# EFFECT OF GROUNDWATER ON OPEN PIT SLOPE STABILITY USING ROCSCIENCE PHASE 2

# Abstract

Mining and construction activities have increased significantly over the period of time and impact the environment to a great extent. While carrying out these activities it has become very essential for the people working on it to effectively analyze subsurface conditions, ground behavior and impact of applied loads to ensure less impact on the natural resources and limit the impact on the environment and humans. Due to mining and construction activities the excavation and landfills are carried out, which can weaken slopes and lands due to displacement of materials within. Slope stability analysis is hence very important in geotechnical field as slope instability can lead to damages to environment and humans. The understanding of geology, soil properties and hydrology is essential in carrying out slope stability analysis. In this research slope stability analysis is carried out to analyze the impact of different materials and ground water on stability of slope. The research uses simulation software wherein the samples collected are considered and tested to obtain geotechnical parameter and factor of safety is calculated for a slope. The research uses Finite Element Method (FEM) approach to predict behavior of the pit slope and evaluate stability of open pit slope. The displacement and factor of safety has been studied using FEM. The method is found to provide accurate results and it is recommended that software should be used to understand slope stability better and should be continuously monitored to identify the slope stability failure in the earlier stages itself and take necessary precautions and actions to avoid slope failure.

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## 1 Introduction

#### 1.1 Introduction

Many of the industrial activities are leading to severe negative impact on the environment. Open pit mining, which is one of the main and popular approach for mining activities in the industry. These human induced slopes created for different functions has led to several geotechnical problems. Open pit mining involves excavation of earth surface to obtain the minerals under the earth for economic purpose (Fell et al., 2014). The process involves cutting slopes and stability of pit slopes is very critical for safe mining operations. Analysis of stability of operating slopes and the pit slope design is very important as slope failures can cause production loss, additional investment for recovery and handling of other damages caused on the site (Zhang, 2015). According to the researchers, slope instability is caused due to sliding of mass of soil or sliding body in straight or curved sliding surface (Abramson et al., 2002). Due to the stress on top of the earth and poor soil strength it can lead to cracks in the slop making it unstable (Duncan et al., 2014). Due to increasing engineering projects, which involve cut and fill slopes there is increased need to study and understand the causes of slop instability and analyze slope stability and stabilization methods to reduce instability in slopes and ensure effective design and construction of landfills, dams, excavations and other constructions (Cheng & Lau, 2014). There are different factors, which influence the stability of slopes and need effective understanding of geology, hydrology and soil properties (Duncan et al., 2014). This research aims at analyzing slope stability using finite element method and the safety factor for slopes is identified when it is influenced by groundwater levels.

#### 1.2 Purpose of the Study

Slope stability analysis has become very critical to ensure the effective construction and management of landfills and excavation (Abramson et al., 2002). Slope failure can lead to damage of property and can cause accidents directly impacting human life (Fell et al., 2014). As there are various factors, which influence stability of slop there are many uncertainties in analysis of the slope stability and the accuracy of the analysis varies from one approach to other and one site to the other (Cheng & Lau, 2014). The uncertainties include site topography, variability of site, engineering properties, groundwater level, the characteristics of subsurface materials and behavior of soil and rock. Shear strength parameters are considered to be important in calculating the resistance of slope failure (Fell et al., 2014). The parameters are random variables and distribution of them across slope varies with site. There is a need to calculate factor of safety with greater accuracy before utilizing the slop for any activity. There are different approaches to calculate factor of safety and have their own strength and weaknesses. The limit equilibrium analysis has limitation of not considering stress and shear strength and does not consider the ground behavior and assumes that safety factors are constant along the slope failure surface. The finite element method enables better analysis of slop stability but the influence of different factors does not ensure the accuracy. This research aims at analyzing the accuracy of finite element analysis, which uses Shear Strength Reduction (SSR) method to calculate safety facto and provide increased accuracy in slope stability analysis.

