Application of Synthetic Nets as an Enabler of Optimised Pit Slopes at Skorpion Zinc Mine

Amory Mumba[1] and Bunda Besa[2](✉)

[1] Skorpion Zinc Mine, Rosh Pinah, Namibia
[2] School of Mines, The University of Zambia, P.O. Box 32379, Lusaka, Zambia
bbesa@unza.zm

Abstract. Pit slope optimization is a fundamental design requirement for open pit mines. Several input parameters are incorporated into the slope design process including the slope angle, commodity price, recoveries and equipment size among others. The quality of the rock mass determines how steep the slopes should be designed for a safe and economic open pit mine. Despite rigorous efforts to optimize pit slopes, rock falls from extremely poor zones still occur. A complex and highly heterogeneous rock mass at Skorpion Zinc mine presents a challenge in steepening the hanging wall slopes for maximum resource recovery; competent limestone rock hosts intrusions and shear zones with extremely weathered sheared sericite schists. These ground conditions have resulted in significant rock falls from shear zones onto existing ramps and often-disrupting production. This paper presents how synthetic high wall safety nets have been applied at Skorpion Zinc mine in optimizing the pit slope angles, reducing clean-up cost and enhancing safety. Slope Stability analysis, using Rocscience software, was conducted on interim pit designs, incorporating angles of slopes with and without safety nets. Results show that the slopes were more stable when covered with synthetic nets than the ones left without support. Hence, the hanging wall inter-ramp slope angles were increased from the actual slope angle of 54° to 61° with an optimal angle being 61°. At this optimal slope angle, Probability of Failure (PoF) of <25% and Factor of Safety (FoS) of 1.2, there is a cost-saving of 8.42% of the total waste stripping i.e., a saving of US $9.6 m. The use of synthetic nets has therefore, enhanced the confidence in optimizing pit slope angles and justified the application in rock fall management at Skorpion Zinc Mine.

Keywords: Optimisation · Skorpion Zinc mine · Slope stability analysis · Rockfall · Synthetic net

1 Introduction

1.1 Location and General Open Pit Layout

Skorpion Zinc Mine is located in Southern Namibia, approximately 50 km north of the Orange River and 25 km north of Rosh Pinah. The mine is located in the Gariep Belt and is an oxide Zinc deposit (Fig. 1).

E. Topal (Ed.): MPES 2019, SSGG, pp. 488–498, 2020.
https://doi.org/10.1007/978-3-030-33954-8_55

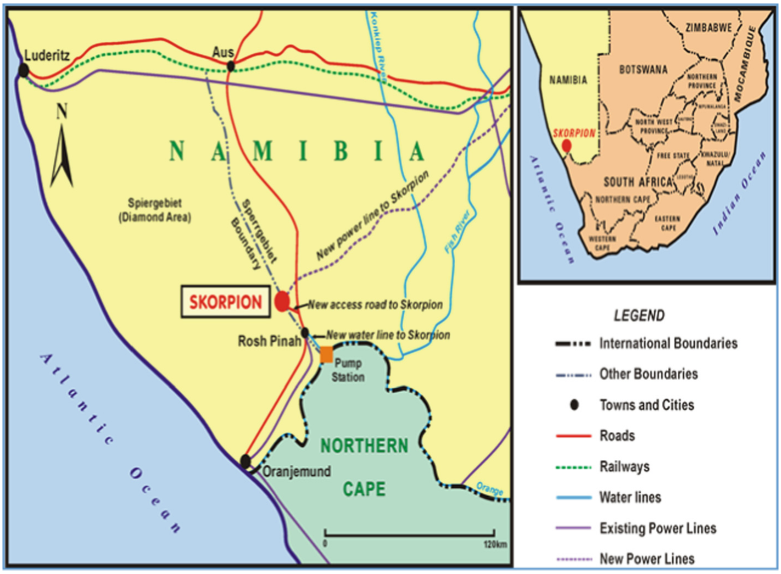

Fig. 1. Location of Skorpion Zinc Mine

With mining having commenced in 2002, the current open pit is deep and has progressed to the 26th bench from surface (i.e. 260 m depth, Fig. 2). The planned depth of the open pit is 310 m, which is based on a life of mine of approximately 2 years. Rock types hosting the ore deposit include volcaniclastic and clastic sediments (felsic tuff, arkose, sandstone, shale, schist, etc.), limestone and rhyolite. The volcaniclasic sediments have been strongly altered during metamorphism and hydrothermal alteration events, and all are deeply weathered.

