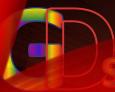
# SLOPE STABILITY ANALYSIS IN ROCKS Part 2 - Wedge failure

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### **SLOPE STABILITY ANALYSIS IN ROCKS**

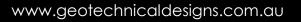
2

This Presentation on Slope stability analysis is divided into three parts. This presentation we will cover Wedge Failure only.

Planar Failure
 Wedge Failure
 Failure in Rock mass

The direction and size of these failures depend upon the following parameter

Joint sets
 Joints dip and dip direction
 Joints frictional properties (c and \$)
 Dip and dip direction of slopes face



## **KINEMATIC ANALYSIS**

Kinematic Analysis is very important method for determining the mode of failures.

This method also determines which joint sets will have planar failure or wedge failure or toppling failure with a particular slope face dip direction. We use Dips software (Rocscience) for determining the mode of failures.

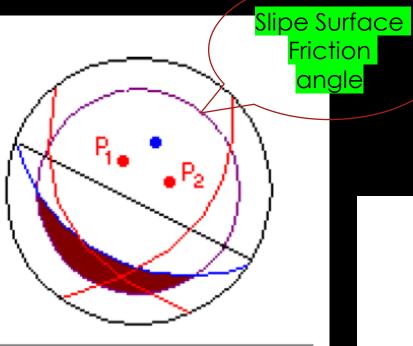
Input dip and dip direction of all the joints, separate poles will develop for each joint sets.



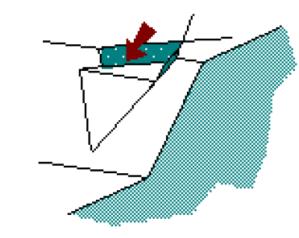
# KINEMATIC ANALYSIS – WEDGE FAILURE

#### Wedge failure, occurs when:

- a) Two intersecting sets of joints strike oblique to the slope.
- b) The line of intersection of the two planes plunges in the direction of slope.
- c) The angle of plunge is lower than the angle of slope.
- d) The line of intersection needs to crop out twice; once to the slope and again on the surface above the slope.
- e) The angle of plunge must be steep enough to produce sliding (>friction angle of the rock material)
- ) i.e-plunge <angle of slope and plunge >friction angle of slope



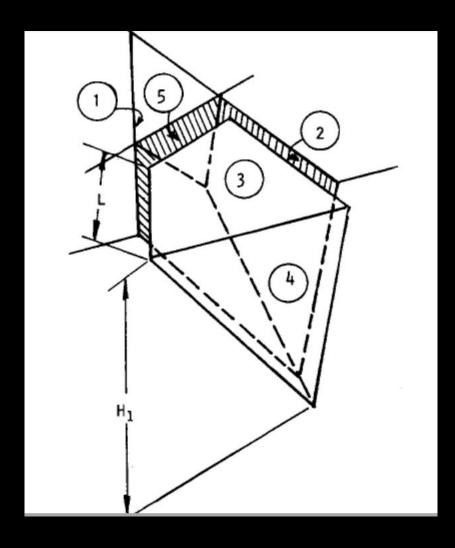
- pole of slope
   × P<sub>12</sub> intersect
- region of critical intersect
- great circle for slope



### WEDGE FAILURE

A wedge can be defined by:

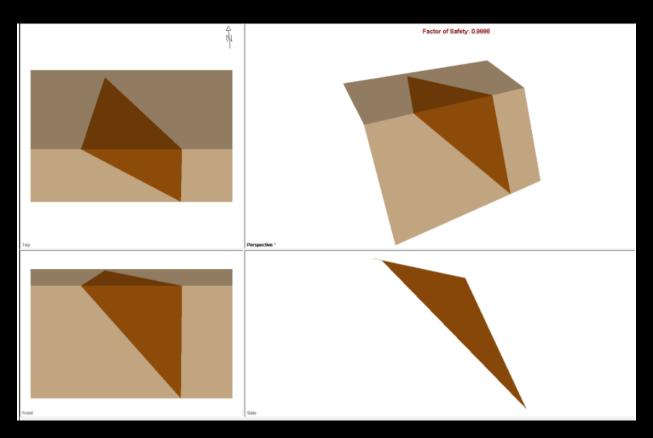
- 1,2 = Failure planes (2 intersecting joint sets)
- 3 = Upper ground surface
- 4 = Slope Face
- 5 = Tension crack
- H1 = Slope Height (vertical distance) refer plane 1
- L = Distance of tension crack from crest, measured along the trace of plane 1





