48 EMBANKMENT CONSTRUCTION – PART 1

The following two sections describe the analysis of an embankment (see Figure 48.1) to be constructed on a soft soil overlaying a layer of dense sand. The soft soil is modeled by means of the Modified Cam Clay model whereas the embankment fill and the dense sand layer are modeled as Mohr-Coulomb materials. For full details of the material parameters used, please refer to the accompanying input file that can be accessed via the welcome window in OptumG2 or via File/Examples.

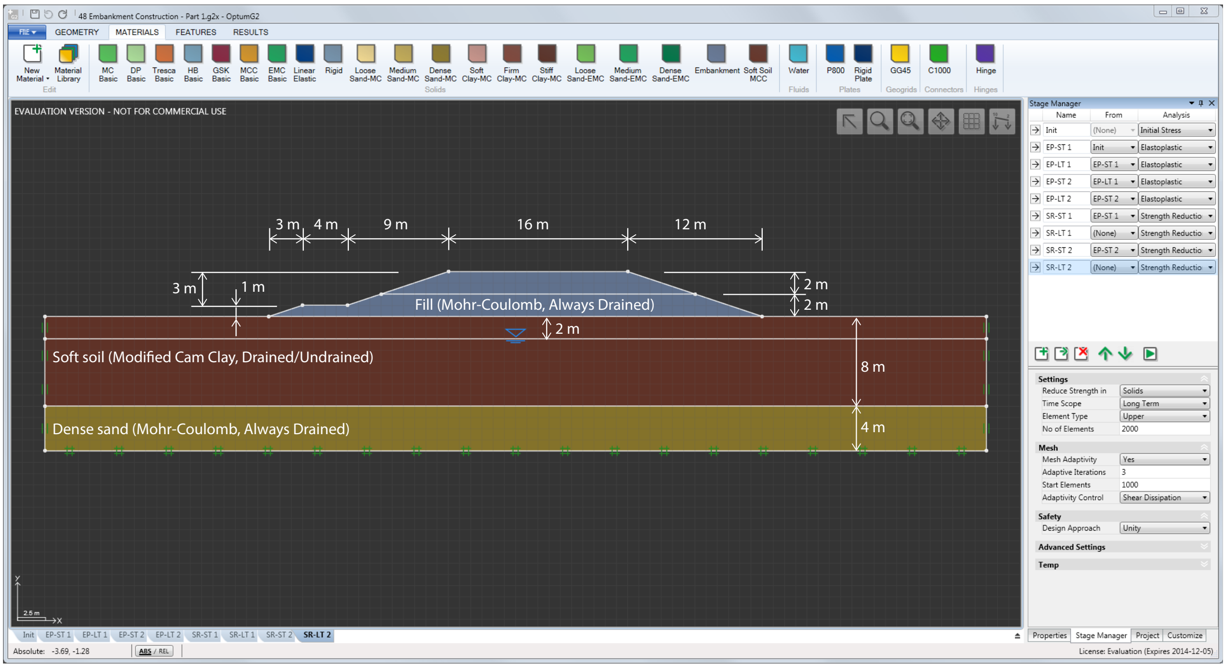

Figure 48.1: Embankment construction: problem setup.

The embankment is constructed in two stages, each 2 m in height as indicated in the figure above. Between each stage, the underlying soft soil is left to consolidate. This type of analysis can be carried out using Consolidation. However, if only the settlements immediately after construction of each stage and the ones induced as a result of full consolidation are of interest, Elastoplastic analysis may be used. That approach is the subject of this section while the time dependent consolidation is covered in the next.

The analysis proceeds by way of five stages:

1. An Initial Stress stage to determine the in-situ stresses and steady state seepage pressures before construction.

2. An Elastoplastic stage, starting from 1 and with Time Scope = Short Term, to simulate the first 2 m of construction.

3. An Elastoplastic stage, starting from 2 and with Time Scope = Long Term, to account for the effects of full consolidation.

4. An Elastoplastic stage, starting from 3 and with Time Scope = Short Term, to simulate the next 2 m of construction.

5. An Elastoplastic stage, starting from 4 and with Time Scope = Long Term, to account for the effects of full consolidation.

In addition, five Strength Reduction stages are used to gauge the factor of safety at various stages of the construction:

I. A Strength Reduction, starting from 2 and with Time Scope = Short Term, to determine the factor of safety immediately after the first construction stage.

II. A Strength Reduction with Time Scope = Long Term to determine the factor of safety after consolidation of the first construction stage.

