Stability with FE Pore-Water Pressure

1 Introduction

One of the most powerful features of GeoStudio is the smooth integration that exists between all the individual programs. For simple pore-water pressure situations, there are several different options that can be used directly within SLOPE/W. However, if the pore-water pressures become more complex, it is sometimes necessary to use SEEP/W to conduct a finite element seepage analysis to compute the pore-water pressure profile. This is achieved by solving the finite element equations for every node in a finite element mesh. Once the finite element equations have been solved, SLOPE/W can be used to determine the critical slip surface by using the pore-water pressures that exist within the finite element mesh at the base of each slice .

The objective of this example is to highlight the use of SEEP/W total heads in a stability analysis. Other features of this analysis include:

- Use of SEEP/W total heads in SLOPE/W
- The use of ϕ^b
- Slip surface grid with a single-point radius
- Stability on upstream and downstream slopes
- Multiple analyses

2 Configuration and setup

A schematic picture of the earth dam being modeled is shown in Figure 1.

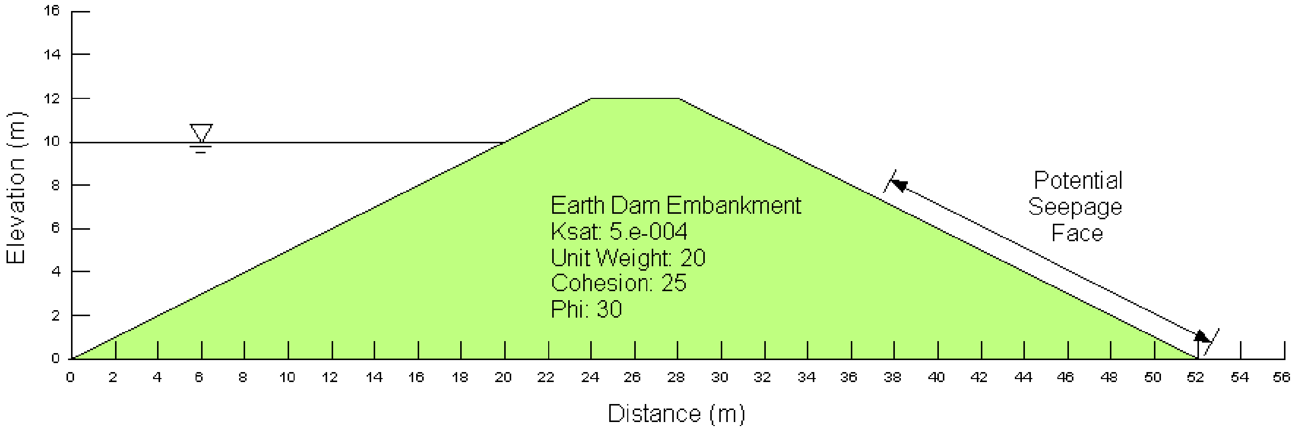

Figure 1 Profile and material properties

In order to reproduce this example, you must have both SEEP/W and SLOPE/W installed in your computer. It is possible to develop the profile in either the SEEP/W or SLOPE/W module; however, the SEEP/W finite element equations need to be solved first, before the pore-water pressure results are available for use within SLOPE/W.

The material property parameters defined for the embankment material within SLOPE/W is shown in Table 1.

Table 1 Material property parameters used in SLOPE/W

Parameter	**Embankment**
Frictional angle ϕ', (degrees)	30
Cohesion c', (kPa)	25
Unsaturated ϕ^b, (degrees)	10
Unit weight γ, (kN/m^3)	20

3 SEEP/W steady state seepage result

In SEEP/W, the presence of an upstream reservoir is reflected in the boundary condition assigned to the upstream face of the embankment. The presence of the upstream reservoir is reflected in SEEP/W by the total head boundary condition of 10 m. A potential seepage face is also included on the downstream face by defining a total flux boundary of Q=0 (potential seepage face). The conductivity function defined in SEEP/W for the embankment material is shown in Figure 2.

