



The Selection of Suitable Shape for Twin Tunnels in the Slope Surface Conditions

Tuan Minh Tran^(✉), Trung Thanh Dang, and Duyen Phong Nguyen

Hanoi University of Mining and Geology, Hanoi, Vietnam

trantuanminh@hmg.edu.vn

Abstract. Two parallel tunnels are used in the field of underground construction not only in Vietnam but also in other countries around the world. Currently, two-tunnel analysis problems are resolved based on simple assumptions, such as circular tunnels in an elastic, isotropic, and continuous environment of rock mass under flat surface conditions. However, many types of different cross-sections of tunnels have been used depending on the intended use of the tunnel and the tunneling technology. The geological conditions are very complicated, consisting of joints, layers, faults, and other parameters. Additionally, there are many different types of tunnel cross-sections, such as arch, horseshoe, curved rectangle, elliptical, oval, and other shapes, and the topographical surface conditions are also complex. This problem requires in-depth research to ensure effective excavation, protection, and utilization of tunnels. This article analyzes the alteration of displacement and stresses around tunnels with different cross-sections under sloped surface conditions using numerical models to select an appropriate tunnel shape. The research results show that under both flat and sloped surface conditions, the suitable tunnel shapes are horseshoe or sub-rectangular, as these shapes minimize displacement along the tunnel boundaries.

Keywords: slopes · non-circular tunnels · rock bolts · shotcrete · numerical simulation

1 Introduction

The rapid growth of the economy in various regions around the world, including in Vietnam, has brought positive changes to infrastructure and transportation, particularly in the areas connecting mountainous regions, lowlands, rural fields, and urban centers. Traffic tunnels through mountains and subway systems have received increasing attention and have been constructed in many countries, including Vietnam [3–11]. The analysis and calculation of twin tunnels have attracted the interest of many scientists. They often assume the problem of twin tunneling in a semi-infinite plane with circular tunnel cross-section in the elastic mediums [1, 2, 4–11]. For non-circular tunnel cross-sections, which is typically solved by the variable complex method, and by converting the section into an equivalent shape [12–14]. These problems typically involved considering changes in internal forces and mechanical alteration (such as plastic zone,

redistribution zone of stress) around tunnels [6–9]. Recently, the excavation of urban tunnels using shield machines has become more common, and the issue of surface subsidence caused by tunnel excavation has also attracted increased interest [4–9]. Nowadays, with the advancements in technology and software, numerical software is being increasingly widely used, leading to greater efficiency in tunnel design [6–8, 10–12]. Currently, specialized software can be developed based on various numerical methods, such as Discontinuous Deformation Analysis (DDA), Finite Element Method (FEM), Discrete Element Method (DEM), and Boundary Element Method (BEM).

The advantage of these methods are model closely resembles actual conditions, taking into many influencing factors of geological and hydrogeological conditions. In addition, the excavated stages and the installation of the tunnel supports can also be simulated in the models. In this paper, the mechanical transformation and stability of the twin tunnels with circular cross-sections, arches, rectangular shapes, and horseshoe tunnels will be analyzed to select appropriate shapes for tunnels.

2 Model and Analytical Problem

2.1 Model Establishing

Consider a practical case consisting of twin tunnels that will be built in an area of slopes, terrain, and varying topographic surface conditions (not flat). Due to the conditions of the construction area, the distance between the two tunnels is reduced to shorten the horizontal lines connecting them and facilitate construction and evacuation work. Therefore, the locations of these two tunnels are designed relatively close to each other. The tunnel span, with a width of $B = 11.0$ m and a height of $H = 9.8$ m, was excavated in an area of relatively solid soil and rock. The problem is analyzed for 4 different types of tunnel cross-sections to consider the mechanical change and the displacement changes of soil and rock around the boundaries of the tunnels, under the condition that the twin tunnels are excavated in parallel together at the same time. Other cases will be considered in further research. The problem model is implemented as shown in Fig. 1. The tunnel span is designed with an aperture of 11 m, excavated in an area primarily composed of soil, with soil and rock parameters calculated by RocLab 1.0 software, described in Table 1.

