Excavation below a Watertable

1 Introduction

This example is about making an excavation below the watertable. The prime objective is to look at the change in pore-pressures and the possibility of creating negative pore-pressures due to the unloading.

A secondary purpose is to demonstrate and check on the use of a moving hydraulic boundary condition on the excavation face. The pore-pressures on the excavation face are unknown – they could be negative, or it is possible that a seepage face could develop. Regardless, a special algorithm is required to establish the correct boundary condition as part of the solution.

2 Problem configuration and setup

The problem configuration is rather simple for this illustrative example, as shown in Figure 1. The soil will be excavated in four stages, with each stage taking away two metres. The initial watertable is 2 m below the ground surface.

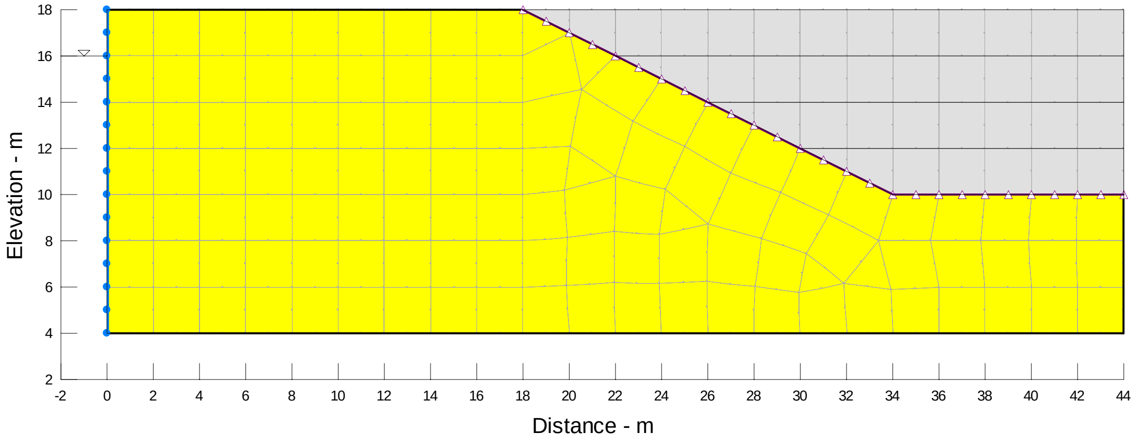

Figure 1 Problem configuration

Throughout the excavation process, and in the long term after the excavation has been completed, it is assumed that the watertable on the left remains at the 16-m level. That is, the hydraulic boundary condition on the left remains the same at all times.

The soil is treated simply as being Linear-Elastic, and Poisson's ratio is equal to 0.334 (1/3). The influence of Poisson's ratio will be discussed below.

The hydraulic properties used for this analysis are entirely arbitrary, selected purely for illustrative purposes. They can be viewed and inspected in the GeoStudio data file.

Important to this type of analysis, is the hydraulic boundary condition on the seepage face. The boundary condition must be a no-flow (Q=0) boundary condition with a potential seepage face.

The analysis here is a fully coupled SIGMA/W analysis.

3 Initial insitu conditions

As with all excavation analyses, the first step in the analysis process is to establish the insitu conditions. Recall that for a 2-D plane strain analysis,

$$K_o = \frac{\nu}{(1-\nu)}$$

So, with ν equal to 1/3, K_o is 0.5. The total unit weigh of the soil has been set equal to 20 kN/m^3, and the unit weight of water is at 10 kN/m^3. These values make it easy to spot check and discuss the results.

4 Pore-pressure response

As is well known, when a saturated clayey soil is loaded, all or part of the load initially goes into the pore-pressure, and then the pore-pressure decreases as the soil consolidates. The reverse is true if the soil is unloaded. The unloading can cause the pore-pressure to become negative and then increase with time as the soil swells. This response is evident in this excavation example.

Figure 2 shows the pore-pressure contours one day after removal of the 2nd layer. Notice that the zero-pressure contour is well below the excavated surface; in fact, the negative pore-pressure is more than -20 kPa below the base of the excavation.

