Construction of a shallow waste disposal

For LUSAS version:	21.0
For software product(s):	LUSAS Bridge plus or LUSAS Civil&Structural plus
With product option(s):	Geotechnical, Nonlinear

Problem Description

This example is taken from the EC project Interclay II [1]. The particular details used in the solution are taken from Potts and Zdravković [2]. A shallow excavation is made, the walls and floor installed, the waste material placed and then covered with sand, clay and rockfill capping layers. Collapse of the waste is modelled by applying an equal load to its top and bottom. The problem geometry is shown in figure 1. The problem is symmetric about the left-hand side and is modelled in plane strain.

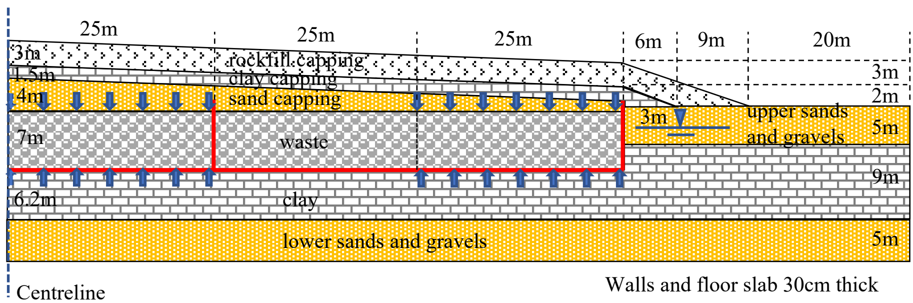


Figure 1: Problem geometry

Keywords

Two phase elements, activation, deactivation, drained/undrained, change of material properties, phreatic surface, restart, graph through 2D.

Associated Files

Associated files can be downloaded from the user area of the LUSAS website.

- ❑ **waste_disposal.lvb** carries out automated modelling of the example.

- Use **File > New** to create a new model of a suitable name in a chosen location.
- Use **File > Script > Run Script** to open the lvb file named above that was downloaded and placed in a folder of your choosing.

Objectives

This example is comprehensive including both excavation and construction as well as drained and undrained behaviour. As the results are compared with those of the original participants in the project, it is solved without interface elements between the wall and the soil. It would take a brave engineer with an unshakable belief in their FE analysis to stand below an unsupported 7m high wall which is only 30cm thick!

The example was solved using the fine integration option.

Preparing the Model Features

A new model is created, set the analysis category as 2D, and specify the model units as kN,m,t,s,C.

Preparing the Model Attributes

Defining the Mesh

- The soil is meshed by two phase plane strain, quadrilateral, quadratic elements (QPN8P).

- The waste and capping layers are meshed by plane strain, quadrilateral, quadratic elements (QPN8).

- The walls and floor slab are meshed by quadratic plane strain beam elements (BMI3N).

All elements are given a characteristic length of 1m

Defining the Geometric Properties

The diaphragm wall, internal partition wall and floor slab are all 30cm thick.

Defining the Materials

The sand, clay and rockfill are modelled by the Modified Mohr-Coulomb model (MMC) with Rankine cut-off. The walls and floor slab by linear elastic (LE) materials. Properties are given in table 1. Additional, hydraulic properties are given in table 2.