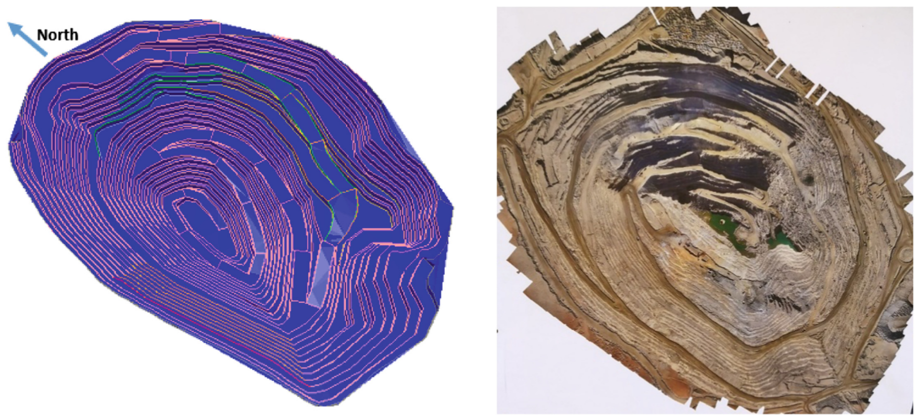

Fig. 2. Skorpion Zinc open pit mine

High-wall instability is considered as one of the largest safety risks at Skorpion Zinc open pit mine. No physical barrier exists between the potential hazard (loose rocks) and human interaction. The area at the base of the high-wall is a high-risk area due to the impact of unreleased potential energy (fall of ground material). When rocks unravel from the top of the high-wall due to slumping or blast vibrations, they pick up speed and increase in velocity, thus become projectiles that can potentially injure people or damage equipment on the lower benches and/or haul ramps. With this background, high wall synthetic safety net installation project was proposed and implemented in October 2018 (Fig. 3).

Fig. 3. Installation of high wall synthetic safety nets

This paper presents how synthetic high wall safety nets have been applied at Skorpion Zinc mine in optimizing the pit slope angles, reducing clean-up cost and enhancing safety. Slope stability analysis, using Rocscience software (SLIDE 2018) [1], was conducted on interim pit designs, incorporating angles of slopes with and without safety nets.

1.2 Geological Setting

The geological model consists of lithological units distinguished by the mine and include, Banded Siltstone-Sandstone-arkose (BSA), Sericite schists, Quartz sericite schist (QSS), Black argillaceous unit and Limestone (including a siliciclastic marker horizon). Many of the lithological units described in the mine are locally interbedded and contacts are gradational.

1.3 Current Geotechnical Issues

A complex and highly heterogeneous rock mass at Skorpion Zinc mine presents a challenge in steepening the hanging wall slopes for maximum resource recovery and reduced waste stripping; competent limestone rock hosts intrusions and shear zones with extremely weathered sheared sericite schists. These ground conditions (high heterogeneity) have resulted in significant rock falls from shear zones onto existing ramps and often-disrupting production and incurring clean-up costs up to 80% of unplanned/unscheduled works. Ongoing monitoring of wall conditions using the Movement and Surveying Radar (MSR) and survey prism monitoring is utilized in managing production and safety risk in affected zones. High wall synthetic safety nets as a failure management strategy have also been applied.

