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Calculation of anchor - steel beam structure support for adit at Vi Kem mine

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KEYWORDS

Vi Kem mine
Anchor-steel frame
Rock mass
Analytic method
Numerical method

ABSTRACT

When supporting the adit with a trapezoidal steel frame was applied at Vi Kem mine, the results showed that the rock mass was slightly compressed and moved on the steel frame at the adit crown. The rock mass on both sides of the adit had almost no displacement. Therefore, the anchor-steel beam structure was proposed to replace the trapezoidal steel frame structure. This structure replaces the trapezoidal steel support frame when the adit sides are stable to reduce the costs of materials and support labor, while helping to increase the speed of adit excavation. The subject of application is the adit along the seam and through the seam at Vi Kem mine. First, the paper classifies the rock mass, calculates the pressure acting on the adit crown according to Protodiakonov, and analyzes the wedge formed on the adit crown using numerical methods. Next, the calculation is made for the new anchor-steel beam structure suitable for the pressure at the adit crown. The construction results show the effectiveness of this new anchor-steel beam structure.

1. Introduction

In underground mines, the support structure is often simple and less diverse. Due to the geological characteristics formed by the eruption and hydrothermal exchange, the rock in the ore-bearing area has high rigidity. In addition, current mining technology mainly uses adits with small cross-sections, from 2.6 ÷ 9 m^2, so most adits are quite stable and rarely need support. The proportion of adits that need support at mines belonging to TKV Minerals Corporation - JSC only accounts for about 20 % ÷ 40 % of the total number of adit meters excavated annually. The rest do not need support.

Currently, underground mines in Vietnam mainly exploit copper, zinc, lead, tin, nickel, gold, and antimony. These mines have solid rock geology, few cracks, and a strength coefficient f ≥ 6. Therefore, most of the adits do not need support; however, the proportion of support by steel frames is still significant, especially in areas with complex geology. This problem requires research on appropriate support solutions to improve production efficiency.

Through the practice of supporting the adit with a trapezoidal steel frame at Vi Kem mine, it can be seen that the rock mass at the top of the adit is compressed and pressed against the steel frame, while both sides of the rock hardly move (Figure 1). Therefore, it is necessary to study and propose an alternative solution to the trapezoidal steel frame to reduce material and labor costs and increase the speed of adit excavation.

Many studies are interested in evaluating rock mass quality to design and optimize underground support structures in Vietnam [1-8] and worldwide [9-16]. Based on the actual construction conditions at the Vi Kem mine, the anchor-steel structure has been effectively applied to replace the steel frame structure to avoid wasting materials, reduce construction volume, and increase construction speed. First, the article classifies rock mass, calculates the pressure acting on the adit crown according to Protodiakonov, and analyzes the wedge formed on the adit crown using numerical methods. Next, the design calculation for the new anchor-steel structure is suitable for the pressure caused by the adit crown.

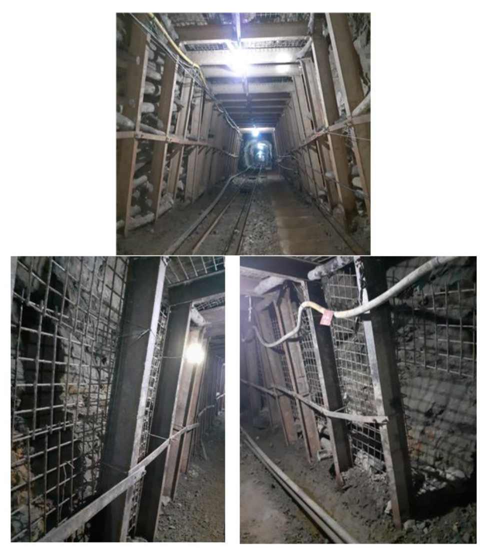

Figure 1. Trapezoidal steel frame at the Vi kem mine.

