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SOME GEOTECHNICAL CONSIDERATIONS FOR PROBABILISTIC ANALYSIS IN SLOPE DESIGN

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Some geotechnical considerations for probabilistic analysis in slope design

INTRODUCTION

- 1) GEOTECHNICAL CHARACTERIZATION.
- 2) BENCH BERM DESIGN.
- 3) INTERRAMP AND OVERALL SLOPE STABILITY.
- 4) GEOTECHNICAL RISK MAP.



Camera rotation \Rightarrow geometrical cone in the stereographic projection.



Priest, S. D. (1985): *Hemispherical Projection Methods in Rock Mechanics*, George Allen and Unwin, London.





Stereographic projection from ATV survey in a geotechnical borehole.



Examples of natural joints/minor faults classified as mechanical.



Examples of wrong calculation of RQD.



From_Depth	To_Depth	Interval	RQD_m	RQD_Pct
30	33	3	3	100



Overestimation of FF/m and sub estimation on the classification systems indexes.

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93.30			2990	NAME T					293
Deede (m)	Hasta (m)	Trama Malida (m)	294,00	CSL D1			PMP1 LOO		0'
291	294	0.55	10.67	20	25	48	26	35	3.36

Crushed material of 0,55m that can not be observed.

09.00 30	8.00		C. T		A		L.			N. The
		Cingrel	234 PESA		196	25	W.	311, 30	Here and	-
Car fills		312	8						Vales.	
Desde (m)	Hasta (m)	Tramo Molido (m)	FF_FINAL	(f/m) 0	GSI_R1	GSI_R2	RMR_B89	RMR1_L90	RMR2_L90	Q'
309	312	1.5		22.67	15	20	39	22	29	0.42

Crushed material of 1,5m that can not be observed.



FF/m calculation

In many database, FF/m is determined as joint total count of borehole length divided for the recovery length. No correction are applied based on dip angle different regarding with the borehole orientation:

$$FF = \sum_{i=1}^{N} FF_i \cos \theta_i$$

There is also corrections if Laubscher (1990) classification system need to be applied.

 TABLE II

 FACTORS TO GIVE AVERAGE FRACTURE FREQUENCY

Sampling procedure	Factor	Average frequency = Sum of individual FF/m (inverse of spacing)
a. One set of three sets on a line, or one set only	1,0	2
b. Two sets of three sets on a line or two sets only	1,5	_
c. All of the sets on a line or borehole core	2,0	
d. Two sets on one line and one on another	2,4	
e. Three sets on three lines at right-angles	3,0	

Desde (m)	Hasta (m)	RECUPERACIÓN (m)	J_30 (f/3m)	J_60 (f/3m)	J_90 (f/3m)	FF (f/m)	FF/m
411	414	3	4	2	0	2	3.03



ė RQD (%) FF/m

ORIGINAL DATABASE

CORRECTED DATABASE



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UCS tests results



PDFs Distribution





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Database Uncertainty





Bedi & Harrison (2012)

Owing to the large number of discontinuities exposed daily in producing open pit mines, a probabilistic approach to evaluating the potential for blocks/wedges to fail is required.

A computer program which uses joints orientation, persistence and spacing statistics must be implemented to develop a probabilistic approach which allows rapid determination of the probability of failure of blocks/wedges for different benches geometries.



By applying the keyblock analysis method of Goodman & Shi (1985) each simulated block can be evaluated to determine whether it is removable from the surrounding rock mass.



Removable blocks in a rock slope

Once a keyblock has been identified, its removability and sliding stability is assessed and accumulated so that the stability of a pit bench can be evaluated.



Random locations of blocks along a bench. Red blocks are unstable (SBlock output)



