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Slope Stability Analysis Methods

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ABSTRACT

The presence of discontinuities, the inherent variability of the rock mass and discontinuity properties, and the uncertainties associated with directions and magnitudes of the in-situstress makes the rock engineering problems challenging. The numerical modeling can assist the ground control engineers in designing and evaluating the stability of the excavations. If extensive geological and geotechnical data are available, then detailed predictions of deformation, stress and stability can be accomplished by performing numerical modeling. If not, still the numerical modeling can be used to perform parametric studies to gain insight into the possible ranges of responses of a system due to likely ranges of various parameters. The parametric studies can help to identify the key parameters and their impact on stability of underground excavations. The priorities of the material testing and site investigation can be set based on the selected key parameters from parametric studies. The most important modeling methods in stability analysis include finite element method, finite difference method, boundary element method and Distinct element method, which are used in three static, quasi-static and dynamic conditions and in both definite and probability modes. In this report, we investigate each of these methods their weaknesses and strengths.

Keywords: Modeling methods, Stability analysis, Finite element method, Finite difference method, Boundary element method, Distinct element method

Introduction

The stability of the amplitudes of this mine and other mines in the region requires considering the dynamic stability of these amplitudes. The key factor for maintaining slope stability is the dynamic stability of the slope under seismic forces. There are four common methods for dynamic analysis of slope stability, however, pseudo-static method is commonly used. Therefore, a lot of engineering experience is accumulated in this method. Aside from this method, finite element method, resistance reduction method, and Newmark block slip method have also been developed [1].

Finite element method is a powerful method for obtaining numerical solutions of a wide range of engineering problems. This method is normally sufficient for any complex and geometrical geometric shape to be applied to any material under different boundary and loading conditions. The totality of the finite element method is appropriate with the required analysis of modern complex engineering systems and designs places where closed form solutions governing equilibrium equations are not normally available. In addition, this method is an efficient design tool so that designers can implement parametric design studies by considering sample designs (differences in shapes, materials, loads, etc.) and analyze them by selecting the optimal design [2].

Multi-stage models quickly for cases such as weak parts of tunnels, drainage stones, underground power plant caves, open-pit mines and slopes, embankments, etc. Can be created and analyzed. Cases such as progressive failure, maintenance interaction and other types of problems can also be shown by software [3].

Definitions

Ore is a natural set of one or more solid minerals that can be mining and processed and sold at a certain profit. Open-pit mining is a ground-level mining that is associated with the creation of stairs and cavities. The

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most prominent feature of open-pit mines is their steep walls, which are composed of two main parts of the stair face (the angle between the wasel line of the heel and the edge of the staircase with the horizon) and the national slope (the angle at which the wasel line makes the lowest heel and the highest edge with the horizon) [4]. To determine the slope angle of the wall, the relationship (1) is used:

$$\tan \propto = \frac{\Delta Y}{\Delta X} \qquad (1)$$

∝: angle of wall slope
ΔY: Wall Height
ΔX: Stair Width

The necessity of stability analysis of stone walls

In recent years, due to the development of infrastructures in areas with rock slopes, in the form of tall buildings, roads, railways, dams, and other stone engineering projects, the stability of rock slopes has become very important [5]. The rapid increase in the world's population has led to an increase in demand for mineral resources, so the stability of the slope in open-pit mining has become a serious threatening issue for the entire mining area [6].
Tensile damage often occurs above the slopes, caused by strengthening the effect of earthquake acceleration and lack of necessary opposition to the slope shell. However, little research has been done in this area. Almost all researchers have focused on the static effect of anchors and anti-slip agents, while little research has been done on dynamic stability. Maintenance structures should be designed not only to eliminate static instability but also to eliminate dynamic instability [7]. Therefore, one of the key factors for maintaining slope stability is the dynamic stability of the slope under seismic action [1].
How to select scientific, reasonable and reasoned mechanical parameters of rock mass in particular to evaluate slope stability based on engineering geological information collected about mining, through mapping information and analysis of engineering geological conditions is very important. The issue of slope stability in open mining is associated with selecting mechanical parameters of rock mass, wall slope, heterogeneity and nonlinear properties of rock mass, which is associated with uncertainty in selecting rock mass parameters. The accuracy and accuracy of gradient analysis results depends extensively on the selection of mechanical parameters of rock mass [6].
Among other factors affecting slope stability is the global slope, which depends on the slope angle of the stairs, the number of stairs, the width of the crossings, the number of crossings, the width of the safety stairs and the width of the working stairs in accordance with the figures (1) [4].

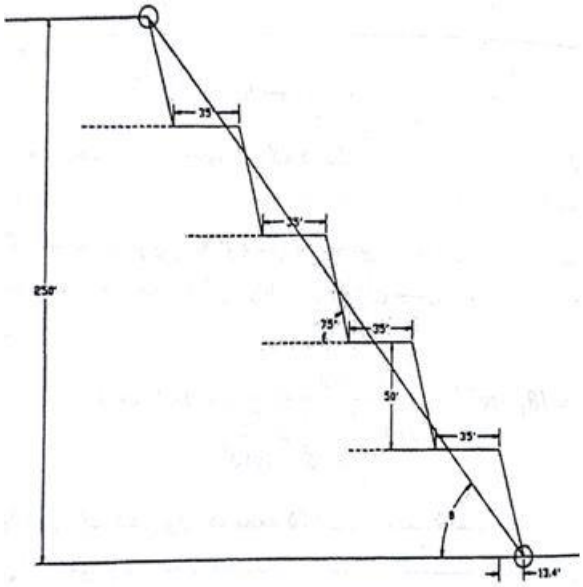


Figure 1. Geometric characteristics of the stairs of an open-pit mine [4].

