

Stability of Parallel Tunnels Driven by Top Heading and Benching Method in Jointed Rock Masses

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Abstract: *Currently in Vietnam, infrastructure construction is progressing rapidly. In the northern region, highway construction requires the building of tunnels through mountains. In major cities such as Hanoi and Ho Chi Minh City, subway lines are being constructed at a fast pace to help reduce traffic jams on the surface. The construction of mountain tunnels as well as subway tunnels are often used two parallel tunnels to increase transport capacity as well as facilitate tunnel operation. Nowadays, the analysis of twin tunnels often relies on assumptions such as circular cross-section tunnels in an elastic, homogeneous, and isotropic medium. The ground surface is assumed to be flat, and the two tunnels are considered to be located in an infinite half-space. Twin tunnels with different cross-sectional shapes have also been studied for various purposes under varying ground surface conditions, using complex variable methods and numerical models. However, the excavation of twin tunnels through mountains involves complex and variable geological conditions. The rock mass may be layered, foliated, fractured, and may even contain silt-filled cavities. Additionally, construction technology and tunnel construction methods are also factors that significantly affect tunnel stability. This requires in-depth studies to ensure the effectiveness of excavation, support, and tunnel usage. In this paper by numerical method investigated the mechanical changes around twin horse-shore tunnels in jointed rock masses, based on parameter analysis using the top heading and benching excavation scheme. The results show that the slope angle of the cracks significantly influences the destruction zone and the excavation impact zone around the two tunnels, especially under varying terrain conditions. The most influential jointed slope angles range from 15° to 60°.*

Keywords: *Parallel tunnels; slopes; non-circular tunnels; jointed rock mass; top heading and benching method; numerical simulation*

1. Introduction

The strong economic development in regions around the world, including Vietnam, has led to significant improvements in infrastructure and transportation-connecting mountainous areas with lowlands, plains with cities, and urban regions. Mountain tunnels and subway systems are increasingly being prioritized and constructed in many countries, including Vietnam. The analysis and design of twin (or double) tunnels have attracted the interest of many researchers, including (Phich, 2007, 2020; Do, 2020-2021; Do, 2016; 2021) and other scientists. To address the above problem, the authors often assume a model of a double tunnel in an infinite half-space with a circular cross-section (Nguyen, 2007; Hung, 2006; Do, 2014, 2020; Do, 2020; Tran, 2008-2015). For non-circular tunnel cross-sections, the problem is often solved using the complex variable function method by converting to an equivalent circular cross-section (Bulutrev, 1994; Fotieva, 1996). The problems of interest often involve changes in internal forces and mechanical behavior, such as plastic deformation zones and pressure distribution zones around the tunnels (Do, 2021 and Do, 2020). In recent years, in Vietnam the excavation of urban tunnels using shield technology has become increasingly common, leading to greater attention on surface subsidence caused by the construction of single and twin tunnels (Do, 2020; Do, 2021; Tran, 2015; 2022).

Nowadays, with advancements in technology, numerical modellings are increasingly being used, offering high efficiency in tunnel design (Do, 2016; Tran, 2015). Numerical methods can be divided into different groups such as: Discontinuous Deformation Analysis (DDA), Finite Element Method (FEM), Difference Element Method (DEM), Boundary Element Method (BEM). The advantage of this group of methods is that the models closely reflect real conditions, simultaneously accounting for many factors

affecting the geological and hydrogeological conditions of the tunnel construction area. Moreover, they can simulate the construction process, including the construction stages and the installation of tunnel support structures. In this paper, the mechanical changes and stability of two horseshoe-shaped tunnels under varying layered inclination angle conditions can be analyzed.

2. Model for the analytical problems

2.1. Model establishing

Considering a real case involving two tunnels that will be built on the mountain slopes with varying surface conditions (non flat). Due to the conditions of the construction area, and to reduce the distance between two tunnels for purposing excavation these tunnels will be designed and placed close to each other. In this study, the reference distance between two tunnels, measured from their centers, is 30 m based on the related projects such as the Hai Van tunnel, Deo Ca tunnel, and Cu Mong tunnel in Vietnam.