#### 1.3 Objectives of the study

• To assess and understand the slope stability required to be carried out before any construction work

- To assess the slope failure possibility in natural or human made slope
- To understand the impact of environmental factors on slope stability
- To analyze the impact of seismic loadings on slopes
- To identify preventive and remedial measures for overcoming slope failure and maintaining slope stability

#### 1.4 Research Questions

- What is the significance of slope stability analysis?
- How is the slope stability analysis carried out?
- What influence des environmental factors have on slope stability?
- What is the impact of seismic loadings on slopes?
- What are the preventive and remedial measures to address slope failure issue and maintenance of slope stability?

#### 1.5 Limitation

This research uses developing computational algorithms based on the theoretical knowledge. The simulation software can have certain limitation such as truncation errors and can cause instability in the solution process. The assumptions made during the development of algorithm can impact the accuracy of final outcome. The research uses a simulation software and hence some factors have been assumed, which can lead to different results or affect the accuracy of the final result. The results from the simulation is limited to impact of some specific materials on the soil and slope stability.

### 2 Literature Review

Slope stability is one of the important areas in geo technical engineering, which is being studied closely as the vulnerability of land to slope failure can increase due to inappropriate leading to increased risk to people, property and infrastructure (Duncan et al., 2014). Slopes exist naturally or are created by humans. Slope stability accidents are considered to be the leading causes of fatalities in many parts of the world occurred during surface mining operations (Cheng & Lau, 2014). Slope be it natural or human created lead to various geotechnical problem. It is essential to understand the complexity of mechanical behavior of soil and the load on the ground to understand the stability of slope (Duncan et al., 2014). The instability of slopes in most cases can be visible in terms of sliding mass of soil, sliding body in straight or curved sliding surface (Fell et al., 2014). Slopes become unstable due to stress on the top and negligible soil strength mainly when the soil is fine-grained (Abramson et al., 2002). This can lead to cracks in the slope and it is a sign of instability of slope occurring at early stage. Slope stability analysis thus, becomes very essential to ensure safety and reliability of the slope and if it is not stable possible remedial measures can be designed to stabilize the slop and avoid occurrence of any major accident (Lee, 2016).

Slope stability problem is one of the greatest problems faced by open pit mining industry. In open pit mining, the mineral deposits are obtained from ground surface and downward due to which pit slopes are formed as the ore is being extracted from the ground (Fell et al., 2014). The pit slopes have to be inclined at some angle to prevent failure of rock mass. Slope stability problem can be categorized in to two, gross stability problem and local stability problem (Ortigao, 2004). Gross stability problem occurs when large volumes of materials come down the slope as a result of large rotational type of shear failure and has deeply weathered soil and rock (Zheng et al., 2005). The local stability problem refers to problem wherein smaller volume

of material affects the slope and the failure effects only one or two benches in one time due to shear plane jointing and slope erosion as a result of surface drainage.

#### 2.1 Factors impacting Slope Stability

To understand the different scales and type of slope instability, the factors affecting them has to be understood using the slope stability analysis techniques.

#### 2.1.1 Slope Geometry

Geometrical slope design includes parameters such as height, area of failure surface and overall slope angle (Fell et al., 2014). The slope stability decreases with increasing height. The overall slope angle of 45 degrees is considered to be safe (Fell et al., 2014). Slope's curvature has increased impact on instability and slope sections, which are convex are recommended to be avoided in slope design (Abramson et al., 2002). The stability keeps reducing with the increasing steepness and height of the slope.

#### 2.1.2 Geological structure

Some of the key structures, which affect slope stability in open pit mines include, direction and amount of dip, joints and discontinuities, faults, which can act as conduits for ground water, provide probable plane of failure and intra-formational shear zones (Cheng & Lau, 2014). Slope instability can occur if starta dips into excavations as steepening of starta is critical for stability of slopes (Duncan et al., 2014). Bedding planes and joints weaken the surfaces. Slope stability depends on shear strength that is present along such surfaces and their orientation with respect to slope and water pressure action on surface (Fell et al., 2014).

