



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

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*Corresponding Author, Received: 13 June 2026, Revised: 30 June 2026, Accepted: 01 July 2026

ABSTRACT: Currently, the Mong Duong Coal Mine is extracting coal seams located beneath surface waste dumps. Roadways beneath these dumps exhibit phenomena such as subsidence, squeezing, and deformation of the support structures shortly after being put into operation. These phenomena are hypothesized to be caused by artificial pressure generated by the surface waste dump above. This article clarifies the influence of the waste dumping height on the internal forces of the steel support structures for both circular and U-shaped (straight wall and semicircular arch) roadways located beneath waste dumps under Mong Duong coal mine conditions. Numerical simulation using Phase² software was employed, based on the geological conditions of cross-section A-A through the central area of the Mong Duong coal mine. The research simulated model was constructed with dimensions of 780 m (width) x 645 m (height). The circular roadway has a diameter of 5 m, while the U-shaped roadway has dimensions of 5 x 5 m; the surveyed roadways are located at a depth of -355 m within a siltstone rock mass. The study cases varied the waste dumping height at 0 m, 50 m, 100 m, 150 m, 200 m, and 217 m. The results indicate that the waste dumping height significantly influences the internal force values in the support structures for both circular and U-shaped roadways. As the dumping height increases, both the moment and normal force in the support structures of these two roadway types increases according to a clear pattern.

Keywords: *Mong Duong coal mine waste dump; Internal forces of steel support structures; Roadways beneath waste dumps, Numerical simulation.*

1. INTRODUCTION

Currently, several underground coal mines in the Quang Ninh region are extracting coal seams located beneath surface waste dump [1-2]. At these mines, roadways beneath the waste dumps exhibit phenomena such as subsidence, squeezing, and deformation of the support structures shortly after being put into operation. These phenomena are hypothesized to be caused by artificial pressure generated by the surface waste dump [3-4].

During the mining process, surface waste dumps are formed and developed according to the dumping progress, which is directly linked to the volume of waste rock generated at each mining stage. In the early stages, the waste dump is in low height, and its influence on the foundation and underlying underground structures remains limited. As the dumping process continues, the waste dump height increases over time, leading to an increase in vertical loads acting on the foundation and expanding the waste dump's influence zone.

The increase in waste dump height not only raises the load values transmitted to the underlying rock mass but also alters the stress state and load

distribution conditions around the roadway. Consequently, the loads acting on the roadway support structure vary according to each dumping stage, as reflected by changes in the moment and normal force within the support structure. Considering the waste dump according to its development progress is essential to accurately assess the unfavourability of each dumping stage and identify potential periods of instability for the support structure.

A considerable number of studies have investigated the loads acting on roadway support structures [5–18]. Nevertheless, most of these studies focus on the effects of natural geological conditions, excavation methods, and support system characteristics.

Recent studies have highlighted the importance of internal force analysis for evaluating the performance and safety of steel support systems in underground excavations. Rotkegel et al. (2024) investigated the load-bearing capacity of steel portal supports at roadway junctions in Vietnamese underground coal mines and demonstrated that the structural response of the support system is closely related to the redistribution of loads around

underground openings. The study indicated that variations in stress conditions may significantly affect the forces acting on steel support members and consequently influence roadway stability. Furthermore, Li et al. (2026) analyzed roadway support behavior under deep complex stress fields and reported that the evolution of surrounding rock stress directly governs the mechanical response of support structures. Their findings emphasized that support loads should be considered as variable rather than constant throughout the service life of the roadway. In addition, recent developments in monitoring technology have enabled the direct measurement and control of axial forces in steel support systems, providing a reliable basis for evaluating support performance under changing loading conditions (Ullah et al., 2024). However, existing studies mainly focus on the effects of geological stress, mining disturbance, and excavation-induced loading. Research concerning the evolution of axial forces and moments in steel supports of roadways located beneath surface waste dumps remains very limited. In particular, the influence of progressive waste dump development on the internal force distribution and structural safety of steel support systems has not been systematically investigated.

Despite the considerable body of research on roadway support behavior and waste dump stability, several important gaps remain. First, most previous studies consider external loading conditions as static and neglect the progressive development process of surface waste dumps. Second, the influence of different dumping stages on the evolution of loads acting on underground roadway support structures has rarely been quantified. Third, limited research has been conducted to evaluate variations in moments, axial forces, and structural safety factors of roadway supports resulting from continuously increasing artificial pressure generated by waste dump growth. Consequently, the mechanism through which waste dump development affects the mechanical behavior of roadway support systems remains insufficiently understood.

To address these research gaps, this study investigates the influence of waste dump development stages on the loading conditions and structural response of an underground roadway support system in the Quang Ninh coal mining region. Numerical modeling is employed to simulate the progressive increase in waste dump height and to evaluate the corresponding changes in stress distribution, roadway deformation, moments, and axial forces within the support structure. The originality of this research lies in considering the waste dump as a time-dependent engineering load

that evolves throughout the dumping process rather than as a fixed surcharge.

The recent studies mainly focus on roadway stability, support systems, numerical simulation of underground excavations, and rock-support interaction under in-situ stress or construction-induced loading conditions [26-30]. However, limited attention has been paid to the influence of surface surcharge loading, particularly surface waste dump development, on underground structures. In particular, the effect of waste dump height on the internal force response of steel roadway supports has rarely been investigated. Therefore, a clear research gap remains regarding the quantitative relationship between surface waste dump height and support internal forces in roadways located beneath waste dumps.

Therefore, this case study was carried out using the geological cross-section AA traversing the central area of the Mong Duong Coal Mine as the basis for analysis, which also represents the location with the maximum dumping height, this article establishes a numerical model using Phase2 software to surveys two types of roadway shapes: circular and U-shaped (straight wall and semicircular arch), located at a depth of -355 m within a siltstone rock mass. The research scenarios vary the waste dumping height at 0 m, 50 m, 100 m, 150 m, 200 m, and 217 m to identify the law of influence of the waste dumping height on the internal forces in the support structure.

