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NGUYEN HUU SA

STUDY ON THE IMPACT OF SURFACE MINE WASTE DUMPS ON THE BEHAVIOR OF ROADWAY STRUCTURES IN THE QUANG NINH COAL REGION.

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THESIS SUMMARY

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Scientific supervisors:

1. Asso.Prof., Dr. Dang Van Kien

2. Asso.Prof., Dr. Dao Viet Doan

Reviewer 1: **Prof., Dr. Do Nhu Trang**

University of Transport Technology

Reviewer 2: **Asso.Prof., Dr. Nguyen Chi Thanh**

Hanoi University of Mining and Geology

Reviewer 3: **Dr. Nguyen Thi Nguyet Hang**

Hanoi University of Civil Engineering

The thesis will be defended before the Academic Review Board at the University level at Hanoi University of Mining and Geology at ….h…., ….. October 2026.

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GENERAL INTRODUCTION

1. The necessity of the study

Operational experience shows that roadways beneath surface waste dumps suffer greater deformation and higher risks of support instability compared to unaffected ones. However, current ground pressure calculations focus primarily on natural topographical and geological conditions, failing to systematically quantify the artificial loads imposed by these dumps. With waste dumps becoming increasingly massive, conducting quantitative assessments of their impact on the mechanical behaviour of underlying support structures is essential. This research holds both scientific and practical significance for the design, maintenance, and operational safety of coal mining in the Quang Ninh region.

2. The purpose of thesis

The study and assessment of the impact of surface waste dumps, considering parameters such as the unit weight of the waste material, the height of the waste dump, and the location of mine workings relative to the waste dump, examines how these elements influence the behaviour of steel structures in mine workings situated beneath the waste dump.

3. Object of this study

Steel support structure for a horizontal mine roadway located beneath a surface waste dump.

4. Scope of this study

In the Quang Ninh coal region, horizontal roadways with circular or straight-walled, single-centred arched cross-sections, supported by steel structures, are situated beneath surface waste dumps and designed for long-term use.

5. Content of this study

The thesis focuses on the following key areas:

- An overview of surface waste dumps and methods for calculating the pressure exerted on roadway structures;
- Development of a numerical model to simulate surface waste dumps and the roadways located beneath them;
- Investigation into the impact of surface waste dumps on the mechanical behaviour of roadway structures;
- Analysis of the influence of waste dumps on the behaviour of steel structures for mine roadways located beneath the waste dump at the Mong Duong coal mine, Quang Ninh.

6. Scientific and practical meaning of this thesis

- *Scientific Meaning*: This study refines the theoretical and methodological framework for evaluating how surface waste dumps impact roadway support structures. It clarifies the distribution and variation patterns of internal forces within these supports based on changing waste dump parameters.
- *Practical Meaning*: The findings offer a reliable scientific basis for designing, selecting, and optimising spacing for steel supports in roadways beneath waste dumps. Furthermore, the results serve as a valuable reference for designing and managing affected roadways, specifically in the Quang Ninh coal region, ultimately enhancing support efficiency and structural stability.

7. Methodology of this study

- Theoretical research: Reviewing, analysing, and synthesising domestic and international literature concerning mine surface waste dumps and mine roadways located beneath them; establishing a theoretical framework to study the impact of surface waste dumps on the mechanical behaviour of support structures for underlying roadways.

- Numerical modelling method: The finite element method (using the Phase2 software) is employed to simulate mine surface waste dumps and the roadways situated beneath them within a 2D context. This involves developing a computational model to investigate influencing factors including a specific case study at the Mong Duong coal mine and analysing the mechanical response of the roadway support structures.

8. The new highlights of this thesis

- The thesis develops a 2D numerical model simulating a surface waste dump and an underlying steel-supported roadway. This model is validated against the 2D half-space solutions of Boussinesq and Hamilton Gray.
- It analyses the dump's impact on the structural behaviour of steel-supported roadways beneath it, specifically circular and semi-circular arched profiles with straight side walls. The analysis evaluates three scenarios: variations in waste rock unit weight, dump height, and roadway location.
- These factors are investigated within the specific context of the Mong Duong mine's surface dump in Quang Ninh. The primary focus is how the dump's height influences the underlying roadway's mechanical behaviour.

9. Primary argument of this thesis

- Argument 1: Changes in the height, volume, and relative position of a surface waste dump alter both the magnitude and the distribution pattern of internal forces within the steel support structures of the underlying mine workings.
- Argument 2: Changes in the cross-sectional shape of mine workings located beneath a surface waste dump alter the magnitude and distribution pattern of internal forces within the support structures.

10. Database

The database used for the research in this thesis includes:

- Geological reports and the current status of waste dumps at coal mines in the Quang Ninh region;
- Geological cross-sections passing through waste dump areas, including underlying coal seams that have been, are being, or will be exploited within the Quang Ninh coalfield;
- Geomechanical conditions of the coal-rock mass, as well as the mechanical and physical properties of waste rock and soil in the Quang Ninh coalfield;
- Relevant scientific studies, research papers, and publications from both domestic and international sources.

11. Thesis outline

This thesis consists of general introduction, 4 chapters, general conclusions, perspectives, published manuscripts and references. The whole content of this thesis is illustrated in 84 pages of A4 size, including 14 tables and 54 figures

CHAPTER 1: LITERATURE REVIEW ON SURFACE WASTE DUMPINGS IN MINES AND CALCULATING PRESSURE ACTING ON ROADWAY STRUCTURES

1.1. Introduction

1.1.1. Type of surface waste dumping

Currently, mine waste dumps, both globally and in Vietnam, can be categorised primarily as follows:

a) Based on location: Depending on their location, surface waste dumps are classified as: internal dumps; external dumps; valley-fill dumps; side-hill dumps; and mixed-type dumps.

b) Based on duration of existence: Depending on the specific characteristics and conditions of the mining operation, waste dumps may be designed as either temporary or permanent.

c) Based on construction technology: Waste dumps are constructed by truck-and-dozer operations; conveyor systems with stackers or unloading bridges; or excavation and dumping using draglines (excavators with suspended buckets). Dumps may also be configured as single-tier or multi-tier structures.

1.1.2. Formation characteristics and origin of waste rock dump materials.

The characteristics of waste rock dumps are among the primary factors governing the stress-strain state of the underlying rock mass, as well as the behaviour of underground workings. These characteristics can be examined through the following:

- Waste rock dumps are formed through a process involving:

+ Incremental dumping of loose material via trucks or conveyors;

+ The self-reorganisation of the rock structure under the influence of gravity;

+ Secondary restructuring driven by rainfall, erosion, leaching, and water saturation;

+ Compaction over time, resulting in a material mass that becomes increasingly dense while retaining its granular (loose) nature.

Crucially, waste dumps are dynamic structures that evolve over time and are highly susceptible to climatic factors. In Quang Ninh, heavy rainfall exacerbates landslide risks and amplifies the load on the underlying foundation. Furthermore, because these materials derive from diverse excavated strata and transport methods, their geotechnical properties are highly heterogeneous

- Material composition: A mixture of clay, silty clay, silty sand, rock fragments, interbedded rock, claystone, siltstone, sandstone, and conglomerate. Particle sizes range from fine-grained soil to large boulders measuring 1–2 meters, with significant heterogeneity in both vertical and horizontal directions.

- Structural state: Characterised by high porosity and low initial density—which increases over time-the material behaves as a loose, granular mass with a structure consisting of a mix of individual particles and rock blocks.

- Origin and composition of waste rock dump materials: Waste rock dumps serve as repositories for waste soil and rock generated by one or more mining operations. The primary lithological composition of the rock strata in the Cam Pha, Hon Gai, and Uong Bi mining areas includes: Quaternary cover, conglomerate, gritstone, sandstone, siltstone, claystone, and carbonaceous claystone. A summary of the physical and mechanical properties of the intact rock is presented in Table 1.1 [28].

Bảng 1.1. Summary of the properties of intact rock types

Region	Rock type	Distribution ratio, %	Bulk density, ρ, g/cm³	Particle density, ρ_s, g/cm³	Compressive strength, σn, MPa	Tensile strength, σ_k, MPa	Cohesion, C, MPa	Angle of internal friction, φ, degrees
Cam Pha	Claystone	3,4	2,667	2,751	28,856	4,597	8,715	31,43
	Siltstone	25,4	2,673	2,749	48,076	5,659	14,714	33,37
	Sandstone	47,7	2,659	2,721	99,956	10,902	37,098	34,45
	Conglomerate	15,3	2,594	2,674	127,313	13,427	43,825	34,4
Hon Gai	Claystone	6	2,58	2,67	35,326	3,286	9,282	29,67
	Siltstone	33	2,65	2,72	60,663	5,923	18,472	32,5
	Sandstone	34	2,63	2,7	117,19	10,424	36,489	34,07

	Conglomerate	14	2,57	2,66	137,56	11,098	41,523	33,93
Uong Bi	Claystone	11	2,63	2,74	29,382	3,669	8,734	31,45
	Siltstone	38	2,68	2,77	46,964	5,354	13,9	32,35
	Sandstone	35	2,67	2,72	107,199	9,499	33,7	33,48
	Conglomerate	7	2,67	2,7	128,981	13,316	51,1	34,63

Table 1.1 shows that the rock types at the mines have an average bulk density of 2.6 g/cm³, with strength ranging from medium to hard and very hard. However, when excavated and deposited in waste dumps, the bulk density, cohesion, and angle of internal friction decrease compared with their intact, in-situ values. Consequently, different rock mass types have different bulk densities, which in turn exert different artificial pressures on mine workings beneath the waste dumps. Thus, different waste rock materials impose different loads on mine workings beneath the waste dumps. Table 1.2 presents experimental results for determining the bulk density of waste rock—in both its natural and saturated states—at coal mines in the Quang Ninh region [28].

