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Study on the Safety Distance between the Mining Area and the Underground Opening for Facilities under Different Rock Mass Conditions at Limestone Quarry

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Abstract

In Japan, a bench cut method is mainly applied for limestone quarries. As most of the mines are located in the mountain regions and steep slope mountains, the shaft and the underground opening for installation of facilities such as crushing equipment are applied in order to provide workability and economic efficiency for transportation and crushing ores. However, as the mining operation proceeds, the level of the pit will be down and the distance between the mining area which is the bottom of the pit and the opening for underground facilities such as crushing equipment become to be short. In order to maintain the safe mining operation and the stability of the underground opening, the appropriate distance between them has to be maintained. Therefore, in order to develop the guidelines for safety distance between the mining area and the underground opening for installation of facilities such as crushing equipment under different rock mass conditions in a limestone quarry, a series of numerical simulations are conducted by means of finite differential code “FLAC3D”.

Keywords: bench cut method, safety, stability, underground opening for facilities

1. Introduction

Currently, more than 200 limestone mines are in operation in Japan. A bench cut method is mainly applied for limestone quarries of the open-pit mine. In general, the limestone ore excavated from a limestone quarry at a high elevation is introduced into the shaft to achieve efficient transportation by utilizing the gravity. After that, the ore is crushed by the underground crusher and transported by the belt conveyor to the facility of processing at the foot. As most of the mines are located in the mountain regions with a steep slope, the shaft and the underground opening for installation of facilities such as crushing equipment are applied in order to provide workability and economic efficiency for the transportation and crushing ores. However, the stability of the shaft and the underground opening is suspected when the rock mass conditions are poor due to the existence of a fractured zone. In addition to that, as the mining operation proceeds, the distance between the surface and the underground opening becomes to be short with the down of the level of the pit. In order to maintain the stability of the underground opening, the appropriate distance between them has to be maintained. However, there are few studies about the influence of the rock mass conditions especially fractured zone and the mining operation on the stability of the underground opening. Therefore, in order to discuss the safety distance between the surface and the underground opening for installation of facilities such as crushing equipment under different rock mass conditions in a limestone quarry, a series of numerical simulations are conducted by means of finite differential code “FLAC3D”.

2. Methodology

2.1 Numerical analysis model

In this study, a numerical model is constructed from actual field data as shown in Fig. 1. This model is constructed from 4 parts. Each part has different properties. As the initial model, the distance from the top of the mountain to the crown of the underground opening for facilities such as crushing equipment is 128 m. The inclined shaft is constructed with 5 m diameter and 75° dip. The dimensions of the underground opening are 45m wide, 45m deep, and 60m high. In order to discuss the influence of the mining excavation with the down of pit level on the stability of surrounding rock mass, the pit floor is excavated to downward every 23 m. The displacement is fixed in both vertical and horizontal direction at the bottom, and the axial displacement is fixed at the side. The slope and the surface are free as the boundary condition. The underground opening for facilities such as crushing equipment is constructed at the bottom of the shaft.

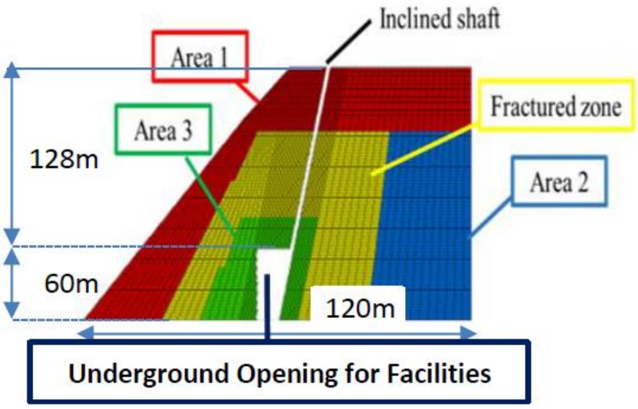


Fig.1 Numerical model (Cross section)

2.2 Properties

Each property is calculated from some experiments as shown in Table 1. The properties of fractured zones were estimated using Geological Strength Index (GSI) based on the results of uniaxial compression test, tensile test, and Rock Quality Designation (RQD) which was obtained from observing drilling cores as shown in Table 2, (Bieniawski, Z.T, 1976; 1978; Jaya Laxmi Singh and Naresh Kazi Tamrakar 2013). Case studies were conducted by adopting the different parameter for the fractured zone. In this study, the Mohr-Coulomb failure criterion is adopted as shown in Fig. 2 and elasto-plastic behavior of the rock mass is used, (Hoek, E et al., 1995). The safety factor is calculated by dividing the strength of rock mass by the in-situ stress to provide a basis of stability assessment as Eq. (1). The failure of the rock mass is assumed to occur when the safety factor is less than 1.

