www.cafetinnova.org

ISSN 0974-5904, Volume 10, No. 02

DOI:10.21276/ijee.2017.10.0229

International Journal of Earth Sciences and Engineering

April 2017, P.P. 346-353

Deformation Prediction of Shield Construction Based Soil Unified Movement Model and Optimization Selection of the Reinforcement Schemes

XU XINXING[1,2*], ZHANG JICHAO[1] AND CHEN HANG[3]

[1]*College of Civil Engineering, Guangzhou University, Guangzhou 510006, China*

[2]*Baiyun District Construction Engineering Quality and Safety Surveillance of Guangzhou, Guangzhou 510006, China*

[3]*Key Laboratory of Transportation Tunnel Engineering, Ministry of Education, Southwest Jiaotong University, Chengdu, 610031, China*

Email: *xuxinxing15@163.com*

Abstract: *In order to control the construction deformation of the tunnel under the existing highway, the pavement deformation under the condition of the tunnel section of shield tunnel in Shanghai was calculated. The deformation of the pavement under the condition of the tunnel was calculated, and numerical simulation is carried out with FLAC3D numerical simulation. In view of the original pavement deformation amount and shield construction deformation increment and over the pavement deformation specification maximum allowable value of contrast the single grouting reinforcement, setting pile and grouting combined with the road pile foundation reinforcement of three different reinforcement scheme is determined. Through the numerical simulation analysis to determine the scheme for the optimal solution, after the construction of the comparison of the actual deformation, second scheme on deformation control is better than expected. It is proved that the prediction with high accuracy and this is an important reference for similar projects.*

Keywords: *shield method， high-speed bridge, pavement deformation, reinforcement schemes, pile*

1. Introduction

As urban subway is gathering pace, subway construction has become one of important ways to solve urban traffic jam. With prominent advantages of high safety feature, quick construction speed and good waterproof quality, shield method emerged as the first choice in construction methods of urban subway in the soft soil area. While most of urban subways traverse existing speedway bridge, which will surely cause deformation of pier and roadbed, increase impact force of carload on roadbed, accelerate destroying of roadbed, thereby impairing lifetime and operation security of speedway. Therefore, it is of important significance to research the technology of controlling deformation caused by tunnel-traversing shield construction under Speedway Bridge.

Zhang Yun [1] suggested using displacement back analysis to get accurate parameters of equivalent circle zone when there is measured displacement. Zhu Caihui [2] suggested gap parameter calculation method and revising model of equivalent circle zone to reflect construction technological level more authentically. Lv Peilin [3] and Chen Jing et al. [4], researched influence of road surface settlement caused by shield construction by changing parameters of equivalent circle zone and construction processing parameters. Mo Zhenze [5] analyzed mechanical effect of different reinforcement measures on roadbed and tunnel segment with down-traversing shield tunnel and made optimized selection. Li Song [6] and Fang Yong [7] analyzed the influence of dynamic construction of shield tunnel on pier foundation of proximity viaduct.

There is little domestic and foreign research on interval tunnel in soft area traversing existing speedway bridge, and the deformation increment of road surface of Speedway Bridge caused by shield construction is not expectable, leading to some potential safety hazards to subway construction. Therefore, how to forecast deformation behavior of road surface and bridge foundation in shield construction can fully control surface settlement in construction of subway down-traversing existing road bridge.

This paper's prototype is construction of one subway interval tunnel in Shanghai down-traversing existing speedway bridge to forecast the surface settlement caused by shield construction, and reveal rules of force deformation for road surface and pier foundation. It further puts forward corresponding reinforcement measures for road surface for the potential safety hazard in the construction course, reduces and controls deformation of road surface and pier foundation, guarantees safety and stability in construction, thereby providing some theory references and technical support for construction of like projects in future.

Received: December 10, 2016; Accepted: February 14, 2017; Published: April 26, 2017
International Journal of Earth Sciences and Engineering, 10(02), 346-353, 2017, DOI:10.21276/ijee.2017.10.0229

2. Project overview

In the project of one Shanghai subway interval tunnel shield traversing existing speedway bridge, the cross dimensions of tunnel is designed as: outside diameter 6.0mm, internal diameter 5.4m, tunnel segment thickness 30cm. There into, the minimum distance from external rim of left tunnel to pier is 2.10m, the minimum distance from external rim of right tunnel to pier is 14.05m. The traversing way is perpendicular vertical down-traversing, with 14m between left and right axial lines, and a burial depth of 23m; Earth pressure balanced shield method is combined with system of shield tail simultaneous grouting and second reinforcement grouting system. The sequence of construction is first left line construction then right line construction; the strength level of lining concrete is C50 and seepage resistance grade is P10. The stratum is mainly soft sandy soil, clay soil, and silty clay. Elastic model is relatively lower. Shield construction is easy to cause larger construction deformation. The buried depth of groundwater level is 15.0m. Equivalent circle zone is an abstract generalization for movement of soil body toward shield tail gap and backfill grouting function. For certain strata configuration condition and construction process, its thickness and its mechanical parameters are fixed. According to project actuality, the project's structural representation is established as shown in figure 1.