Table 1.2. Summary of experimental results for determining the bulk density of waste rock in natural and saturated states

	Region	**Waste dump name**	**Number of samples**	**Natural bulk density, ρ_{tn}, t/m³**	**Saturated bulk density, ρ_{bh}, t/m³**
1	Cam Pha	BT. Trong - L.Tri D.Nai	4	2,274	2,428
		BT. Dông K.Sim D.Nai	4	2,292	2,428
		BT. Dông C.Son	6	2,228	2,376
		BT. B.Nau - Cao Son	4	2,082	2,180
2	Hon Gai	BT.V 7+8 Ha Tu	4	2,062	2,208
		BT. CB.H Tu	4	2,188	2,32
		BT. CB.N Beo	4	2,370	2,523
3	Uong Bi	BT.M Khe	4	2,073	2,240

1.2. Current status of coal seams beneath waste dumps in the Cam Pha area, Quang Ninh

At the Mong Duong coal mine: Beneath the Mong Duong mine waste dump lies an area managed and exploited by the Mong Duong coal mine, encompassing several coal seams: V.G (9), V.K8, V.7b, VL (7), V.M (6), V.N (5), V.0 (4), V.4a, and V.3. Among these, seams V.G (9), V.K8, and V.7b have already been exploited; in the area beneath the waste dump, these seams are distributed between the -150 and +30 elevation levels [5], [8]. The geological cross-section along line A-A—covering the mine waste dump area as well as the exploited and unexploited coal seams—is illustrated in Figure PL1.2.1.

At the Khe Cham coal mine: an area managed and exploited by the mine lies beneath the Bang Nau mine waste dump. All coal seams in this area lie beneath the Bang Nau waste dump, including V11, V12, V13.1, V13.2, V14.1, V14.2, V14.4, V14.5, V15, V16, and V17. Currently, seams V.14.2 and V.14.5 are being exploited. The geological cross-section along line VIIII—covering the mine waste dump area as well as the exploited and unexploited coal seams—is illustrated in Figure PL 1.2.2. At the Duong Huy coal mine: Beneath the Khe Tam – Duong Huy waste dump lies an area managed and exploited by the Duong Huy coal mine, encompassing coal seams V.6a, V.6, V.7a, V.7, V.8, V.9, V.10, V.11, V.12, V.13, V.14, V.15, and V.15b. Among these, seams V.13, V.14, V.15, and V.15b have been exploited in the area beneath the waste dump, spanning elevations from +0 to +100. The geological cross-section along line V—covering the area with the mine waste dump as well as both exploited and unexploited seams—is illustrated in Figure PL 1.2.3.

At the Quang Hanh coal mine: Beneath the Quang Hanh coal mine's waste dump lies an area managed and exploited by the Quang Hanh coal mine, encompassing coal seams V1, V2, V2a,

V2b, V3, V3a, V3b, V4, V5, V6, V10, V11, V12, V15, V16, V17, V18, V19, and V20. Of these, seams V19 and V20 are located near the surface and have already been exploited [7], [12]. Figure PL 1.2.4 illustrates the geological cross-section along line IVa, covering the area with the mine waste dump and both exploited and unexploited seams. At the Ha Lam coal mine: Beneath the Nui Beo coal mine waste dump lies an area managed and exploited by the Ha Lam coal mine, encompassing several coal seams: V.13(9), V.11, V.10, V.9, V.7, V.6, V.5, V.4, and V.3. Among these, seams V.13 and V.11 have already been exploited; in the area beneath the waste dump, these seams are distributed between the -100 and -150 elevation levels. Figure PL 1.2.5 presents a geological cross-section along line 40, covering the mine waste dump area and both exploited and unexploited coal seams.

At the Nui Beo coal mine: Beneath the Nui Beo coal mine waste dump lies an area managed and exploited by the Nui Beo coal mine, which includes the following coal seams: V31a, V4(1), V5(2), V6(3), V7, V7(4), V9, V9(6), V10, V11(2), V11(8), and V13. Of these, seams V.11(8) and V.11 have already been exploited. Many coal seams—which have been, are being, or will be exploited—lie beneath the mine waste dump. Consequently, it is essential to study methods for calculating the pressure the waste dump exerts on the underground mine workings (gateways/tunnels) beneath it. Such research is necessary to determine the appropriate support system type and structural parameters, ensuring the stability of these workings throughout their operational lifespan.

1.3. Overview of Methods for Calculating Internal Forces in Steel Support Structures for Mine Roadways

Steel support frames commonly stabilise mine roadways. Depending on operating conditions, a frame may consist of multiple segments connected with either rigid or friction-based joints. The support frame shape also varies by application, ranging from trapezoidal, rectangular, square, and arched to horseshoe-shaped or circular.

Various methods exist for calculating internal forces in roadway support structures; the primary approaches include:

- Analytical Calculation Method: This method uses mechanical equations and equilibrium conditions to determine the rock pressure on the support structure, then calculates the internal forces—axial force (N), shear force (Q), and bending moment (M)—within the structure. While simple and efficient, this approach depends heavily on assumptions about geological conditions and the distribution pattern of the applied loads.

- Elastic Foundation Method: This approach treats the rock mass surrounding the roadway as an elastic foundation, while modelling the support structure as an elastic beam or arch. Loads and internal forces in the structure are determined from the relative displacement between the rock mass and the support, with the foundation reaction force depending on the support's displacement. This method better represents rock–support interaction and is well-suited for roadways under high pressure or complex geological conditions.

- Rock–Support Interaction Method: This method considers the simultaneous interaction between the rock mass and the support structure, where the load on the support depends on rock-mass deformation after excavation. The equilibrium state is determined at the intersection of the rock mass response curve and the support system characteristic curve; this allows assessment of tunnel convergence, support loads, and the overall stability of the rock-support system.

- Numerical modelling methods: These methods use numerical computation to simulate interactions between the rock mass and the support system. They are particularly well-suited to tunnels with complex geological conditions, high pressure, or intricate geometries. Two common categories of these methods include:

+ Finite element method: The rock mass is discretised into elements, while the support system is modelled with beam or frame elements; this allows determination of internal forces and displacements within the support.

+ Finite difference method and discrete element method: These are suitable for problems involving large deformations, failure, fracturing, and collapse of the rock mass; they allow for the simulation of deformation processes and the transfer of loads onto the support system.

Conclusion to Chapter 1

During waste dumping, the unit weight of the waste material—comprising soil and rock—can vary with material type, particle size, dump formation duration, and other factors. The height of a waste dump evolves during dumping, and mine workings (underground galleries or tunnels) may be located at various positions relative to the dump: beneath its centre, under its slopes, or entirely outside its footprint.

In the Quang Ninh coal region, many coal seams—currently being exploited, previously exploited, or yet to be exploited—lie beneath these waste dumps. Consequently, the associated mine workings are subjected to artificial loads from the mine waste dumps above them.

Various methods calculate internal forces in mine support structures, including analytical methods, the elastic foundation model, displacement-based methods, and numerical methods (such as the finite element method, finite difference method, and discrete element method).

CHAPTER 2: DEVELOPMENT OF A NUMERICAL MODEL SIMULATING A MINE SURFACE DUMP AND UNDERLYING MINE WORKINGS

2.2. Development of the Numerical Model

The software program Phase2 is based on the finite element method. In this approach, the domain under study is discretised into a mesh of finite-sized elements connected at nodal points. This method transforms the solution of a system of differential equations into a system of algebraic equations that relate nodal forces to nodal displacements via a "stiffness matrix." Shape and interpolation functions describe the stress and strain behaviour within each element. Phase2 enables the simultaneous simulation of geological conditions, surface dump loads, mine support structures, and the construction sequence as it occurs in practice. The results provide data on internal forces within support structures, stress and strain distributions, and more.

In this study, the numerical model is developed based on the assumptions above, with the surface dump represented as a trapezoidal distributed load applied to the model surface. The steps for developing and validating the numerical model include:

- Step 1: Constructing a numerical model using a homogeneous rock mass;
- Step 2: Applying a trapezoidal load to the model's surface (representing the load from the mine surface dump);
- Step 3: Verifying the reliability of the numerical model by referencing the classical problem—originally formulated by Boussinesq (1885)—of determining the additional stress distribution within an elastic semi-infinite medium subjected to surface loading (including solutions for both concentrated and uniformly distributed loads). - Hamilton Gray (1936) provided a solution for the problem of linearly distributed loads, including trapezoidal load distributions—a configuration consistent with the numerical model (BTBM) employed in this study under identical boundary conditions.
- Step 4: Utilise the validated model to simulate the excavation of the mine roadway under various scenarios: varying the unit weight of the waste material in the dump, adjusting the height of the dump, and altering the relative positioning between the roadway and the dump. This analysis covers both circular and straight-walled, semi-circular arched roadway

profiles. The details of this research will be presented in Chapter 3.

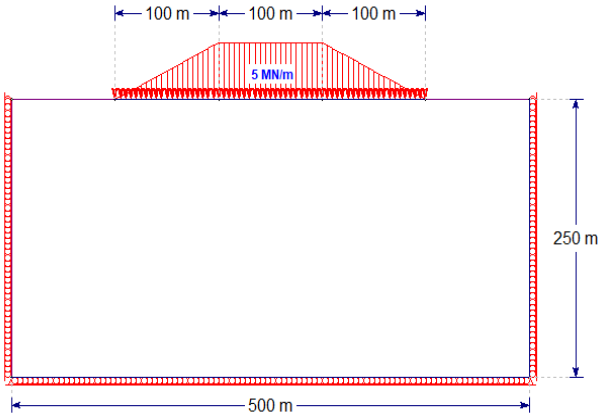


Figure 2.1. Numerical model for simulation problems

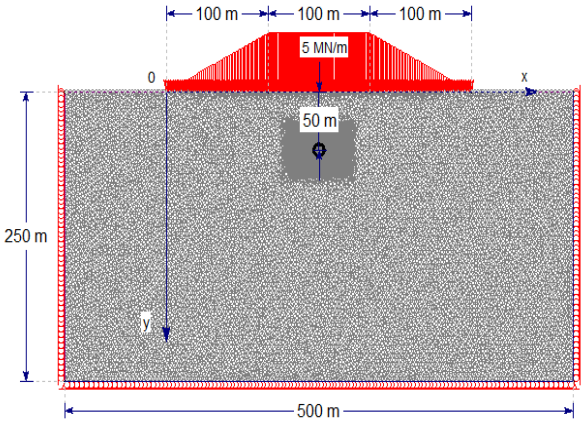


Figure 2.2. Meshing and boundary fixation in modeling

2.2.1. Model Dimensions

The model dimensions were determined by evaluating various sizes to minimise boundary-condition effects, ensure displacements and stresses near the boundaries align with the initial (in-situ) stress field, and satisfy semi-infinite-medium requirements. A 2D plane-strain model measuring 500 × 250 m was selected, featuring a surface waste dump with a base width of 300 m and a crest width of 100 m (Figure 2.1). This model is used consistently to investigate how the unit weight of the waste material, the waste dump height, and the relative positioning of the mine drift to the surface waste dump affect the behaviour of the steel support structures.

