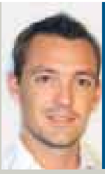
A comparison of finite elements (SSR) and limit-equilibrium slope stability analysis by case study



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INTRODUCTION

The purpose of this study was to evaluate the benefits of carrying out slope stability analysis using finite elements (FE) in addition to the more common limit-equilibrium (LE) method. Several slope stability projects were drawn from our archives for this exercise, although for the sake of brevity, the results of only three are presented herein.

The LE analyses were conducted using the Rocscience limit-equilibrium software, Slide, using circular and non-circular analysis based on the GLE/Morgenstern-Price method of slices. The FE analyses were carried out with Phase², a 2D elasto-plastic finite elements stress analysis program by Rocscience, based on the Shear Strength Reduction (SSR) technique (Dawson *et al* 1999; Griffith & Lane 1999; Hammah *et al* 2004) which is automated into the software.

The SSR technique involves reducing Mohr-Coulomb strength parameters c' and ϕ' by a "strength reduction factor" (SRF) until non-convergence occurs within a specified number of iterations and tolerance. The lack of convergence indicates that stress and displacement distributions that satisfy equilibrium conditions cannot be determined. The SRF which corresponds to the point at the last convergence state is equivalent to the safety factor.

SLOPE 1

Slope 1 comprised brine and sludge ponds which were proposed to be constructed within an existing coal slurry storage facility. The idea was to utilise the coal slurry in the construction of the compartment walls, and cover the walls with earth and plastic liners. The final embankment height was approximately 7 m.

Due to the coal slurry having very low stiffness and shear strength properties, it was expected to cause significant construction difficulties. Deformation, however, is not considered in LE analysis (Figure 1) and would therefore be overlooked, but is considered in the FE analysis (Figure 2), provided accurate stiffness and deformation data is used.

