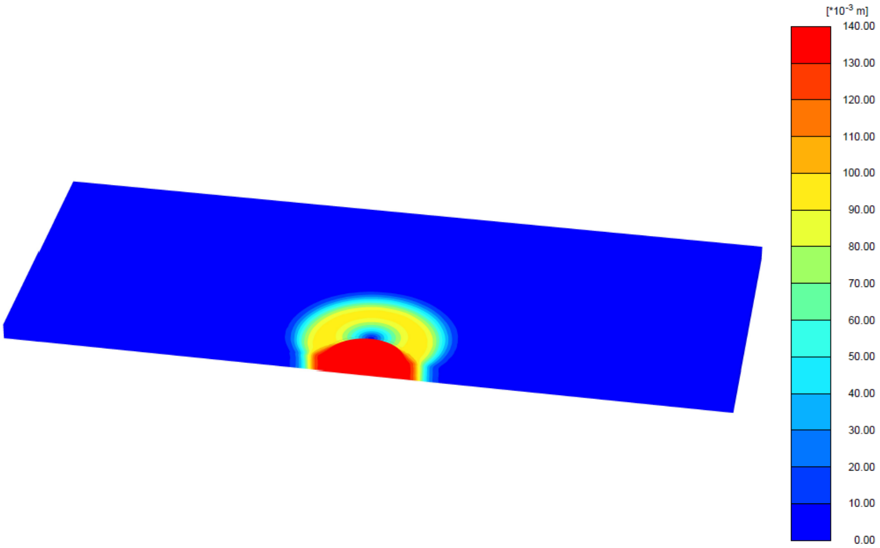

Figure 2 Total displacements at failure, R_{inter} = 1.0

Verification: The analytical solution for the ultimate capacity of the cylinder is derived by Randolph & Houlsby (1984) and reads:

$$\frac{P}{s_u D} = \pi + 2\Delta + 2cos\Delta + 4\left[\cos\frac{\Delta}{2} + \sin\frac{\Delta}{2}\right] \tag{1}$$

where

$$\sin\Delta = R_{inter} \tag{2}$$

Comparison between analytical and PLAXIS 3D results for the ultimate capacity values is presented in Table 1. In order to obtain the PLAXIS 3D results a point (interface node) located at the right side of the cylinder is used, i.e. with coordinates (25.0, 0.0, 0.5), assuming axes origin as displayed in Figure 1.

Table 1 Comparison between analytical and PLAXIS 3D results for the ultimate capacity values

R_{inter} (-)	Analytical	PLAXIS 3D	Error (%)
1.0	298.5 kN/m	300.8 kN/m	0.9
0.8	289.1 kN/m	290.9 kN/m	0.7
0.6	277.2 kN/m	279.0 kN/m	0.7
0.4	263.3 kN/m	265.3 kN/m	0.9
0.2	247.1 kN/m	250.0 kN/m	1.3

The initial slope of the load-displacement curve, where the soil behavior is assumed to be elastic, can be expressed according to Baguelin, Frank & Said (1977) as:

$$K_{xx} = \frac{8\pi E'(1-\nu')}{(1+\nu')\left[(3-4\nu')\ln\left(\frac{R}{r_0}\right)^2 - \frac{2}{3-4\nu'}\right]} \tag{3}$$

Assuming R equal to 22.5m and r_0 equal to 2.5 m, based on Eq. (3), the horizontal elastic stiffness K_{xx} equals 85940 kN/m.

Figure 3 presents the load-displacement curves obtained in PLAXIS 3D for various R_{inter} values. The analytically calculated K_{xx} value is plot as well.

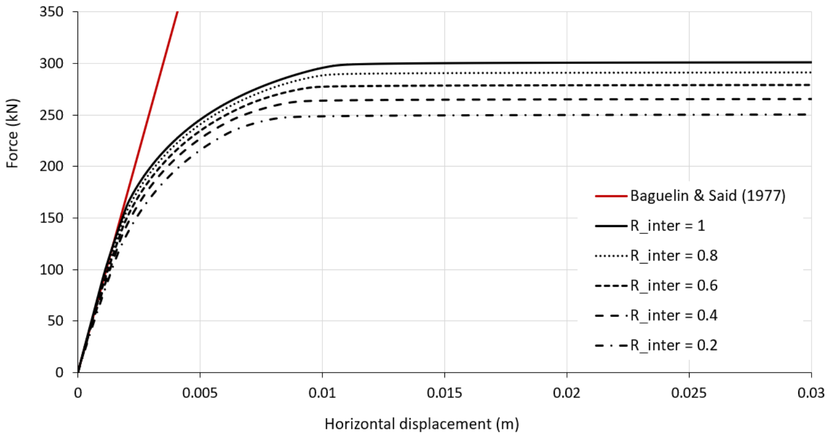

Figure 3 Load-displacement curves obtained in PLAXIS 3D for various R_{inter} values

Based on Figure 3, the ultimate horizontal capacity is reached for horizontal displacement of 0.02 m, i.e. 0.4% of the pile diameter D. The corresponding ultimate capacity values are used in Table 1 to calculate the relative error. It is concluded that PLAXIS 3D results are in close agreement with the analytical solution for both the ultimate capacity and the initial elastic stiffness of a laterally loaded cylinder under undrained soil conditions.

REFERENCES

[1] Baguelin, F., Frank, R., Said, Y. (1977). Theoretical study of lateral reaction mechanism of piles. Géotechnique, 27(3), 405–434.

[2] Randolph, M., Houlsby, G. (1984). The limiting pressure on a circular pile loaded laterally in cohesive soil. Géotechnique, 34(4), 613–623.