2.2.2. Finite element mesh generation and assignment of initial boundary conditions

The rock mass is discretised into 6-node triangular finite elements. As the model dimensions are sufficiently large to minimise the influence of boundary conditions, zero-displacement constraints are applied to the model boundaries in both the Ox and Oy directions, as illustrated in Figure 2.2.

The coordinate convention used in Phase 2 is as follows: x represents the horizontal direction, y represents the vertical direction, and z represents the direction perpendicular to the model plane. The input parameters for the rock mass in the model are presented in Table 2.1.

Table 2.1. Properties of rock mass

STT	Paramater	Unit	Value
1	Unit weight	kN/m^3	20,0
2	Deformation modulus (E)	MPa	4611,0
3	Poisson's ratio (μ)	-	0.3
4	Uniaxial compressive strength of intact rock (σ_{ci})	MPa	37,8
5	GSI	-	50,0
6	Rock mass material constants, mi	-	7,0
7	D	-	0,5
8	m_b		0,6472
9	s		0,0013
10	a		0,5057
11	Lateral earth pressure coefficient (K0)	-	0,5
13	Failure criterion	-	Hoek-Brown

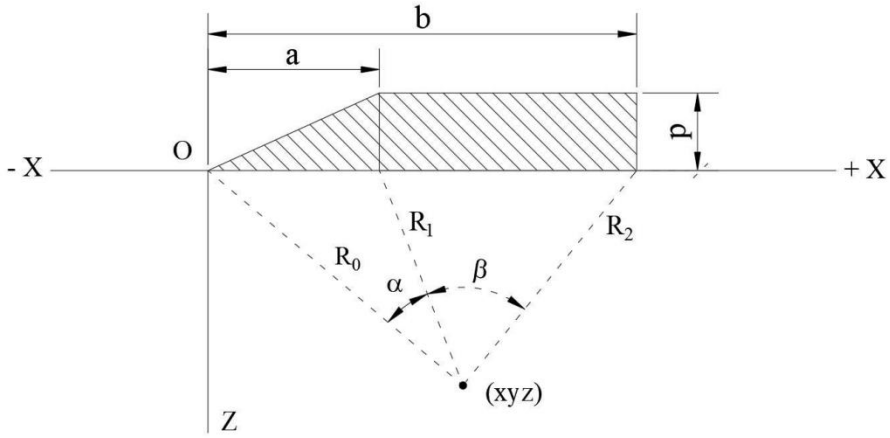


Figure 2.3. The problem of an elastic infinite half-space

2.3. Model Verification

2.3.1. Analytical solution for a semi-infinite half-space subjected to surface loading

The problem assumes the soil or rock mass is a two-dimensional semi-infinite half-space (Oxz-plane), where Ox and Oz represent the horizontal and vertical axes, respectively; the medium is elastic, homogeneous, and isotropic. Under surface loading, additional stresses develop within the soil or rock mass and are distributed throughout space.

The distribution of additional stresses in an elastic semi-infinite half-space subjected to surface loading has been studied by numerous authors. Boussinesq (1885) provided solutions for concentrated loads and uniformly distributed loads, while Hamilton Gray (1936) developed a solution for trapezoidally distributed loads [42]. This approach is applicable to the type of loading used to simulate surface waste dumps in this study, as illustrated in Figure 2.3 and expressed by equations (2.5) through (2.7).

The stress results in the x and z directions for any given stress element within an elastic semi-infinite half-space are calculated using the following formulas:

- Horizontal stress

$$\sigma_x = \frac{p}{\pi a}\left[a\beta + x\alpha + \frac{az}{R_2^2}(x-b) + 2z log_e \frac{R_1}{R_0}\right] \qquad (2.5)\ [42]$$

- Vertical stress

$$\sigma_z = \frac{p}{\pi a}\left[a\beta + x\alpha - \frac{az}{R_2^2}(x-b)\right] \qquad (2.6)\ [42]$$

- Shear stress:

$$\tau_{xz} = -\frac{p}{\pi a}\left[z\alpha - \frac{az^2}{R_0^2}\right] \qquad (2.7) \qquad [42]$$

Here, x and z are the two-dimensional coordinates within an infinite elastic half-space Oxz; R0, R1, and R2 are the radial distances from the observation point to the locations of the loads on the surface; α, β are the angles formed by R_0R_1 and R_1R_2, respectively; a and b represent the widths of the loaded segments along the Ox axis; p denotes the load intensity, expressed as force per unit length. In a plane-strain model, the thickness in the direction perpendicular to the cross-section is conventionally taken as 1 m. Consequently, a load of P = 5 MN/m is equivalent to a surface pressure of p = 5 MPa.

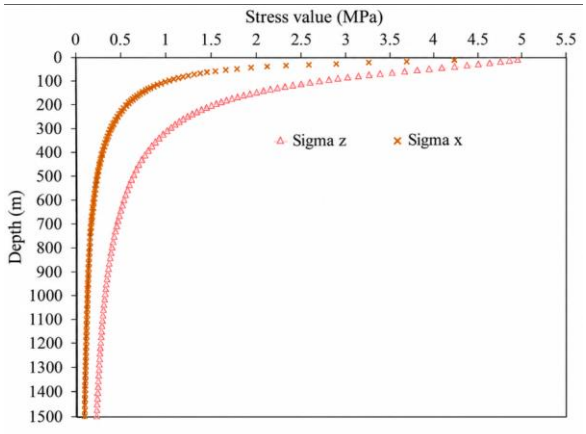


Figure 2.4. Relationship between stress components Sigma z and Sigma x and depth

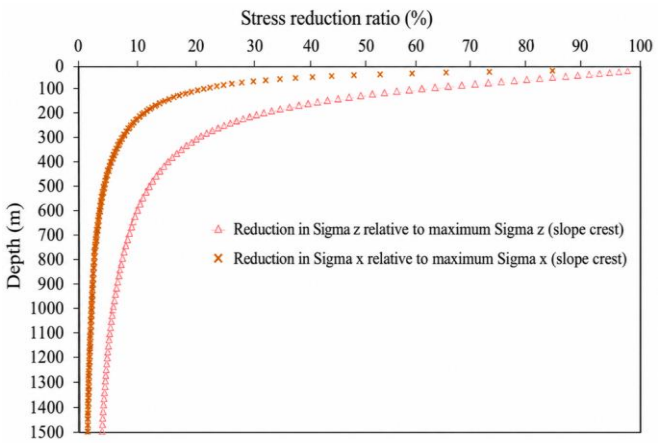


Figure 2.5. Relationship between the stress reduction ratios (Sigma z and Sigma x) and depth

2.3.2. Investigation of the limiting depth and the suitability of the verification model dimensions

Based on Figure 2.1, equations (2.1) and (2.2), and the characteristics of a surface waste dump, determine the limiting depth beyond which surface loads' influence on the soil and rock mass becomes negligible. Using model parameters P = 5 MN/m, a = 100 m, b = 150 m, and b − a = 50 m, along with equations (2.5), (2.6) and Figure 2.3, the stress distributions (σz and σx) were calculated down to a depth of 1,500 m at a location directly beneath the slope crest (Figures 2.4 and 2.5).

The results indicate that both σz and σx decrease with depth. Within the upper 200 m, the influence of the surface load is significant, with σz reaching approximately 1.5–5 MPa. At 500 m, σz drops to about 0.6 MPa (about 12% of the initial value), and at 1,000 m, it further decreases to about 0.22 MPa (about 4.9%). These findings show that the impact of surface loads diminishes rapidly with depth and becomes minimal at greater depths.

For σx, the influence of surface loading is clearly evident at depths of less than 200 m, with peak values ranging from approximately 0.5 to 4.23 MPa. As depth increases, σx gradually decreases; at a depth of 500 m, it drops to about 0.23 MPa (a 4.6% reduction), and at 1,000 m, it reaches approximately 0.11 MPa (a 2.3% reduction) (Figure 2.5).

These results indicate that the impact of surface loading is concentrated primarily within the top 200 m. Since the mine roadway in the research model is situated at a depth of 50 m, the effect of the surface waste dump load is significant. The model dimensions—500 m in width by 250 m in height—satisfy the research requirements while minimizing the influence of boundary conditions.

Furthermore, given the assumed surface surcharge, the additional stress induced by this load becomes negligible at depths exceeding 1,000 m below the ground surface. In this study, the "limiting depth" is defined as the point at which the additional stress resulting from surface loading diminishes to a negligible level compared to the stress values observed in the zone of significant impact. This threshold depends on the magnitude and distribution of the surface load, as well as the geometric parameters of the problem. Based on this, a depth of 1,000 m has been selected as the limiting depth for evaluating the influence of surface loading within the scope of this study.

2.3.3 Development of a Verification Model

The solution for the distribution of additional stresses within an elastic half-space subjected to surface loading serves as a suitable basis for investigating the impact of a surface waste dump on the behavior of underground roadway support structures. Given the significant

computational requirements and complex conditions of this problem, a numerical approach using the software Phase2 is employed. To ensure reliability, the numerical model is verified by comparing its results with the analytical solution provided by Hamilton Gray (1936).