III. A Strength Reduction, starting from 4 and with Time Scope = Short Term, to determine the factor of safety immediately after the second construction stage.

IV. A Strength Reduction with Time Scope = Long Term to determine the long term factor of safety after consolidation of the second construction stage.

V. A Strength Reduction, starting from 5 and with Time Scope = Short Term, to determine the short term factor of safety after consolidation of the second construction stage.

In this example, the majority of the deformations take place in the two long term stages 3 and 5. The stage displacement of these two stages are shown below. The vertical displacement of the center of the embankment is about 17 cm in each of the two stages.

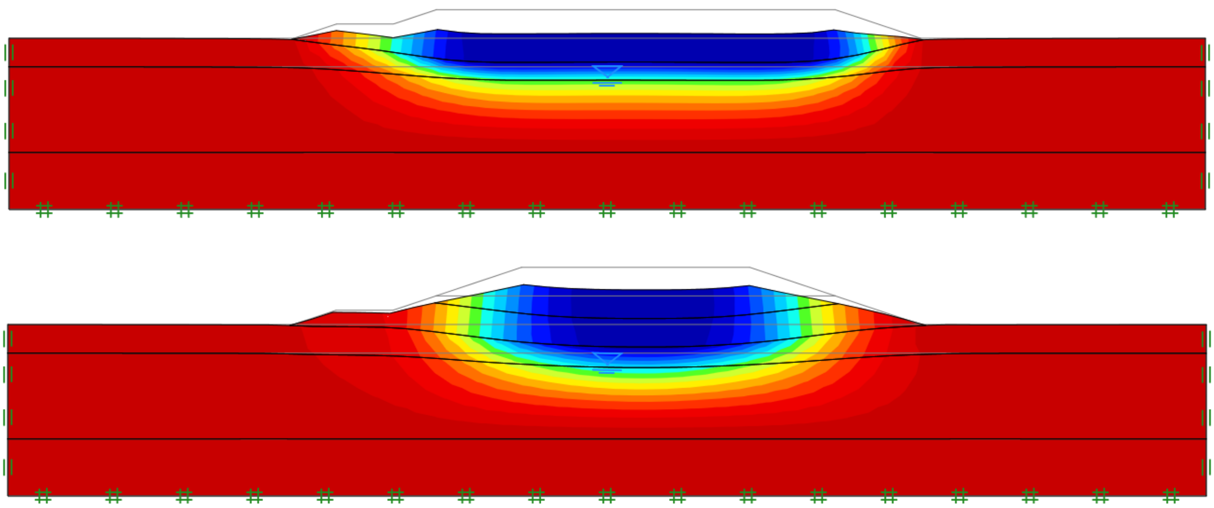

Figure 48.2: Vertical stage displacements for Stages 3 and 5. The deformations are scaled by a factor of 10.

The factors of safety are:

$$
\begin{aligned}
&\text{I.} \quad \text{(Short Term)}: \quad FS_s = 1.55 \pm 0.02\\
&\text{II.} \quad \text{(Long Term)}: \quad FS_s = 3.12 \pm 0.03\\
&\text{III.} \quad \text{(Short Term)}: \quad FS_s = 1.54 \pm 0.01\\
&\text{IV.} \quad \text{(Long Term)}: \quad FS_s = 2.52 \pm 0.02\\
&\text{V.} \quad \text{(Short Term)}: \quad FS_s = 1.78 \pm 0.01
\end{aligned}
\tag{48.1}
$$

As expected, the long term stability decreases as the height of the embankment increases. For the short term stability, the increase in embankment height is compensated by the increase in undrained shear strength as a result of consolidation of the soft soil, to an extent that the short term stability at the completion of construction and dissipation of all excess pressure is greater than at any point during construction. The factors of safety and associated distributions of shear dissipation are shown in Figure 48.3.