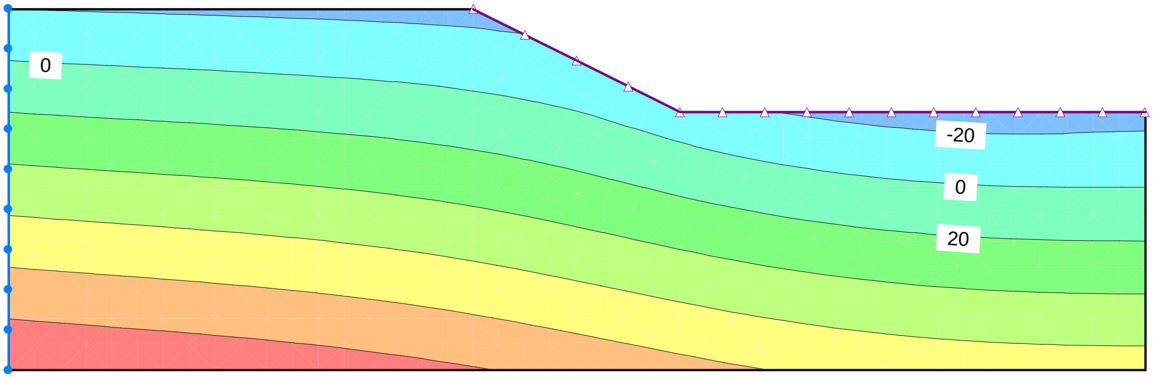

Figure 2 Pore-pressure contours after removing the 2nd layer

Figure 3 shows the pore-pressure conditions one day after the 4th layer has been removed. Negative pore-pressures still exist, but a seepage face has started to develop at the toe of the cut.

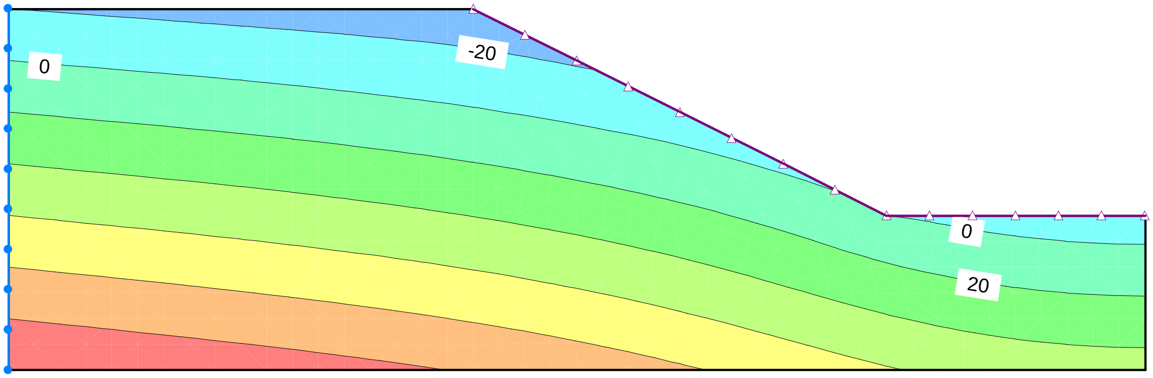

Figure 3 Pore-pressure contours after removing the 4th layer

Figure 4 shows the long term conditions about 2 months (60 days) after the excavation was completed. Now the pore-pressure distribution represents a long-term steady-state seepage condition. There is a seepage face (zero pore-pressure) at the cut toe and along the base of the excavation; the same as what one would get from a steady-state SEEP/W analysis.