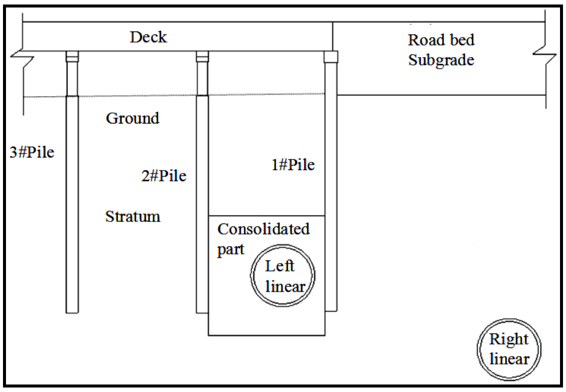


***Fig.1** The relative position of the running tunnels and bridge*

The shield adopts single slurry grouting system. Simultaneous grouting and shield driving advance simultaneously. Through simultaneous grouting system, while shield advances to form shield tail gap, in extremely short time period of forming gap in shield tail, the simultaneous grouting fills it to be compact, making surrounding rock soil mass supported timely to effectively prevent collapse of soil mass and control surface settlement.

2. Deformation prediction model for shield down-traversing speedway

2.1 Prediction of theoretical deformation

Set the distance from focus to tunnel's central point is d . The smaller the value, the softer the soil quality, and the bigger surface settlement caused; on the contrary, the harder the soil quality, the smaller the surface deformation caused.

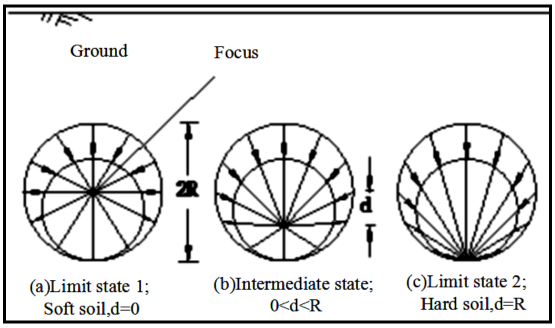


***Fig.2** Schematic diagram of uniform ground movement model*

Literature [8] tells us that soil mass loss for unit length in shield construction V_{loss} is:

$$V_{loss} = \pi(Dg/2 - g^2/4) \qquad (1)$$

Where $g = Gp' + U_{3D} + w$; $Gp' = \alpha Gp$; gap parameter is Gp' =0.25m, consider grouting filling should be multiplied by a coefficient α . Clay: $\alpha = 0.116(h/D) - 0.042$; h is buried depth of tunnel axle, being 20.5m; D is outside diameter of tunnel, being 6.0m; U_{3D} is 3D elasto-plastic deformation of soil mass in front of road header, then according to onsite measurement; w is construction factor. See literature [9] for concrete calculation. Combining the characteristics of this project, we figured out that: g-42mm.

We can deduce that general solution of $S_{\max}$ (the largest settlement of the surface above tunnel axle of d) is:

$$S_{\max} = \frac{4R(h+d)}{R+d} - 4\sqrt{R^2\left(\frac{h+d}{R+d}\right)^2 - \frac{V_{loss}}{\pi}} \qquad (2)$$

When d=R, the upper bound solution (maximum value) of $S_{\max}$ is:

$$S_{\max\ upper} = 2h + 2R - 2\sqrt{(h+R)^2 - 4V_{loss}/\pi} \qquad (3)$$

When $d = 0$, the lower bound solution (minimum value) of $S_{\max}$ is:

$$S_{\max\ lower} = 4h - 4\sqrt{h^2 - V_{loss}/\pi} \qquad (4)$$

For any soil mass, $S_{\max}$ value caused by one certain soil mass loss is always within $\left[S_{\max\ upper}, S_{\max\ lower}\right]$, being [12.2mm, 21.4mm] by calculation. For double-line effect, consider it is needed to multiply a coefficient β to magnify, 1< β <2, which is related to strata parameters and tunnel axle distance.