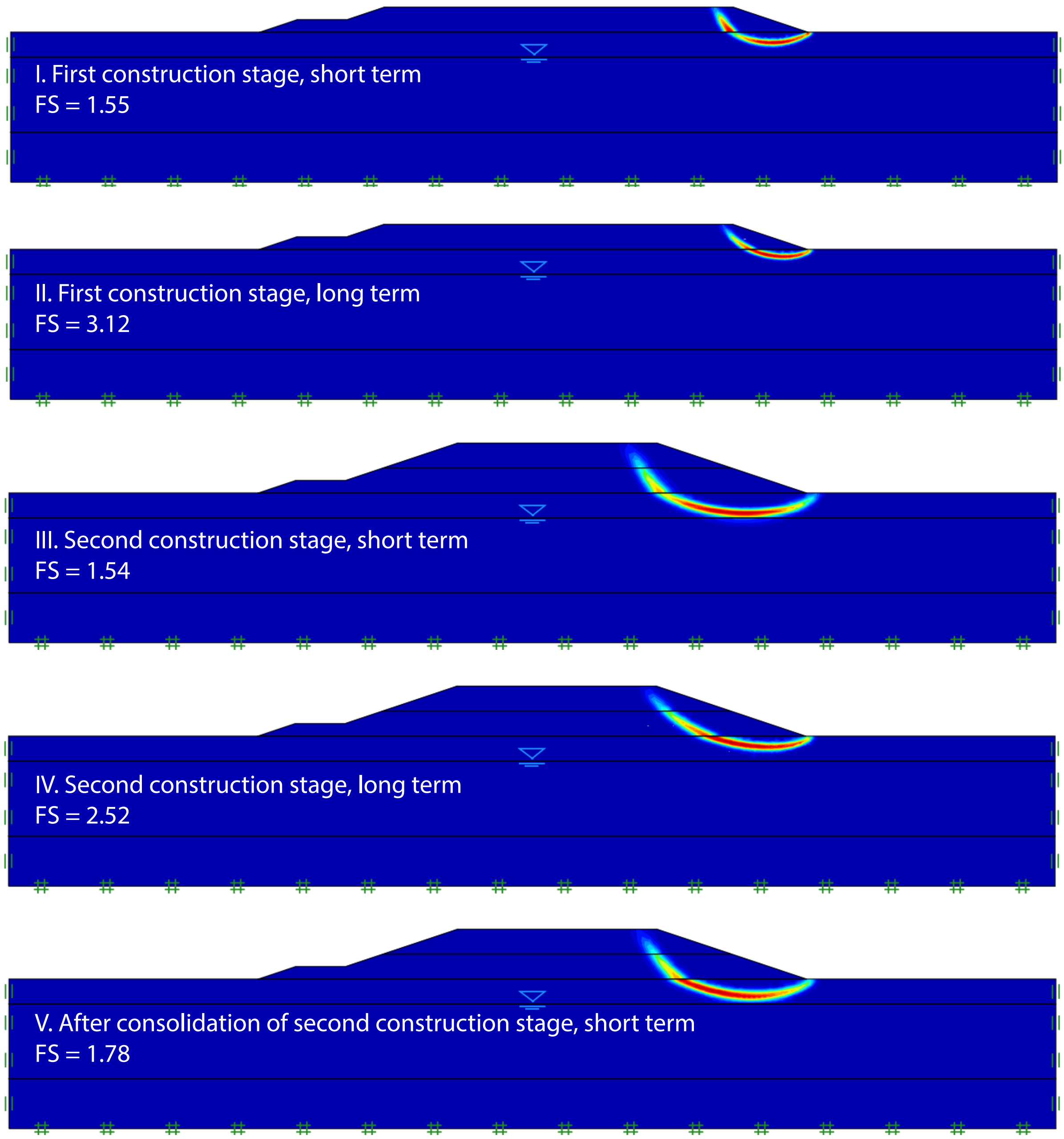

Figure 48.3: Distributions of shear dissipation from Strength Reduction analysis.

In summary, this example demonstrates the capabilities of OptumG2 to rapidly carry out analyses that provide the essential information required for the design of the embankment, namely the short and long term deformations and the factors of safety. What is missing is information about the variation of excess pore pressures with time after each construction stage. That analysis is covered in the next example.

49 EMBANKMENT CONSTRUCTION – PART 2

The second part of the example concerns the consolidation of the embankment after each construction stage, i.e. the dissipation of excess pore pressure with time. Two different situations are considered. The first one as sketched in the previous example and the second one with pre-installed drains underneath the embankment is shown in Figure 49.1. In OptumG2, drains may be modeled by means of the Zero Excess Pressure BC.

