Time-dependent support pressure of underground gold mine in Indonesia

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Abstract. The mines expand slowly into deeper deposits through underground mining, and it is related to geotechnical challenges concerned with unexpected failure. The radius of the failure zone and the extent of rock mass deformation in the precinct of opening can be restrained by the implementation of internal support pressure. It is essential to primarily understand the time-dependent behavior of the rock mass. This study aimed to estimate the support pressure of underground gold mine in weak rock mass zone in Indonesia and evaluate the time-dependent support pressure. Rock mass quality Q-system is used as the basis for analysis in this study. To understand the time-dependent behaviour of the rock mass, the support pressure related to the short-term rock mass quality were evaluated. In this study of opening excavated in the weak rock mass, support pressure may progressively increase with time attributable to the creep behavior of the rock mass. The time-dependent behavior of rock mass is indispensable to be contemplated in the long-term design and continuance of underground excavation.

1. Introduction

The limitation of resources causes the mines to expand slowly into deeper deposits through underground mining [1,2]. Deep mining is related to some questioning of geotechnics concerned with unexpected failure and considerable deformation in underground structure [3].

When the underground opening is excavated in the rock at depth, the nearby stress field is disturbed. Consequently, the stresses in the environs of the underground excavation are altered, and it leads to induced new stresses. If the stresses are high enough in the weak rock mass, a failure zone surrounds the underground opening. It may affect the short-term instabilities that can take place throughout and following the operation. In this regard, the state of equilibrium may be achieved through the failure in the unsupported opening. The radius of the failure zone and the extent of rock mass deformation in the precinct of opening can be restrained by the implementation of internal support pressure [4].

In the published original 1974 paper, Barton [5] complemented the support recommendations by providing the estimation of support pressure. When a critical support pressure is more than the internal pressure given by the tunnel lining, it can affect failure to the rock mass encircling the tunnel. An action that is commonly intended to deal with similar cases is to implement adequate support behind the face of the tunnel as an endeavor to restrict the strain to a bearable intensity. The behavior of rock mass encircling the tunnel would be elastic, and no failure takes place if the critical support pressure is less than the internal support pressure [6].
The support pressure is an improved concept of typically used stress approximation methods—‘method of applied loads’ and ‘dead-load stresses’[7]. At first, Terzaghi [8] acquired the support pressure criteria which fairly relevant to present practice for intermediate-size tunnels in challenging rock conditions, and are in fact, quite commonly used. For the estimation of support pressure, Unal [9] proposed an approach based on Rock Mass Classification (RMR). Barton [10] provided the empirical correlation for ultimate support pressure by analyzed 200 underground openings using rock mass quality (Q). Singh [11] given the empirical correlation through the study of support pressure for 30 tunnel appliances corresponding to the short-term rock mass quality (Qi).

Besides, the stability and the rock mass behavior encircling an excavation are controlled by a number of factors including the geometry of the excavation, the rock mass strength, the induced stresses encircling the opening, the groundwater condition, and weathering process, as well as the blasting or construction activities [12,13]. Geotechnical information has to be concerned to determine the support system[14]. Rock mass quality is widely used for the estimation of support pressure [15].

The advance of the tunnel face and time-dependent behavior of the host rock encircling underground excavation in a weak rock mass can cause the worsening ground pressure and tunnel wall convergence. The collapse of an underground excavation can happen several days or years following the excavation [16]. Consequently, in the soft and weak rock mass, the time-dependent characteristics of rock mass should be considered in the long-term design and improvement of underground excavation [17,18]. Besides, sufficient knowledge of the time-dependent behavior of underground excavation in weak rock mass has not yet been fully developed [19], and it is essential to primarily understand prior to the substantiation stage.

The aim of this study is to estimate the support pressure of underground gold mine in weak rock mass zone in Indonesia by using the approach of Barton [11] and evaluate the time-dependent support pressure using the correlation Singh [11]. The used analysis in this study based on the rock mass quality Q-system suggested by Barton, Lien, and Lunde [11].

