NATIONAL UNIVERSITY OF ENGINEERING PROFESSIONAL SCHOOL OF GEOLOGICAL ENGINEERING



DESIGN OF A SLOPE STABILIZATION SYSTEM FOR A TRAWLING HILL

COURSE: GEOLOGY APPLIED TO CONSTRUCTIONS

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1. INTRODUCTION

The stability analysis of slopes allows to know the conditions in which the rocky massif is found, is a very important activity and basis for more detailed studies or planned constructions. The activities indicated in class and the application of the method in the trawling hills have been carried out along 22.5 m (geomechanical station located at 12 ° 01'10 "S / 77 ° 02'46"O).



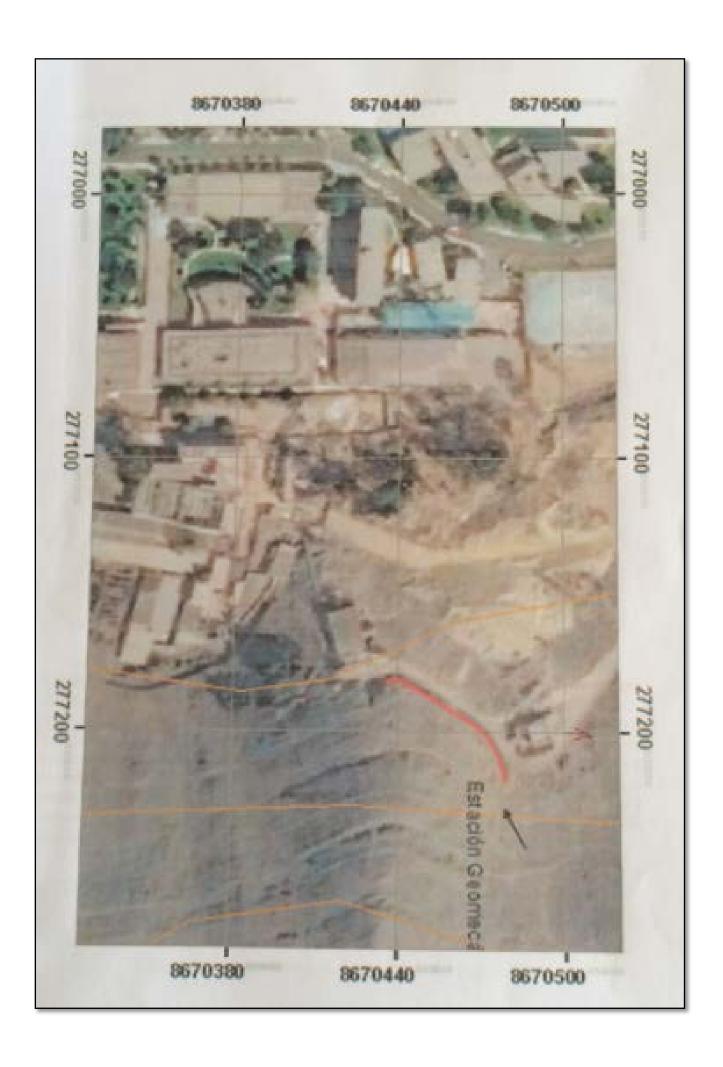
Figure 1: Location of the geomechanical station

2. JUSTIFICACIÓN

One of the most important applications of geological knowledge is in the area of constructions, constructions that require a previous study of the state of the rocky massif on which one wants to make a work. This is how we take the study or analysis of slope stability, an indispensable tool during our training.

3. OBJECTIVE

The objective of the work is to establish a geomechanical station and follow the methodology explained in class, to later analyze the information taken from the field and formulate conclusions regarding the stability of the slope.



4. SYNTHESIS

For the fulfillment of the proposed objectives, after some theoretical sessions on geomechanical stations and stability analysis of slopes; the field work consisted mainly of data collection (100 data) required in formats for the characterization of the rocky massif.



Figure 2: Field data collection procedure.

With the information obtained from the field, the scanning was done, first in MS Excel and then the data transfer to the program Dips (signature RockScience). Already in the Dips, we start to generate graphs of the traces and poles of the discontinuity planes, highlighting the presence of families (clouds of accumulation of more information), with the information on the slope in the zone of data collection we can verify if Some type of instability (generation of planar, circular, wedge or overturn breaks). For the analysis will be necessary to use established tables or methods of calculation of information with which we do not count, such as the angle of friction, density of the mass, among others. Finally we will use some other RockScience programs to determine the safety factor.