### **SOFTWARE - SWEDGE**

SWedge is a quick, interactive, and simple-to-use analysis tool for evaluating the geometry and stability of surface wedges in rock slopes. Wedges are defined by two intersecting discontinuity planes, the slope surface, and an optional tension crack.





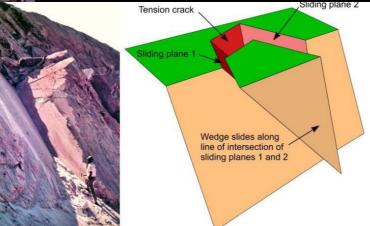
# WEDGE FAILURE PICTURES







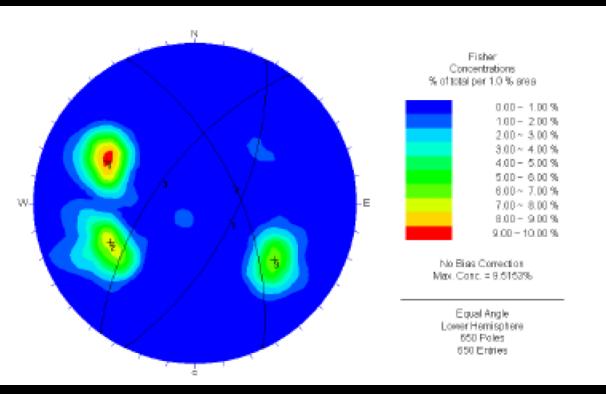


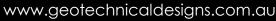




### **SOFTWARE - SWEDGE**

**Stereonet View** - The Stereonet View in SWedge displays a stereographic projection of plane orientations in your model's Input Data (Slope, Upper Face, Tension Crack, Joint 1, and Joint 2).







### **DECIDING FACTORS FOR SLOPE STABILITY**

The factor which determines the Failure of Wedge are as follows:

- 1. Water Pressure in joints.
- 2. Shear Parameters of Slip plane.
- 3. Seismicity



### DECIDING FACTORS FOR SLOPE STABILITY

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Shear Strength - Wedge slope stability analysis involves the shear strength of the sliding surfaces.
There is relationship between the shear strength of a sliding surfaces and the effective normal stress acting on the joint planes.
Sliding Surfaces can be more than two.
Mohr – Coulomb

 $\tau_i = c_i + \sigma_{ni} \tan \phi$ 

 $\begin{aligned} \tau_i &= \text{Shear strength of the } i^{\text{th}} \text{ joint} \\ \sigma_{\text{ni}} &= \text{Normal Stress of the } i^{\text{th}} \text{ joint} \\ c_i &= \text{cohesion of the } i^{\text{th}} \text{ joint} \\ \phi_i &= \text{friction angle of } i^{\text{th}} \text{ joint} \\ \text{There are more strength criteria for analyzing slope stability. But here we are explaining the Mohr-Coulomb Criteria only for understanding.} \\ &= \text{Normal Stress of the } i^{\text{th}} \text{ joint} \\ \text{Stress of the } i^{\text{th}} \text{ joint} \\ &= \text{Stress of the } i^{\text{th}} \text{ joint} \\$ 

### SWEDGE- EXAMPLE 1

This example will show the basic modelling and data interpretation.

This software will provide the slope stability analysis and design for wedge stability in open pit mines and rock slopes. Input Data – Input the know parameters in the project settings:

Input the Units in which you want to analyze the slopes.

Analysis Type is **Deterministic** where input parameters are known for e.g. c and  $\phi$  of failure plane and dip of joints.