2. Materials and methods

2.1. Study area
The current study was carried on the underground gold mine in Indonesia. It is located at 255 meters below the ground level in a weak rock mass zone. The study site comprises three lithological units—high density veins, medium-density veins, and quartz sericite. Table 1 illustrates the geotechnical characterization of this site.

| No. | Geotechnical Domain     | Type       | UCS (MPa) | GSI | Joint roughness number, \( J_r \) | Rock Mass Quality-Q | Classification |
|-----|-------------------------|------------|-----------|-----|-------------------------------|---------------------|----------------|
| 1.  | High density veins      | Alteration | 60        | 62  | 0.5                           | 11.3                | Good           |
| 2.  | Medium density veins    | Alteration | 80        | 66  | 0.5                           | 15                  | Good           |
| 3.  | Quartz sericite         | Alteration | 70        | 68  | 0.5                           | 19                  | Good           |

2.2. Methodology
Barton [11] established the below empirical correlation for ultimate support pressure.

\[
p_v = \frac{0.2}{J_r} Q^{\frac{1}{3}}
\]  

(1)

\[
p_h = \frac{0.2}{J_r} Q_w^{\frac{1}{3}}
\]

(2)
Where

\[ p_v = \text{ultimate roof support pressure in MPa}, \]

\[ p_h = \text{ultimate wall support pressure in MPa}, \]

\[ Q_w = \text{wall factor}. \]

After multiplying \( Q \) by a factor, the wall factor \( (Q_w) \) is obtained as given in Table 2 depends on the magnitude of \( Q \).

| Range of \( Q \) | Wall factor, \( Q_w \) |
|-----------------|----------------------|
| >10             | 5.0\( Q \)           |
| 0.1-10          | 2.5\( Q \)           |
| <0.1            | 1.0\( Q \)           |

Related to the short-term rock mass quality \( (Q_t) \), Singh [11] provided the empirical correlation of support pressure.

\[
p_v = \left( \frac{0.2}{f} \right) Q_t^{-0.33} f' f'' MPa \tag{3}
\]

\[
f = 1 + \left( \frac{H - 320}{800} \right) \geq 1 \tag{4}
\]

\[ f' = 1, \text{ the correction factor for tunnel closure in non-squeezing ground,} \]

\[
f'' = \log(9.5 t^{0.25}) \tag{5}
\]

where \( H \) is tunnel depth below ground level in meters and \( t \) is time in months after excavation.

Eq. (3) can be used with short-term wall rock mass quality \( (Q_{wi}) \) instead of \( Q_t \) to evaluate the wall support pressure using correlation by Singh [11]. After multiplying \( Q_t \) by a factor, the short-term wall rock quality \( (Q_{wi}) \) is obtained as given in Table 3 depends on the magnitude of \( Q \).

| Range of \( Q \) | Short-term wall rock quality, \( Q_{wi} \) |
|-----------------|-----------------------------------|
| >10             | 25.0\( Q \)                       |
| 0.1-10          | 12.5\( Q \)                       |
| <0.1            | 5.0\( Q \)                        |

3. **Results and discussion**

Based on rock mass quality (Q-value), the ultimate roof and wall support pressure were estimated (see Figure 1) for underground gold mine in weak rock mass zone by using the approach of Barton [11]. Related to the short-term rock mass quality, the support pressure was evaluated (see Figures 2 and 3) in addition to the time-dependent support pressure using the correlation Singh [11].
Figure 1. Ultimate roof and wall support pressure for underground gold mine in weak rock mass zone

Figure 2. Time-dependent roof support pressure for underground gold mine in weak rock mass zone

Figure 3. Time-dependent wall support pressure for underground gold mine in weak rock mass zone

The present study examines the time-dependent support pressure using the correlation Singh [11]. In addition, to analyze the ultimate support pressure, evaluation of support pressure utilizing the approximation of Barton [11] is still relevant. The results of the study show that the estimation of support pressure using the correlation Singh [11] has not reached the ultimate support pressure by
Barton [11] yet after ten years. However, the study of time-dependent support pressure of underground excavation in the weak rock mass is essential to primarily understand the time-dependent behavior of the rock mass.

In this study of opening excavated in the weak rock mass, support pressure may progressively increase with time attributable to the creep behavior of the rock mass. Therefore, the time-dependent characteristics of rock mass should be considered in the long-term design and improvement of underground excavation.

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