Slope Stability with Rocscience software

Rocscience Inc. has traditionally been recognized for stress analysis software, such as Examine3D and Phase2. However in recent years a great deal of development effort has been devoted to slope stability software at Rocscience.

The stability of slopes is of great importance to civil, geotechnical and mining engineers worldwide. Stability analyses are required for a wide variety of engineering projects, such as:

- open pit mines
- road cuts
- dams
- embankments
- tailings piles
- natural slope stabilization

There are many different approaches to the analysis of slope stability, ranging from simple kinematic analysis using stereonets, to the various widely used limit equilibrium methods, to sophisticated numerical methods. These approaches can be generally categorized as follows:

- Stereonet analysis
- Limit equilibrium methods
- Rockfall simulation
- Numerical methods

In recent years, with the computing power now available on desktop computers, numerical methods such as finite element, finite difference, and discrete element analysis, are becoming more commonly applied to slope stability problems.

The choice of analysis method will depend on:

- the nature of the problem (soil or rock? 2D or 3D? circular or planar failure?)
- the quality and type of input data which is available (groundwater, strength parameters)
- the type of analysis results which are required (deterministic or probabilistic? support requirements?)
- the level of expertise, and preferences of the engineer or analyst

Although there are a great many commercially available slope stability programs on the market, there is a need for easy to use, and reliable software. Such software must satisfy all engineering requirements – accuracy of results, an easy to use and intuitive interface which allows the engineer to assess the results, and generate professional looking output, for inclusion in reports, papers and presentations. All of this and more, is delivered by ROCSCIENCE software.

No less than 6 ROCSCIENCE programs, can be used for the analysis of slope stability. Four of these programs – SLIDE, SWEDGE, ROCPLANE and ROCFALL – are specifically designed for slope stability analysis. Two other programs – DIPS and PHASE2 – can be used for slope stability, although this is not their primary application.

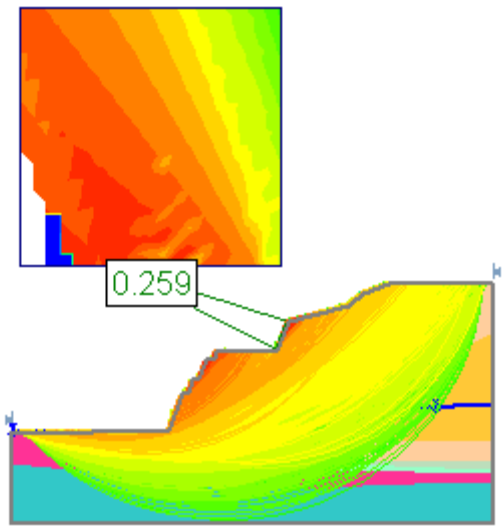
According to the general categories of stability analysis methods listed above, the ROCSCIENCE software which can be used for slope stability analysis, can be grouped as follows:

• Stereonet analysis	DIPS
• Limit equilibrium methods	SLIDE, SWEDGE, ROCPLANE
• Rockfall simulation	ROCFALL
• Numerical methods	PHASE2

The current suite of ROCSCIENCE software therefore provides slope stability analysis capability, in all general categories of slope stability analysis. Further program developments are under consideration.

The following information outlines the uses and capabilities of the currently available ROCSCIENCE programs, and also the ways in which they can be used together to solve slope stability problems.

SLIDE – 2D limit equilibrium analysis of slope stability



SLIDE is our very popular 2D slope stability analysis program, which uses conventional 2D limit equilibrium methods, to analyze slope stability. Features include:

- Bishop, Spencer, Janbu, GLE (General Limit Equilibrium) and other analysis methods
- Circular, composite or non-circular surfaces can be analyzed.
- Several search methods and search refinement options are available, which allow the user to quickly determine the critical slip surfaces with the lowest factor of safety
- Loading: external, seismic, support
- Several different ways to model pore pressure

As of SLIDE version 4.0 (AVAILABLE MARCH 1, 2002), the following new and important features will be available:

