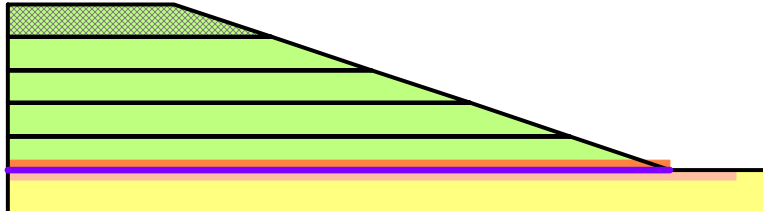


Embankment on Geofabric

1 Introduction

This example demonstrates how a geofabric can be included as reinforcement in the staged construction of an embankment on soft ground, and how the potential slip between the ground and the geofabric can be modeled with interface elements. The different colored layers at the bottom of the embankment show the geofabric and interface elements.



The primary purpose is to illustrate the behavior of the geofabric and frictional forces on either side of the geofabric. The secondary purpose is to show that the geofabric itself and the slip friction forces do not enter into the stability analysis. The geofabric affects the ground stresses, which in turn affect the stability.

2 Problem configuration and setup

The complete problem configuration and setup is shown in Figure 1. The foundation is treated as a somewhat soft weak material. The embankment is deemed to be a sandy material.

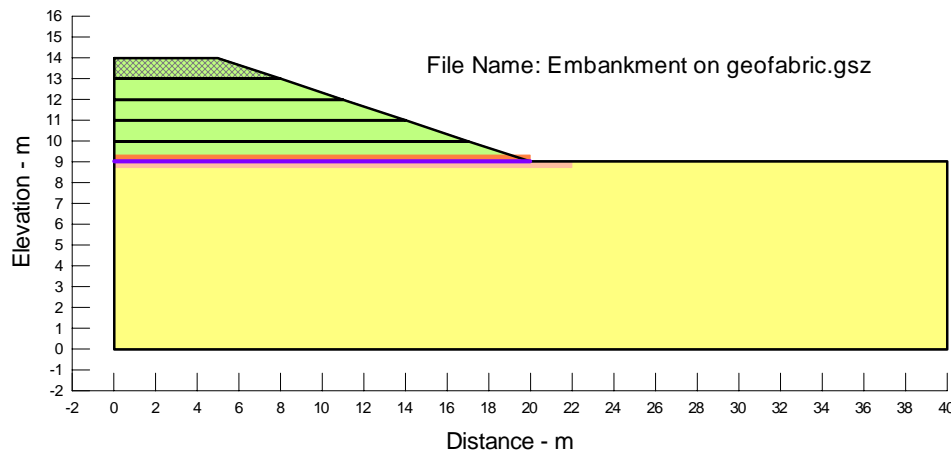


Figure 1 Problem configuration and setup

The embankment is constructed in five one-metre lifts.

Once the embankment has been constructed, the intention is to check the stability using the finite element stresses. The initial insitu stresses are consequently required, even though Linear Elastic material properties are used in the SIGMA/W analysis.

Figure 2 shows the sequential analysis procedure.

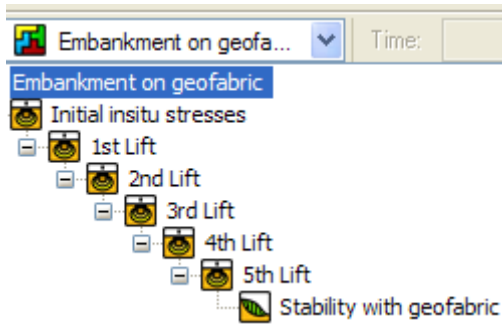


Figure 2 Sequential analysis steps and stages

Special attention has to be given to the interface elements and geofabric at the toe of the embankment. In order to completely isolate the geofabric from the embankment and from the foundation materials, it is necessary to have a short interface segment beyond the toe, as shown in Figure 3. Without this short interface segment, the geofabric will be connected to the foundation material, as shown in Figure 4. By the fact that the geofabric and the foundation soil have a common node (at Point 15) means the two materials are connected. Furthermore, the foundation soil region needs an extra point, like Point 16.