#### 2.1.3 Ground water

Ground water can have adverse impact on the slope stability as it causes more up thrust and drive water forces upwards. Ground water alters cohesion and frictional parameters and reduces normal effective stress (Duncan et al., 2014). The chemical and physical effect of the pure water pressure on the joint filling material can alter cohesion and friction of discontinuity surface reducing the frictional resistances (Fell et al., 2014). This reduces shear resistance along the plane by reducing normal stress acting on it. The water pressure in pores of rock cause decrease in comprehensive strengths of the slope as confining stress gets reduced (Ge et al., 2009)

#### 2.1.4 Lithology

The rock mass strengths are determined by rock materials forming a pit slope and is affected by faulting, discontinuities previous works, folding and weathering (Duncan et al., 2014). The reduced rock mass strength is identified by circular, raveling and rock fall instability like formation of slope (Abramson et al., 2002). The pit slopes, which have weathered or alluvium rocks at surfaces have reduced shear strength, which reduces further if water seepage occurs.

#### 2.1.5 Dynamic Forces

The blasting and vibration in open pit mining leads to increased shear stresses, which results in dynamic acceleration of materials and creates stability problem in the slope surface. The forces lead to ground motion and fracturing of rocks (Ge et al., 2009). According to Sage (1976), poorly designed blasting can impact bench stability and can also cause rock mass failure (Abramson et al., 2002). The blast damage causes back break, which reduces bench face

angle and hence for blasting of small scale slopes it is recommended that smooth blasting approach is used (Ortigao, 2004). The impact of blasting is less on large scale slopes as the back break and blast damage of benches have lesser impact.

#### 2.1.6 Cohesiveness

The properties of rock or soil influence its resistance from being deformed or broken by forces such as gravity (Ge et al., 2009). The actual cohesion between soil and cohesion is caused due to electrostatic forces in the clays and cementing by NaCl, FE2O3 and other chemical and root cohesion (Duncan et al., 2014). Slopes, which have less cohesion between rock and soil tend to have lesser stability. The factors, which strengthen the cohesive force include friction, cementation of grains due to silica deposition, stickiness of particles as it helps soil grains to stick together, man-made reinforcements can help in preventing some material movement (Cheng & Lau, 2014). The factors, which weaken the cohesive strength include high water content, which weakens cohesion and adds weight to the mass, undercuts the slopes, vibrations from earthquakes, blasting can create vibrations and alternating expansion by wetting and contraction also reduces the strength of cohesion (Ge et al., 2009).

#### 2.2 Methods of Slope Stability Analysis

#### 2.2.1 Limit Equilibrium Methods

Limit equilibrium method is still widely used method for slope stability analysis. These methods are widely used due to its simplicity and need of fewer parameters, which are topography, slope geometry, static and dynamic loads, geology, hydrogeologic conditions and geotechnical parameters (Cheng et al., 2007). These methods however, do not consider ground

behavior and safety factors are assumed to be constant along failure surface. In these methods slopes are cut into fine slices so that their base can be compared with a straight line and then form the equilibrium equations (Cheng & Lau, 2014). The differences in the value of safety factor derived in different methods are mostly lower than 6% (Guyer, 2013). Some of the main limit equilibrium methods are ordinary method of slices, Bishop's modified method, Janbu's generalized procedure of slices, Morgenstern and Price's method and Spencer's method (Ortigao, 2004). The ordinary method of slices is mainly used when slip surface is circular and the moment equilibrium is around center of circle (Guyer, 2013). This method is applicable to slopes, which are non-homogeneous and soils where slip surface can be approximated to a circular form (Cheng et al., 2007). Using this method hand calculations can be done and is not effective or accurate for effective stress analysis when high pore water pressures exist. Bishop's modified method is effective for slop surface, which are circular and equilibrium conditions are satisfied by vertical equilibrium and overall moment equilibrium (Cheng & Lau, 2014). This method has similar application as ordinary method of slices but it provides more accuracy than the ordinary method of slices mainly while analyzing high pore water pressures. Even in this method calculations can be done by hand and also using spreadsheet.