1.4 Pit Slope Optimisation

The term "optimisation" is derived from mathematics, particularly mathematical programming and basically refers to the study of problems in which one seeks to maximise or minimise some function. This approach may use a "heuristic" algorithm to arrive at a near optimal solution. Simply put, a heuristic is a problem solving technique in which the most appropriate solution of several, found by alternative methods, is selected at successive stages. The concept of optimisation in mining was first applied in the 1960s to pit design and addressed the problem of determining the optimal pit outline based on given technical and economic data. In the last decades of the 20th century, the growing processing power of computers has made possible to apply a number of methods for the determination of ultimate pits. These methods are: Lerchs-Grossmann method [2, 3], network or maximal flow techniques [4, 5], floating cone method [6, 7] the Korobov algorithm [8], the corrected form of the Korobov algorithm [9], parameterization techniques [4, 10] and dynamic programming method [11–15], which assumptions and algorithms determine the today's direction of the design in open pit mining. The algorithms of the above-counted methods are the core of the programs which are used in the computer designing methods. The main goal of these methods, almost all of which are based on block models, is the optimal open pit outline with the steepest dip of the final slopes under technological and physical constraints, and minimal costs of mining desirable blocks, in other words, the maximum net profit. The complexity of the geological conditions of a deposit and dynamism of the economic indicators define the choice of the most adequate method of design for the mining operation [16]. During the study of pit slope optimization at Skorpion Zinc mine i.e., with or without synthetic safety nets, the cross section through a rockfall prone zone as shown in Fig. 4 was used for the analysis.

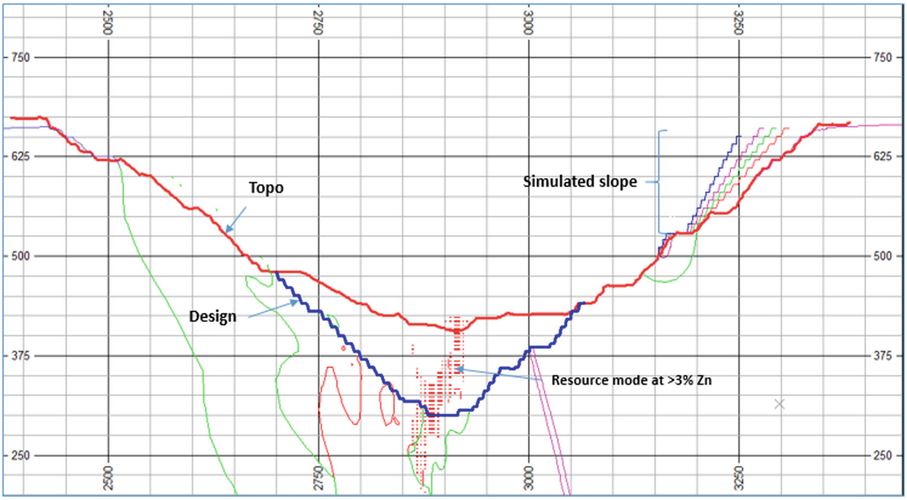

Fig. 4. Representative section across area of concern

1.5 Stability Analysis

Slope stability analysis was conducted to understand the effect of modifying slope angles in order to achieve safe and economic pit slopes. A sensitivity analysis was conducted using a Rocscience software (SLIDE 2018) [1] which uses Limit Equilibrium Algorithms to determine the factors of safety and probability of failure. The method used in the analysis is the Bishop's simplified method. In this method, circular slip surfaces are examined, and the one rendering the lowest safety factor is selected [17].

The shear strength parameters were obtained from the Skorpion Zinc Mine geotechnical database. Tables 1 and 2 present the input parameters used in the analysis while Figs. 5 and 6 show snapshots of the SLIDE 2018 [1] model used in the stability analysis. The Arkose (ARK) material analysed is a Calcerous greywacke while LMST is an altered carbonate with calcerous arenite.

