

# Numerical Simulation on the Stability of Surrounding Rock of Horizontal Rock Strata in the Tunnel



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## Abstract

By taking "Xi Shan Highway Tunnel" as the research object, it has studied the stability of surrounding rock which was excavated in horizontal rock strata. Adopting numerical simulation method, the numerical model of the tunnel has been established. It obtained the horizontal and vertical direction variables of the surrounding rock. According to the calculated results, the construction method can be optimized to ensure the safety and quality of the construction.

**Keywords:** Highway tunnel; Horizontal rock strata Stability of surrounding rock; Numerical simulation

## Introduction

The stability of tunnel surrounding rock refers to the self-stability of the surrounding rock without any supports, mainly reflected in two aspects, which are surrounding rock deformation and failure [1-3]. The essences of the stability analysis of surrounding rock are the analysis and evaluation of rock mass medium, the relationship between stress and strain. A large number of engineering practices shows that [4-7], the stability of tunnel surrounding rock is not only associated with the quality of geological structure and groundwater, but also with the excavation and supporting of the tunnel of time and form.

The length of Xishan tunnel is 13.63km, and it is the second longest highway tunnel in China. The main and auxiliary work of the tunnel is through the horizontal rocks. Because of its poor stability of tunnel surrounding rock, there is more likely to occur arch block off during the construction, it is one of the important factors affecting the tunnel construction safety. How to ensure the stability of surrounding rock of tunnel level plays a crucial role in tunnel construction and safety operation.

By taking Xishan super-long highway tunnel as the research object, factors affecting the failure mechanism and stability of surrounding rock deformation after excavation are researched.

## Analysis Of Stability And Failure Characteristics Of Surrounding Rock In Horizontal Rock Strata

The stability of surrounding rock is not only determined by the strength of the rock, but also depends on the integrity of the

surrounding rock structure. The structure of rock mass is divided into five categories: the complete structure, block structure, catalectic structure, layered structure and granular structure, which are also the basic types of the tunnel surrounding rock structure in the horizontal rock area [8].

The rock mass of the horizontal layered structure is a simple sedimentary rock, which can be composed of a single lithology, and can also be formed by the combination of different lithological layers. The level is often the intercalated sliding between layers connecting level is weak, the damage mostly to the top curve subsidence and separation. When the subsidence is large, layers appear broken failure. Large span underground cavern excavation in layered rock is clearly layered, and the more prominent problem is the stability of surrounding rock.

The comprehensive effect of tunnel surrounding rock stability depends on many factors, the main factors are: physical and mechanical properties, structure and construction of rock mass, natural stress state of rock mass and geological structure influence, groundwater, rock under static and dynamic load, tunnel's geometry and the construction scheme.

According to the factors affecting the stability of tunnel surrounding rock, influence factors of surrounding rock stability of tunnel in horizontal stratum area can be summarized into three types [4]:

- i. The geological factors: rock stress, physical and mechanical properties of the rock, structure of the rock, rock composition and physical and chemical properties, etc.;

ii. The engineering factors: the shape and size of the tunnel section and the high-span ratio; the construction factors: tunnel construction methods, support time and support methods etc.

iii. The geological factors are the main factors that influence the stability of surrounding rock.

The destruction of surrounding rock of the tunnel is mainly depended on the stability of surrounding rock [9]. The failure mode of surrounding rock is varied with its structural characteristics, and its failure mechanism is also different in different damage stages, and it is related to the shape of the tunnel. For horizontal strata, due to the rock level and surrounding rock itself of low strength and bad cementation, leading to deformation and failure in the process of excavation of the surrounding rock. It has its special characteristics and failure modes are:

- i. Fragmentation loose;
- ii. The expansion and drum inside;
- iii. Crushing failure;
- iv. Sliding failure;
- v. Underground water failure.

### Numerical Simulation Analysis On Stability Of Surrounding Rock In Horizontal Rock Strata

With the development of science and technology, the numerical simulation theory and method to solve the problem of the tunnel have developed rapidly. Due to the successful application of various numerical methods [10-12], the understanding of the engineering geological phenomena of many tunnels has been deepened, and the quantitative process of the tunnel engineering disciplines has been greatly promoted. In this paper, software called MIDAS/GTS is used to analyze the stability of the surrounding rock in horizontal rock strata.

