

Study on the Influence of Cover Plate on the Safe Operation of Highway in Shallow Burial Tunnel Construction

Jiancong Xu^{1,2,*} and Yuan Hu²

¹Key Laboratory of Geotechnical and Underground Engineering of Ministry of Education, Tongji University, China

²Department of Geotechnical Engineering, Tongji University, Shanghai 200092, China

*Corresponding author

Abstract—The rapid increase of transportation makes it necessary construct shallow burial Tunnel under skew-crossing highway in China. Thus, the prediction of the influence on the safe operation of skew-crossing highway in the tunnel construction plays a key role in the optimal design and construction of tunnels, to avoid any damage to the existing highway during and after tunnel construction. In this study, the numerical analysis combining with the case in Fujian province, P.P. China, using finite element program ABAQUS, has made it possible allow for the situation of the tunnel under skew-crossing highway with a small angle. The influence of cover plate on the safe operation of highway in shallow burial tunnel construction was researched. The study results are shown as follows: the construction of tunnel has great impact on the operating highway; the larger the vehicle load on the highway, the greater the settlement of highway; the use of cover plate may be the effective measure to control the highway settlement; there is an zone of highway settlement influenced by cover plate stiffness and vehicle load, beyond which their influences on highway settlement are greatly reduced. The influence of the distance between tunnel face and highway on the safety of highway in operation has also been highlighted.

Keywords—tunnelling construction; numerical modeling; highway; cover plate; settlement

I. INTRODUCTION

Recently many tunnels are often constructed under crossing the highway in operation. In addition, in many cases, the new tunnel is often excavated adjacent to the already existing highway. Thus, the prediction of the influence of new tunnel construction on the existing highway plays a key role in the optimal design and construction of tunnel in order to avoid any damage to the existing highway during and after the construction of tunnel.

Interactions between the construction of tunnel and the existing highway were studied in the past using a variety of approaches such as physical model tests, field observations, empirical/analytical methods and finite element methods.

A 3D finite element simulation was used to study on the response of the highway under which the tunnel were constructed [1]. The result of simulation shows that the construction of tunnel may lead to the tensile failure of highway and the deformation is larger in the bottom and crown

of tunnel. In order to test the validity of reinforcement measures used in Wenxiang Tunnel for Zheng-Xi special passenger railway, the field monitoring was conducted [2]. From the feedback of field implement and monitoring result, the effect of reinforcement measures is significant.

Using FLAC3D studied on the short-term ground movements of the twin shield tunnel traversing beneath the subgrade of high-speed railway [3]. The field monitoring was adopted to investigate the region and control standard of ground settlement on the highway caused by the tunnel construction [4~6].

The purposes of three dimensional numerical simulation are to obtain the tunneling-induced settlement and the optimal excavation sequence for the tunnel. In the paper, the numerical analysis combining with the case in Fujian province, P.P. China, is used to study on the influence of cover plate on the safe operation of highway in shallow burial tunnel construction under skew-crossing highway with a small angle. In order to conduct the rigorous analysis, a 3D numerical model is used by the finite element program ABAQUS, which reveals the behaviours and characteristics of the twin tunnels under skew-crossing highway with a small angle. The tunnel excavation sequences and the temporary support system of tunnel can be simulated in this model. In addition, some other factors of the tunneling process such as the interaction between twin tunnels and the effect of vehicle load on twin shallow burial tunnels are simulated in the study.

II. ESTABLISHING NUMERICAL MODEL OF TUNNEL IN CONSTRUCTION

The step-by-step approach is adopted to simulate the construction process of tunnel. Each excavation step corresponds to an advancement of tunnel face with 1.5 meter length, which is in accordance with reality. A schematic view of the model is provided in Figure 1. In Figure 1, it may be shown that the intersection angle between Xiashaxi Tunnel and Shen-Hai Highway is about 30 degrees.

A. Selecting Calculation Parameters of Model

Two series of numerical analyses are carried out to study the response of highway subjected to tunneling. Each series includes three groups of data, seen in Table 1. Each series

consists of 61 numerical calculation steps in which various stiffness of cover plate under the highway and vehicle loads acting on the highway are considered. Table I lists the program of all numerical analyses conducted in this study.