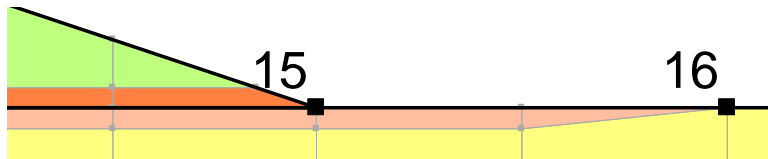


Figure 3 Interface elements beyond the toe

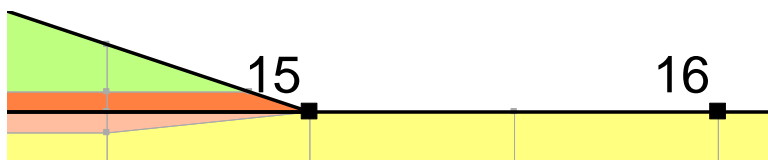


Figure 4 Interface elements up to the toe

3 Material properties

The material properties for this example are completely arbitrary. They were selected purely for the purpose of illustrating the analysis procedure and are not intended to represent any particular real field situation.

Of importance, from a SIGMA/W feature and capability point of view, is the fact that the frictional properties are different on the top from the properties on the bottom.

The geofabric is modeled as a beam with no flexural stiffness; that is, the moment of inertia I is specified as zero. The geofabric has stiffness (E) and a cross-sectional area. This being a 2D analysis, the thickness into the page is unity (1 m). The geofabric therefore is a strip 1 m wide. The thickness is consequently the area.

The frictional strength below the geofabric is specified as 50 kPa. Above the geofabric, the friction between the geofabric and the embankment material is specified with $c = 10$ kPa and $\phi = 30$ degrees.

The geofabric has tensile capacity, but no compressive capacity. The option of “Allow Compression” is therefore unselected.

4 Response of reinforcement

Figure 5 shows the tension in the geofabric as each embankment lift is placed. What is rather interesting is that the maximum tension is more toward the embankment toe area for Lifts 2 and 3. Ultimately, however, the maximum tension is under the center of the embankment. Also note that there are no compression (positive) forces in the geofabric.

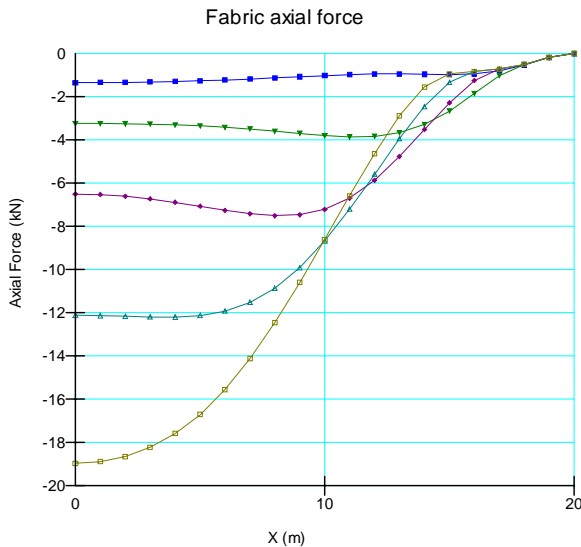


Figure 5 Tension in the geofabric

Figure 6 and Figure 7 show the slip forces on the upper and lower sides of the interface elements.

The negative values on the upper side of the interface means the shear forces acting on the embankment materials are pointing to the left; that is, they are resisting movement of the embankment to the right, which it logically will want to do.

The positive forces on the lower side of the interface means the shear forces are putting a drag on the foundation material to the right.

The sign convention, as with all forces in SIGMA/W, is that a positive value points to the right and a negative value points to the left.

Of interest is the response that the slip forces change direction as the lifts are being placed, for the first three lifts.