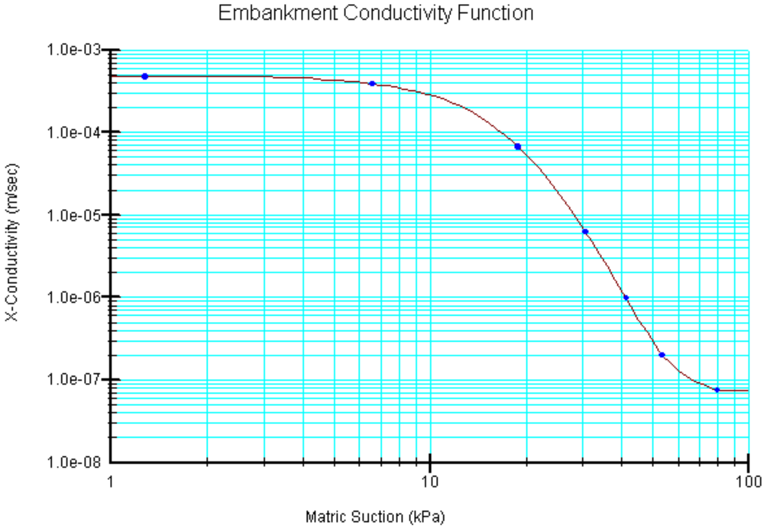

Figure 2 Conductivity function defined in SEEP/W for the embankment

Figure 3 shows the steady state results of the seepage analysis, including the location of the phreatic surface and the development of a downstream seepage face; the velocity vectors and the pressure head contours. Note the presence of negative pore-water pressures above the phreatic surface (P=0 contour).

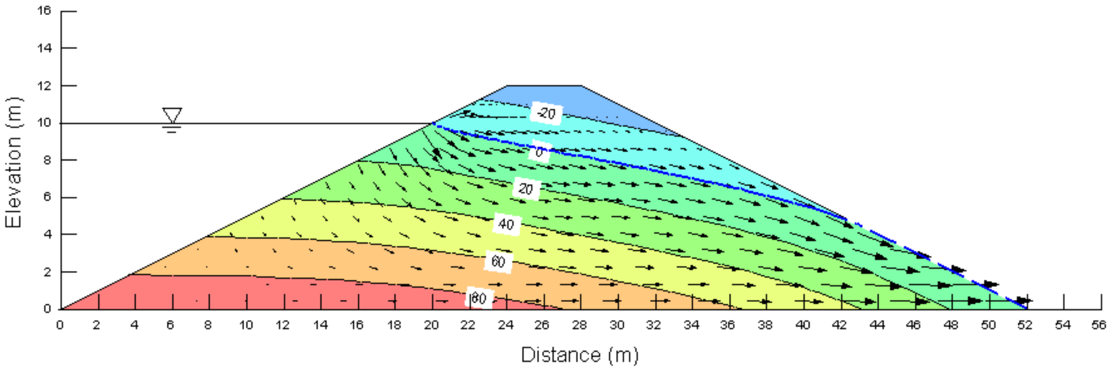

Figure 3 Results obtained from the finite element simulation

4 SLOPE/W downstream stability

Now that the total heads have been computed for every node within the profile, a stability analysis can be completed to determine the stability of the downstream face using the finite element computed pore-water pressure profile. Figure 4 shows the location of the search grid and the location of a single radius point for the stability analysis. Note that the water appears as a shaded zone with water force arrows acting on the ground surface line within the SLOPE/W module automatically. The vertical weight of the water and the horizontal hydrostatic force needs to be included in the SLOPE/W analysis as these forces affect the stability of the slope. There were not needed to solve the finite element seepage equations in SEEP/W. Internally, SLOPE/W develops the shaded water layer by referring to the positive pressures that exist on the ground surface line.