2.2 Model building

3D numerical calculation model is established using FLAC3D, as shown in figure 3. This speedway is two-way and includes 9 driveways, 32m wide. Establish model with proportion of 1:1. Size dimension: length x width x height= 136.5m×65.0m×69.0m. The distance from left and right bound to outer side of tunnel is greater than 3D, and the distance from lower bound to outer side of tunnel is greater than 4D; Adopt displacement boundary condition, and adopt linear-elastic material for shield steel shell, tunnel segment, solid grouting cement paste. Reinforcement measure is by applying equivalent simulation of mechanical parameters to reinforced area. The mechanical parameters of various materials in the model are as shown in table 1.

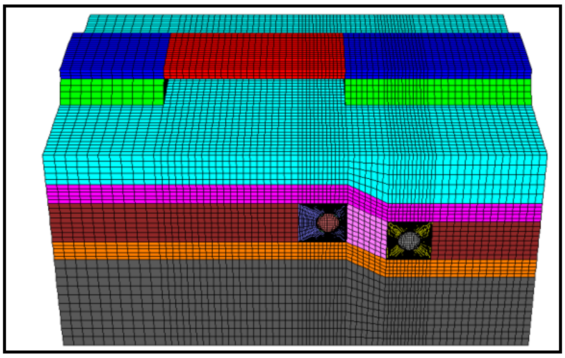


Fig.3 *3D Three-dimensional computational mode*

Table.1 *Mechanical parameters of the model materials*

Material description	Elastic modulus (MPa)	Poisson ratio	Weight density (kN/m^3)	Cohesion power (kPa)	Angle of internal friction (°)
Miscellaneous fill	10	0.28	18.5	10	12
Silty clay	13	0.28	19.4	30	15
Silty clay	15	0.28	19.7	35	20
Clay soil	21	0.30	20.2	40	28
Shield steel shell	2.1×10^5	0.30	78.5	-	-
Lining segment	3.4×10^4	0.20	25.0	-	-
Solid grouting cement paste	2.5×10^2	0.23	21.0	-	-
Roadbed	1.5×10^3	0.20	23.7	-	-

2.3 Analysis on result

2.3.1 Optimization of construction sequence for road surface deformation

The constructional deformation caused by subway interval tunnel shield down-traversing existing highway bridge mainly includes roadbed deformation and pier deformation. The deformation increment is closely related to the tunnel construction sequence. The disturbance deformation to strata caused by first constructed tunnel influences the increased deformation caused by later constructed tunnel to some extent. Combined action of construction of two tunnels together influences general deformation increment of road surface. Therefore, to lower influence of shield construction on road surface of existing speedway, pier deformation and internal force to the largest extent, it is necessary to make reasonable optimized selection for the sequence of shield down-traversing. Figure 4 is deformation drawing of road surface at bridgehead position under different sequences of construction obtained by forming model and arranging monitoring points at bridgehead and road surface.

Figure 4 tells us that when left line shield tunnel approaches existing buildings, the tunnel down-traversing sequence of first left line then right line causes smaller deformation than the sequence of first right line then left line. The maximum deformation of road surface at bridgehead in the sequence of first left line then right line is 10.5mm, while the maximum deformation for road surface at bridgehead in the sequence of first right line then left line is 15mm.

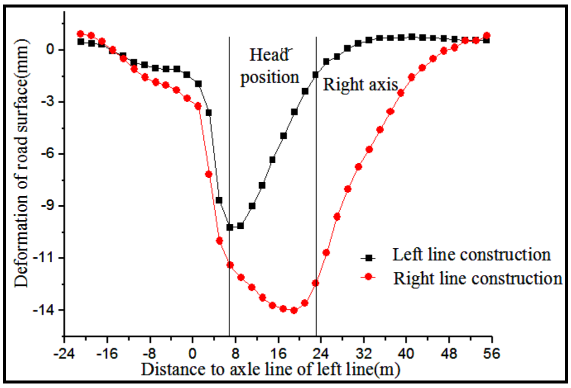


Fig.4 *The road surface deformation increment caused by construction sequence*

Secondly, due to different rigidity of bridge foundation and roadbed, the deformation at the joint of bridge head and roadbed has an obvious sudden settlement, and the gradient is steeper than right roadbed of bridgehead, indicating large sudden change of deformation occur near bridgehead, which greatly influences roadbed deformation band. With increase of the distance to axle center of left and right lines, deformation increment of road surface dwindles away. When the distance exceeds 30m,the deformation is small, and the influence of construction of tunnel shield down-traversing on its deformation is negligible. The maximum deformation of roadbed and bridgehead increases from 8mm and 11.0mm before right line construction to 9.5mm and 15.5mm after right line construction, indicating tunnel left line deforms from bridgehead, and shield down-traversing produces large influence on deformation of bridgehead, while right line construction contributes little to deformation of bridgehead; While the maximum deformation to the road surface above center line of tunnel axle line in left and right lines caused by left and right lines construction is up to 15.5mm, showing tunnel excavation influences greatly the deformation of road surface, and we should not neglect its detrimental effect on normal operation of speedway.