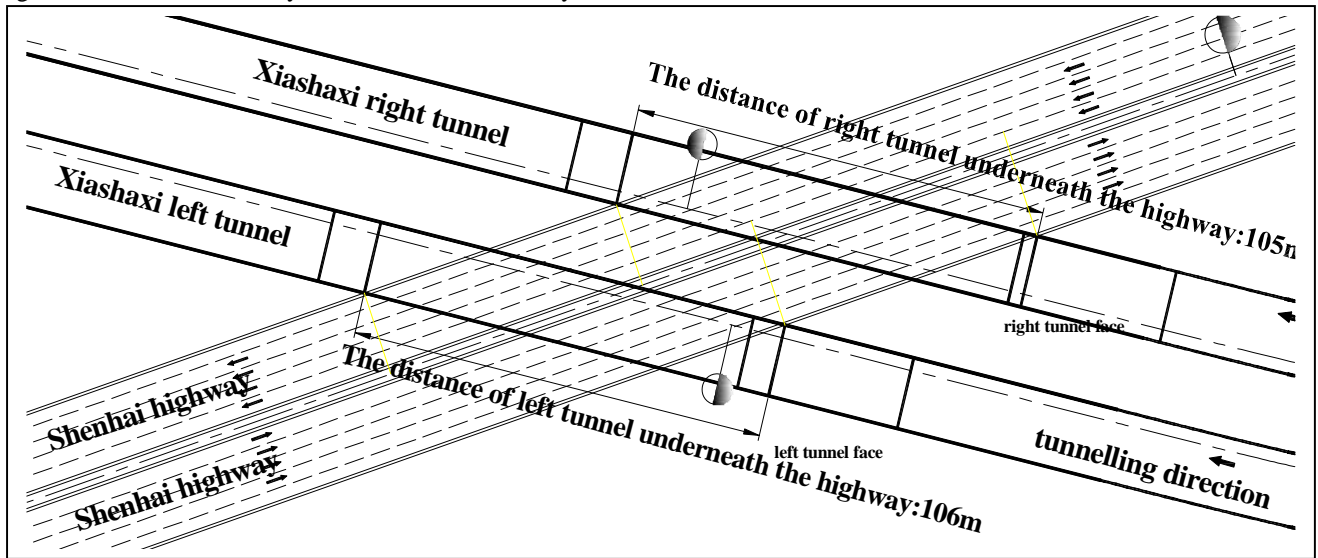


FIGURE 1. PLAN VIEW OF XIASHAXI TUNNEL UNDERNEATH SHEN-HAI HIGHWAY.

TABLE I. SUMMARY OF NUMERICAL ANALYSES SIMULATING TUNNELLING UNDERNEATH THE HIGHWAY.

Variables		Objectives
Stiffness of cover plate E_c (MPa)	Highway load L (kPa)	
75	12	Effect of stiffness of cover plate
10000	12	
25500	12	
25500	0	Effect of highway load
25500	12	
25500	24	

Vehicle load is simplified to the uniformly distributed load on the highway in the study. The minimum vehicle load (i.e., 1.5 MN), representing a load acting on the highway, is determined based on Chinese Highway and Tunnel Design General Specifications (JTGD60-2004).

Besides the program of numerical analyses listed in Table I, three extra numerical analyses are carried out to simulate the interaction between twin tunnels and the settlement of highway caused by the tunnel construction.

B. Finite Element Meshing and Boundary Conditions

In order to avoid the boundary effect, a full model of twin tunnels with a height of 60 m and a width of 140 m is established. The length of model is equal to 150m. Figure II gives a full view of finite element mesh to simulate the influence on the safe operation of skew-crossing highway in the tunnel construction. As illustrated, the existing highway is located directly above being constructed twin shallow burial

tunnels. The intersection angle between the highway and the twin tunnels is about 30 degrees. The twin tunnels are rigidly constructed underneath the highway. The tunnel, which is 10 m in height (H), is buried at the depth of 5.6 m below the ground surface. The tunnel is 150 m length. Each section of the left tunnel is constructed at six sub-steps. Each excavation step corresponds to an advancement of tunnel face with 1.5 m length, which is equal to 0.15 D (D is one half of tunnel width). The horizontal spacing between the twin tunnels is approximately 2.1D (i.e., 21 m). In the numerical analyses for the highway subjected to tunneling, the excavation sequence of twin tunnels and the geometry of the tunnels are identical to the reality.

The lateral and bottom boundaries of model are fixed using roller and pinned supports respectively, which may be seen in Figure III. The model consists of 17732 elements and 20072 nodes. Eight-node brick elements are used to model the part of soil and the twin tunnels. Four-node shell elements are used to simulate the initial support system in Figure IV. The validity of mesh density is evaluated, by halving the current mesh density and re-running the numerical analysis. It is indicated that the computed results based on the full and half mesh size only differ by 2%, suggesting that current meshing is sufficiently fine.