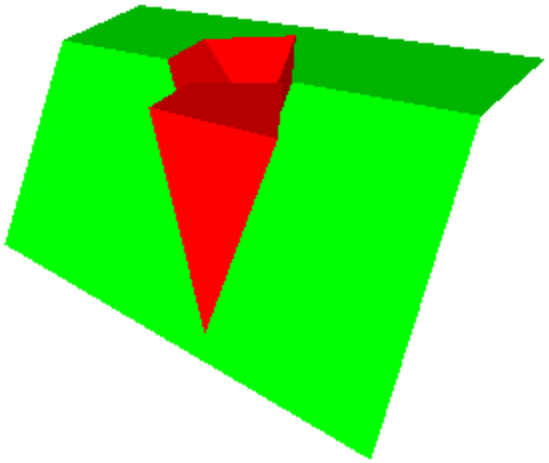
- Much improved modeling of support. Explicitly model the effects of geotextiles, grouted tiebacks, soil nails, micro piles or end anchored support. User defined support allows any support force diagram to be defined.
- Built-in groundwater analysis engine. SLIDE 4.0 contains a completely self contained groundwater analysis program, allowing the user to define and analyze a groundwater problem, and view the results, all within the overall SLIDE program. The pore pressure results from a groundwater analysis, can be directly used by the slope stability analysis.

SLIDE 4.0 contains most of the analysis features frequently requested by engineers, for the 2D analysis of slope stability problems. It's ease of use is unmatched by any other comparable program, at any price. Very complex models can be created easily in SLIDE, due to modeling and interface features not available with any other slope stability software. In addition, the data interpretation and results presentation features of SLIDE 4.0, are state-of-the-art.

Related Rocscience software

Very simple 2D planar failure, can be analyzed with ROCPLANE, which also provides probabilistic analysis capability, not currently available in SLIDE. Advanced users may wish to model a slope stability problem with PHASE2, and compare results with the SLIDE limit equilibrium analysis.

Swedge – 3D wedge stability for slopes



SWEDGE is a very simple to use program for evaluating the stability of surface wedges formed in rock slopes, defined by two intersecting discontinuity planes, the slope surface, and an optional tension crack.

A key feature of SWEDGE is the PROBABILISTIC analysis capability. Statistical distributions can be defined for all input parameters, and a probability of failure can be determined. All statistical output can be easily viewed and exported to other programs, for further analysis, reports and presentations. Other features include water pressure, external and seismic forces, active or passive bolt support, and shotcrete support.

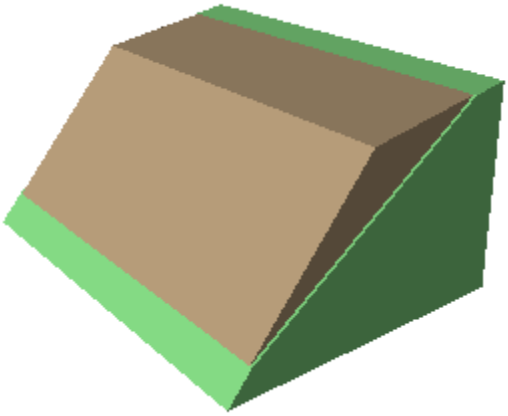
SWEDGE is commonly used for the analysis of wedges formed in rock cuts, open pit mine slopes, and similar applications. SWEDGE is another very popular ROCSCIENCE program. Although it is very easy to use, it provides a comprehensive stability analysis of tetrahedral surface wedges in slopes, for both DETERMINISTIC (safety factor) and PROBABILISTIC (probability of failure) types of analysis.

Related Rocscience Software

DIPS, the ROCSCIENCE stereonet analysis program, can be used to identify joint sets from raw orientation data input. Mean joint orientations can be automatically loaded into SWEDGE, and the actual wedges formed by different combinations of joint sets, can be viewed and analyzed. Statistical standard deviations calculated for joint sets in DIPS, can be entered as probabilistic input data in SWEDGE

RocPlane – 2D planar failure for slopes

ROCPLANE is a very similar program to SWEDGE, except that the ROCPLANE analysis is applicable to 2D planar failure in rock slopes, rather than 3D wedge failure.



ROCPLANE has the same PROBABILISTIC analysis capability as SWEDGE, and allows the user to determine a probability of failure for a planar wedge in a slope, by entering statistical distributions for input parameters such as shear strength, joint orientations and water pressure.