2. RESEARCH SIGNIFICANCE

Using the Mong Duong Coal Mine as a case study, this research contributes to a better understanding of the interaction between surface waste dump development and the mechanical behavior of underground roadway support systems. The study evaluates the evolution of stress distribution, axial forces, and moments in steel supports during different waste dump development stages. The results provide a scientific basis for assessing roadway stability, identifying critical loading stages, and optimizing support design for underground excavations located beneath waste dumps. The findings can support safer roadway management and improve the long-term sustainability of underground mining operations in similar geological and mining conditions.

3. BACKGROUND

3.1 Geological Conditions of the Research Area for Numerical Modeling

Mong Duong Coal Mine, located in Quang Ninh

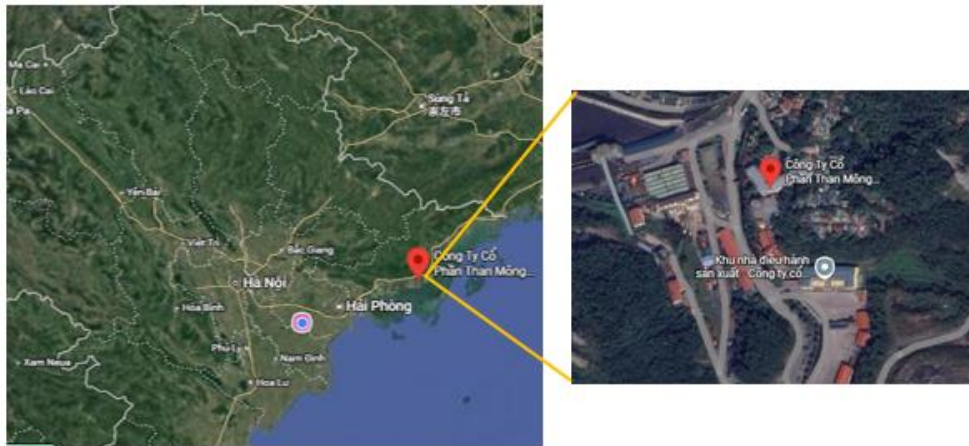


Fig. 1 Location of the research area

Province, Vietnam, is a major underground coal mine characterized by deep mining and complex geological conditions. Several active coal seams are currently being extracted beneath the Mong Duong waste dump, where the increasing dump height significantly affects the stress distribution, roadway stability, and support performance.

Mong Duong Coal Mine is situated in Cam Pha City, Quang Ninh Province, in the northeastern coal mining region of Vietnam. The location of Mong Duong Coal Mine is shown in Fig. 1.

Mong Duong coal mine has been continuously exploiting to greater depths and is currently preparing mining development at the -400 level. However, at the shallower mining level of -110, where roadway cross-sectional areas are 9.6 m² and 11 m² and located beneath the surface waste dump, the roadways are supported by SVP22 steel arch support combined with reinforced concrete lagging panels, with a support spacing of 0.8 m per set. After a period of operation, the roadway experienced significant squeezing deformation, resulting in a reduction of the usable cross-sectional area to approximately 5÷7 m², requiring re-excavation and enlargement, as shown in Fig. 2.

At the -250 level, additional roadways located beneath the waste dump were excavated in siltstone with a cross-sectional area of 17.9 m² and supported by CBII-22 steel arches with a support spacing of 0.8 m per set. After long-term service, these roadways also experienced squeezing and subsidence deformation, reducing the usable cross-sectional area to approximately 11m² and necessitating re-excavation and enlargement, as shown in Fig. 3.

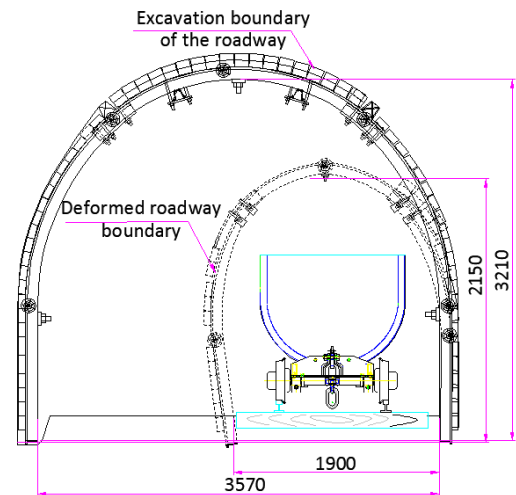


Fig. 2 Deformation state of the crosscut roadway at the -97,5 ÷ -110 level

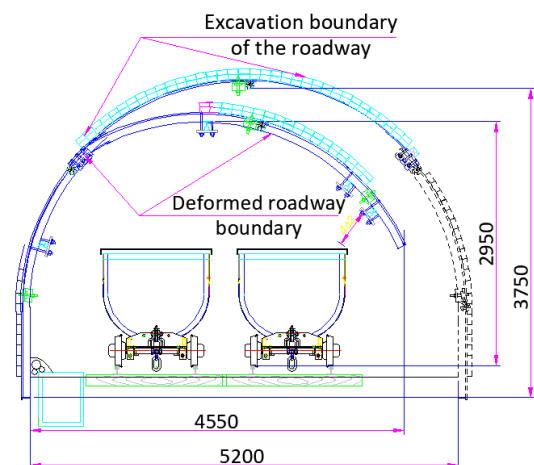


Fig. 3 Deformation state of the crosscut roadway at the -250 level

To investigate the mining pressure acting on roadways located beneath the Mong Duong coal mine waste dump, geological cross-section A-A, which passes through the center of the mine, was selected. This cross-section illustrates the surface waste dump and the underlying coal seams is showing on Fig.4 [1].

On cross-section A-A, from the +30 level upwards is the waste dump area. The downward waste dump area consists of various rock mass types, including conglomerate, gritstone, sandstone, siltstone, and coal seams. However, the conglomerate and gritstone layers are insignificant with thin bedding; the sandstone and siltstone with large thicknesses are dominated. The rock types on cross-section A-A are described as follows [1,2]:

- + Waste rock layer: Composed of irregularly sized boulders and fragments of conglomerate, gritstone, sandstone, siltstone, and claystone, arranged in a highly chaotic manner. This is a product of open-pit mining from the Cao Son mine (seams 10, 9, and seam outcrops). This layer is currently unstable, featuring a porous structure with numerous small cavities.

