TRIAXIAL TEST WITH HARDENING SOIL MODEL

This document describes an example that is used to verify the elasto-plastic deformation capabilities of the Hardening Soil model of PLAXIS. The problem involves axial loading under triaxial test conditions.

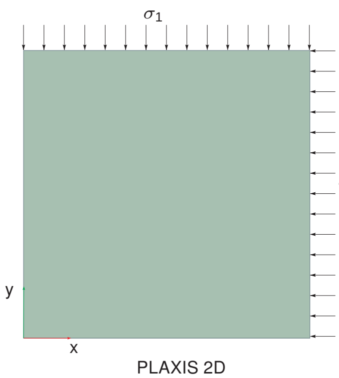
Used version:

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

Geometry: A triaxial test is conducted on the geometry displayed in Figure 1 for PLAXIS 2D and PLAXIS 3D respectively.

In PLAXIS 2D, an *Axisymmetric* model is used, simulating a square sample 1 m $\times$ 1 m. *Line loads* are assigned to the right and top model boundaries. In PLAXIS 3D, the geometry is modelled as a cubic sample 1 m $\times$ 1 m $\times$ 1 m. *Surface loads* are assigned to the right, top and front model faces.

As illustrated in Figure 1, the lateral stresses σ_2 and σ_3 are represented by distributed loads on the right and front side respectively. The axial stress σ_1 is represented by a distributed load on the top of the model.



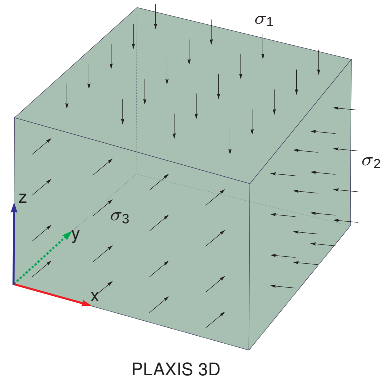


Figure 1 Triaxial test: model geometries and loading conditions

Materials: The soil behavior is modelled by means of the Hardening Soil model. The unit weight γ is set equal to zero. The remaining model parameters are:

E_{50}^{ref} = 2.0 · 10^4 kN/m^2 E_{oed} = 2.0 · 10^4 kN/m^2 E_{ur}^{ref} = 6.0 · 10^4 kN/m^2

m = 0.5 c'_{ref} = 1 kN/m^2 φ' = 35°

ψ = 5° p_{ref} = 100 kN/m^2

Meshing: In order to create a very coarse mesh, *Expert mesh settings* are used. In both PLAXIS 2D and PLAXIS 3D, the *Relative element size* is set to 20, while the *Coarseness factor* equals 1.

Calculations: In the Initial phase zero initial stresses are generated by using the *K0 procedure* (γ = 0). The calculation type in the following Phases 1, 2 and 3 is *Plastic analysis* and the *Tolerated error* is set to 0.0001.

With respect to the boundary conditions in Phases 1, 2 and 3, in PLAXIS 2D, the right (x_{max}) boundary is set to *Free* and the bottom (y_{min}) boundary is set to *Normally fixed*. The default boundary conditions for the other two boundaries are appropriate. In PLAXIS 3D, the right (x_{max}) and the front (y_{min}) boundaries are set to *Free*, while the bottom boundary (z_{min}) is set to *Normally fixed*. The default boundary conditions for the other three boundaries are appropriate.

The sample is subjected to the following loading sequence:

- Isotropic loading (compression) to -100 kN/m^2

  In PLAXIS 2D, the loads applied to the top and the right boundary are activated and set equal to -100 kN/m^2. Additionally, in PLAXIS 3D, the load applied to the front boundary is activated as well and set equal to -100 kN/m^2.

  After the isotropic loading, the *Reset displacements to zero* option is selected for the subsequent load cases (Phases 2 and 3). Both of them start from the isotropic loading phase (Phase 1).

- Axial compression until failure

  In both PLAXIS 2D and PLAXIS 3D, the value of the vertical load applied to the top boundary is set equal to -450 kN/m^2.

- Axial extension until failure

  In both PLAXIS 2D and PLAXIS 3D, the vertical load applied to the top boundary is deactivated.

Output: The values of the vertical stress at failure are given in Table 1. Figure 2 illustrates the development of the vertical stress against the vertical strain (any selected stress point is valid). Compression is expressed with negative strain values and extension with positive strain values.

Table 1 Vertical stress at failure

Model	Compression (kN/m^2)	Extension (kN/m^2)
PLAXIS 2D	-372.86	-26.06
PLAXIS 3D	-372.85	-26.06

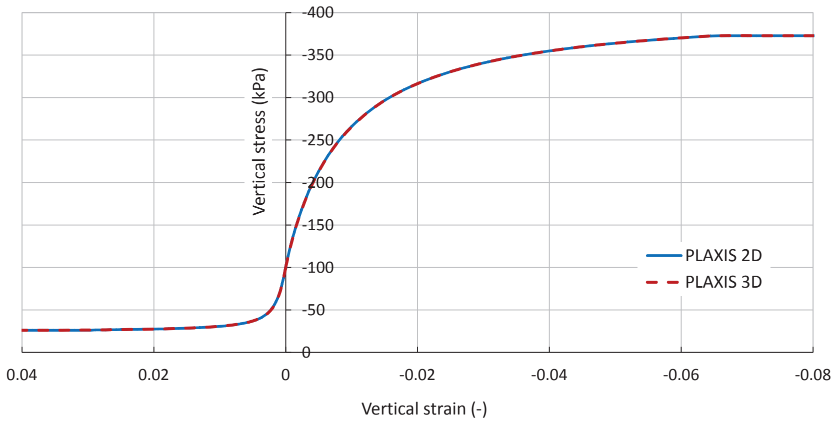


Figure 2 Compression and extension stress-strain curves

Verification: The theoretical solution to the failure of the sample is given by Eq. (1), based on the Mohr-Coulomb criterion:

$$f = \frac{|\sigma_1 - \sigma_3|}{2} + \frac{\sigma_1 + \sigma_3}{2} \cdot \sin\varphi - c \cdot \cos\varphi = 0 \tag{1}$$

Failure occurs in compression at:

$$\sigma_1 = \sigma_3 \cdot \frac{1 + \sin\varphi}{1 - \sin\varphi} - 2c \cdot \frac{\cos\varphi}{1 - \sin\varphi} = -372.86\,\text{kN/m}^2$$

Failure occurs in extension at:

$$\sigma_1 = \sigma_3 \cdot \frac{1 - \sin\varphi}{1 + \sin\varphi} + 2c \cdot \frac{\cos\varphi}{1 + \sin\varphi} = -26.06\,\text{kN/m}^2$$

The analytically obtained results are in perfect agreement with PLAXIS.