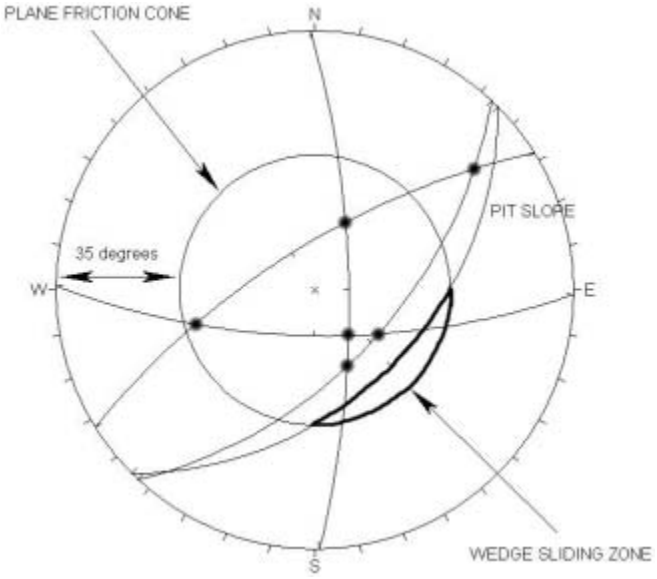
In addition, ROCPLANE allows the user to easily carry out a sensitivity analysis, to determine which input parameters have the greatest effect on the safety factor.

Although true 2D planar failure in slopes is a relatively rare situation, the simplicity of the ROCPLANE program allows the user to easily gain an appreciation of the effect of different input parameters (eg. water pressure and shear strength). ROCPLANE is both a useful analysis tool for professional engineers, and also an instructive program for civil and geotechnical engineering students.

Related Rocscience Software

As with SWEDGE, the DIPS stereonet program can be used to identify joint sets, which can then be entered as input data for ROCPLANE. Statistical standard deviations calculated for joint sets in DIPS, can be entered as probabilistic input data in ROCPLANE.

DIPS – stereonet analysis of orientation data



DIPS, is a program for the graphical and statistical analysis of orientation data, using stereonets. The main purpose of DIPS, is the contouring of orientation data on the stereonet, so that significant joints sets can be identified, from the raw input data.

After joint sets and their corresponding mean orientations have been identified, a preliminary analysis of possible failure modes, can be performed graphically on the stereonet. Although DIPS is not specifically designed as a slope stability analysis program, it is possible to carry out stability analyses using a stereonet.

On a stereonet, the possibility of:

- PLANAR sliding
- WEDGE sliding
- TOPPLING

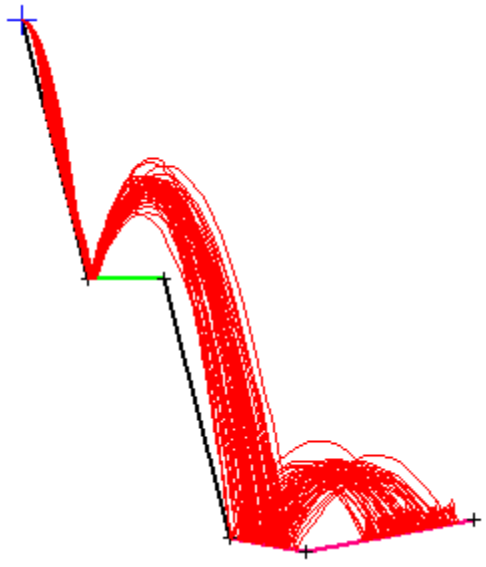
can all be quickly evaluated, based on kinematic and friction angle considerations. Although precise numerical values of safety factor cannot be derived from a stereonet analysis, it is possible to estimate probabilities of failure, based on the percentage of orientations which fall within a potential sliding or failure zone on the stereonet.

An example of such an analysis (planar sliding, wedge sliding and toppling), can be found in the DIPS tutorial manual, available on the ROCSCIENCE website. Other methods of stability analysis using stereonets, are possible, contact ROCSCIENCE for details.

Related Rocscience Software

Mean joint orientations obtained from DIPS, can be imported into SWEDGE, or entered as input data in ROCPLANE. Preliminary kinematic analysis with DIPS, allows the user to select potential failure plane orientations, for input into SWEDGE or ROCPLANE. Potential wedge or planar failures identified on a stereonet, can then be visualized in SWEDGE or ROCPLANE.

RocFall – 2D risk analysis of rockfalls on slopes



ROCFALL is a 2D rockfall simulation program.

