Study on Construction Monitoring of Zhuanyang Avenue to Sports Center South Station of Subway

Min Si [*,1], Yu Yu [2], Yawei Shen [2], Guangyue Ma [2] , Xiaochun Fan [2]

[1]*Design and Research Institute Co.,Ltd,* Wuhan University of Technology, Wuhan ,Hubei 430070, P.R. China
[2]*School of Civil Engineering & Architecture,* Wuhan University of Technology, Wuhan, Hubei 430070, P.R. China

***Abstract* - Metro Construction monitoring plays an indispensable role in the process of subway construction. This paper combines engineering examples of Zhuanyang Avenue to Sports Center South Station in Wuhan Metro Line 3, and the construction monitoring of the shield tunnel is deeply analyzed. According to the engineering characteristics of Zhuanyang Avenue to Sports Center South Station of Subway, the corresponding scheme of construction monitoring is put forward, and the monitoring data is analyzed in detail. Comparing the actual test data of ground settlement with the Peck formula, it can be known that there are some differences between the two curves, but it can well predict the area and the shape of soil section. In addition, the maximum deformation of the left line interval convergence is 3.31mm on the 32th ring. The maximum displacement at the bottom of the arch is raised up to 1.10mm on the 5th ring. The maximum displacement of vault settlement is 0.71mm on the 25th ring and 32th ring. The results have some guidance for the future subway construction.**

Keywords - ***Metro construction monitoring; Test method; Surface subsidence; Interval deformation; Dome and vault settlement***

I. INTRODUCTION

Design scope of Zhuanyang Avenue to Sports Center South interval in Wuhan metro line 3 first-stage project is: right DK0+493.00 to right DK1+640.40,left DK0+493.00 to left DK1+640.40, The right line is 1147.418m(long chain is 0.018m) and the left line is 1147.389m(Short chain is 0.011m. North-south on the whole, the interval, lay along the Dongfeng Avenue, Sports Center South Station in north, Zhuangyang Avenue in south. interval line spacing is 14 ~ 17m, the buried depth of tunnel ranges from 4.68m to 20.07m. The minimum radius of curvature in line plane is 3000m, maximum longitudinal slope is 24.700‰. Shield method construction is adopted in this interval. Communication channel is set up at the right DK1+050.000; Two shield machine is used from Zhuanyang Avenue to Sports Center South, and period of plan is nine months.

II. THE PURPOSE AND PRINCIPLE OF THE CONSTRUCTION MONITORING OF THE METRO INTERVAL

A The Purpose of The Construction Monitoring of The Metro Interval

In the construction process, the influence of shield interval on the surrounding buildings, the ground surface and the adjacent underground pipelines is very large [1], so the main purpose of monitoring is not only to ensure the safety of these affected objects, but also to maintain the stability of the tunnel structure, so as to avoid accidents[2~3]. Specific content as follows:

1) To understand the deformation of shield segment and surrounding soil and evaluate stability of the structure;

2) To understand the influence of the shield tunneling on the platform of the elevated overpass, and to evaluate the stability of the overpass;

3) To fully understand the influence of the surrounding environment in construction process, and achieve real-time monitoring on the surrounding buildings, underground water level, pipeline, to ensure their safety.

4) The daily management of the construction is carried out through the comprehensive information, providing reliable information for the optimization and reasonable organization construction, guiding the construction, improving technology of construction, and arranging reasonable schedule of construction, to achieve dynamic design and informational construction;

5) Accumulating the information, to provide a reference for similar projects.

B The Principle of The Construction Monitoring of The Metro Interval

Safety monitoring starts construction excavation, until the stability of the structure and the surrounding environment. Safety monitoring should follow the following principles[4~5]:

1) Key monitoring principle. Urban rail transit shield interval is mainly based on settlement monitoring, including ground settlement and pipeline settlement, settlement of surrounding buildings and tunnel deformation of segment lining, and the surface settlement is focused on monitoring project. The surface subsidence is the most reliable index to reflect the actual situation of soil, which directly reflects the deformation and stability of shield tunneling and soil under various loads.

2) The abnormal information in the monitoring process should be recorded in time, and make a relevant report

submitted to the departments in order to make an analysis of the abnormal situation and reduce the impact on the project.

3) For different monitoring items, it is best to set up in the same or similar monitoring sections, so you can post data processing in the analysis of the relevance of the monitoring project and get the results of a comprehensive analysis.

