Timodaz School

First Training Course

THM behaviour of clays in deep excavation with application to underground radioactive waste disposal

July 7th – 9th, Lausanne

Determination of model parameters from laboratory tests results and constitutive simulations

Exercise on Laboratory Experiment

François B., Collin F.

1 Triaxial tests

Five conventional drained triaxial tests have been performed on five specimens of Boom Clay at two different cell pressure values ($\sigma_3 = 0.7$ and 2.6 MPa), maintaining a back pressure equal to 0.3 MPa (Coll, 2005). The deviatoric phase has been conducted controlling the axial strain (ε_1). During the tests, the total axial stress (σ_1) and the volumetric strain (ε_v) have been recorded. The deviatoric stress evolution ($q = \sigma_1 - \sigma_3$) and the volumetric strain evolution have been plotted with respect to axial strain for each test. The experimental data are reported in the annexed spreadsheet and are illustrated in Figure 1.

Figure 1

2 Additional information

Through appropriate isotropic compression tests, the preconsolidation pressure of Boom Clay has been evaluated to 6 MPa. Also, the swelling C_s and compression C_c indices have been assessed to 0.504 and 0.173, respectively. The initial void ratio e_0 of Boom Clay is around 0.65.

3 Work to be done

1. Calculate the material parameters relative to the Drucker-Prager model and the Cam-Clay model.

Elastic parameter: Young modulus: E_0
Poisson ratio : υ
Non-linear parameter: n^e

and alternatively Bulk modulus: K_0
Shear modulus. G_0

Shear strength parameters (Drucker-Prager): Cohesion: c'
Friction angle: φ'.
Dilatancy (Drucker-Prager): Dilatancy angle: ψ

Cam-Clay plastic parameters: Hardening parameter: β
Equivalent friction angle (for c'=0): φ'_{eq}
Preconsolidation pressure: p'_c

Some useful relations to determine the materials parameters are reported in Annex 1.

2. Thanks to the integration tool "lawyer.exe", simulate the triaxial test at the two effective confining pressures reported in Figure 1 with the determined materials parameters. Check the validity of the determined material parameters. If needed, adapts the material parameters to fit as much as possible to the experimental curves.

Some explanations for the use of the integration tool are presented in Annex 2.

4 Appendix 1

Elastic relations:

The elastic parameters must be determined in the linear part of the results (at low axial strain).

$$E = \frac{q}{\varepsilon_1}$$

$$\upsilon = \frac{\varepsilon_3}{\varepsilon_1} = \frac{\frac{1}{2}(\varepsilon_v - \varepsilon_1)}{\varepsilon_1}$$

$$E = E_0 \left(\frac{\sigma_3}{\sigma_{3,0}} \right)^{n^e} \qquad \text{with } \sigma_{3,0} = 1 \, MPa \text{ in "lawyer.exe".}$$

$$K = \frac{E}{3(1-2\upsilon)} \qquad \text{and} \qquad G = \frac{E}{2(1+\upsilon)}$$

Plastic relations:

$$\phi = Sin^{-1} \left(\frac{3M}{6+M} \right) \qquad \text{where M is the slope of the critical state line in the p'-q plane}$$

$$c = c_{q-p'} \frac{Tan\phi'}{M} \qquad \text{where } c_{q-p'} \text{ is the y-coordinate of the critical state line in the (p'-q) plane at p'=0.}$$

$$\beta = \frac{1+e_0}{\lambda - \kappa} \qquad \text{with } \lambda = \frac{C_c}{\ln 10} \quad \text{and} \quad \kappa = \frac{C_s}{\ln 10}$$

5 Appendix 2

The simulation of experimental test with the lawyer.exe integration tool requires three main steps to be accomplished:

- A phase of data definition in the data file
- The calculation
- A postprocessing phase to obtain the results in an Excel file.

TIMODAZ

The data file

a) Each parameter introduced in the data file is preceded by a keyword
ex:

COHES.   50e3

where "COHES." is the keyword and "50e3" is the value of the parameter.

b) The sign convention considers the traction as positive while compression is negative.

c) Each line starting with "*" is a comment and is not read by "lawyer.exe".

d) The data file is divided in groups of data. Each group of data is preceded by a keyword.
ex:

STATE
*
========== STRESS =============================
*
SIGXX. -2.3E6
SIGYY. -2.3E6
SIGZZ. -2.3E6
SIGYZ. 0
SIGXZ. 0
SIGXY. 0
*
======== TEMPERATURE INITIALE ====================
*
TEMP0. 22.5

"STATE" is the keyword that precedes the group of data which define the initial state of the material.

e) Description of each group of data.

PRINT: Define the option of printing. / *Let it unchanged.*

ALGORITHME: Define the convergence criteria. / *Let it unchanged.*

TYPE: Define the considered degree of freedom of the simulated case. In the present case: XX YY ZZ and TT (for displacement in the three orthogonal directions + temperature). / *Let it unchanged.*

MATERIAL: Define the type of constitutive law used with the corresponding material parameters. In the present case, DRUCKERPRAGER is used. It considered the drucker-prager as well as the Cam-Clay constitutive law. / *Let it unchanged.*

Then, the data file includes the value of the material parameters with their corresponding keyword. / *You have to modify the values of the parameters.*