The tunnel used has a width of $B = 11.0$ m and a height of $H = 9.8$ m, excavated in an area with relatively stable rock and soil conditions. The analysis was performed for horse-shoe tunnels in jointed rock mass to assess mechanical changes, as well as the displacement of soil and rock around the tunnels when they are excavated in parallel by top heading and benching method. In addition, the influence of joint networks will also be considered in the research models. Initially, the tunnels in a continuous medium will be simulated, and then the models will incorporate additional parameters related to joint networks. The results of the model are shown in Figure 1. The tunnel is excavated in an area of primarily composed of rock parameters calculated by RocLab 1.0 software, described as in Table 1. Characteristics of joint networks in the model are described in table 2 using Barton-Bandis criterion. Tunnels applied supports by rock bolts and steel mesh and shotcrete, parameters of them can be seen in Tables 3 and 4.

Tab. 1. Characteristics of rock mass

Parameters	Value
Unit weight of rock γ , MN/m ³	0.02
Tensile strength of rock mass σ_t , MPa	0.1
Cohesion of rock mass C , MPa	0.15
Friction angle φ , Degree	25
Young's modulus E , MPa	1000
Poisson Ratio μ	0.3

Tab. 2. Characteristics of joint networks

Parameters	Value
Bedding spacing, m	5
JCS, MPa	90
JRC, MPa	9
Friction angle, degree	28
Normal stiffness of joints, MPa	100000
Shear stiffness of joints, MPa	10000

Tab. 3. Characteristics of rock bolts

Parameters	Values
Diameter of rebar of rock bolts d , mm	20
Modulus of steel bar of rock bolts E_t , MPa	200000
Tensile capacity of rock bolts P_c , MN	0.1
Residual tensile capacity of rock bolts P_{re} , MN	0.01
Rock bolt pattern $a \times b$, m	2.0×1.5
The length of rock bolts L , m	4.0

Tab. 4. Steel mesh and shotcrete

Parameters	Values
Wire mesh with diameter B40×40, mm	0.4
The thickness of shotcrete, mm	30
Young's Modulus	36000
Poisson Ratio	0.15
Compressive strength σ_c , MPa	41
Tensile strength σ_{ts} , MPa	5.0

The theoretical model is developed for the problem under homogeneous conditions (Figure 1a) and extended using finite element method (FEM) numerical software to account for varying jointed inclination angles in different soil and rock types, as shown in Figures 1b, 1c, and 1d, respectively. In the study, jointed inclination angles of 15°, 30°, 45°, 60°, 90°, and 165° are used in the model to evaluate and analyze the mechanical behavior around two horseshoe-shaped tunnels under varying ground surface conditions, with particular focus on the effect of changing jointed inclination angles.