4) Monitoring design should be based on certain principles to determine, such as choosing the selection of the monitoring whether it has operability and the cost savings, etc. In the selection process of the monitoring points, the geological conditions, construction conditions and environment factors should be taken into consideration.

III. MONITORING CONTENT

To determine the monitoring contents of the interval by the indexes of the proposed shield interval including the geological parameters, the importance degree, the design requirements, and the construction method, etc[6], as shown in Table 1.

Table 1. CONSTRUCTION MONITORING CONTENTS OF SHIELD INTERVAL

Serial number	Monitoring project	Monitoring instrument	Monitoring purpose
1	Surface subsidence	Precision level, Invar rods	To master the influence of tunnel construction process on the surrounding soil, underground pipelines and surrounding buildings and scope
2	Underground pipeline settlement		
3	Building settlement		
4	Tunnel vault subsidence and horizontal convergence	Total station, Leica reflective film	To understand the displacement law and the size of supporting structure in the initial stage of the tunnel construction.
5	Pressure of Tunnel soil	VW-1 Frequency receiving apparatus, Earth pressure gauge	In the tunnel construction process. to understand the surrounding rock pressure, steel support axial force, distribution and size of force in initial support and lining
6	Lining ring internal force and deformation monitoring	Pressure box, frequency recorder, Total station	
7	Horizontal displacement of soil	PVC test tube Sinco measuring instrument	To master variation regularity of surrounding soil in the metro construction process
8	Groundwater level	Water level hole, Water level gauge	Master the influence of underground water on the surrounding environment.

IV. MONITOR DESIGN

A Monitoring Point Arrangement

Zhuanyang Avenue to Sports Center South interval shield tunnel construction monitoring points were arranged according to the requirements of design.

1) the land subsidence points along the channel direction: consider the influence on elevated overpass in tunnel excavation process fully, analysis monitoring data conveniently. The surface subsidence point of axis is the tunnel axis direction, shield interval to reach 100 m range, setting watchpoints every 5 ~ 10 m, other surface monitoring points of the central area of spacing between 18~20m, the surface subsidence point of axis adopt mark the actual location of measuring points and if it is difficulties to loft accurate location, can be adjusted back and forth on the axis direction;

2) tunnel horizontal sedimentation tank monitoring cross section layout: consider the influence on elevated overpass in tunnel excavation process fully, analysis monitoring data conveniently. Shield interval to reach 100 m range, setting settlement monitoring cross section every 30m, including shield originating and ending position all and above connecting passage are set the monitoring cross section, the rest of the section layout monitoring cross-section every 40 ~ 60m, the monitoring section settlement points from the center line of the route to the outside set from dense to sparse, seven points were arranged each monitoring section Figure 1.;

3) Elevated overpass cap and vertical and horizontal differences settlement layout: monitor all caps in shield

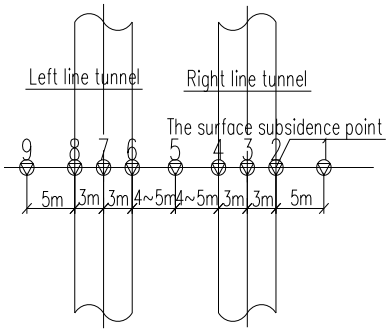

Figure 1. Surface Monitoring Section Points

interval comprehensive, to ensure that the shield smoothly;

4) the ground building subsidence points: usually arrangement of measuring points in each building in the process of tunnel construction influence scope , according to the structure of buildings, and other factors, such as building materials determine the observation point, the general layout at the corner of the building, the spacing should be no more than 20 m;

5) pipeline settlement monitoring: measuring point set in the ground within the scope of influence in the process of tunnel construction, choose indirect monitoring method to monitor, in the tunnel axis above the line monitoring appropriate chooses directly method. the spacing should be no more than 20 m;

6) tunnel segment level convergence, vault, arch bottom deformation: combining with the surface monitoring cross section, the Monitoring points set in tunnel below

monitoring cross section, facilitate data comprehensive analysis, verify each other Figure 2.

