Strip Footing on Unsaturated Soil with BBM

Keywords

2D, Plane Strain, Barcelona Basic Model.

Problem Description

This example deals with a flexible footing resting on a 10m x 10m body of elasto-plastic soil. The soil is first dried, resulting in a negative pore water pressure occurring towards the surface. The footing is then loaded before being wetted back to full saturation at the surface.

Discretisation

The problem is modelled using 144 QPN8P elements discretised into the finite element mesh shown in Figure 1. The vertical boundaries are restrained from moving in the horizontal direction and in both vertical and horizontal directions at the bottom.

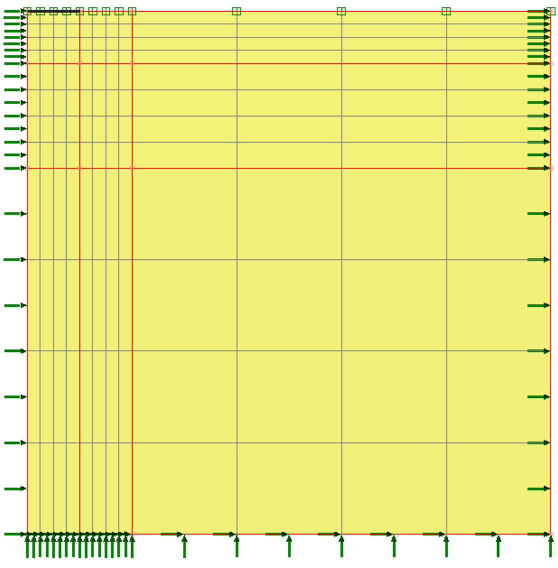

Figure 1: Finite element mesh showing supports.

Material Properties

The soil is modelled using the Barcelona Basic Model (BBM). Table 1 gives the material properties for the BBM. Table 2 gives two phase properties and Table 3 gives KO initialization properties needed for fully defining the initial state. Many of these properties vary with depth, these variations are shown in subsequent Tables (4-6). Additionally, the piecewise soil-water characteristic curve is defined by the data in Table 7.

Table 1: Barcelona Basic material properties*

Compression index at fully saturated state, λ_0	Swelling index, κ	Poisson's ratio, ν	Gradient of critical state line, M	Stiffness at infinite suction control, r
0.1	0.01	0.3	0.86	0.9
Increase in stiffness with suction control, β	Reference pressure p_{c0}	Elastic stiffness due to suction κ_s	Atmospheric pressure p_{atm}	Initial void ratio, e
0.012	1	1E-8	1	1.9

*See Table 4 for Density variation

Table 2: Two Phase material properties*

Solid bulk modulus, K_s	Bulk modulus of fluid phase, K_f (absolute value)	Hydraulic conductivity in global X direction, k_x	Hydraulic conductivity in global Y direction, k_y	Hydraulic conductivity in global Z direction, k_z
Incompressible	2.2E6	1E-8	1E-8	1E-8
Density of fluid	Irreducible saturation	Degree of saturation to be considered as fully saturated	Partially saturated	Curve tolerance
1 t/m^3	0	1	Piecewise linear	0

*See Table 5 for Porosity variation and Table 7 for draining/filling curve definition

Table 3: K0 Initialisation material properties*

Poisson's ratio for unloading, ν_{K0}	Coefficient of lateral earth pressure of normally consolidated clay	Specific volume of soil on normal consolidation line
0.41866	0.72	2.8

*See Table 6 for Over-consolidation ratio variation

Table 4: Soil density variation with depth

Depth (m)	Density
0	2.213
1	2.191
3	2.147
5	2.107
10	2.088

Table 5: Porosity variation with depth

Depth (m)	Porosity
0	0.480
1	0.470
3	0.450
5	0.430
10	0.420

Table 6: Over-consolidation ratio variation with depth

Depth (m)	Over-consolidation ratio	Depth (m)	Over-consolidation ratio
0	200.000	6	3.892
0.1	82.530	7	3.702
0.2	42.545	8	3.559
0.5	18.553	9	3.448
1	10.556	10	3.359
2	6.558		