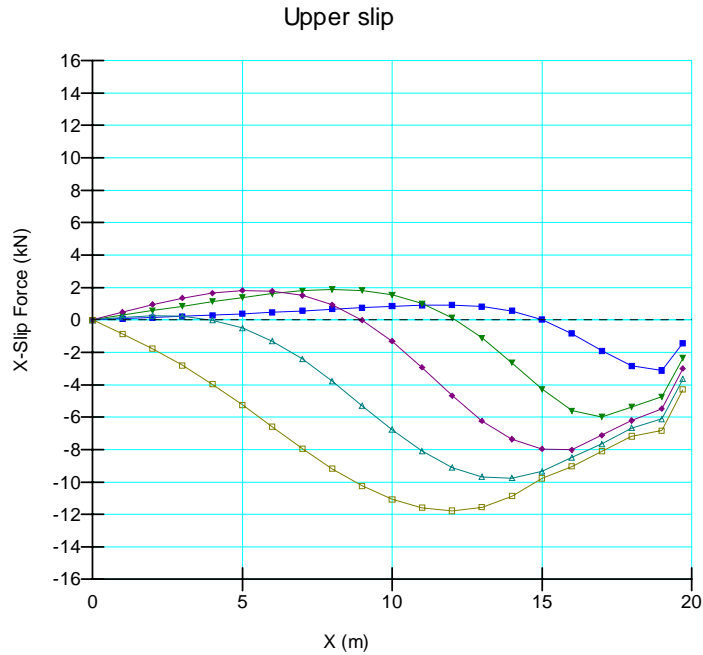


Figure 6 Slip forces on the top of the interface elements

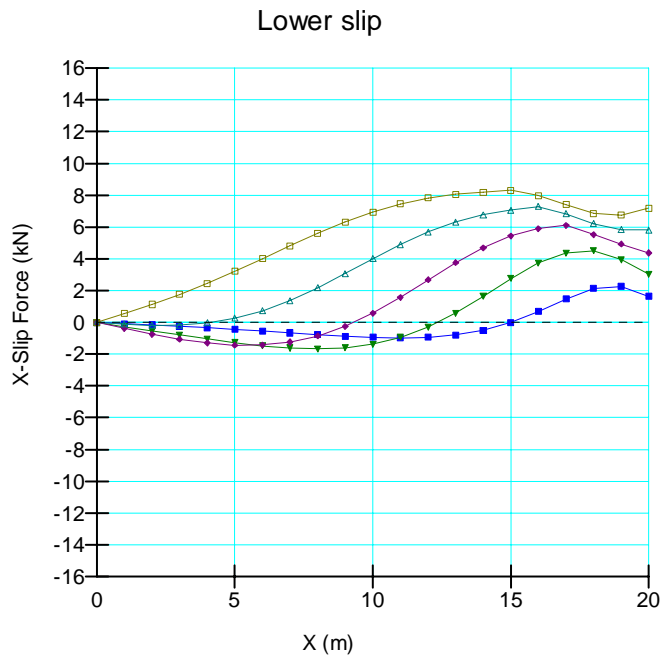


Figure 7 Slip forces on the bottom of the interface elements

The upper and lower slip forces in the above two figures are not the same at each corresponding stage. The reason for this is that the geofabric absorbs some of the strain energy. This becomes evident if we plot the upper, lower and middle interface forces, as in Figure 8. Now the algebraic sum of the three forces at any location along the geofabric is zero, as they correctly must be. Take, for example, a point at $X = 10$ m. The data values at this point are +6.95, +4.11 and -11.06, and the sum is zero.

Another way to look at it is that the values with time (load steps) for the three nodes make up a group, as in Figure 9. The sum of the three values at each time always adds up to zero.