Above analysis shows that in the strata soft clay soil dominates, when the distance between axle lines of left and right lines is 14m, the maximum settlement deformation of road surface for roadbed caused by interval tunnel shield down-traversing existing speedway bridge can apply unified soil mass movement model; Numerical calculation analysis and theoretical calculation show that: the prediction interval for deformation of speedway road surface caused by construction sequence of first left line then right line is [12.2mm,21.4mm], while road surface deformation increment figured out by numerical calculation of left and right lines shield tunnel is 15.0mm. This shows that: unified soil mass theory has satisfactory predictive validity for settlement deformation caused by construction of shield tunnel in soft soil area, and the span of superimposed effect coefficient β of double-line tunnel is [1.0,1.47].

2.3.2 Onsite measurement of deformation

The key for whether the deformation of roadbed and bridgehead caused by this interval tunnel down-traversing existing speedway exceeds the expected value is to consider whether the superposed summation of deformation increment caused by existing road surface deformation and shield construction can meet requirements on safety design in existing specifications, Therefore the deformation condition of existing road surface and bridgehead are key factors influencing road surface safety.

(a) Drawing of onsite road surface deformation

(b) Drawing of onsite bridgehead deformation

Fig.5 *Maps of field deformation*

Figure 5 is the onsite deformation drawing before construction of the tunnel at juncture of bridgehead and road surface roadbed. Figure 5 shows that, at juncture of bridge and roadbed, differential settlement diversity is obvious in the long course of settlement and deformation under effect of carload impact due to large difference in rigidity. Onsite measurement of data shows that: The maximum differential settlement of bridgehead is 11.0mm, and the maximum differential settlement of roadbed is 18.0mm. The deformation of roadbed above axle line center of left and right tunnels is 23.0mm ,meeting safety regulations of Evaluation Standard for Road Technical State JTGH20-2007, hence this speedway is in corresponding security operation period. However, down-traversing of shield tunnel will make the deformation of bridgehead and roadbed continues to increase, hence the junction of Speedway Bridge and roadbed has large potential safety hazard for driving.

2.3.3 Prediction over roadbed deformation after down-traversing

To master the final value of deformation caused by construction of interval tunnel down-traversing existing Jingfu Speedway Bridge's key part and the position of the maximum deformation, it is necessary to apply carload on calculation model to make reasonable prediction over road surface deformation for existing speedway road surface after down-traversing of shield based on existing road surface deformation, thereby laying certain theoretical basis and technical direction for subsequent construction. Based on original model, the paper increases corresponding car load whose value is taken as $20kN/m^2$. The calculated road surface deformation is as shown in figure 6.

Figure 6 tells us that due to different rigidity of bridge and roadbed, the construction deformation caused by interval tunnel down-traversing existing speedway bridge is mainly roadbed, while bridge deformation is very small, basically within 5mm. While for roadbed deformation, due to influence of tunnel excavation, based on numerical simulation for original reinforcement scheme, the maximum deformation is located above center of left and right line tunnel, about 38mm; And the deformation dwindles away with increase of the distance to central point of left and right lines axle line. When the distance exceeds 30m, the deformation is basically kept at 30mm.