- + Conglomerate: Grey to light grey in color, with quartz as the primary grain component.

- + Gritstone: Relatively common in the stratigraphic column, with a grain size transition from conglomerate to sandstone.

- + Sandstone: Light to dark grey, the most prevalent rock type in the stratigraphic column.

- + Siltstone: Grey to dark grey, featuring a layered structure and relatively solid bonding; distributed between coal seams or acting as the roof and floor of the seams.

- + Claystone: Interbedded within coal seams or located on the roof and floor.

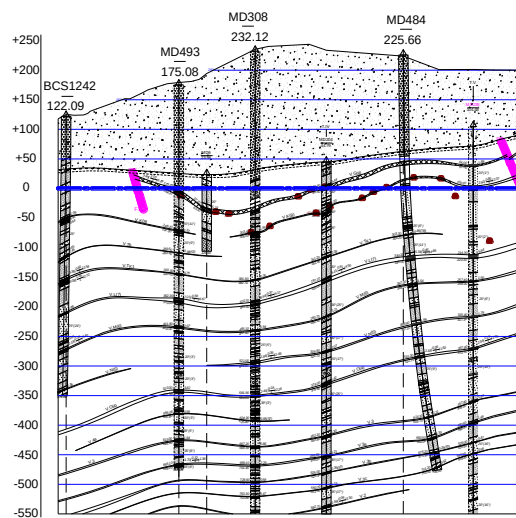


Fig.4 Geological cross-section A-A through the Central area of the Mong Duong coal mine

3.2 Numerical Model Development and Input Parameters

Based on the conditions of waste dumping height, geology, topography, and the occurrence of rock strata and coal seams (including thickness and structure of both) from geological cross-section A-A through the central area of the Mong Duong coal mine, a numerical simulation was conducted.

To investigate the influence of the Mong Duong waste dump height on the internal forces of the roadway support structure, numerical simulations were carried out using the Phase² software. It is a finite element analysis software widely used for underground excavation and support design in geotechnical engineering. In coal mining, it provides an effective tool for evaluating the axial force and moment of roadway support structures, enabling the assessment of support performance and structural stability under different geological conditions.

Case studies were established for the period before the formation of the surface waste dump and after its formation, with the dumping progress simulated in 50 m increments per stage to investigate the influence of the waste dump on the mechanical behavior of the steel support structure for the roadway located beneath the dump. The research model has dimensions of 780 m in width and 645 m in height. The surveyed roadway is positioned at a depth of -355 m within a siltstone rock mass. In the first survey case, the roadway boundary is circular with a diameter of 5 m (Fig. 2). In the second case, the roadway is U-shaped (straight wall and semicircular arch) with dimensions of 5 m in width and 5 m in height (Fig.5).

The input parameters used in the numerical model were selected based on the geological investigation data of the Mong Duong coal mine waste dump, laboratory testing results, field measurements, and published studies. The geotechnical properties of the rock mass adopted in the numerical simulation are summarized in Table 1 [1,2]. The rock mass behavior was simulated using the Hoek–Brown failure criterion (2002), and the corresponding rock mass parameters were determined according to the Geological Strength Index (GSI), intact rock properties, and disturbance factor, as listed in Table 2. The technical parameters of the numerical model and the steel support system were determined from the mine design documents, field investigations, and previous studies, and are presented in Table 3 [18–21]. These parameters were selected to ensure that the numerical model accurately represents the geological conditions and support characteristics of the study area.

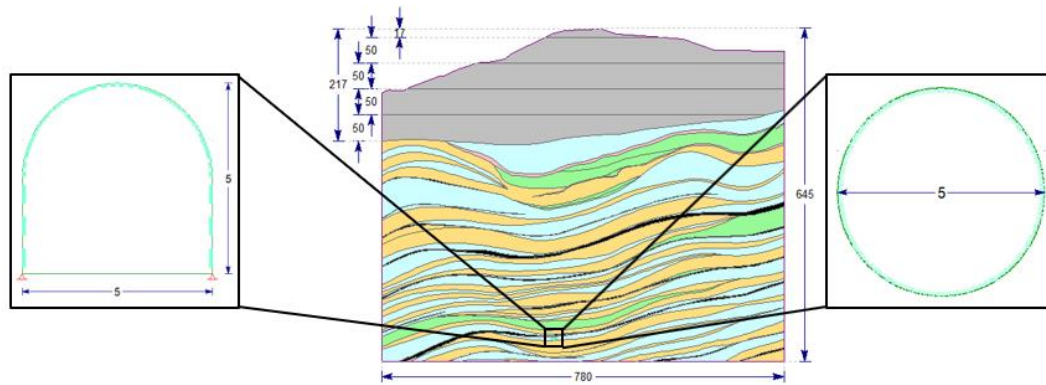


Fig .5 Model for the circular and U-shaped (straight wall and semicircular arch) roadway case

Table 1 Properties of rock mass

No	Parameter	Unit	Conglomerate	Claystone	Siltstone	Sandstone	Coal	Waste rock
1	Unit weight	MN/m ³	0.0263	0.0258	0.0262	0.0264	0.014	0.02
2	Young Modulus	MPa	13400	3180	10600	11100	2140	733.2
3	Poisson's ratio	-	0.2	0.2	0.2	0.2	0.12	0.25
4	Intact uniaxial compressive strength	MPa	108.5	20.3	37.8	104.9	10.5	17

Table 2 Rock mass parameters in the Hoek–Brown model

No	Parameters	Symbol	Value
1	Geological Strength Index	GSI	50
2	Intact rock constant	m_i	7
3	Disturbance Factor	D	0.5
4	Reduced value of the material constant	m_b	0.6472
5	Constants for the rock mass	s	0.0013
6	Constants for the rock mass	a	0.5057
7	Failure criterion		Hoek-Brown

