Soft Ground Coupled Consolidation

1 Introduction

This example is about constructing an embankment in delayed stages on a soft foundation so that some of the excess pore-pressure is allowed to dissipate before subsequent lifts are placed.

The soft foundation is modeled using the non-linear Modified Cam-Clay (MCC) constitutive relationship.

2 Problem configuration and setup

The problem configuration is presented in Figure 1. The embankment is five metres high and the side slope is 3h:1v. The embankment is to be constructed in five lifts, each one metre thick.

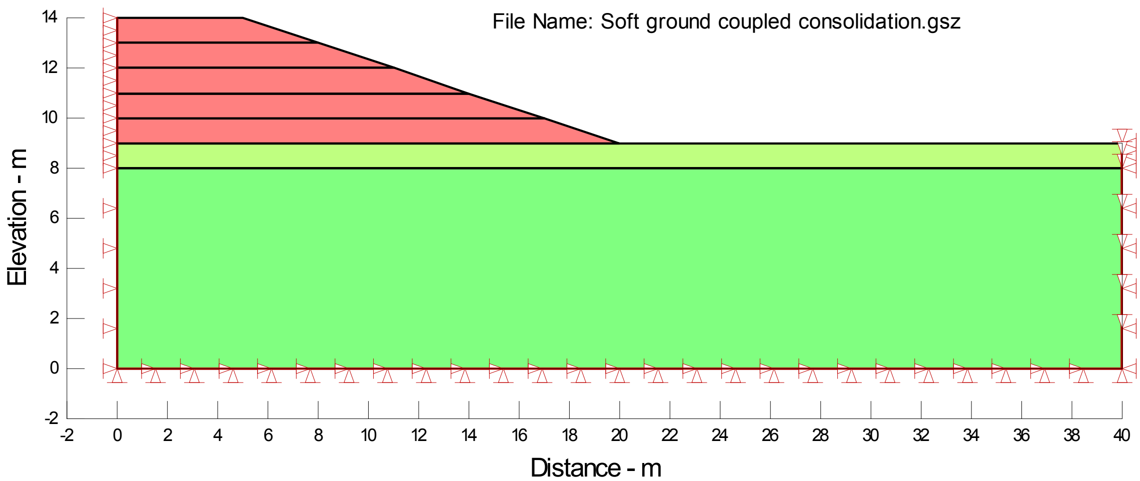

Figure 1 Problem configuration

The upper metre of the foundation is considered to be desiccated, fractured and over-consolidated. The fractured nature of this crust is believed to be such that it gives the soil a high permeability, and is porous enough that the water table will at all times remain 1 m below the original ground surface.

The foundation soil is slightly over-consolidated. The OCR ratio is 1.2 and the initial void ratio is 1.5.

The embankment material is considered to be granular and will not develop any excess pore-pressure due to loading.

3 Insitu conditions

Since the foundation soil will be modeled using the MCC soil model, it is mandatory to establish the state of stress in the ground before the embankment loading starts. Remember that the past stress conditions are required to establish the starting yield surface for the MCC model.

The initial starting pore-pressure conditions are defined with a watertable 1 m below the original ground surface.

For the insitu analysis, the foundation soil is treated as being linear elastic with Poisson's ratio equal to 0.334. This converts to a K_o value of 0.5.

4 Embankment material

The embankment material is treated as a relatively soft Linear-Elastic material with an activation pore-pressure (suction) of -10 kPa.

The properties of the embankment material are not considered to be all that relevant, and therefore are kept to be fairly simple. The prime purpose here is to look at the pore-pressure in and consolidation of the soft foundation. There is no need to unnecessarily complicate the analysis with a non-linear soil model for the embankment soil.

5 Hydraulic boundary conditions

The hydraulic boundary condition is specified around the perimeter of the desiccated crust, as illustrated in Figure 2. The boundary condition is H = 8 m. This makes the pore-pressure zero at the initial watertable position and -10 kPa at the original ground surface. This boundary condition is maintained for all the loading analyses.