Slope stability design and analysis methods

Tunnel design methods and mineral slopes are divided into three categories: analytical methods, observational methods and experimental methods. This method includes methods such as closed form solutions, numerical methods, simulations (electrical, photoalastic) and physical modeling. Observational methods are based on actual measurement of ground movements during drilling and analysis of ground movements, which can be used to determine instability. Among the sub-methods of this method are the new

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Austrian tunneling method and convergence restriction used in the stability analysis of the tunnels. Empirical methods are based on statistical analysis of stability of underground cavities constructed in different locations. Stone engineering classification methods are among the most prominent empirical methods [8].

Empirical methods

Hook et al. have provided the adhesion and internal friction angle of the rock mass in different modes specifically to solve the rock slope stability problems. To design slopes with different degrees of weathering, blocks and samples of the brain are collected from different amplitudes of the desired range. The samples are prepared as standards of the International Society of Rock Mechanics and are tested for stretching, pressure, three-axis resistance. The average single-axis pressure resistance and material stability of each aeronto-aerant and non-aerene rock materials are determined from the test results. GSI values of each aeronamed rock mass can be used to estimate the properties of rock mass (i.e. equivalent to the properties of rock mass) for analysis and design of slopes [5].

Hook also presents how to calculate the safety factor of a slope with a fall-prone plate and the relationship between slope height functions and slope angle for plate loss and circular fall, and categorizes the slopes in open-pit mines according to their status and the issues they cause according to Table 1 [4].

Table 1
Categories of outdoor mines slope issues [4].

Solving method	Conditions problem	Group
No consideration of slope stability is necessary.	Mining of high-cut, shallow deposits in favorable geological and climate conditions: slope angles are not economically important and low slopes can be used.	A- Low slopes
Typically, approximate analysis of slope stability is sufficient.	Mining with variable alloy and in geological and logical climate conditions: Slope angles are important, but they do not play a key and critical role in determining the economic status of mining.	B- Medium slopes
Typically, detailed geological and groundwater studies followed by comprehensive sustainability analysis are necessary.	Low-alloy mineral mining and unfavorable geological and climate conditions: Slope angles are key and critical in terms of both mining economy and safety.	C- Critical slopes

Numerical methods of slope stability analysis

Rock masses are the best description of batch, heterogeneous, non-isotropic and non-elastic materials. Different from materials produced in a way such as metals or plastics, physical properties and mass engineering of rocks cannot be easily defined or created. Therefore, rocks mass are complex materials for mathematical modeling in closed forms. Therefore, the use of numerical modeling to design and evaluate the engineering properties of stone is inevitable. The masses of rocks are in equilibrium before any underground drilling. This equilibrium state will be corrupted by excavations that are created within the masses of rocks. Normally suitable for heterogeneity and natural discontinuity of rock masses, different types of deformation and failure can occur in the excavation area. Mathematical or numerical analysis is necessary to estimate the position and intensity of failures and to calculate the magnitude of the displacements created in the drilling area. Numerical techniques are effective and powerful tools for analyzing and designing stone engineering structures. Most numerical methods used to solve rock engineering problems can be classified into three main categories [9]:

1- Continuous Methods: Finite Element Method [1,5]. Boundary Element Method [7] and Finite Difference Method [5].

2- Discontinuous Methods: Distinct Element Method [5,7,10] and discontinuous deformation method.

3- Two-purpose methods: FEM/BEM hybrid, BEM/DEM hybrid, FEM/DEM hybrid and other hybrid methods [9].

Continuous methods

In continuous methods, the scope of the problem is divided into much smaller elements, so that their behavior can be estimated using simplified numerical techniques with degrees of limited freedom. This procedure is known as separation. The hypothesis consistently suggests that deformation of all points in the scope of the problem must be continuous. Therefore, all node points always share with other parts by forming mesh and during the deformation process they must always remain in each other's neighborhood. Therefore, in the continuous method of rotation and

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separation of meshing is not allowed. The main problem with the continuous method is that the assumption of continuity is not always realistic for simulating large deformations and clear failure levels. Several developments have been proposed to improve shortcomings.

Discontinuous methods

Continuous methods are suitable for solving problems in which the main factor in rock mass behavior is not the status of discontinuity. As mentioned above, due to the fundamental assumptions of continuous mechanics, deformation of all points in a continuous region must be continuous. Therefore, numerical methods based on continuity are not suitable for simulation of structures that can be opened or slipped along discontinuity or fractures in pristine rock play a prominent role in the stability of rock mass. Most boundary element, finite element and lagrangian programs of finite difference are able to represent a limited number of discontinuity using the logic of "common surface element" or "slip lines". However, they cannot perform a large number of cross discontinuity. Also, their ability is limited only to small rotation and deformation calculations. Finally, they are incapable of automatically detecting new connections between blocks that develop during simulation. Accordingly, discontinuous methods have been developed to overcome the mentioned limitations of continuous methods [9].