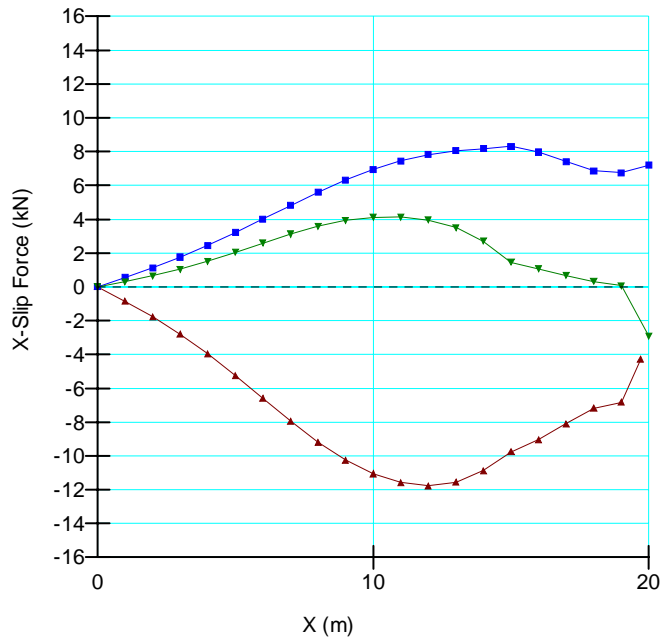


Figure 8 The upper, middle and lower interface slip forces

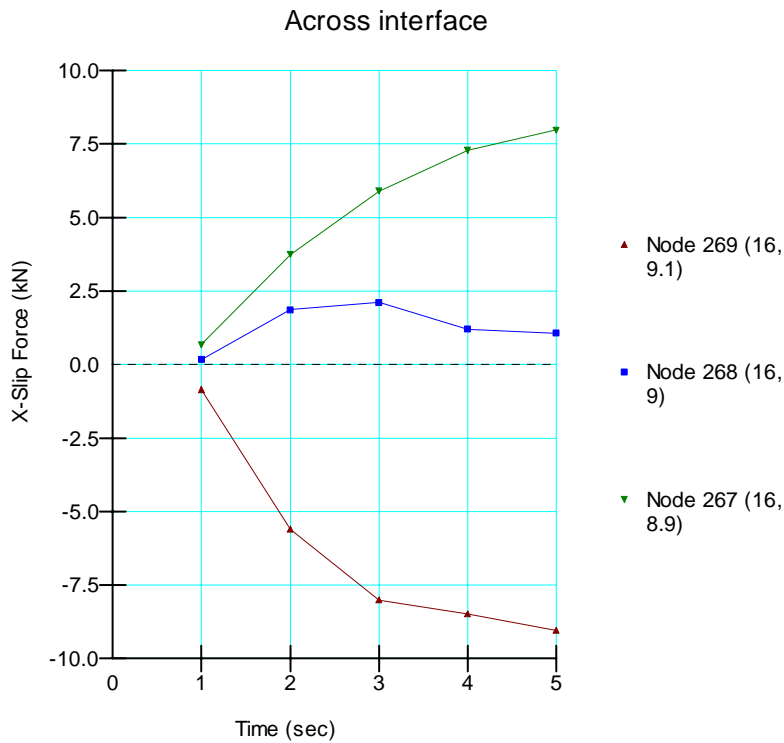


Figure 9 The upper, middle and lower interface slip forces with time

5 Stability

The resulting embankment and foundation stresses can be used in SLOPE/W to do a stability analysis, as illustrated in Figure 10. However, there are several issues that need to be recognized and appreciated.

- The tension in the geofabric itself does not enter into the safety factor calculations. The geofabric alters the stresses, which in turn are used in the stability analysis, but the geofabric itself does not enter into the calculations. The geofabric forces come into play in a conventional Limit Equilibrium analysis, but not when the SIGMA/W computed stresses are used in the stability calculations.
- In reality, the interface material is very thin and therefore does not affect the shear strength along the slip surface. The interface materials are therefore ignored in the stability calculations if the potential slip surface crosses the interface elements. Sliding along the geofabric is a different issue and has to be addressed separately.
- The interface elements are also not considered in the slice discretization.

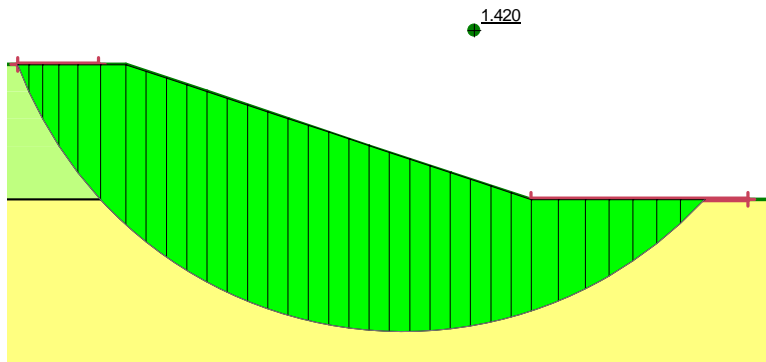


Figure 10 Stability analysis of reinforced embankment

The data file was saved with a new name, the geofabric and interface materials were removed, and then the analysis was repeated. Without the reinforcement, the factor of safety is 1.253, as shown in Figure 11.

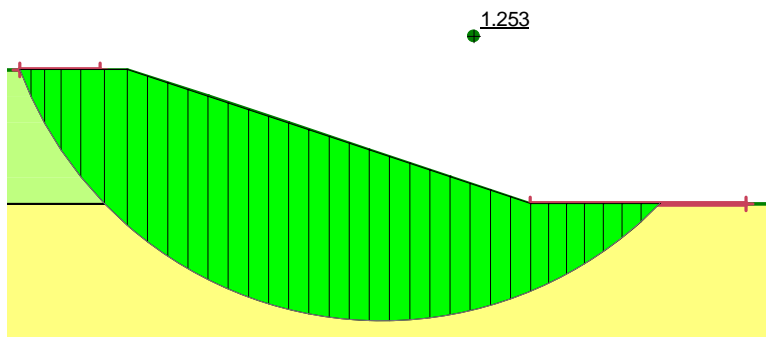


Figure 11 Stability with no reinforcement

The modified file is not included; this exercise is left up you, the reader.