Table 1. Input parameters used in the stability analysis with SLIDE 2018

Name	Property	Distribution	Mean	Std. Dev.	Rel. Min	Rel. Max
ARK	Cohesion (kPa)	Normal	43	28.2843	43	180
ARK	Phi (°)	Normal	30.914	2.8284	8	31
ARK	Unit weight (kN/m^3)	Normal	20	0.39156	19	30.3
LMST	Cohesion (kPa)	Normal	12235	2.8	12235	13200
LMST	Phi (°)	Normal	32	1	25	36
LMST	Unit weight (kN/m^3)	Normal	25	1.2	18	24

Table 2. Safety net properties

Support type	End anchored
Force application	Active
Force orientation	Parallel to reinforcement
Out of plane spacing	1 m
Anchor capacity	100 kN

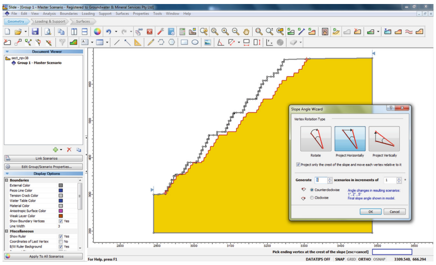

Fig. 5. Snapshot of the Slide 2018 model used in the stability analysis

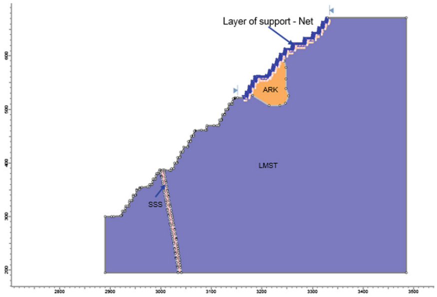

Fig. 6. The actual model used for stability analysis

The slope stability evaluation was carried out for one sector that is prone to rock falls and is supported by high wall synthetic safety nets. Tables 3 and 4 as well as Figs. 7 and 8 show results obtained from SLIDE 2018 [1] models.

Table 3. Stability analysis results from SLIDE 2018 – slope without net

Slope angle (°)	FoS	PoF
54	1.32	9.2
56	1.29	10.6
58	1.24	14.7
60	1.18	23.9
62	1.08	38.3
64	1.01	50.7
66	0.91	68.0

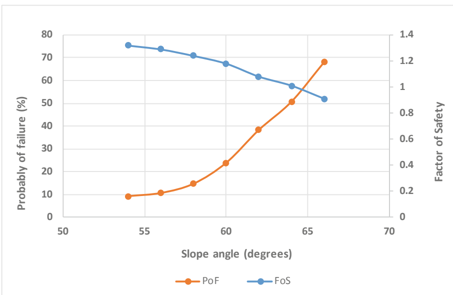

Fig. 7. Probability of failure versus factor of safety without synthetic safety nets

Table 4. Stability analysis results from SLIDE 2018 – slope with net

Slope angle (°)	FoS	PoF
54	1.48	3.9
56	1.319	8
58	1.295	10
60	1.273	11.7
62	1.121	27
64	1.034	36
66	0.966	52

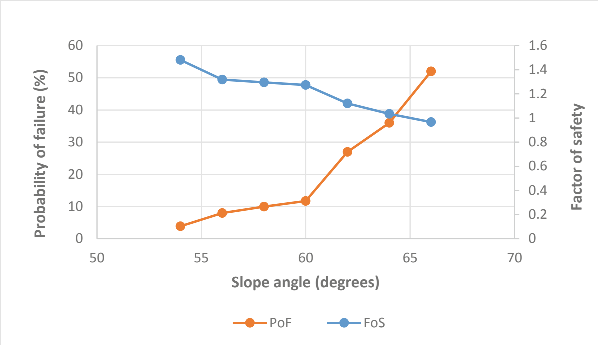

Fig. 8. Probability of failure versus factor of safety without synthetic safety nets

The determination of the acceptable slope angle for open pits is a key aspect of the mining business, as it implies seeking the optimum balance between the additional economic benefits gained from having steeper slopes, and the additional risks resulting from the reduced stability of the pit slopes [18]. The difficulty in determining the acceptable slope angle is related to geological uncertainties within the rock mass. These uncertainties are accounted for in the process of slope design and different methodologies have been used for this purpose. This paper reviews three acceptability criteria successfully applied at some mines and adopted at Skorpion Zinc. The three design acceptability criteria were adopted as a guide in optimizing the pit slopes. These are presented in Tables 5, 6 and 7.