C. Constitutive Model and Calculation Parameters

The basic plastic model is developed to describe the non-linear response of soil materials. It consists of five basic model parameters (E , ν , c , ρ , ϕ). The parameters E (modulus of elasticity) and ν (Poisson's ratio) denote the deformation characteristics of soil modeled in the numerical simulation. The parameters c and ϕ refer to the cohesive strength and the

critical friction angle, respectively, which represent soil strength. The parameter ρ refers to soil density. All the parameters of soil listed in the Table II.

Tunnel liner and temporary support system are simulated by the finite elements with the perfect elastic behaviour.

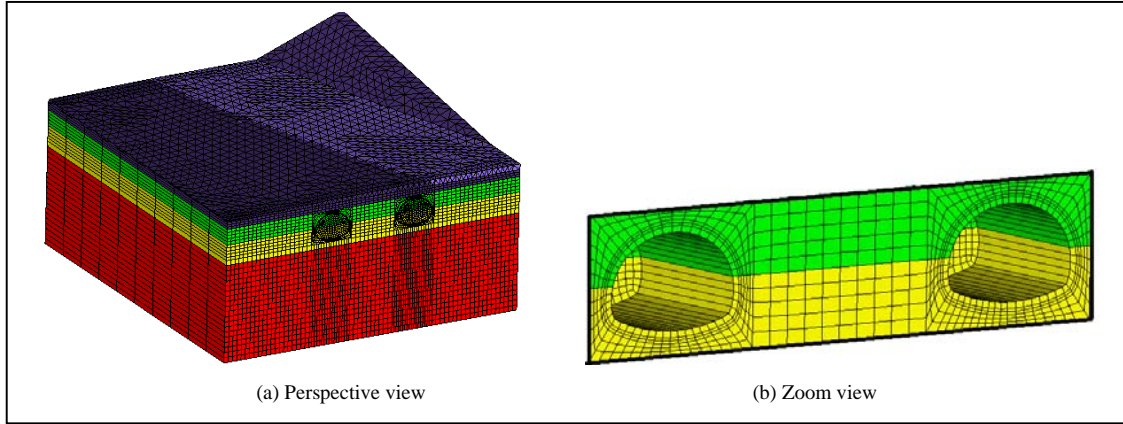


FIGURE II. PERSPECTIVE VIEW OF THE DEVELOPED NUMERICAL MODEL INTRODUCED INTO ABAQUS.

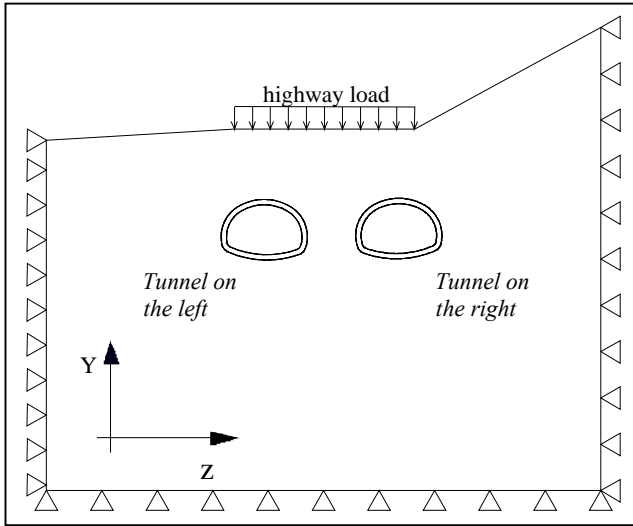


FIGURE III. TYPICAL CROSS SECTION VIEW OF THE TWIN TUNNELS CONSTRUCTED UNDERNEATH THE HIGHWAY.

D. Procedure of Numerical Analysis

Numerical simulation is modeled according to the following procedures:

First, it establishes the initial boundary and the initial stress conditions of model.

Second, the twin tunnel excavation sequence may be seen in the Figure IV. It simulates the advancement of tunnel using zero stiffness to soil to be excavated. That is, the excavated soil is simulated by deactivating soil elements. In the meantime, the shell elements representing tunnel lining and temporary support system are activated. Then, the action above-mentioned is not repeated until one tunnel ring is all excavated and its temporary support system is all activated. Furthermore, it activates the secondary lining of tunnel.

Before tunneling, the vehicle loads are pre-defined by applying the load to the grid point of model on the surface of

highway. The vehicle loads simulated in this study is therefore independent of other factors, such as the advancement distance of tunnel.

Third, it does not repeat Step 2 above-mentioned until the completion of tunneling.