The verification model has dimensions of 500 m (width) × 250 m (height). The surface waste dump is represented as a trapezoidal distributed load, with a top width of 100 m, a base width of 300 m, and a load intensity of 5 MN/m—corresponding to a waste dump height of 250 m and a unit weight of 20 kN/m³. The geotechnical parameters are presented in Table 2.1.

2.3.4 Verification Results

The initial (in-situ) stress state in the rock mass is simulated by accounting for gravity. This gravitational stress field is characterised by parameters in which the vertical stress is determined based on the unit weight of the rock mass and the depth of the point under consideration. Since the research problem focuses on the impact of a waste dump—which acts as an additional vertical surface load—the vertical stress component is of primary importance. This thesis compares the vertical stress component as calculated via analytical methods and numerical modelling.

The verification results for the additional stress—obtained through both analytical methods and the numerical model (Phase2)—are presented in Figure 2.6, which compares the vertical stress values at observation points located along the central axis beneath the waste dump.

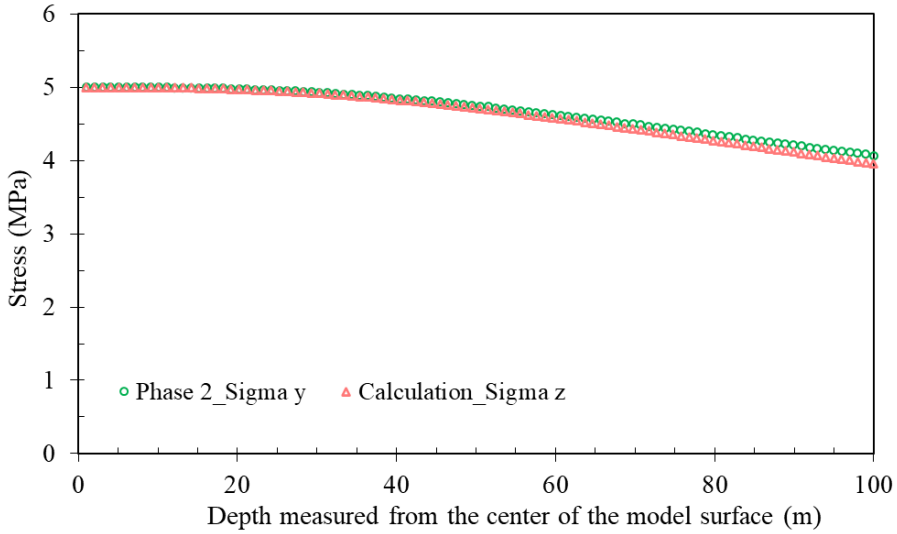


Figure 2.6. Verification results for stress values using analytical methods and software

Both the analytical results and the numerical model assume a homogeneous, elastic rock mass with no failure yet. Figure 2.6 shows that the distribution and variation trend of σy with depth, as derived from the numerical model, align with the analytical results; the numerically simulated stress curve closely follows the theoretical values. The average discrepancy between the two methods is approximately 2.0%, primarily due to differences in boundary conditions and computational approaches.

Given the minor deviation and the fact that the stress distribution trend almost perfectly matches the theoretical solution, the numerical model developed in this thesis using the Phase2 software accurately captures the mechanical nature of load transfer from the surface to the underlying rock mass. These verification results confirm the validity of the numerical simulation procedures employed in Phase2 for constructing the model and investigating the parameters used to support the thesis's arguments. Consequently, the model is sufficiently reliable for use in subsequent analyses presented in Chapter 3 regarding the impact of mine surface waste dumps on the mechanical behaviour of support structures for mine roadways

located beneath them.

2.4. Case Studies

2.4.1. Geometry and Dimensions of Underground Openings Beneath a Waste Dump, and Support Structures

The investigation considers two types of underground openings: circular and straight-walled with a semi-circular arch. The model dimensions are 500 m in width by 250 m in height. The waste dump is modelled as a trapezoidal distributed load, with a base width of 300 m, a top width of 100 m, and a maximum height of 250 m. The circular opening has a diameter of 5 m and is positioned 50 m below the ground surface, while the straight-walled opening with a semi-circular arch measures 5 m in width and 5 m in height and is also located 50 m below the ground surface. These configurations are illustrated in Figure 2.7. In the simulation scenarios, the support structure for the mine roadway is modeled using beam elements equivalent to SVP33 steel arches; the parameters for this support structure are presented in Table 2.2.

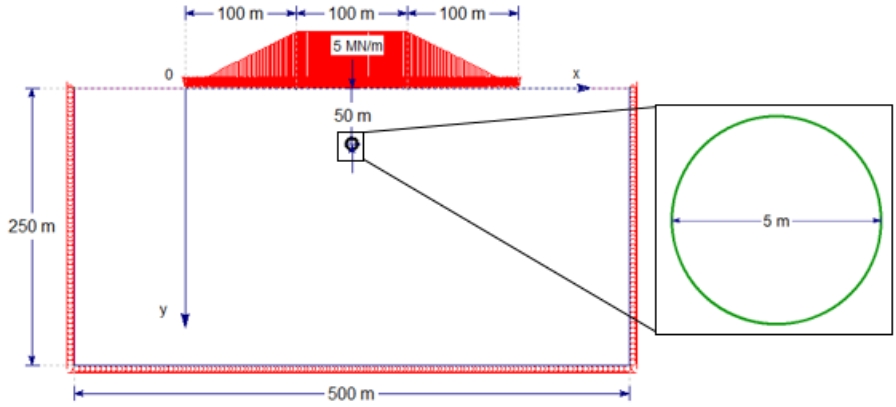


Figure 2.7. Numerical model for circular roadway

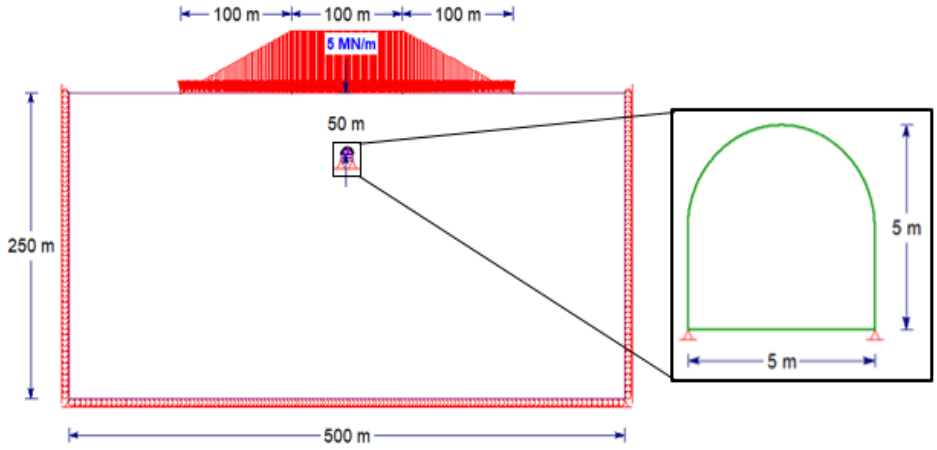


Figure 2.8. Numerical model for roadway with straight side walls and a semi-circular arch.

Figure 2.2. Parameters of steel rid-SVP33

STT	Parameters	Symbl	Value	Unit
1	***Circular roadway***			
	Diameter	D	5,0	m
2	***Straight-walled semi-circular arched roadway***			
	Wall height	h	2,5	m
	Width	b	5,0	m

	Crown Radii	R_v	2,5	m
3	***Steel rid-SVP33***			
	Support spacing	l	0,5	m
	Cross-section height	-	0,137	m
	Cross-sectional area	S	0,00425	m^2
	Modulus of deformation	E	200000	MPa
	Poisson's ratio	μ	0,35	-
	Compressive strength	σ_n	500	MPa
	Tensile strength	σ_k	500	MPa
	Mass per unit length	-	33	Kg/m

2.4.2. Influence of the unit weight of waste soil and rock on the behavior of the retaining structure

The unit weight of waste dump material depends primarily on its composition, degree of weathering, particle size, and compaction state. Loose, highly weathered waste soil and rock typically exhibit a lower unit weight, whereas fragmented rock and larger rock blocks have a higher unit weight; compacted material possesses both a higher unit weight and greater stability. In this study, the unit weight is considered within the range of 14–22 kN/m³, specifically using the values γ = 14, 16, 18, 20, and 22 kN/m³. The model configuration is illustrated in Figure 2.9.

2.4.3. Influence of the waste dump height on the mechanical behavior of the retaining structure

In this study, the height of the waste dump is examined at levels of H = 50, 100, 150, 200, and 250 m. The model configuration is illustrated in Figure 2.10.