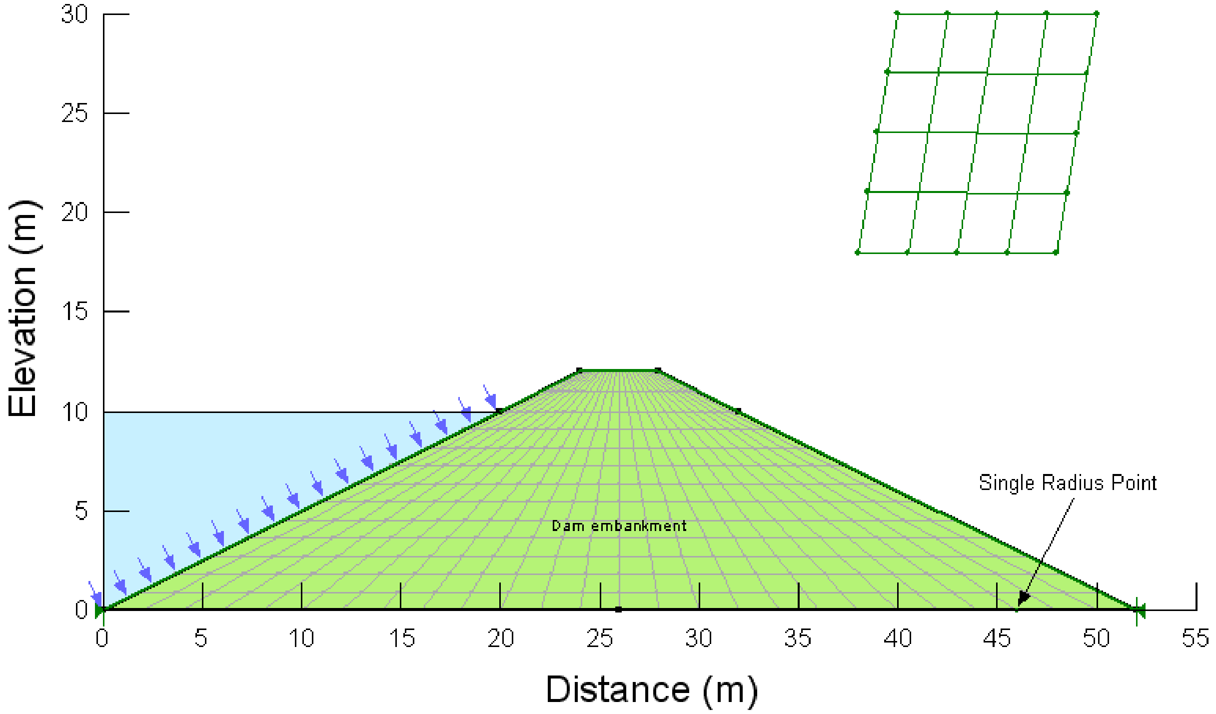

Figure 4 Earth dam embankment as defined in SLOPE/W with the shaded water layer and water force vectors

The finite element mesh still appears within the SLOPE/W module, but the finite element equations are not solved as part of the stability analysis. The pore-water pressures at the base of each slice will be determined from the heads computed at the finite element nodes. It is for this reason that a piezometric line is NOT drawn within SLOPE/W. The stabilizing weight of the water is modeled automatically from the finite element computed positive pore-water pressures that exist on the ground surface line.

Figure 5 shows the location of the critical slip surface and the factor of safety for the downstream face. Note that a phreatic surface is drawn within the embankment, even though a piezometric line was not defined with SLOPE/W. The phreatic surface is part of the SEEP/W results, superimposed on the critical slip surface. Also note that the critical slip surface has passed through the single radius point at the bottom of the embankment.