XKI...	Reference bulk modulus	> 0	[Pa]
XGI...	Reference shear modulus	> 0	[Pa]
XN....	Nonlinear elastic exponant	[0-1]	[-]
PHI...	Friction angle	< 0	[°]
COHES.	Cohesion (= 0 if B=1)	> 0	[Pa]
BETA..	Hardening parameter (read only if B=1)	< 0	[-]
PCI...	Critical pressure (read only if B=1): PCI=p'c/2.781	< 0	[Pa]
B.....	Binary value: B=0: Drucker-Prager; B=1: Cam-Clay	0 or 1	[-]
PSI...	Dilatancy angle (read only if B=0)	< 0	[°]
DILAS.	Thermal expansion coefficient of solid skeleton	> 0	[°C^{-1}]
DILAF.	Thermal expansion coefficient of water	> 0	[°C^{-1}]
DEVT..	Thermo-plastic parameter		[-]
GAMA..	Thermo-plastic parameter		[-]

The parameter related to the numerical integration (FACINC, XKAUX. XGAUX. INCMAX) must not be changed.

STATE: Define the initial state of the material. It includes the six components of the stress tensor and the temperature. / *You have to modify the values of the parameters.*

LOAD: Define the loading path. *You have to modify it, if necessary.*

SIGIMP defines the degree of freedom stress-controlled
DEFIMP defines the degree of freedom strain-controlled
TEMIMP define the temperature as a degree of freedom.

FIN mentions that each degree of freedom has been defined.

1 100 1	*Let it unchanged*
A B C D E F G H	A B C D E F control the variation of the degree of freedom in the XX YY ZZ XY YZ XZ directions, respectively
	G is the time step (let G=1 by default)
	H controls the variation of temperature during the time step.
	You have to modify A B C D E F H (not G), if necessary.

CALCUL: Launch the calculation. / *Let it unchanged.*

EXIT: Finish the calculation process. / *Let it unchanged.*

TIMODAZ

The calculation

When data input phase is completed. Save the data file with a given name (ex: data001) and launch the calculation clicking on the lawyer.exe. In the appearing DOS window, enter the name of the data file and press enter.
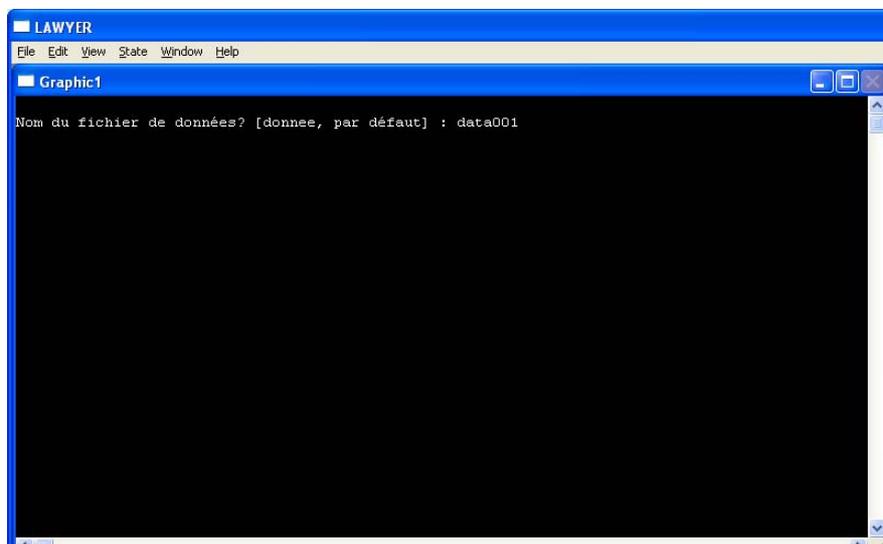
The postprocessing of the result.

When calculation is finished, open the PPtool_v1-1T.xls file to edit the result in an Excel file.
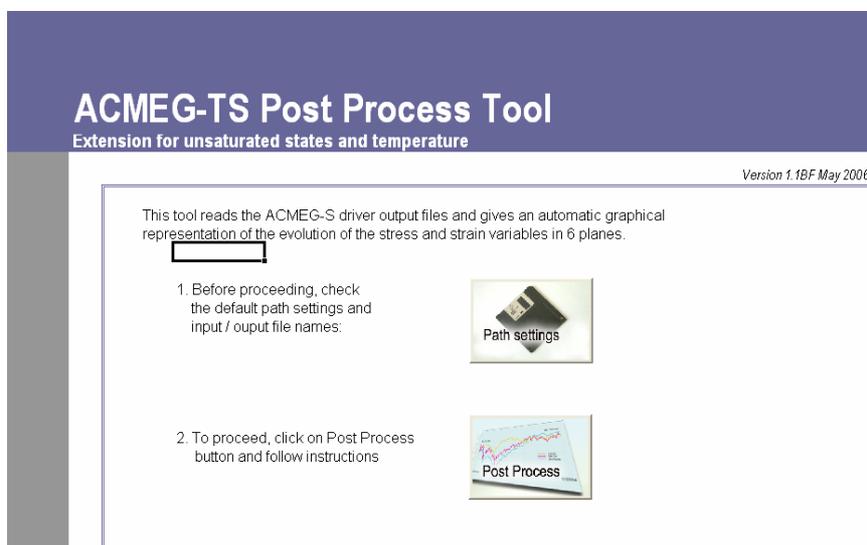
The "path settings" button enables to define the working directory, the name of the file containing the result of calculation (FT45 - *let it unchanged*) and the name of the postprocessed result file.

The "post process" button enables to launch the post-processing of results clicking on the subsequent "OK" button.

The information in the "path settings" button must be completed before launching the post processing of results.