

Is Stress Important to the Stability of Underground Wedges?

This article discusses the conditions under which stress effects need to be taken into account, when analyzing the stability of underground wedges. It describes how stress has been incorporated into *Unwedge 3.0*, the new Rocscience program for performing such analysis.

roc science
software tools for rock and soil

Geomechanics
software used
worldwide by
geotechnical
engineers

Article prepared for RocNews
Spring 2004

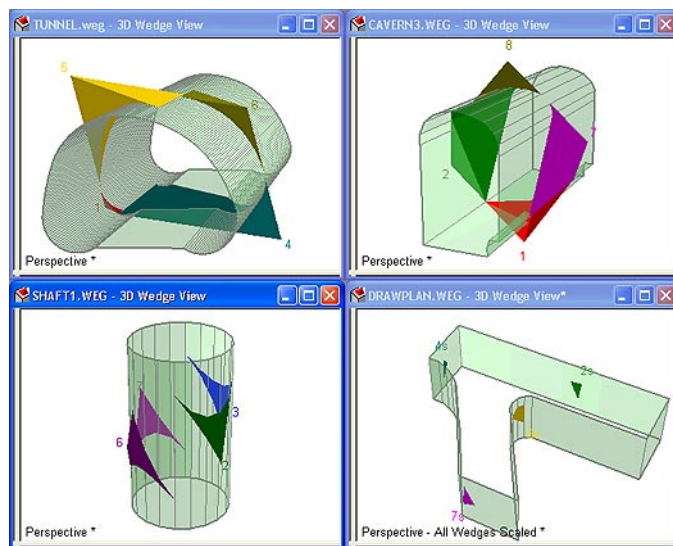
Is Stress Important to the Stability of Underground Wedges?

In most analyses on the stability of underground wedges, it is assumed that stress does not influence stability. But is this assumption always valid? And if it is not, how do we deal with stress in analysis?

This article discusses conditions under which stress effects need to be accounted for, and describes how stress has been incorporated into *Unwedge* 3.0, Rocscience's program for performing underground wedge stability analysis.

The influence of stress on the stability of wedges

Most approaches for analyzing the stability of wedges that occur around underground excavations, including that implemented in previous versions of *Unwedge*, assume low stress excavation environments. Under such conditions, stress has little impact on calculated factor of safety values and can be safely ignored. This assumption is often reasonable for excavations in jointed rock masses at relatively shallow depths¹. It also helps to significantly simplify stability calculations.



Excavation models - tunnel, cavern, vertical shaft, drawpoint.

The assumption of zero stress leads to very conservative results, however, for certain cases. Let us look at the stability of a wedge in the roof of an excavation, for example. Such a wedge fails by falling under the influence of self-weight. With stress omitted, traditional analysis will predict that the wedge has a factor of safety of zero and can remain in place only when supported.

Many practical situations defy this prediction. Roof wedges located in deep underground excavations have been observed to be stable. In one research project it was suggested that conventional underground wedge stability analyses are commonly too conservative because they ignore stress². The stability of wedges at significant depths can be explained by the clamping effect of the surrounding stress field. The components of confining stress normal to the discontinuity planes, which form a wedge, mobilize shear resistance sufficient enough to keep the wedge in place.

Unfortunately, including stresses into wedge stability analysis is not a trivial exercise. This may partially explain why practical analysis tools, which allow the important influence of stress on wedge failure mechanisms to be accounted for and captured in design, have been absent for so long from the geotechnical software market.

A few papers have been published on the topic that suggest solution techniques.

In most cases the suggested techniques use one or both of the following simplifying assumptions:

- A two-dimensional wedge and stress geometry
- In situ stresses act on the discontinuity planes that form wedges.

Neither of these assumptions allows comprehensive understanding of stress effects on wedge stability. The geometry of wedges is clearly three-dimensional. The same applies to the state of stress. As well, due to the fact that excavation in a stressed rock mass leads to re-distribution of stresses around the created opening, the stresses acting on the faces of a wedge are often very different from *in situ* conditions.

How stresses are calculated in *Unwedge* and included in stability analysis

The primary goals of underground wedge design are to establish likely failure mechanisms, to identify the most important factors influencing stability, and to estimate the amount of support required to stabilize wedges.

