OptimalSlope: a software to determine optimal pitwall shapes which maximises mining financial returns while minimising carbon footprint

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Introduction: the overall steepness of the pitwalls of an open pit mine has a massive influence on the financial return of the mine. A novel design methodology is here proposed so that overall steeper pitwalls are employed without compromising the safety of the mine.
In current practice pitwall profiles are planar in cross-section. Here, a new geotechnical software, OptimalSlope, is employed to determine depth varying optimal pitwall profiles for each slope sector of the mine. OptimalSlope seeks the solution of a mathematical optimization problem where the overall steepness of the pitwall, *i.e.* crest to toe, is maximized for an assigned stratigraphy, rock properties and Factor of Safety (FoS). Bench geometries (bench height, face inclination, minimum width) are imposed into the optimization as constraints which bind the

maximum local inclination of the sought optimal profile together with any other constraint due to any geological discontinuities that may influence slope failure. The optimal profiles are always steeper than their planar counterparts (*i.e.* the profile exhibiting the same FoS), generally up to 8 degrees depending on rock type and constraints.

To showcase the financial gains that can be realized thanks to OptimalSlope the design of a Chilean copper mine is first carried out for planar pitwalls; second for optimal pitwall profiles around 2 degrees steeper determined by OptimalSlope.

Methodology: the copper deposit employed as case study is a real deposit provided by a mining company collaborating with the Delphos Mine Planning Laboratory of the University of Chile. Given the geotechnical properties of the rock and the stratigraphy, two roughly uniform slope sectors can be identified. In each pit sector, one representative cross section is assumed to design the pitwall profile. The rock geotechnical parameters are reported in table 1. The values adopted for the economic parameters and metallurgical recovery together with the discount rate assumed are listed in Table 2.

Table 1 Rock geotechnical properties

	Uniaxial Compressive Strength (UCS) [MPa]	**Geological Strength Index (GSI) [-]**	**mi [-]**	**Damage factor (D) [-]**	γ **[kN/m3]**
Pit sector 1	65	45	15	1	25.9
Pit sector 2	50	45	12	1	25.9

Table 2 Economic parameters and metallurgical recovery

Copper price [USD/lb]	3
Selling cost [USD/lb]	0.85
Reference mining cost [USD/t]	3.4
Processing cost [USD/t]	6.1
Metallurgical recovery [%]	85
Mining Cost Adjustment Factor [USD/bench]	0.13
Discount rate (%)	10
Processing method limit [mtpy]	5
Mining limit [mtpy]	10

The procedure to calculate the Ultimate Pit Limit (UPL) and pushbacks is the same irrespective of the shape of the pitwall profile adopted, *i.e.* planar or optimal profile. We calculated the representative pitwall profiles for the specified pit depth in each sector: in case of planar pitwalls employing stability charts whereas for optimal pitwalls employing Optimal Slope. Then we assigned the pitwall profiles into the pit optimizer (Geovia Whittle 4.7.3) and ran it to produce the UPL.

Results and Conclusions: the pitwall profiles obtained as result of the pit design process performed are plotted in Figure 1. The Factor of Safety of all the pitwall profiles were verified by performing a Limit Equilibrium (LE) analysis with the Morgenstern-Price method in Slide 2. In all the cases the FoS found is less than 1 % from the target value of 1.3. This is an important verification by an independent geotechnical software that the pitwall profiles found by Optimal Slope are as safe as the planar ones.

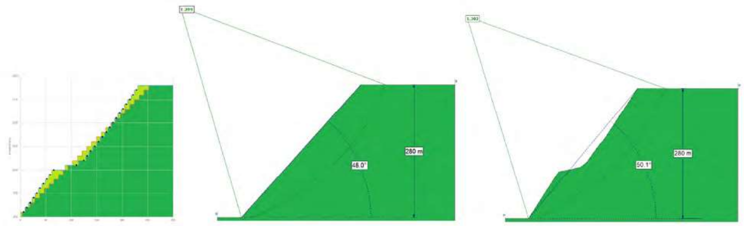

Figure 1 UPL pitwalls for sector 1: a) comparison between the pitwall profile for the traditional design (planar pitwall is in blue) and the optimal design (optimal pitwall is in orange, the black dots represent the coordinates obtained as output from Optimal Slope); b) failure mechanism and FoS determined by LE analysis of Slide 2 for the planar profile; c) failure mechanism and FoS determined by LE analysis of Slide 2 for the optimal profile (the black dots represent the coordinates obtained as output from Optimal Slope)

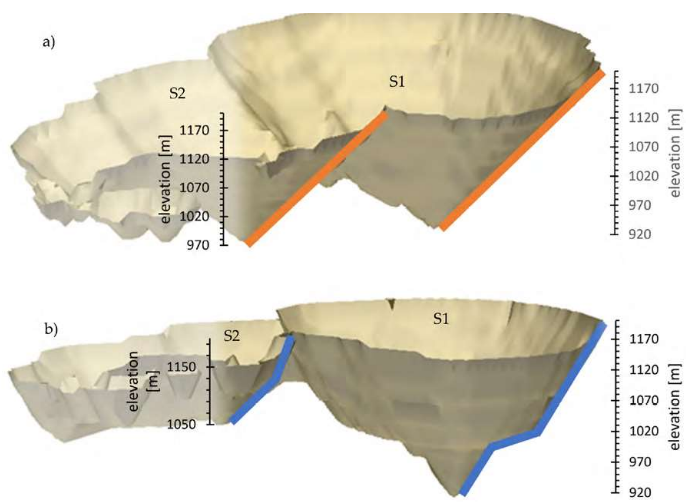

Figure 2 Ultimate Pit Limit of a) case of traditional design b) case of optimal profile. The UPL is a multi-pit shell with two different pit bottoms, one for each pit sector.

In Figure 2a and 2b are plotted the 3D views of the Ultimate Pit Limits obtained for the traditional design based on planar pitwall and for the design based on optimal pitwalls respectively. In both cases a multi-pit shell made by roughly two conical shapes, one per mine sector, is obtained.

Table 3 Pit optimization economic and metallurgical results

UPL output	**Planar pitwalls**		**Optimal pitwalls**	
	S1	**S2**	**S1**	**S2**
Overall Slope Angle [deg]	48	43.8	50.1	51.3
HUPL [m]	270	220	280	150
Waste [tonnes]	23,707,500		20,651,462	
Ore [tonnes]	59,314,446		59,232,285	
NPV [USD]	34,561,747		46,231,284	
Internal Rate of Return [%]	13.9		15.8	
Life [year]	12.22		12.12	
Payback [year]	3.89		3.57	
NPV increase [%]	**33.8**			

In Table 3 the key output data for the two design cases are provided. The Net Present Value (NPV) for the design based on optimal pitwalls is around 12 $ million higher than the NPV of the design based on planar pitwalls so leading to an increase of 34 % over the traditional design. This increase can be attributed mainly to a very substantial decrease of rockwaste of about 15 %, whilst the amount of orebody extracted is similar.