5. TECHNIQUES USED

For the field work, manual measurement of the required properties in the format provided in class (starting point distance, rock type, structure, geometry, aperture, fill, presence of water, alteration, resistance, observations). Additionally we take the properties of the slope (75 ° / 310 °).

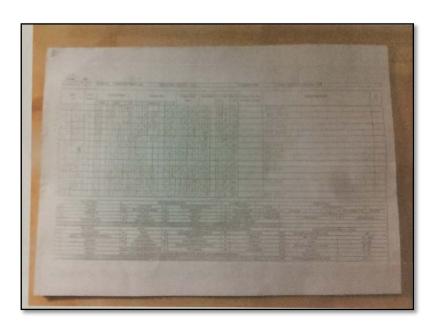


Figure 4: Format filled with field information

• After the fieldwork, the information was passed to the Excel program. We then pass the data to the Dips program.

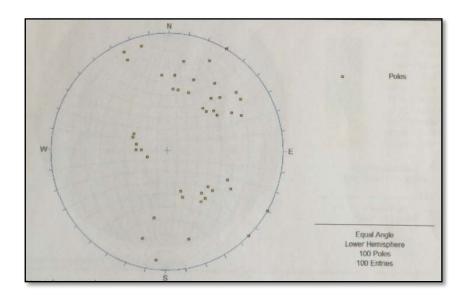


Figure 5: Representation of poles of discontinuities.

• Plotting points will show (in the window of contours or clouds) the zones with the highest concentration of poles of generated planes.

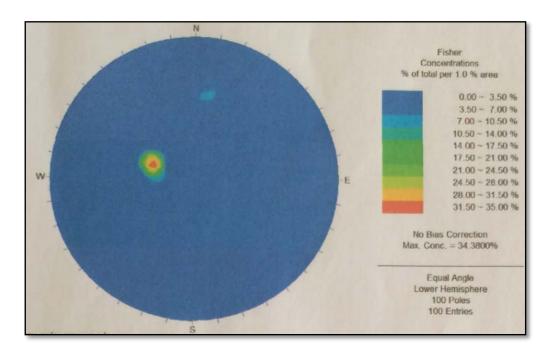


Figure 6: Representation of clouds of concentration of poles.

 In each zone of greater concentration we draw the poles of the planes with which we are going to carry out the work of stability analysis. Three planes have been detected according to the poles.

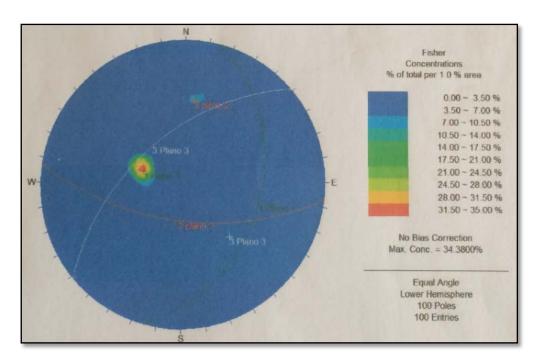


Figure 7: Representation of the planes from the clouds of poles.

• The determined planes are best visualized in a large plane plot window. Where we can visualize their properties of Dip and Dip direction.

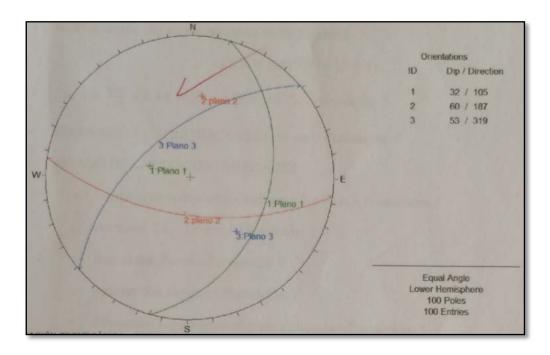


Figure 8: Representation of the planes of discontinuities and their properties.

