SOFT SOIL CREEP MODEL

This document validates the Soft Soil Creep model in PLAXIS. The undrained triaxial creep behaviour of Haney clay is simulated, using the material parameters reported by Matsui & Abe (1988). The results are compared with test data provided by Vaid & Campanella (1977), including constant strain rate shear tests and undrained triaxial creep tests. An extensive validation of the Soft Soil Creep model is presented by Stolle, Bonnier & Vermeer (1997).

Used version:

- PLAXIS 2D - Version 2016.00

Geometry: In PLAXIS 2D a quarter of the real dimension of the test set-up is simulated (17.5×17.5 mm^2). Figure 1 illustrates the model geometry. The specimen surfaces (top and right hand sides in Figure 1) are set to *Drained* (seepage) whereas the other boundaries are set to *Closed*. In addition, the left and bottom model boundaries are set to *Normally fixed*, while the right and top boundaries are set to *Free*. *Line loads* equal to 525 kN/m/m are applied to the top and right model boundaries. A *Prescribed displacement* is also applied to the top model boundary. The latter is not visible in Figure 1 as it is only activated to simulate constant shearing rates, as explained further below.

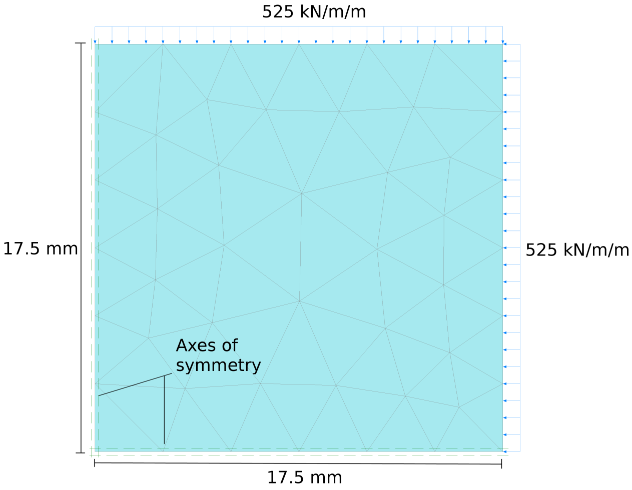

Figure 1 Model geometry and generated mesh (PLAXIS 2D)

Hint: If default PLAXIS units are selected, the model geometry in Version 2016.00 (or later) of PLAXIS 2D, should be generated by using the *borehole* option. If the model is built in mm, then the *create polygon* option may be used alternatively. This is because in Version 2016.00 (or later), a limitation is set regarding the minimum value of the area of a generated polygon, which is 0.001 (length unit)^2. In both cases the water table is set at the bottom of the model.

The considered triaxial tests performed by Vaid & Campanella (1977) were completed by initially consolidating the samples under an effective isotropic confining pressure of 525 kPa for 36 hours and then allowing them to stand for 12 hours under undrained conditions before starting the shearing part of test. The end-of-consolidation pre-consolidation pressure p_p^{eq} was found to be 373 kPa. This value was determined by simulating the consolidation part of the test (Stolle, Bonnier & Vermeer, 1997). The pre-consolidation pressure p_p^{eq} of 373 kPa is less than 525 kPa, which would have been required for an over-consolidation ratio *OCR* of 1. It is apparent that the pre-consolidation pressure not only depends on the applied maximum consolidation stress, but also on creep time. This initial isotropic pre-consolidation pressure p_p^{eq} = 373 kN/m^2 is obtained by specifying a *POP* of 432.4 kN/m^2 in the *Initial* tabsheet of the *Material sets* window.

Material: The Soft Soil Creep model is used to simulate the behaviour of the Haney clay. The unit weight γ is selected equal to zero. The *Undrained (A)* drainage type is used. The adopted material parameters are summarized in Table 1.