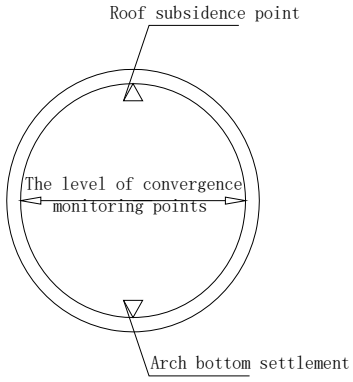

Figure 2. segment monitoring points

B The Number of Measuring Points

Combining with the actual situation according to design requirements, Zhuanyang Avenue to Sports Center South Station shield interval each monitoring project monitoring statistics are shown in Table 2.

Table 2. NUMBER OF MONITORING STATISTICS

monitoring program	monitoring point arrangement	unit	quantity
Surface subsidence	44 group axis surface point layout, section layout 24, 9 points each section	point	304
Dome and vault settlement	below in each section for a total of 48 group	point	96
Segment convergence	below in each section for a total of 48	strip	48
elevated overpass	Shield effect within the scope of each pile caps are arranged 2 to 4 points	point	246
The ground settlement of structures	According to the actual situation setting	point	10-20
underground utilities	Rigid pipe on both sides of axis in 15 m scope, spacing of monitoring points is 15 m	point	30-50

C Embedding and Testing Method of Testing Point

1) Observing in the cave or outside and inspection surrounding environment.

Inside interval tunnel: ①Whether the hinge joint of the shield is close; ②pipe segment's cracking and damage; ③ Pipe segment's misplaced and developing trend. ④Pipe segment's surrounding Water seepage situation; ⑤Shield tail situation of mortar leakage; ⑥ Main construction parameters and other conditions of shield machine.

Interval tunnel outside: ①the situation of the ground's settlement; ②The displacement of the steel column of an elevated bridge; ③ Cracking situation of elevated grade separation bearing platform; ④ Cracking situation of surrounding building; ⑤Cracking situation of road surface.

surrounding environment: ① The cracking and deformation of the surrounding buildings , interval tunnel and the elevated grade separation; ② road surface and settlement above the interval tunnel; ③The lower part of the tunnel section and near the pipeline's damage and leakage; ④ whether the interface of the underground pipeline is damaged, some of the subsidiary parts are cracking and seepage[7].

2) ground settlement above the tunnel

Method of embedding: using total station instrument to find position of the measuring point, punch drill wear road surface, and then make the ordinary level logo insert under the pavement; for not hardened ground measuring points directly drive into the rebar and indicate the monitoring points, at last protect monitoring points Figure 3.

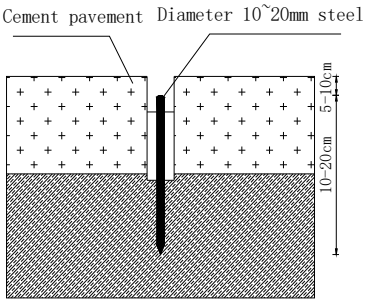

Figure 3. schematic diagram of embedding ground settlement point

Testing method: when monitoring ground settlement, place outside tunnel construction influence scope 2-3 starting point, using starting point to measure other points, in order to ensure the accuracy of the starting point , that need to check regularly by setting standards on the basis of the standard. The measurement is based on national two level and the use of precision level machine. According to the level of the control point, the monitoring route is measured by subsidiary wire or a closed route ,measure the displacement of the monitoring points.

3) settlement and displacement of the surrounding buildings Installation method

building monitoring points determine the embedding method according to the material of the building, generally using expansion bolt or steel nails drive into architectural objects Figure 4..

Measuring method: Measurement is based on the requirement of national two level, according with demanding index of various accuracy in national two level, according to the standard control point[8], The deformation of each monitoring point can be calculated by using the enclosed lead or closed route to coupling measurement in monitoring line.

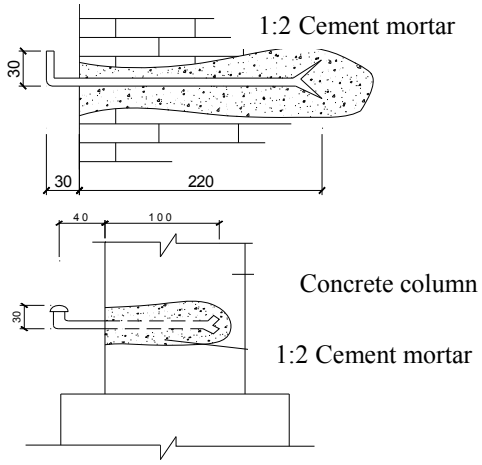

Figure4**.** Schematic diagram of the surrounding buildings embedding measuring points (unit: mm)

4) Underground pipeline settlement

The monitoring of pipeline is carried out by direct measurement and indirect measurement. General section adopts indirect measurement method, to take direct monitoring of visible equipment (such as valve well, pumping wells, manhole, inspection shaft, etc.) Figure 5..