III. CALCULATION RESULT ANALYSIS

It is important to control the highway settlement that the highway surface settlement caused by the excavation of tunnel is accurately calculated.

The 3D surface deformation may be seen in Figure V. By comparing the surface deformation of highway before tunnel excavation and after, it is obvious that the surface settlement of highway above the left tunnel is quite different from the surface settlement of highway above the right tunnel. The shape of ground settlement above left tunnel looks like the trough, not similar to the surface settlement above the right tunnel. This may be caused using the cover plate to control highway settlement. That is, the cover plate provides highway extra stiff-ness to control the highway settlement.

Figure VIa and Table III show the development of highway surface settlement under different vehicle load in the case of stiffness of cover plate $E_c = 25.5$ GPa. Figure VIa shows as follows: (1) the vehicle load on the highway causes an increase in the surface settlement of highway; (2) the larger the highway load, the greater the settlement; (3) the maximum settlement measured above the twin tunnels is 15.6 mm; (4) in addition, the settlement profile is asymmetric. That is, the maximum settlement of highway is not located over the mid-point between the two tunnels. Figure VIb and Table III shows the development of highway surface settlement using the different stiffness of cover plate in the case of highway load $L = 12$ kPa.

The situation of $E_c = 75$ MPa is used to simulate the case that the cover plate is not used to control the highway settlement by giving the cover plate the same stiffness of soil.

In Fig.6b, the surface settlement of highway above left tunnel with $E_c=75$ MPa is 96% larger than that with $E_c=25.5$ GPa. It shows that the use of cover plate may be the effective measure to control highway settlement above left tunnel. Comparing the curve of $E_c=10$ GPa and $E_c=25.5$ GPa in Fig.6b, the surface settlement above left tunnel of $E_c=10$ GPa

is 52% larger than that of $E_c=25.5$ GPa as seen in the Table III.

In Figure VI, it is obvious that the stiffness of cover plate and the highway load have little influence on the surface above the right tunnel. It may be explained by the reason that the surface above the right tunnel is beyond the effect zone.

TABLE II. CALCULATION PARAMETERS FOR THE MODEL.

	Variables				
	Unit weight γ (kN/m ³)	Elastic Modulus E (MPa)	Poisson ratio ν	Friction angle φ (°)	Cohesive strength c (kPa)
Gravel soil	19.50	75	0.3	20	15
Clinosol	19.6	25	0.3	12.5	10
Strong weathered granite	22.0	500	0.28	24	200
Moderately weathered granite	25.5	13000	0.2	45	850
Cover plate	24.0	25500	0.2		
Tunnel lining	24.0	30000	0.2		

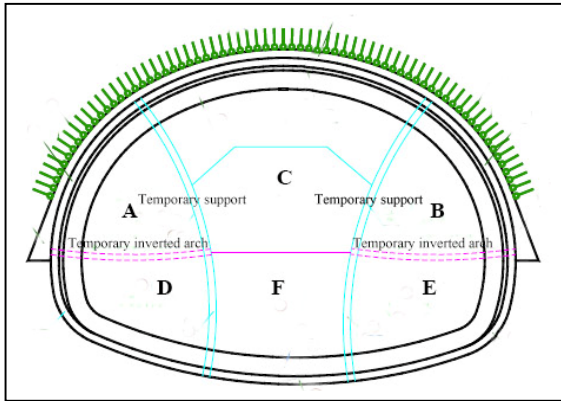


FIGURE IV. PERSPECTIVE VIEW OF THE DEVELOPED NUMERICAL MODEL INTRODUCED INTO ABAQUS.

IV. CONCLUSIONS

It is well known that the interaction between tunnel and highway is complex in construction. In this study, a 3D numerical model for the tunneling process is developed. The model may be used to predict the ground movements and structural forces induced in the excavated process of two tunnels in parallel. The main construction aspects of tunnel are been simulated in the model. In particular, the condition on the small angle between tunnel and highway is modeled. Parameters taken from the Xiashaxi Tunnel are adopted as a reference case. The study results are shown as follows:

- (1) The larger the vehicle loads on the highway, the greater the settlement of highway.
- (2) The use of cover plate may be the effective measure to control the highway settlement.
- (3) There is a zone of highway settlement influenced by cover plate stiffness and vehicle load, beyond which their influence on highway settlement is greatly reduced.

