Investigation Of the Influence of The Relative Position Between the Tunnel and The Waste Dump on The Mechanical Behavior of Roadway Support Structures in The Quang Ninh

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***Abstract*—The development of massive surface waste dumps in the Quang Ninh coal region has significantly altered the stress state of underlying rock masses, imposing "artificial pressure" on underground roadways. This paper investigates the mechanical behavior of steel support structures in roadways located beneath these dumps. Using numerical modeling (Phase2 software), we analyze the influence of the relative position of the roadway on internal forces (bending moment M and axial force N). Two profiles-circular and straight-wall semi-circular arch-are compared. Results indicate that internal forces increase proportionally with the dump's unit weight and height. Circular supports demonstrate superior stability and lower peak internal forces compared to arched structures.**

***Index Terms*—Font: Times New Roman, Size:9] About four(minimum) key words or phrases in alphabetical order, separated by commas.**

I. INTRODUCTION

The Quang Ninh coal basin is the largest coal mining center in Vietnam, accounting for over 90% of the national reserves. Annual exploitation of 40-50 million tons of coal generates approximately 200 million m^3 of waste rock, much of which is deposited in massive surface dumps like Bang Nau, Dong Cao Son, and Chinh Bac. These dumps can reach heights of 300 to 400 meters. The accumulation of this vast rock mass creates significant "artificial pressure" that disrupts the primary stress field of the underlying strata. Field observations at mines such as Mong Duong and Khe Cham III have shown that roadways beneath waste dumps experience severe deformations, including the buckling of steel arches and floor heaving, often exceeding the design limits of trtunnelional support systems. Trtunnelional calculation methods often neglect this surface loading, necessitating a quantitative investigation into the "Waste Dump – Rock Mass – Roadway – Support" interaction.

Quang Ninh, Viet Nam is the largest coal mining centre in Vietnam, playing a key role in national energy security. Open-pit and underground mining processes in Cam Pha, Hon Gai, and Uong Bi areas have generated huge amounts of waste rock, creating large-scale surface waste dumps such as Cao Son, Bang Nau, Chinh Bac… with waste dumping heights that can reach 120 ÷ 540 m. Notably, many of these waste dumps are located directly on areas with coal seams and tunnel systems being mined below.

The existence of surface waste dumps changes the initial stress state in the rock mass, creating additional artificial loads acting on underground structures [1,2,4,11]. Production practices at the Mong Duong, Khe Cham, and Nui Beo mines show that tunnels located beneath the waste dump frequently experience severe deformation, subsidence, and compression of the supporting structures, more so than areas unaffected by the waste dump. At the Mong Duong mine, many tunnels were compressed, reducing the usable area from 11 m² to 5 m², requiring multiple expansions and support work, resulting in increased costs and safety risks. Although mine waste dumps can be classified in various ways according to location (inside/outside), terrain (valley/slope) or dump creation technology [3,5,6,8,10], the assessment of their impact on underground structures is still limited:

- Theoretical Methods:

The pressure hypotheses of Protodiakonov and Tsimbarevich only consider the weight of rock on the mine roof and do not take into account the depth of the tunnel and additional loads from the surface. The theories of Bierbaumer or Terzaghi, although they take into account depth, only apply to shallow tunnels or tunnel entrance areas. Therefore, there are no specific quantitative guidelines for tunnels located deep under waste dumps hundreds of meters high.

- Numerical Methods:

A 2D simulation using software such as FLAC, UDEC, Plaxis, and Phase2 has been applied to simulate the stress-strain state of the rock mass [12]. However, domestic (Vietnam) studies have only approached this at a preliminary level. Some initial results mainly stop at surveying the influence of the waste dump on the displacement of vertical shafts or a few specific tunnels; finding the detailed law of internal force distribution in the structure to optimise the structural parameters of steel support structures has not yet been systematically studied.

- Gap in international research:

In the world, research works related to surface waste dumps mostly focus on the problem of slope stability under the influence of surface water and groundwater [7,9], risk assessment, ecological restoration, or temperature field variation due to the self-ignition of waste rock and interbedded rock [13,15-19]. At the same time, the approaches to waste dump planning mainly prioritize minimizing mine acid emissions [4]. Due to the unique geological characteristics of large countries (such as China or European and American countries), coal seams are often located at very great depths or in waste disposal areas that do not overlap with underground mining systems. Therefore, quantitative studies on the complex interplay of "waste dump - rock mass - mine tunnel - support structure" have hardly been published.