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Project Settings				?	×
General Sampling Ran	ndom Numbers	Design Standard	Project Summ	ary	
Metric, stress as MP m, MN, MN/m, MPa,		~			
Analysis Type	○ Proba	abilistic	Combination	IS	
Block Shape	OBasa	Joint 🗹 Indu	ide Socket Wed	lges	
			ОК	Cance	

# **SWEDGE – INPUTS**

# The Input Data dialog for a Deterministic analysis is organized under three tabs: Slope, Joints, and Forces.

Deterministic Input Data 🔤 ? 🔺 🗙	Deterministic Input Data 🔤 ? 🔺 🗙	Deterministic Input Data
Deterministic Input Data       { A X         Slope       Joints       Forces       Water         Slope       Upper Face       Dip (deg):       12 (a)         Dip Direction (deg):       185 (a)       Dip Direction (deg):       185 (a)         Height (m):       33       Image: Slope Dip Direction (deg):       185 (a)       Image: Slope Dip Direction (deg)       0         Length (m):       29.5677       Image: Dip Direction       Upp Direction       0       Specify Location         Overhanging       Use Slope Dip Direction       Use Bench Width to Maximize       12       Use Bench Width to Maximize	Slope     Joint 1       Joint 1     Joint 2       Dip (deg):     □       Dip Direction (deg):     125 ÷       Waviness (deg):     0       Shear Strength Model:     Mohr-Coulomb	Slope       Joints       Forces       Water         Seismic       Seismic Coefficient       0       Direction:       0         Direction:       #       Trend*       Plunge*       Force (MN)         Hortz. & Inters. Trend
Book Properties       Unit Weight (MN/m3):       0.026	$\tau = c' + \sigma'_n \tan \phi'$ $c [MPa]: 0 Phi [deg]: 35$ $\tau = c' + \sigma'_n \tan \phi'$ $c [MPa]: 0 Phi [deg]: 35$ $Joint Parameters$	Type of Forces
Import From Dips Apply OK Cancel	Import From Dips OK Cancel	Import From Dips OK Cancel

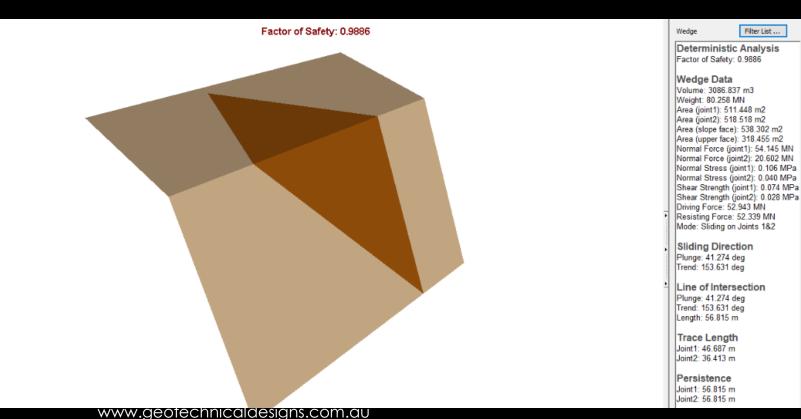
Type of Forces

- 1. Water Pressure
- 2. Seismic
- 3. External Forces



# **3D-PERSPECTIVE VIEW - INTERPRETATION**

- Factor of safety = 0.989 Just in equilibrium.
- In static case FOS shall be 1.5 or more and to achieve it, either we will change
- Friction Parameter of Joint Planes
- Slope Inputs or
- Provide Supports



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#### CHANGE SLOPE PARAMETERS TO INCREASE FOS OF SLOPE STABILITY

If you look at the Slide 11 the Geometry of the slope has been given.
The initial height of slope was 33m. Now change it to 20m.