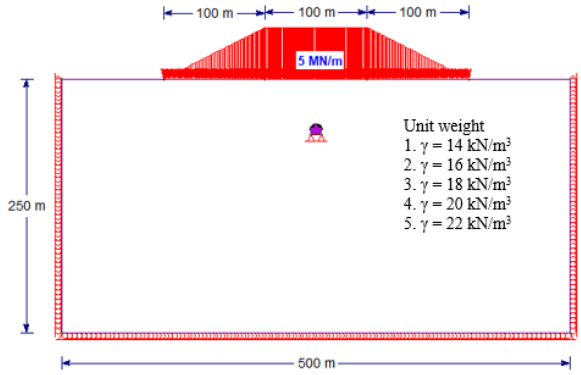


Figure 2.9. Case study model of changes in the bulk density of waste rock and soil

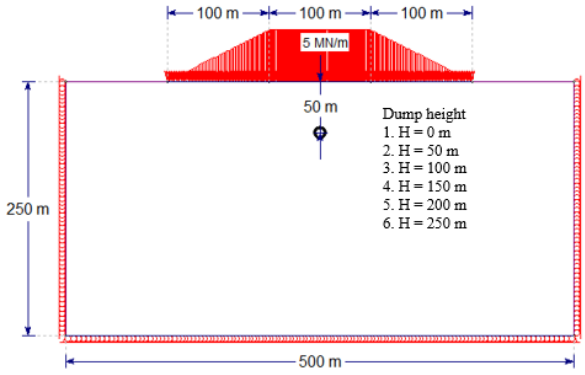


Figure 2.10. Case study model of waste dump height variation

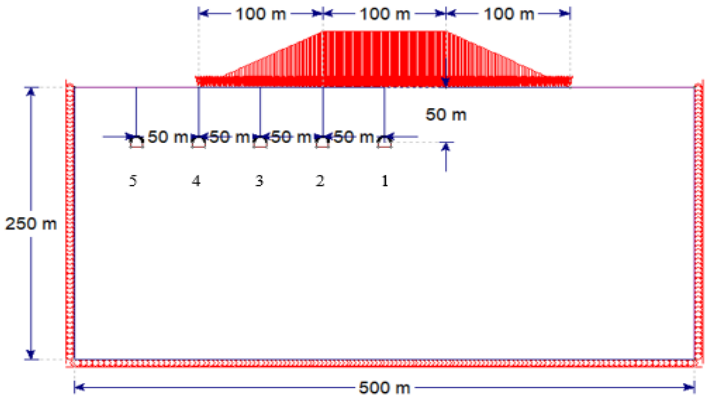


Figure 2.11. Case study model of mine roadway placement in relation to waste dumps

2.4.4. Influence of the mine roadway's location relative to the waste dump on the mechanical behavior of the support structure

In addition to the unit weight of the waste material and the height of the waste dump, the position of a mine roadway relative to the surface waste dump significantly affects the stress state and internal forces within the support structure. Variations in the roadway's location alter the mechanism by which loads are transmitted from the waste dump to the rock mass, leading to differences in the behavior of the support structure.

This thesis examines five potential locations for the mine roadway: (1) beneath the center of the waste dump; (2) beneath the crest of the slope; (3) beneath the mid-slope; (4) at the toe of the waste dump; and (5) outside the footprint of the waste dump. These scenarios are used to compare and evaluate the extent to which the location of the waste dump influences the support structure of the mine roadway (Figure 2.11).

Chapter 2 Conclusion

Based on the classical analytical problem concerning the distribution of additional stresses within an elastic semi-infinite half-space subjected to surface loading, this thesis develops a numerical model using the software Phase2 to investigate the impact of surface mine waste dumps on the behavior of underground mine roadway support structures. The numerical model has also been validated; the results indicate that the vertical and horizontal additional stress distributions obtained from the numerical model align with the theoretical solutions provided by Hamilton Gray.

Drawing on an analysis of how surface mine waste dumps are formed through surface-level dumping, this study examines the influence of such dumps on the mechanical behavior of support structures for both circular roadways and roadways with straight sidewalls and semi-circular arched roofs. The investigation covers the following scenarios:

1) The impact of the unit weight of the waste rock/soil on the mechanical behavior of the support structures;

2) The impact of the height of the waste dump on the mechanical behavior of the support structures;

3) The impact of the relative positioning of the mine roadway with respect to the waste dump on the mechanical behavior of the support structures.

The details and findings regarding these scenarios are presented in Chapter 3.

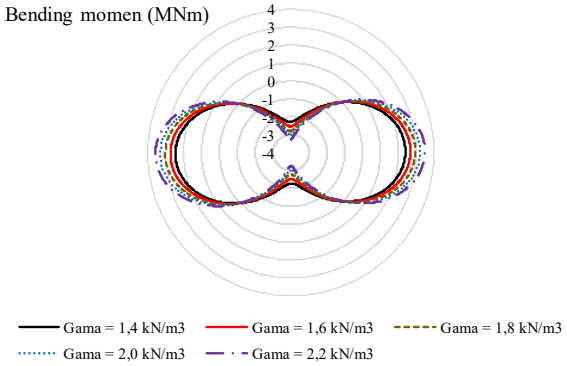
CHAPTER 3: STUDYING THE IMPACT OF SURFACE MINE WASTE DUMPS ON THE MECHANICAL BEHAVIOR OF MINE-OPENING SUPPORT STRUCTURES

3.1. Impact of the unit weight of waste rock/soil on the mechanical behaviour of support structures

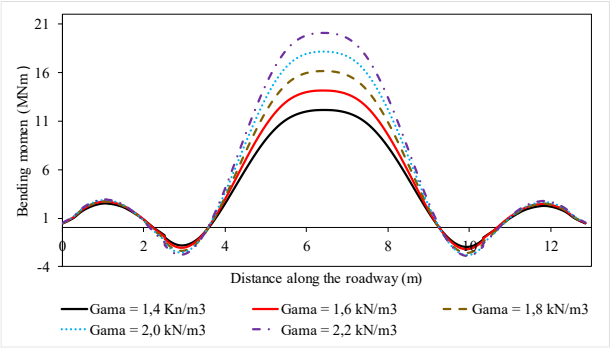
This case study evaluates the influence of the unit weight of waste rock/soil on the internal forces (bending moment M and axial force N) in steel support structures for mine openings specifically circular profiles and structures with straight sidewalls topped by a semi-circular arch located beneath a surface waste dump. The unit weight values examined are γ = 14, 16, 18, 20, and 22 kN/m³. Figure 2.10 and Tables 2.1 and 2.2 present the model and input parameters.

The summarised charts showing the bending moment (M) within the support structures for both types of mine openings, as the unit weight varies, are presented in Figure 3.1. Figure 3.2 summarizes the axial force diagrams for steel support structures in circular mine roadways and in roadways with straight side walls and semi-circular arched roofs, under various

scenarios involving changes in the unit weight of the waste rock/soil.

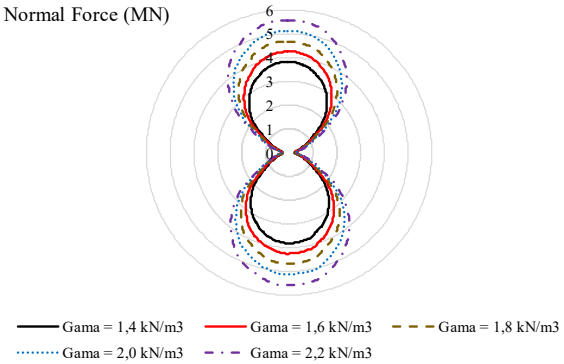


a. Bending moment in circular roadway structure

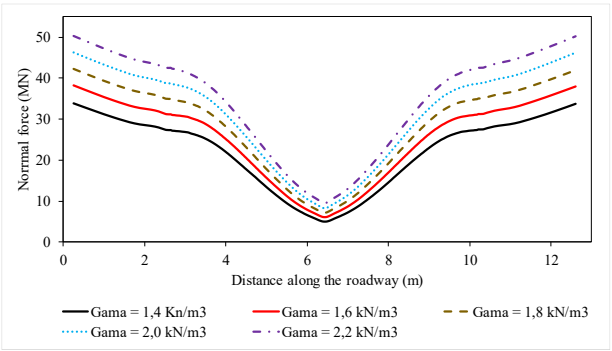


b. Bending moment in U shape roadway structure

Figure 3.1. Effect of unit weights of rock on bending moment (M) in steel structures



a. Normal forces in circular roadway structure



b. Normal forces U shape roadway structure

Figure 3.2. Effect of unit weights of rock on normal forces (N) in steel structures

Analysis of results:

Figures 3.1 and 3.2 show that as the unit weight of the waste rock increases, both the bending moment (M) and axial force (N) in the roadway support structures also increase. The bending moment (M) peaks at the roof of the roadway, while the axial force (N) peaks at the sidewalls for circular cross-sections and at the base of the walls for straight-wall, semi-circular arched cross-sections.

Under identical unit weight conditions, the internal forces within a circular support structure are lower than those in a straight-wall, semi-circular arched structure; this is because the closed circular geometry allows for a more uniform distribution of internal forces. Furthermore, the rate of increase in internal forces is greater for the straight-wall, semi-circular arched structure than for the circular structure as the unit weight of the waste rock rises.

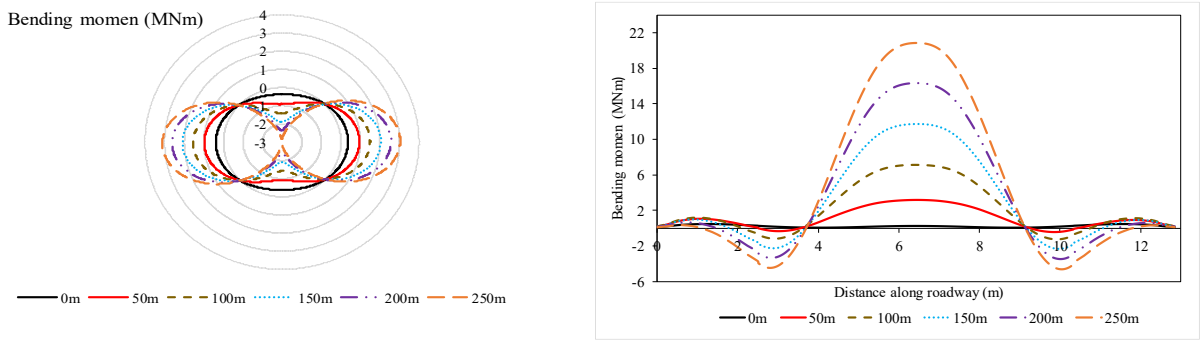
3.2. Influence of waste dump height on the mechanical behaviour of support structures

This case study evaluates the impact of waste dump height on the internal forces (M and N) in steel support structures for both circular and straight-wall, semi-circular arched roadways beneath a waste dump. The waste dump height was analysed at intervals of h = 0, 50, 100, 150, 200, and 250 m, representing the progression of the waste dump from its initial state (prior to dumping) up to a height of 250 m. The model and input parameters are detailed in Figure 2.10, Table 2.1, and Table 2.2. The summarised results for the bending moment (M) for both types of roadway cross-sections are presented in Figure 3.3.

A summary of the axial force diagrams for steel support structures in circular mine roadways and in roadways with straight side walls and semi-circular arched roofs—under varying waste-pile heights is presented in Figure 3.4.