For the stability analysis, we include the dip / dip direction of the measured slope in the field (75 $^{\circ}$ / 310 $^{\circ}$ - plane 4)

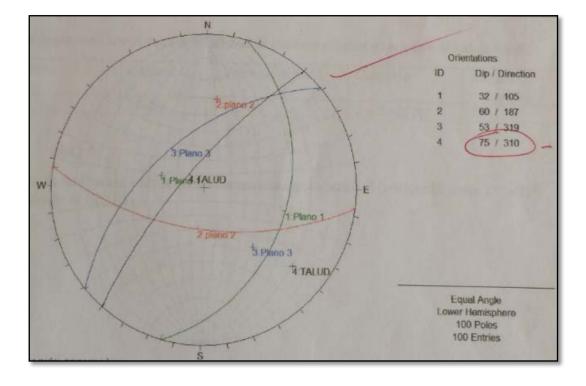


Figure 9: Representation of planes of discontinuity and slope.

RMR CALCULATION

- Resistance of the rock matrix (Mpa) 70 Mpa Score: 7
- RQD (we have 100 discontinuities in 22.5 meters)

$$RQD = 100^{-0.1\gamma}(0.1\lambda + 1)$$

$$\lambda = \frac{100}{22.5} = 4.44, RQD = 0.187 = 18.7\% - score: 3$$

- Separation between diaclases: 10 cm score: 8
- State of discontinuities
 - Length of discontinuity: between 3 and 10 m Punctuation: 2
 - Opening: 0.1 1.0 mm Score: 3
 - Roughness: Mild Score: 0
 - Filling: Unfilled Score: 6
 - Alteration: Slightly altered Score: 5
- Groundwater
 - Dry general condition Score: 15

RMR: 49

We compare it with the quality chart of rocky masses in relation to the RMR index.

Class	Quality	RMR Rating	Cohesion	Angle of
				friction
III	Average	41-60	2-3 kg/cm2	25° - 35°

JRC: 5

The angle of internal friction we will then take will be 36 $^{\circ}$ (intermediate between 25 $^{\circ}$ - 35 $^{\circ}$ added to the JRC)

ANALYSIS OF STABILITY OF TALUD

Planar break:

Conditions:

- The sliding plane is parallel with the slope wall ($\pm 20^{\circ}$).
- The plane of rupture should appear on the face of the slope.
- Requires side take-off surfaces to allow sliding material to exit.
- The dip of the slope must be greater than the dip of the plane of rupture, and this in turn is greater than the angle of internal friction $(\beta > \alpha > \varphi)$.

Wedge break:

Conditions:

- The two planes should appear on the surface of the slope and meet the condition of $\psi > \alpha > \varphi$, where ψ is the slope angle measured in the direction of the slope surface.
- The intersection line should be buried in the direction of slope dip.
- It occurs in massifs that have at least two families of discontinuities whose planes are cut.

Break by overturn:

Conditions:

- $\beta > \varphi + (90 \alpha)$
- The break plane must have an approximately parallel course (± 20 °) relative to the slope plane.

Data to be taken for calculations:

Density of quartzite: 2650 kg/m3

Resistance to compression: 900 – 4700 kg/cm2

Seismic coefficient: 0.2

Internal friction angle: 36°

With the established parameters and the determined data, we proceeded to analyze each plane, resulting in:

- 1. Planar breakage is generated due to plane 3 (53 ° / 319 °)
 - $310^{\circ} + 20^{\circ} > 319^{\circ} > 310^{\circ} 20^{\circ}$
 - $75^{\circ} > 53^{\circ} > 36^{\circ}$

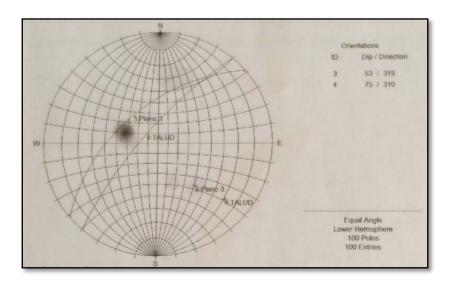


Figure 10: Graphic diagram showing the plane 3 and the plane of the slope.

2. A wedge-type break is generated by the intersection of planes 3 and 2. In the stereographic network it can be seen that the intersection falls right in the critical zone.