Table 1: material properties

Material	Sands and gravels		Clay	Concrete	Sand capping	Clay capping	Rockfill capping	Waste
	Upper	Lower						
Model	MMC	MMC	MMC	LE	MMC	MMC	MMC	LE
Density (t/m^3)	2.039	2.039	2.039	2.446	2.039	2.039	2.039	3.058
Young's Modulus (MPa)	25	100	15	Wall and slab 560000 Part.wall 28000	25	5	2500	10
Poisson's ratio	0.2	0.2	0.3	0.15	0.2	0.2	0.2	0.2 collapse 0.0
Friction angle (^{o})	35	35	28	-*-	35	25	40	-*-
Dilatancy angle (^{o})	17.5	17.5	7	-*-	17.5	0	20	-*-
Cohesion (kPa)	1	1	1	-*-	1	1	1	-*-
K_0	0.5	1.0	1.0	-*-	0.5	0.8	0.5	-*-
Tensile cutoff (kPa)	0	0	0	-*-	0	0	0	-*-
Porosity	0.2	0.2	0.2	-*-	-*-	-*-	-*-	-*-
Hydraulic conductivity (m/day)	0.1	0.1	$1x10^{-5}$	-*-	-*-	-*-	-*-	-*-
Saturation	Partial	Full	Full	-*-	-*-	-*-	-*-	-*-

Table 2: hydraulic properties

Bulk modulus water	Density fluid	Saturation at residual water content	Saturation at full water content
$2.1x10^6$ kPa	1 t/m^3	0.0	1.0

The upper layer of sand and gravel is partially saturated with properties defined above and below the phreatic surface. The clay and lower sand layers are fully saturated. It is very important not to assign partially saturated properties to these layers as during the undrained stages of the solution large negative pore pressures are generated which would be interpretated as a change in saturation if partially saturated properties are assigned resulting with the loss of the stabilising suction force.

Running the Analysis

Initial Conditions

Initial K_0 ground conditions are established under gravity loading. The phreatic surface, defined on the righthand side of the model, is used to set the ground water conditions (figure 2) by setting the porewater pressures along the edge and bottom of the model, the lines of which are highlighted in black. The wall, floor slab, waste and disposal capping are all deactivated.

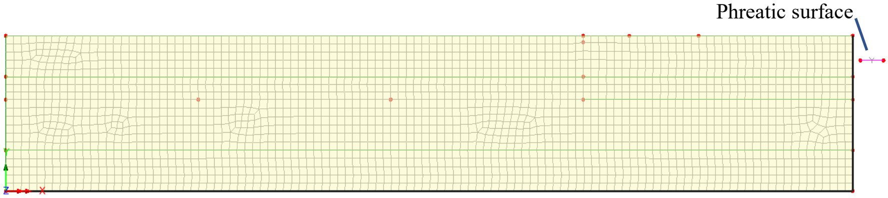


Figure 2: Initial conditions

Install perimeter wall

The perimeter wall is activated (figure 3).

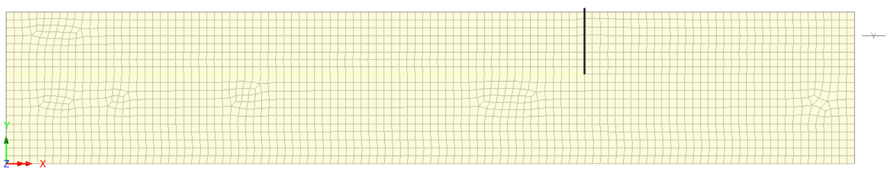


Figure 3: Installation of wall

The perimeter wall is modelled by beam elements sandwiched between two continuum elements representing the soil. There is an overlap of the areas occupied by the beam elements and that occupied by the continuum elements leading to double counting of the weight of soil and wall (figure 4). To mitigate the effect of double counting, the density of the wall is changed at different stage of the solution. When the wall is activated the difference in density between the wall and the soil is used ($0.407t/m^3$=2.446-2.039). When the disposal is excavated, the soil on the inside of the wall is removed so the wall density is increased to $2.854t/m^3$ and finally when the waste is deposited the density is set to zero. This is because the average density of the waste and soil exceeds that of the concrete wall. No changes were made to the floor slab because the double counting of the weight of the floor is not large compared to the other vertical loads from the waste and capping layers.

Obviously, for thick walls modelled by beams this is an important consideration but as the wall gets thicker using continuum elements becomes an attractive option.