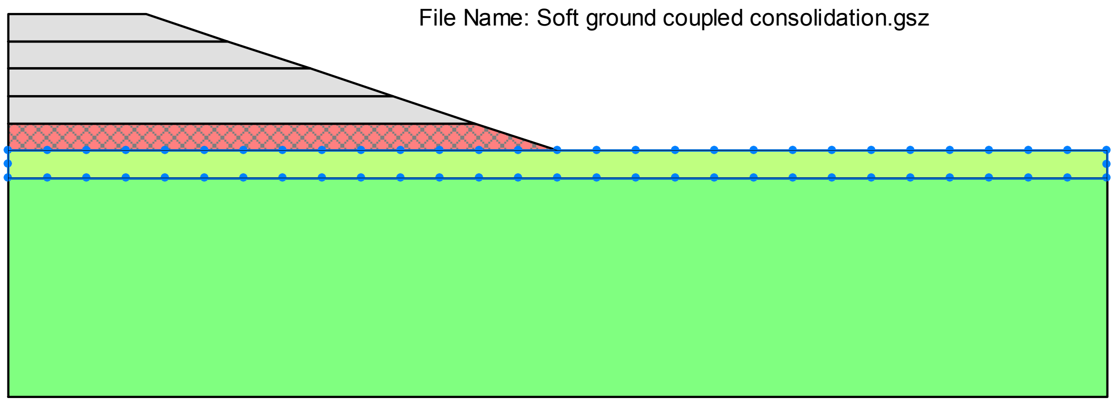

Figure 2 Hydraulic boundary condition

6 Analysis tree

The analysis sequencing and steps are illustrated by the analysis tree in Figure 3.

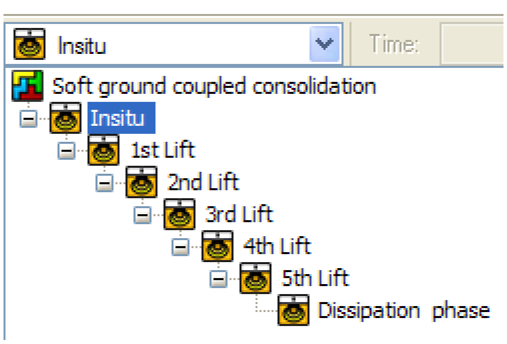

Figure 3 Analysis tree

The duration for each lift is 6 days. The lift is placed on the first day, and then an additional 5 days are allowed for consolidation.

The final lift is placed on Day 25 and then pore-pressures are allowed to dissipate for 35 days.

7 Pore-pressure response

The pore-pressure response 1 m below the desiccated crust and 1 m off the center-line is shown in Figure 4. As is clearly evident, the pore-pressure rises as each lift is placed and then dissipates with time. Eventually, the pore pressure would revert back to the initial insitu conditions, but the analysis has not been run long enough here to reach that position.

Of interest is the response that the maximum pore-pressure actually occurs when the 4th lift is placed, not when the final and 5th lift is placed. The difference is small, but it is of interest because it is likely for most counter-intuitive.

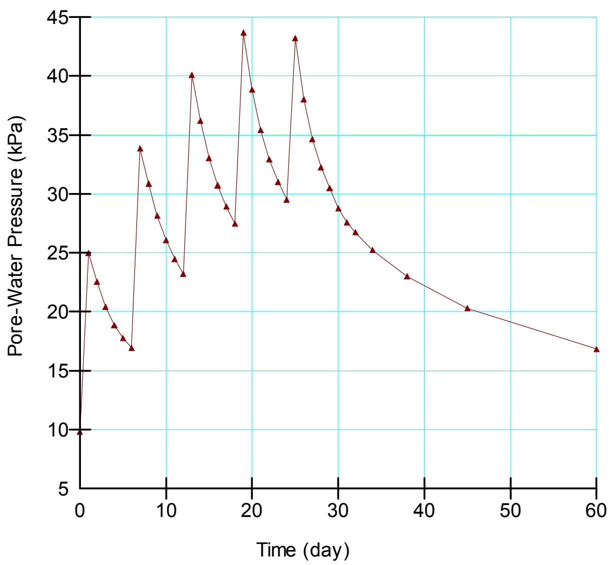

Figure 4 Pore-pressure response beneath the center of the embankment

Figure 5 presents the pore-pressure build-up along a profile at the center-line of the embankment. Worth noting is that the pore-pressure remains zero at the original watertable position and the pore-pressure in the embankment soil is equal to the specified activation pressure equal to -10 kPa.

Figure 6 shows the final dissipation stage as the conditions migrate back to the initial hydrostatic conditions.

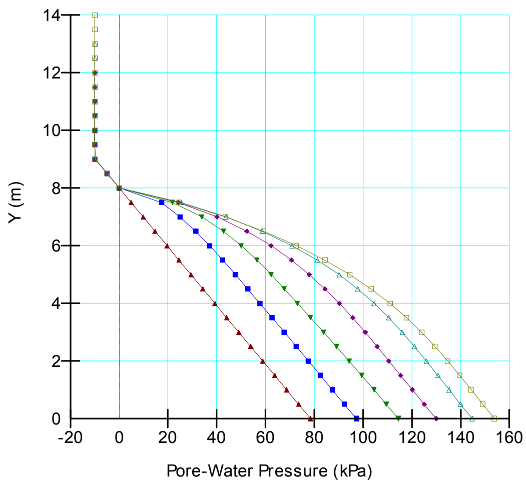

Figure 5 Pore-pressure build up along center-line profile.