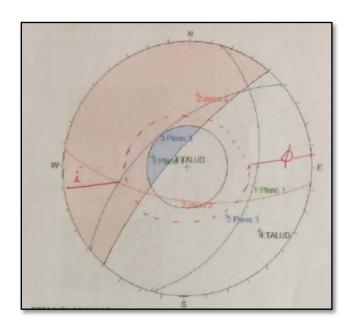


Figure 11: Representation of critical areas for wedge-type rupture.

3. No plane generates rupture by toppling or overturn, since they do not satisfy the two conditions.

$$-\beta > \varphi + (90 - \alpha)$$

- The break plane must have an approximately parallel course (± 20 °) relative to the slope plane.

DETERMINATION OF THE SAFETY FACTOR FOR EACH CASE

 Planar Break (Plan 3): We make use of the RocPlane program. Safety factor: 1.07

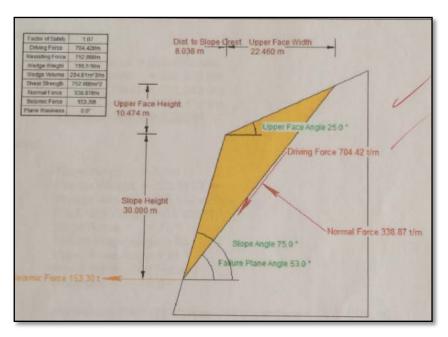


Figure 12: 2D representation of the analysis for the case of planar rupture.

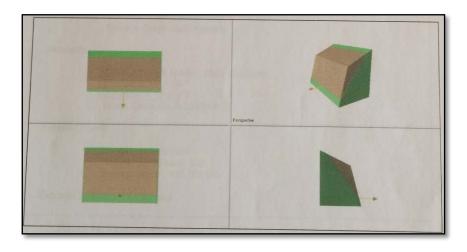


Figure 13: Views and 3D rendering of the planar break case.

Further details of the data considered for the case of planar rupture are presented below.

```
RocPlane Analysis Information
  Document Name:
  RocPlane1
  Job Title:
  RocPlane - Planar Wedge Stability Analysis
  Analysis Results:
               Analysis type = Deterministic
               Normal Force = 338.865 t/m
               Resisting Force = 752.983 t/m
               Driving Force = 704.422 t/m
               Factor of Safety = 1.06894 V
  Geometry:
              Slope Height = 30 m
              Wedge Weight = 766.511 Vm
              Wedge Volume = 294.812 m^3/m
              Rock Unit Weight = 2.6 t/m^3
              Slope Angle = 75 °
              Failure Plane Angle = 53 °
              Upper Face Angle = 25 °
              Bench Width: Not Present
              Waviness = 0 "
              Intersection Point (B) of slope and upper face = (8.03848, 30)
              Intersection point (C) of failure plane and upper face = (30.499, 40.4735)
              Failure plane length ( Origin -> C ) = 50.6783 m
              Slope length (Origin -> B) = 31.0433 m
              Tension Crack: Not Present
Strength:
             Shear Strength Model: Mohr-Coulomb
             Friction Angle = 36 °
             (Cohesion = 10 t/m<sup>2</sup>) 20 - 30.
             Shear Strength: 752.983 t/m^2
Seismic Force:
             Direction: Horizontal
             Seismic Coefficient: 0.2
             Seismic Force: 153.302 t/m
External Forces: Not Present
```

Figure 14: Report generated by the RockPlane for the case of planar rupture.

2. Wedge break (planes 2 and 3): We use the Swedge program. Security factor: 1,591.

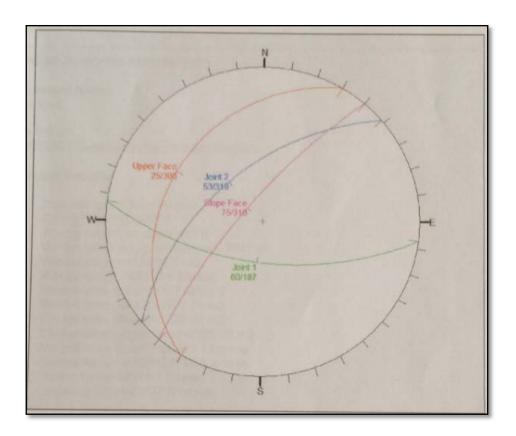


Figure 15: Projection generated with the Swedge, taking only the planes that generate the break.