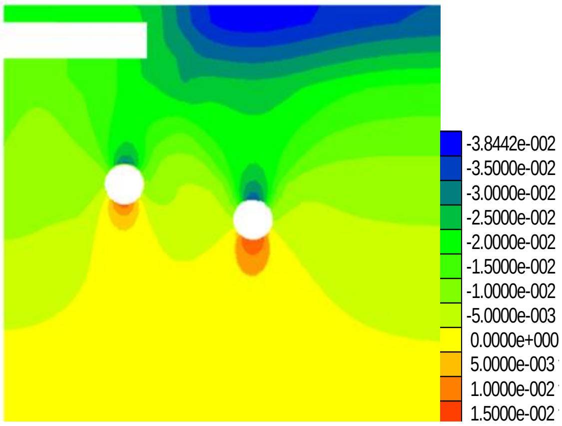


Fig.6 *Schematic of roadbed deformation*

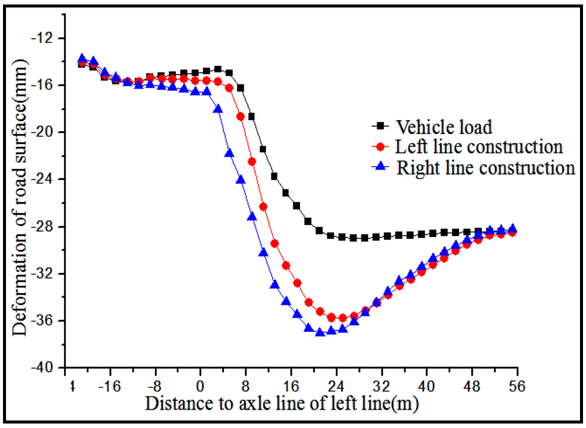


Fig.7 *Prediction curve of road surface deformation in construction of first right and then left*

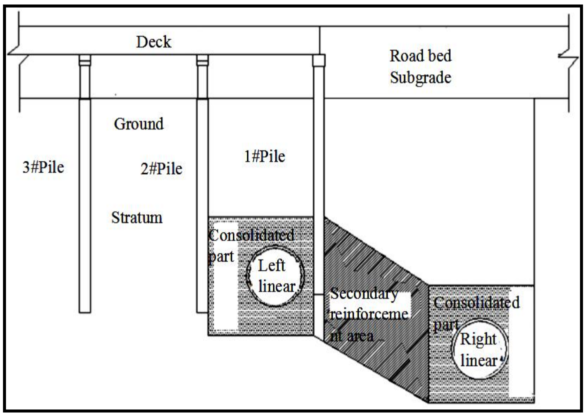
Figure 7 is the prediction curve of road surface deformation by construction sequence of first right then left obtained by numerical simulation. Related specifications and literature tell us the maximum permissible differential settlement is 20mm at junction of bridge and roadbed; In operation course of standard speedway with designed speed per hour of 100~120km/h, the maximum permissible roadbed deformation is 30mm. Therefore numerical calculation indicates: in the course of this project's shield down-traversing existing speedway, bridgehead deformation is still controlled in the permitted band of specifications, while under joint action of carload and shield disturbing load, existing road surface deformation exceeds corresponding regulations, causing certain potential safety hazard to safe operation of speedway; Therefore, to guarantee normal operation of this speedway after subway down-traverses it, the deformation increment of road surface should not exceed 7mm, which puts forward higher requirements on this reinforcement scheme of interval tunnel down-traversing this speedway bridge.

After optimization of construction sequence, the maximum deformations of bridgehead and road surface are 21.5mm and 38.0mm, exceeding the allowable value for deformation regulated by related state specification. Therefore, it is needed to make optimized selection for original reinforcement scheme.

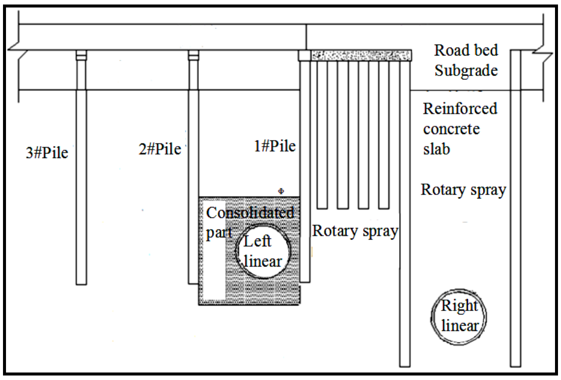
2.4 Optimized selection of reinforcement scheme

2.4.1 Design of reinforcement scheme

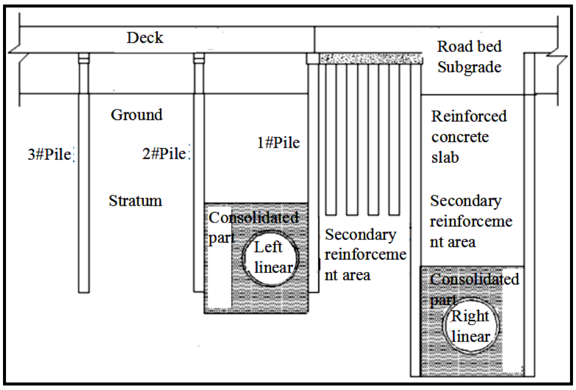
After combining the suggestions put forward by reference design personnel and actual condition of the project, following reinforcement schemes are put forward: Scheme 1: grouting reinforcement: based on original reinforcement scheme, reinforce the range of 3m in external rim on left side of right line tunnel through ground grouting and combining simultaneous grouting and second reinforcement grouting, and take it as main reinforced area. The grouting pressure is controlled at about 1.2MPa; Meanwhile, to reduce deformation superimposed effect at bridgehead caused by left and right lines construction, adopt sleeve valve pipe for ground grouting reinforcement between the reinforced areas on left and right lines. The pressure of grouting is controlled at 0.8MPa. It is called secondary reinforced area. Scheme 2: based on original reinforcement scheme, knock a row of 29m-long Φ 1000@_2m jet grouting piers respectively into left and right sides of external rim of right tunnel, reinforce jet grouting piers between left and right lines (four rows Φ 500 jet grouting pier @_2m, 20m long;Armored concrete slab is 1.5m thick). The reinforced range is the same with above. Scheme 3: based on scheme 2, apply ground grouting to right tunnel, combine simultaneous grouting and second reinforcement grouting for reinforcement, with reinforced scope same with above; Schematic diagram for elaborating different reinforcement schemes is as shown in figure 8.