Table 5. Slope design acceptability criteria – 1 [19]

Criteria	Type of slope	Consequence of failure	Acceptability Values	
			FoS	PoF (FoS<1.5)
1	Individual Benches: small (50m) temporary slopes not adjacent to haulage roads	Not Serious	1.3	20%
2	Any slope of a permanent or semi-permanent nature	Moderately serious	1.6	10%
3	Medium sized (50 -100m) and high slopes (<150m) carrying major haul roads or underlying permanent mine installations	Very serious	2	5%

Note; The actual criteria used at Skorpion Zinc mine is subject to a more thorough analysis of the consequences of failure.

Table 6. Slope design acceptability criteria – 2 [20]

Category	Description	Acceptable PoF
1	Critical slopes where failure may affect continuous operations and pit safety	<5%
2	Slopes where failures have a significant impact on costs and safety	<15%
3	Slopes where failure has no impact on costs and where minimal safety hazards exist	<30%

Table 7. Slope design acceptability criteria – 3 [21]

Slope Scale	Consequence of failure	FoS	PoF [Fos<1]
Bench	Low-High	1.1	25%-50%
	low	1.15-1.2	25%
Inter-ramp	Medium	1.2	20%
	High	1.2-1.3	10%
	Low	1.2-1.3	15%-20%
Overall	Medium	1.3	5%-10%
	High	1.3-1.5	<5%

1.6 Acceptability Criteria and Optimal Pit Slope

The shaded cells in Tables 5, 6 and 7 relate to Skorpion Zinc mine current assessment of the acceptability criteria that was applied to the Pit slopes. The probabilities of failure associated with acceptability criteria are in the range of 10%–25%. The corresponding factors of safety lie between 1.2 and 2.6. The slope performance with respect to acceptability criteria for Skorpion Zinc mine is presented in Tables 8 and 9. The unsupported slopes exceeded the minimum factor of safety and the PoF. However, the operation of the slope presented a risk that may have been unacceptable. Therefore, additional restraint to the slope and a comprehensive monitoring programme was implemented to reduce the risk level to within acceptable levels.

Table 8. Summary of acceptability criteria

Design	FoS (Supported)	PoF (%) (Supported)	FoS (Unsupported)	PoF (%) (Unsupported)	Compliance with acceptability criteria	
					FoS	PoF
54	1.48	3.9	1.32	9.2	Compliant	Compliant
56	1.319	8.0	1.29	10.6	Compliant	Compliant
58	1.295	10.0	1.24	14.7	Compliant	Compliant
60	1.273	11.7	1.18	23.9	Compliant	Compliant
62	1.121	27	1.08	38.3	noncompliant	noncompliant
64	1.034	36	1.011	50.7	noncompliant	noncompliant
66	0.966	52	0.91	68		

Table 9. Slope performance criteria

Criteria	Performance of slope with respect to acceptability criteria	Interpretation
1	Satisfies all three criteria	Stable slope
2	Exceeds minimum mean factor of safety but violets one or both probabilistic criteria	Operation of slope presents risk that may or may not be acceptable; level of risk can be reduced by comprehensive monitoring programme.
3	Falls below minimum mean FoS but satisfies both probabilistic criteria	Marginal slope; minor modifications of slope geometry required to raise mean FoS to satisfactory levels.
4	Fall below minimum mean FoS and violates both probabilistic criteria.	Unstable slope; major modifications of slope geometry required; rock improvement and slope monitoring may be necessary.