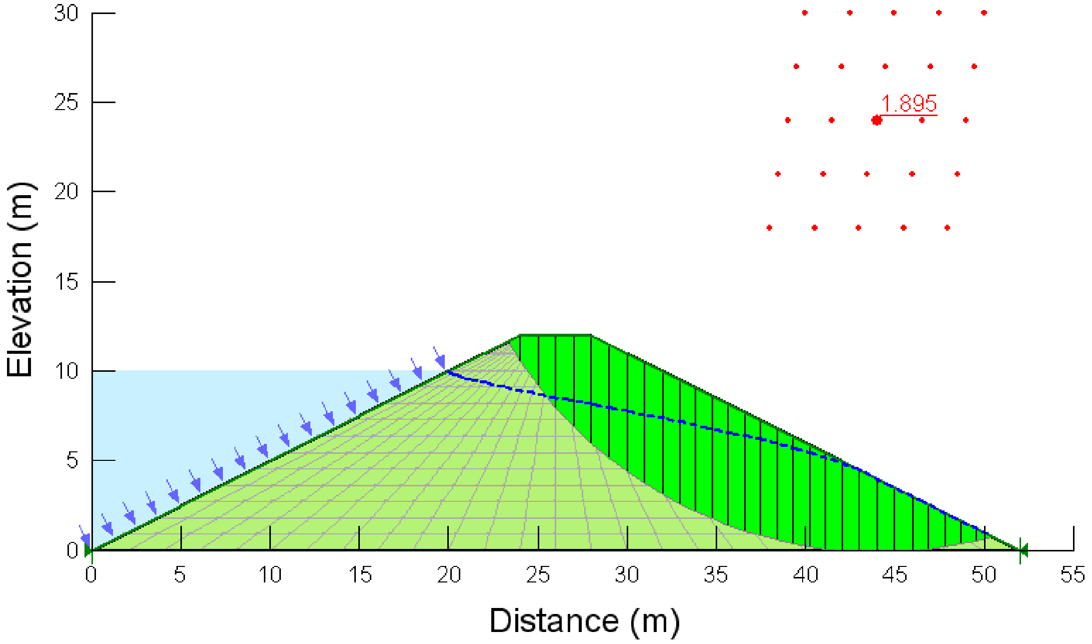

Figure 5 Factor of safety and critical slip surface of downstream slope

In assigning the material properties for the embankment material, an advanced parameter, ϕ^b =10° was also defined. A graph of strength versus slice number (Figure 6) shows that for the slices that exist above the phreatic surface (slices 1 and 2), there are actually three strength components; cohesion, friction and suction. In this example, the additional strength due to suction is relatively small.

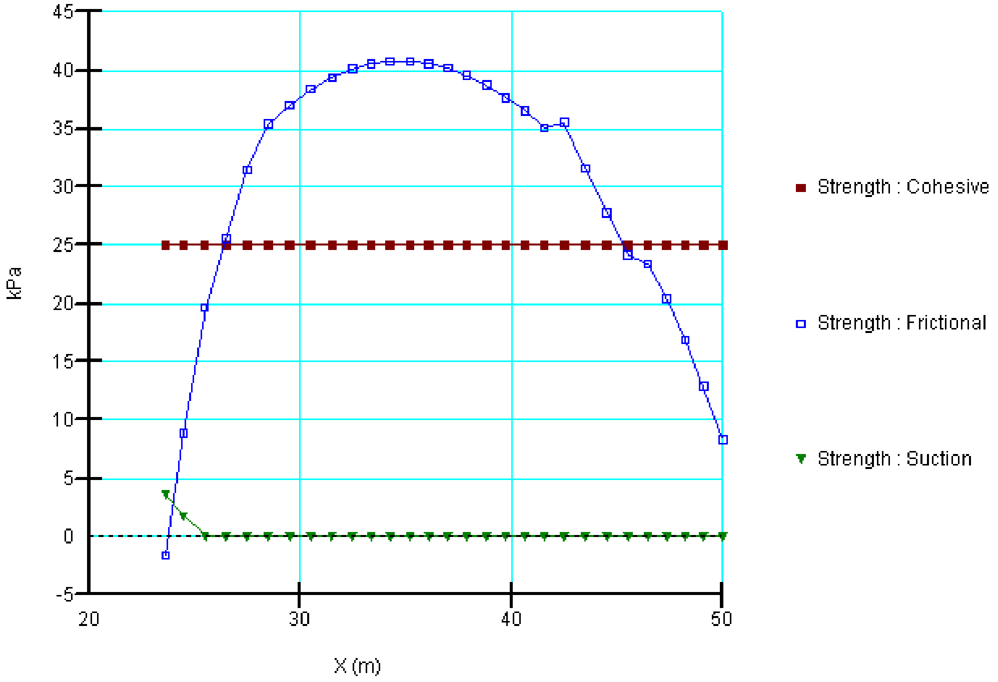

Figure 6 Graph of strength versus slice number showing the presence of a strength component due to suction

5 SLOPE/W upstream stability

In this analysis, the slip surface direction of movement has been changed to be from right to left and the search grid and radius has been moved to look at stability of the upstream embankment.