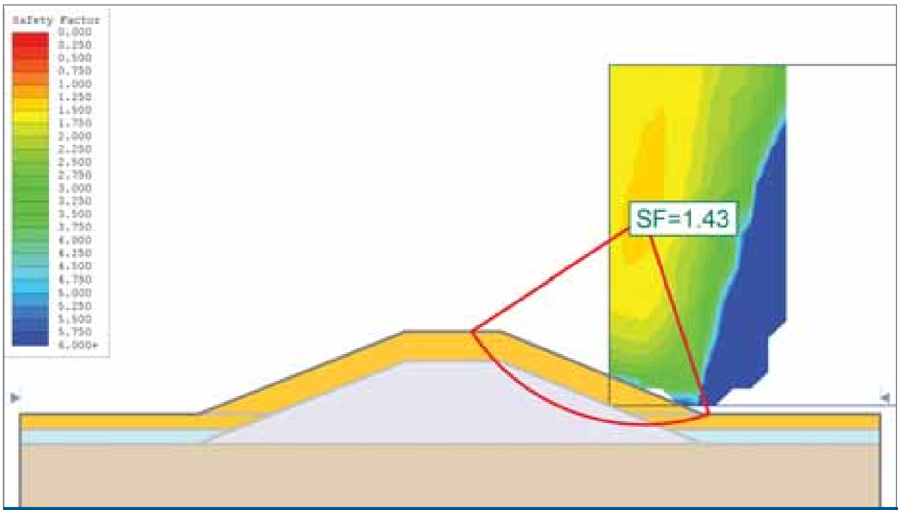

Figure 1: Slope 1 – LE analysis

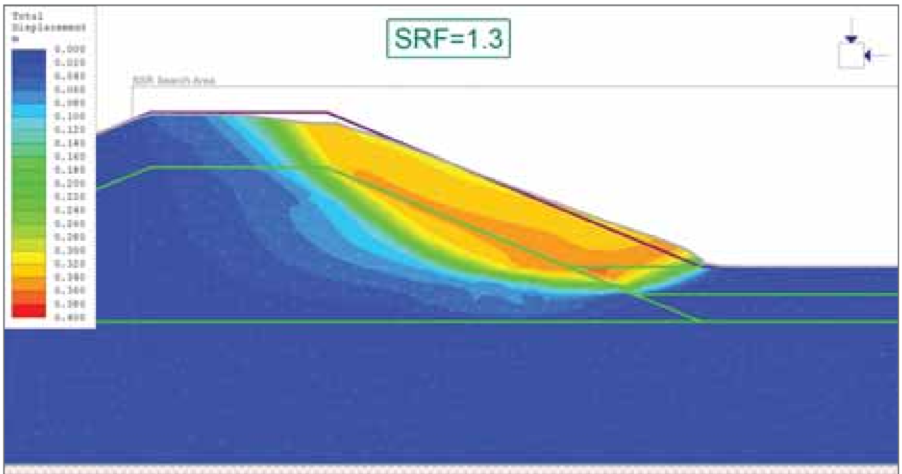

Figure 2: Slope 1 – FE SSR method (contours of total displacement)

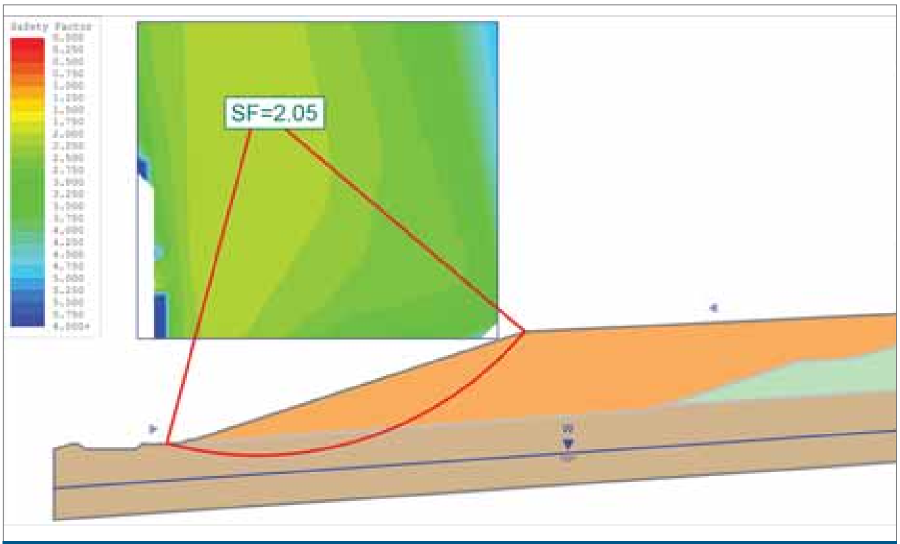

Figure 3: Slope 2 – LE analysis (circular slip surface)