Observations:

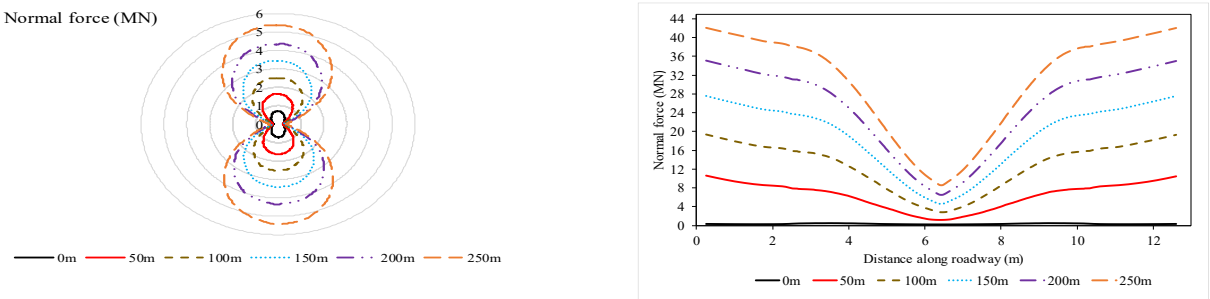
The results in Figures 3.3 and 3.4 show that as the surface waste dump height increases, the internal forces in the mine roadway support structures also increase; this holds for both circular cross-sections and straight-wall, semi-circular arch cross-sections. Under identical conditions, both the magnitude and the rate of increase of these internal forces are greater for the straight-wall, semi-circular arch supports than for the circular supports. This is because the straight-wall, semi-circular arch configuration functions as an open support structure, whereas the circular configuration acts as a closed support structure.



a. Bending moment (M) in circular roadway

b. Bending moment (M) in U shape roadway

Figure 3.3. Tổng hợp biểu đồ M trong KCC thép ứng với các chiều cao bãi thải



a. Normal forces (N) in circular roadway

b. Normal forces (N) in U shape roadway

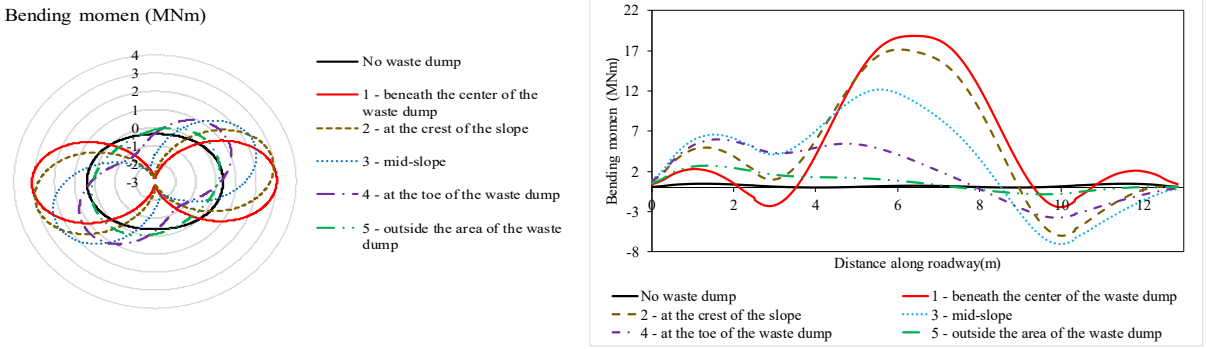
Figure 3.4. Effect of waste dump heights on axial force in steel structures

3.3. Influence of the relative position between the mine roadway and the waste dump on the mechanical behavior of the support structure

This study aims to evaluate the influence of the mine roadway's position relative to a surface waste dump on the internal forces within the steel support structures of circular roadways and roadways with straight sidewalls and semi-circular arches. Five positions were investigated: (1) beneath the center of the waste dump; (2) at the crest of the slope; (3) mid-slope; (4) at the toe of the waste dump; and (5) outside the area of the waste dump. The input parameters are presented in Tables 2.1 and 2.2.

The combined diagrams of the bending moment M within the support structures for both types of the roadway, based on their relative positions to the waste dump, are shown in Figure 3.5. The combined diagrams of the axial force N within the steel support structures, corresponding to the various relative positions of the roadway with respect to the waste

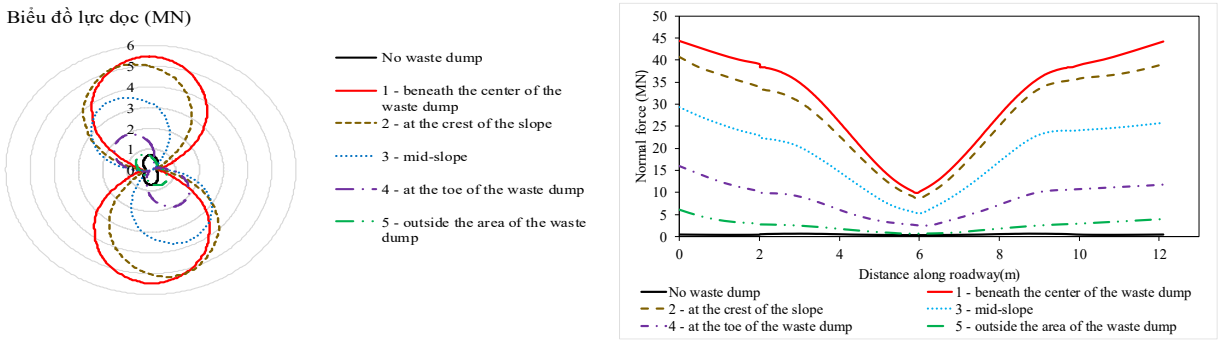
dump, are presented in Figure 3.26.



a. Bending moment (M) in circular roadway

b. Bending moment (M) in U shape roadway

Figure 3.5. Effect of waste dump heights on bending moment in steel structures



a. Normal forces (N) in circular roadway

b. Normal forces (N) in U shape roadway

Figure 3.6. Effect of surface waste dump-roadway position on axial force in steel structures

Observations:

The analysis results indicate that the relative position between the mine drift and the surface waste dump is a dominant factor influencing the distribution of internal forces within the support structure:

Regarding the distribution pattern: Without a surface waste dump, the bending moment diagram is symmetrical about the roadway axis. When the roadway is located beneath the centre of the waste dump, both the bending moment and axial force reach their maximum values while maintaining symmetry. As the roadway shifts toward the slope toe or moves entirely outside the waste dump footprint, the internal forces tend to decrease. Concurrently, the internal force diagrams become increasingly asymmetrical because of the waste dump load's eccentricity. Beyond the waste dump limits, the magnitude and configuration of the internal forces gradually revert to the state observed when no waste dump is present.

Regarding the sensitivity of internal forces: Bending moments are significantly more sensitive, often leading to eccentric bending and stress concentrations, particularly in the area beneath the slope of the waste dump. In contrast, axial forces vary more stably, primarily reflecting the overall compressive state of the support structure.

Regarding the influence of structural geometry: While the geometry of the roadway structure does not alter the aforementioned patterns of internal force variation, it does determine the degree to which the structure is subjected to unfavourable conditions. Closed-form structures experience lower internal forces and more stable load-bearing behaviour.

Conversely, open-form structures (such as U-shape) are more sensitive to changes in the roadway's position and are more susceptible to adverse effects induced by bending moments.

Chapter 3 conclusion

In Chapter 3, this thesis employs numerical simulations to evaluate the impact of surface waste dumps on the behaviour of roadway structures. The analysis considers three key factors: the unit weight of the waste material, waste dump height, and the roadway's relative position to the dump, across two structure types: circular and U-shaped roadways. The results indicate the following:

First, increasing the unit weight of the waste material increases both the bending moment (M) and the axial force (N) in the roadway structures, regardless of shape.

Second, as the waste dump height increases, internal forces in the support structures also rise; the bending moment (M) is more sensitive than the axial force (N), particularly in open (non-closed) structures.

Third, the roadway's relative position to the surface waste dump significantly influences the internal forces. A roadway located beneath the centre of the waste dump represents the most unfavourable scenario; as the position shifts toward the flanks, the toe, or areas outside the waste dump footprint, both the bending moment (M) and the axial force (N) tend to decrease.

These research findings provide a basis for identifying critical (unfavourable) conditions, selecting appropriate locations for mine roadways, and choosing suitable support structures. Furthermore, they offer guidance for the design and reinforcement of support systems in environments affected by surface waste dumps.

CHAPTER 4: STUDYING THE IMPACT OF SURFACE WASTE DUMPS ON THE STRUCTURES' BEHAVIOR BENEATH THE MONG DUONG COAL WASTE DUMP, QUANG NINH

4.2. Conditions of the Mong Duong Coal Waste Dump

To investigate the impact of the waste dump on steel structure behaviour, this thesis utilises geological cross-section AA, which passes through the centre of the Mong Duong coal, where the waste dump reaches a maximum height of 217 meters.

According to cross-section AA, the upper portion consists of a layer of waste rock, while the underlying strata comprise conglomerate, gritstone, sandstone, siltstone, and coal seams. Sandstone and siltstone are the predominant lithologies, whereas conglomerate and gritstone occur in thinner layers. The waste material consists of a heterogeneous mixture of conglomerate, gritstone, sandstone, siltstone, and claystone, characterised by non-uniform particle sizes and irregular distribution.

In this study, the mine working is situated within a siltstone layer at a depth of -355 meters, representing typical geological conditions for the central area of the mine. Selecting cross-section AA and this specific location ensures the model accurately reflects field conditions and provides a basis for evaluating how the height of the waste dump influences the behaviour of the steel structures.

4.3. Model Development and Input Conditions

Based on the theoretical findings in Chapter 3 and the geological and topographical conditions, including the orientation of rock strata and coal seams at cross-section A-A in the central area of the Mong Duong coal, this thesis develops a numerical model. The model

incorporates surface waste dump heights ranging from 0 to 217 m, with 50 m increments per dumping stage. The model is 645 m high and 780 m wide, with a mine drift located at a depth of -355 m within a siltstone layer.