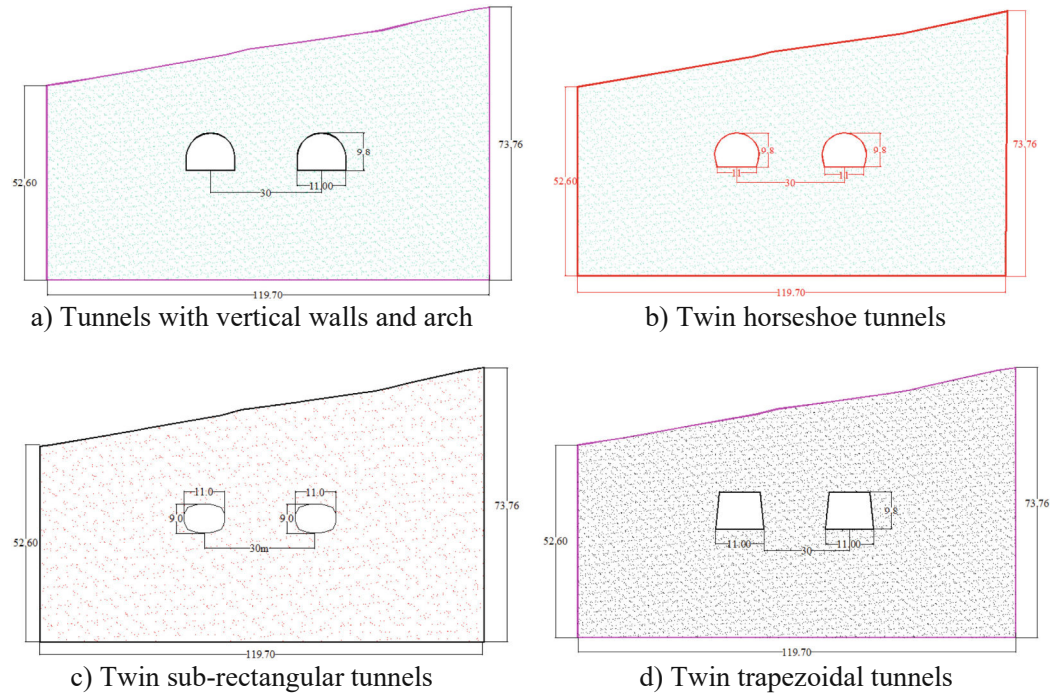


Fig. 1. Theoretical model for analytical problem

2.2 Numerical Modeling for Case Study

The model for problems can be simulated by using the numerical software in Phase 2 (one software has good features and is widely used in the geotechnical analysis) with the input parameters as Table 1 and the theoretical model (Fig. 1). Analysis results for the total displacement distribution of the soil and rock mass around the tunnels can be observed in Fig. 2.

Table 1. Input parameters for the model in this studying

Unit weight of rock	γ	0.018	MN/m ³
Tensile strength of rock mass	σ_t	0.02	MPa
Cohesion of rock mass	c	0.05	MPa
Friction angle	ϕ	19	Degree
Young's modulus of rock mass	E	300	MPa
Poisson ratio of rock mass	μ	0.30	—
Residual friction angle	ϕ_{re}	15	Degree
Residual strength	c_{re}	0.0	MPa
Span of tunnels	B	11	m
Criterion of material	M-C		—

The tunnels are supported by rock bolts combined with steel mesh shotcrete. Based on the numerical method, the parameters of rock bolts and steel mesh shotcrete can be

selected in the models. The characteristics of rock bolts and the shotcrete combined with steel mesh are described in Tables 2 and 3.