At FoS 1.2, Fig. 9 shows the optimal pit slope angle at Skorpion Zinc mine without application Synthetic safety net while Fig. 10 shows the optimal pit slope angle after application of Synthetic safety net.

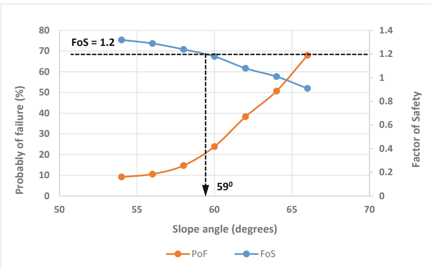

Fig. 9. Optimal pit slope angle without Synthetic safety net.

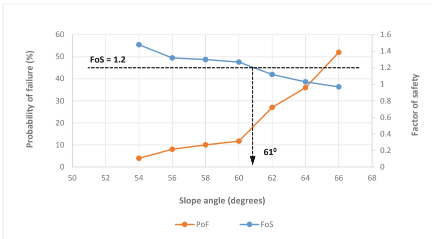

Fig. 10. Optimal pit slope angle after application of Synthetic safety net.

As can be seen from Figs. 9 and 10, at FoS of 1.2, the optimal pit slope for Skorpion Zinc mine improved from 54° to 61°. This is a huge improvement in terms of economic benefits of the pit.

1.7 Cost Analysis

Figure 11 shows the cost analysis for the use of synthetic safety nets versus non-use of the nets at Skorpion zinc mine. According to the figure, there is a US$9.6 m reduction in the total cost of clean-up operations when synthetic safety nets are used in pit design representing approximately 8.42% reduction.

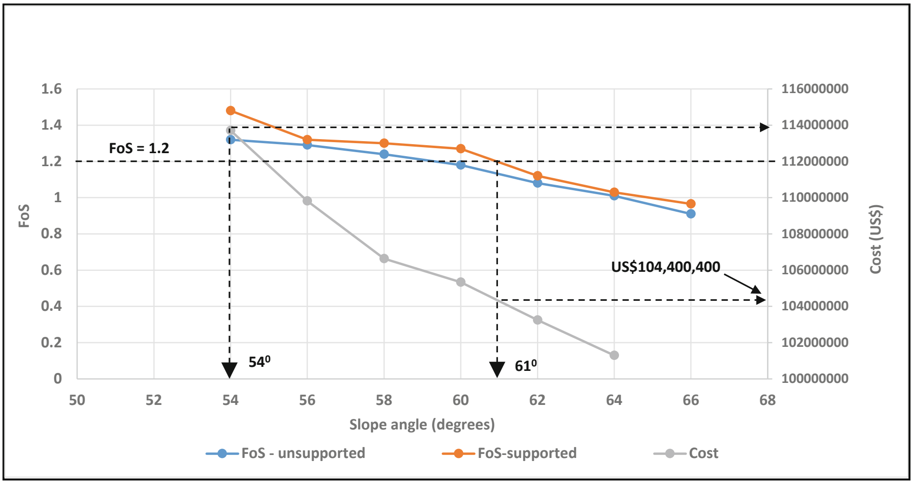

Fig. 11. Cost analysis for the use of synthetic safety nets versus non-use of the nets.

1.8 Conclusion and Recommendations

Results show that the slopes were more stable when covered with synthetic nets than the ones left without support. Hence, the hanging wall inter-ramp slope angles were increased from 54° to 61°. At optimal slope angle i.e. 61°, PoF of <25% and FoS of 1.2, there is a cost saving of 8.42% of the total waste stripping (i.e., US$9.6 m). The use of synthetic nets has, therefore, enhanced the confidence in optimizing pit slope angles and justified its application in slope management at Skorpion Zinc Mine. It was, recommended that all identified potentially unstable zones should be covered with high wall synthetic nets to maximise the slope angle and enhance safety.