The difference in factor of safety is due to the different stress conditions with and without the reinforcement. Consider the differences, for example, in Figure 12 and Figure 13, which present contours

of deviatoric (q) stress. It is clearly evident that the stress conditions are different for the situations with and without the geofabric.

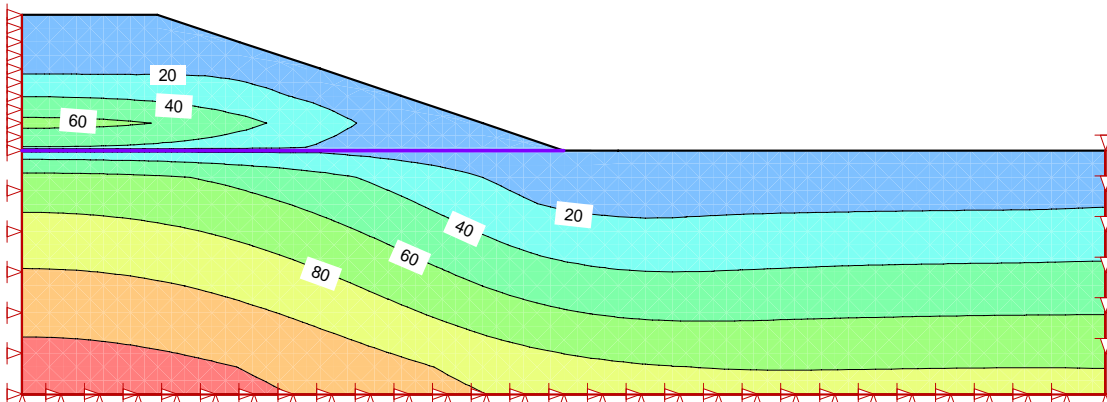


Figure 12 Deviatoric (q) stress contours with reinforcement

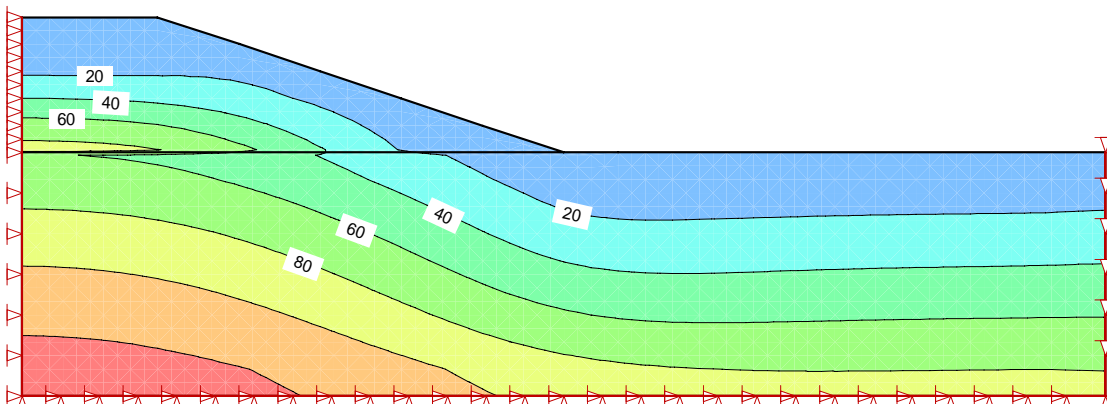


Figure 13 Deviatoric (q) stress contours with no reinforcement

There are other ways to look at the differing stress state condition; the above is just one illustration.

6 Concluding remarks

This example demonstrates how beam elements can be used to model the effects of geofabric reinforcement, and it presents discussions on how to interpret the slip forces and how the stresses from this type of SIGMA/W analysis can be used in a SLOPE/W stability analysis.

A word of warning about specifying slip material properties - the natural tendency is to make the cohesion zero and only rely on the frictional component of the sliding resistance. The problem, however, can become numerically unstable very quickly if there is any opportunity for the normal stress on the slip surface to approach zero or become negative. Generally, for numerical reasons, it is better to include some cohesion in the slip material property. Remember, it is better to get a good approximation of the solution, rather than no solution at all due to lack of convergence.

Stability is just one issue in the analysis, design and construction of reinforced embankments on soft ground. Other issues like long term settlement, for example, are beyond this illustrative example, but may be equally important.