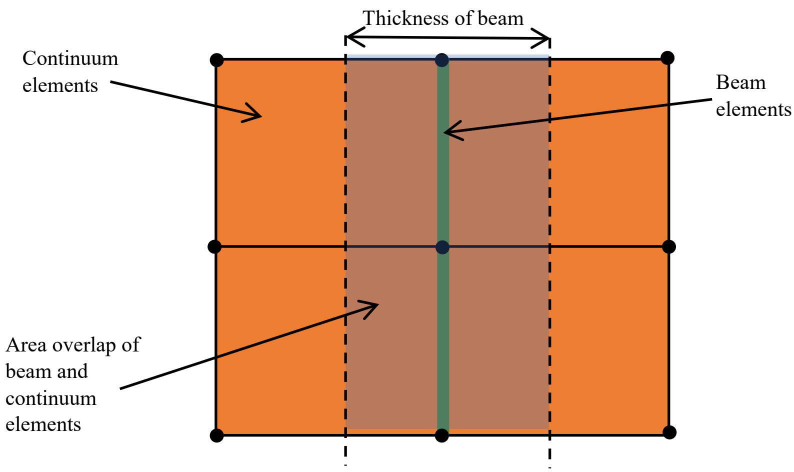


Figure 4: Double counting of beam area in weight calculations

Undrained excavation

The clay layer is set to undrained and the soil excavated (figure 5). As the excavation proceeds the stress applied to the clay is reduced and the soil expands. The undrained conditions result with negative suction stresses developing in the clay. The pore water pressures in the drained sand and gravel layers do not change.

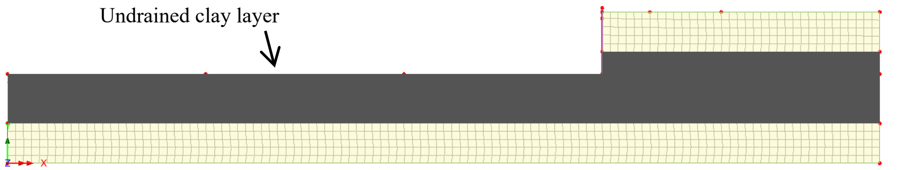


Figure 5: Undrained excavation

Installation of floor slab and partition wall

The floor slab and partition wall are active (figure 6).

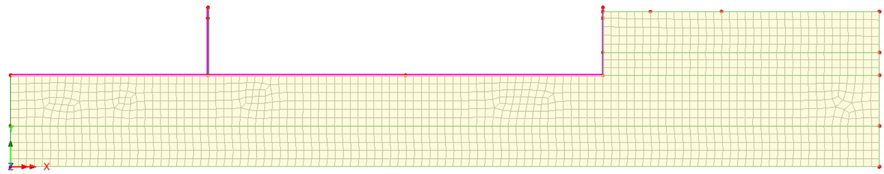


Figure 6: Installation of floor and partition wall

Dissipate excess pore water pressure

The excess pore water pressure, or in this case suction, is allowed to dissipate. To do this, the undrained clay layer is assigned drained properties; the original pore water pressures are reassigned to the boundary lines marked in black in figure 7, and the pore water pressures under the slab are set to zero.

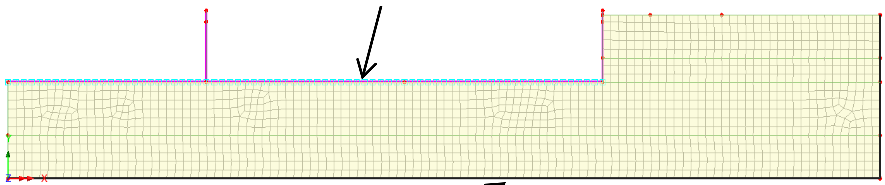


Figure 7: Boundary conditions for dissipation of excess pore water

Fill waste

The clay layer is again assigned undrained properties. The waste is then activated and the gravity load gradually applied over the stage (figure 8).