In the context of expanding waste dumps and increasingly deeper underground mining, quantitatively assessing the impact of artificial pressure from waste dumps on the behaviour of the tunnel structures is a pressing requirement. This study focuses on building and verifying a 2D numerical model to analyze the impact of a typical trapezoidal positive waste dump on the tunnel below.

The model surveyed for a tunnel is U-shaped with a straight wall and semicircular arch (5 × 5 m) represents an open support structure, under the assumption of a homogeneous rock mass. The weight of the waste dump is assigned by the distributed load acting directly on the model in numerical simulation. The research results provide an important scientific basis for optimizing the selection of cross-sectional shape and parameters of steel support structures, ensuring safety and economic efficiency for coal mines in Quang Ninh.

II. RESEARCH METHODOLOGY

The study utilizes the finite element software Rocscience RS2 (Phase2) to simulate the stress-strain state of the rock mass and support structures. A 2D plane strain model is employed, with dimensions of for theoretical studies and for the Mong Duong case study.

A. Numerical model for the U-shaped tunnel

This study implemented a 2D plane strain model based on the finite element method using Phase2 software. The numerical model allows simultaneous simulation of geological conditions, surface waste dump loads, tunnel structures, and construction phases under real-world conditions. The results can provide data on internal forces, stress distribution, and strain in the tunnel structure.

A 6-node triangular element is used to describe the rock mass. The model has dimensions of 500 m wide and 250 m high. The model surface is freely assigned, while horizontal displacement is restricted to the two edges of the model, vertical displacement is assigned to the bottom of the model, and all directions are fixed at the two bottom corners (Figure 1).

In this study, the waste dump is simulated using a trapezoidal load with a small base width of 100 m, a large base width of 300 m, and a load pressure of 5 MN/m applied to the top surface of the model. The Hoek-Brown failure criterion (2002) is assigned to a homogeneous and isotropic rock mass located beneath the waste dump (Table 1).

The steps for constructing the numerical model and verifying the model include:

- Step 1: Constructing the numerical model with a homogeneous rock mass;
- Step 2: Assigning the trapezoidal load to the surface model; This step will verify the reliability of the numerical model with Hamilton Gray's solution for linearly distributed loads, including trapezoidal loads – suitable for the surface waste dump model in this study under the same boundary conditions.
- Step 3: Excavate and apply the tunnel support structure.

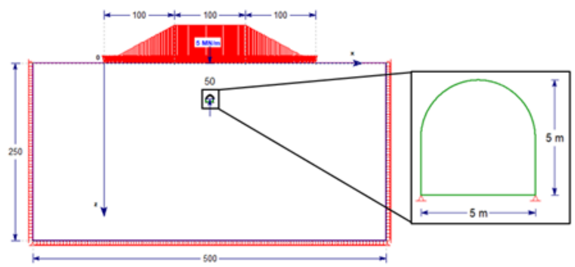

Figure 1. Geometric dimensions of the model

Table 1. Properties of rock mass

N^0	Input parameters	Unit	Value
1	Density	*MN/m^3*	0.0262
2	Deformation modulus	*MPa*	4611
3	Lar expansion coefficient	-	0.3
4	Compressive strength of monolithic rock	*MPa*	37.8
5	GSI	-	50
6	Material constant of crushed stone m_i	-	7
7	*D*	-	0.5
8	m_b		0.6472
9	*s*		0.0013
10	a		0.5057
11	Lane pressure coefficient (K_0)	-	0.5
13	Fault model	-	Hoek-Brown

B. Comparison of numerical and analytical models for the problem of a semi-infinite space subjected to surface loading

The problem considers the rock environment as a two-dimensional semispace Oxz with the Ox axis as the horizontal direction and the Oz axis representing depth. This space has no dimension limitations along the Ox and Oz axes and is assumed to be elastic and isotropic in all directions.