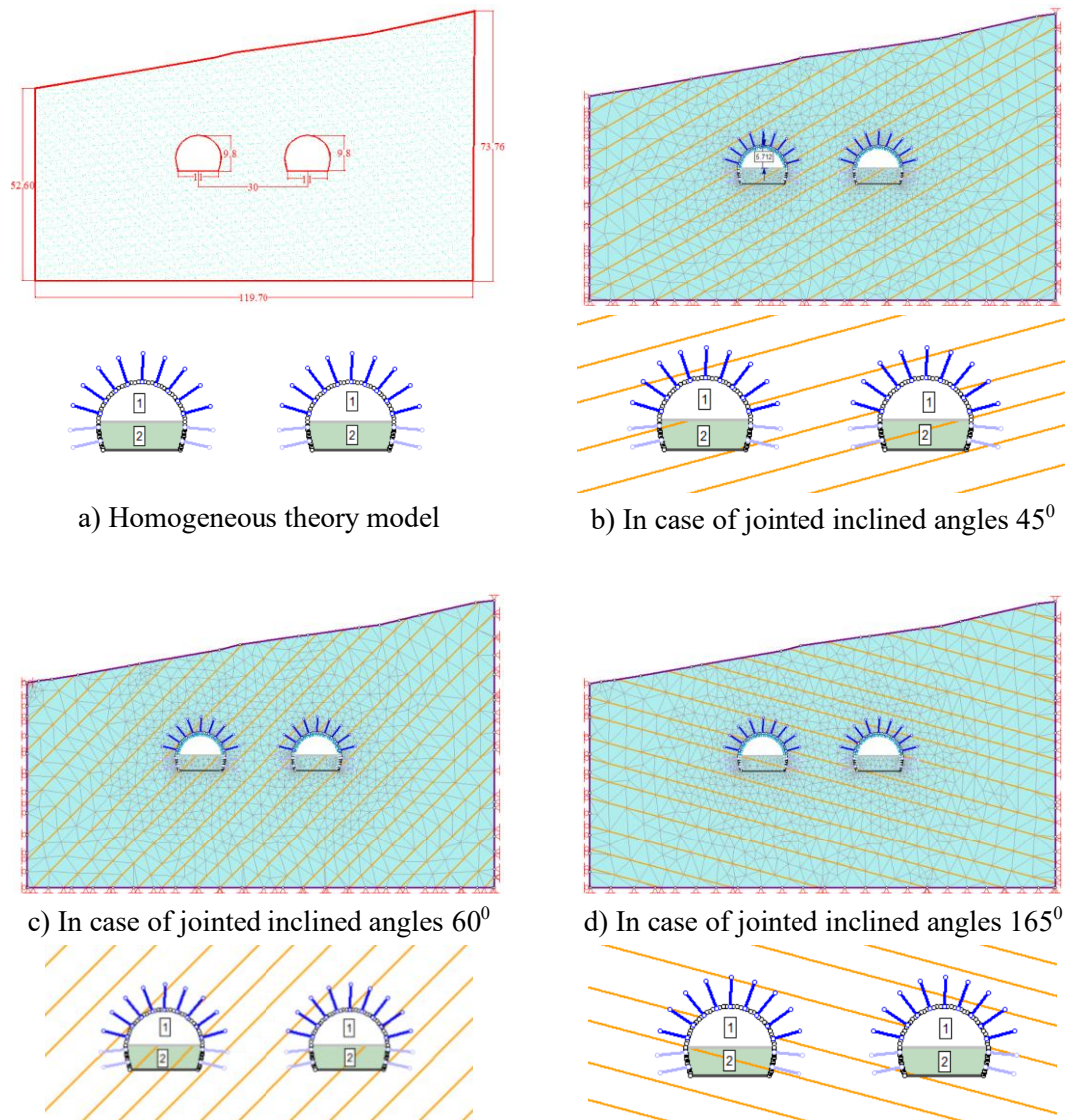
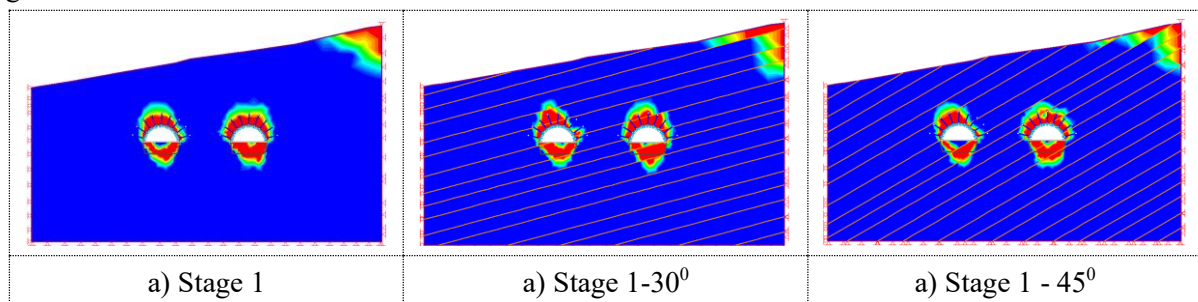


Fig. 1. Theoretical models in the study

2.2. Analysis results for the problem

Using the analytical model, can obtain the stress distribution, displacement, and deformation of the rock and soil around the tunnels under different conditions. One of the most noticeable factors is the variation in the pressure distribution area or plastic zone around tunnels. The extent of rock and soil failure around the tunnels in each case can also be determined through the analysis, the results can be shown in Figure 2.



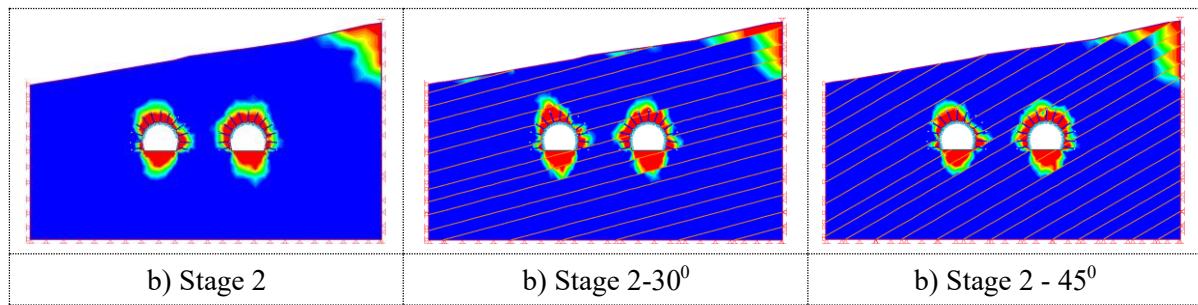


Fig. 2a. Changes in the failure zone around two tunnels with different jointed inclination angles