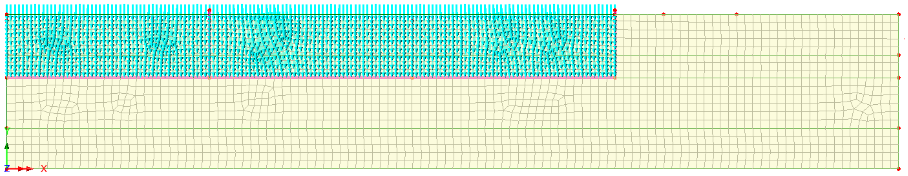


Figure 8: Fill disposal with waste

Add sand capping

The sand capping is added in a single increment (figure 9).

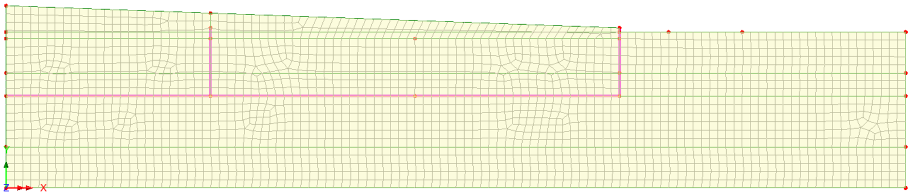


Figure 9: Add sand capping

Add clay capping

The clay capping is added in a single increment (figure 10).

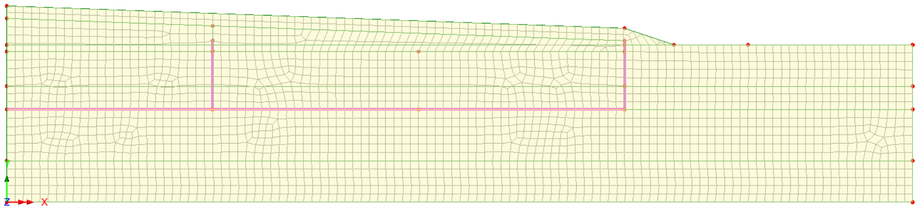


Figure10: Add clay capping

Add rockfill capping

Add rockfill capping in a single increment (figure 11)

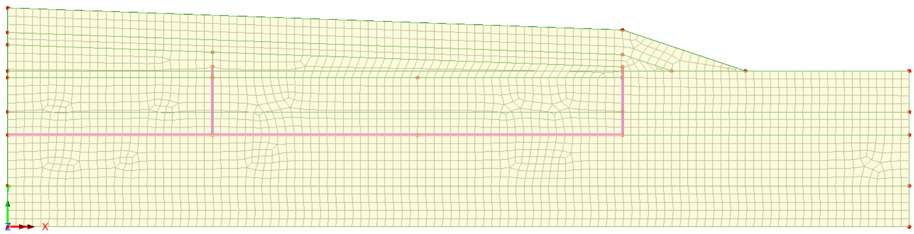


Figure 11: Add rockfill capping

Dissipate excess pore water pressures again

The excess pore water pressure is allowed to dissipate. To do this, the undrained clay layer is assigned drained properties; the original pore water pressures are reassigned to the boundary lines marked in black in figure 12, and the pore water pressures under the slab are set to zero.

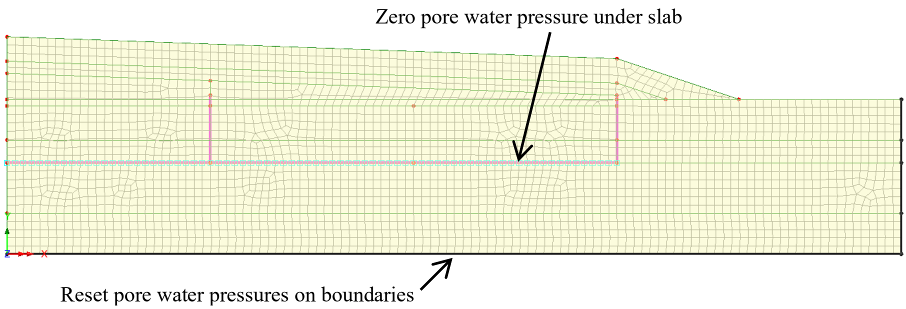


Figure 12: Dissipate excess pore water pressures

Collapse waste

The Poisson's ratio of the waste is set to zero and a uniform load applied to the top and bottom (figure 13). Automatic loading is used to increase the load to 125 MPa.