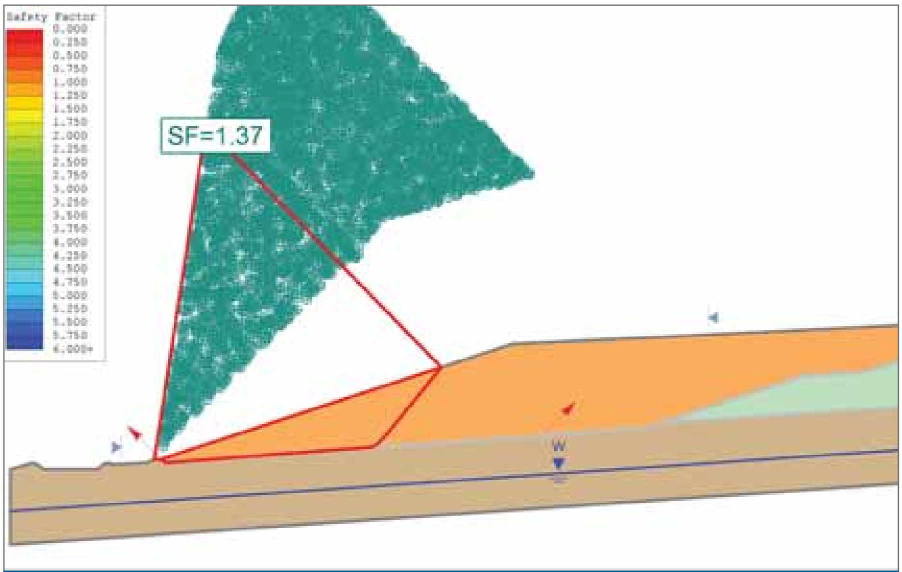

Figure 4: Slope 2 – LE analysis (block search)

Slope 1 discussion

The FE SSR method returns a lower safety factor / strength reduction factor of 1.3, which is on the limit for temporary water retaining embankments. This can be related to the "Serviceability Limit" as displacements of 30 cm to 40 cm may not cause complete failure of the facility, but may compromise the liner system. It must be emphasised, though, that displacements are only meaningful if accurate stiffness and deformation moduli are used.

SLOPE 2

Slope 2 consisted of a lined tailings facility on a sloping foundation such that the liner has the potential to act as a "slip surface". The liner was modelled as a thin material layer with c' = 0 and ϕ' = 14.5° and the final height of embankment approximately 80 m.

In this instance a circular slip surface (Figure 3) does not represent well the critical slip surface which includes the liner, creating a wedge-type failure. This surface can be better determined in Slide using either a block search (Figure 4) or path search.

Slope 2 discussion

The FE SSR method returned a slightly lower safety factor than the LE block analysis and both were significantly lower than the LE circular slip surface analysis. In this instance, the FE analysis assisted in defining the most appropriate slip surface which can then be analysed in Slide using either a block or path search.