Figures 7 shows the new location of the search grid and radius. The presence of the reservoir is still automatically included based on the computed SEEP/W pore water pressure on the upstream slope.

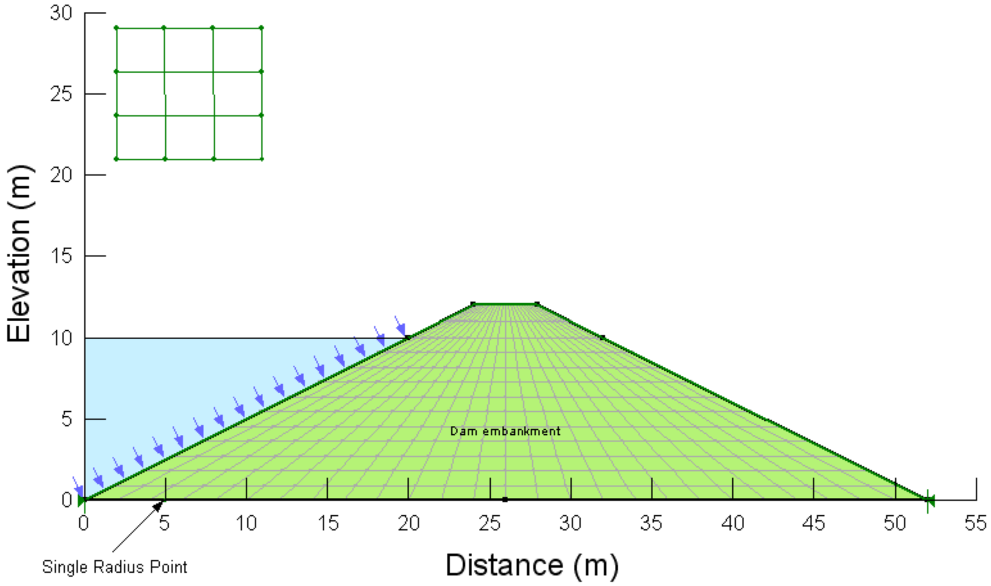

Figure 7 Location of the grid and radius used to analyse upstream stability

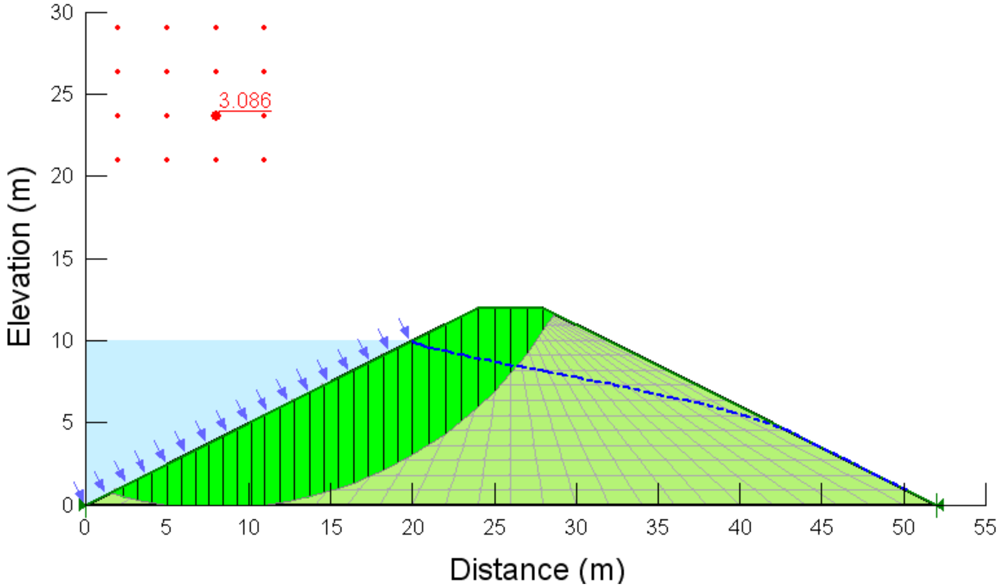

Figure 8 Factor of safety and critical slip surface of upstream slope

Figure 8 shows the computed factor of safety for the critical slip surface and Figure 9 shows the individual slice forces acting on Slice #8, which is located half-way up the submerged slope where the water is 6 m deep.