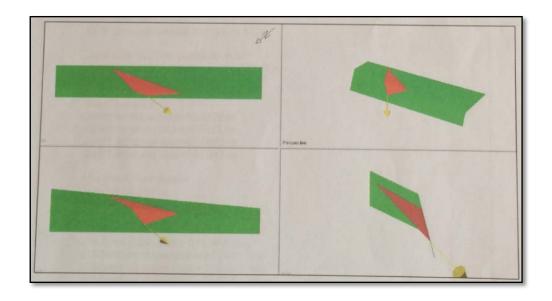


Figure 16: Views and 3D rendering of the planar break case.

Further details of the data considered for the case of wedge breakage are presented below.

```
Swedge Analysis Information
 Document Name:
 Swedge1
 Job Title:
 SWEDGE - Surface Wedge Stability Analysis
 Analysis Results:
      Analysis type=Deterministic
      Safety Factor=1.59078
      Wedge height(on slope)=30 m
      Wedge width(on upper face)=47,7847 m
      Wedge volume=16299.8 m3
      Wedge weight=42379.6 tonnes
      Wedge area (joint1)=787.925 m2
      Wedge area (joint2)=3271.74 m2
      Wedge area (slope)=1326.92 m2
      Wedge area (upper face)=2228.28 m2
      Normal force (joint1)=26000.1 tonnes
      Normal force (joint2)=29713.8 tonnes
      Driving force=30549,7 tonnes
      Resisting force=48597.9 tonnes
      Seismic Force
      Seismic force=8475.91 tonnes
      Failure Mode.
      Sliding on intersection line (joints 1&2)
     Joint Sets 1&2 line of Intersection:
     plunge=31.3898 deg, trend=256.373 deg
     length=104.045 m
     Trace Lengths:
     Joint1 on slope face=40.4229 m
     Joint2 on slope face=70.5461 m
     Joint1 on upper face=68.2683 m
     Joint2 on upper face=149.843 m
     Maximum Persistence.
     Joint1=104.045 m
     Joint2=149.843 m
    Intersection Anglés
    J1&J2 on slope face = 111.468 deg
    J1&Crest on slope face = 44,7441 deg
    J1&Crest on upper face = 135.577 deg
    J2&Crest on slope face = 23,7883 deg.
    J2&Crest on upper face = 18.5963 deg
    J1&2 on upper face = 25.8271 deg
```

Joint Set 1 Data: dip=60 deg, dip direction=187 deg cohesion=2 tonnes/m2, friction angle=36 deg Joint Set 2 Data: dip=53 deg, dip direction=319 deg cohesion=2 tonnes/m2, friction angle=36 deg Slope Data: dip=75 deg, dip direction=310 deg slope height=30 meters rock unit weight=2.6 tonnes/m3 Water pressures in the slope=NO Overhanging slope face=NO Externally applied force=NO Tension crack=NO Upper Face Data: dip=25 deg, dip direction=300 deg Seismic Data: Seismic coefficient=0.2 Direction=line of interesection J1&J2 trend=256.373 deg, plunge=31.3898 deg Wedge Vertices: Coordinates in Easting, Northing, Up Format 1=Joint1, 2=Joint2, 3=Upper Face, 4=Slope Point 124: 0, 0, 0 Point 134: 22.8, 14.7, 30 Point 234: -38.6, -55, 21.4 Point 123: 86.3, 20.9, 54.2

Figure 17: Report generated by the Swedge for the case of wedge-type breakage.

6. CASE OF A TRUNK SHAPE TUNNEL

We will take the premise and the case that we will build a tunnel in the shape of a trunk of dimensions 11m x 8m (model of the Santa Rosa tunnel) and we have the families so far determined. We will do the stability analysis for that tunnel using the software Unwedge (from RockScience).

We plot the families and add an axis of advance for the tunnel (axis of advance taken: 310°).