Table 7: SWCC definition

Pore Pressure (kPa)	Relative Permeability	Effective Saturation	Pore Pressure (kPa)	Relative Permeability	Effective Saturation
0	1.000	1.000	-18	0.182	0.427
-0.01	0.940	0.969	-19	0.177	0.420
-0.1	0.826	0.909	-20	0.172	0.414
-0.5	0.668	0.817	-25	0.150	0.387
-1	0.577	0.760	-30	0.134	0.366
-2	0.477	0.691	-35	0.121	0.348
-3	0.417	0.646	-40	0.111	0.333
-4	0.375	0.613	-45	0.103	0.320
-5	0.343	0.586	-50	0.095	0.309
-6	0.318	0.564	-55	0.089	0.299
-7	0.296	0.544	-60	0.084	0.290
-8	0.279	0.528	-65	0.079	0.282
-9	0.263	0.513	-70	0.075	0.274
-10	0.250	0.500	-75	0.072	0.267
-11	0.238	0.488	-80	0.068	0.261
-12	0.228	0.477	-85	0.065	0.255
-13	0.218	0.467	-90	0.063	0.250
-14	0.210	0.458	-95	0.060	0.245
-15	0.202	0.449	-100	0.058	0.240
-16	0.195	0.442	-105	0.056	0.236
-17	0.188	0.434			

Loading Conditions

The test is split into three separate phases. Firstly, a suction of 100kPa is applied to the upper surface for the first part of the test lasting 1E8 seconds. Secondly, a load of 100kPa is applied directly to the nodes under the position of the footing (top left in Figure 1) over another period of 1E8 seconds. Finally, the nodes at the surface of the soil are wetted back to full saturation with this part of the test also lasting 1E8 seconds.

Theory

The aim of this example is to demonstrate the plastic collapse under the footing when wetting. This is a key feature of the BBM however, due to the complex nature of the problem there is no analytical solution to compare to. Because of this, an example using a different ‘flavour’ of the BBM has been chosen from [1].

Modelling Hints

In order to be able to apply a suction, the pore pressure at the top of the soil is initially fixed at zero while gravity is applied using the structural support for pore water pressure. To dry the soil, an applied displacement pore water pressure is applied, and this is scaled using load curves. The wetting phase resorts back to using a fixed support for the surface, and a free support under the footing.

Comparison

The behaviour of the drying, loading and wetting of the flexible footing was compared against [1] with the results from Sheng et al. shown in black and LUSAS in red/blue in Figure 2. It can be seen that the uniform shrinkage during the drying phase agrees well to the published result and good agreement is also found during the loading phase. Although some difference occurs during the wetting phase there is still clear collapse behaviour observed which would not occur without the BBM. Some differences are expected due to the model used in [1] having some variation for the LUSAS BBM. Figure 3 shows a contour plot of the final displacements while Figure 4 shows the final pore water pressures – notably it can be seen that there is still a build-up of suction beneath the footing.