Table 1 Soft Soil Creep model parameters for Haney clay

Parameter	Symbol	Value	Unit
Modified compression index	λ^*	0.1055	-
Modified swelling index	κ^*	0.01635	-
Secondary compression index	μ^*	0.004	-
Initial void ratio	e_{init}	0.896	-
Poisson's ratio	ν'_{ur}	0.15	-
Cohesion	c'	0.0	kN/m^2
Friction angle	φ'	32.0	°
Dilatancy angle	ψ	0.0	°
Coefficient of lateral stress	K_0^{nc}	0.61	-
Permeability	k_x , k_y	0.0001	m/day
Over-consolidation ratio	*OCR*	1.0	-
Pre-overburden pressure	*POP*	432.4	kN/m^2

Meshing: The *Very coarse* option is selected for the *Element distribution*. A stress point with coordinates (0.184 mm, 0.184 mm) is selected to be used for plotting part of the results. The generated mesh is illustrated in Figure 1.

Calculations: To study the shearing rate effects on stress-strain behaviour, the soil is initially consolidated under an effective isotropic confining stress equal to 525 kPa. For that purpose a *Plastic* calculation is used and the option *Ignore undrained behaviour* is activated. After the isotropic loading phase, the displacements are reset to zero. Undrained triaxial compression tests are performed under constant rates of vertical strain $\dot{\epsilon}_1$ and constant horizontal stress σ_3. The vertical load is deactivated and the prescribed displacement is activated. Various loading rates are simulated by applying prescribed displacements at different velocities. As such, a total of 12% axial strain (vertical displacement of 2.1 mm) is applied in 8.865 days (0.00094%/min), 0.0556 days (0.15%/min) and 0.00758 days (1.10%/min) respectively. *Plastic* calculation type is used. The *Tolerated error* is set equal to 0.001 and the *Max load fraction per step* is set equal to 0.01. The selected number of *Max steps* should be at least 1000.

To study the creep strain evolution under constant deviatoric stress, the soil is initially consolidated under an effective isotropic confining stress equal to 525 kPa. For that purpose a *Plastic* calculation is used and the option *Ignore undrained behaviour* is activated. Then deviatoric stress is applied in undrained loading. External stress is kept constant and the sample is subjected to undrained creep. The applied deviatoric stresses q are 323.4 kPa, 300.3 kPa and 278.3 kPa. *Plastic* calculation type with *Time interval* equal to 0 is used to apply a certain deviatoric stress. A subsequent *Plastic* analysis is used with non-zero time interval to allow for creep. *Time intervals* are selected such that exceed the time needed for the sample to fail, i.e. 0.5 days for q equal to 323.4 kPa, 1.5 days for q equal to 300.3 kPa and 2.0 days for q equal to 278.3 kPa. For all *Plastic* calculations, the *Tolerated error* is set equal to 0.001. The *Max load fraction per step* is set equal to 0.01 for every calculation Phase except for the one in which the applied deviatoric stresses q equals 323.4 kPa. For higher accuracy, a *Max load fraction per step* equal to 0.001 is selected for this calculation Phase. The selected number of *Max steps* should be at least 1000.

Hint: When using the Soft Soil Creep model to simulate creep, time is always taken into account. However, in this particular example, zero time is used for the *Plastic* calculation in which the isotropic loading is applied (Phase 1 for both study cases) and for the *Plastic* calculation in which deviatoric stress is applied under undrained conditions (Phases 2, 3 and 4 in the second study case). As discussed above, the consolidation part of the test was simulated by Stolle, Bonnier & Vermeer (1997) and a POP value of 432.4 kN/m^2 is used to simulate the condition of the sample after consolidation. Thus, the stress state obtained after the above mentioned plastic calculations is assumed to be the initial stress state of the samples prior to shearing. By using a zero time interval, the end-of-consolidation pre-consolidation pressure p_p^{eq} is forced to remain equal to 373 kPa.