2. Calculation of adit crown pressure

2.1. Crown pressure according to the coefficient of stability (f) of M.M Protodiakonov

M.M Protodiakonov (1911) proposed many calculation methods, but the most popular is the classification of soil and rock according to the coefficient of stability f, where he divided soil and rock into 10 levels corresponding to the strength coefficient f = 0 ÷ 20. Based on model experiments and actual observations, Protodiakonov assumed that after excavation, the adit crown formed

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a subsidence dome and moved straight towards the adit's void. The weight of the subsidence dome is the cause of pressure on the support structure. The pressure dome has a parabolic shape and is represented by the following equation:

$$b = \frac{a}{f} \quad (1)$$

Vi Kem mine with an adit cross-section of (2.6 ÷ 6.5) m^2, the rock mass around the tunnel is usually of good quality, low crack density, and the average and significant strength coefficient is usually $f \geq 6$. When the tunnel side is stable ($f \geq 6$), the pressure acting on the supporting structure will be determined according to the pressure dome hypothesis of Protodiakonov (1931).

For an adit with a cross-section as shown in Figure 2, the maximum width of the adit will be used to calculate the crown pressure, as it will be safer. Thus, the height of the crown pressure dome at the top acting on the supporting structure is determined for two cases, f = 6 and f = 8, and the half width of the adit a = 3.61/2 = 1.805 m, then the corresponding pressure dome height is 0.3 m and 0.226 m.

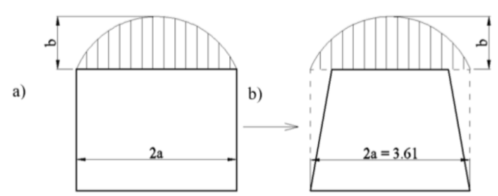


Figure 2. Calculation scheme on adit crown by Protodiakonov (1931).

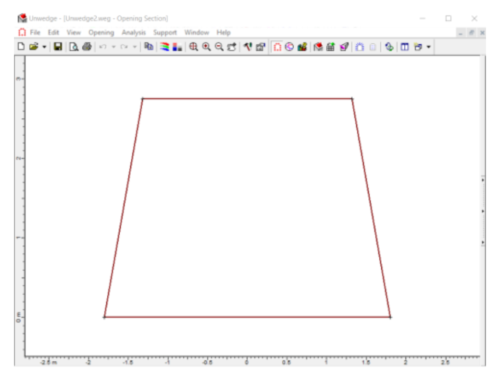
2.2. Wedge analysis method with the Unwedge program

With the Unwedge program, it is possible to identify dangerous wedges appearing around the tunnel from at least three different fracture planes. The orientation of the three separate fracture planes must always be determined for Unwedge analysis. Using block theory, Unwedge determines all possible wedges formed by the intersection of the three fracture planes and the excavation plane. Once the wedge coordinates have been determined, the geometric properties of each wedge can be calculated, including:

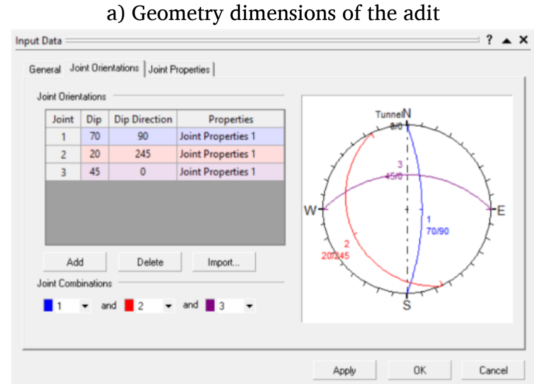
- Weight of the wedge
- Surface area of the wedge
- Vertical force vector for each wedge plane
- Unsupported safety factor of the wedge from this basis to select the support structure to support the wedge within the allowable safety range.

