PHI-C REDUCTION AND COMPARISON WITH BISHOP'S METHOD

This document describes an example that is used to verify the ultimate limit state capabilities of PLAXIS. The problem involves the stability of an embankment. PLAXIS results are compared with Bishop's method of slices (Verruijt, 2001). The influence of the load distribution in PLAXIS 3D is studied as well.

Used version:

- PLAXIS 2D - Version 2018.0
- PLAXIS 3D - Version 2018.0

Geometry: Embankment stability is calculated by means of phi-c reduction. In PLAXIS 2D, the *15-noded* mesh elements are used. The embankment has a slope of 1:2 (vertical:horizontal). A *line load* with width equal to 3.0 m is applied at the crest, 0.5 m away from the edge. Figure 1 illustrates the model geometry in PLAXIS 2D.

In PLAXIS 3D, the model is extended by 1 m in y-direction (plane strain conditions) and *10-noded* mesh elements are used. The applied *surface load* covers an area of 3.0 m $\times$ 1.0 m. Figure 2 illustrates the model geometry in PLAXIS 3D.

In order to present PLAXIS results, a point A is selected at the edge of the embankment's crest.

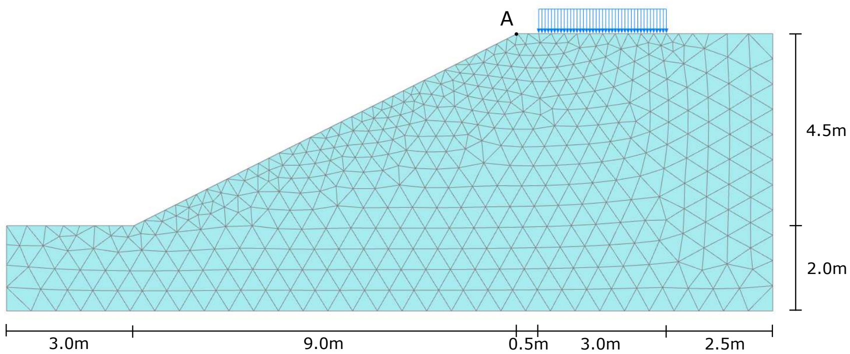

Figure 1 Model geometry and generated mesh (PLAXIS 2D)

Materials: The Mohr-Coulomb model is used, considering associated plasticity. The dry unit weight γ is set equal to 16 kN/m^3 and the *Tension cut-off* option is deactivated. The remaining soil properties are:

Soil: E' = 2600 kN/m^2 c' = 5 kN/m^2 ν' = 0.3 φ' = 20° ψ = 20°

When the phi-c strength reduction method is applied, use of Mohr-Coulomb criterion with non-associated flow rule ($\varphi' \neq \psi$) may lead to non-unique or fluctuating solutions. The limit equilibrium method proposed by Bishop does not consider dilatancy, but may be regarded to follow an associated flow rule.

Meshing: In PLAXIS 2D, the *Very fine* option is used for the *Element distribution* to generate the mesh. The mesh is locally refined at the area where the load is applied with a *Coarseness factor* of 0.5. The remaining top boundary at the left of the load (including the slope line and the top boundary of the foundation) is refined with a *Coarseness factor*

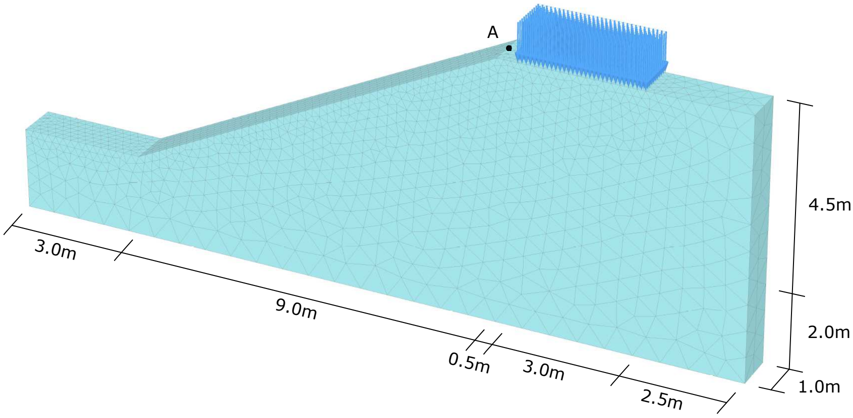

Figure 2 Model geometry and generated mesh (PLAXIS 3D)

equal to 0.8. The generated mesh is illustrated in Figure 1.

In PLAXIS 3D, the *Fine* option is used for the *Element distribution* to generate the mesh. The whole top model boundary (apart from the area at the right of the applied load) is refined with a *Coarseness factor* of 0.3. The generated mesh is illustrated in Figure 2.