Bench Berm Design

Joint sets Friction Cohesion Bench and Fault Stack and Bisk Dientation Dientation Spacing Length Dientation Dientation Spacing Length P30 2000 120 61 45 85 P30 2000 120 61 45 85 150 120 240 p P50 1880 220 270 215 278 150 120 240 p F60 830 180 81 65 113 300 240 420 p Random set 00 00 00 00 00 p	Init lets Friction Cohesion Bench and Fault Stack. and Risk Operation Dp of Range Man Max Include? 790 3000 130 81 85 150 120 240 p 650 180 220 220 276 376 150 120 240 p 150 120 240 p 150 120 240 p 150 120 240 p 150 120 240 p 150 120 120 240 p 150 120 240 p 150 120 120 120 p 150 120 140 p 150 121 17 129 150 120 p </th <th>Joint sets Dip [79.0 [77.0 [85.0 [16.0 [46.0 [53.0</th> <th>n Dip dr (300.0 (189.0</th> <th>Range</th> <th>Spacing Mean</th> <th>T</th> <th>Bench</th> <th>and Fault</th> <th>Y</th> <th>Sta</th> <th>ack and Risk</th> <th></th> <th></th> <th></th> <th></th> <th></th>	Joint sets Dip [79.0 [77.0 [85.0 [16.0 [46.0 [53.0	n Dip dr (300.0 (189.0	Range	Spacing Mean	T	Bench	and Fault	Y	Sta	ack and Risk					
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Bench Berm Design

I-Site Calibration

	Dominio 1									
DipDir 170°										
ID	Dip	DipDir								
19	50	153								
20	45	146								
21	58	204								
22	58	134								
23	56	170								
24	56	153								
25	56	148								
26	70	224								
27	58	203								
28	62	213								
29	60	153								
30	58	162								
31	41	157								
32	51	161								
33	51	193								
34	62	180								

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	s s	

Dominio 1 DipDir 150° Dip DipDir ID

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I-Site Calibration (Persistence)





Back-Break calculation



This screen shows the probability of failure expressed as a depth of failure of a bench (SBlock output)

Back-break and spill material or pile of rubble (SBlock output)





Cumulative Distribution for the Bench Widths



90% of the benches will be greater than 9,5 m (SBlock output)

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Bench Berm Design

Calibration



PoF > 30 %



20 % < PoF < 30 %



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Bench Berm Design

Calibration









Calibration







Example of Limit Equilibrium Method (GLE)

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Interramp and Overall Stability Analysis



Montecarlo simulation for calculated the FoS

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Interramp and Overall Stability Analysis



Example of 2D Numerical Modelling Analysis.





Surface Response Method





Acceptability Criteria

		Acceptability Criteria						
Slope Scale	Consequences of	Factor of Safety [FOS]	Factor of Safety [FOS]	Probability of Failure				
·	Failure	(min)	(min)	(max)				
		(Static)	(Pseudo-static)	P[FOS≤1]				
Bench	Low - High	1.1	N/A	25 - 50%				
	Low	Low 1.15 - 1.2		25%				
Inter-ramp	Medium	1.2	1.0	20%				
	High	1.2 - 1.3	1.1	10%				
	Low	1.2 - 1.3	1.0	15 - 20%				
Overall	Medium	1.3	1.1	10%				
	High	1.3 - 1.5	1.1	5%				

READ & STACEY (2009): "GUIDELINES FOR OPEN PIT SLOPE DESIGN".



Risk-based Slope Design Approach



Risk Based Slope Design, Contreras, L.F. (SRK, 2013)





Concept of Probability of Failure of the Slope

Risk Based Slope Design, Contreras, L.F. (SRK, 2013)



Conceptual Basis for estimation of the economic impact of slope failure





Slope Failure Impacts:

- Disruption of planned ore feed to plant.

- Additional costs to restore site.

Failure Impact = NPV_{reference} - NPV_{with failure}

The Economic Risk Map as a Tool for Pit Slope Optimization, Contreras, L.F. (SRK, 2015)



Final Comments



Example of Construction of the economic risk envelope for year 2019. a) Probability distribution graphs. b) risk map result.

An Economic Risk evaluation approach for pit slope optimization, Contreras, L.F. (2015)



Risk Acceptability Matrix for Economic Impact

	Level	Range M\$		Ri	sk Catego	ory	
	5	> 200	н	н	н	н	н
act	4	100 - 200	м	м	н	н	н
dml	3	50 - 100	L	м	М	м	н
2		10 - 50	L	L	L	м	м
	1	< 10	L	L	L	L	L
		Range %	<10%	10-20%	20-50%	50-80%	>80%
		Level	1	2	3	4	5
				Likeliho	bod		

An Economic Risk evaluation approach for pit slope optimization, Contreras, L.F. (2015)



Economic Risk Map Example