Table 3 Parameters of the roadway and steel support structure

No	Parameters	Symbol	Value	Unit
1	Circular roadway parameters			
	Diameter	R	5	m
2	Parameters of U-shaped roadway (straight wall and semicircular arch)			
	Height	h	5	m
	Width	b	5	m
	Arch radius	R	2.5	m
3	SVP33 steel support			
	Spacing	l	0.7	m
	Section height	-	0.137	m
	Cross-sectional area	S	0.00425	m ²
	Young modulus	E	200000	MPa
	Poisson's ratio	μ	0.35	-
	Compressive strength	σ_n	500	MPa
	Tensile strength	σ_k	500	MPa
4	Numerical model parameters			
	Dimensions (width x height)	-	780 x 645	m x m
	Roadway depth	-	-355	m
	Lateral earth pressure coefficient	K	0.5	-

A 6-node triangular element is used to describe the rock mass. The waste dump is filled following the progress from 0 m to 217 m. Therefore, the number of elements and nodes on whole model fluctuate from 58681 elements, 29893 nodes to 62244 elements, 31680 nodes respectively. All elements are meshed well in quality. The model has dimensions of 780 m wide and 645 m high.

The simulation procedure consists of four main steps. Step 1: Establish the numerical model based on the geological conditions of the Mong Duong coal mine waste dump.

Step 2: Assign the material properties to the model.

Step 3: Conduct numerical simulations for waste dump heights of 0, 50, 100, 150, 200, and 217 m.

Step 4: Export the results and evaluate the changes in the axial force and moment of the roadway support structure.

The investigated cases were developed based on the ultimate dumping configuration of the Mong Duong Coal Mine waste dump. The waste dump height was considered at six stages of development: 0 m, 50 m, 100 m, 150 m, 200 m, and 217 m.

4. RESULTS AND DISCUSSION

4.1. The influence of waste dumping height on the internal forces in the steel support structure of the circular roadway

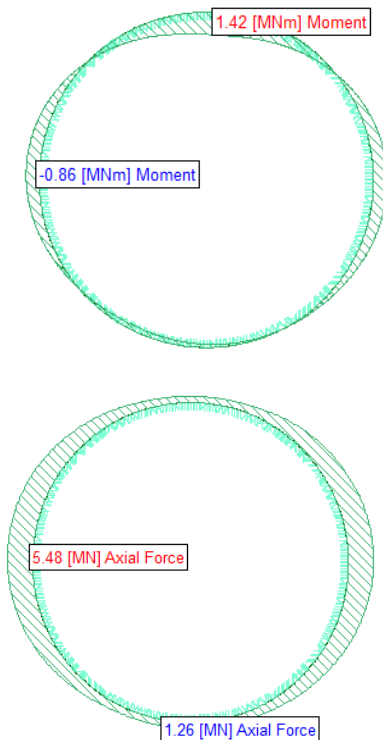


Fig.6 Moment and normal force for the circular roadway without the waste dump

The moment and normal force results for the circular roadway's steel support structure under various waste dumping height (0 m, 50 m, 100 m, 150 m, 200 m, and 217 m) are presented in Fig.6 to Fig.11.

The 0 m level represents the original ground surface prior to waste dumping. Therefore, the internal force distribution in the steel support system at this level is taken as the reference baseline for comparison with those under subsequent waste dump height conditions.

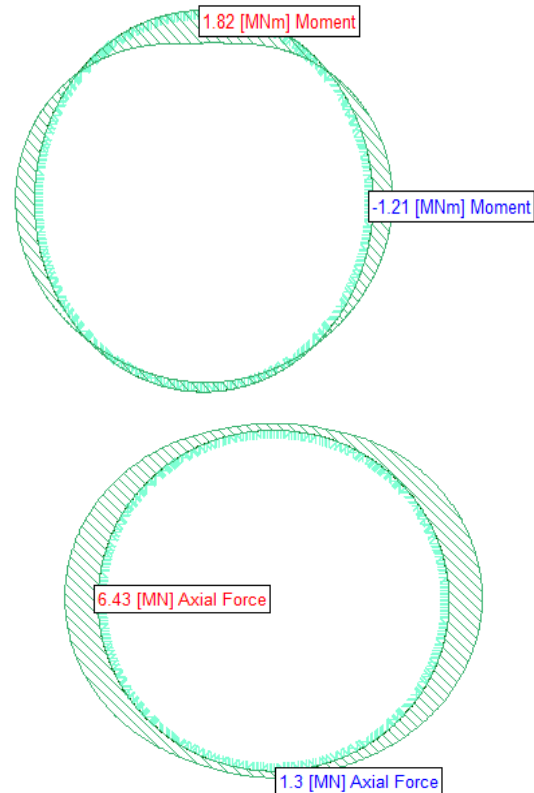


Fig.7 Moment and normal force for the circular roadway with a waste dumping height of 50 m

Summary of moment and normal force diagrams for the steel support structure under various waste dumping height (0 m, 50 m, 100 m, 150 m, 200 m, and 217 m) for the circular roadway case, as shown in Fig.12 and 13.

Based on the moment and normal force results for various waste dumping heights shown in Fig.6 to Fig.11, the summary moment diagram in Fig.12, and the summary normal force diagram in Fig.13, it is observed that as the waste dumping height increases according to the dumping progress (height from 0m to 217 m), the internal forces (moment and normal force) in the support structure also increase accordingly.