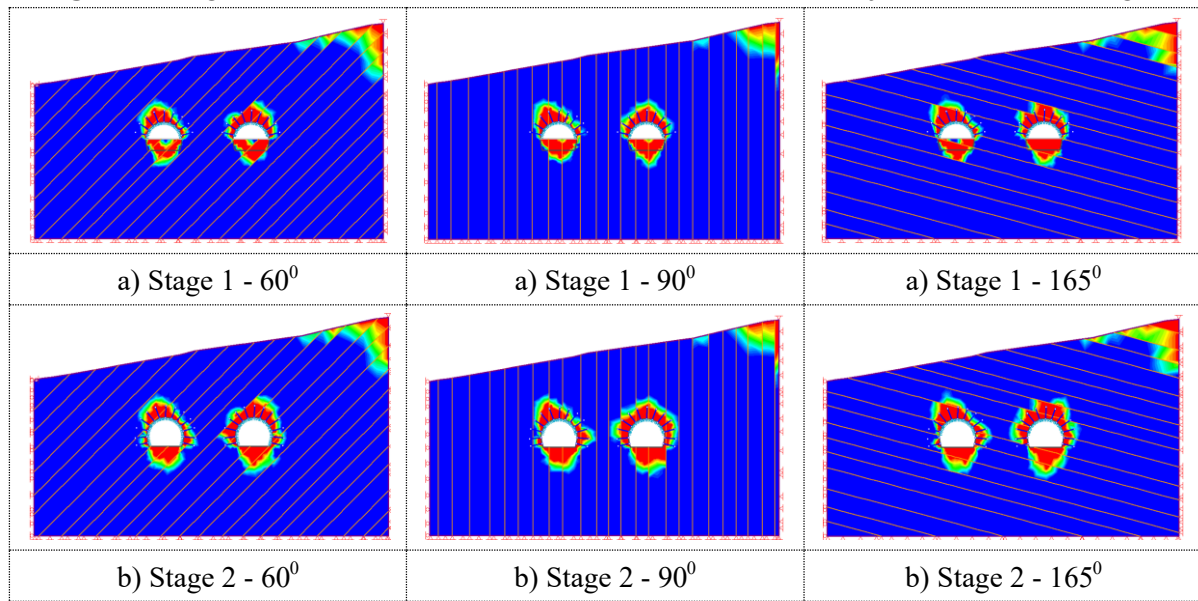


Fig. 2b. Changes in the failure zone around two tunnels with different jointed inclination angles

Observing the results in Figure 2, it is evident that the failure zones around the tunnels vary depending on the jointed distribution and slope angles. These failure zones differ significantly from those in a homogeneous rock mass. This highlights that the diversity and complexity of the rock mass require tunnel stability designers to be flexible in calculating and predicting pressure distribution, as well as in designing and selecting appropriate support structures for the two tunnels under varying slope conditions and jointed rock mass.

Through the analysis process, charts illustrate the relationship between the distribution of principal tensile stress and the total displacements of rock and soil around two tunnels under different jointed inclination angles were also obtained. The results are presented in Figures 3 to 6.