Finite element method

Finite element method is the most commonly used method for analyzing geotechnical problems. Finite element method is widely used to solve problems in practice. So there's a lot of experience available for different types of problems [9]. Finite element method is a powerful method for obtaining numerical solutions in a wide range of engineering problems. This method is typically used to model any complex geometric shape and is sufficient for any material under different boundary and loading conditions. Finite element method is suitable for analyzing modern complex engineering systems and places where closed form solutions governing equilibrium equations are not normally available. In addition, this method is an efficient design tool, which designers can implement parametric studies of the design by considering the design samples (differences in shapes, materials, loads, etc.) and finally achieve the optimal design. This method was started in aerospace industry as a tool for studying stress in complex aerial structures. This method was developed by matrix analysis method used in aircraft design. The basis of the finite element method is that the structure can be divided into small elements with finite dimensions called finite elements. Then, the whole structure is considered by tinkering with these connected elements in a limited number of connections called node points [2]. In this method, the physical problem is numerically modeled by separating the amplitude of the problem to small sizes and as standard elements. Compared to the boundary element method, the finite element method has good flexibility to deal with heterogeneous and nonlinear materials. But this method is not normally suitable for analyzing the masses of rocks whose behavior is mainly governed by the drainage handle [9].

Advantages of finite element method

In this method, the properties of each element are evaluated individually, so one obvious advantage is that we can combine the properties of different materials for each element. So there is no limit to heterogeneity. There are no restrictions on shape, so irregular and optional shapes do not cause difficulty and, like all numerical approximations, are implemented on the described outline. However, this method is a continuous method and requires continuity to continue the approximate solution for many places. One of the important advantages of finite element method is that it uses boundary conditions in the formation of tinkering equations. This is relatively easy and does not require any special technology and with a lot of testing to satisfy the boundary conditions, it prescribes the conditions for each finite element after the algebraic equations are achieved.

Limitations of finite element method

The finite element method has achieved a high level of progress for solving problems, however, this method will lead to realistic results only if the multiple properties of the modeled materials are properly defined. One of the frustrating aspects of using finite element method is the error caused by insufficient accuracy in the input information in the computer, which ultimately leads to errors as a result of all the steps and the final result.

Finite differencing method

The main difference between finite element method and finite difference is the explicit design of the implemented solution to solve a weak form of differential equations, otherwise these two methods are mathematically identical. In the method of limited difference, the continuous environment is defined by a network of separate points in which displacements, speeds, and accelerations are calculated. By implementing an explicit solution in the method of limited difference in processing time and memory required by avoiding solving large sets of equations is

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reduced. Linear modeling process with finite difference method is slower than finite element method. Therefore, the limited difference method is more suitable for solving nonlinear problems, or for solving physical instability problems [9]. A sample of limited difference analysis can be seen in figure 2:

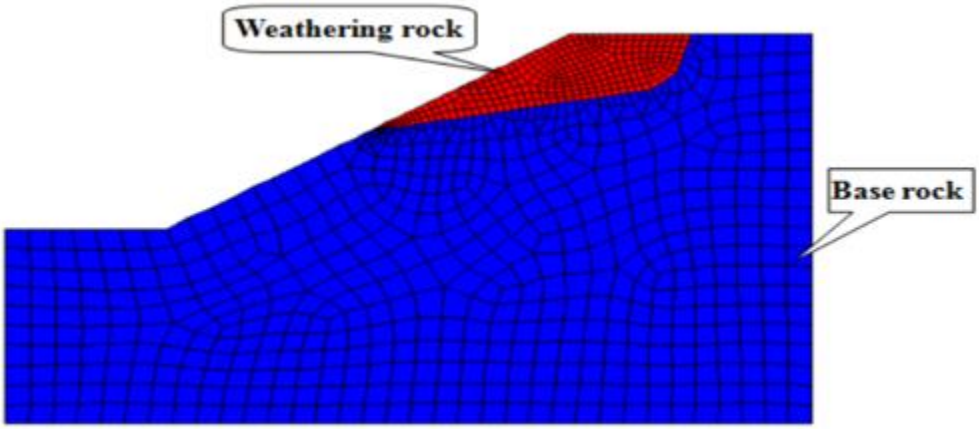


Figure 2. Sample of a mesh network in numerical modeling using FLAC3D software [11].

Boundary element method

In the boundary element method, only the geometric boundaries of the model, such as drilling surfaces and internal surfaces of materials, are separated and the internal range is defined by mathematical method and continuously indefinitely. This method is more suitable for solving problems that have homogeneous materials and linear elastic behavior. The boundary element method is not suitable for nonlinear and heterogeneous materials. Compared to other numerical methods, the boundary element method has a rapid calculation speed and it is easy to create meshing. The main application of this method is to evaluate the distribution of stresses around underground excavators. Also, the boundary element method can be used to perform failure analysis and simple deformation. The basic assumption of this method is elastic deformation and therefore the estimated deformations are the only elastic component of deformation. Typically, in this method, to detect the failure zone around drilling, the rock mass resistance rate to stress is used as a criterion [9].