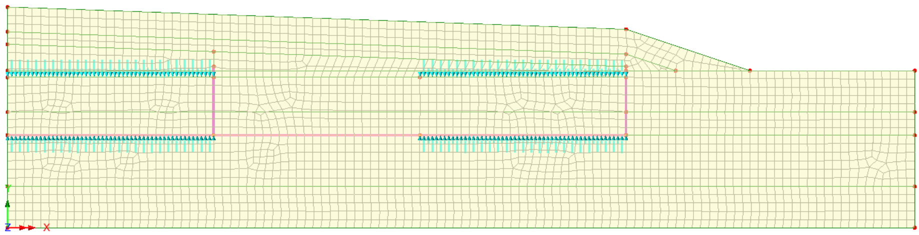


Figure 13: Load applied to collapse waste

A global distributed load is used rather than a face load because the boundaries of the waste are not exactly straight at activation following the displacement of the slab and walls during earlier stages of the analysis.

It is convenient to display just the waste when assigning the collapse loads (figure 14).

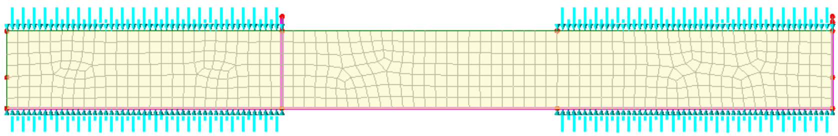


Figure 14: Apply loads with just the waste visible

Viewing the Analysis

Figure 15 shows the suction pressures at the end of the undrained construction of the waste disposal. The red zone marks areas for which the pore water pressure is greater than zero. Under the slab and at the bottom of the perimeter wall large suction pressures are generated by the undrained loading of the clay. At the top of the wall, the upper sand and gravel layer is drained and does not apply any suction. The water in the saturated part of the sand does, however, apply a small hydrostatic pressure. Figure 16 shows the long term or steady state flow conditions established once the pore water has had time to fully infiltrate the clay layer.

The waste disposal is then filled and capped. Figure 17 shows the excess pore water pressures generated in the clay layer with the long term, steady state pressure distribution shown in figure 18. Figure 19 shows the vertical stress distribution after the application of the collapse load.