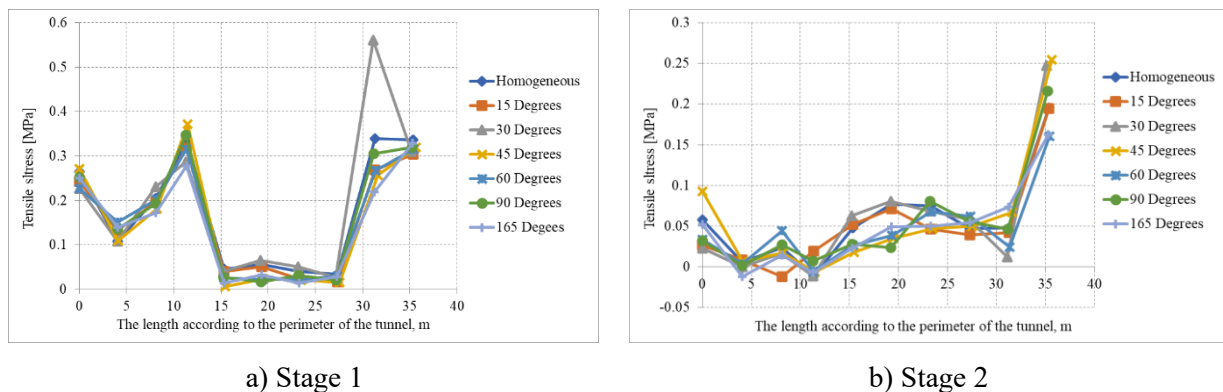
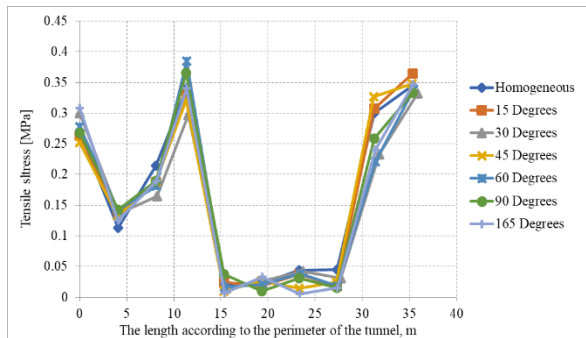
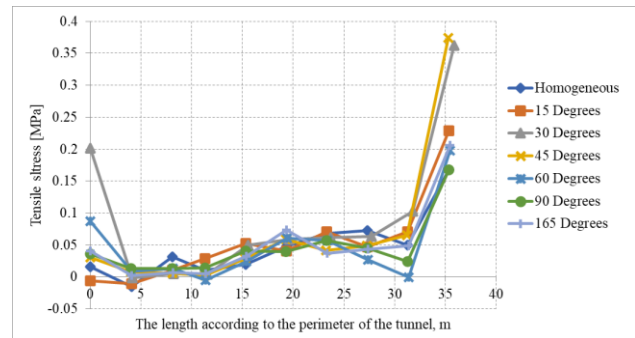


Fig. 3. The distribution of tensile stress in the rock mass around the left tunnel

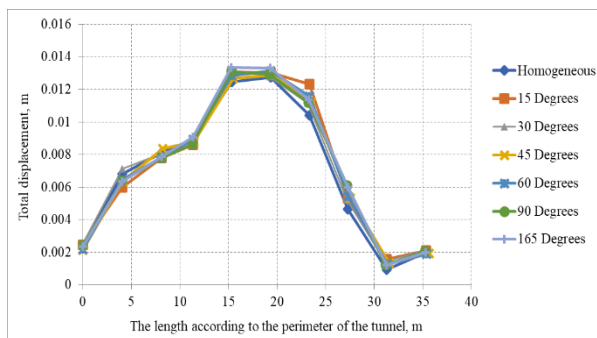


a) Stage 1

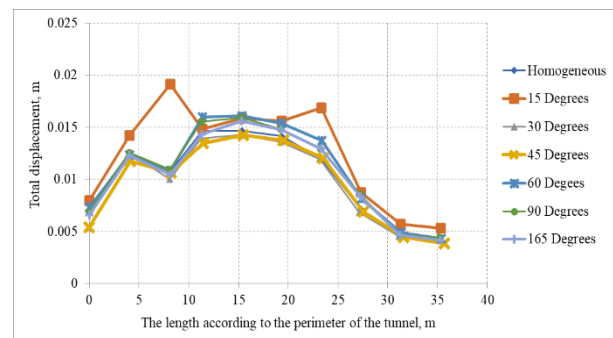


b) Stage 2

Fig. 4. The distribution of tensile stress in the rock mass around the right tunnel

