BETTER SLOPE STABILITY BEGINS WITH TRUSTED METHODS TO INCREASE SAFETY

Take advantage of combined analysis methods with Bentley’s Geotechnical Analysis Software.
This e-book will help you discover precise and complete slope stability analysis with Bentley. You will see an introduction to slope stability, an overview of the limit equilibrium and finite element methods, and a quick look at real-world projects that utilized each method.

If you have questions, or need more information, please click here.

Buy PLAXIS applications at Virtuosity

Virtuosity, a wholly owned division of Bentley, is an eCommerce store that makes it easy for organizations to buy 12-month, practitioner-named product licenses at an affordable price and the personalized training and on-demand learning you need to be successful.
Ensure your analysis software is reliable and achieves your desired factor of safety

A common geotechnical challenge involves assessing slope stability of structures such as dams, levees, reinforced walls, slopes, mines, and excavations. Engineers rely on numerical modeling to design, evaluate, and solve slope stability problems with a high level of precision.

Bentley’s geotechnical analysis software allows you to handle common and complex geotechnical analysis of soil or rock slopes. Three-dimensional analysis enables you to consider site geology and increase accuracy when calculating safety factors. Bentley slope stability applications ensure that you are keeping infrastructure safe and reliable. Their capabilities analyze models using both the limit equilibrium method (LEM) and finite element method (FEM). While users may choose to analyze in one method, it is recommended to run both methods in a combined analysis to provide a robust, thorough, and fully informed report for all involved stakeholders.
LIMIT EQUILIBRIUM METHOD

Theory

Analysis of slopes using the limit equilibrium method (LEM) is common in geotechnical engineering practice. PLAXIS LE software uses LEM, which offers an efficient toolset to gain insight into the design of projects where slope safety concerns are anticipated, or to understand the causes that lead to a failed slope. LEM techniques consider the equilibrium of a soil or rock mass and its tendency to slide due to gravitational influences. A potential slip surface below the ground surface is assumed. The forces, moments, or stresses resisting movement are compared to those contributing to movement. A factor of safety (FOS) is output, where a $\text{FOS} \leq 1.0$ indicates instability. With the relatively fast LEM calculation times, numerous potential slip surfaces can be analyzed and investigated while predicting the stability of a design case.

PLAXIS LE includes the most current analytical method of slices techniques in both 2D and 3D with related assumptions on the inter-slice forces and different considerations of force and moment balance. A comprehensive set of material shear strength relationships from the linear Mohr-Coulomb, through nonlinear, drained, and undrained, and including unsaturated and anisotropic options, enable most soil and rock types to be represented. The input material parameter requirements generally require less laboratory or in-situ testing to determine than a finite element analysis, for example.

We see that 3D analysis provides a more realistic representation of most sites and removes some of the conservatism built into 2D analysis, and so 3D analysis is becoming a requirement on more projects. The presence of water is of primary concern when analyzing slopes because water tends to decrease stability. Pore water pressures can be modeled using field data, Ru coefficients, water table, or piezometric surface specifications. Advanced climatic integration can be considered over time. Reinforcement spacing, retaining structures, static and dynamic loading, and slope reshaping are all common scenarios that can be modeled with LEM.
LIMIT EQUILIBRIUM METHOD

Practice

LEM can be applied to a wide range of stability situations involving both natural and human-made slopes. It is used in many industries, from mining to infrastructure, for road cuts, open-pit mining, foundation excavations, embankments, dams, levees, landfills, and mine tailings.

In a typical workflow for a section of road in sloping terrain requiring cut and fill, a geotechnical engineer can input a terrain mesh and import boreholes and piezometric readings into PLAXIS Designer. Then using the various geometric data adjustment tools, one would intersect and merge the ground surface and geostrata surfaces, thus preparing 3D meshed volumes suitable for an LEM analysis. Next, cut and fill operations are executed to define a final slope design or a set of design scenarios. A slope stability analysis model is generated from PLAXIS Designer and the details of the material properties, the parameters, and the shear strength method that best represents each layer are input.

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The material layers that may be above the water table are assigned as unsaturated and any relevant rock layers are assigned anisotropic bedding. A load is applied to the road surface and it can be set whether it should be uniform or distributed and at what angle it is applied. The portion of the cut slopes requiring reinforcement will have the anchor type, spacing, and orientation input.

With initial setup complete and an automatic slip surface search method chosen, the entire selected length of roadway is analyzed at multiple locations at a 100-meter interval. In the output module, the engineer spatially examines a contour map of the factor of safety, looking at the relative risk along the 1 kilometer alignment. The engineer can select locations of interest and take a closer look at the estimated 3D failure mass and the noncircular critical slip surface where weak zones are present. One can also toggle through the 10 next most critical results to gain a sense of the variation at each location.

Having identified a slide location of interest, a separate model is exported, and a probabilistic analysis using the Monte Carlo method is executed. This reduces risk by understanding the probability of failure and the influence of material parameter variation. The speed of LEM calculations make this possible in a 2D or 3D analysis. Next, the model is input with the pore water pressures vs. time calculated from a finite element groundwater analysis. In output, a factor of safety vs. time graph is examined, which predicts the influence of precipitation events along the roadway over the course of the next year.

LEARN MORE BY WATCHING THE VIDEOS BELOW

INTRODUCING PLAXIS LE
Discover the capabilities of the limit equilibrium method.

SLOPE STABILITY AND GEOMETRY
See how you can achieve better slope stability analysis.
BGC Engineering Inc., Vancouver, BC, Canada

BGC Engineering Inc. required a precise, real-world slope stability analysis of a complex tailings dam and wanted to ensure that the new structure would be appropriately and reliably designed.