Table 2. Characteristic of rock bolts

Parameters	Symbol	Values
Diameter of rebar of rock bolts, mm	d	20
Modulus of steel bar of rock bolts, MPa	E_t	200000
The tensile capacity of rock bolts, MN	P_c	0.1
Residual tensile capacity of rock bolts, MN	Pre	0.01
Rock bolt pattern axb, m	axb	2 x 1.5
Length of rock bolts, m	L	4.0

Table 3. Parameters of steel mesh and shotcrete

Parameters	Symbol	Values
Wire mesh with diameter B40x40, mm	ϕ	4.0
The thickness of shotcrete, mm	d	30
Young's Modulus of shotcrete, MPa	E_c	36000
Poisson ratio	μ	0.15
Compressive strength of steel, MPa	σ_c	41.0
Tensile strength, MPa	σ_{ts}	5.0

Observing the displacement distribution results in Fig. 2, it is found that the total displacement distribution around the circular tunnel has the smallest influence area, followed by the horseshoe-shaped tunnel and, finally, the straight-walled arch tunnel. The total displacements are largest near the tunnel boundaries (red color) and decreased farther into the rock mass (blue color). A graph of stress and total displacement values at different positions along the tunnel boundary was created to observe the stress-deformation changes around the tunnels. The purpose of this is to evaluate the role of shape in the changes in stress and displacement values on the tunnel boundary, thereby determining the most effective cross-sectional type for the tunnels.

From the above analysis, the relationship between vertical stress and total displacement at the tunnel boundaries of these tunnels in the model can be obtained for five different tunnel shapes when the topographical surface is inclined from right to left (Fig. 2). The results are shown in Figs. 3, 4, 5 and 6.