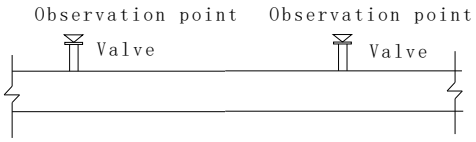

Figure5. schematic diagram of underground pipe line subsidence monitoring

5) segment of peripheral convergence and vertical deformation

Embedding method: First, to release the convergence point in the tube in accordance with the design requirements, electric hammer drilling in the site of measurement, at both ends are respectively embedded expansion bolt and hook, The diametrical direction of circular segment will be better.

Measurement method: Measurement is also according to the requirements of national two level standards, in line with the accuracy requirements of the national two level, choose the corresponding convergence measurement, In each monitoring recording the time temperature data and temperature correction of data.

D Monitoring control

The control standard of the construction monitoring of shield tunnel have shown in Table 3:

V. ANALYSIS AND DISCUSSION OF MONITORING RESULTS

A Ground Settlement

The final cumulative settlement data at 59 and 179 section on the left line of shield interval and the final cumulative tunnel boring machine data at 39,139section on the right line of shield interval show in TABLE 4.

Table 4.MONITOR PROJECT CONTROL TABLE

Number	Monitoring projects	Allowable displacement control	Displacement average rate control	Maximum displacement control value
1	Ground settlement	-30mm	1mm/d	3mm/d
2	Vault settlement	-20mm	1mm/d	3mm/d
3	Surface uplift	+10mm	1mm/d	3mm/d
4	Elevated interchange settlement	-10mm	1mm/d	3mm/d
5	Rigid pressure line	±10mm	1mm/d	3mm/d
6	Rigid non pressure pipeline	±10mm	2mm/d	3mm/d
7	Horizontal convergence	10mm～-30mm	1mm/d	3mm/d
8	Elevated interchange slope	2‰pile space，Inclined end settlement divided its distance：0.002		

Table 5.STATISTICAL MEASUREMENT OF ACCUMULATED SETTLEMENT OF HORIZONTAL SECTION （UNIT：MM）

location		Cumulative settlement of each point								
		1	2	3	4	5	6	7	8	9
L	59					-20.68	-37.60	-114.92	-30.56	-5.75
	179					-8.62	-10.29	-15.44	-13.57	-4.68
R	39	-25.82	-37.80	-302.35	-215.40	-112.72				
	139	-21.83	-23.93	-64.03	-28.04	-0.11				

According to Table 4 :

1) Due to the same geological condition during the tunnel boring machine crossing and the very closing construction parameters, so the settlement curve of the four section almost the same, present the tendency of being small at both ends and big in the middle.

2) Two lines buried depth become more and more big as the tunnel excavation, so each line's cumulative settlement in

behind section is smaller than the former section. So in the early stages of excavation is the key period of construction, should be monitored frequently.

3) The maximum amount of settlement -302.35mm appears at the right line of the 39 ring of the 3 measuring points, this is because the two time's injection haven't caused in time, although other parts of the settlement have some differences, and some more than the control value, due to the surface without buildings and the shield tunneling parameters are appropriate, have a good posture, and no leakage occurred.

The distribution law of surface subsidence by Peck formula[9]:

$$S(x) = S_{\max} e^{-x^2/2i^2} \tag{1}$$

$$S_{\max} = \frac{V_i}{\sqrt{2\pi} i} \tag{2}$$

$$i = \frac{H}{\sqrt{2\pi}\tan\left(\frac{\pi}{4} - \frac{\phi}{2}\right)} \tag{3}$$

$$V_i = V_L \pi R^2 \tag{4}$$

$S(x)$ ——Settlement value from the axis of the tunnel（mm）;

$S_{\max}$ ——Maximum settlement value of tunnel axis（mm）;

V_i ——Stratum loss of tunnel unit length（m^3/m）;

i——Point of inflection in subsidence curve;

H——Buried depth of tunnel;