Based on geological data, at Vi Kem mine, the adit is excavated through a main fracture system with a slope angle of 65 ^{0} to 90 ^{0}. With this fracture system, it is very difficult to form wedge blocks due to the tectonic movement process and the construction process using the drilling and blasting method. In the rock mass around the adit, micro-cracks can form, which are conditions for creating small local wedge blocks that cause instability to the tunnel after excavation. To calculate in a safe direction, this calculation assumes that there is a second fracture surface perpendicular to the main fracture eye, and a third fracture with a direction perpendicular to the adit axis. Figure 3 shows input data such as the cross-sectional geometry of the adit, the orientation of the three fracture surfaces, and the fracture's properties according to the Mohr-Coulomb model, with friction angle φ = 37 ^{0} and cohesion force c = 0 (T/m^2).

The results in Figure 4 show that there are four wedge blocks, 1, 4, 5, and 8, formed by three joints and adit excavations. Of the four wedge blocks, three 1, 4, and 5, have high and stable safety factors, with no risk of shifting into the tunnel. Wedge block 8 weighs 0.151 tons, has an adit length of 1.7 m, a height of 0.2 m, and a safety factor of FS = 0.685, so a support solution is needed (Figure 4).



a) Geometry dimensions of the adit



b) Orientations of the joint

Figure 3. Adit and joint datas in Unwedge program.

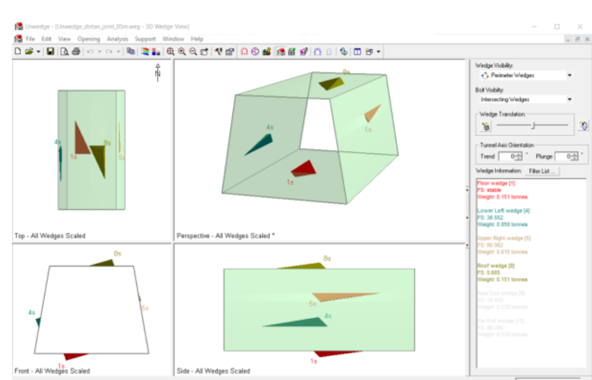


Figure 4. Illustrates the formation of wedge blocks and the associated safety factor for these blocks.

3. Calculation of the anchor-steel beam structure

From the results of the analysis and evaluation of the rock mass around the adit of Vi Kem mine as well as the load acting on the support structure analyzed in section 2, it can be seen that the maximum pressure dome calculated by Protodiakonov is 0.3 m when f = 6, while the analysis of the formation of a wedge block with a height of 0.2 m can appear at any position on the adit crown. For simple and safe calculations, the anchor-steel beam structure will be designed for the maximum value of the pressure dome calculated by Protodiakonov (Figure 5).

❖ *Loading on the steel frame*

The rock pressure on the adit using the anchor-steel beam structure is determined similarly when other supporting structures for the adit with a trapezoidal cross-section are used. To simplify the calculation, the load caused by the pressure dome is considered to be evenly distributed as in Figure 6 and is calculated according to the formula:

$$q_n = b.\gamma_{crown}.L.\cos\omega \ , \quad T/m \quad (2)$$

where: γ_{crown} is weight of rock, T/m^3; L is distance between two steel beam, m; ω is inclination angle of the adit; b is height of pressure dome at the top of the adit, m.

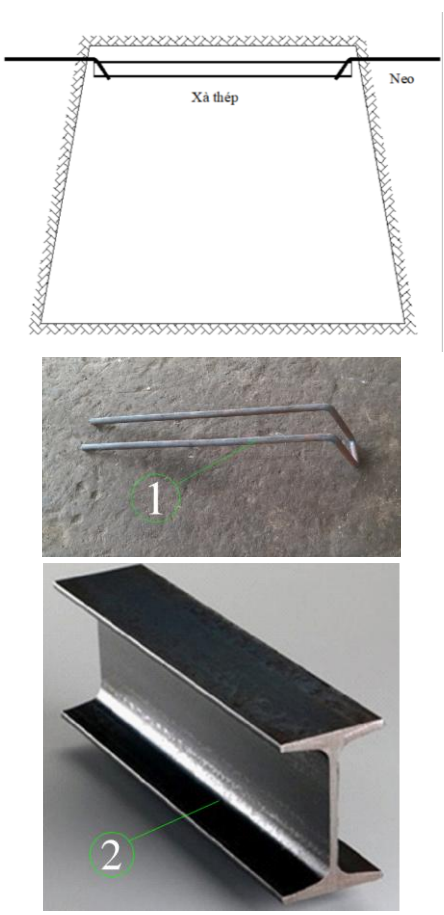


Figure 5. Composite structure of anchor – steel frame; (1) U-shaped anchor, (2) I-shaped steel beam.

