Iranian Journal of Engineering Geology
Autumn 2022, Vol.15, No.3

Dynamic stability analysis of rock-slopes of the Sungun mine using equilibrium and numerical methods

Gh. Barzegari[1*], M. Fathi[2]

Abstract

In this paper, stability analysis of the slopes on Sungun mine was investigated. Sungun mine located in East Azerbaijan province, 45 km north of Varzaghan city. In order to investigate the stability coefficient and the rate of displacement on the slopes, three sections were selected and analyzed by numerical and equilibrium methods using SLIDE and UDEC models. The results showed that the coefficient of slope stability against failure in static conditions is more than 1.4 and in dynamic conditions with cosidering of the design based acceleration (DBA) of 0.35 g, it will be in the range of 0.92 to 1.2. In the case of applying acceleration of 0.42 g, the safety coefficient decreased to 0.8 and 1.05 and in most of the mine area, especially by Janbu method, it will be less than 1 and occurance of instability in wide range of the studied mine area is possible. However, in the extraction benches even with the application acceleration of 0.35 g, a limited chance of failure is possible. Based on the numerical analysis results, the displacements in the western part of the mine (downstream of the mine slopes) are generally higher than the eastern part of the mine. The maximum dynamic displacement in DBA of 0.42 g will be happen at section 2 (middle part of the mine) with the amount of more than 40 cm. In the entire of the mine area, the occurrence of toppling failure is dominant.

Keywords: *Slope stability, Rock slopes, Limit equilibrium, Numerical analysis, Sungun mine*

[1] Associate Professor, Department of Earth Sciences, University of Tabriz, Tabriz, Iran
[2] MSc., Department of Earth Sciences, University of Tabriz, Tabriz, Iran
* Corresponding Author

Extended Abstract:

1. Introduction

Since the behaviour of a rock mass depends more on discontinuities and the presence of discontinuities has a great impact on the stability of rocks, therefore mainly numerical methods (finite element, discrete element and combined) is using to stresses analysis. Numerical modelling is an efficient method that is widely used in rock engineering (Bakhtiyari et al., 2017). The most common method of slope stability analysis is the equilibrium method. This method is used to evaluate the stability of slopes in two modes with structural control (plane, wedge and toppling failure) and non-structural control (circular or spoon failure). The result of each equilibrium method is a function of the degree of accuracy applied to the selected hypotheses of that method (Qian et al., 2017).

Extensive studies have been conducted by various researchers to investigate the instability of rock slopes and failures by various methods, among them, Barzegari and Fathi (2018) have zoned the failure potential of rock slopes of Sungun mine using rock mass score (SMR) and analytical hierarchical analysis (AHP). Zheng et al. (2021) have studied the rock slope of the Taiping mine in south-western Mongolia. Azarafza et al. (2020a) have studied the stability of discontinuous rock slopes under structural fractures based on wedge and planar failure scenarios using fuzzy key block analysis algorithm. Azarafza et al. (2020b), in another study, also examined the discontinuous rock slope located in the sixth phase of the South Pars gas complex based on the KGM algorithm (key group method) and compared the results obtained from the model with UDEC software. Sarfaraz and Amini (2020) have modelled toppling failures on rocky slopes using UDEC and Phase2. Comparison between two numerical modelling showed that UDEC software provides better results than Phase2 software. Meng et al. (2021) have studied the performance of pre-stressed cables to reinforce rock slopes using software (UDEC). In this study, they analysed the reaction of armed and unarmed rock slopes against dynamic force, as well as the effect of cable slope and distance on stability results. Azhari (2012) has investigated the stability of tectonic blocks of Choghart mine under earthquake loading. Huang (2014) evaluated the safety factor of the slopes against failure in the Sindak open pit mine. Soren et al. (2014) have investigated the slope stability of open pit mines using the finite element method. Lana (2014) have studied the failure mechanism in the slopes of the Fileti mine in Brazil using numerical modelling.

In this study, the stability coefficient of the slopes of Sungun mine has been studied using equilibrium methods (Bishop and Janbu methods) and numerical analysis with SLIDE and UDEC modelling based on the acceleration due to design basis earthquake of faults in the region.

2. Materials and Methods

In this paper, the dynamic stability of rock slopes of Sungun mine has been investigated by limit equilibrium and numerical analysis. The study area is located in the tectonic-sedimentary zone of Azerbaijan. The faults of the region are mainly compressive mechanisms and sometimes have a strike-slip component and are of great importance from a tectonic seismic point of view. According to the latest earthquake risk zoning map, Ahar and Varzeqan cities are among the areas with relatively high risk, which the design basis acceleration of the area is 0.35 g.

In slopes stability analysis using equilibrium method, the factor of safety determined based on the ratio of shear strength on slip surfaces to shear stress required to occurrence of failure. This ratio depends on various parameters and its value reducing through the impact of pore pressure and earthquake acceleration. Failure occurs when the driving force component overcomes the resisting forces. Due to interaction of slope face and discontinuities dip and strike, joint density, alteration and low strength of the rock mass, as well as planar, wedge and toppling failures, there is also the potential for circular failure in some of the mine slopes. In this study, limit equilibrium stability analysis was performed using Bishop and Janbu methods. In order to stability analysis, three critical section in the mine area were considered so that they are perpendicular to the slope and includes all geological structures. Based on the available evidence and hydrogeological studies, the coefficient of pore water pressure in the rock mass is considered between 0.1 to 0.15 bar and in saturated conditions this value is taken about 0.5 bar. The seismic acceleration based on the earthquake hazard map and the maximum possible acceleration of faults in the project area, is obtained 0.35 and 0.45 m/s^2 respectively. In numerical analysis, Mohr-Coulomb criteria was applied and the shear strength parameters were determined using Hock-Brown criteria and Roclab software.