#### Geological condition of Xishan tunnel

The length of Xishan highway tunnel is 13.63km, the main tunnel and ancillary works across the horizontal rock tunnel is one of the important factors affecting the safety of the tunnel construction. The tunnel is through 17 fault fracture zones, faults in the entry section are relatively concentrated. In the 200m range, there are a total of eight faults, and some of the faults are more possibility to occur inrush. Karst development is

in the tunnel site, and the geological condition is very complex.

#### Establishment of calculation model of the tunnel

In the cross section of the model, the horizontal is the X direction, the vertical direction is Z, and the Y direction is along the tunnel axis. In the finite element model, the left and right away to the tunnel are 3 times of the tunnel span, the upper boundary is taken to the surface, the lower boundary is to the 3 times the height of the tunnel. Boundary conditions imposed displacement constraints: the left and right sides apply X to the constraints, the front and back surfaces (vertical axis of the two sides) apply Y to the constraints, the bottom surface applies Z to the constraints, the upper surface is set to be the free surface. In accordance with the “tunnel structure near the subdivision of the grid, away from the loose” principle, automatic division of the finite element mesh, the entire model has nearly 30 thousand nodes and more than 140 thousand units. The passivation and activation of the grid units are to realize the tunnel excavation and support. It changes the “boundary conditions” in the “element” to reinforce the surrounding rock strata. The excavation surface of a single element is extracted from the rock solid to simulate the initial shot Crete support structure. The calculation model of tunnel is shown in Figure 1.

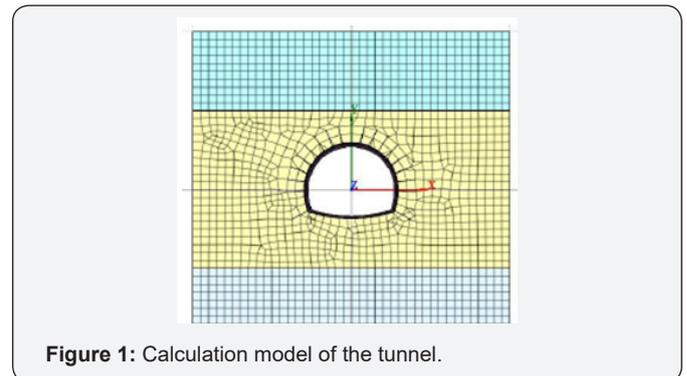


Figure 1: Calculation model of the tunnel.

#### Parameter settings in the calculation model

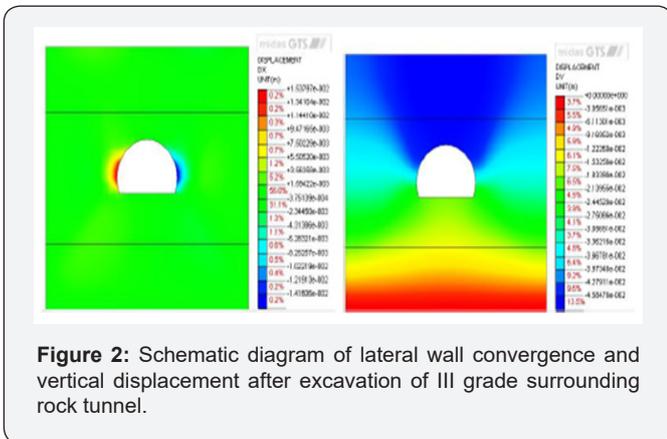
In the calculation of model, according to the characteristics of the horizontal strata in Xishan tunnel, the rock is assumed as ideal elastic-plastic body. The rock has been wreathing seriously, So the parameters obtained from the experiments should be cut to get closer to the true state of the surrounding rock. According to the geological survey data, the surrounding rock grade of Xishan tunnel is mainly based on the III and IV grade rocks. The physical and mechanical parameters of the materials in the model are set as Table 1.

Table 1: Physical and mechanical parameters of materials in the model.