According to classical mechanics, when an external force is applied to a semi-infinite space, the rock elements in the environment will be affected by the external force and form internal forces (stresses) that tend to resist the deformation of the rock elements caused by the external force. The intensity of the distribution of internal forces per unit area is called the additional stress caused by the external force and is analysed into stress components along the directions of the soil and rock elements under study.

The solution to the problem of distributing additional stress in an elastic semi-infinite space subjected to surface loading has been published by many authors. For example, Boussinesq in 1885 provided a solution to the problem of concentrated loads and uniformly distributed loads on an infinitely elastic half-space surface. Regarding the problem of additional stress distribution due to trapezoidal loads, Hamilton Gray published results in 1936 as shown in Figure 2 and formulas 1÷4

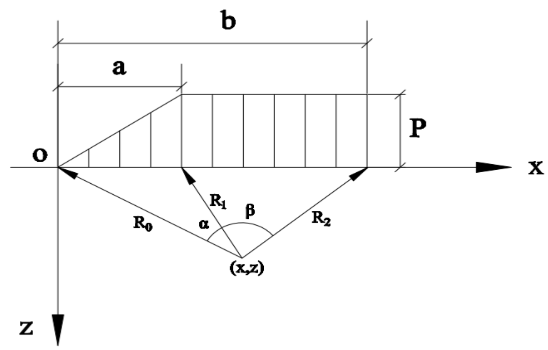

Figure 2. Scheme for calculating the semi-infinite space

The x- and z-axis stress results of any stress element in an elastic infinite half-space are calculated using the formula:

- Normal stress, σ_x

$$\sigma_x = \frac{p}{\pi a}\left[\alpha\beta + x\alpha + \frac{az}{R_2^2}(x-b) + 2z\log_e\left(\frac{R_1}{R_0}\right)\right] \quad (1)$$

- Normal stress, σ_z, σ_y

$$\sigma_z = \frac{p}{\pi a}\left[a\beta + x\alpha - \frac{az}{R_2^2}(x-b)\right] \quad (2)$$

$$\sigma_y = \frac{2p}{\pi m a}\left[a\beta + x\alpha + z\log_e\left(\frac{R_1}{R_0}\right)\right] \quad (3)$$

- Shear stress:

$$\tau_{xz} = -\frac{p}{\pi a}\left[z\alpha - \frac{az^2}{R_0^2}\right] \quad (4)$$

Where: x, z are two-dimensional coordinates in the elastic infinite half-space Oxz; Ro, R1, R2 are the coordinate radii from the observation point to the load positions on the surface; α, β are the angles formed by R0-R1 and R1-R2 respectively; a, b are the widths of the load edges along the Ox axis; p is the load intensity in terms of force per unit length.

The solution to the problem of distributing additional stress in the elastic infinite half-space subjected to surface loads provides a suitable theoretical basis for studying the influence of the waste dump on the behaviour of the underground support structure. In this study, to minimize the complexity of calculations while ensuring accuracy, a numerical model is built based on the analytical solution of Hamilton Gray (1936).

The results of verifying the distribution of additional stresses using analytical and numerical models are shown in Figure 4. The component stress values (σz and σx) were collected at observation points located on the axis of symmetry directly below the centre of the waste dump. From Figure 4, it can be seen that the distribution law and variation trend of the principal stresses (σz and σx) with depth obtained from the numerical model are completely compatible with the analytical solution. The simulated stress curves closely follow the theoretical values, accurately reflecting the mechanism of load transfer from the surface to the rock mass.

The difference between the numerical simulation and analytical results for σz and σx is only about 2.0%. With negligible structural deviations and a stress distribution trend that matches the theoretical solution, it can be affirmed that the Phase2 software algorithm and the numerical model constructed accurately reflect the mechanical nature of the problem. Therefore, this model is completely reliable for subsequent parametric analyses of the influence of the waste dump on the tunnel support structure.