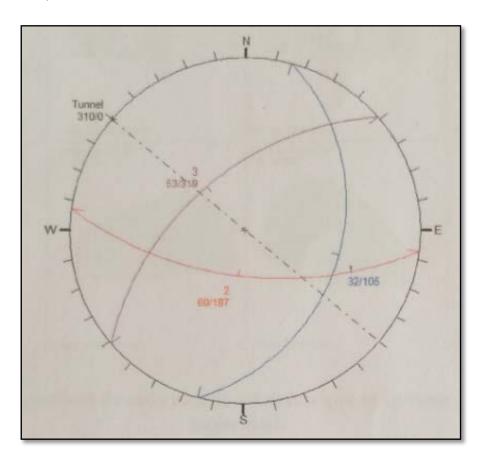


Figure 18: Stereographic projections of the families of discontinuities and the axis of advance of the tunnel (310 °).

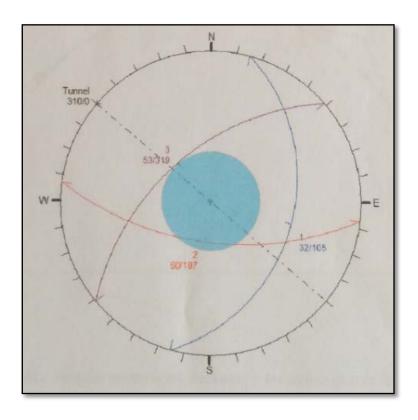


Figure 19: Projections of the families and axis of the tunnel, including the angle of friction (36 °).

Next we will see the results after having put the dimensions to the tunnel, we notice that there are 7 wedges, 6 of them have a factor of security well above the allowed (1.5), one of them has security factor 0.00.

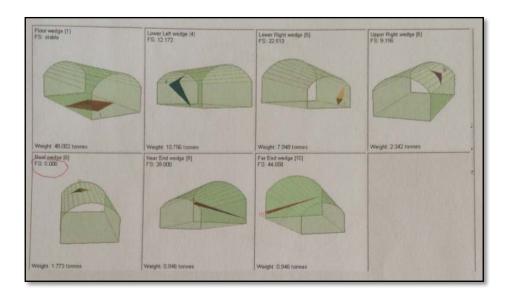


Figure 20: Perspectives of each of the wedges that are formed and their safety factors.

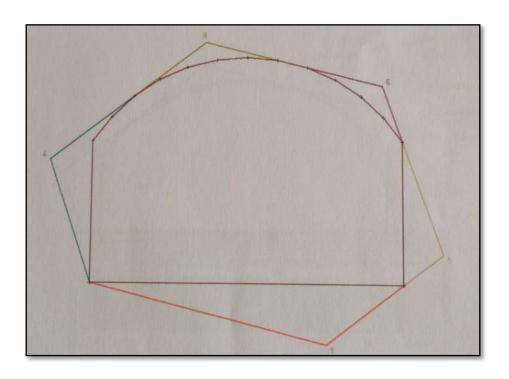


Figure 21: Cross section of the tunnel and wedges that are formed.

To have a safety factor within the permissible, we will add a tunnel support in the part of the wedge 8. We first add 1 t / m2 to the part of the wedge 8 (safety factor of 1,692).

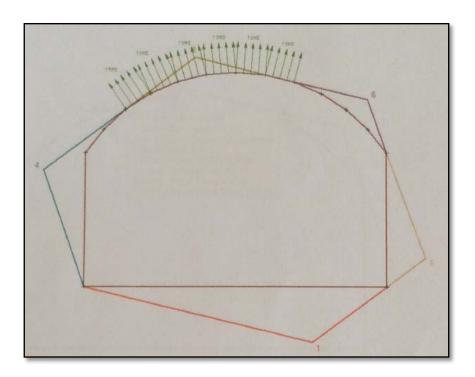


Figure 22: Diagram showing the pressure located on the wedge part 8.

If we add a layer of shotcrete of 10 cm, 2.6 t / m3 and 200 t / m2; we will have a safety factor of 92.9.

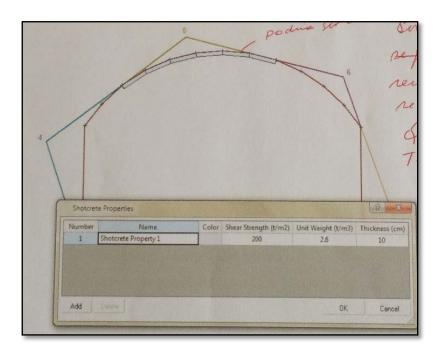


Figure 23: Shotcrete scheme and properties.