Three types of roadway cross-sections are investigated: (1) circular, with a diameter of 5 m (Figure 4.1); (2) U-shaped, 5 m wide and 5 m high (Figure 4.2); and (3) U-shaped with an inverted arch, 5 m wide and 5 m high (Figure 4.3). Three cross-sectional shapes were selected to compare the influence of surface waste dumps on the behaviour of both closed and open support structures under the actual conditions present at the Mong Duong mine.

The model's input parameters are based on the geological conditions of the Mong Duong coal waste dump and are presented in Table 4.1. The technical specifications for the model and the steel support structures are provided in Table 4.2.

Table 4.1. Input parameters for the rock mass

STT	Parameter	Unit	conglomerate	Claystone	Siltstone	Sandstone	Coal	Waste rock
1	Bulk density	MN/m^3	0,0263	0,0258	0,0262	0,0264	0.014	0.02
2	Deformation modulus	MPa	13.400	3180	10.600	11.100	2140	733.2
3	Lateral coefficient	-	0,2	0,2	0,2	0,2	0.12	0.25
4	Compressive strength of intact rock	MPa	108,5	20,3	37,8	104,9	10.5	17
5	Failure model	-	Hoek-Brown					

Table 4.2. Input parameters for the roadway and steel structure

STT	Parameter	Symbol	Value	Unit
1	Circular roadway			
	Diameter	D	5,0	m
2	U-shaped roadway			
	Height	h	5,0	m
	Width	b	5,0	m
	Radii	R	2,5	m
3	U-shaped roadway with an inverted			
	Wall height	h	1,8	m
	Width	b	5,0	m
	Radii of crown	R	2,5	m
	Wall foot-invert distance	R’	0,7	m
4	Model dimensions			
	Width x height	-	645 x 780	m x m
	Burial depth of roadway	-	-355	m
	Laterial pressure coefficient	K	0,5	-

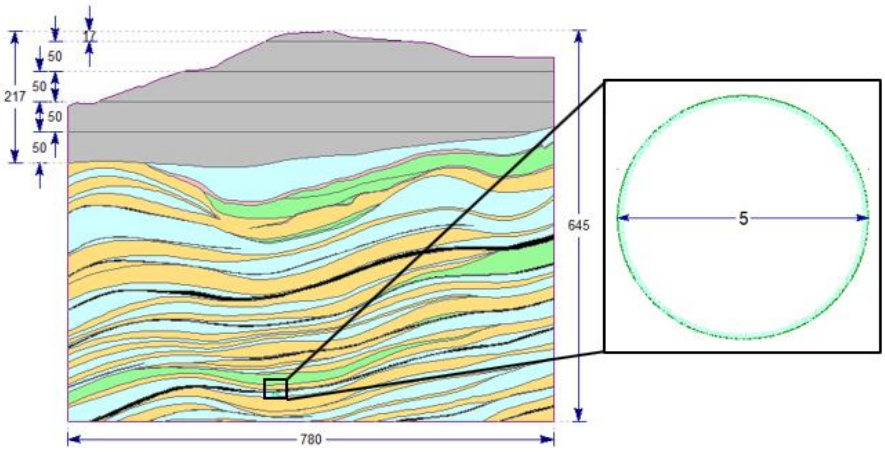


Figure 4.1. The numerical model for a circular roadway

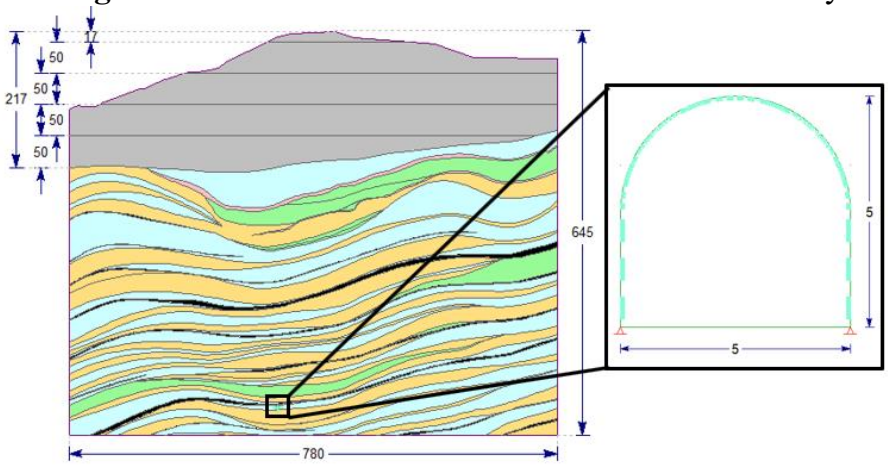


Figure 4.2. The numerical model for a U-shaped roadway

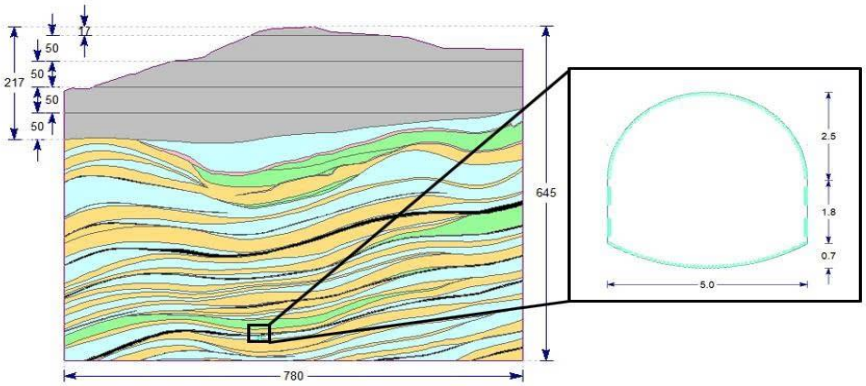


Figure 4.3. The numerical model for a U-shaped roadway with an inverted

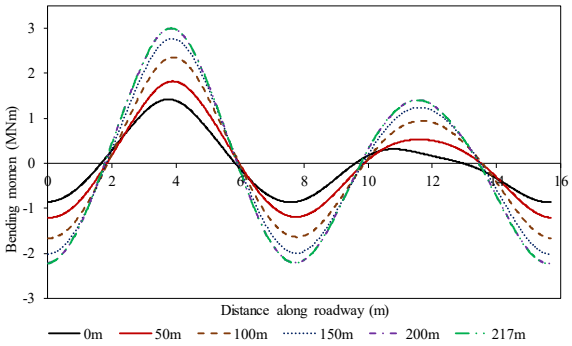


Figure 4.4. Effect of H on bending moment in circular roadway

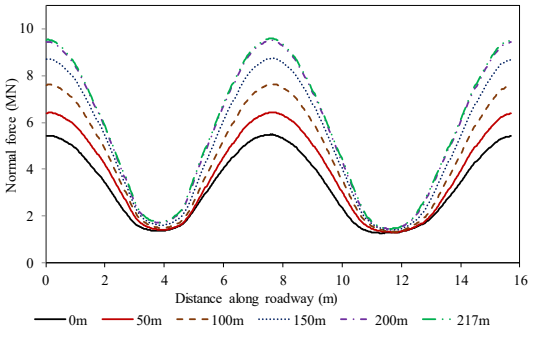


Figure 4.5. Effect of H on normal forces in circular roadway

4.4. Impact of waste dump height on internal forces in circular roadway

Figures 4.4 and 4.5 present the bending moments and axial forces in the circular roadway, both without a surface waste dump and with waste dump heights (H) of 50 m, 100 m, 150 m, 200 m, and 217 m.

Figures 4.4 and 4.5 show that as the surface waste dump height increases from 0 to 217 m, both the bending moment and axial force in the roadway structures increase. At H = 0 m, 50 m, 100 m, and 150 m, the internal forces are symmetric because the waste dump load is distributed relatively uniformly. At heights of 200 and 217 m, however, the geometry of the waste dump, which tapers toward the top, combined with the off-centre position of the mine roadway, results in an asymmetric load distribution. This causes the internal forces within the circular structure to shift slightly along the roadway axis, though the magnitude of this shift remains minor.

At a waste dump height of 217 m, the bending moment in the roadway structure increases by approximately 1.75 times, and the axial force increases by approximately 2.1 times, compared to the scenario without a waste dump.

4.5 Impact of waste dump height on internal forces in roadway structure with U-shaped

The bending moments and axial forces within the roadway structure are presented in Figures 4.6 and 4.7. These results cover scenarios both without and with waste dump heights (H) of 50 m, 100 m, 150 m, 200 m, and 217 m.

Figures 4.6 and 4.7 show that as the surface waste dump height increases, the bending moment in the support structure also rises. Between heights of 0 m and 150 m, M increases gradually and remains relatively symmetrically distributed. At 200 m –217 m, the bending moment increases significantly and exhibits an asymmetric distribution, with the values on the right-side wall exceeding those on the left. This occurs because, as the waste dump grows in height, its surface is no longer level; the resulting elevation difference between the two sides creates an eccentric load on the roadway, causing the bending moment to increase more sharply on the side with the greater waste dump height.

Without a waste dump, the maximum and minimum bending moments are 3.15 MNm and 0.34 MNm, respectively. When the waste dump reaches a height of 217 m, these values increase to 3.73 MNm and 0.65 MNm, an increase of approximately 1.18 times and 1.91 times, respectively.

Regarding the axial force, the values generally increase with waste dump height while remaining relatively symmetric. This suggests that the axial force is less sensitive to the eccentric loading caused by the waste dump compared to the bending moment. Without a waste dump, the maximum and minimum axial forces are 4.50 MN and 1.40 MN, respectively. At a height of 217 m, these values increase to 12.15 MN and 2.47 MN, respectively—an increase of approximately 2.70 and 1.76 times.