The Janbu's Generalized procedure of slices can be used for slope having any slip surface and satisfies the condition of force equilibrium (Cheng et al., 2007). This method is applicable for non-circular slip surfaces and for shallow, long planar surfaces, which fail and are not parallel to the ground surface. The other limit equilibrium method includes Morgenstern & Price's method, which can be used for any shape of slip surface and satisfies all conditions of equilibrium (Cheng & Lau, 2014). This method is one of the accurate procedure and is applicable to all slope geometrics as well as soil profiles virtually. It is a well establishes and rigorous equilibrium procedure (Zhang, 2015). The Spencer's method can also be used for any shape slip surface and is also an accurate procedure and can be applied to all soil profiles and

slop geometrics. It is the simplest equilibrium procedure for calculating factor of safety (Huang, 2014).

#### 2.2.2 Finite Element Methods

The different limit equilibrium methods are developed on arbitrary choice of a series of slip surfaces and defining them in a manner that they give minimal value of safety factor (Guyer, 2013). But in recent times the intensive use of numerical analysis methods have given access to constraints and deformations within formations that constitute sub-soil (Zheng et al., 2005). It is hence essential to know behavior law of the considered formation and volume of ground has to be divided in to geometric elements, which are subjected to action of close elements (Hammouri et al., 2008). The calculations in this method involves determining displacements and stress fields, which are compatible with behavior law, mechanic equations and adopted behavior law (Stacey et al., 2003). The finite element method enables calculation of stresses and deformation state in rock mass with respect to its self weight with assumption of behavior law adopted. The finite element method analyzes the slope stability by considering the static permission, relationship between stress and strain and does not consider irregular slope geometry shape and limitation of material inhomogeneity (Zheng et al., 2005). The finite element method provides various advantages as compared to traditional limit equilibrium method. In finite element, there is no need for assumptions to be made in advance about location of failure of the shape of slope (Hammouri et al., 2008). This method considers that failure can occur naturally due to the different zones within soil mass and where soil shear strength is not able to sustain applied shear stresses (Zheng et al., 2005). The other advantage of this method it does not have to consider the concept of slice and no assumptions about the slice side forces have to be made. This method maintains global equilibrium till failure is reached (Huang, 2014). This method enables considering realistic soil compressibility data and solutions provide information about deformations at working stress levels (Stacey et al., 2003).

The finite element method has the ability to monitor progressive failure up to overall shear failure including the shear failure.

#### 2.2.3 Shear Strength Reduction (SSR) Technique

The raid development in computer technology and constant development of the approaches of calculating slope stability promoted the use of finite election method in the geotechnical practice (Huang, 2014). The finite element method is very effective in ca practically consider all kinds of geometry, model key aspects of different behavior of the materials such as stress paths and combined stress-pore pressure variations (Stacey et al., 2003). Shear Strength Reduction (SSR) technique helps in finding slope factor of safety. The factor of slope safety can be referred to as ratio of actual shear strength of the soil to minimum shear strength required to prevent failure or it can be considered as factor by which soil shear strength must be reduced to bring slope to verge of failure (Hammouri et al., 2008). In the SSR technique elasto-plastic strength is assumed for all materials and material shear strengths are reduced progressively till it collapses (Zhang, 2015). This approach provides various advantages over traditional limit equilibrium technique wherein it eliminates need for prior assumptions of failure mechanisms such as type, shape and location of surface failures (Stacey et al., 2003). The SSR finite element technique automatically implements critical failure mechanism and eliminates artificial separation of slope issues into the slip surface failures and those involving failure of deformed wedges (Huang, 2014). The SSR technique minimizes expertise essential in finding critical failure mechanisms for some specific slope problems. In some situations, these can go unnoticed by the slope engineers.