Scheme 1



Scheme 2



Scheme 3

Fig.8 *Schematic of reinforcement projects*

2.4.2 Evaluation on indices of reinforcement schemes

According to different reinforcement schemes, use FLAC3D for calculation; compare the construction deformation increment of different reinforcement schemes under the same stress relief of 30%, as shown in figure 9.

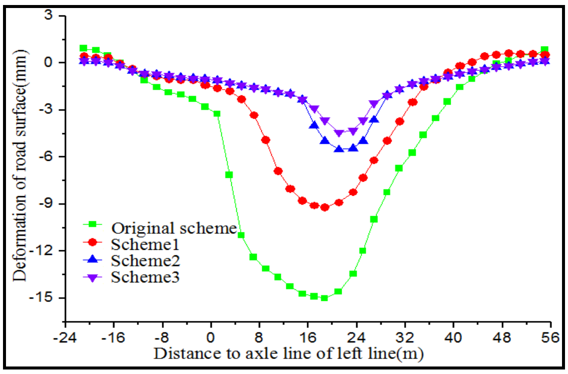


Fig.9*. Pavement deformation curve of reinforcement schemes*

Figure 9 shows that: after applying three different reinforcement schemes to roadbed, road surface deformation and bridgehead deformation are significantly alleviated. The maximum deformation of road surface is respectively 9.0mm, 5.55mm, 4.5mm; bridgehead settlement is respectively: 2.1mm, 1.5mm, 1.5mm; and the deformation trend in different schemes is more gentle than before reinforcement, deformation decrement of some regions exceeds 70%, showing obvious reinforcement effect and the requirements of design specification is met. Contrastive analysis shows that: reinforcement effect of the three reinforcement schemes: scheme 1<scheme 2<scheme 3; according to result of numerical analysis, make contrastive analysis on the three schemes: In scheme 1, the maximum deformation of roadbed exceeds category of alert value; comparison of scheme 2 and scheme 3 can meet requirements of design regulation. Figure 8 shows that although construction of scheme 2 is slightly inferior to scheme 3 in controlling maximum settlement of bridgehead and roadbed deformation, it just needs to reinforce left shield tunnel by grouting, while scheme 3 needs to reinforce left and right shield tunnels, with illdefined reinforcement effect relative to scheme 2. Considering larger advantage of scheme 2 in engineering work load and construction period, we finally select the reinforcement measures in scheme 2 when the two schemes all conform to requirements of regulation.

2.4.3 Influence of reinforcement scheme on pier foundation

Implementation of reinforcement scheme not only influences deformation of road surface and bridge, but also has primary influence on horizontal shift and mechanical behavior of pier foundation. Considering piers 1# and 2# (as shown in figure 8) is near the tunnel the most, we take pier foundations 1# and 2# for example to form model through FLAC3D, and make predictive analysis on their horizontal shift. The effect prediction over influence of reinforced shield excavation construction on horizontal shift of pier foundation is as shown in figure 10.

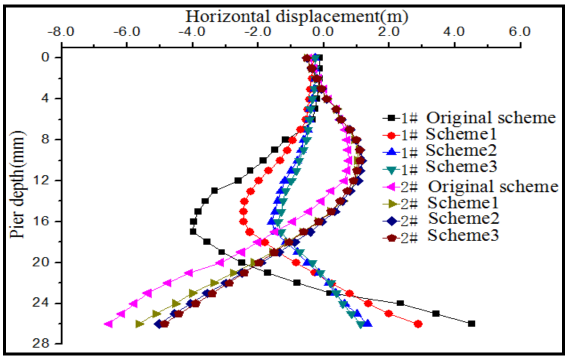
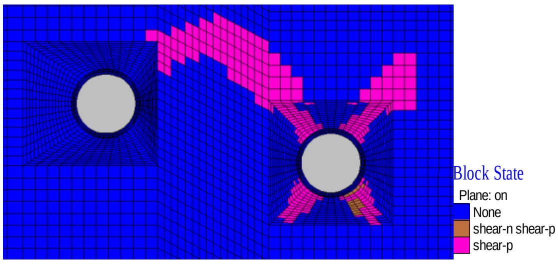