V_L——The loss rate of formation volume, that is percentage of unit length to shield volume per unit length;

ϕ ——Internal friction angle of soil, weighted average value of soil;

R——Shield diameter（m）

In order to verify the applicability of the Peck formula(1) to the lateral settling tank, to choose empirical formulas to verify the stability of the above four sections of the settling tank [10]

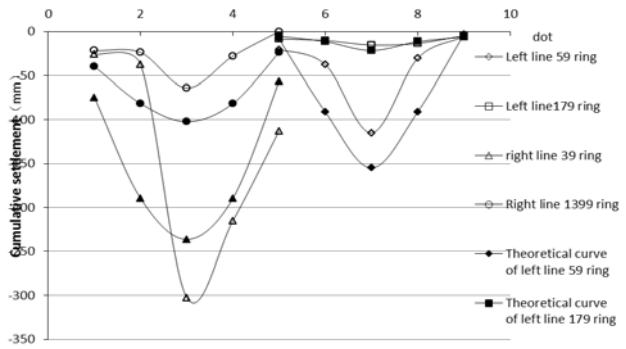

Figure6. Theoretical and measured comparison chart of cross-sectional

Table 4According to the actual situation of Zhuan yang Avenue to Sports Center Station interval, VL is 1.0%, R is 6.0m, the left line 59 ring buried depth H1 is 5.1m, 179 ring buried depth H2 is 7.5m, the right line 39 ring buried depth H3 is 4.9m, 1,39 ring buried depth H4 is 7.1m.

Table 5The theoretical calculation curve of the left lane of 59 ring and 179 ring and the right lane of 39 ring and 139 ring is obtained by peck formula, as shown in Figure 6.

According to Figure 6 shows that the theoretical curve calculated by Peck formula and the Curve still has some differences, but it can better predict the settler area of soil section. We can adjust each parameter value according to the actual situation. It plays a vital role in the use of practical engineering.

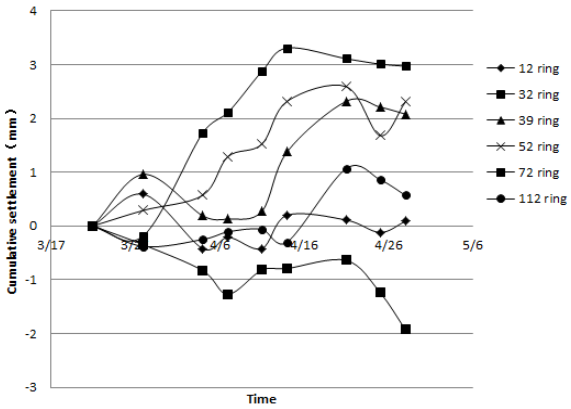

Figure7. The convergence time process lasted Figure of the left line segment

B *Interval Convergence*

The left line segment convergence monitoring data at April 2014 is shown in *Figure 7.*.

According to Figure 7 shows that the maximum convergence deformation of the left line segment is 3.31mm on the 5 ring about at April 19. The segments between 39 ring to 72 ring was trend to outwardly deformed, but have remained stable. The rest of the curve is about 0.0mm axis fluctuations in little change, showing stable trends within the design value range.

C *Arch Bottom Settlement*

The left line segment monitoring data at April 2014 is shown in Figure 8..

Figure 8 shows that the maximum arch bottom settlement is upward bulge 1.10mm on the 5 ring about at April 7. Other relatively large displacement, is in ring 45 at 4 April settlement reached 0.71mm and ring 99 at 7 April settlement reached 0.61mm. Over time, dome settlement gradually reduced steady. The rest of the curve is also true, showing a relatively stable trend in the range of design

values.

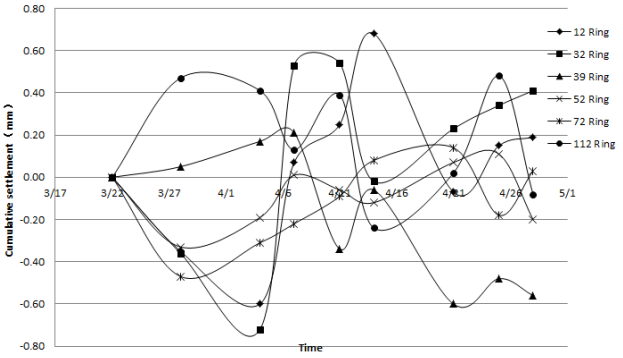

Figure8. The left line arch bottom settlement last graph

D Vault Settlement

The left line segment monitoring data at April 2014 is shown in Figure 9..