To calculate the slope stability effectively using SSR technique it is essential to choose a proper constitutive model for stability analysis and among several commonly used linear and non-

linear constitutive models, elastic-perfectly plastic model with Mohr-Coulomb failure criterion is widely adopted (Cheng et al., 2007). This model is effective as the sudden transition of soil behavior from elastic to plastic state in elastic-perfectly model helps in identifying factor of safety while applying strength-reduction technique. The steps involved for Mohr-Coulomb materials for systematic searching for critical factor of safety value that brings a previously stable slope to verge of failure are to develop a finite element model of slope considering deformation and strength properties for the slope materials. The model should then be computed and maximum total deformation in slope has to be recorded. In the next step, the value of factor of safety F should be increased and the factored Mohr-Coulomb material parameters should be calculated. The new strength properties should be entered into the slope model and has to be computed again. The maximum total deformation should be recorded. The process then should involve repeating the second step of increasing factor of safety and computing again and recording maximum total deformation of slope till the model does not converge to a solution, which includes the critical factor of safety value just beyond which failure of slope occurs. The computation should be repeated by reducing material strength till slope fails.

#### 2.3 Rocscience Software for Slope Stability

Rocscience is one of the organizations, which offers geotechnical software that are used by various customer segments (Rocscience, 2016). Slope stability analysis is one of the important software at Rocscience and the program includes analyzing soil and rock stability using limit equilibrium and finite element analysis and 2D and 3D modeling. Phase 2 is one of the powerful software tool developed by Rocscience and uses 2D finite element programs for applications in soil and rock stability analysis (Rocscience, 2016). Phase 2 software can be used for range

of engineering projects such as slope stability probabilistic analysis, groundwater seepage and dynamic analysis capabilities. This software helps in carrying out slope stability analysis using finite element approach's sheer strength reduction method (Rocscience, 2016). It includes steady-state, finite element groundwater seepage analysis options within the program. It also has the option to determine pore pressure and flow and gradient based on user defined hydraulic boundary conditions and conductivity of the material (Rocscience, 2016). The analysis is fully automated and can be used with Mohr-Coulomb strength parameters. The slope models are imported and exported between Slide and Phase 2 enabling the user to easily compare the results form limit equilibrium and finite element methods (Rocscience, 2016). The software provides the option of carrying out the analysis of complex slope models in a very short period.

# 3 Methodology

Research using scientific methods enable researcher to develop new theories or verify existing hypothesis (Creswell, 2013). This research is an experimental research, which is mainly used in sciences such as physics, chemistry, geotechnical, sociology and other areas. Experimental research is collection of different research designs, which use controlled and manipulated testing approaches to understand causal processes (Christensen et al., 2013). In this research approach one or more variables are manipulated to determine their effect on the chosen dependent variable (Creswell, 2013). Experimental method is a systematic approach to research wherein the researcher manipulates certain variables and controls and measures any changes in the other variables with respect to the manipulated variable (Bartz-Beielstein, 2006). In this research approach, there is time priority as experimental research is based on causal relationship in which causes precedes effect. The magnitude of correlation is excellent and

consistency in causal relationship is high (Robsinson, 2014). In this research method researcher manipulates one variable and control/randomizes the rest of the variables.

There are many complex systems in physical sciences, which are studied by developing models of the underlying physics on computer and by using computationally intensive methods to understand and learn about the behavior of the systems or the response of the systems to certain event. Such methods are called simulations (Christensen et al., 2013). The mathematical models, which drive the simulations are based on theory. Computer simulations are techniques, which study complex systems or phenomenon. Experiments to be carried out in laboratories on computer uses theoretical model and the equations are transformed into computable algorithm, which can be run on the computer and the dependent variables, which are derived from the computation stimulate evolution of system being studied (Bartz-Beielstein, 2006). Some of the simulators or software have sophisticated graphical techniques, which are often used to transform output of the research into graphics and videos. By using simulations, the experimental setups on computer can provide much wider variety of initial condition, which can be studied and much more detailed can be obtained (Robsinson, 2014). Modelling and simulations are of increased value in scientific discovery as it provides additional insights about the system being studied, which are often not practical and impossible to determine through real-world experimental and theoretical analysis (Christensen et al., 2013).