Distinct element method

In classical particle models, pristine rock is represented by a set of distinct elements attached to each other with connection springs, which can develop shear or tensile failure due to stress caused by external load [7]. In Distinct element method, discontinuity is simulated as a common chapter between rigid or shapable separate blocks. Motion along discontinuity is governed by linear and nonlinear force-displacement connections in both shear and normal directions. In continuous methods, movement is not an independent element, but is restricted by other elements in its neighborhood. In the Distinct element system, the movement of blocks is allowed independently due to the forces on the boundary surfaces or other external loads, in accordance with the equations of movement. After a series of calculations that track the displacement of blocks, contact forces and displacements are found at the common levels of the blocks. Calculations are based on a step-by-step algorithm, and the duration of each step is chosen so that the speeds and accelerations within a time step can be assumed to be constant, and the disturbances cannot be published from a separate element greater than the neighborhood immediately. For nondeformable blocks (rigid), the material of the stone and the hardness of the common season between the blocks define the time step value. For deformable blocks, the time step value comes from the size of the area, and the hardness of the system includes the contributions of pristine rock modulators and hardness in the connections. The order of calculations in the Distinct element method follows a cyclical procedure which is repeated intermittently between the application of Newton's second law to move in blocks and the force-displacement law in connections. With the knowledge of connection movements and the use of force-displacement law, the connection forces are calculated. Newton's second law determines the amount of movement of blocks from the action of forces on them. For formable blocks, movement in network points is calculated from constant strain elements within the blocks. Then, the new stresses of the main model within the elements are calculated [9].

Types of stability analysis methods of slope walls

The stability analysis methods of the walls are divided into three categories according to the type of forces analyzed:
- Static

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- Pseudo-static
- Dynamics [5, 12]

Static analysis

Most commonly accepted methods for analyzing slope stability are in static conditions, such as limit equilibrium analysis and finite element method. Partial equilibrium methods are widely accepted for slope stability analysis. In these methods, the potential slip surface is estimated before analysis and then the partial equilibrium analysis is performed according to the soil mass above the slip surface. Critical slip surface and safety factor are obtained using Monte Carlo technique and stresses are obtained in soil or rock using finite element method. Different equilibrium methods are available. Bishop 1955, 1957, Morgrenston and Price 1965, Spencer 1967 and Sarma 1979. These methods will not pay attention to the strain stress behavior of soil mass during calculation of stresses, while the basis of stresses in soil mass to soil stress-strain behavior is well known. Due to the high speed of computers, numerical methods have become common for analyzing continuous problems. Finite element method is widely used to calculate stresses within soil mass. Finite element method uses soil strain stress characteristic to calculate stresses in soil mass [13].

Pseudo-static analysis

In an active seismic region, tremors are one of the most important factors that can cause the slopes to fail. Therefore, in these areas, slope analysis is necessary under dynamic conditions. Also, a slope becomes unstable when shear stresses on the potential break surface exceed the shear strength of the soil. Additional stresses caused by earthquake increase stresses on these surfaces and reduce the safety factor more. The easiest method for dynamic analysis of slopes is quasi-static analysis. In the quasi-static method, the safety factor against slippage is obtained by the outcome of horizontal and vertical forces. Seismic forces are typically obtained from the multiplication of horizontal and vertical seismic coefficients in the weight of potential slippery mass. Although the quasi-static method for analyzing the dynamic stability of slope is a simple and direct method that cannot simulate the actual dynamic effects of earthquakes by applying a constant quasi-static acceleration in one direction [13]. Pseudo-static method is commonly used, so a lot of engineering experience is accumulated in this method [1]. In this method, seismic load becomes an inertia force, so that dynamic problems based on experimental formulas become static models. This method adjusts the seismic coefficient values in vertical and horizontal directions in order to simulate seismic action. This method is only associated with the values of seismic waves while it has no means of analyzing the effect of waveforms [7].

Stages of pseudo-static method

In the quasi-static method, there are 2 main steps to import Dynamic Load:
1- Inserting seismic coefficients for vertical and horizontal directions.
2- Choosing the stage where the seismic load is applied.

Seismic coefficients

Seismic coefficients are non-lateral coefficients that provide the maximum acceleration of the earthquake as a fraction of the gravity acceleration. Common values range from 0.1 to 0.3. When a seismic coefficient is defined, an additional physical force will be used for each element in the mesh:

Seismic force = Seismic coefficient × force

Which is equal to: Seismic coefficient of × zone {area or volume] × unit weight of element materials
Accordingly the physical force is actually simplified the weight of the limited element itself [3].