It was suggested that conventional underground wedge stability analyses are too conservative because they ignore stress.

Rocscience engineers realized that for the new Unwedge to be highly useful to practitioners, the stress calculation approach adopted had to facilitate the following:

- Realistic estimation of the stresses around excavations, and
- Quick computation that requires minimal input data and numerical modelling expertise.

The challenge was to ensure that the stress analysis component in *Unwedge* would not distract rock engineers from their primary goals of analyzing the stability of underground wedges.

Stress distributions around excavations

The pattern of re-distributed stresses around an excavation is determined by several factors. These include the magnitudes and directions of the *in situ* principal stresses, the orientation of the *in situ* stresses relative to that of the opening, the geometry of the opening, stress interactions with nearby excavations, and the elastic or plastic deformational behaviour of the rock mass.

To simplify the computation of the stress state around an excavation, *Unwedge* makes two primary assumptions:

- The rock mass material behaves as an elastic continuum, and
- The stress state is the same at every tunnel cross-section

The first assumption ignores the presence of discontinuities during the calculation of stresses. It is usually adequate for modelling stresses, especially in hard rock masses. The second assumption allows the use of two-dimensional numerical modelling approaches. Two-dimensional stress models of geotechnical excavations are much more simple, and to date are the most prevalent stress analysis methods.

The two-dimensional stress state assumption is valid when the ratio of the length of an excavation to its width exceeds six, and an excavation section that is more than three widths away from the end of an excavation is being analyzed. However, the assumption excludes the incorporation of stresses into the analysis of end wedges.

Two-dimensional stress models of geotechnical excavations are much more simple, and to date are the most prevalent stress analysis methods.

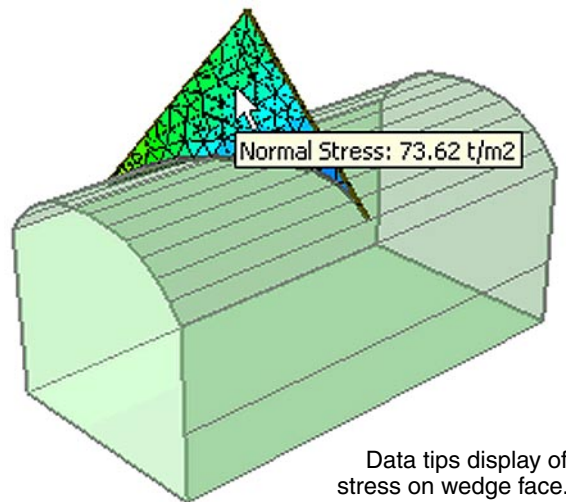
This is because the spatial distribution of stress at the ends of excavations is highly three-dimensional, varying rapidly over short distances in the direction along the excavation axis.

The boundary element method of stress analysis

Numerical methods offer the most generalized means of calculating stresses around excavations. One of the most simple (from the user point of view, but not from the mathematical perspective), easy to use numerical approaches is the Boundary Element Method (BEM). The BEM is powerful for analyzing problems that involve elastic, homogeneous materials.

In the BEM only the surfaces of excavations are represented with elements. The method treats the rock mass surrounding an opening as an infinite continuum. The BEM's discretization of surface boundaries only, endows it with several advantages. It results in much smaller numbers of elements, which in turn lead to improved speed of computation. It also allows the BEM to model problems that have large geometrical extents. Perhaps most important for use with wedge stability analysis, the BEM does not require too

much numerical modelling skill or experience from users. These latter features facilitated the creation of an automated stress analysis module in Unwedge, and seamless integration of stress results into stability calculations.



Data tips display of stress on wedge face.

The steps for factoring stress into the stability calculation of a wedge

Once the stresses around an excavation have been calculated with the BEM, the following steps are used in Unwedge to include them in stability analysis:

- Each discontinuity surface of a wedge is discretized into elements. Stresses at the centroid of each element are then calculated. Stress vectors are subsequently determined for the elements. Each element stress vector is resolved into a normal vector and shear vector.