$$\text{Safety factor} = \{c \cos\varphi + [(\sigma_1+\sigma_3) / 2 \ \sin\varphi]\} / [(\sigma_1+\sigma_3) / 2] \quad (1)$$

Table 1 Properties of each rock mass condition

	Unit weight (kN/m^3)	Young's modulus (GPa)	Poisson's ratio (-)	Internal friction angle (deg)	Cohesion (MPa)	Tensile strength (MPa)
Area 1	26.5	3.37	0.25	20.2	1.54	1.53
Area 2	26.5	15.2	0.25	39.0	3.29	2.10
Area 3	26.5	1.03	0.25	8.74	0.40	0.92

Table 2 Properties of fractured zone

	Unit weight (kN/m^3)	Young's modulus (GPa)	Poisson's ratio (-)	Internal friction angle (deg)	Cohesion (MPa)	Tensile strength (MPa)
GSI 36	26.5	1.68	0.25	15.6	0.83	1.12
GSI 47	26.5	3.15	0.25	19.3	1.12	1.49
GSI 58	26.5	6.82	0.25	26.7	1.80	1.82
GSI 70	26.5	15.2	0.25	39.0	3.29	2.10

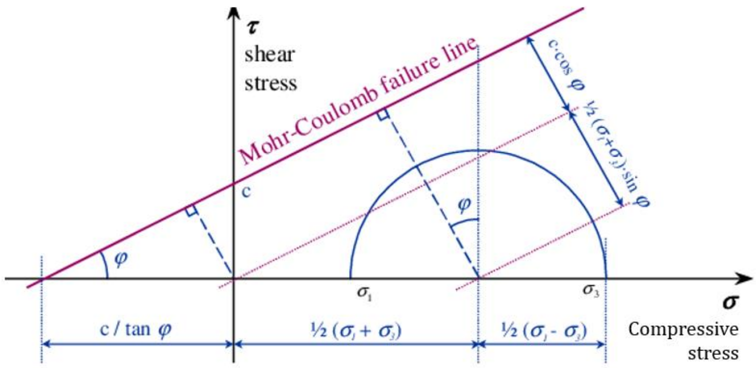
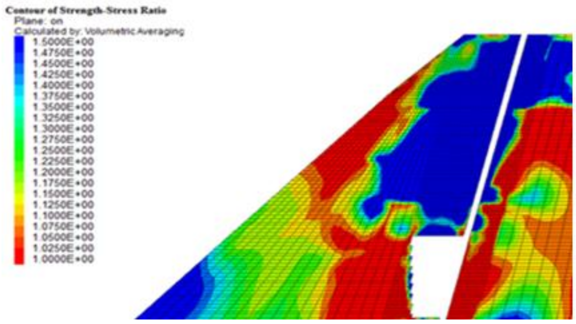


Fig. 2 Mohr-Coulomb failure criterion.

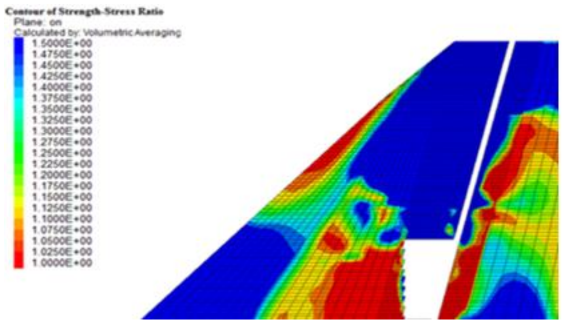
3. Results and Discussion

3.1 Influence of fractured zone on the stability around the underground opening for facilities

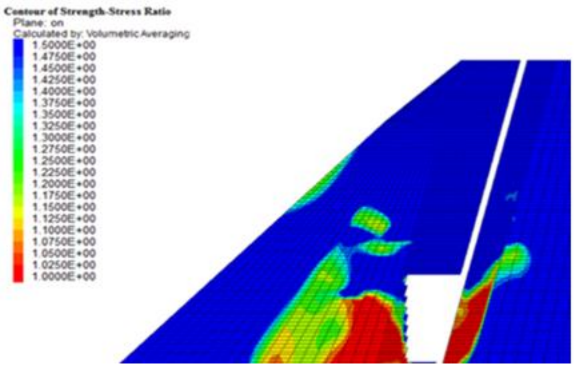
Figs. 3 (a)~(d) show the distribution of safety factor around the shaft and the underground opening for facilities such as crushing equipment. Based on the results, the unstable area is expanding widely to the slope surface when the rock mass condition in the fractured zone is poor (GSI = 36, 47) while it is limited near the underground opening when the rock mass condition is fair (GSI = 58, 70). These results indicate that the rock mass condition in the fractured zone strongly affects the stability around the underground opening, meaning that the mining design to excavate with down of pit level has to be planned with considering the rock mass conditions in the fractured zone. Additionally, it is difficult to proceed the mining operation with the down of pit level when the rock mass condition in the fractured zone is poor (GSI = 36) because the unstable area is expanded widely to the slope surface compared to other cases.