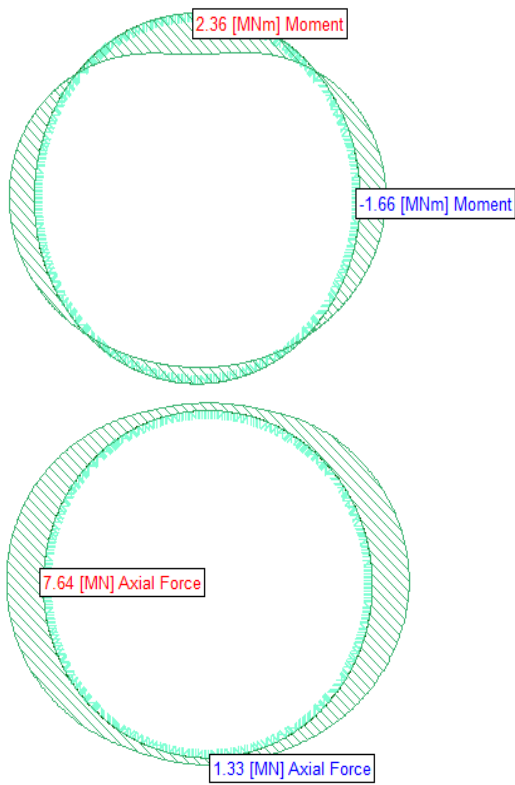


Fig.8 Moment and normal force for the circular roadway with a waste dumping height of 100 m

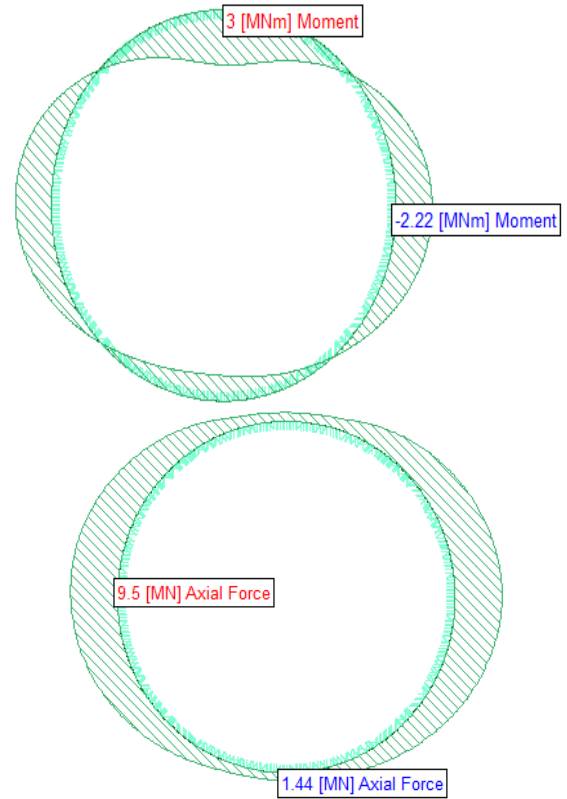


Fig.10 Moment and normal force for the circular roadway with a waste dumping height of 200 m

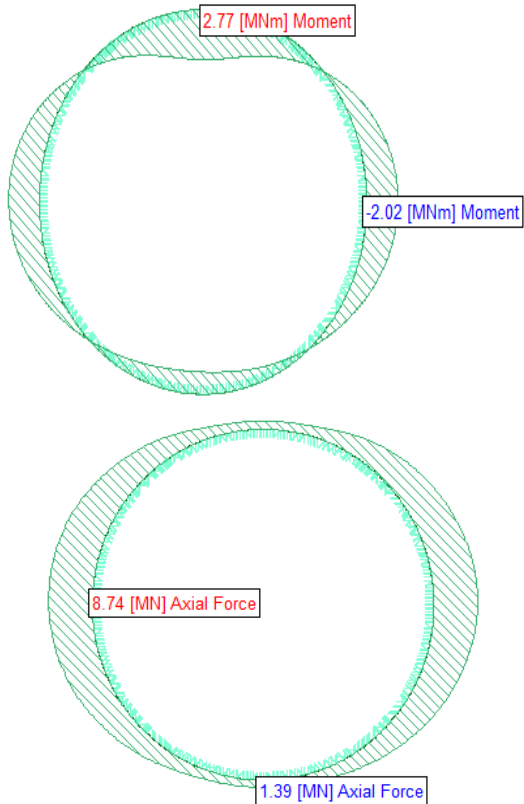


Fig.9 Moment and normal force for the circular roadway with a waste dumping height of 150 m

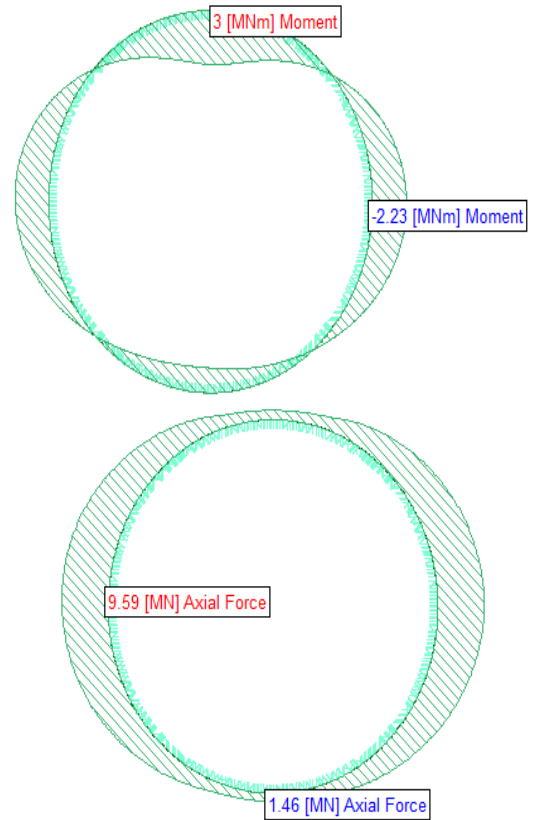


Fig.11 Moment and normal force for the circular roadway with a waste dumping height of 217 m

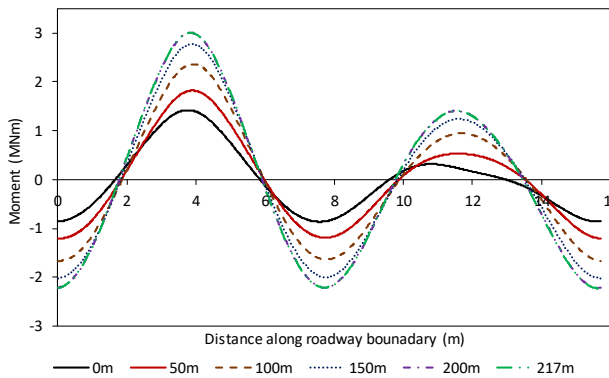


Fig.12 Summary of moment diagrams for the circular roadway under various waste dumping height