#### Unit weight to 0.027 MN/m<sup>3</sup>

. Select the **Slope** tab and enter the following data:

· ·		_
Slope Height (m)	20	
Slope Dip (°)	65	
Slope Dip Direction (°)	45	
Upper Face Dip (°)	10	
Upper Face Dip Direction (°)	45	
Unit Weight (MN/m3)	0.27	

Slope	Upper Face	Tension Crack
Dip (deg):         65 ★           Dip Direction (deg):         45 ★	Dip (deg):         10 ★           Dip Direction (deg):         45 ★	Dip (deg) 70 -
Height (m): 20	Bench Width Width (m): 21.07 Use Slope Dip Direction	<ul> <li>Minimum FS Location</li> <li>Specify Location Trace Length (m): 1</li> <li>Use Bench Width to Maximize</li> </ul>
Rock Properties Jnit Weight (MN/m3): 0.027		
	w Slope Param	



#### INCREASE JOINTS PARAMETERS TO INCREASE FOS OF SLOPE STABILITY

If you look at the Slide 11, the joints friction parameters of the slope has been given.
Increase the friction parameters of the joints, so that the FOS of this slope increases.

2. Select the <b>Joints</b> tab and enter the following data:				
Joint 1 Dip (°)	45			
Joint 1 Dip Direction (°)	52			
Joint 1 Cohesion (MPa)	0.025			
Joint 1 Friction Angle (°)	30			
Joint 2 Dip (°)	70			
Joint 2 Dip Direction (°)	18			
Joint 2 Cohesion (MPa)	0			
Joint 2 Friction Angle (°)	35			

Determ	inistic Input Data —			? ▲ ×
Slope	Joints Forces Water			
	Joint 1		Joint 2	
	Dip (deg):	45 🜩	Dip (deg):	70 🜲
	Dip Direction (deg):	52 🜩	Dip Direction (deg):	18 🜩
	Waviness (deg):	0	Waviness (deg):	0
	Shear Strength Model:	Mohr-Coulomb ~	Shear Strength Model:	Mohr-Coulomb ~
	$\tau = c' + \sigma'_n \tan \phi'$		$\tau = c' + \sigma'_n \tan \phi'$	
	c [MPa]: 0.025	Phi [deg]: 30	c [MPa]: 0	Phi [deg]: 35
		New Joir	nt Paramete	rs
Impor	t From Dips		Apply	OK Cancel

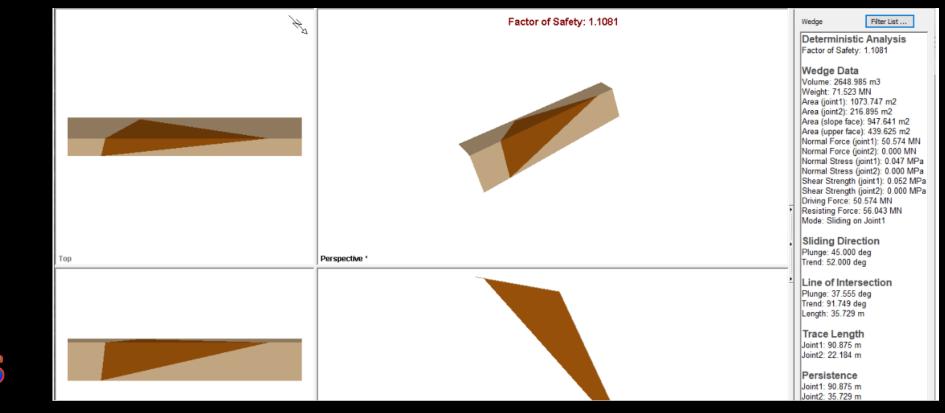


#### FACTOR OF SAFETY AFTER CHANGES Increase in FOS after reducing the slope height and Increasing Joint friction parameters

#### \*Initial FOS = 0.989

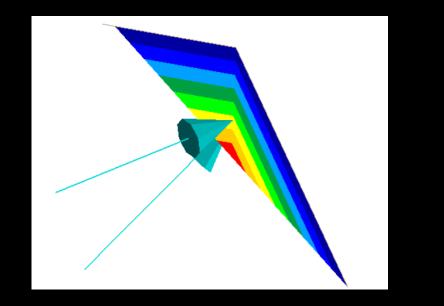
#### **After Changes = 1.108**

#### But FOS is still less than the required 1.5.



#### WATER PRESSURE

- The Filled Fissures option assumes extreme conditions of heavy rainfall such that maximum (average) values of water pressure are applied on the failure planes.
- Now on applying full water pressure FOS has reduced to 0.57.