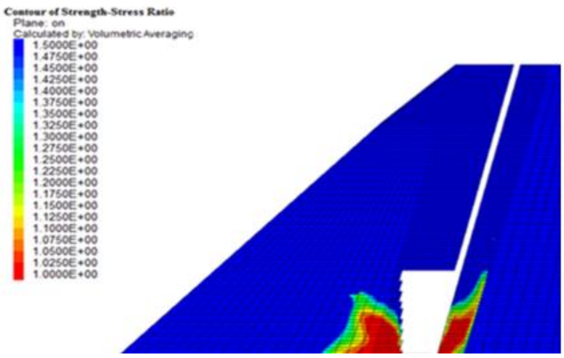
(a) GSI = 36



(b) GSI = 47



(c) GSI = 58

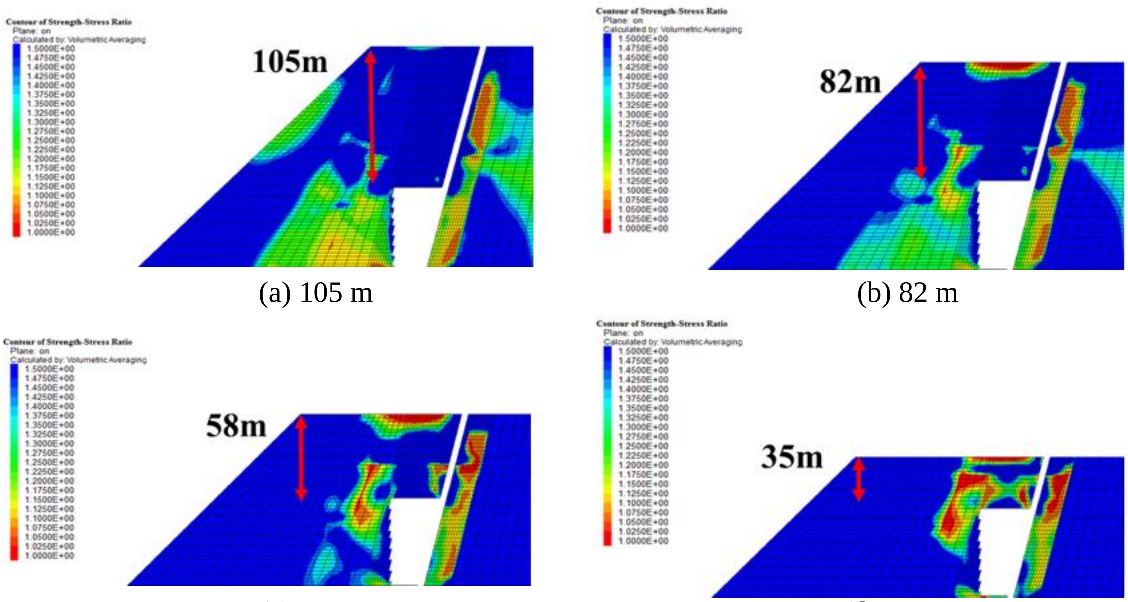


(d) GSI = 70

Fig. 3 Distribution of safety factor around the shaft and the underground opening for facilities under the different rock mass conditions for the fractured zone.

3.2 Stability around the underground opening for facilities after the excavation with down of pit level

As an example of the analysis result, Figs. 4 (a)~(d) show the stability of surrounding rock mass in different distance between the surface and the underground opening for facilities such as crushing equipment when the GSI is 47 in the fractured zone. From these figures, the unstable area is expanded above the underground opening with decreasing the distance from the surface. These results mean that a certain distance has to be left between the surface and the underground opening to maintain the stability above the underground opening. Additionally, the stability above the underground opening is suspected when the distance is 58 m and 35 m based on the distribution of safety factor. This fact indicates that mining operation is possible to continue until the distance between the surface and the underground crushing facility is 82 m. In the case of GSI 58 and 70, the mining operation is possible until the distance is 58 m.



(a) 105 m (b) 82 m

(c) 58 m (d) 35 m

Fig. 4 Stability of surrounding rock mass in different distance between the surface and the underground opening for facilities (GSI = 47).

4. Conclusion

In this study, in order to investigate the effect of the fracture zone and the underground opening for installation of facilities such as crushing equipment on the stability of surrounding rock mass, numerical analysis is performed using three-dimensional stress analysis software FLAC3D. As a result, it is revealed that the rock mass condition in the fractured zone strongly affects the stability around the underground opening. Additionally, the appropriate distance between the surface and the underground opening have to be left with considering the rock mass condition in the fractured zone in order to maintain the stability around the underground opening.

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