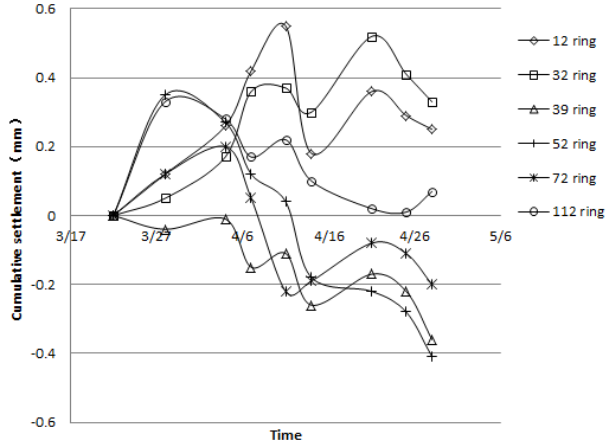

Figure9.The left line vault settlement last graph

According to Figure 7 shows that vault from 1 ring to 32 ring began to have a downward settlement trend. The maximum is 0.72mm on the 25th ring and 32th ring. As the effect of secondary grouting initially appeared, it slightly upturned and be stable. 39 ring to 85 ring vault settlement data has been around 0.0mm fluctuations. 39 ring settlement reached 0.60mm at April 21. At the beginning, vault of 99 ring to 139 ring at is bulge state. 99 ring bulge upward 0.61mm at March 28. 152 ring was downward trend, the maximum settlement reached 0.44mm.

VI. CONCLUSION

Combined with the construction situation of Zhuanyang Avenue to Sports Center South Interval, proposed monitoring program, obtained the following conclusions:

(1) For surface subsidence, selected left and right lines two cross section of Zhuanyang Avenue to Sports Center South Interval, compared the actual monitoring data with the date calculated by the formula Peck, we can know that the actual monitoring data and the theoretical curve calculated by Peck formula still be some differences, but the size and shape soil section of the settling tank can be better predicted.

(2) For interval convergence, select the monitoring data of left line 1 to 152 ring in April. The maximum deformation of the left line interval convergence is 3.31mm on the 32th ring. The segments between 39 ring to 72 ring was trend to outwardly deformed, but have remained stable.

(3) Arch bottom and vault settlement also selected the monitoring data of left line 1 to 152 ring in April. The maximum arch bottom settlement is upward bulge 1.10mm on the 5th ring. The maximum vault settlement is 0.72mm on the 25 ring and 32 ring. Settlement of the remaining positions basically stable, there is little volatility.

REFERENCES

[1] Chen Jie, Chen Rong. The implementation and management of monitoring and measurement of line 1 in Chengdu Metro. Hydropower station design,114-116,03,2010.

[2] Xu Shun-ming.Research on construction control of Guangzhou rail transit shield tunnel,Wuhan University, Wuhan,ON,China,2012.

[3] Wan-Li. Research on construction monitoring technology of highway tunnel, Chang'an University, Xi'an ,ON,China,2006.

[4] Yang Cheng-bin. Study on safety and early warning system of subway construction monitoring,Xi'an University of Science And Technology, Xi'an ,ON,China,2013

[5] Li Wen-hua. Research on construction control technology of large cross section, ultra small horizontal and double line metro tunnel,Jilin University, Changchun ,ON,China,2013

[6] Hao Xiao-hong, Cui Jangli, Jin Guo-jin. Design and application of tunnel monitoring information database management system, Well construction technology,24 (4),38-42,2003,06.

[7] Zhang Ye-wei, Yang Xi-nan. Long distance shield tunnel construction phase measurement method optimization [J]. Journal of East China Jiaotong University, 28,48-52,06,2011.

[8] Sauri S. Back Analysis of measured displacement of tunnels. Rock Mech and Rock.Engineering,1983, (16):173-180.

[9] Pan Mei-ze, Jiang Bing-yu, Huang Tao. Applicability analysis of Peck formula in predicting ground settlement of shield tunnel in Tianjin [J].Surveying and Mapping Science, 03:53-55,03,2010.

[10] Peck R.B.Tunneling in soils.In:10th ICSMFE. Stockholm, 1981: 607-628.