Calculations: In the Initial phase, initial stresses are generated by setting the *Calculation type* to *Gravity loading*. Then the embankment is subjected to the following load cases:

- Analysis 1: phi-c reduction without additional loading
- Analysis 2: phi-c reduction after applying external loading equal to 30 kN/m^2

The *Tolerated error* is set equal to 0.001 in all calculation phases. For the phi-c reduction analyses, in both PLAXIS 2D and PLAXIS 3D, the *Max steps* option is set equal to 200.

Output: Figure 3 illustrate the results of the phi-c reduction analyses in PLAXIS 2D and PLAXIS 3D for the point A. In case of no additional loading (Analyis 1), factor of safety equals 1.540 in PLAXIS 2D and 1.551 in PLAXIS 3D. In case of an external loading equal to 30 kN/m^2 (Analysis 2), factor of safety equals 1.261 in PLAXIS 2D and 1.273 in PLAXIS 3D. Figures 4 and 5 present the failure mechanisms in PLAXIS 2D and PLAXIS 3D for the Analysis 1, in terms of total deviatoric strains.

Verification: Based on Bishop's slip circle method a factor of safety equal to 1.534 is obtained for the initial condition of no additional loading at the crest (Verruijt, 2010). Figure 6 depicts the corresponding failure mechanism, which is in agreement with the one obtained in PLAXIS (Figures 4 and 5).

The difference between the Bishop results and the PLAXIS 2D results equals 0.4%, while the difference with PLAXIS 3D results equals 1.1%. It is concluded that PLAXIS results are in good agreement with the result obtained with Bishop's method.

Influence of 3D effects: In order to study the influence of 3D effects in PLAXIS 3D, safety factors are calculated for various loading cases in which the width of the loading surface, in out-of-plane direction, is changed. For the present analyses a wider model geometry is considered (model length in y-direction equals 18 m) and the following areas are subsequently loaded to 30 kN/m^2: 3×3 m^2, 3×6 m^2, 3×12 m^2 and 3×18 m^2. Figure 7 illustrates the total displacement contours for each model.

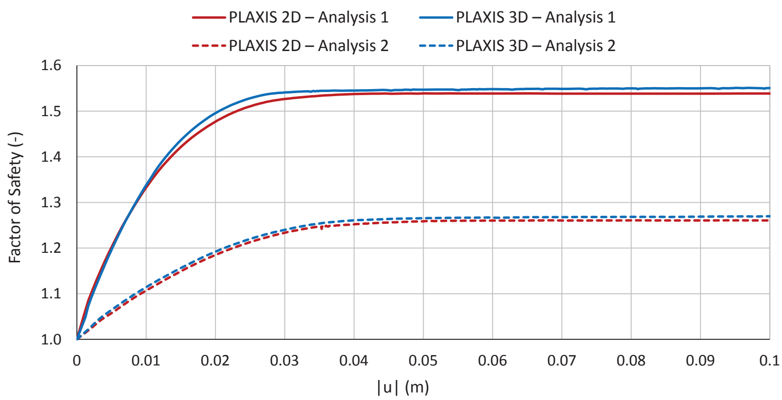

Figure 3 Factor of safety against total displacement of point A for Analyses 1 and 2 (PLAXIS 2D and PLAXIS 3D)

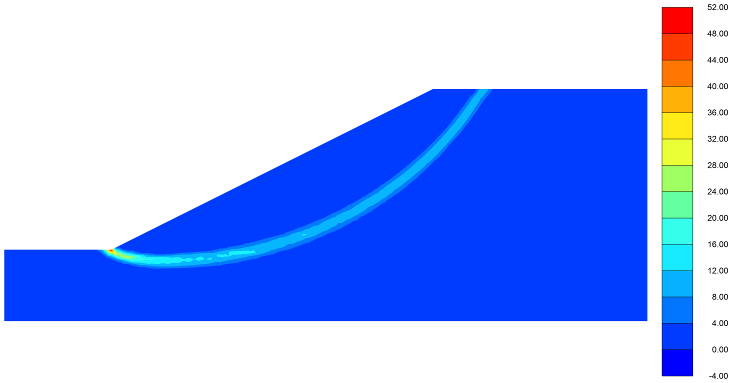

Figure 4 Failure mechanism for Analysis 1 in PLAXIS 2D (total deviatoric strains)

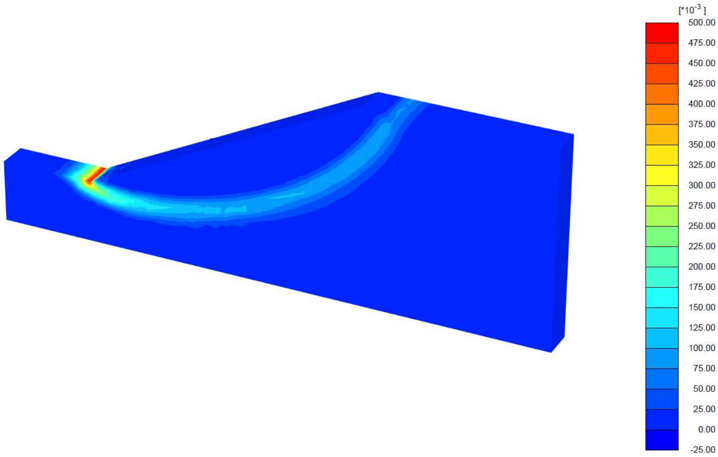

Figure 5 Failure mechanism for Analysis 1 in PLAXIS 3D (total deviatoric strains)