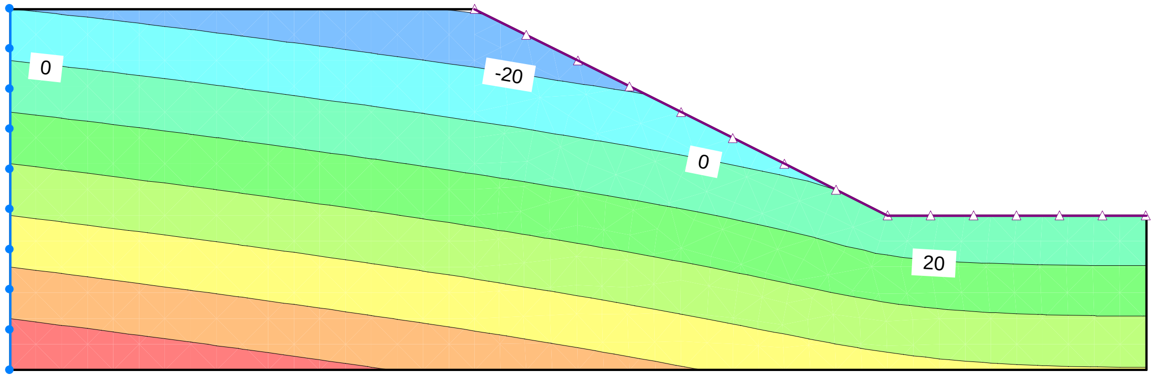

Figure 4 Pore-pressure contours at the end on Day 80

Another way to look at the results is to plot the pore-pressure at a particular location for the duration of the analysis. Figure 5 shows the pore-pressure with time at a location just below the final excavation level and slightly to the left of the final cut toe. Note how the pore-pressure decreases each time a layer is removed and recovers with time.

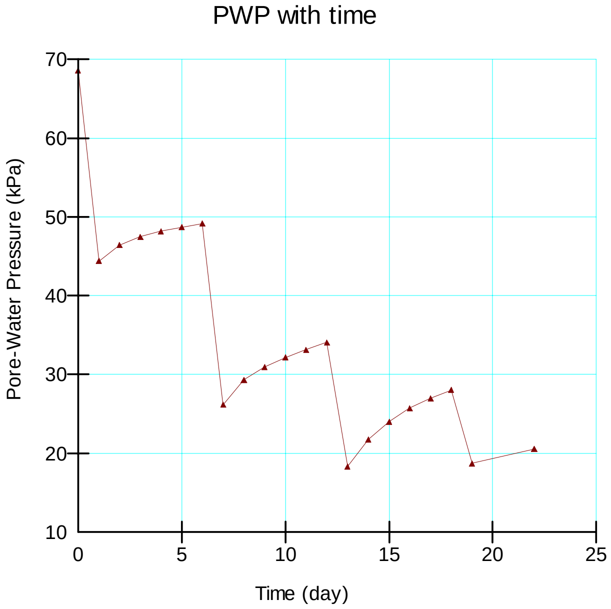

Figure 5 Pore-pressure with time below and to the left of final cut toe

Figure 6 shows the pore-pressure changes at the final cut toe. Notice that the pore-pressure goes to zero, since a seepage face has developed at that location.

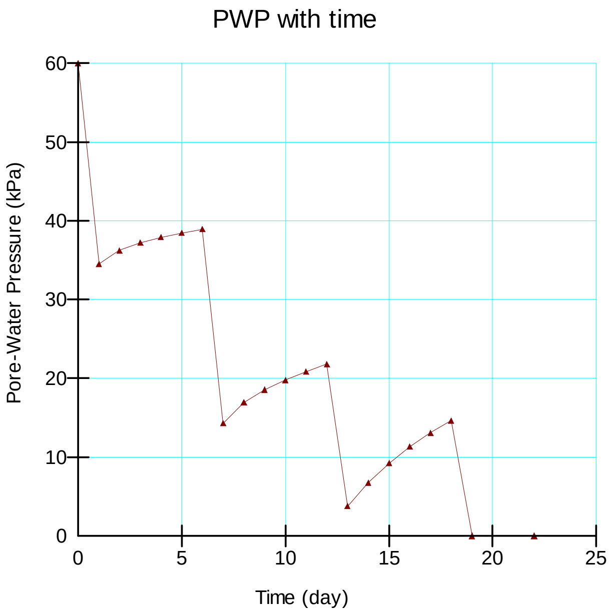

Figure 6 Pore-pressure with time at final cut toe

Special mention must be made of how to look at the excess pore-pressures in a case like this. Figure 7 shows the excess pore-pressure at the final cut toe. The graph indicates that the excess at the end is -60 kPa. The initial pore-pressure before excavation started was +60 kPa. The amount of change is -60. So, the sum of the initial plus the change results in zero, which is the final pore-pressure. In this case, the excess pore-pressure is actually the change in pore-pressure.