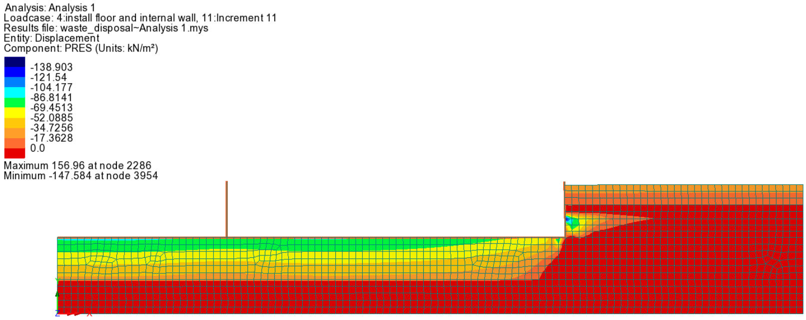


Figure 15: Suction pressure after installation of floor slab and partition wall

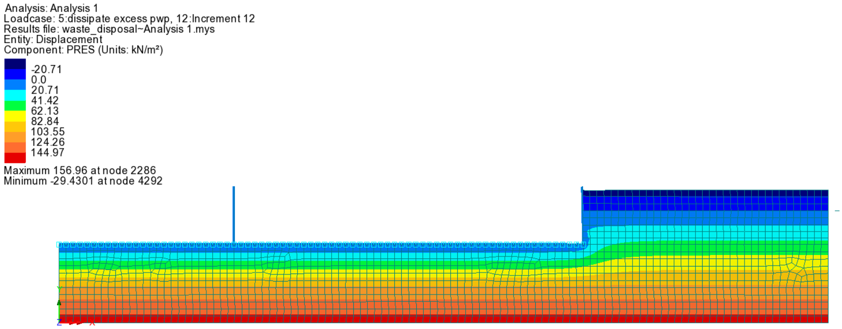


Figure 16: Steady state pore water distribution

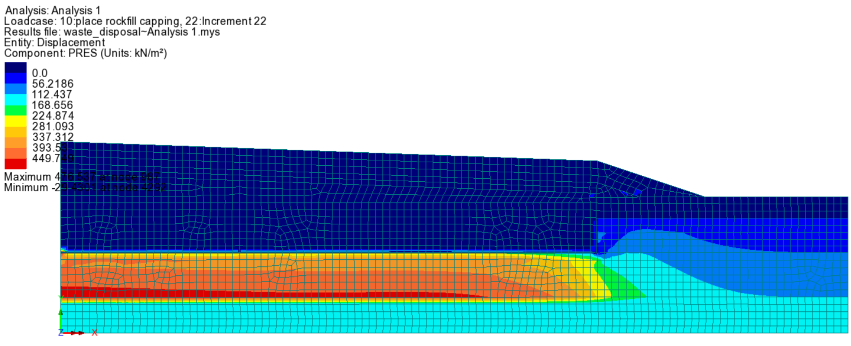


Figure 17: Excess pore water pressure at end of loading

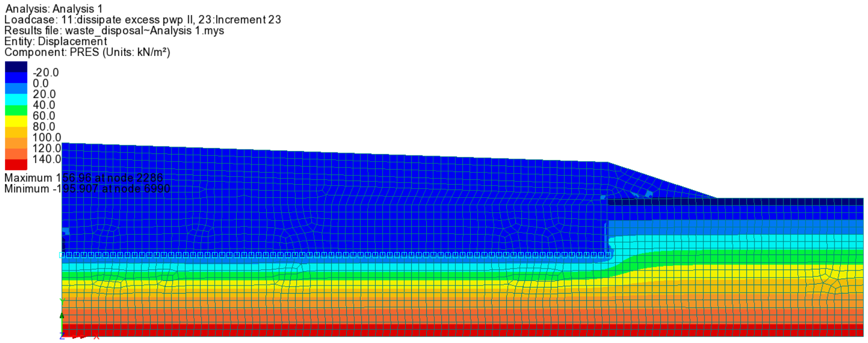


Figure 18: Steady state pore water pressure at end of loading

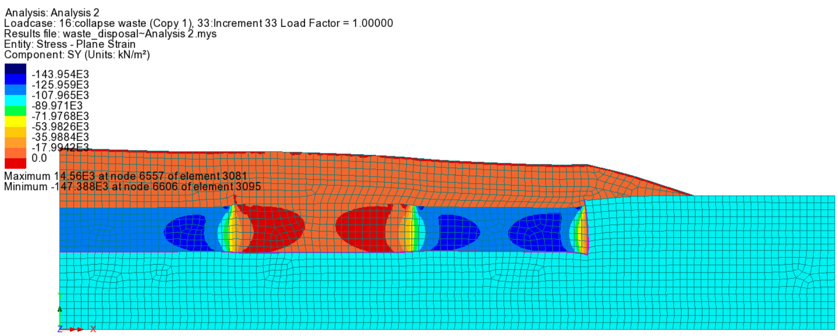


Figure 19: Vertical stress distribution after collapsing waste

Figure 22 plots the displacements below the slab. These are extracted from the model using the **Utilities > Graph through 2D…** dialog show in figure 20. The grid offset is set to (0,11.2) so that the horizontal distance is measured from the centreline along the floor of the excavation. Figure 21 illustrates the generation of the section line using the cursor.