Safety factor determination methods

One of the main topics of slope stability analysis is determining the safety factor of the slip surface. Partial equilibrium method, partial analysis method, shear strength reduction method [11,14] are the main methods for determining the safety factor [12]. Rock slope stability is normally analyzed using partial equilibrium methods or partial analysis linked to numerical methods [14]. Hybrid methods such as finite element resistance reduction method [1,15] Dynamic Resistance Reduction Method [7] Finite Element Extreme Analysis [15] are used in practice to analyze stability and determine the safety factor.
The traditional method for calculating the safety factor is the limit equilibrium method. This method assumes that the slip body is like a rigid body that cannot reflect the strain stress behavior of rock and soil masses. Therefore, this assumption makes a difference with reality. In 1975, the resistance reduction method was presented by Zienkiewics. And this method was widely used to determine the safety factor [16].
In recent years, with the rapid development of computer technology, the method of reducing finite element resistance has attracted the attention of many researchers. In this way, a large number of finite element analysis software has been developed to analyze slope stability. The finite element method not only satisfies the equilibrium conditions of the forces, but also combines the stress-strain behavior of the materials, but also does not require assuming (guessing)

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the position of the slip surface. Thus, the results of the calculation are more reasonable and correct.

Partial equilibrium method

The limit balance method is in practice and is commonly used method to evaluate slope stability [14]. Limit equilibrium methods are used in most cases to analyze slope stability and engineering design of slopes. The limit equilibrium method has a simple and adaptable basis so that the slope is considered as a set of vertical shears and the slip surface is determined by geometrical relationships. Then each incision is analyzed using force rules or instantaneous equilibrium proportional to their contribution to slope stability. Over the past century, a variety of limit balance techniques have been developed to determine stability conditions. In recent years, to accurately calculate the hidden cutting forces under the soil and water penetration conditions, advanced quantitative methods such as finite element analysis and finite difference have been developed and combined with limit equilibrium algorithms. The key indicator in slope stability analysis is safety factor. It is commonly defined as the shear force ratio resistant to the shear force of the stimulus along the failure surface. To better calculate the safety factor and to detect the failure level, methods have been made using the "Ground Gravity Increase Method" or "Resistance Reduction Method" or local safety factor method [17].

Among the methods of partial equilibrium analysis are the methods proposed by Janbo, Bishop [7], Morgan Stern, Price and Spencer. Reviewing different limit balance methods and discussing their weaknesses and competencies can be found in Duncan (1996) and Krahn's articles (2003).

However, the limit equilibrium method (which is grounded on the components method for slopes) does not provide unique safety factors according to the inherent assumption underlying it. These assumptions include the need to define the distribution of internal cutting forces, as well as the shape of the failure surface, in advance. The limited element partial analysis on the other hand precisely provides the upper and lower boundaries of the safety factor [15].

Limit analysis method and strength reduction method

The method of partial analysis in soil mechanics is based on elastic-plastic theory. In the method of Limit analysis, shear stress at a point of slip surface is equal to shear strength. Currently, this can be meaningful in two ways, one is the loading method and the other is called the strength reduction method. Zienkiewics suggested increasing the load or reducing soil resistance to calculate the slope safety factor [11] and accordingly, in 1975, the Strengh reduction method was proposed by Zienkiewics [16].

Given that strengh reduction method was widely used as a physical concept, Zheng combined the method of Limit analysis and numerical simulation. Accordingly, Griffiths used the strengh reduction method to obtain the position of the failure level [11] and then this method has been widely used to calculate the safety factor [16].

Strengh reduction method includes co-orditation and progressive reduction in adhesion and tensile strength of hidden particle joints in soil. Classically, shear resistance reduction technique is only used in numerical methods and this action continues until shear failure is dominant. In a configuration that expects a shear-tensile failure, it is better to select the shear-tensile strength reduction method to investigate both local tensile and shear cracks.

The relationship (2) shows how much weaker the crushing stone has become than its initial resistance [10] Resistance Reduction Method (SRM) is accepted in several known finite element programs (PLAXIS, GEO5) or Finite Difference (FLAC) [14].

FOS= 1/SR= (Initial strength)/(Failure Strength) (2)

So that FOS is the safety factor, residual resistance SR, initial strength of initial strength and failure strength of failure level.

Resistance (strength) reduction method is also used to analyze the stability of airborne rock slopes, so that shear strength parameters of rock slope materials are reduced sequentially to eliminate slope stability. Then, the safety factor of the airborne rock slope is obtained considering that the final failure state of the slope is affected by tensile damage and shear damage affected by the earthquake. Accordingly, the shear strength parameter has a big impact on slope safety [11].

The basics of shear strength reduction method were first proposed by Zienkiewics in 1975, which can be defined as the ratio of maximum soil shear strength to actual shear stress produced in slope when external loads remain unchanged. The basis of resistance reduction is that C rock mass resistance index and φ values are divided into a group of new values C' and φ' by ω reduction factor, then new values c' and φ' are used in experimental calculations as new parameters of materials in finite element calculations.

When the slope condition matches the critical refractive state, the supposed ω reduction coefficient is in accordance with the slope safety factor, and the slip surface within the slope is the potential slip surface of the slope [18]. The parameters c' and φ' are obtained from the following formulas:

In the method of resistance reduction by placing the slope in the equilibrium state of the shear strength, the amount of ω reduction factor is equal to the safety factor.