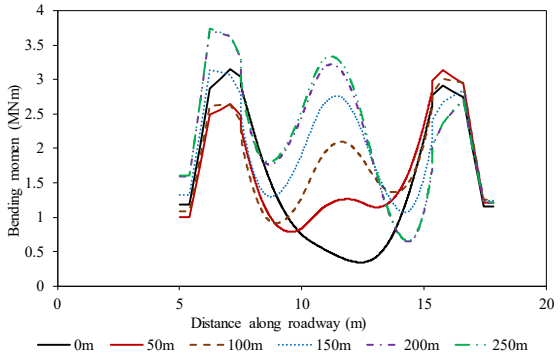


Figure 4.6. Effect of H on bending moment in U-shaped roadway

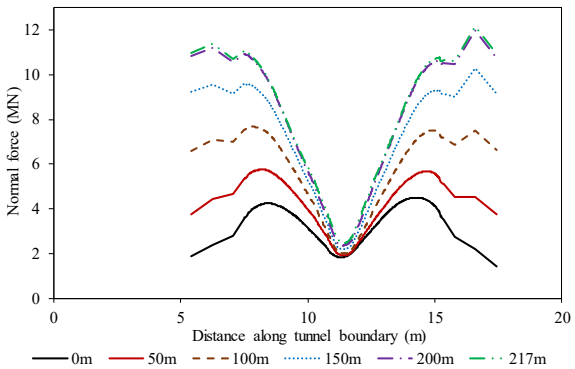


Figure 4.7. Effect of H on normal forces in U-shaped roadway

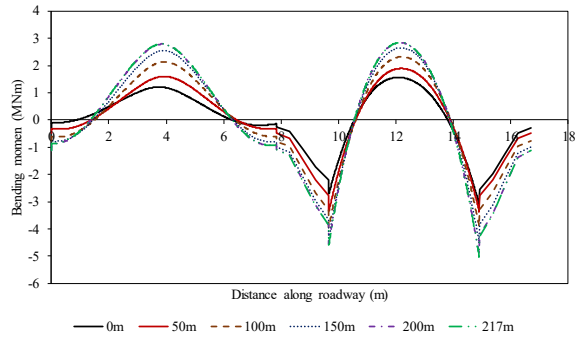
4.6. Impact of waste dump height on internal forces in the roadway structure for U-shaped with an inverted arch

The bending moments and axial forces in a U-shaped structure with an inverted arch are presented in Figures 4.8 and 4.9 for scenarios with no surface waste dump and for waste dump heights of 50 m, 100 m, 150 m, 200 m, and 217 m.

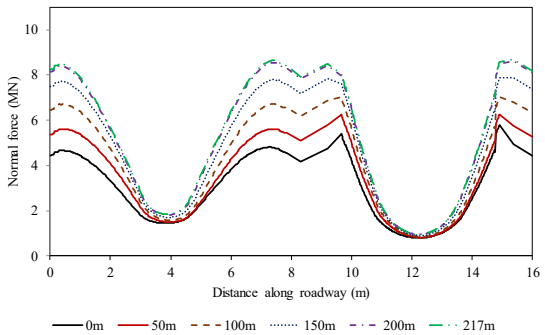
Figures 4.8 and 4.9 show that as the surface waste dump height increases, the bending moments in the support structure also increase. At heights from 0 m to 150 m, bending moment increases gradually and exhibits a relatively symmetrical distribution. As the height reaches 200 m to 217 m, the bending moment increases significantly and becomes asymmetrical, with the values on the right-side wall exceeding those on the left-hand wall.

Without a waste dump, the maximum and minimum bending moments are 3.10 MNm and 1.57 MNm, respectively. When the waste dump reaches a height of 217 m, these values become 5.03 MNm and 2.85 MNm, an increase of approximately 1.62 and 1.82 times, respectively.

Regarding the axial force, the values generally increase with the height of the waste dump but maintain a relatively symmetrical distribution; this suggests that normal forces are less sensitive to the asymmetrical loading imposed by the waste dump compared to bending moment. Without a waste dump, the maximum and minimum normal force values are 5.79 MN and 0.80 MN, respectively. When the waste dump height reaches 217 m, these values increase to 8.69 MN and 0.96 MN, respectively, an increase of about 1.50 and 1.20 times.



Hình 4.8. Effect of H on bending moment in U-shaped roadway with an inverted



Hình 4.9. Effect of H on normal forces in U-shaped roadway with an inverted

Chapter 4 conclusion

In Chapter 4, the thesis quantitatively investigates the influence of surface waste dumps on the behaviour of steel structures for roadways, based on actual conditions at the Mong Duong coal. Three types of cross-sectional profiles were analysed: circular, U-shaped, and U-shaped with an inverted arch. For surface waste dump heights (H) of 0 m, 50 m, 100 m, 150 m, 200 m, and 217 m, the results indicate the following:

The height of the surface waste dump is a dominant factor influencing the internal forces within the roadway structures. As the height of the waste dump increases, both the bending moments and axial forces within the roadway structures also increase, reflecting the rise in load exerted by the surface waste dump upon the underlying roadway.

GENERAL CONCLUSIONS AND PERSPECTIVES

General Conclusions

This dissertation synthesises the formation characteristics, origins, and current status of waste dumps at mining sites in the Quang Ninh coal region and internationally, along with methods for calculating internal forces in roadway structures.

A two-dimensional numerical model was developed and validated using the software Phase2 to simulate surface waste dumps. This model was used to investigate how variations

in the unit weight of waste rock, the waste dump height, and the relative positioning between the roadway and the waste dump affect the behaviour of steel structures for both circular and U-shaped roadways. The theoretical findings indicate the following:

- Changes in the unit weight of waste rock influence the internal force behaviour of both circular and U-shaped roadway structures. As the unit weight of the waste rock increases, the internal forces within both roadway structure types also increase. Across all scenarios involving variations in the unit weight of waste rock, the internal forces in circular roadway structures remain lower than those in U-shaped roadway structures.

- Changes in the waste dump height also affect the internal force behaviour of both circular and U-shaped roadway structures. As the waste dump height increases, the internal forces within both roadway structure types increase. Across all scenarios involving variations in the waste dump height, the internal forces in the circular roadway structures remain lower than those in the U-shaped roadway structures.

- Changes in the relative position between a roadway and a waste dump affect the internal forces within the roadway structure, whether circular or U-shaped. Internal forces reach their maximum when the roadway is located directly beneath the centre of the waste dump. As the roadway's position shifts toward the crest, the mid-slope, the toe of the waste dump, or beyond its perimeter, both the bending moment and the axial force decrease in a clear, consistent pattern. Across all these positional variations, the internal forces within a circular roadway structure remain lower than those in a U-shaped roadway structure.

Practical research conducted at the Mong Duong coal mine waste dump indicates the following:

The waste dump height at the Mong Duong coal mine dictates the internal forces in any roadway structure. As the waste dump height increases, both the axial force and bending moment in the roadway structure rise, clearly reflecting how the increased load from the waste dump affects the support system below.

The roadway shape influences the internal forces in its steel structure when it lies beneath a waste dump. Both theoretical analysis and empirical findings from the Mong Duong coal mine demonstrate that, under the load of a surface waste dump, the internal forces within a circular roadway structure are lower than those in U-shaped or inverted U-shaped roadway structures.

Perspectives

- Design and construction entities, as well as underground coal mine operators, must account for the additional (artificial) pressure exerted by surface waste dumps on the steel roadway structures located beneath them.

- The research presented in this thesis is limited to "positive" waste dumps (those deposited on the ground surface). Further research is required for "negative" waste dumps, such as those placed within open-pit mine voids, ravines, or valleys.

- The scope regarding support structures is currently limited to steel structures. Future research should investigate other types, including rock bolts, rock bolts combined with shotcrete and wire mesh, continuous concrete linings, and hybrid support systems.

- The scope regarding roadways is currently limited to horizontal (level) roadways. Further study is needed for inclined roadways and vertical shafts.

- The analysis of pressure acting on support structures currently considers only strata pressure and the additional pressure from surface waste dumps. Consequently, further research is necessary to examine scenarios where roadways are subjected to a combination of pressures, including strata pressure, artificial pressure from waste dumps, groundwater pressure, and other pressures that emerge during mining and excavation operations.

- In light of the trend toward digital transformation and the application of technologies from the Fourth Industrial Revolution (Industry 4.0), the Vietnam National Coal and Mineral Industries Group (Vinacomin) needs to increase investment in the research and implementation of digital technologies, specifically artificial intelligence (AI), big data, and digital twin modelling. These tools can simulate and forecast the impact of waste rock dumps on mine roadway support structures and develop scenarios to support decision-making in the design, construction, and reinforcement of mine roadways. Adopting these technologies will enhance safety, optimise support solutions, and minimise the impact of waste rock dumps on underground mining operations.

PUBLISHED AND SUBMITTED MANUSCRIPTS

Other papers:

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2. Đặng Văn Kiên, Đỗ Ngọc Anh, Lê Chí Kiên, Ngô Đức Quyền, Mai Xuân Thanh Tuấn, Nguyễn Hữu Sà (2022), Nghiên cứu ảnh hưởng của tương quan vị trí đường lò phía dưới bãi thải mặt mỏ đến ứng xử cơ học của kết cấu chống giữ đường lò tại vùng than Quảng Ninh, *Hội nghị Toàn Quốc Khoa Học Trái Đất và Tài Nguyên với Phát Triển Bền Vững Hà Nội, 11-11-2022(ERSD 2022).*

International journal:

1. Dang van kien[1]*, Vo Trong Hung[1], Bui Xuan Nam[1], Nguyen Huu Sa[1] (2023), Research on the Effect of the Mine Waste Dump on the Stability of Tunnels Below in the Quangninh Coal Area by Numecical Method, *Journal of the Polish Mineral Engineering Society (Tháng 9 năm 2023).*

2. Nguyen Huu Sa[1,2], *Dao Viet Doan[2] (2026), Research on the influence of waste dump height on the internal forces of steel roadway supports: A case study in mong duong mine, quang ninh, vietnam, *International Journal of GEOMATE (Geotechnique, Construction Materials and Environment) ISSN: 2186-2982 (P), 2186-2990 (O), Japan*.