Output: In Figure 2 the effect of the shearing rate on stress-strain behaviour is illustrated. The selected stress point is used to generate PLAXIS results. Figure 3 depicts the creep evolution under different constant deviatoric stresses. Figure 4 presents results of creep rupture time, i.e. creep time up to an infinite creep rate ($\dot{\epsilon} = \infty$). It is indicated by asymptotes in Figure 3.

Validation: In Figure 2 to 4, PLAXIS results are compared with experimental data provided by Vaid & Campanella (1977). As it can be seen in Figure 2, the results of the undrained triaxial tests with different rates of strain are compared well with the experimental data. The higher the shearing rate (faster test), the higher the undrained shear strength.

Figure 5 illustrates schematically the effective stress path in undrained triaxial tests, under slow (path S) and fast (path F) strain rates.

During the considered undrained triaxial tests, the following applies:

$$\dot{\epsilon}_v = \dot{\epsilon}_v^e + \dot{\epsilon}_v^c = 0 \;\Rightarrow\; \dot{\epsilon}_v^e = -\dot{\epsilon}_v^c \tag{1}$$

in which, $\dot{\epsilon}_v$ is the total volumetric strain rate, $\dot{\epsilon}_v^e$ is the elastic volumetric strain rate and $\dot{\epsilon}_v^c$

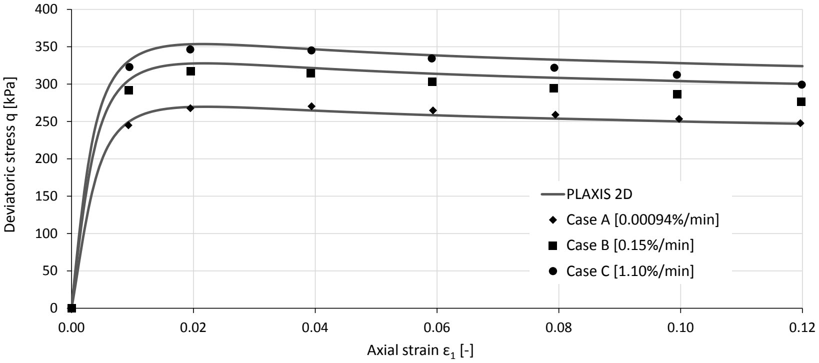

Figure 2 Shearing rate effects on stress-strain behaviour

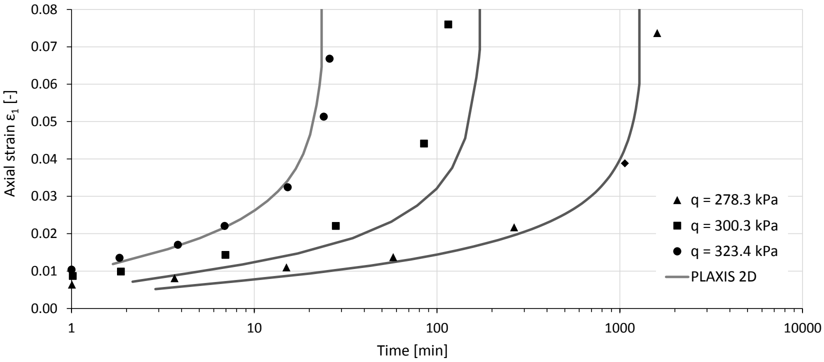

Figure 3 Creep evolution under different deviatoric levels

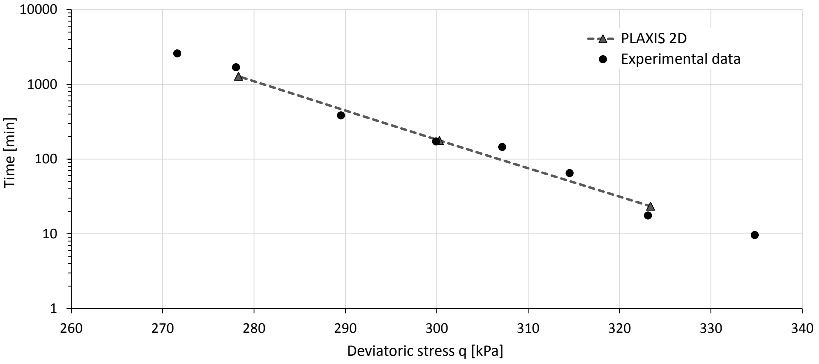

Figure 4 Creep rupture life

is the creep volumetric strain rate.