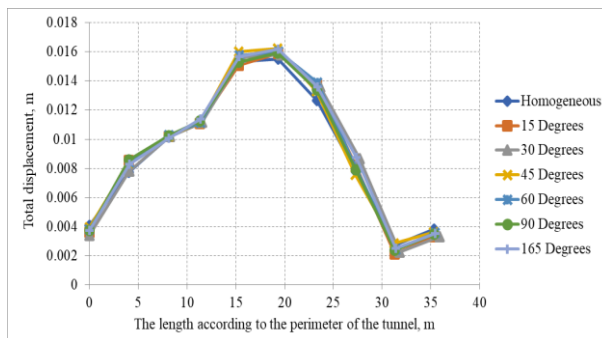


a) Stage 1

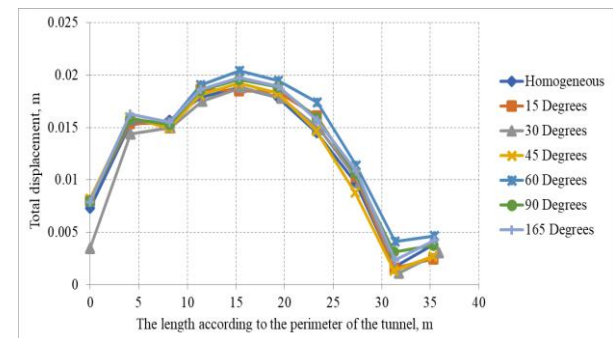


b) Stage 2

Fig. 5. Total displacement of rock mass around the left tunnel



a) Stage 1

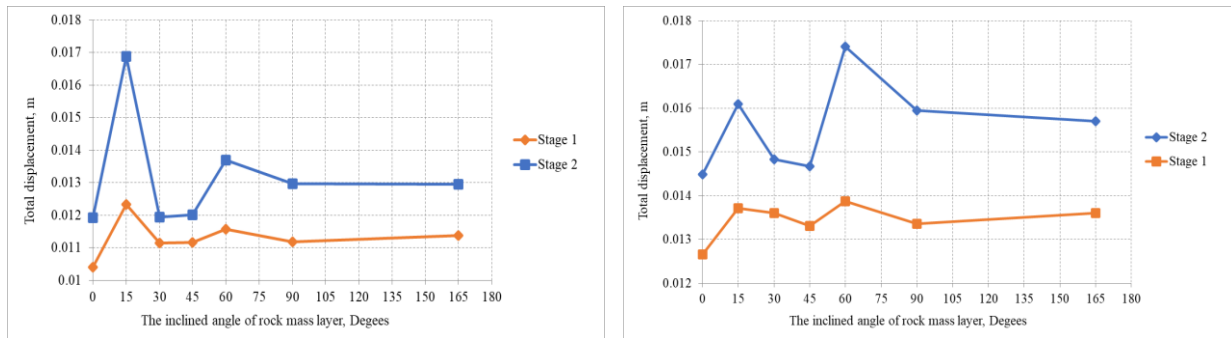


b) Stage 2

Fig. 6. Total displacement of rock mass around the right tunnel

The analysis results show that the distribution and rules of tensile stress and rock displacement on the tunnel boundary in different rock-soil jointed layering cases are very different. This shows that tunnel excavation in rock mass is different from that in homogeneous environment. Here, the rock displacement in rock mass with rock jointed angle of 15° and 60° has a larger value than in the corresponding homogeneous environment.

By the research results, the relationship between the displacement on the top of the tunnel and the slope angle of the rock layer in the two stages of excavation and tunnel supports. The results are shown in Figure 7.



a) Total displacement on the top of the left tunnel b) Total displacement on the top of the right tunnel

Fig. 7. The total displacement on the top of twin tunnels

The results in Figure 7 show that in Stage 1, the displacements at the top of the tunnel are still small. However, after the tunnel is further excavated and deepened, the cross-sectional area increases, leading to a corresponding increase in the displacement at the tunnel crown (in Stage 2). From the graph, it can be observed that the displacement values in both Stages 1 and 2 are larger on the top of the left and right tunnels when the slope angles of the rock layer are 15° and 60° , respectively. This indicates that greater attention must be paid to the calculation and design of tunnel stability during excavation and support in these cases compared to others.

3. Conclusions

Based on both theoretical analysis and the results of the numerical model, it can be seen that ground surface conditions have a significant influence on the distribution of stress and displacement in the rock mass, as well as on the tunnel boundaries in different cases.

Under flat ground surface conditions, the stress and displacement values are symmetrical around the tunnels. However, when the ground surface has a slope as in the studied case the stress and displacement values tend to shift to the left. This is because the slope descends from right to left; as a result, the stress and displacement values on the right side of the tunnels are greater than those on the left. This phenomenon can be explained by the difference in terrain elevation: in a homogeneous medium, stress and displacement increase with depth into the mountain.

In the case of two tunnels excavated in jointed rock mass with varying jointed inclination angles, it was found that for jointed inclination angles of 15° and 60° , the displacement and stress changes were more pronounced than in some other cases. However, all cases followed the same pattern of variation, indicating the need for more in-depth studies to clarify the complexity of the rock and soil environment.

Numerical analysis models should be applied in the analysis and design process, allowing for the early prediction of rock pressure and the preliminary selection of initial support structures. However, flexibility is needed when updating geological conditions for each section and area of the tunnel as it is excavated in practice, to ensure the effectiveness of the analysis.

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