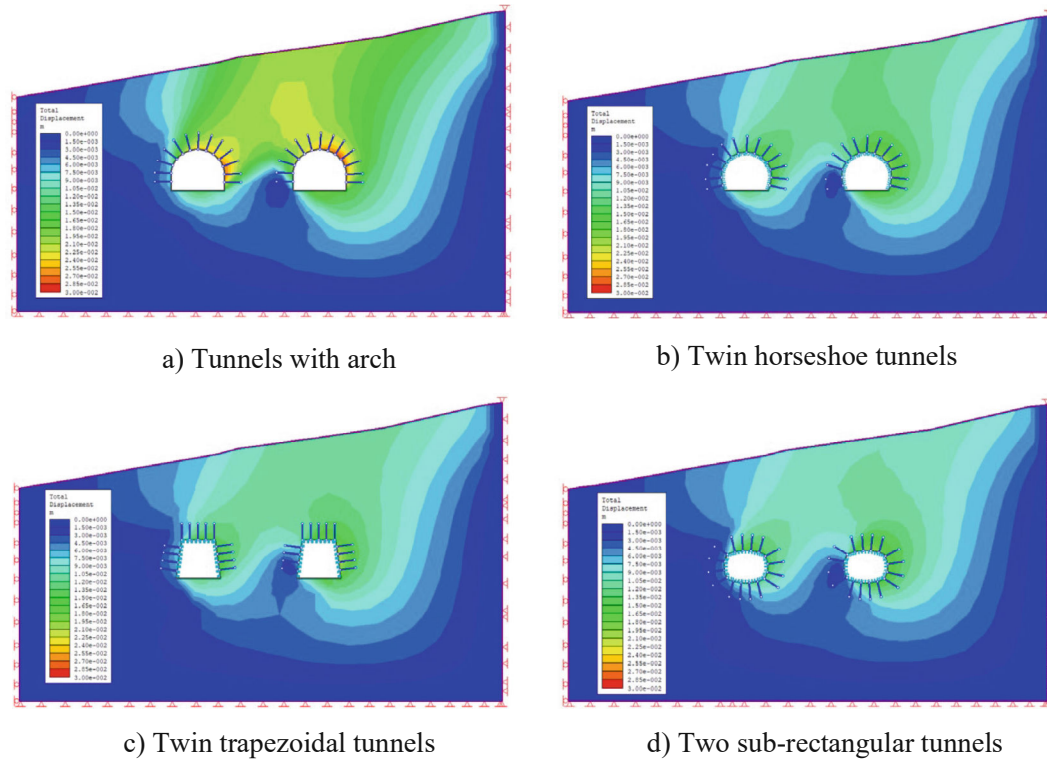


Fig. 2. Displacement distribution around two tunnels

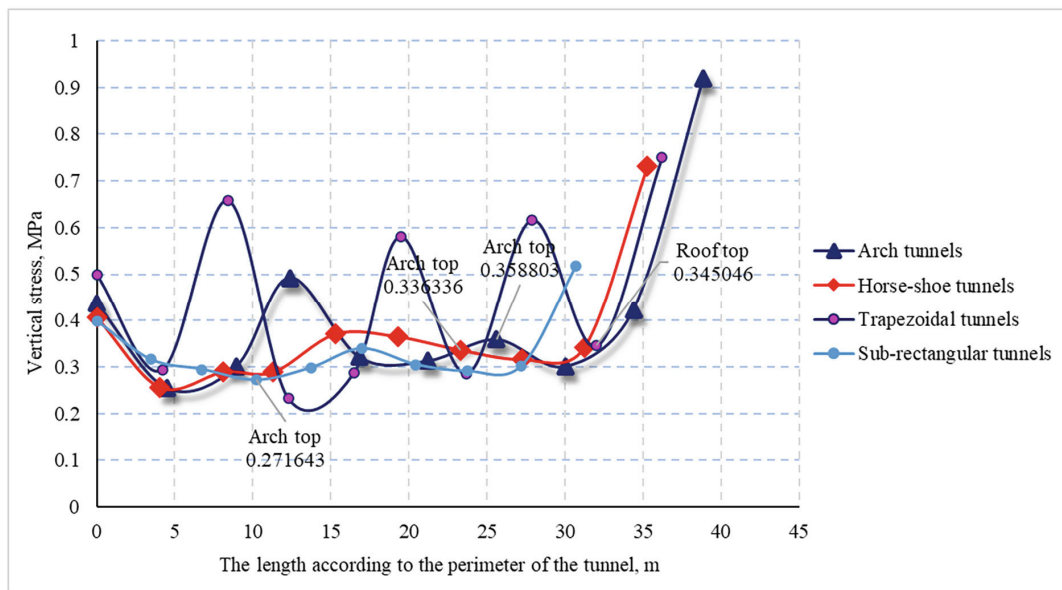


Fig. 3. The distribution of vertical stress on the boundary of the left tunnel

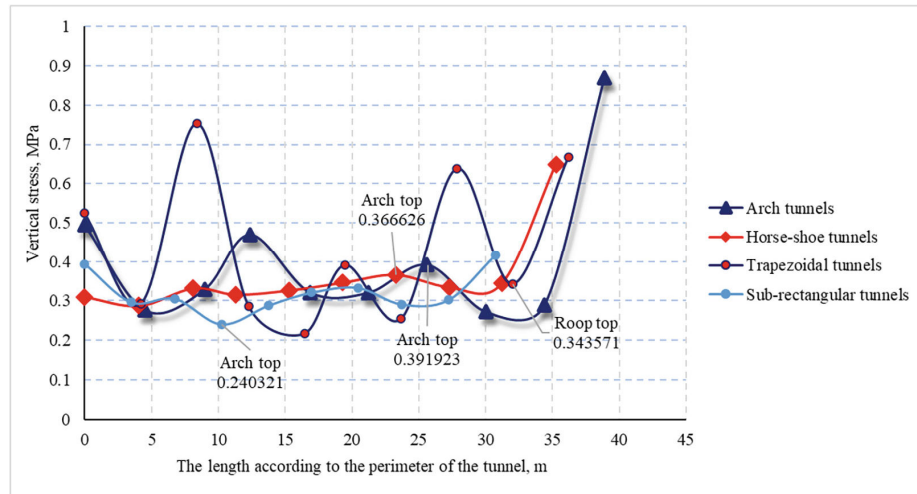


Fig. 4. The distribution of vertical stress on the boundary of the right tunnel

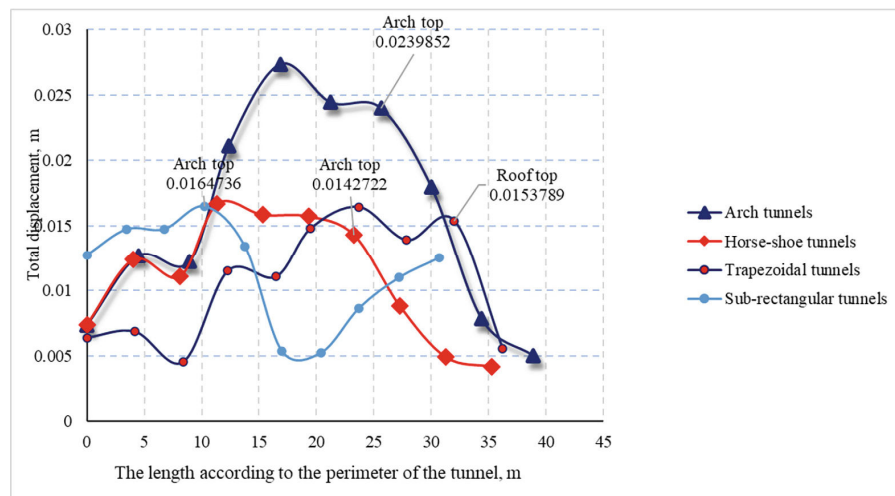


Fig. 5. The distribution of total displacement on the boundary of the left tunnel

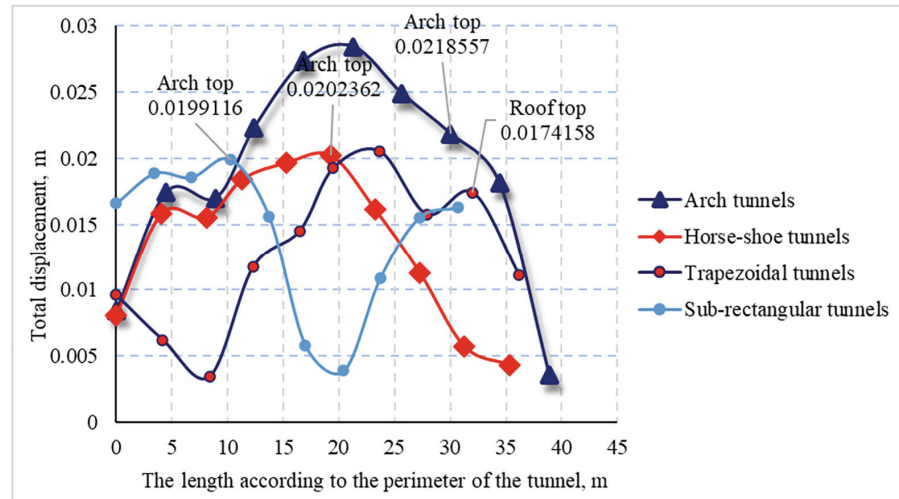


Fig. 6. The distribution of total displacement on the boundary of the right tunnel

The results from Figs. 3, 4, 5 and 6 show that, for each tunnel cross-section tunnel (left or right), the stress and displacement values at the top of the arch (at a position where there is danger) potentially destabilizing the tunnel will have different values. However, the stress on the roof of a horseshoe-shaped tunnel is the lowest, indicating that this case is the most stable shape. To clearly observe the difference between the two tunnels under surface variation, a comparative analysis was conducted using a numerical model with the same conditions for two tunnels under horizontal surfaces.

The results of the numerical model for displacement distribution around these tunnels are shown in Fig. 7. Because the ground surface is flat and the problem model is symmetric, the determination of the stress and total displacement on the boundary of tunnels can be resolved in any tunnel (left or right). After analysis, the relationship between the variation of stress and displacement at the tunnel boundary can be seen in Figs. 8 and 9.