Fig.10 *Horizontal displacement of reinforcement projects*

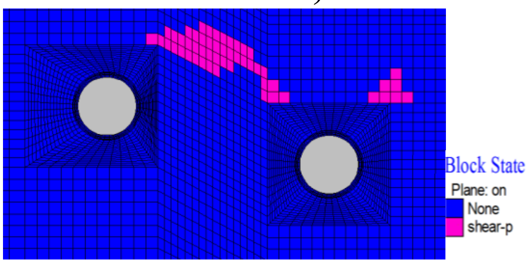
According to deformation curve of pier foundation caused by shield construction before and after reinforcement: scheme 2 and scheme 3 have similar effect of reinforcement, and deformation trends are almost the same. Take scheme 2 for example for analysis, we conclude that: the reinforcement effect of implementation of reinforcement scheme on horizontal shift and mechanical behavior of pier body is mainly embodied in influence on pier foundation 1#_, yet with little influence on mechanical behavior of pier foundation 2#. In scheme 2, as two rows of dense jet grouting piers are knocked in, the horizontal shift of pier body 1# reduces to 1.8mm from 4mm before reinforcement, and horizontal position of pier toe reduces to 1mm from 4mm; the longest horizontal displacement is 1.8mm, located at 18m of pier body. The longest horizontal displacement of pier 2#_ is at pier toe, being 5mm. The effect of reinforcement is obvious, and intended effect is achieved. The pier foundation stability can be further guaranteed.

2.4.4 Distribution of plastic zone

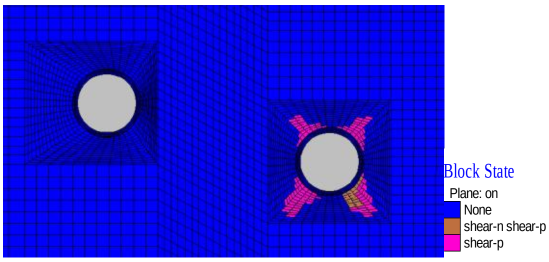
Characteristic of distribution of plastic zone is an important index to evaluate one project's construction stability and disturbance degree, and reflects the influence degree of shield construction on road surface settlement.



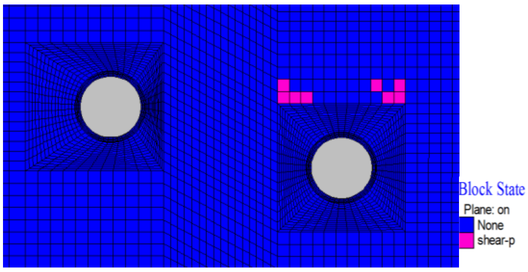
(a) Plastic zone distribution diagram (Original scheme)



(b) Plastic zone distribution diagram (Scheme 1)



(c) Plastic zone distribution diagram (Scheme 2)



(d) Plastic zone distribution diagram (Scheme 3)

Fig.11 *Plastic zone distribution diagram of enforcement projects*

Figure above shows that the volume of plastic zone caused by interval tunnel shield down-traversing existing speedway bridge on disturbance of reinforced strata are significantly smaller than that of the non-reinforced scheme. Contrastive analysis in (b) and (c) tells us the volume of plastic zone in reinforcement by grouting of sleeve valve pipe is smaller than the volume of plastic zone in reinforcement using pier foundation, indicating grouting reinforcement can reduce volume of plastic zone more. According to (b) and (d), although using pier to reinforce secondary reinforcement zone can reduce disturbance influence on strata by right tunnel excavation, effect is less obvious than scheme 1 and scheme 3. Comparison of scheme 1 and scheme 3 shows: For ground grouting reinforcement, using pier for reinforcement has more obvious effect than simply using grouting reinforcement; which is because protection of two rows of dense pier makes the disturbance of right line tunnel for the soil mass on two sides smaller.

3 Verification of reinforcement scheme

According to analytic result of numerical simulation, the second reinforcement scheme is adopted in construction. After construction of this interval of tunnel shield, monitor the deformation on bridge road surface and bridgehead caused by construction at this position. Table 2 is comparison of numerical analysis results between measured value of total deformation of road surface after construction and adoption of scheme 2.