We also add a bolt for the support. In this case we obtain a safety factor of 5.297 (2 m long bolt).

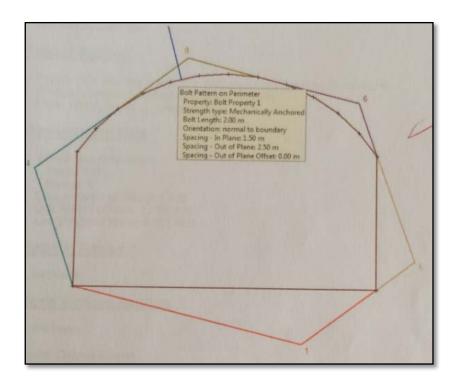


Figure 24: Diagram showing a bolt in the wedge area.

Unwedge Analysis Information

Document Name

File Name: Unwedge 1

Project Settings

Project Title: Stability Analysis of Wedges for Underground Excavations

Wedges Computed Perimeter and End Wedges

Units: Metric, stress as tonnes/m2

General Input Data

Tunnel Axis Orientation:

Trend: 3101 Plunge: 0"

Design Factor of Safety: 1,500 Unit Weight of Rock: 2,700 tim3 Unit Weight of Water: 0.981 Vm3

Seismic Forces

Not Used

Scale Wedges Settings

Not Used

Joint Orientations

Joint 1

Dip: 32"

Dip Direction: 105"

Joint 2

Dip: 60*

Dip Direction: \$87°

Joint 3

Dp: 53

Dip Direction: 319"

Joint Properties

Joint Properties 1

Water Pressure

Constant: 0 tonnes/m2.

Wayiness: 0"

Shear Strength Model: Mohr-Coulomb

Phi: 351

Cohesion: 10 tonnes/m2

Tensile Strength: 0 tonnes/m2

Bolt Properties

Bolt Property 1

Bolt Type: Mechanically Anchored Tensile Capacity: 10 tonnes Plate Capacity: 10 tonnes Anchor Capacity, 10 tonnes Shear Strength Unused **Bolt Orientation Efficiency: Used** Method: Cosine Tension/Shear

Shotcrete Properties

Shotcrete Property 1 Shear Strength: 200,00 µm2 Unit Weight 2,600 t/m3 Thickness 10.00 cm

Support Summary

Summary of Perimeter Bult Patterns

Number of Bolt Patterns on Perimeter: 1

Perimeter Bolt Pattern: 1

Property: Bolt Property 1 Strength type: Mechanically Anchored

Bolt Length: 2.00 m

Orientation: normal to boundary

Pattern Spacing - In Plane: 1.50 m

Pattern Spacing - Out of Plane: 2.50 m

Pattern Spacing - Out of Plane Offset 0.00 m

Wedge Information

Floor wedge [1]

Factor of Safety: stable Wedge Weight 48,002 tonnes

Lower Left wedge [4]

Factor of Safety: 12.172 Wedge Weight: 10.756 tonnes

Lower Right wedge [5]

Factor of Safety: 22.513

Wedge Weight: 7.948 tonnes

Upper Right wedge [6]

Factor of Safety: 9.196

Wedge Weight 2.042 tonnes

Roof wedge [8]

Factor of Safety: 5 297

Wedge Weight: 1.773 tonnes

Near End wedge [9]

Factor of Safety: 39,000

Wedge Weight 0.946 tonnes

Far End wedge [10]

Factor of Safety: 44,058

Wedge Weight: 0.946 tonnes

7. LIMITATIONS

The present work is strictly developed as a practice, not having an economic or project objective; Being able to have detailed in an integral way the geology and other aspects that we consider very important.

8. CONCLUSIONS

- The slope in the trailing hills was characterized by the plane 75 ° / 310 ° from the point of the geomechanical station and with view to the East.
- Three main families of discontinuities were identified: 32 $^{\circ}$ / 105 $^{\circ}$, 60 $^{\circ}$ / 187 $^{\circ}$ and 53 $^{\circ}$ / 319 $^{\circ}$.
- Planar rupture is generated by the presence of the family of plane 3: 53 ° / 319 ° (SF: 1.07), wedge is formed by the presence of families of planes 2 and 3 (60 ° / 187 ° and 53 ° / 319 °) with safety factor 1.59.
- In the case of a tunnel, we have a wedge with a safety factor below the permissible, it is recommended to use bolts or pressure in the wedge area 8 with the specified characteristics.