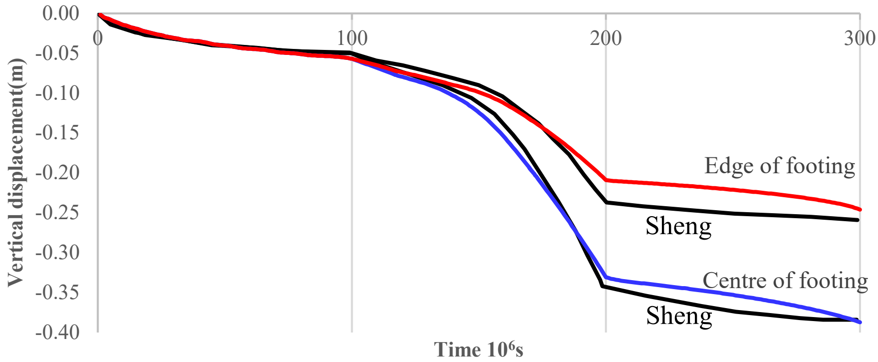

Figure 2: Displacement versus applied load

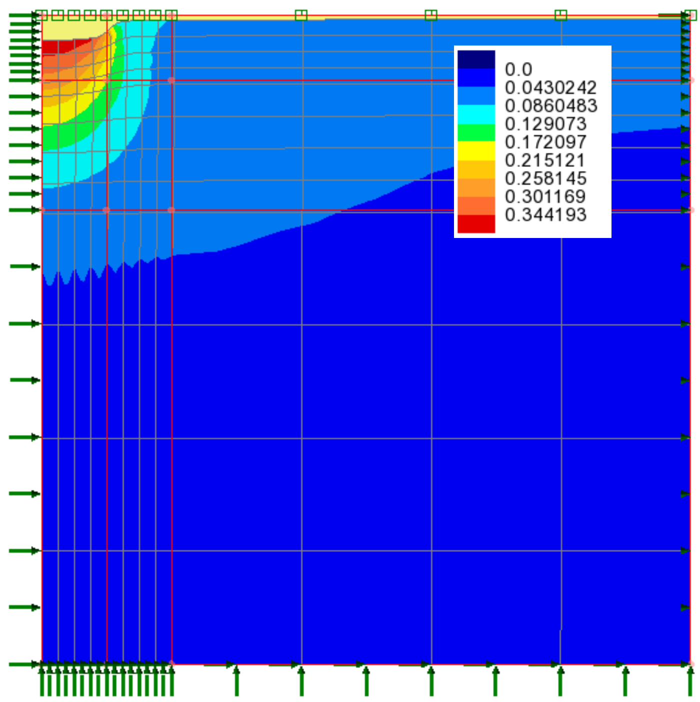

Figure 3: Displacement contours at end of wetting (m)

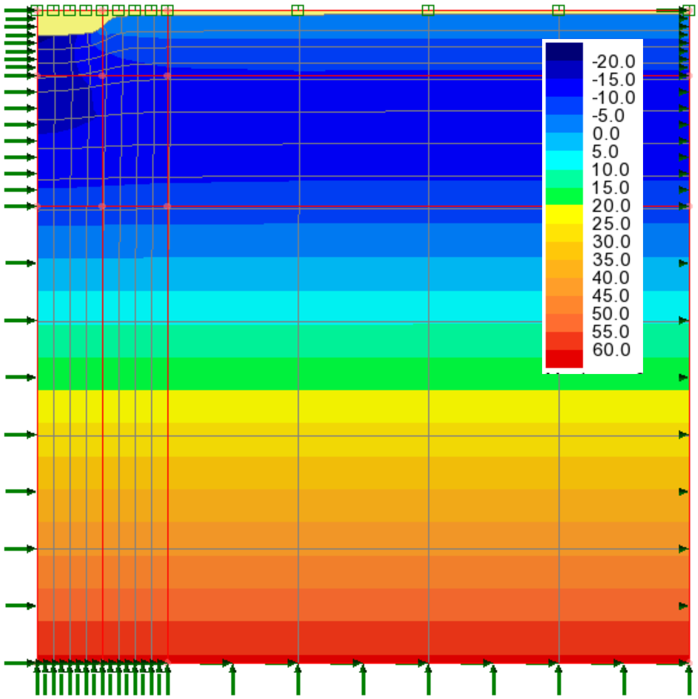

Figure 4: Pore water pressure after wetting

References

[1] Finite element formulation and algorithms for unsaturated soils. Part II: Verification and application Sheng, D, Smith D.W, Sloan, S.W. & Gens, A. Int. J. Numer. Anal. Meth. Geomech., 27:767–790 (2003).

Input Data

Strip Footing on Unsaturated Soil with BBM.mdl