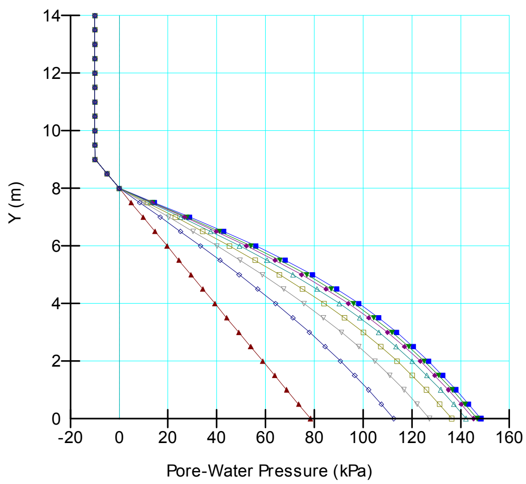

Figure 6   Final dissipation stage

8   Settlements

The settlement along the original ground surface on Day 6 is shown in Figure 7. Of interest is that the maximum settlement is not under the center of the embankment, but about 5 m in from the embankment toe. This is due to the two-dimensional flow or two-dimensional consolidation as indicated by the flow vectors in Figure 8. There is some lateral flow where the settlement is the maximum but under the center-line the flow is all upward. This illustrates the benefits of a 2-D consolidation analysis.

Eventually, the settlement is the maximum at the center-line, as shown in Figure 9.

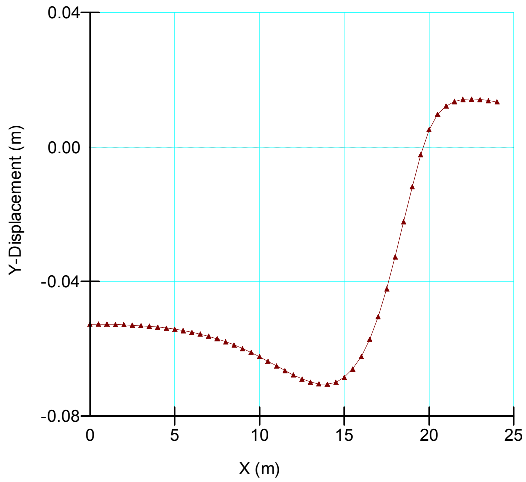

Figure 7 Settlement along original ground surface

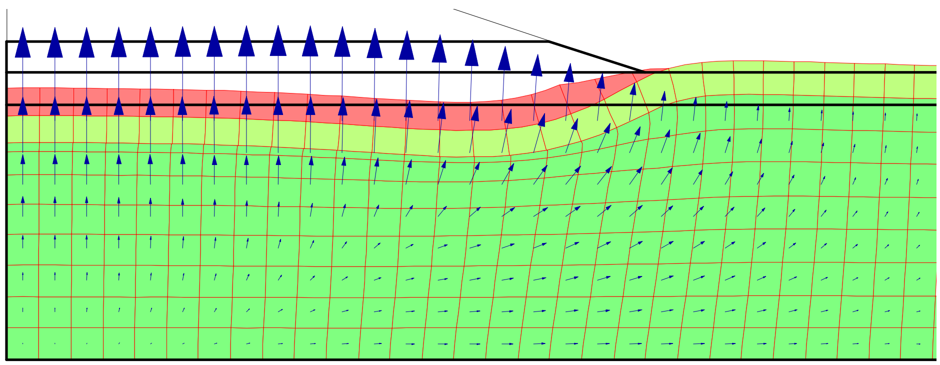

Figure 8 Two-dimensional flow vectors on Day 6

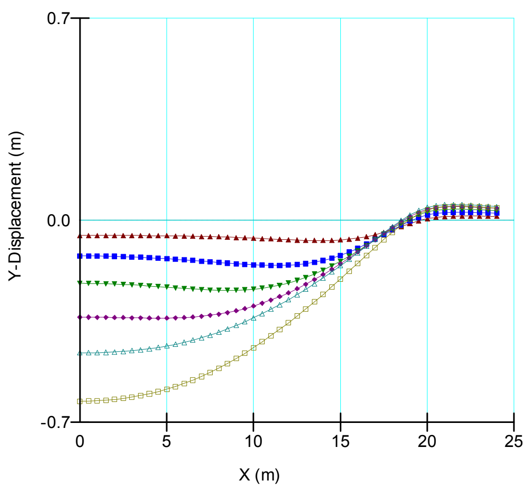

Figure 9 Settlement with time along the original ground surface

9 Excess pore-pressures

A movie is included that shows how the excess pore-pressures develop and dissipate with time. Watching the movie provides a good mental image of the time-dependent process.

10 Concluding remarks

This example clearly demonstrates the power of doing a coupled consolidation analysis with staged loading and dissipation.

The pore-pressures at any stage could now be used in SLOPE/W to check on the stability. Also, an analysis could be done by placing all the fill at once, and then checking on the stability. These types of analyses are left up to the reader as an exercise.