References

1. Rocscience Inc.: Slide Version 8.0 - 2D Limit Equilibrium Slope Stability Analysis, Toronto, Ontario, Canada (2018). https://www.rocscience.com
2. Alford, G.G., Whittle, J.: Application of Lerchs-Grossman pit optimisation to the design of open pit mines. In: Open Pit Mining Conference, Calgary, Canada, pp. 201–207 (1986)
3. Lerchs, H., Grossmann, I.F.: Optimum design of open pit mines. CIM Bull. **58**, 47–54 (1965)
4. François-Bongarçon, D., Guibal, D.: Algorithms for parameterizing reserves under different geometrical constraints. In: Proceedings of 17th Symposium on the Application of Computers and Operations Research in the Mineral Industries (APCOM: AIME), New York, pp. 297–230 (1982)
5. Yegulalp, T.M., Arias, J.A.: A fast algorithm to solve the ultimate pit limit problem. In Proceedings of 23rd Symposium on the Application of Computers and Operations Research in the Mineral Industries (APCOM: AIME), Littleton, Colorado, pp. 391–397 (1992)

6. Berlanga, J.M., Cardona, R., Ibarra, M.A.: Recursive formulae for the floating cone algorithm. In: Mine Planning and Equipment Selection, Rotterdam, Netherlands, pp. 15–25 (1988)
7. Lemieux, M.: Moving cone optimizing algorithm. In: Weiss, A. (ed.) Computer Methods for the 80 s in the Mineral Industry, AIME, New York, pp. 329–345 (1979)
8. Korobov, S.: Method for determining optimal open pit limits. Ecole Polytechnique de l'Université de Montréal, Montreal, Technical report EP74-R-4, p. 24 (1974)
9. Dowd, P.A., Onur, A.H.: Open-pit optimization—part 1: optimal open-pit design. Trans. Inst. Min. Metall. (Sect. A: Min. Ind.) **102**, 95–104 (1993)
10. Matheron, G.: Paramétrage des contours optimaux (Centre de Géostatistique et de Morphologie mathématique), Internal report N-403; Note géostatistique 128, Fontainebleau, p. 54 (1975)
11. Johnson, T.B., Sharp R.W.: A three-dimensional dynamic programming method for optimal ultimate open pit design. Bur. Min. Invest. 7553 (1971)
12. Koenigsberg, E.: The optimum contours of an open pit mine: an application of dynamic programming. In: APCOM, New York, vol. 17, pp. 274–287 (1982)
13. Wilke, F.L., Wright, E.A.: Determining the optimal ultimate pit design for hard rock open pit mines using dynamic programming. Erzmetall **37**, 139–144 (1984)
14. Wright, A.: The use of dynamic programming for open pit mine design, some practical implications. Min. Sci. Technol. **4**, 97–104 (1987)
15. Yamatomi, J., et al.: Selective extraction dynamic cone algorithm for three-dimensional open pit designs. In: Proceedings of 25th Symposium on the Application of Computers and Operations Research in the Mineral Industries (APCOM) (Australasian Institute of Mining and Metallurgy), Brisbane, pp. 267–274 (1995)
16. Galić, I.: Mining design using specialized software, Master's thesis, Faculty of Mining, Geology and Petroleum Engineering, Zagreb, p. 95 (2002). (in Croatian)
17. Zhenhua, H., Seifollar, N.: Understanding and optimizing the geosynthetic-reinforced steep slopes **19**, 5802 (2014). Texas, USA (2015)
18. Terbrugge, P., et al.: A risk evaluation approach for pit slope design, Johannesburg, South Africa (2008)
19. Priest, S.D., Brown, E.T.: Probabilistic stability analysis of variable rock slopes. Trans. Inst. Min. Metall. Sect. A: Min. Ind. **92**, A1–12 (1983)
20. SRK Consulting: Acceptable probabilities of failure, mining rock slopes (Fitwaola report) (2011)
21. Read, J., Stacey, P. (eds.): Guidelines for Open Pit Slope Design, CSIRO Publishing (2009)