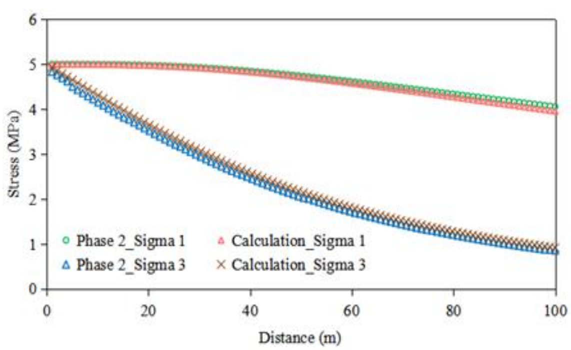

Figure 4. The result comparison between numerical and analytical models

C. INFLUENCE OF THE RELATIVE POSITION BETWEEN THE TUNNEL AND THE WASTE DUMP

The objective of this case study is to clarify the influence of the tunnel's position relative to the waste dump on the behavior of tunnel support structures located beneath the waste dump. The cases investigating the relative position of the waste dump to the tunnel below are shown in Figure 9: 1) tunnel located below the center of the waste dump, 2) tunnel located at the top slope of the waste dump, 3) tunnel located in the middle of the waste dump slope, 4) tunnel located at the foot of the waste dump, and 5) tunnel located outside the waste dump. The input parameters of the model are shown in Tables 1 and 2. The results of the distribution of bending moment and normal force in the tunnel structure are presented in Figures 10 and 11.

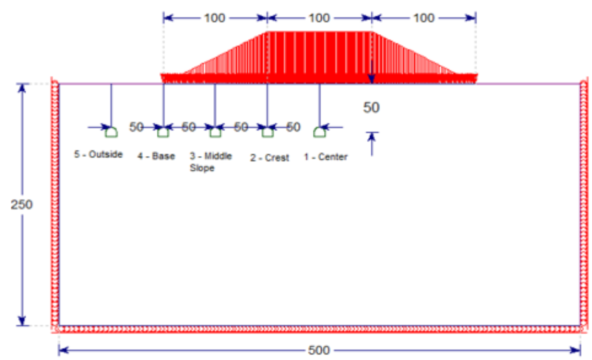

Figure 9. Position of the tunnel compare to the waste dump

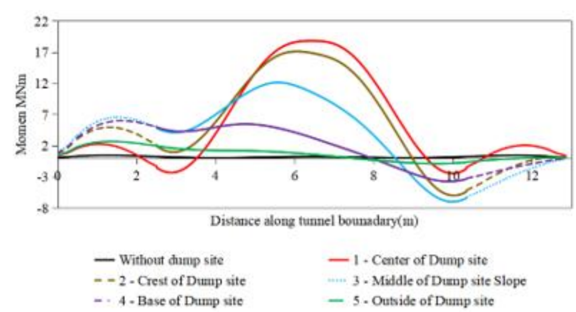

Figure 10. Effect of the relative position between the tunnel and the waste dump on the bending moment in the tunnel structure

The analysis of Figure 10 shows that the geometric correlation between the tunnel and the waste dump significantly influences the distribution pattern and the maximum bending moment in the tunnel structure. As the tunnel moves from the centre of the waste dump outwards (from position 1 to position 5), the amplitude and value of the bending moment tend to decrease significantly, and the bending moment distribution along the contour also changes greatly.

The maximum bending moment tends to shift from the tunnel crown to the side ones (Figure 10). The specific analyses are as follows:

- Location 1: When the tunnel is directly under the centre of the waste dump, the support structure is subjected to the strongest symmetrical artificial pressure. The bending moment reaches its maximum positive value (approximately 20 MNm) at the arch apex, while the largest negative moment region (approximately -3 MNm) appears at the tunnel shoulders. This reflects the very high stress state around the tunnel, especially at the tunnel crown, due to the waste dump.
- Location 2: When moving to the top of the slope, the trend of bending moment variation is almost identical to position 1, but the maximum bending moment value at the arch peak has decreased (reaching approximately 17 MNm). However, the negative bending moment at the right shoulder region increases to near the lowest point on the graph (reaching nearly -6 MNm), indicating an increase in the degree of asymmetry of the applied load caused by the slope effect of the waste dump.
- Location 3: At this position, the bending moment at the shoulder continues to decrease significantly to approximately 12 MNm. Notably, the negative moment region at the shoulder expands and reaches a minimum bending moment across the entire curve (approximately -7 MNm). This phenomenon reflects a shift in the stress distribution region and an increase in the lateral thrust component from the waste dump side pressing on the support structure.
- Location 4: When the tunnel is located at the foot of the waste dump, the bending moment diagram undergoes a fundamental change in shape. The maximum bending moment at the shoulder decreases sharply, to only about 5 MNm, and the diagram shows that the negative and positive bending moment values tend to be more evenly distributed along the circumference, indicating that the influence of the waste dump load has significantly decreased.
- Location 5: When the tunnel is located entirely outside the waste dump area, the bending moment decreases to a very low level (below 2.5 MNm) across the entire tunnel circumference. Although the diagram shows the eccentric loading of the tunnel structure, it gradually approaches the tunnel's state when the waste dump above is not considered.