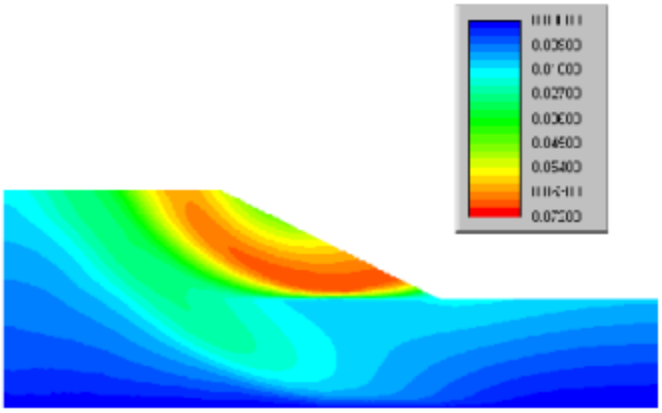
Although simple in concept, the latest version of ROCFALL incorporates many advanced features not available with other similar programs.

A ROCFALL analysis is different from other ROCSCIENCE slope stability software. The ROCFALL analysis does not model the overall failure of a slope, but performs a risk analysis of rockfalls (ie. rocks which break free of the slope surface, and travel down the slope), using Monte Carlo sampling of probabilistic input parameters. The statistical input parameters may include the rock mass and initial velocity, the coefficient of restitution of each slope segment, and other slope surface properties.

The ROCFALL analysis lets the user instantly view rock trajectories, and analyze the distribution of rock endpoints (ie. the final resting locations of the rocks). All statistical information is easily available, such as velocity and kinetic energy distributions, and bounce height envelopes. All data can be graphed, or exported to other programs for further analysis.

The ROCFALL analysis can be used to design the location, size and strength of rockfall barriers on the slope.

Phase^2 – finite element analysis



PHASE2 is a 2D elasto-plastic finite element program, for the analysis of stresses and displacements, as well as support analysis, for underground or surface excavations.

A finite element program such as PHASE2, can be used for the analysis of slope stability. Two possible approaches to this are:

1. Increase the gravity field stress loading, until the slope becomes unstable (ie. solution does not converge, due to large displacements along failure zone)
2. Decrease the shear strength of the material(s), until the slope becomes unstable. The critical shear strength reduction factor, can be taken as the safety factor of the slope.

A document which discusses the second method (shear strength reduction) using PHASE2, can be found on the ROCSCIENCE website,
http://www.rocscience.com/library/pdf/SlopeStabilityUsingPhase2.pdf.

Although slope stability using advanced numerical methods, is a relatively new field, it is becoming more common, since such analyses can now be routinely performed on desktop computers. The advantage of slope stability analysis with a finite element program, is that no assumptions need to be made about the shape or location of slip surfaces. Also, the many assumptions which are inherent in conventional limit equilibrium analyses (for example, the orientation of interslice forces), are not necessary or applicable to the finite element approach.

However, slope stability using a finite element program, also requires more care and attention to the analysis, and generally requires a greater level of experience and expertise on the part of the user.

Related Rocscience Software

Although SLIDE and PHASE2 do not directly interact with each other, it is interesting to compare the results of a SLIDE slope stability analysis, with a PHASE2 slope stability analysis. Although the limit equilibrium and finite element methods are very different, the two programs will lead to similar results, when used correctly.

Conclusion

Slope stability is a major concern for geotechnical and mining engineers worldwide, and consequently, a great deal of effort at ROCSCIENCE is dedicated to slope stability analysis software. Of the software which is currently available from ROCSCIENCE, half of all programs are either specifically dedicated to slope stability analysis (ie. SLIDE, SWEDGE, ROCPLANE and ROCFALL), or can be used for slope stability analysis (ie. DIPS and PHASE^2).

Some of these programs can be used together to analyze slope stability (for example, DIPS and SWEDGE). Or alternatively, a preliminary analysis could be carried out with one program, and more detailed final design with another (for example, ROCPLANE and SLIDE, or SLIDE and PHASE2). As with all ROCSCIENCE software, the programs are very easy to learn and use. They are also state of the art engineering analysis tools, which satisfy many different engineering analysis requirements, from initial problem exploration, to the generation of high quality professional reports and presentations.