Assignment 9: Cam-Clay

1 Simple shear

1. Kaolin is reconstituted to a slurry and is then permitted to re-consolidate one-dimensionally. It eventually reaches a vertical effective stress of 100 kPa in a Simple Shear Apparatus:

   (a) Estimate its water content

   (b) Predict its undrained shear strength

   (c) It is then permitted to drain while it continues shearing; predict its drained shear strength.

   (d) What volumetric change will the sample eventually suffer during its drained shearing? How would this estimate be changed if a pre-consolidation stress of 1000 kPa had first been imposed during the initial setting-up.

2. London Clay is normally consolidated to 1000 kPa and then permitted to swell back into equilibrium (with zero pore pressure) under a normal stress of 50 kPa

   (a) Predict both drained and undrained shear strengths using SSA Cam Clay.

   (b) Estimate the pore water pressure consistent with your estimate of the undrained shear strength. Comment on the magnitude in relation to the probable behavior of heavily over-consolidated London Clay exposed in an excavation.

2 Triaxial tests

1. Establish expression for TX compression Cam Clay parameter M as a function of ϕ_{crit}. Assume that the test eventually come to mobilize ϕ_{crit} in the vertical plane. Hint: Use earth pressure co-efficient to relate different component of stresses.

2. A saturated clay is characterized by these Cam-Clay parameters: $M = 0.87$, $\lambda = 0.091$, $\kappa = 0.035$ and $\Gamma = 2.072$ at $p' = 1kPa$. Consider two different soil specimens consolidated to the same $p'_c = 100kPa$. Specimen A is isotropically consolidated to $p'_0 = 100kPa$, while Specimen B is anisotropically consolidated to $p'_0 = 100kPa$ with $K_c = \sigma'_{1c}/\sigma'_{3c} = 2.0$.

   (a) Sketch the initial states, paths and yield surfaces for each specimen in $q - p'$ and $v - \ln p'$ space.

   (b) Use the MCC model to predict the undrained shear strength fro the two speciments. Compare your results.

   (c) Use the MCC model to predict the drained q_f at failure.

3. Weald clay is reconstituted as a saturated slurry and isotropically consolidated to $p' = 100kPa$, before being allowed to swell back to 70kPa. Use OCC.
   (a) What will be its water content?
   (b) It is then to be subjected to undrained triaxial compression. At what deviatoric stress q might the sample yield? Estimate the axial strain at yield (assuming effective Poisson's ratio of 0.15).
   (c) If q is allowed to increase a further 10% as the undrained test progresses, search for a consistent value of the mean effective stress p' at that stage.
   (d) What ultimate undrained strength q_u should be recorded?
   (e) What volumetric strain should occur if the sample were finally allowed to drain while shearing continued, and what would be the ultimate strength?

3 Material parameters and constitutive law

1. Develop Modified Cam-Clay parameters for Young San Francisco Bay Mud from the triaxial compression data and consolidation test data provided. Use $\kappa = 0.2\lambda$

2. Develop the stiffness matrix in the cam-clay.ipynb file provided. Simulate two undrained triaxial tests using the parameters derived in the previous problem for the Modified Cam-Clay model. In addition to parameters determined above, use $N = 4$ and $\nu = 0.2$

   (a) Isotopically consolidated undrained compression test of normally consolidated clay. Normally consolidated to 100 kPa and then sheared in undrained conditions. For the undrained shear part of the test:
      i. Determine the initial void ratio before shearing.
      ii. Plot deviatoric stress q versus axial strain ε_a
      iii. Plot the stress path in $q - p'$ plane and the state path in $e - \ln p'$ plane
      iv. Plot excess pore pressure u versus axial strain
   (b) Isotopically consolidated undrained compression test of overconsolidated clay. Normally consolidated to 450 kPa isotopically, unloaded isotropically to 100 kPa and then sheared in undrained conditions. For the undrained shear part of the test:
      i. Determine the initial void ratio before shearing.
      ii. Plot deviatoric stress q versus axial strain ε_a
      iii. Plot the stress path in $q - p'$ plane and the state path in $e - \ln p'$ plane
      iv. Plot excess pore pressure u versus axial strain

   Note: For the overconsolidated condition, use the elasto-plastic D matrix after the stress state reaches the yield surface. Use the elastic D matrix before yielding.

• **Parameter values which fit soil data**

	London Clay	**Weald Clay**	**Kaolin**	**Dog's Bay Sand**	**Ham River Sand**
$\lambda*$	0.161	0.093	0.26	0.334	0.163
$\kappa*$	0.062	0.035	0.05	0.009	0.015
$\Gamma*$ at 1 kPa	2.759	2.060	3.767	4.360	3.026
$\sigma*_{c,\ virgin}$ kPa	1	1	1	Loose 500	Loose 2500
				Dense 1500	Dense 15000
ϕ_{crit}	23°	24°	26°	39°	32°
M_{comp}	0.89	0.95	1.02	1.60	1.29
M_{extn}	0.69	0.72	0.76	1.04	0.90
w_L	0.78	0.43	0.74	--------------	--------------
w_P	0.26	0.18	0.42	--------------	--------------
G_s	2.75	2.75	2.61	2.75	2.65

Note: 1) parameters $\lambda*$, $\kappa*$, $\Gamma*$, $\sigma*_c$ should depend to a small extent on the deformation mode, e.g. SSA, BA-PS, TA-AS, etc. This may be neglected unless further information is given.
2) Sand which is loose, or loaded cyclically, compacts more than Cam Clay allows.