Modelling and simulations enable researcher to mimic the real-world system and can be experimented on by considering different conditions and hence this research approach provides in-depth understanding of the system and impact of the external forces on the system (Robsinson, 2014). The successful simulation studies not just compute numbers but also make use of variety of techniques to draw various inferences from the numbers, which are computed (Bartz-Beielstein, 2006). It makes use of calculation techniques that can be used to consider complex mathematical and theoretical aspects. Simulations and laboratory experiments both

have to manage uncertainties, which is found to be negligible. A simulation software, which has capacity to accurately mimic a complex phenomenon includes increased level of information about the phenomenon and some of the variables such as temperature, pressure, wind velocity and other are evaluated at thousands of points by the computer as it stimulates the system (Walliman, 2010). Modelling and simulation is not carried out to verify proposed theory but to observe and replace computation of theory, which has not been deeply studied or has certain area, which has not been studied deeply in the real-context. Modelling and simulations provide an effective means to understand the phenomenon or system more effectively by considering different dependent variables and applying them at different levels in the system (Robsinson, 2014).

# 4 Modelling Simulation for this Research

In modelling simulation process the open pit mine design will be drawn to find factor of safety for the chosen area. The steps involved in the analysis of the slope stability using Phase 2 software are

1<sup>st</sup> Step: Specifying all the critical points number in the design chart.

2<sup>nd</sup> Step: Measuring each of the critical point and calculating their x-y coordinates

3<sup>rd</sup> step: Putting the coordinates of each lines' critical points one by one in the Phase 2 software to complete the cross section of open pit mine.

4<sup>th</sup> Step: Defining each plane with specified material

5<sup>th</sup> Step: Meshing the part of cross section of mine

6<sup>th</sup> Step: Entering the property parameters to different materials of work

7<sup>th</sup> Step: Starting the simulation

Rocscience Phase 2 software analysis report is provided in the Appendix.

#### 4.1 Meshing

Mesh Setup			? ▲ ×
Mesh and Discretization Sett	ings		
Mesh Type:	Graded	•	
Element Type:	3 Noded Triang	jles 🔻	
Gradation Factor;		0.1	
Default Number of Nodes o	100	Ad⊻anced ♥	
Discretize Mest	r	ОК	Cancel

Figure 1: Mesh Set-up for Open Pit Slope

The next process in simulation is to generate finite element mesh. Phase 2 software enables researcher to form meshing in simple two-step process. In this user is required to discretize the boundaries and then mesh can be generated. The simulation software also provides option to configure various mesh setup parameters before mesh can be generate. Mesh setup has to be done to begin with simulation but there are default parameters in effect if the user aims not to use mesh setup option. In this research study the type of mesh used is graded and mesh element type is 3 nodes triangle. Using this mesh and element type researcher will be able to carry out slope stability analysis accurately.

#### 4.2 Materials Assigned

The chosen materials are then assigned to the cross section, which include weeribee formation, MBC formation, fyansford formation, material 4 and material 5. As shown below the simulation allows the user to select properties and define each property of different materials. The below figures represent the choices made in the simulations of the different materials and its application on the slope with details of its frictional angle and peak of the slope, which would be considered to compute the slope stability and the impact of different materials on the slope stability.

efine Material Properties	? ×
werribee formation     MBC formation	werribee formation
fyansford formation Material 4	Name: werribee formation Material Color:
Material 5	Initial Element Loading: Field Stress & Body Force  Unit Weight: (kN/m3): 20
	Strength Stiffness Datum Dependency Stage Factors Statistics
	Failure Criterion: Mohr Coulomb 🔹 🔟 🔯 Material Type: Plastic 💌
	Tensile Strength (peak) (kPa): 0 Tensile Strength (resid) (kPa): 0
	Fric. Angle (peak) (deg.): 5 Fric. Angle (resid) (deg): 5
	Cohesion (peak) (kPa): 30 Cohesion (resid) (kPa): 30
	Dilation Angle (deg): 0
	Jointed Material Joint Options
	☑ Apply SSR (Shear Strength Reduction)
+ · × 🖬 🔻	OK Cancel