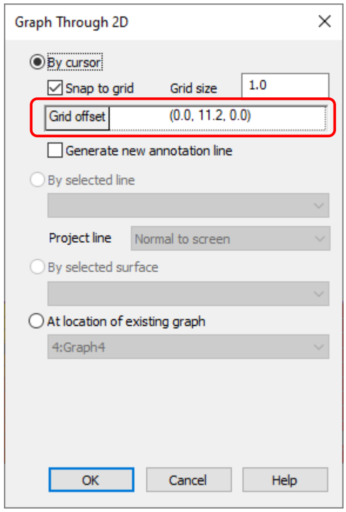


Figure 20: Graph Through 2D

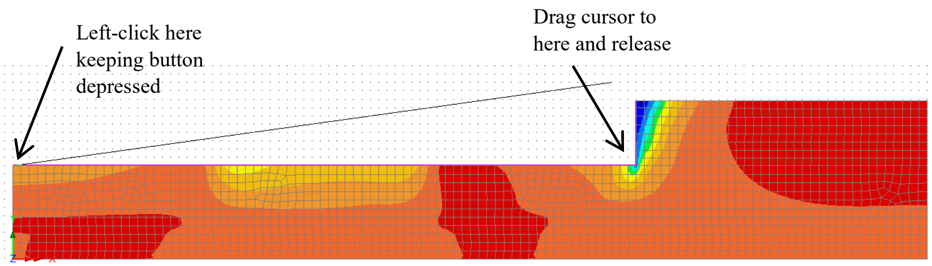
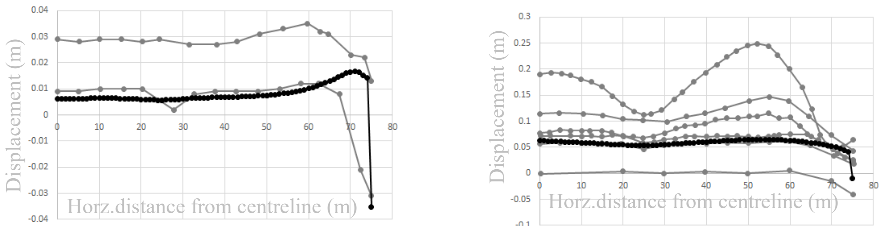


Figure 21: Generation of section line

The grey points in figure 22 are data points taken from figures in Potts and Zdravković [P1] and are results for unidentified participants in the Interclay II project. The black points are the LUSAS solution. Other than noting that the grey points show that the LUSAS results are comparable to other software, the other results will not be considered further in the following.

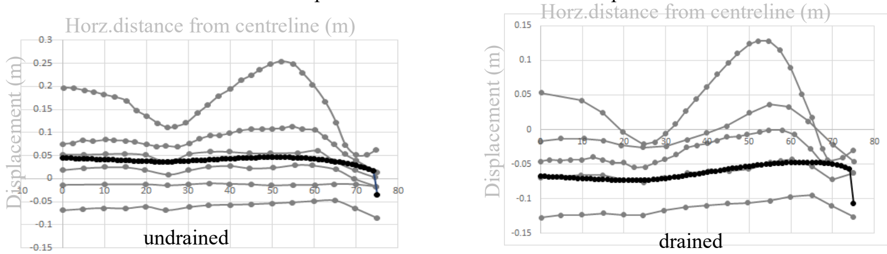
The two plots in the first row in figure 22 show the slab displacements after construction of the waste disposal walls and floor. For the undrained stage the results show a very small displacement of a few millimetres. Under the perimeter wall the displacement increases sharply as the point carries addition weight. Over time, as the ground water is drawn in the suction pressure decreases and the soil expands lifting the slab by approximately 5cm.