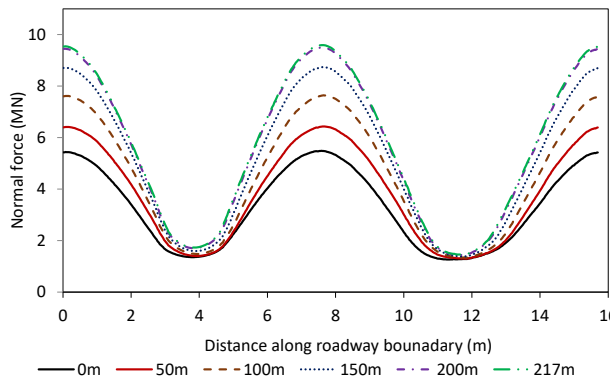


Fig.13 Summary of Normal force diagrams for the circular roadway under various waste dumping height

In cases without dumping and at low dumping levels (0m, 50m, 100m, 150m), the internal forces in the support structure exhibit symmetry across the roadway axis because the formed surface of the waste dump has a uniform elevation. However, at dumping heights of 200m and 217m, the waste dump's crest width is narrowed and the roadway is eccentrically positioned to higher dump portion on one side and the other side is lower. This causes the eccentric loading acts on the roadway. Consequently, the internal forces within the circular roadway's support structure also show signs of asymmetrical. This effect is insignificant. Fig.12 and Fig.13 further demonstrate that upon completing the dumping to a height of 217m, the moment in the support structure increases by 1.75 times, while the normal force increases by approximately 2.1 times compared to the case of without the waste dump.

4.2. The influence of waste dumping height on the internal forces in the steel support structure of the U-shaped roadway

The moment and normal force results for the U-shaped roadway steel support structure under

various waste dumping heights (0 m, 50 m, 100 m, 150 m, 200 m, and 217 m) are presented in Fig.14 to Fig.19.

The 0 m level represents the original ground surface prior to waste dumping. Therefore, the internal force distribution in the steel support system at this level is taken as the reference baseline for comparison with those under subsequent waste dump height conditions.

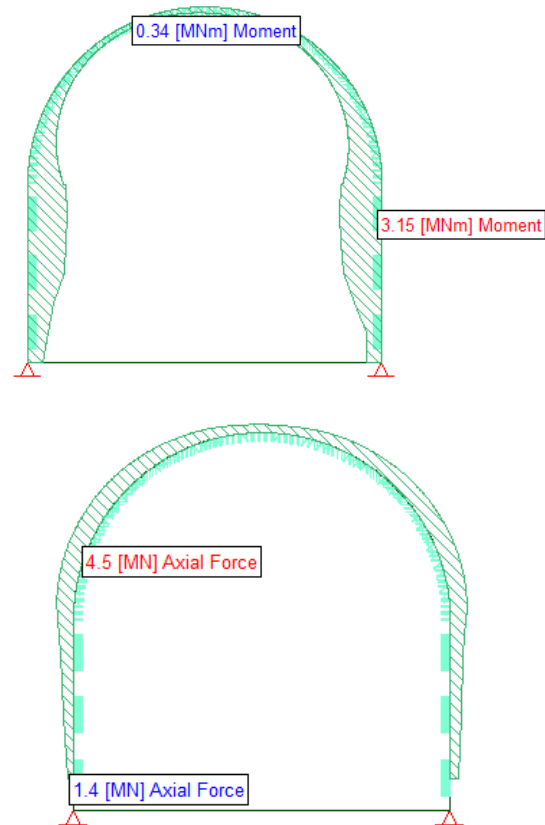


Fig.14 Moment and normal force for the U-shaped roadway without the waste dump

Summary of moment and normal force diagrams for the steel support structure under various waste dumping height (0 m, 50 m, 100 m, 150 m, 200 m, and 217 m) for the U-shaped roadway case, as shown in Fig.20 and Fig.21. From the results shown in Fig.14 to Fig.19 and the summary diagrams in Fig.20 and Fig.21, it can be observed that as the waste dumping height increases, the moment values in the support structure also increase proportionally. At lower dumping heights (0 m to 150 m), the moment increase is minimal and the distribution is relatively uniform across the roadway's axis of symmetry. However, at significant heights (200 m to 217 m), the moment increases rapidly and distinctly, showing an asymmetrical distribution across the roadway axis, with the moment on the left wall being smaller than that on the right wall.

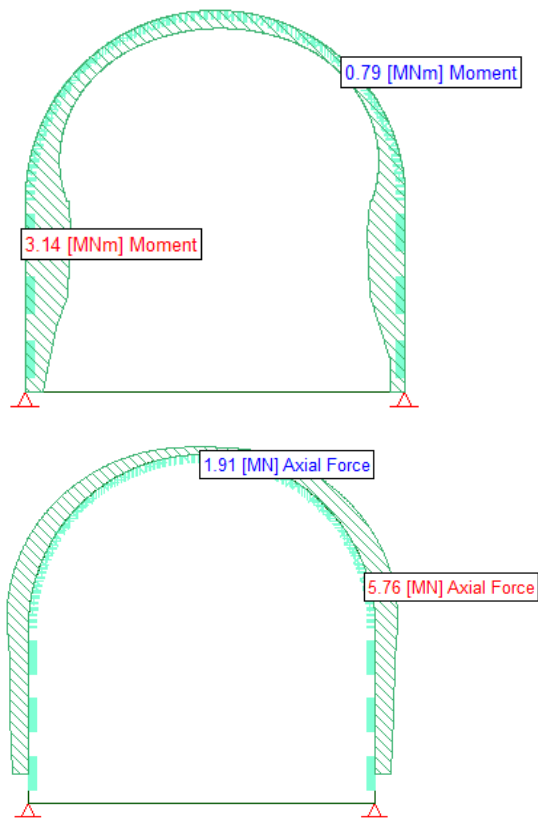


Fig.15 Moment and normal force for the U-shaped roadway with a waste dumping height of 50 m