MISA 100 D DIP DIP LINEA No 4 LONGITUD : 15.4 cota: UBICACIÓN: CERED UNI (E1277776,76) FECHA: 03/06/16 HOJA NO: REALIZADO POR: PINO [NJ: 8670456,13] DIST. TIPO **ESTRUCTURA** GEOMETRIA ABERTURA Ho. RELLENG A ALT RESIS ESTRUCTURA DEL OBSERVACIONES (m) ROCA 0 (w) (R) MACIZO ROCOSO TIPO D DIP DIP LARGO (m) CR 10 0 ESP 20 cm S LA R4 14 D E A 124 ESACIALIENTO 15 CM ESP. 200M 15cm 18 ESP. 15cm D, LA RA 0 15: FM LA 184 D A 86. 15 cm LA RA A LA R4 D LA 24 GEOMETRIA ALTERACION TIPO DE ESTRUCTURA (R) RUGOSIDAD TIPO DE ROCA FORMA: FRESCA LISA E ESTRIADA P CONTACTO LITOLOGICO PULIDA DIACLASA P PLANAR R RUGOSA LA LEVEMENTE ALT PIZARRA D A B C D BRECHA SET DE DIACLASAS BX O ONDULADA SD CALIZA ALTERADA VETA DISCONTINUA 10 FALLA VN CONTINUA FT I IRREGULAR C ARENISCA MA MUY ALTERADA MANTOS FOLIACON MT IA INTENS ALTERADA LUTITA DIQUE DX FT ZONA CIZALLE GRANODIORITA RESISTENCIA ESTIMADA (Mpa) CRITERIO GENERALIZADO DE HOEK - BROWN EXTREMADAMENTE DURA AGUA MUY BUENA RELLENO MB LEVEMENTE FRACTURADO 100 - 250 LF MUY DURA S SECO BUENA SIN RELLENO FRACTURADO B 50 - 100 F DURA HUMEDO R4 H REGULAR LIMOS Y FRAGMENTOS DE ROCA MUY FRACTURADO R 25 - 50 MF MODERADAMENTE DURA GOTEO SUAVE R3 Gs POBRE OXIDOS INTENSAMENTE FRACTURADO 5 - 25 IF: BLANDA FLUJO CONSTANTE R2 MUY POBRE MP SULFURO 1-5 TRITURADO MUY BLANDA No D = CANTIDAD DE DISCONTINUIDADES DEL MISMO TIPO ENTRE LOS ESPACIOS MEDIDOS. Rt 0.25-1 ARCILLA EXTREMADAMENTE BLANDA A PIRITA

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			REL												LF		LE	VEM		FRAC				MB		MUYB	MARKET PROPERTY.		R6 R5	MUY DURA			100 - 250	
			SIN	RELL	ENO		-		S			UME	-		F	_				TURAC				В		BUE	_		84	DURA			50 - 100	
	L	MOS	YFRAD			ERO	CA.	-	H	-	10.0	-	JAVE		MF	7 3				CTUP				R	-	REGU	_		83	MODERADAMENTE DURA			25 - 50	
				XIDO					Gs				STAN		3F		INTE	NSA	MENT	EFRI	CTU	RADO		P		POB			R2	BLANDA			5 - 25	
			SI	JLFU	10				T						-		TO COLUMN		TO (T)	HO A PA	n			MP		MUY P	UBRE		R1	MUY BLANDA			1-2	
-			A	RCILL	A				5577	0000	1195/6	134554	- mil	CANT	DALLES	AMES	DEL	MISN	O TIP	OEN	TRE	LOS E	SPAC	CIOS N	EDIDO	05.	A 104 T TO 1	1000 FOR	RO	EXTREMADAMENTE BLANDA			0.25 - 1	
4	_	_	- 1	PIRIT			-		No D	= CA	MILITA	AD DE	CIS	CONT	NOID.	ALC: U	-		100	Charles To T	120000	GERSON.	A STREET	THE STATE OF				() () ()	NU					