In the second row of figure 22 the slab displacements following the filling of the disposal and its capping are shown. During undrained loading there is a settlement of about 2cm which increases by a further 11cm as the excess pore water pressures dissipate.

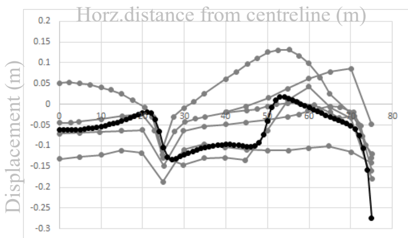


undrained drained

Slab displacement after construction of disposal



Slab displacement after filling and capping of disposal



Slab displacement after collapse of waste

Figure 22: Slab displacements at different solution

The final plot of the slab displacement (figure 22) is for the collapse of the waste. The expected results would be that there is little to no change in displacement as long as the waste weight does not increase, perhaps, with some redistribution of the mass causing some small changes.

The application of a load, top and bottom, to the waste was adopted as a convenient way to collapse the waste for the participants in the project. In the absence of shear from the partition wall, applying the load to the uncompressed waste might have produced a reasonable solution but in fact large displacements result. The FE mesh is continuous both along the top edge of the waste with the sand capping and along the bottom edge with the slab. The majority of the collapse load is carried by the stiffer material, which is the waste at the top and the slab at the bottom. This results with the collapse load pulling the slab upwards at points where the upper collapse load has not been fully transmitted downwards.

Finally, figure 23 shows the position of point B at which the displacements are compared in figure 24. The results of the participants in Interclay II are drawn in grey and those of LUSAS in black.

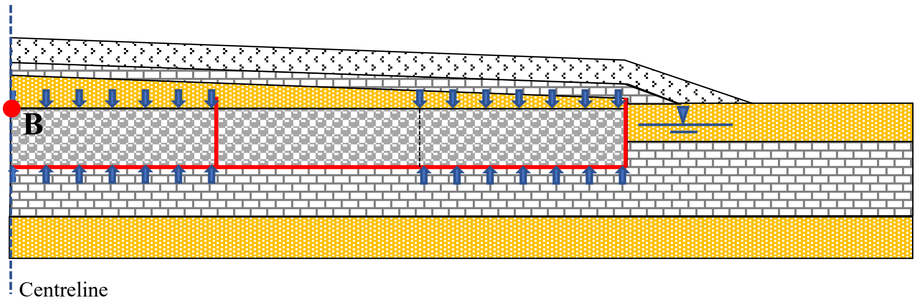


Figure 23: position of point B

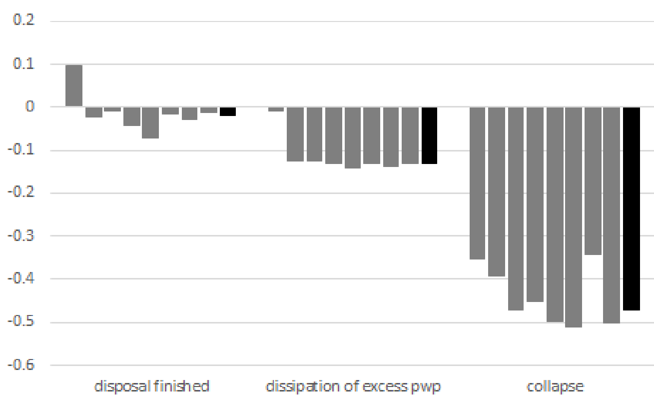


Figure 24: Comparison of displacements at point B for different stages

REFERENCES

I1 Interclay II, EUR 15285, 1993.

P1 Potts D.M. and Zdravković, Finite element analysis in geotechnical engineering application, Thomas Telford Books, 2001.