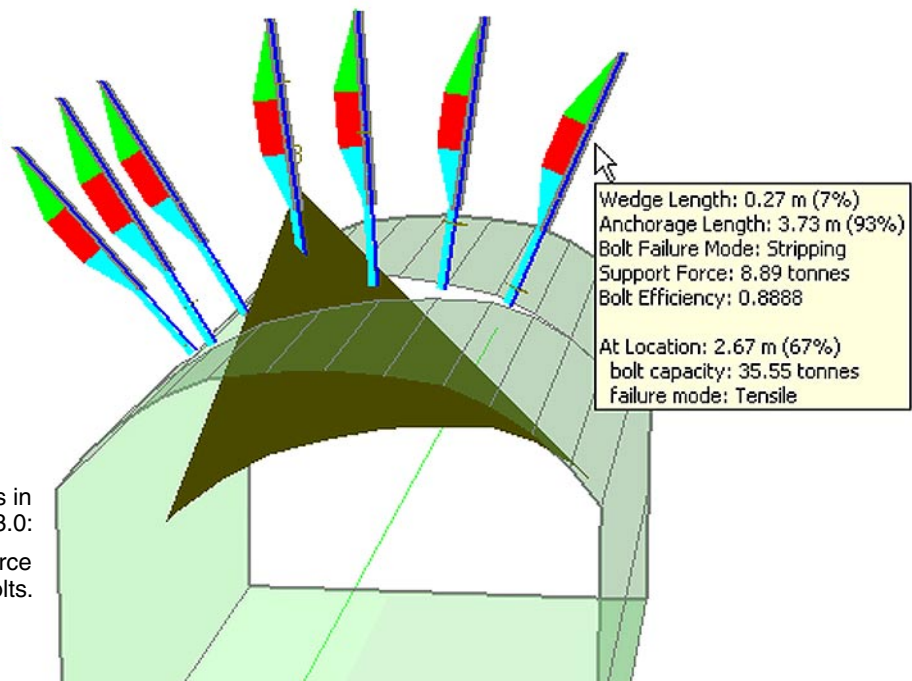
- The normal and shear stress vectors for an element are used to obtain a normal force vector and a shear force vector by multiplying the respective stress vectors with the element area. All force vectors calculated for the elements are then summed up to obtain an overall normal force and an overall shear force for the wedge surface.
- The overall normal and shear forces calculated for each discontinuity surface are then included with other forces such as self-weight and support pressure acting on a wedge to calculate its failure direction and factor of safety.

Concluding remarks

With its ability to take stresses into account when calculating the mode of failure and the factor of safety of a wedge, *Unwedge 3.0* has expanded the range of underground wedge stability situations rock engineers can analyze. Now engineers have the tools to perform more comprehensive study interactions between stress and the failure or stability of wedges. Technical details on how stress is actually incorporated into the stability equations of underground wedges will be published in a paper³ at Gulf Rocks '04, the 6th North American Rock Mechanics Symposium (NARMS) in Houston.

Roof wedge [8]
FS: 2.319

- Bolt Mode: Pullout
- Bolt Mode: Tensile
- Bolt Mode: Stripping



Visualizing results in
Unwedge 3.0:
Display of support force
diagrams on bolts.

To facilitate better comprehension and appreciation of model behaviour, *Unwedge* 3.0 provides powerful graphical tools for visualizing results.

The program's rich visualization capabilities allow more people to better understand the modelling of underground wedges. Only so much insight can be gained from numbers, as a result of which situations often arise when a modeller does not understand

his/her results. By visualizing wedge failure directions, stress distributions on wedge surfaces, etc., the modeller can "see" events unfolding and understand how different assumptions and factors affect stability. The graphical capabilities in *Unwedge* 3.0 also benefit non-technical audiences. A few minutes spent watching wedge behaviour can eliminate hours of tedious discussion.

¹ Hoek, E., P.K. Kaiser and W.F. Bawden. Support of underground excavations in hard rock, Balkema, Rotterdam, 2000.

² Kaiser, P.K., M. Diederichs, S. Tazici. Cable bolt performance during mining induced stress changes – three case examples in Rock Support in Underground Construction (eds. P.K. Kaiser & D.R. McCreath), AA Balkema, Rotherdam, pp. 377-384, 1992.

³ Curran, J.H., B. Corkum and R.E. Hammah. Three-dimensional Analysis of Underground Wedges under the Influence of Stresses. To be presented at the 6th North American Rock Mechanics Symposium, Gulf Rocks '04.