Figure 2: Assigning Werribee Formation properties to slope

Define Material Properties		? X
werribee formation     MBC formation	MBC formation	
<ul> <li>fyansford formation</li> <li>Material 4</li> <li>Material 5</li> </ul>	Name:     MBC formation     Material Color:       Initial Element Loading:     Eigld Stress % Body Earce     Init Weight: (MV/m3):	•
	Strength       Stiffness       Datum Dependency       Stage Factors       Statistics         Failure Criterion:       Mohr Coulomb       Image: Coulomb       Image: Criterion: Mohr Coulomb       Image: Criterion: Mohr Coulomb       Image: Criterion: Coulomb	• 0 30
	Cohesion (peak) (kPa): 20 Cohesion (resid) (kPa): Dilation Angle (deg):	20
	Jointed Material Joint Options	
	☑ Apply SSR (Shear Strength Reduction)	
🕂 • 🗡 🗈 🝸	ОК	Cancel



efine Material Properties	R.					
<ul> <li>werribee formation</li> <li>MBC formation</li> </ul>	fyansford formation					
fyansford formation	Name: fyansford formation Material Color:					
Material 5	Initial Element Loading: Field Stress & Body Force  Unit Weight: (kN/m3):					
	Strength         Stiffness         Datum Dependency         Stage Factors         Statistics					
	Failure Criterion: Mohr Coulomb    Material Type: Plastic					
	Tensile Strength (peak) (kPa):     0     Tensile Strength (resid) (kPa):     0					
	Fric. Angle (peak) (deg.):     27     Fric. Angle (resid) (deg):     27					
	Cohesion (peak) (kPa): 9 Cohesion (resid) (kPa): 9					
	Dilation Angle (deg): 0					
	Jointed Material Joint Options					
	☑ Apply SSR (Shear Strength Reduction)					
+ · 🗙 🖻 🖷	OK Cancel					

Figure 4: Assigning Fyansford Formation properties to slope



Figure 5: Cross Section of Slope with Assigned Materials

Material Type	Unit Weight	Undrained Strength	Drained Strength	
material Type	(kN/m²)	S <sub>u</sub> (kPa)	c' (kPa)	Φ' (deg)
Fyansford Formation	19	100	9	27
MBC Formation	12	160	20	30
Werribee Formation	20	120 + 2.5 kPa/m	5	30

Table 1: Geotechnical Parameters

Material unit	Unit weight (kN/m <sup>3</sup> )	Effective friction angle, ¢' (deg)	Effective cohesion, c' (kPa)
Overburden	20	30	5
MBCS (intact/unmined)	11.5	30	150
MBCS (broken coal, at the base of the pit)	11.5	30	20
Ligneous clay (CL, silty clay)	20	20	0
Sandy silt	20	30	0
Fill	18	30	0

Table 2: Parameters for Stability Assessment

The above tables highlight the estimated geotechnical parameters considered for stability analysis. And parameters adopted for stability assessment. The geotechnical parameters of the materials considered in the slope include its weight, undrained and drained strength and the angle of its force on the slope. The internal elements of the materials considered for slope stability analysis included composition of different material units, which have different friction angle and cohesiveness and influence the slope stability in different manner.

#### 4.3 Computation

The above figure shows the choice of material, the color representation of the chosen material, its unit weight, frictional angle and cohesion and the Shear Strength Reduction Factor is applied. The SSR method, which is used in this research Mohr-Coulomb. The Apply SSR box is checked as the research uses model with joints. SSR option in the Phase 2 software allows researcher to automatically carry out finite element slope stability analysis and compute critical strength reduction factor for the respective model. After SSR analysis is computed the results will provide critical Strength Reduction Factor (SRF), which will automatically be displayed. The maximum shear strain contours will be shown by default as it tends to highlight the critical failure zone.