Figure 8 presents the results of the various considered load cases. Factor of safety is plot

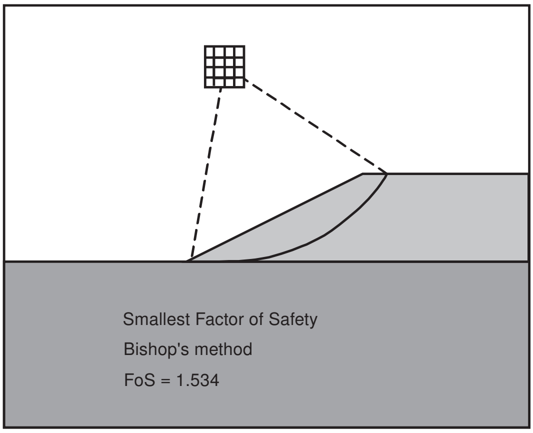

Figure 6 Bishop's slip circle method result

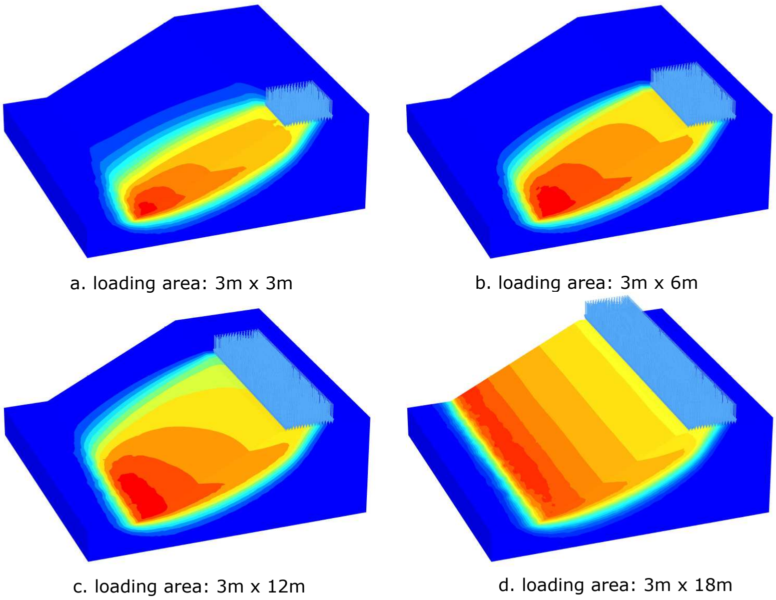

Figure 7 Total displacement contours after phi-c reduction for the various loading surfaces (PLAXIS 3D)

against the total displacement of a point located at the crest of the embankment, at *y* equal to 1.5 m (out-of-plane direction). The safety factor decreases with increasing loading surface as expected. The results of the case in which an area of 3×18 m^2 is loaded are comparable to the PLAXIS 3D model in the first part of this validation, i.e. load over the full width of the model.

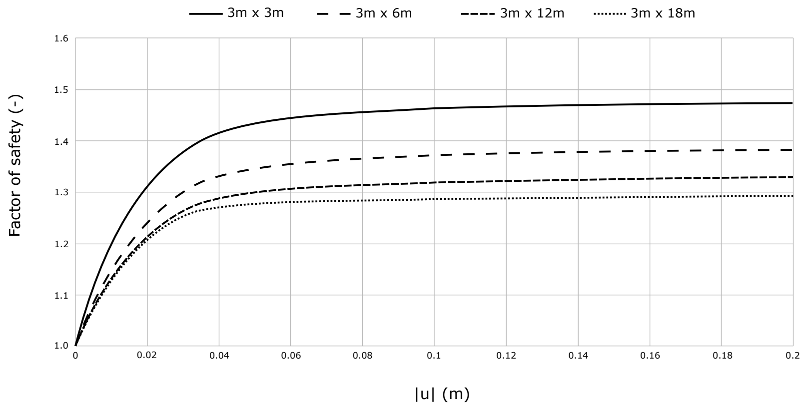

Figure 8 Factor of safety against total displacement of point A - influence of 3D effects

REFERENCES

[1] Verruijt, A. (2001). Soil mechanics. Delft University of Technology.

[2] Verruijt, A. (2010). STB2010. `http://geo.verruijt.net/`. Accessed January 25, 2016.