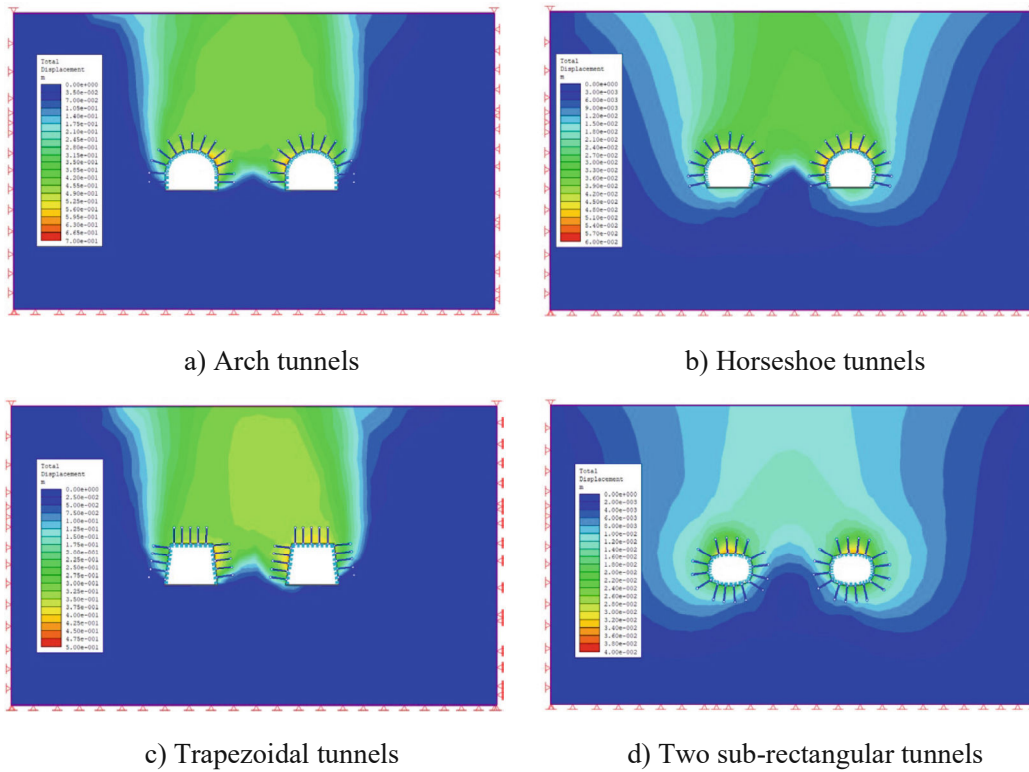


Fig. 7. Displacement distribution of rock mass around tunnels

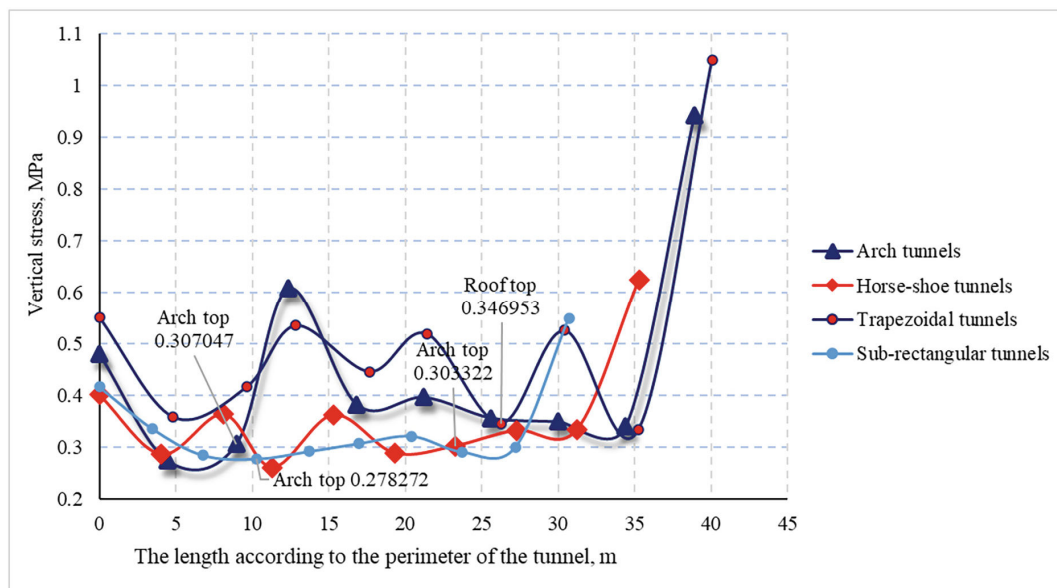


Fig. 8. The vertical stress on the boundary of the left tunnel under flat surface conditions