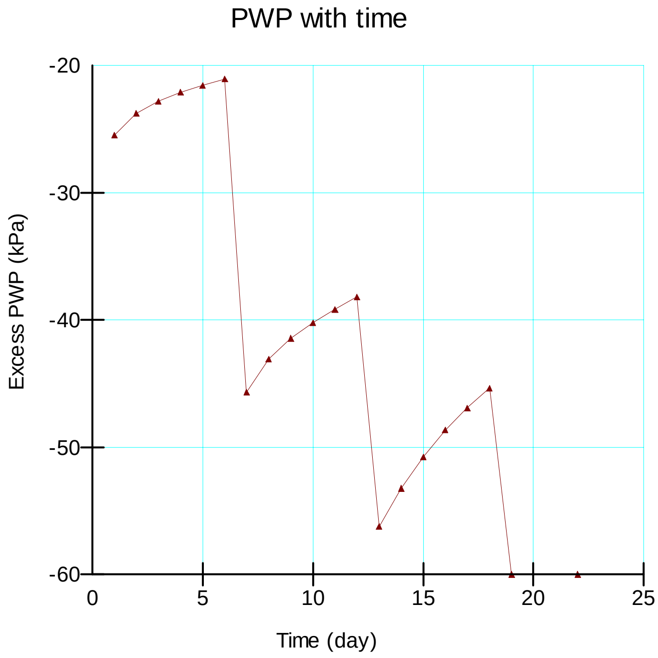

Figure 7 Excess pore-pressures at the final cut toe

5 Bulk modulus

The pore-pressure response is influenced to some extent by the bulk modulus, which is defined as,

$$K_b = \frac{E}{3(1-2\nu)}$$

When Poisson's ratio ν is one-third (1/3), K_b is equal to E. That is, the bulk modulus is equal to the soil stiffness modulus E. Physically, this means that the stiffness of the soil plus the water is equivalent to the stiffness of the soil grain structure.

If we assume water is completely incompressible ν is 0.5, and then K_b goes to infinity.

Under field conditions, water likely always has some entrained air bubbles and therefore is never completely incompressible, and therefore K_b has some finite value even for saturated conditions.

This example was re-run with ν equal to 0.45 (data file and results are not included).

The follow two graphs show the difference in pore-pressure response when ν is changed from the earlier 0.334 to 0.45. Generally, the pore-pressures remain elevated longer all else being the same.

We recommend that you start with ν equal to one-third to establish a base case. Then you can try other ν values to determine what the effect is of considering different K_b values.

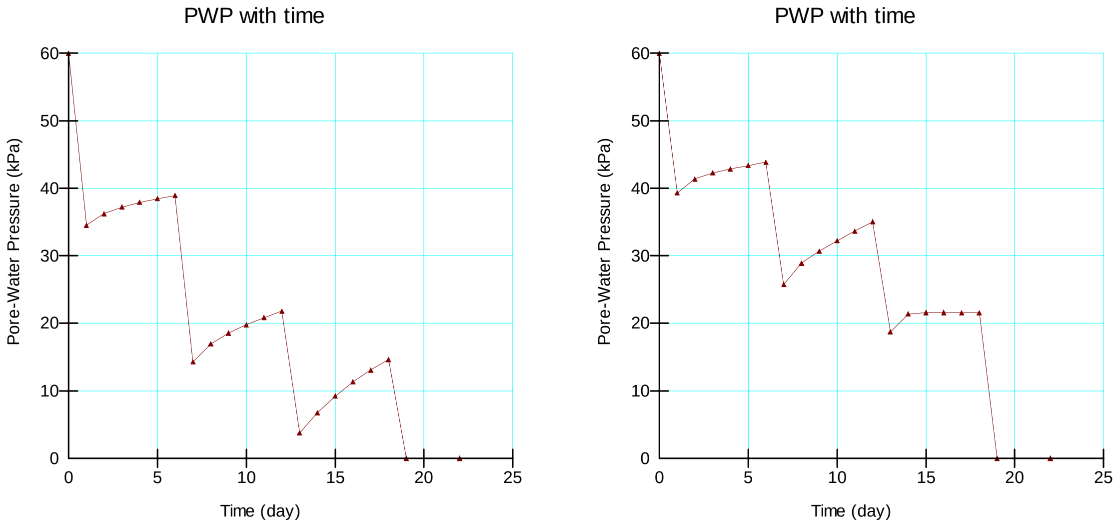

Figure 8 Pore-pressure comparisons with *v* = 0.334 and 0.450

The most important parameter when it comes to real time calculations is the hydraulic conductivity. You should resolve what conductivity is appropriate and the effect it has on the solution before being too concerned about the bulk modulus.

6 Concluding remarks

This example demonstrates that SIGMA/W has all the capabilities and features to analyze the case of making an excavation below the water table, and to correctly compute the pore-pressure response.

Critical to this analysis is the ability to accommodate a moving hydraulic boundary condition where the extent of a potential seepage face comes from the solution.