Table 2. *Comparison of deformation and predictive value of shield after reinforcement*

Position	Accumulative deformation after construction (mm)	Accumulative deformation before construction (mm)	Deformation caused by shield (mm)	Predicted shield deformation (mm)	Error (%)
Road surface	19.36	18	1.36	1.5	10.29
Bridgehead	16.80	11	5.80	5.55	-4.30

Note 1: *Deformation caused by shield=accumulative deformation after construction-accumulative deformation before construction (long-term accumulative deformation under impact of car load)*

Note 2: *error =(predicted shield deformation-shield deformation)/shield deformation×100%*

The comparison of deformation after construction and predicted deformation in table 2 shows that scheme 2 delivers better effect in controlling deformation of bridge road surface and bridgehead in construction of shield down-traversing. The road surface deformation caused by construction in actual measurement is 1.36mm, and error is 10.29%. But the deformation value is smaller than predicted value and error can be regarded as favorable for controlling deformation. Therefore scheme 2 outperforms the anticipation in controlling road surface deformation; The actually measured deformation for bridgehead is 5.80mm, and error is 4.30%, reaching anticipated requirements on controlling of bridgehead deformation.

Comparison of measured value and numerical simulation prediction proves accuracy for deformation prediction in scheme 2, and adopting reinforcement scheme 2 can control deformation of bridge road surface and bridgehead caused by shield construction to the extent of meeting design standard, meeting Safety Regulations of Evaluation Standard for Road Technical State JTGH20-2007, and able to guarantee corresponding safe operation of this speedway.

4 Conclusion and discussion

We can know from analysis on influence of certain subway interval tunnel shield traversing existing speedway bridge in Shanghai on deformation behavior and mechanical behavior of bridge, pier and road surface:

- Adopting unified soil mass movement model to predict surface deformation caused by shield construction is accurate and highly credible, and can well predict the construction deformation degree caused by interval tunnel shield in soft soil area down-traversing existing speedway bridge. Under this operating mode, two-way superimposed effect coefficient's value β should be within [1.0,1.47].
- The verification through numerical simulation and reinforcement scheme shows that it is needed to analyze the influence of double-line construction sequence on surface settlement in construction of shield double-line tunnel down-traversing existing road bridge. The sequence of first constructing left line of tunnel then right line of tunnel in this paper causes the smallest road surface deformation, but still exceeds requirements of design specification; therefore to guarantee safe operation of existing speedway, we should pre-reinforce road surface.
- Three different roadbed pre-reinforcement schemes mainly covering grouting reinforcement and sheet pier are put forward. After contrastive analysis, we know that: the three reinforcement schemes all can effectively reduce maximum deformation of road surface and bridge deformation, alleviate sudden change of deformation of bridgehead. However, only scheme 1 and scheme 2 can meet design requirements, and scheme 1 still fails to solve maximum roadbed deformation exceeding alert value. After synthesizing engineering work load, construction period, pier foundation deformation, plastic zone volume of scheme 1 and scheme 2, we can conclude that scheme 2 is the optima reinforcement scheme.
- The paper determined superiority of the scheme through numerical simulation and monitoring after onsite construction, but due to limit of energy, the author failed to make realtime dynamic monitoring of road surface deformation in the course of construction. Dynamic monitoring of road surface in construction is of strong guidance significance for the deformation condition in construction course and for subsequent construction, thus needing further research.

Acknowledgment

This work was supported by the Guangzhou science and technology project under NO. GDBSH 2013012.

References

[1] Zhang Yun. Chinese Journal of Rock Mechanics and Engineering, 21(2002)388.
[2] Zhu Caihui. Rock and Soil Mechanics, 32(2001)158.
[3] Lv Pei-lin. China Railway Science, 28(2007):12.
[4] Chen Jing. Railway Survey and Design, 15(2011) 80.
[5] Mo Zhen-ze. Journal of China & Foreign Highway, 25(2011) 204.
[6] Li Song, Yang Xiao-ping, Liu Ting-jin. Railway Engineering, 16(2012) 74.
[7] FANG Yong, HE Chuan. Journal of Railway Engineering Society, 11(2009) 56.
[8] Huo Jun-shuai, Wang Bing-long, Zhou Shun-hua. China Railway Science, 32(2011) 71.
[9] Lee K M, Rowe R K, Lo K Y. Canadian Geotechnical Journal, 29(1992)929.
[10] Ministry of Communications of the People's Republic of China. TJG H 20-2007 Evaluation Standard for Road Technical State [S]. Beijing: People's Communication Press, 2008
[11] Ministry of Communications of the People's Republic of China. TJT O73.2-2001. Technical Specification for Maintenance of Road Asphalt Pavement [S] Beijing: People's Communication Press, 2001.