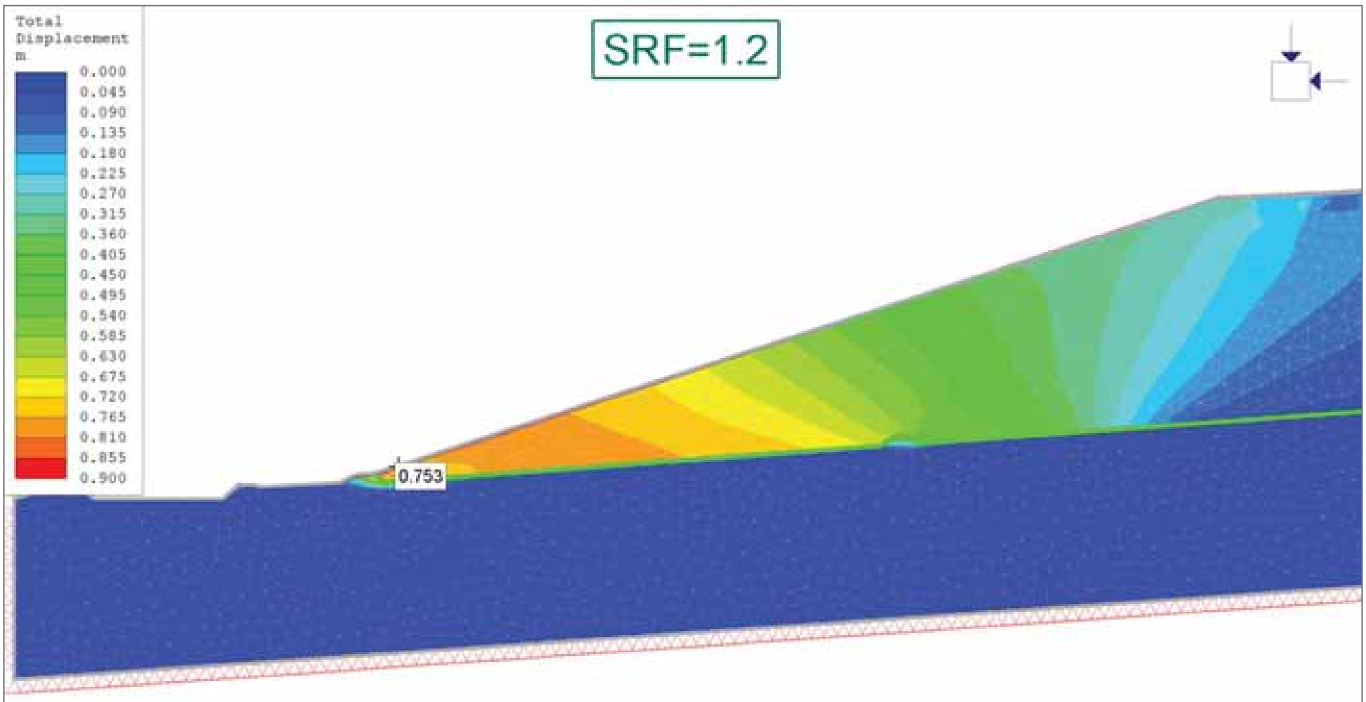

Figure 5: Slope 2 – FE SSR method (contours of total displacement)

Deformations of up to 0.75 m are shown in the FE analysis which, although large, is insignificant due to the scale of the facility. These deformations are, additionally, not exactly representative due to using assumed deformation properties of the materials, and not known values.

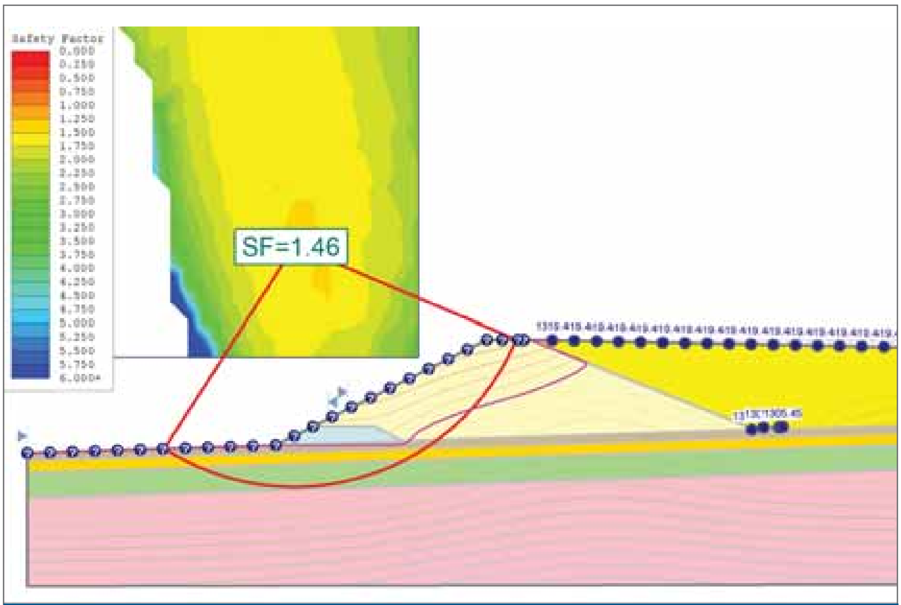

Figure 6: Slope 3 – LE analysis

SLOPE 3

Slope 3 comprised a tailings impoundment with multiple foundation horizons of variable strength. The facility was additionally modelled with a leak in the liner by inserting an opening in the liner at approximately two-thirds the height of the embankment. The final height of the facility is approximately 25 m.

The complexity of this model advocates the possibility of multiple potential failure surfaces – for example, circular or wedge failures through the saturated zone, or failures through one of the weaker foundation layers. The lowest LE safety factor, which was (perhaps unexpectedly) along a circular slip surface through the foundation soils is shown in Figure 6.