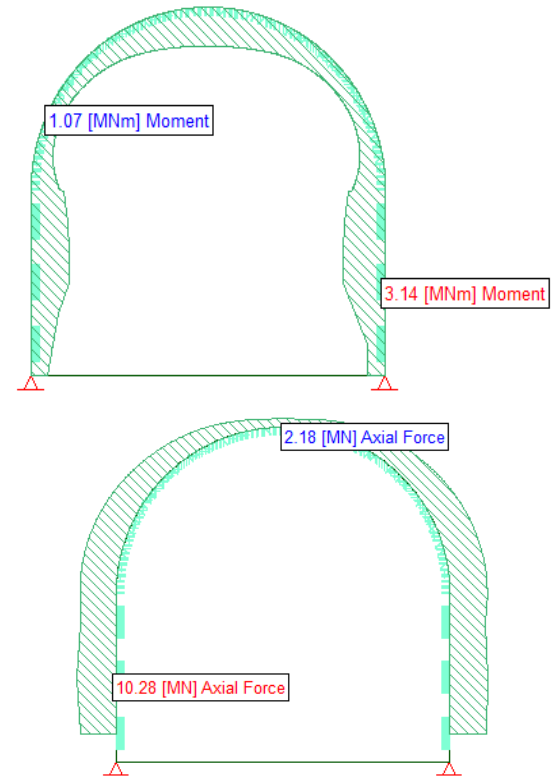


Fig.17 Moment and normal force for the U-shaped roadway with a waste dumping height of 150 m

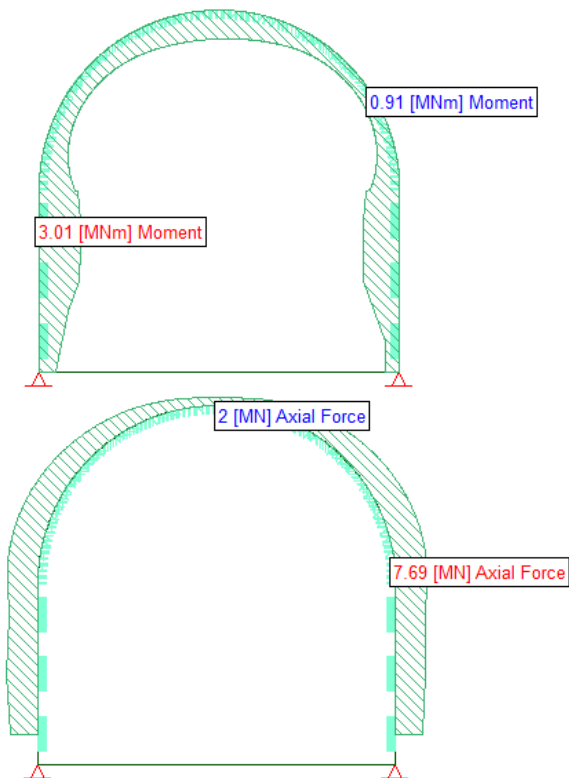


Fig.16 Moment and normal force for the U-shaped roadway with a waste dumping height of 100 m

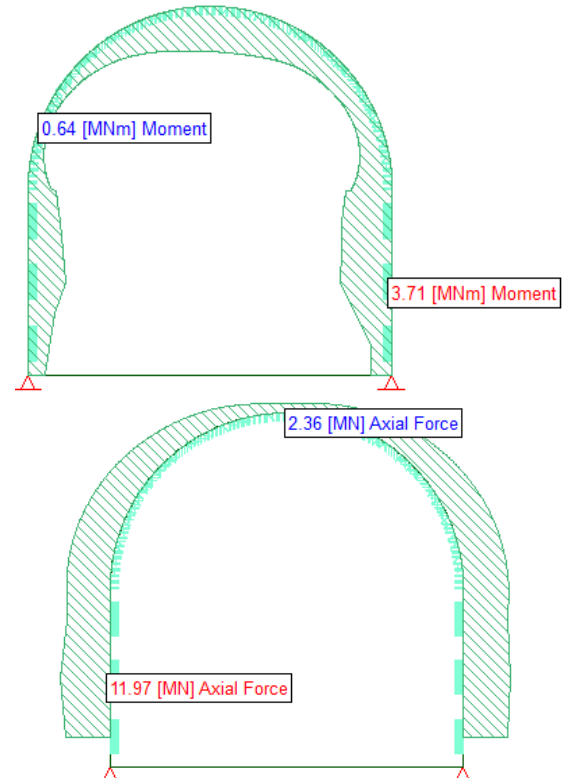


Fig.18 Moment and normal force for the U-shaped roadway with a waste dumping height of 200 m

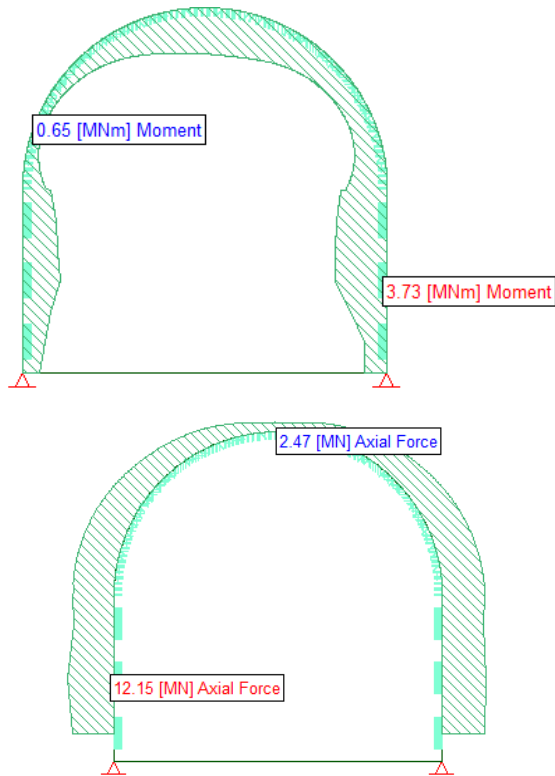


Fig.19 Moment and normal force for the U shaped roadway with a waste dumping height of 217 m