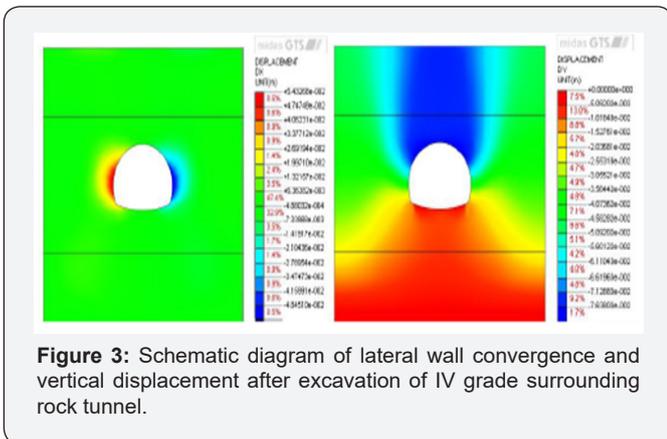
Names	$\gamma(kN / m^3)$	$\phi(^{\circ})$	$C(MPa)$	$E(Gpa)$	$\mu$
III grade surrounding rock	21	44	1.1	11	0.25
IV grade surrounding rock	20	30	0.4	3	0.3

**Results and analysis of the calculation**

- i. The lateral wall convergence and vertical displacement after excavation of the III grade rock tunnel are shown in Figure 2. It can be seen from the above, III grade surrounding rock tunnel excavation of the maximum level of convergence of the lateral wall is about 16mm, and the maximum settlement value of the tunnel vault is approximately 46mm.
- ii. The lateral wall convergence and vertical displacement after excavation of the IV grade rock tunnel are shown in Figure 3. It can be seen that IV grade surrounding rock tunnel excavation of the maximum level of convergence of the lateral wall is about 55mm, and the maximum settlement value of the tunnel vault is approximately 80mm.



**Figure 2:** Schematic diagram of lateral wall convergence and vertical displacement after excavation of III grade surrounding rock tunnel.



**Figure 3:** Schematic diagram of lateral wall convergence and vertical displacement after excavation of IV grade surrounding rock tunnel.

From the above simulation analysis data can be seen:

After the excavation of IV grade surrounding rock tunnel, both the horizontal convergence of the lateral wall and the vertical displacement of the vault is larger than that of the surrounding rock after excavation of the III grade surrounding rock tunnel.

After the excavation of the horizontal rock tunnel, the lateral wall of the surrounding rock has a convergence trend.

The Convergence of the side wall is basically a whole side of the tunnel section convergence phase the offset of convergence of both sides, this is due to the tendency of layered rock to rock resistance on both sides of the differences caused by the impact, but relatively to the tunnel section and the whole structure will not.

The vertical displacement of the vault soil is obviously larger than that of the other parts after the excavation of the horizontal rock tunnel. This is because the horizontal rock strata, tunnel excavation, horizontal plate at the crown level emptied, equivalent to support and on both sides of the arch wall horizontal beam plate, and generally horizontal rock formation is difficult to form a pressure arch or stable pressure arch, which makes the vault rock to bear fairly big rock pressure.

According to the results obtained from the above calculation, the following measures are put forward for the construction of horizontal rock strata in Xishan tunnel:

- i. To avoid the the vault crown settlement of the tunnel, it should strengthen arch bolt, ensuring that the arch and the overlying rock solid or unperturbed perturbation closely, the formation of “pressure arch”, the diameter of 22 cement mortar bolt is used for anchor.
- ii. After the anchor is buried, in the arch and side wall set steel mesh, and timely shot Crete, using flexible composite support to adjust the tunnel side wall convergence deformation, the effect of tunnel surrounding rock and the structure of control at a minimum. Reinforcing steel mesh with double laying made of  $\phi 6$  round steel, the mesh size is 20cm×20cm. Selecting C25 shot Crete, each layer thickness is 4-6cm, the total thickness is 20cm.
- iii. Timely closed in the arch, so that the tunnel section is closed as soon as possible into the ring, improve stability, and strengthen the monitoring measurement, especially the vault displacement monitoring.

**Conclusion**

The special stratigraphic structure of the horizontal strata of the Xishan tunnel makes the interlinear jointing ability greatly reduced, and the tunnel duration is tight, so the tunnel construction has a great risk. In this paper, the stability of the horizontal strata during the construction of Xishan Tunnel is analyzed by numerical simulation method. The construction measures are put forward. In the tunnel construction, the construction safety is still needed to ensure the construction safety and construction quality.

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