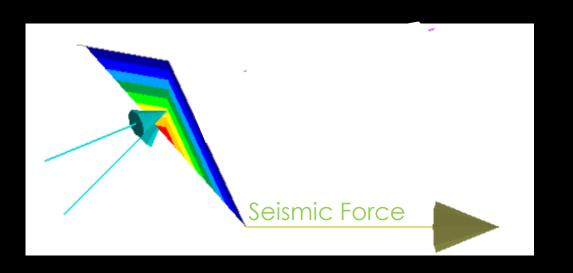
terministic Input Data	
Slope Joints Forces Water	
Ponded Water Pressure Unit Weight (MN/m3): 0.00981	Joint Water Pressure Unit Weight (MN/m3): 0.00981
Slope Face Type: Impervious	Pressure Distribution Model:
Ponded Water Depth (m): 0	Filled Fissures $\checkmark$
Note: Pressure Distribution Model is unavailable when Pervious Slope Face is selected.	Hu: 1
Import From Dips	Apply OK Cance



# SEISMIC FORCE

Seismic Coefficient of 0.2 and direction of seismicity has be adopted

- $\blacktriangleright$  at Plunge = 0° and Trend = 52°
- On applying seismicity the FOS will further reduced to 0.48



Seismic	
Seismic Coefficient	0.2
Direction:	
User Defined	$\sim$
Plunge (deg):	0
Trend (deg):	52



#### **SUPPORT MEASURES-ROCK BOLT**

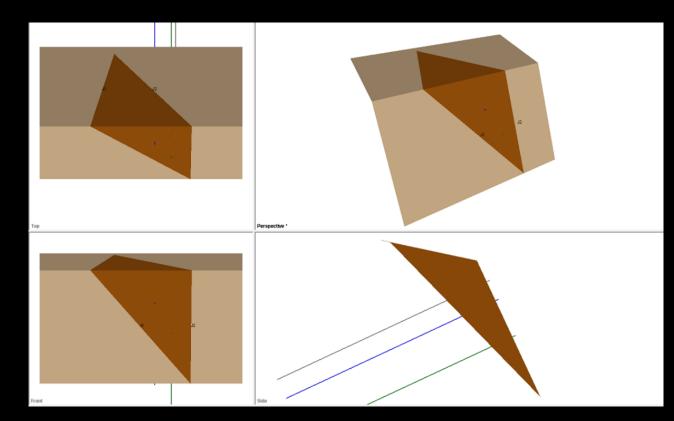
To increase FOS of Slope, we are providing Rock Bolt and Shotcrete of following parameters:

#### **ROCK BOLT**

- $\blacktriangleright$  Rock Bolt capacity = 0.2 MN
- Length 35m (can be reduced)
- Direction of Rock Bolts

Bolt Properties					?	×
Bolt Property 1	Bolt Pro	operty 1				
	Name:	Bolt Property 1	Color:	$\sim$		
	Type:	Simple Bolt Force $$	Bolt Model:	Active	OPassive	e
	Force:	0.2 MN				
4 × 🕞 🖬				ОК	Cance	el

Add Spot Bolt	? ×
Orientation Trend / Plunge Trend: 5 • ° Plunge: 25 • °	Bolt Length Length: 34 m Bolt Properties Bolt Property 1 OK Cancel



# **SUPPORT MEASURES-SHOTCRETE**

To increase FOS of Slope , we are providing Rock Bolt and Shotcrete of following parameters:

#### **Shotcrete**

- Shotcrete Thickness = 100mm
- Shear Strength of Shotcrete = 1MPa
- Direction of Rock Bolts

Shotcrete	?	×
Shotcrete (Slope Face On Thickness (m):	( <u>x)</u>	
Shear Strength (MPa):	1	L
Apply OK	Cancel	



### FACTOR OF SAFETY AFTER SUPPORT MEASURES (FOS 1.525)

- Factor of safety increase from 0.48 to 1.525 after applying
- Rock Bolts
- Shotcrete

Therefore it is very important to provide **support system** to counter act forces

- Water Pressures
- Seismicity and
- Sliding force of Wedge



### THANKS FOR WATCHING PRESENTATION

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