Based on Eq. (1), creep compaction is balanced by elastic swelling. According to Eq. (2), the slower a test is performed (t' increases), the larger the creep compaction ϵ_v^c is and,

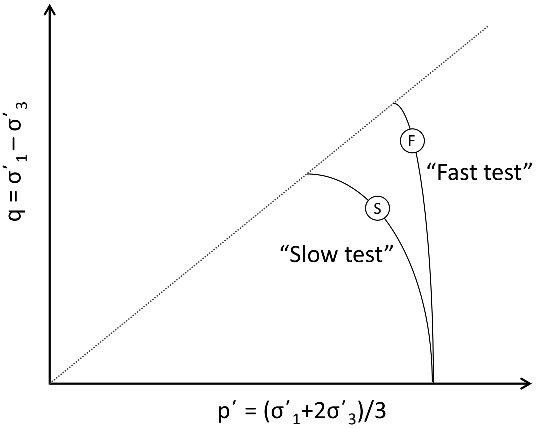

Figure 5 Strain rate dependency of the effective stress path in undrained triaxial tests

based on Eq. (1), the larger the elastic swelling ϵ_v^e is as well.

$$\epsilon_v = \epsilon_v^e + \epsilon_v^c = -a \ln\left(\frac{\sigma'}{\sigma'_0}\right) - (b - a) \ln\left(\frac{\sigma_{pc}}{\sigma_{p0}}\right) - c \ln\left(\frac{\tau_c + t'}{\tau_c}\right) \tag{2}$$

In Eq. (2), ϵ_v is the total volumetric logarithmic strain due to an increase in effective stress from σ_0' to σ' during a time period of τ_c + t'. For further explanation of Eq. (2) refer to Section 9.3 of the Material Models Manual.

Eq. (3) implies that elastic swelling results in decrease of the mean effective stress p'.

$$\dot{p}' = K_{ur} \dot{\epsilon}_v^e \tag{3}$$

in which, K_{ur} is the elastic bulk modulus for unloading-reloading.

Regarding fast tests with high strain rates, time for creep is limited. Assuming the extreme case of a very fast test, it yields $\dot{\epsilon}_v^c = 0$, and consequently, based on Eq. (1), $\dot{\epsilon}_v^e = 0$. Hence, in this extreme case, there is no elastic volumetric change and as a result neither mean effective stress change. This implies a straight vertical effective stress path in p'-q plane (see Figure 5).

As illustrated in Figure 3, the amount of creep depends on the applied deviatoric stress q or rather on the applied stress ratio q/p. For relatively small stress ratios (e.g. for q equal to 278.3 kPa), creep rates are small and they decrease in course of time. For relatively large stress ratios (e.g. for q equal to 323.4 kPa), creep rates increase with time and samples fail when strain rates become infinitely large. PLAXIS results are in good agreement with the experimental data.

Figure 4 illustrates the creep rupture life results. In agreement with Figure 3, for high deviatoric stresses creep rupture life decreases. PLAXIS results are well compared with the experimental data.

REFERENCES

[1] Matsui, T., Abe, N. (1988). Verification of elasto-viscoplastic model of normally consolidated clays in undrained creep. In Proceedings, 6th International Conference Numerical Methods in Geomechanics. volume 1, 453–459.

[2] Stolle, D., Bonnier, P., Vermeer, P. (1997). A soft soil model and experiences with two integration schemes. Numerical Models in Geomechanics, 1(12), 123–128.

[3] Vaid, Y., Campanella, R. (1977). Time-dependent behavior of undisturbed clay. Journal of the Geotechnical Engineering Division, 103(7), 693–709.