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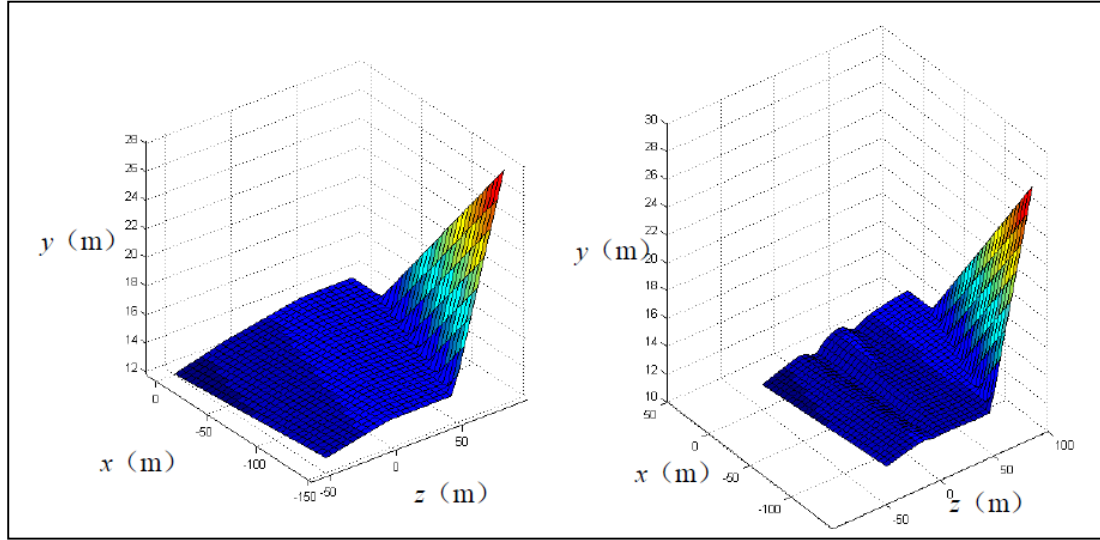


FIGURE V. SURFACE SETTLEMENT OF HIGHWAY ABOVE THE TWIN TUNNELS.

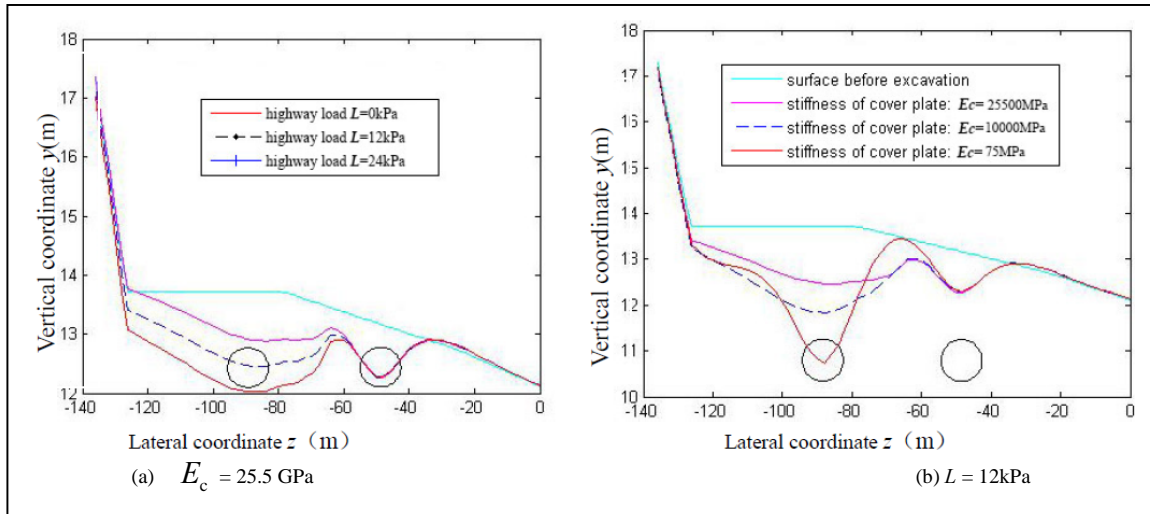


FIGURE VI. NORMAL SURFACE DISPLACEMENT OF HIGHWAY FOR LINING RING 3 OF LEFT TUNNEL WITH SCALE FACTOR=100.

TABLE III. DEVELOPMENT OF SURFACE SETTLEMENT DURING THE EXCAVATION OF TUNNEL.

Variables		Max. normal displacement (mm)
Stiffness of cover plate E_c (MPa)	Highway load L (kPa)	
75	12	30.7
10000	12	20.2
25500	12	15.6
25500	0	13.1
25500	12	15.6
25500	24	18.8