#### 4.4 Interpretation



# Figure 6: Critical SRF 1



Figure 7: Shear Strength Reduction 1







Figure 9: Critical SRF 2

d-



Figure 10: Shear Strength Reduction 2



Figure 11: Soil Profile 2



Figure 12: Critical SRF 3



Figure 13: Shear Strength Reduction 3



Figure 14: Soil Profile 3



Figure 15: Critical SRF 4



Figure 16: Shear Strength Reduction 4



#### Figure 17: Soil Profile 4

After computing the SSR analysis the Strength Reduction Factor is automatically displayed and the maximum shear contours is shown by default as it tends to highlight critical failure zone. The above figures show the analysis using Finite Element Method, which provides the strength reduction factor based on the stress applied at different points on the slope. The four critical SRF's obtained by measuring it at different points on the slope are 1.44, 1.47, 1.59 and 1.64. The graphs, which are plotted between SRF and maximum total displacement displays the displacement of the materials on the slope with respect to critical SRF. The total displacement when the critical SRF is 1.44 is 86.909m, at critical SRF the displacement is 82.636, at critical SRF of 1.50 the displacement is 94.553 and at critical SRF of 1.64 the displacement is 95.668 m. The above Figure 7, Figure 9, Figure 11, Figure 13 represent soil formation from the slope stability analysis of open pit cross section with 2 water tables, with only 1<sup>st</sup> water table with only 2<sup>nd</sup> water table and with no water tables.

The graphs represent the results of SSR Analysis. Each data point highlights the Strength Reduction Factor against Maximum Displacement for one iteration of SSR analysis. The Maximum Displacement provides the maximum displacement value which occurred at each point in the model during stress analysis, which was computed using the SRF value. The green data point represents the point for which stress analysis results achieved convergence, which means that the model is unstable at that point. The data points in red represent analysis for which stress analysis has not achieve convergence within specified tolerance, which highlights that the slope is still stable at that point in spite of the stress of different materials.

## 5 Conclusion

Slope stability analysis is considered important to ensure safety of the environment and humans. There are different factors, which influence the slop stability, which include impact of different materials, geological factors and human activities, which can deteriorate the strength of the slope and lead to instability in the slope. There are different approaches to analyze slope stability, which includes limit equilibrium and finite element method. Limit equilibrium method has several limitations as the slope surface and some factors are assumed as constant, which can lead to inaccurate outcomes. Finite element method on the other hand provides many advantages such as no need of assumptions of location of failure in the slope, considers relationship between stress and strain, does not consider irregular slope geometry shape, analyzes failure of slope in any condition with or without soil mass. This research using the modelling simulation method determines the factor of safety. The research uses the Rocscience Phase 2 software and built-in functions for finite element method in the software simulator for determining the factor of safety and failure surface applying strength reduction method. The factor of safety for soil slope was obtained by finite element analysis and provided an accurate analysis of the SRF and enabled effective slop failure investigations. The outcome of the simulation showed that as the factor of safety increases the displacement increases and also the displacement is influenced by the water presence in the soil but to a smaller extent. The difference in material also has different impact on the shear strength reduction. The finite element method should be used to determine the materials, which reduces the displacement of the soil formation, which can then be used to analyze the potential of slope and also assess its stability level.

## 6 Recommendations

Slope failure in an open pit mine is currently identified and avoided using conventional techniques of using certain approach to reduce stress on the slope or applying strengths at different angles, which consumers more time for carrying out the necessary tasks. There is loss of time, production and money invested in such processes and the conventional system are effective only when slope is nearing its failure. It is suggested that instead computer simulation should be used to find exact location of slope failure at the beginning when tension cracks begin to form and which can then later lead to slop failure. The sites can have automatic and continuous slop monitoring system, which can regularly monitor the exact location of slope failure in a mine and highlight the possible cracks and weaker areas in the slope, which will enable the people working in the mine to take necessary actions to overcome the possible slope failure or avoid causing further crack in the slope by changing their work activities and procedures.

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Zhang, Y (2015), The Study Methods and the New Progresses of Slope Stability, 2nd International Conference on Machinery, Materials Engineering, Chemical Engineering and Biotechnology 8 Appendix: Phase2 Analysis Information: Project1