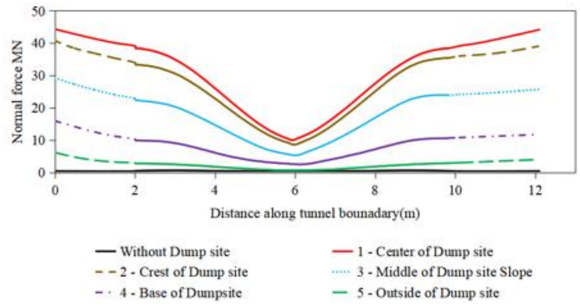

Figure 11. Effect of the relative position between the tunnel and the waste dump on the normal forces in the tunnel structure

Figure 11 shows how the relative position of the surface waste dump directly affects the strength and distribution pattern of the normal force in the support structure. Overall, the normal force graphs at all positions have a symmetrical shape, decreasing gradually from both ends of the perimeter and reaching a minimum value at the tunnel roof.

Position 1, The support structure withstands the greatest pressure in the entire graph. The compressive normal force reaches its maximum value at both ends of the wall base (~44 MN) and remains high throughout the wall height, reflecting the very strong overall compressive impact from the weight of the symmetrical waste dump above. At positions 2 and 3, the normal force tends to decrease in intensity but still remains very high (maximum values at the side/base of the wall reach approximately 40 MN and 29 MN, respectively). At positions 4 and 5, the artificial pressure created by the waste dump has significantly decreased. The maximum normal force at position 4 has sharply decreased to below 16 MN. At Position 5, the compressive axial force value is only below 5 MN. In summary, the above results confirm that the spatial region from Position 1 to Position 3 is the most unfavourable loading area, causing maximum bending moment at the tunnel crown, and maximum normal force at the tunnel base and walls. From Positions 4 and 5, the internal forces in the support structure have decreased significantly, but clearly show the support structure resisting eccentric loading caused by the waste dump. This is the core scientific basis for calculating local reinforcement or adjusting the support spacing parameters using SVP steel in the tunnel segments located in this hazardous impact zone.

III. CONCLUSION

This study used numerical simulations to systematically investigate the influence of surface waste dumps on the behaviour of tunnel structures, through three main groups of factors: the bulk density of the dumped rock, the height of the waste dump development, and the relative position between the tunnel and the waste dump. Based on the analysis of bending moments and normal forces for a U-shaped typical with a straight wall and semicircular arch structure currently applied in the Quang Ninh mining area, the results obtained allow us to draw the following conclusions:

Firstly, the bulk density of the dumped rock is a parameter that directly influences the magnitude of internal forces in the tunnel structure. As the density of the waste dump increases, both the bending moment and normal force in the support structure increase according to a clear and consistent pattern, regardless of the tunnel's shape.

Secondly, the waste dump height – through its increase over time – influences the development of internal forces in the support structure through an accumulation mechanism. The results show that the bending moment increases rapidly and is most sensitive to the height of the waste dump, especially for U-shaped support structures, while the normal force increases relatively steadily and reflects the overall compressive state.

Thirdly, the relative position between the tunnel and the waste dump is a determining factor in the degree of unfavourable internal forces in the support structure. When the tunnel is located below the centre of the waste dump, the internal forces reach their maximum value; when shifting towards the top of the slope, the middle of the slope, the foot of the waste dump, and outside the waste dump area, the bending moment and normal force gradually decrease according to a clear pattern.

These scientific results and arguments are an important basis for selecting unfavourable calculation cases, proposing solutions for rational adie layout, and guiding the reinforcement of support structures under conditions of surface waste dumps.

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