3. Results

The results of equilibrium analysis show that the factor of safety against failure in the static state is more than 1.4. The results showed that in the case of applying the base acceleration equal to 0.35 g, the coefficient of stability in all three sections of mine area is in the range between 0.92 to 1.2. In this case, the minimum safety factor of 0.92 and 0.95 have been obtained for sections 2 and 3, respectively, using Janbu method. In the state of applying base acceleration equal to 0.42 g, the factor of safety in both Janbu and Bishop will be in the range of 0.8 and 1.05 in all sections, and occurance of failure in almost the entire mine area is expected. The results show that the safety factor obtained in Bishop method are slightly higher than Janbu method.

The results obtained from numerical analysis in dynamic conditions show that in the section 1 at the northwestern part of the mine area, the maximum displacement will be happen in benches about 12 and 35 cm and in the surface areas of the slope is about 9 and 30 cm. Also in the northeastern part of the mine, the maximum displacement in benches is about 8 and 28 cm and in surface areas is about 7 and 25 cm. The results of section 2 in the middle-west part of the mine, showed that the maximum displacement in benches is 18 and 73 cm and in the surface areas of the slope is about 15 and 60 cm. Maximum displacement in the middle-eastern part of the mine, in benches will be 16 and 50 cm, and in the surface areas of the slope will be 15 and 45 cm. The results of numerical analysis of the section 3 in the southwestern part of the mine, indicate that the maximum displacement in benches is 15 and 50 cm, and in the surface areas of the slope, is about 12 and 40 cm. Also in the southeastern part of the mine, the maximum displacements in benches is 14 and 45 cm and in the surface areas of the slope will be about 13 and 35 cm.

4. Conclusion

The results showed that the coefficient of slope stability against failure in static conditions is more than 1.4 and in dynamic conditions with cosidering of the design based acceleration (DBA) of 0.35 g, it will be in the range of 0.92 to 1.2. In the case of applying acceleration of 0.42 g, the safety coefficient decreased to 0.8 and 1.05 and in most of the mine area, especially by Janbu method, it will be less than 1 and occurance of instability in wide range of the studied mine area is possible. However, in the extraction benches even with the application acceleration of 0.35 g, a limited chance of failure is possible. Based on the numerical analysis results, the displacements in the western part of the mine (downstream of the mine slopes) are generally higher than the eastern part of the mine. The maximum dynamic displacement in DBA of 0.42 g will be happen at section 2 (middle part of the mine) with the amount of more than 40 cm. In the entire of the mine area, the occurrence of toppling failure is dominant.

References:

Barzegari, G., Fathi, M., 2018. Zonation of Rock-Slope Failure Potential of Sungun Copper Mine Based on SMR and Analytic Hierarchy Process (AHP). Journal of Iranian Association of Engineering Geology, 11(2): 99-113.

Azarafza, M., Akgün, H., Feizi-Derakhshi, M.R., Azarafza, M., Rahnamarad, J. and Derakhshani, R., 2020a. Discontinuous rock slope stability analysis under blocky structural sliding by fuzzy key-block analysis method. Heliyon, 6(5): 03907.

Azarafza, M., Akgün, H., Ghazifard, A. and Asghari-Kaljahi, E., 2020b. Key-block based analytical stability method for discontinuous rock slope subjected to toppling failure. Computers and Geotechnics, 124: p.103620.

Azhari, A., Yarahmadi, A., and Faramarzi, L., 2012. Dynamic analysis of tectonic blocks 1 and 2 of Choghart Open-Pit mines under earthquake. in 9th International Congress on Civil Engineering, Isfahan, Iran.

Bakhtiyari, E., Almasi, A., Cheshomi, A., & Hassanpour, J., 2017. Determination of shear strength parameters of rock mass using back analysis methods and comparison of results with empirical methods. European Journal of Engineering Research and Science, 2(11): 35-42.

Bednarczyk, Z., 2017. Slope stability analysis for the design of a new lignite open-pit mine. Procedia engineering, 191: 51-58.

Huang, Y. H., 2014. Slope stability analysis by the limit equilibrium method: Fundamentals and methods. American Society of Civil Engineers.

Lana, M.S., 2014. Numerical modeling of failure mechanisms in phyllite mine slopes in Brazil. International Journal of Mining Science and Technology, 24(6): 777-782.

Meng, Z., Hou, Y., Guo, L., Wang, F., Liu, K., Qi, G. and Ma, J., 2021. Discrete element simulation analysis of the bending and toppling failure mechanisms of high rock slopes. Geofluids, 2012 (84):1-12.

Qian, Z. G., Li, A. J., Lyamin, A. V., & Wang, C. C., 2017. Parametric studies of disturbed rock slope stability based on finite element limit analysis methods. Computers and Geotechnics, 81: 155-166.

Sarfaraz, H. and Amini, M., 2020. Numerical simulation of slide-toe-toppling failure using distinct element method and finite element method. Geotechnical and Geological Engineering, 38(2): 2199-2212.

Soren, K., Budi, G., & Sen, P., 2014. Stability analysis of open pit slope by finite difference method. International Journal of Research in Engineering and Technology, 3(5): 326-334.

Zheng, Y., Wang, R., Chen, C., Sun, C., Ren, Z. and Zhang, W., 2021. Dynamic analysis of anti-dip bedding rock slopes reinforced by pre-stressed cables using discrete element method. Engineering Analysis with Boundary Elements, 130: 79-93.