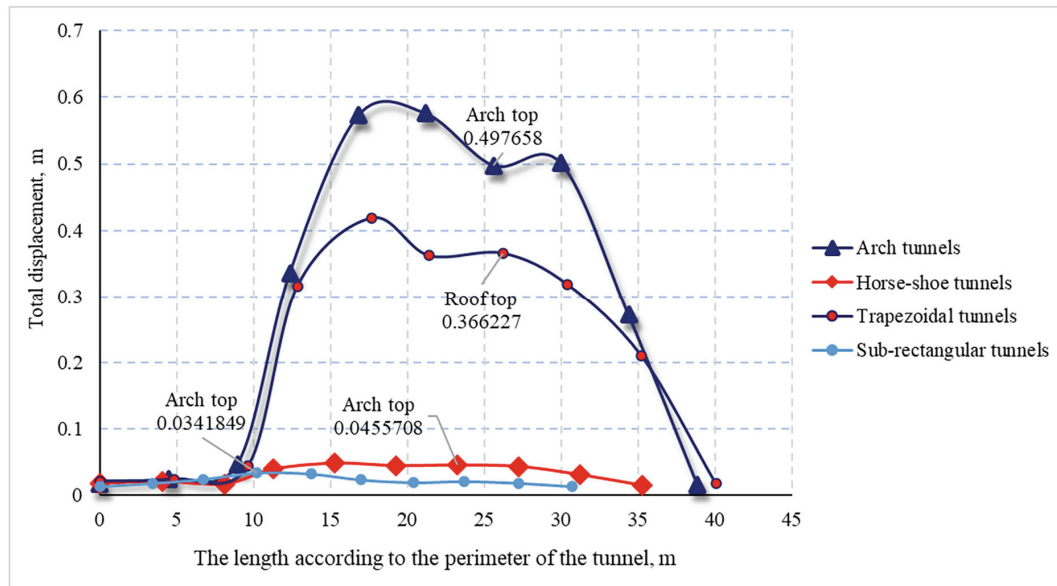


Fig. 9. Displacement on the boundary of the left tunnel under the flat surface condition

By analysis, can be obtained the displacement values at the roof of the tunnels respectively for the two cases in which the ground surface is flat and changed as shown in Table 4.

Table 4. Displacement values on the top of tunnels, m

Circular tunnels	Arch tunnels	Horseshoe tunnels	Trapezoidal tunnels	Sub-rectangular tunnels	Surface conditions
0.818713	0.497658	0.045571	0.366227	0.0341849	Flat
0.097767	0.023985	0.014272	0.016379	0.0164736	Slope

3 Conclusions and Discussions

The analysis results show that the boundary condition of the soil surface has a significant influence on the values of stress and displacement in the soil mass and at the tunnel boundaries in other cases.

Stress and displacement values are symmetric around the tunnels in the case of flat ground surface conditions. However, when the ground surface is altered, as in the research problem, the stress and displacement values tend to skew to the left due to the slope of the surface from the right side. The stress and displacement values are greater on the boundary of the left tunnel side. It can be explained by the difference in elevation of the topography: in a homogenization problem, as stress and displacement increase deeper into the mountain, the values become higher.

For both cases, where the ground surface is flat and sloped, the suitable cross-section for these two tunnels should be a horseshoe arch or sub-rectangular shape. In these cases,

the stress and displacement values at the top of the tunnel will be smaller than in other cases, indicating that this shape provides the most stability.

The numerical analysis model and numerical method should be applied in the analysis and design process to predict rock pressure early and to select the initial support structure in tunnels preliminarily. However, when using the numerical model, users must be creative and flexible when updating geological conditions in each section of the design process.

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