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$$\varphi' = \arctan(\tan\frac{\varphi}{\omega}) \quad (۲)$$

$$C' = \frac{c}{\omega} \quad (۳)$$

Where the reduction factor ω, C adhesion, φ internal friction angle, c/ and φ/ are numerical values of C and φ after reduction, respectively [16].

Principles of finite element resistance reduction method

The main methods of slope stability analysis can be divided into two categories: limit equilibrium method and finite element analysis method. In the past, finite element analysis was often based on the slope of the plastic area, the stress field and the displacement field in order to evaluate and calculate the stress distribution and calculate the safety factor index by partial equilibrium analysis method, but the results were not largely understood and used. The resistance reduction method uses the safety factor for the previous difficult situation in finite element analysis [18]. When slope stability is analyzed by finite element method, as long as the slope is unstable, the calculated results will not converge. The safety factor of slope stability will be obtained directly by examining the calculated convergence, after reducing the material resistance based on the theory of finite element method.

$$\tau = \frac{c+\sigma\tan\varphi}{\omega} = \frac{c}{\omega} + \sigma\frac{\tan\varphi}{\omega} = c' + \sigma\tan\varphi' \quad (5)$$

$$c' = \frac{c}{\omega}\tan\varphi' = \frac{\tan\varphi}{\omega} \quad (۶)$$

So that τ shear stress and σ are primary stresses.

The definition of safety factor in finite element analysis is in good agreement with the definition used in the limit equilibrium method and both methods act according to the resistance rate of the slip surface to the slip force.

Slope failure criteria in finite element resistance reduction method

In the process of gradient stability analysis, the reduction in material resistance is continuously carried out to degrade the slope.

The three main criteria of judgment are as follows:

1) Whether the results of the finite element method converge: In simple modes, if the results of the finite element program calculation are not convergent, the slope is in an unstable state.

2) Whether the plastic area is expanding or not: If the plastic area has spread from the bottom to the top of the slope, the slope in question is in an unstable state.

3) Whether the displacement curve - time suddenly changes or not: Unlimited slope slip due to slope instability will cause stress and sudden displacement on the rock slip surface, which will continue [17].

In order to fully understand the method of resistance reduction in stability analysis of a homogeneous soil slope with different failure criteria and solving problems related to slope instability, the finite element platform of RS2 software can be used. An example of the determination of the main failure level in a wall is shown in figure 3.

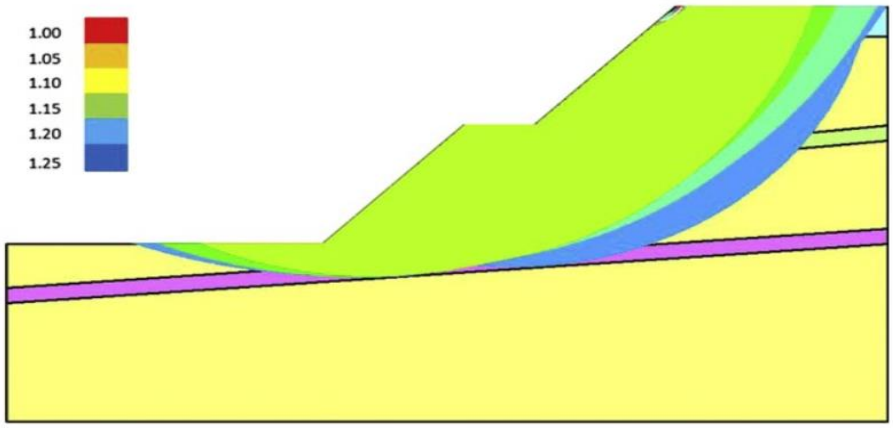


Figure 3. A design of a slope that displays the main failure as a shallow slip in the slope shell [14].

Newmark displacement analysis

This method is based on limit equilibrium methods and by receiving the history of acceleration- time of earthquake in order to calculate the displacements resulting from earthquake. Newmark (1965) proposed a sliding block method to calculate the permanent displacement of the slope, assuming that the potential failure surface is completely plastic and the sliding block is quite rigid. Newmark (1965) used a very simple integral technique to calculate block displacement on the ramp when introducing the slip displacement criteria. Few efforts have been made to improve

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Newmark's outline for calculating displacements along an Non-flat surface [3].

Conclusive and probability methods

In principle, both limit equilibrium and resistance reduction are definite methods, but they can be easily adapted for probability models. In a definitive analysis, slope stability is evaluated using a given safety factor (FOS) that is based on certain values of input parameters. In a probability analysis, each variable is defined as a statistical distribution, and slope stability is evaluated using reliability index (β) or probability of failure (pf).

In most cases, partial equilibrium analysis is an unknown surface critical slip surface that has the lowest safety factor or β (trust index) and therefore it is necessary to use trial and error methods or optimization techniques. For this purpose, and since the processing power of personal computers has increased, Monte Carlo simulations have been accepted into commercial software packages. Suitable for this complex problem, both methods of partial equilibrium and reduction of resistance have their own advantages and disadvantages.

The partial equilibrium method requires fewer details about the location and provides satisfactory results in most samples [14] if the water pressure is properly modeled. The results of a probability analysis are observed in figure (4).