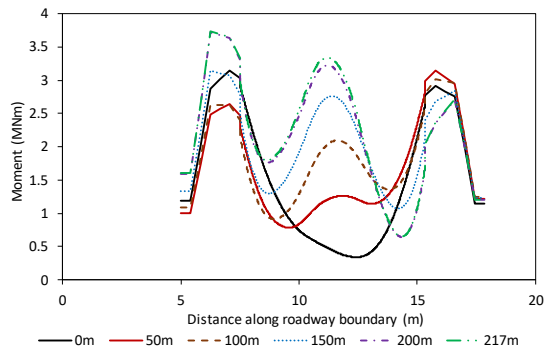


Fig.20 Summary of moment diagrams for the U-shaped roadway under various waste dumping height

The transition from a symmetrical distribution at low heights to an eccentric distribution at greater heights occurs because the dump surface is flat when the height is low. As the height increases, the dump topography becomes uneven and shifts toward the right side (where the surface is higher than on the left). This creates eccentric loading on the roadway, affecting the moment in the steel support frame, resulting in higher values on the side with the greater dumping height and vice versa. Without the waste dump, the maximum moment is 3.15 MNm and the minimum is 0.34 MNm. Upon completion of dumping at a height of 217 m, the maximum moment reaches 3.73 MNm (an increase of approximately 1.18 times), and the minimum

reaches 0.65 MNm (an increase of approximately 1.9 times).

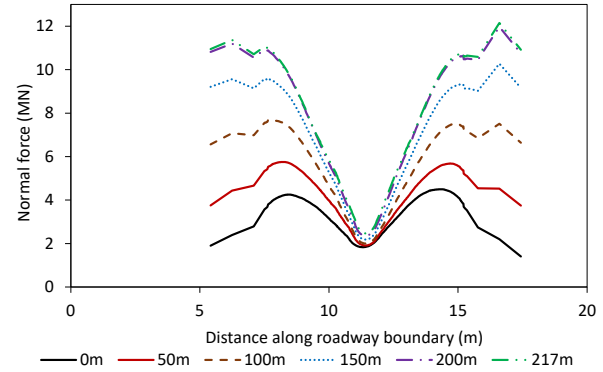


Fig.21 Summary of Normal force diagrams for the U-shaped roadway under various waste dumping height

Fig.14 to Fig.21 also demonstrate that, overall, the normal force values in the steel frame increase steadily with the dumping height. The normal force distribution remains fairly symmetrical across the roadway axis throughout the entire dumping process. This indicates that the normal force is less sensitive to eccentric loading compared to the moment.

Without the waste dump, the maximum normal force is 4.5 MN and the minimum is 1.4 MN. When dumping is complete, the maximum normal force increases to 12.15 MN (approximately 2.7 times), while the minimum normal force reaches 2.47 MN (an increase of approximately 1.76 times).

From the simulation results shown in Fig.6 to Fig.21 the following conclusions are obtained: The axial force increases more rapidly than the moment because the surface waste dump imposes a dominant vertical surcharge that is directly transferred to the support system, leading to a stronger axial compression effect. The asymmetry of internal forces at higher dump heights is mainly caused by the non-uniform development of the waste dump, resulting in an uneven stress distribution and eccentric loading on the roadway. This eccentricity induces additional moments in the support structure.

From an engineering perspective, these results indicate that roadway support design beneath waste dumps should consider both increasing axial forces and growing moment effects associated with load eccentricity, particularly under higher dump conditions.

From the numerical simulation results presented in Fig.6 to Fig.2 it can be observed that both the axial force and moment in the steel support system increase with the increase in the height of the waste dump. This indicates that the surcharge effect induced by the waste dump plays a dominant role in governing the internal force distribution of the

roadway support structure.

As the height of the waste dump increases, the additional loading transmitted to the underground structure becomes more significant, leading to a continuous rise in axial force and moment in the steel supports. This trend suggests that the structural demand on the support system increases notably under higher waste dump conditions.

Therefore, in the design of steel support systems for roadways located beneath the Mong Duong coal mine waste dump, it is necessary to account for the increasing internal forces associated with waste dump height. Appropriate design measures such as reducing support spacing, increasing steel section dimensions, or selecting higher-strength steel should be considered to ensure adequate resistance to the growing axial force and moment demands.

These findings provide a practical basis for optimizing the design of steel support systems under conditions of increasing waste dump height.

5. CONCLUSIONS

Based on the technical and natural conditions of the Mong Duong coal mine waste dump, as well as the rock mass conditions of the roadway located beneath the dump, a research model was developed to study the influence of waste dumping height on the internal forces in the support structure. Based on the results, the following conclusions are drawn:

The waste dumping height progress at the Mong Duong coal mine governs the state of internal forces in the underlying roadway support structure. As the dump height increases, both the normal force and moment in the support structure increase, clearly reflecting the effect of increasing surface waste dump loads according to the height development progress, which impacts the roadway support structure below. The roadway shape influences the internal forces of the steel support structure for roadways located beneath the waste dump. Under the actual conditions of the Mong Duong coal mine waste dump, the internal force values in the circular support structure are smaller than those in the U-shaped (straight wall and semicircular arch) support structure under the influence of surface waste dump loads. In the case of the circular roadway: The moment in the support structure increases by 1.75 times compared to the case studies without the waste dump, while the normal force increases by approximately 2.1 times compared to the case studies without the waste dump. In the case of the U-shaped roadway (straight wall and semicircular arch): The moment in the support structure increases by 1.2 times compared to the case studies without the waste dump, while the normal force

increases by approximately 2.7 times compared to the case studies without the waste dump.

In the design of steel support systems for roadways located beneath the Mong Duong coal mine waste dump, appropriate design measures should be adopted, such as reducing the spacing between support sets, increasing the steel section size, or using higher-strength steel, in order to ensure sufficient load-bearing capacity corresponding to the increasing height of the surface waste dump.

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