❖ *Calculation of steel beam*

The internal forces calculation diagram of steel beam is shown in Figure 6.

+ Maximum shear force Q_{max}:

$$Q_{max} = P = q_n\left(a + \frac{l}{2}\right) \quad (T) \quad (3)$$

+ Maximum bending moment M_{max}:

$$M_{max} = \frac{q_n}{8}(l^2 - 4a^2) \quad (T.m) \quad (4)$$

+ Check the strength of steel beam

Steel beam must satisfy the following condition

$$\frac{|M_{max}|}{W_x} \le [\sigma_u] \quad (5)$$

where: W_x is section modulus of the steel beam, m^3; σ_u is allowable stress of the steel beam material, T/m^2;

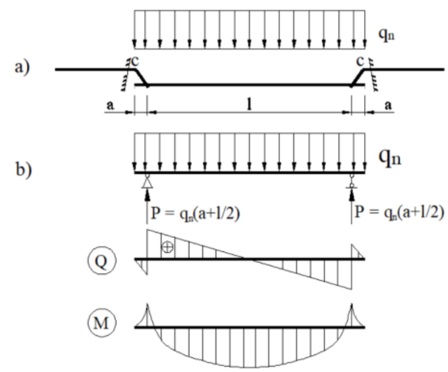
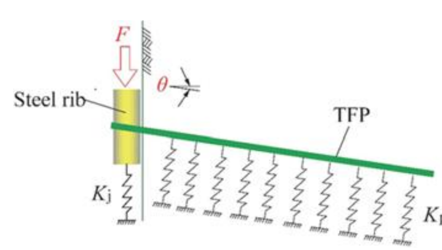


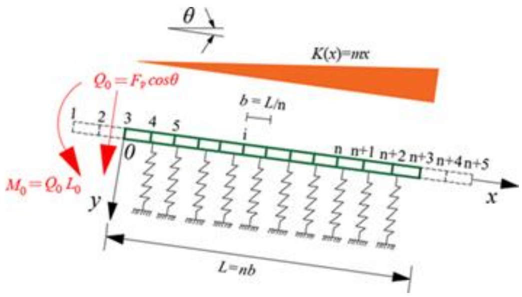
Figure 6. Calculation diagram of anchor-steel beam; a) load diagram acting on anchor - steel beam, b) calculation diagram for steel beam.

❖ *Calculation of anchor structure*

In the study of Chen et al. (2021), the anchor structure was studied at an angle of 10 ^{0} to the horizontal, which has the task of locking the steel frame to prevent the tunnel from displacement when subjected to vertical loads during the excavation tunnel in the soft soil condition. The load F due to the H steel frame acting on the anchor structure will cause shear force and moment (Figure 7). In this study, because the anchor is inserted in soft soil, the load-bearing capacity of the anchor will depend on the soil resistance and the diameter of the anchor bar (the anchor is not destroyed), meaning that the harder the soil, the more effective the load-bearing capacity of the anchor. In soft soil, the anchor has a diameter of ∅42 ÷ ∅140 mm, and a length of 1.7 m ÷ 2.8 m (0.2 ÷ 0.3 of the tunnel width). The length of the anchor depends on and is inversely proportional to the stiffness of the soil.



a) Mechanical of steel and anchor



b) Mechanical analytic of anchor using finite difference method

Figure 7. Calculation scheme for Anchor by Chen et al. (2021).