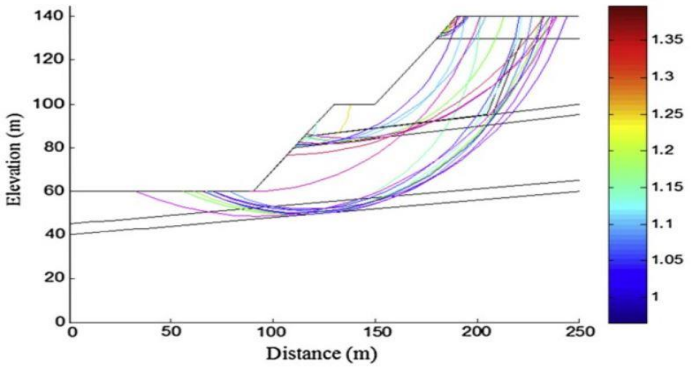


Figure 4. Changes in safety factor for hypothetical slip surfaces in a probability analysis [14].

Dynamic analysis

In most existing methods for dynamic analysis of slopes, it is important to find slope displacement instead of safety factor. Prevost and et al (1985), Daddazio (1987) and Elgamal and et al (1990) used the relationship between forming soil type and soil behavior model. And they concluded that although slope displacement is a very important criterion for slope design, determining the safety factor of slope when under dynamic load is still important. In this experiment, permanent slope displacement is achieved under dynamic force action using finite element analysis.

Therefore, in order to obtain safety factor, displacement, and stresses in the soil during the whole period from the beginning to the end of the earthquake, a method by Krishnamurthy (2007) suggested that the slope safety factor be obtained using finite element analysis combination. The static and dynamic stresses and Monte Carlo technique proposed by Nanzio (1996) are achieved to obtain critical landslide levels, and the assumptions of this method are dry and elastic soil [13].

Dynamic analysis of resistance reduction

In calculating slope stability in the traditional method, only shear break surface is considered. Under the influence of earthquakes, the failure surface includes tensile damage and shear failure so that the formation of shear-tensile failure surface. The dynamic method of resistance reduction is a complete calculation under seismic load, which considers shear-tensile failure. There is no assumption in the calculation process and when calculating the safety factor, all problems are analyzed in a dynamic path, so this method can fully reflect the dynamic effect of the earthquake.

Tensile hazard often occurs above the slopes due to the effect of earthquake acceleration and lack of essential protection of the slope crust. A sample of a shear-tensile injury is observed in figure (5). There are many potential safety problems when an earthquake occurs. However, little research has been done on this structure using quasi-static method, time history analysis method and dynamic resistance reduction method. Time history analysis method is widely used in dynamic slope analysis.

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Time history analysis method normally ignores tensile damage, but dynamic method considers reducing shear-tensile failure resistance. The dynamic reaction of the slope is different under the influence of different seismic waves and also the safety coefficients of each are different. Therefore, when designing a seismicity, it is better to use several different seismic waves to calculate the safety coefficients, which can avoid potential hazards [7].

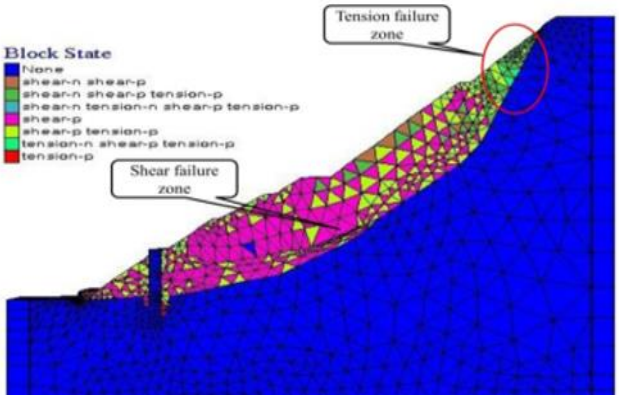


Figure 5. Post-earthquake shear-tensile damage [7].

Dynamic analysis using time history analysis

This method is widely used in dynamic slope analysis and the differential equation of node displacement is shown in relation (7):

$$Mu'' + Cu' + Ku = -MIu_g'' \quad (۷)$$

Where u" u', u' are in order of acceleration, speed and material displacement at t time. While M, C, k, u"g are mass matrix, adjustment matrix, hardness matrix and earthquake acceleration respectively. I offers unit vector [16]. The main stages in this analysis consist of 4 steps:

- Reconstruction of earthquake input data
- Filter seismic loading input speed
- Riley adjustment
- Dynamic slope stability analysis

Requirements before analysis

According to what has been stated, before entering the dynamic analysis stage of the domain, information should be predetermined, the most important of which includes:

- Earthquake information is restored and filtered.
- Unlock unopened model.
- Enter pre-calculated Riley adjustment coefficients.
- Maximum earthquake power frequency [3].

Reconstruction of earthquake inlet

Earth motion data during earthquakes are usually prepared as earth surface data, however for a dynamic analysis of seismic input should be applied to the bottom of the model instead of the earth's surface. Therefore, the surface information of the earthquake should be opened and simplified. To do this, once the initial earthquake information is used in the same model to simulate the movement of the earthquake correctly. An example of acceleration-time history of earthquakes obtained from surface data is observed in figure (6).