Slope 3 Discussion

This analysis returned very good correlation between the LE and FE methods (see Figure 7 for FE method) and gave excellent confirmation of the failure surface. Carrying out the FE analysis in parallel with the LE would have saved much time/effort spent searching for the worst-case slip surface during the LE analysis.

CONCLUSION

This study supported our opinion that the FE SSR technique is an extremely useful method of carrying out slope stability analyses in addition to the typical LE analysis. The Slide model imports to Phase[2] directly and the SSR technique is fully automated, so running the analysis is quick and easy.

Carrying out both LE and FE analyses results in excellent verification of the worst-case failure surface and generally gives very good confirmation of the safety factor against failure. Some interpretation of results based on the engineer's experience is needed, such as when dealing with displacements in the FE analysis, but that is generally the case with most aspects of geotechnical engineering anyway.

NOTE

The list of references is available from the authors.

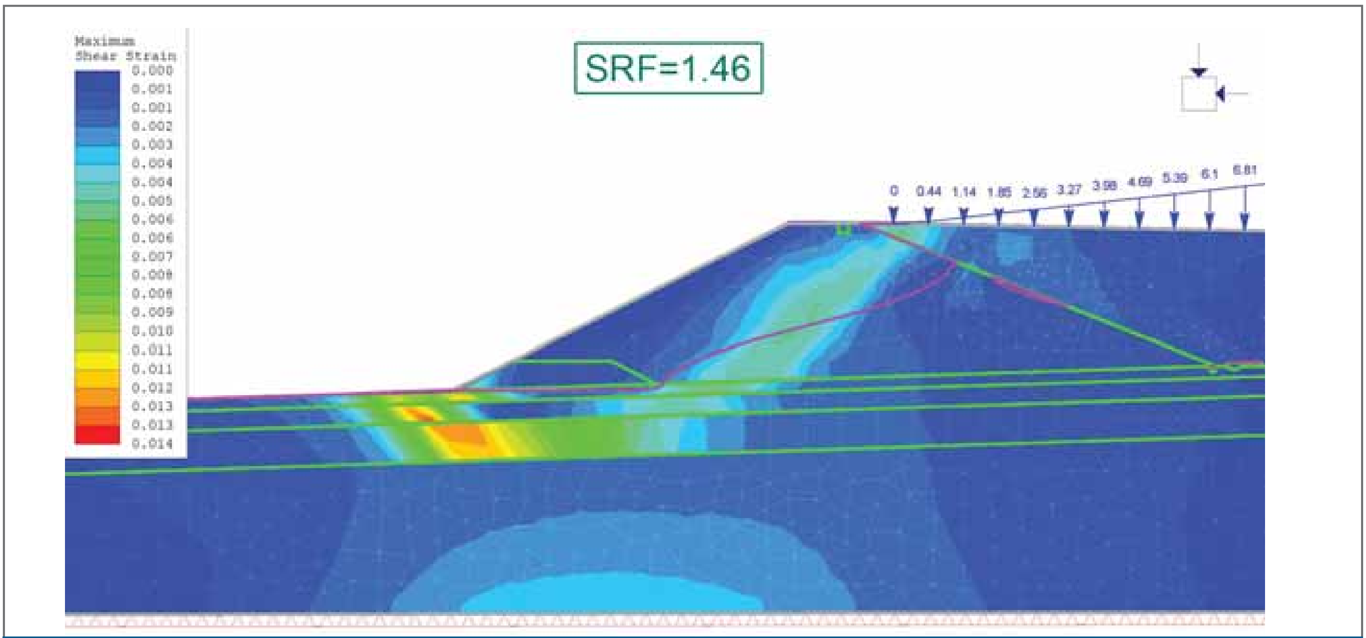

Figure 7: Slope 3 – FE SSR method (contours of maximum shear strain)

Source:
http://www.saice.org.za/downloads/monthly_publications/2013/2013-Civil-Engineering-April/#/0