To design a tailings dam structure model that would fulfill strict requirements, BGC Engineering selected two PLAXIS applications. The first phase involved creating a numerical model within PLAXIS Designer. This 3D model was necessary to fully represent the complex lithology of the foundation, geometry of the dam, and position of the water table. The second phase involved analyzing the numerical model for slope stability analysis using PLAXIS LE. In the case of upstream stability at the bend in the abutment, 2D sections could not reasonably resolve the pseudo-static seismic stability, so a 3D stability model was required. To perform the LEM slope stability analysis in 3D, PLAXIS LE was integrated with PLAXIS Designer conceptual modeling software to improve interaction between geometry building and analysis.

BGC Engineering took advantage of the 3D functionality of PLAXIS LE to gain a better understanding of the dam and managed to exceed design criteria. The project team gained valuable insight in combining both 2D and 3D analysis for a complete geotechnical design.

**Project Playbook:** PLAXIS LE, PLAXIS Designer
Theory

When considering safety in the context of slope stability analysis and PLAXIS’s finite element software, users will typically run one or more safety analyses after running any number of deformation, consolidation, or coupled flow-deformation analyses. This enables the user to assess whether the design’s factor of safety requirements are met, both during a project and long after a project is completed. For example, geotechnical engineers must analyze the factor of safety for flood defenses for a once in 100 years flood event. Or they may inspect the effects of individual or combined slope remediation techniques on the factor of safety, such as deep soil mixing methods or soil nailing.

In our safety analysis, the shear strength, cohesion, and tensile strength are reduced with each subsequent calculation step until the model reaches failure. When the failure occurs, the corresponding strength reduction factor is considered the factor of safety on soil strength.

Other methods usually require additional input and constraints on the failure mechanism to calculate the factor of safety. But the power in our FEM-based method lies in the fact that the most prevalent failure mechanism will form automatically in those areas where the shear strength is overcome by the shear stress. This can lead to circular and noncircular failure mechanisms, made apparent when inspecting various plots in the output program.

Slope stability analysis performed in either PLAXIS or PLAXIS LE will give similar factors of safety in many situations. However, users can capture the full mechanics of soil, water, and deformation as a result of using PLAXIS, providing:

- Advanced soil models
- Consolidation analysis
- Sophisticated, fully coupled methods
- Capabilities for precipitation and other time-dependent groundwater boundary conditions

Benefits include improving the estimates of the resulting stress, pore pressures, and deformation, which give a more realistic and accurate factor of safety, but may be considered less conservative as well. In this way, PLAXIS offers users a sophisticated tool to perform slope stability analysis.
**FINITE ELEMENT METHOD**

**Practice**

When performing slope stability analysis in PLAXIS, users will need to consider several practical aspects in their analysis that can affect the reliability of the resulting factor of safety. First, care should be taken that the mesh is sufficiently refined, because a mesh that is too coarse will overestimate the factor of safety. The user should also ensure that a safety analysis includes enough calculation steps to enable the failure mechanism to fully develop. Another aspect is the influence of suction. Performing a safety analysis based on prior calculations where suction is included will typically lead to higher factors of safety. Such safety factors are more realistic, but care should be taken, as they are, in fact, less conservative than safety factors when suction is ignored.

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The factor of safety can be directly read from the software’s Calculation Information table once the computation has finished, but is usually assessed through curve plots. The user should select a monitoring point in the general area where slope failure may be expected. After the safety analysis calculation is completed, a curve plot is generated of the displacements versus factor of safety for the point in question. In principle, the curve should reach an asymptote that corresponds to the factor of safety.

From the same curve, it can be recognized whether failure occurs based on the idea that a small step or increase in the factor of safety should lead to a large change in displacement. If this is not the case, the safety analysis should be run with a larger number of calculation steps. An inspection of shaded plots of either the incremental displacements, which show the displacements in the last calculation step, or the shear strains will point the user to the failure mechanism that occurs.

**Note**

*It should be noted that slopes with a factor of safety less than 1 are not typically modeled within our finite element solution. Slopes of that type are not stable in the first place, which would lead any of the phases preceding the safety analysis to terminate prematurely with a soil collapse error. However, our PLAXIS LE solution can analyze these slopes.*
**Tokyo City University, Tokyo, Japan**

When the cities of Tokyo and Kochi recognized that torrential rains were causing embankments to collapse, leading to a disastrous landslide, Tokyo City University initiated a project to create a more efficient drainage method to avoid saturation and prevent collapses at the embankment bases. They looked for a comprehensive digital approach to visualize and analyze the effects of a new drainage system.

The team launched an investigation to see whether the capillary barrier served to generate a more efficient drainage method. Upon further experimentation, the team confirmed a large-scale collapse phenomenon due to precipitation. However, they could not gain a clear result regarding the drainage method due to the local collapse of the slope.

They chose PLAXIS 3D to model and analyze the use of the capillary barrier as a potential solution. Using Bentley’s geotechnical application, they established a 3D model, which was used to calculate hydraulic conductivity and visualize water collection in the drainage pipe. The model enabled them to analyze the effectiveness of the new drainage method, clearly verifying and confirming its success.

**Project Playbook:** PLAXIS 3D
ACHIEVE EXCELLENCE IN SLOPE STABILITY ANALYSIS

Obtaining a reasonable factor of safety in your geotechnical designs is crucial. We provide the trusted methods and reliable analysis to make your projects safe and computationally sound.

Get started with PLAXIS. Whether you choose FEM, LEM, or a combination of the two to strengthen your analysis, you can rely on our slope stability analysis applications.