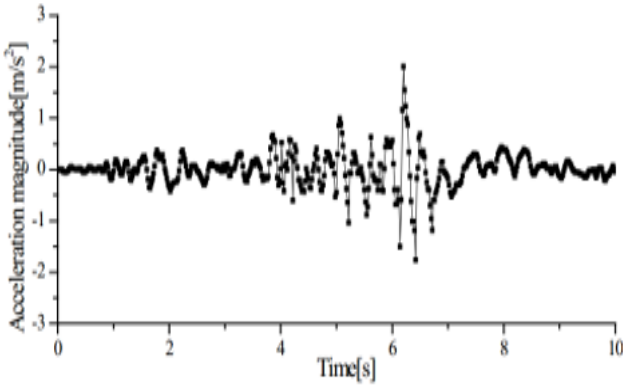


Figure 6. An example of a seismic acceleration curve - Input time on a rock slope [7].

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Steps needed to rebuild acceleration history - time

After applying the acceleration-time history at the top of the model and obtaining speed information, the speed results are halved and then the halved speeds are applied at the bottom of the model. In the following information, the input speed is converted to stress. This stress defines the input of upward wave movement within the model. However, the actual movement at the bottom of the model matches the movement of the reflected upward and downward waves of the model.

The top of the model is a free surface, and shear stress is zero at the free level. In order to establish this issue, upward and downward waves must be equal at the top of the model. Therefore, it can be concluded that the speed history used in the base of the model must be given a second surface motion [3] In figure 7, the speed-time history sample is observed after data reconstruction.

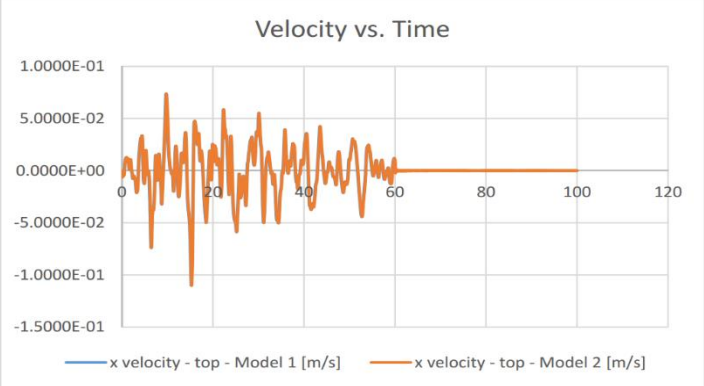


Figure 7. Sample speed-time curve derived from acceleration history- time after data reconstruction [3].

Filtering seismic loading input speed

When modeling seismic loading, both the frequency content of the input waves and the speed of the system waves will affect the numerical accuracy and accuracy of the wave transfer. Kuhlemeyer and Lysmer (1973) showed that in order to accurately present the transmission of waves through a model, the size of the element must be in accordance with the relationship (8):

$$Element\ size \leq \frac{\lambda}{10} \qquad (٨)$$

So that λ wavelength is related to the highest frequency component which contains tangible and evaluatable energy. Observing this rule may lead to a huge amount of calculations. Fortunately, for most earthquakes, the larger part of the input wave power is placed in smaller frequency components. By filtering the input speed and removing high frequency components, the use of coarse mesh will not have a significant impact on the results. Accordingly, the frequencies of incoming waves are filtered without losing a significant proportion of earthquake power.

Rayleigh damping

In a dynamic system, the relationship (9) is established:

$$[M]\left(\frac{d^2x}{dt^2}\right) + [C]\left(\frac{dx}{dt}\right) + [K](x(t)) = F_{stat} + F_{dyn} \qquad (٩)$$

The X(t) displacement as a function of time, [M] the mass matrix, the [C] Damping matrix, and the [K] stiffness matrix.

$$[C] = (\alpha_M)[M] + (\beta_k)[K] \qquad (١٠)$$

Where: the α_M and β_K are constants with S^{-1} and S units, respectively, and [K] is the linear matrix the stiffness of the structure. Therefore, C is composed of relative mass state and relative state of stiffness.

The procedure α_M and β_K the appropriate selection of adjustment values is as possible as provided for linear systems by the above equation [3].

Conclusion

As studied in this presentation, in order to analyze the stability of surface and underground drilling rigs, different numerical analysis methods including finite element methods, finite difference method, boundary element method, separate element method which should be selected according to ground conditions, drainage rate, type of layering and type of soil and mineral and type of drilling, amount and conditions of groundwater and the desired life of the structure, the type of project analysis method. And due to the seismic conditions of the region, which is one of the most influential factors on the stability of structures, each of the above methods can be used in three static, quasi-static and dynamic conditions. In case of uncertainty in the initial data values, the probability method should be used instead of the definitive method in each of the

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above methods. Accordingly, one of the most important factors in obtaining a result with maximum adaptation to reality and obtaining the best prediction of the future situation of the structure with the minimum possible cost is choosing the appropriate method of analysis according to the specific conditions of the structure instead of imitation and mere use of the results of other projects.

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