In the Vi Kem mine conditions, the anchor structure is installed in a hard rock mass, which means that the anchor is destroyed before the rock mass surrounding the anchor structure, so the anchor will receive the entire load transmitted from the steel frame. To calculate for safety similar to that in weak soil, choose the length of the anchor structure from 0.2 to 0.3 of the adit width. The calculation diagram of the anchor structure is shown in Figure 8. The load acting on the U-shaped anchor structure transmitted by the steel frame at the contact position between the anchor structure and the steel frame is load P. The load P acting on the U-shaped anchor structure is vertical and downward. Figure 8 shows that the dangerous position on the anchor structure is the contact position between the anchor structure and the adit boundary (position C). At this position, the internal force in the anchor structure, including shear force (Q) and moment (M), reaches its maximum value, so this will be the calculation position to check the strength of the anchor structure, from which the appropriate anchor structure size can be selected and designed.

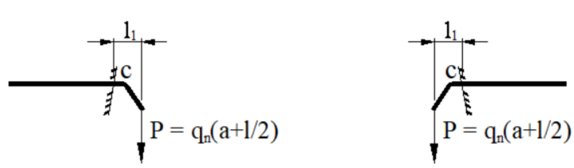


Figure 8. Calculation diagram for anchor structures.

Determine internal forces in the anchor structure U:

+ Maximum shear force Q_{max}:

$$Q_{max} = P = q_n\left(a + \frac{l}{2}\right) \quad (T) \quad (6)$$

+ Maximum bending moment M_{max} at position C:

$$M_{max} = P.l1 \quad (T.m) \quad (7)$$

+ Check the strength of the U shaped anchor structure U: Use theory 4 to test the strength of U-shaped anchor structures.

$$\sigma_{td} = \sqrt{\sigma^2 + 4\tau^2} \leq [\sigma] \quad (8)$$

$$\sigma = \frac{|M_{max}|}{2W_x} \quad (9)$$

$$\tau = \frac{2Q_{max}}{2\pi R^2} \quad (10)$$

where: W_x is section modulus of the U shaped anchor structure, $W_x = 0.1d^3$, m^3; $[\sigma]$ is allowable stress of the anchor structure material, T/m^2; τ is shear stress; d và R are diameter and radius of the anchor.

3.1. Result evaluation of adit excavation

The adit using the experimental anchor-steel frame structure does not use support on both sides of the adit. Therefore, adit excavation by the drilling and blasting method needs to minimize the impact of vibration on the sides as well as the crown of the adit. Increasing the density of drill holes on both sides and around the adit boundary is applied. Qualitative results show that the two sides of the tunnel are relatively flat and stable. The anchor-steel frame structure has been installed, and the structure works stably (Figure 9). Due to the excavation using the drilling and blasting method, it is inevitable that there are some positions where the ends of the steel frame are not close to the adit boundary. This can be overcome by measuring the width of the adit crown after blasting and then cutting the steel frames or welding them. The support system shows that the construction volume of the anchor-steel frame structure is significantly reduced compared to the construction of the steel frame structure due to the reduction of steel column materials and wooden inserts on the two sides of the adit (Figure 9). After testing the anchor-steel frame structure, it shows that the support structure works stably.

Figure 9. Some images of mine tunnel support using steel bolt-beam structures.

4. Conclusion

In underground mines, the adits are excavated in relatively hard and stable rock mass. Most adits are not supported. However, the support structure is still used for adits in areas with complex geological conditions. The anchor-steel frame structure is a new support structure and has been tested effectively. This study determined the pressure acting on the adit crown using the theoretical solution of Protodiakonov and the wedge block analysis method using the Unwedge program. Proposed a design calculation method for the anchor-steel frame structure based on the crown pressure.

The anchor-steel frame structure is suitable for adits with flat crown (adits with trapezoidal, rectangular, and square cross-sections), the geological conditions around the adit are relatively stable with hard side walls and small crown pressure.

The anchor-steel frame structure is a suitable alternative to the steel frame structure. It is simpler and easier to construct than steel frame structures. It reduces material and construction costs compared to steel frame structures when constructed in relatively stable geological conditions, where steel frames have excess capacity to work, causing waste.

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