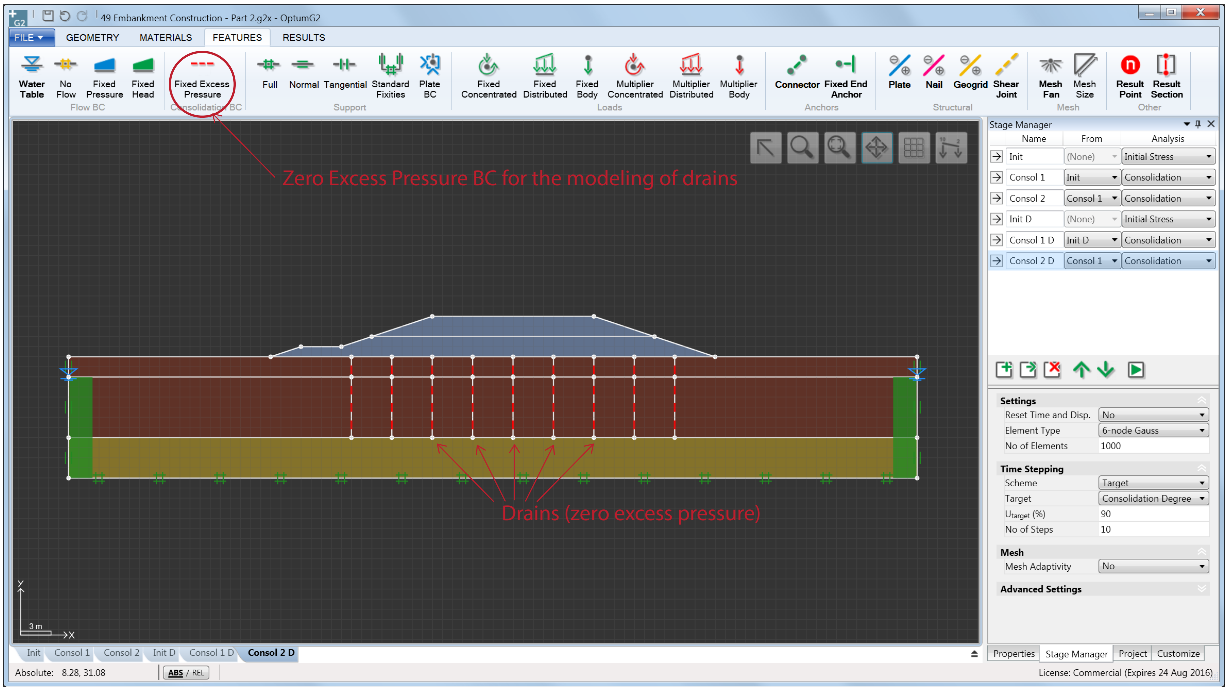

Figure 49.1: Embankment with drains.

In each of the two situations (drains or no drains), the problem is modeled by using an Initial Stress stage. This is linked to a Consolidation stage accounting for the construction of the lower part of the

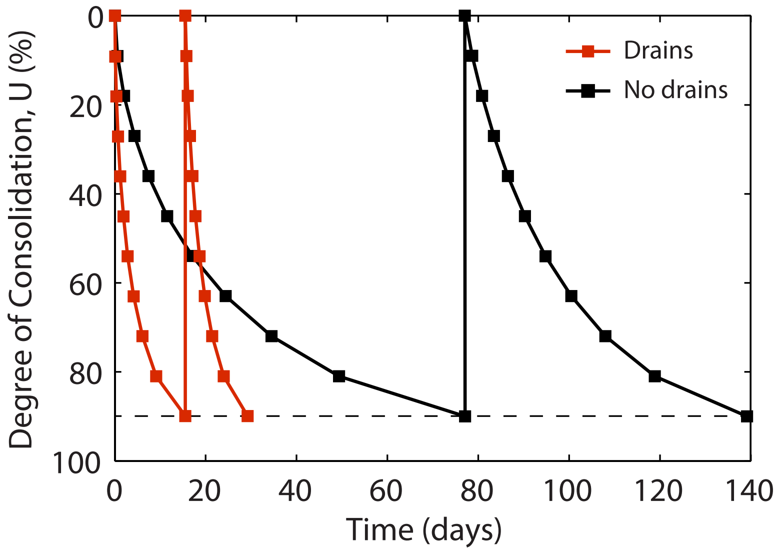

Figure 49.2: Degree of consolidation versus time with and without drains.

embankment. Finally, a second Consolidation stage, accounting for the upper part of the embankment is defined and linked to the previous stage. In both Consolidation stages, the Target scheme with Degree = 90% is used. It should be noted that in the case where drains are used, these are included already in the Initial Stress stage. In other words, it is assumed that the drains have been placed well in advance of the actual construction and that a steady state seepage pressure distribution exists before construction.

The degree of consolidation with time for each of the two situations is shown in Figure 49.2. As expected, the drains facilitate a significantly more rapid consolidation. Note also, the the rate of consolidation increases between the two construction stages. This is a consequence of the stress dependence of the Modified Cam Clay model which implies an increase in Young's modulus with effective mean stress. As such, the coefficient of consolidation, $C_v = KE/\gamma_w$, increases accordingly.