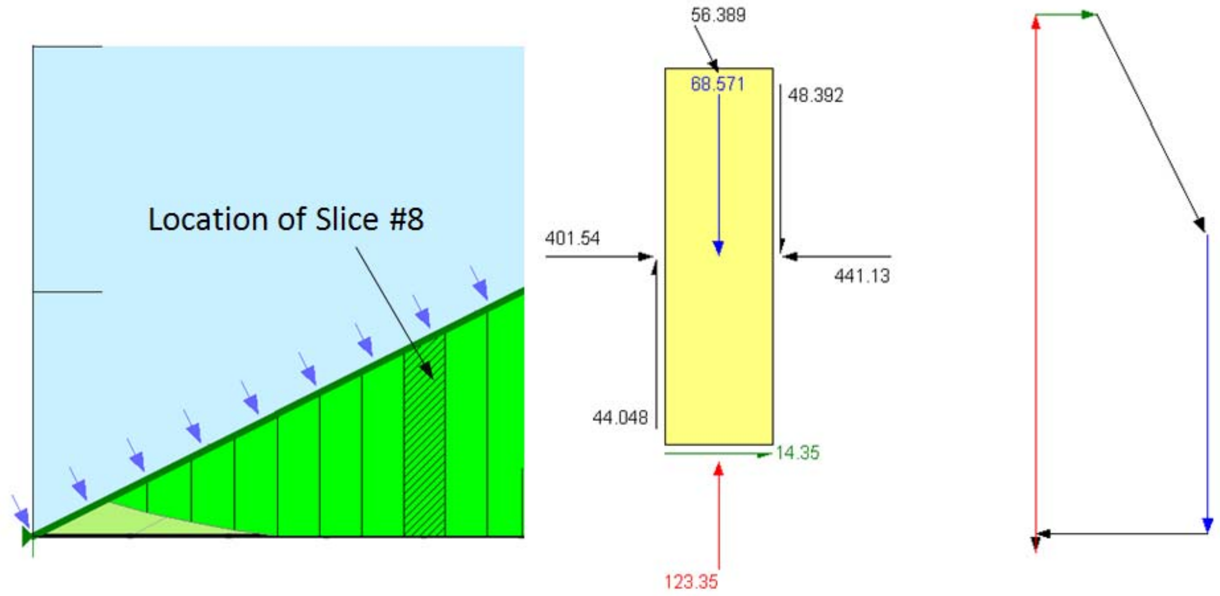

Figure 9: Slice forces for slice #8

By hand calculation, the water force (F) acting on the top of the slice can be calculated as follows:

$F_V = (\gamma \text{ x } H_W) \text{ x } b_V \text{ x unit depth}$

$F_H = (\gamma \text{ x } H_W) \text{ x } b_H \text{ x unit depth}$

where:

γ = unit weight of water

H_W = height of the water at the top, centre of the slice

b_V = width of the slice as given in the slice force information

$b_H = b_V * \tan(\alpha)$

α = angle of the slope

For slice #8, with a water depth of 6 m, a slice width (b_V) of 0.85714 m and a slope angle (α) of 26.57-degrees, the vertical and horizontal water forces would be:

$F_V = (9.807 \text{ x } 6) \text{ x } 0.85714 \text{ m x } 1 \text{ m} = 50.436 \text{ kN}$

$F_H = (9.807 \text{ x } 6) \text{ x } [0.85714 \text{ m x } \tan(26.57)] = 25.223 \text{ kN}$

.

The resultant force (F) is therefore computed as:

$F^2 = \sqrt{(F_H^2 + F_V^2)} = \sqrt{(25.223^2 + 50.436^2)} = 56.39$ kN which corresponds exactly with the line load acting at the top of the slice as shown in Figure 9.