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Deformation analysis on metro shield tunnel under-crossing railway box culvert

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Abstract: With the rapid development of urban rail transit network，a large number of subway shield tunnel near or even close to the railway box culvert construction. The shield tunneling excavation causing the unloading of neighborhood soil, inevitable role in the railway box culvert. In this paper, the numerical simulation method has been applied, a detailed analysis on the deformation mechanism of the railway box culvert effect by the shield tunnel construction, relying on the Beijing Metro Line through railway box culvert project. The calculation show that: when the shield tunnel excavation face away from the monitoring sites 3D （D:Shield tunnel diameter）distance, the railway box culvert began to appear settlement, After 3D spacing through monitoring sites, the railway box culvert settlement gradually stabilized. The shield tunnel underground crossing the railway box culvert, larger differential settlement would appear on both sides of the settlement joint, inevitable role in the operation safety of the train above the bridge. Before advancing of the shield machine, grouting reinforcement at the tunnel vault，could effectively reduce the railway box culvert settlement and differential settlement between two sides of settlement joint. The results of this paper has certain reference significance for the design and construction of the relevant engineering.

Keywords: Railway box culvert, shield tunnel, deformation response, grouting reinforcement

0 Perface

With the continuous development and utilization of urban underground space in our country, rail transit has been developed rapidly[1-3].As an important method of tunnel construction, shield method is widely used in the process of metro tunnel construction.Due to the overall planning of metro lines,The construction of shield tunnel is likely to be through a large number of buildings.Shield method construction process has caused the unloading of soil, changed the original stress state of soil, induced the additional internal force and deformation of buildings,caused the settlement or tilt of buildings.Many scholars at home and abroad have studied on this question[4-11],But the existing research focuses on the tunnel underneath passing the general buildings (such as shopping malls, overpass, houses,teaching buildings, etc.).For the deformation response of the tunnel underneath passing the railway bridge box culvert,it is lack of analysis and research[12-15], mainly manifested in the following two aspects:

(1) We usually carry out grouting reinforcement the tunnel vault in the process of Shield tunnel underneath passing the railway bridge box culvert. but for the effect of the grouting reinforcement,it is lack of analysis and research.

(2) Restricted by box culvert span,there often exists settlement joint between the different box culverts of the same bridge. shield tunnel construction induced uneven settlement of settlement joint, inevitably affect the operating safety of the train above the bridge. The current research is lack of the deformation mechanism of the settlement joint on both sides of the bridge .

In this paper, the numerical simulation method has been applied, a detailed analysis on the deformation mechanism of the railway box culvert effect by the shield tunnel construction, relying on the Beijing Metro Line through railway box culvert project

1 Project summary

1.1 Project introduction

The Beijing Metro Line tunnel construction apply shield method and the tunnel overburden soil depth is about 10 m ~ 19 m. Shield tunnel structure use C50, permeability grade P10 precast reinforced concrete segment, which the outer diameter is 6000 mm, the thickness is 300 mm, the inner diameter is 5.4 m and the ring wide is 1.2 m. lining segment is divided into 6 block. Between block and block is connected by bolt and apply staggered joint ,as well as between ring and ring.In which,the railway box culvert,which is passed by shield tunnel,is the only special environmental risk source in the tender.The railway box culvert is C35 four hole steel frame bridge,and is composed of three parallel box culvert bridge. From north to south is: bridge ① is the single-arch box culvert and its aperture is 12m; bridge ② is the double-arch box culvert and its aperture is 2×15m; bridge ③ is box culvert and its aperture is 12m. Between two Intermediate across, as well as between both sides across, set settlement joint with 20 cm wide. The relative position between tunnel and rail box culvert is shown in Figure 1.

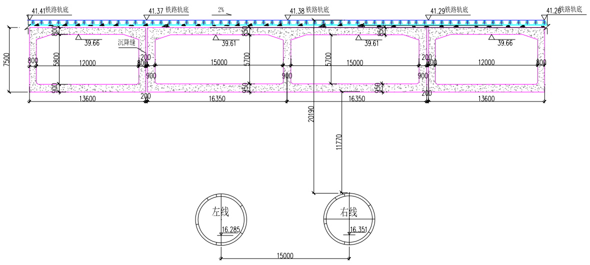


Fig.1 Relationship of shield tunnel and Railway box Calvert (unit: mm）

1.2 Engineering geological and hydrogeological conditions

The layer of the research worksite scope mainly includes artificial accumulation the quaternary holocene diluvium and quaternary rushed diluvium late Pleistocene. The cross section of strata roughly concludes artificial filled soil, powder soil filling soil, silty sand, coarse sand, gravel, silt, silty clay, silt, local silty clay, silt, coarse sand and gravel. In the research range within the scope of worksite, landform type is single and the submarine groundwater dynamic type is mainly infiltration and runoff, which is given priority to atmospheric precipitation infiltration, the lateral groundwater flow and "skylight" leakage recharge mode,excretion in lateral flow and the flow down way, aqueous petrofabric of quaternary thick layer of gravel soil, aqueous petrofabric hydrogeology is stronger. According to the area between the geotechnical engineering detailed survey report ,within the scope of the maximum drilling depth 47 m, there are three layer groundwater, which groundwater type is a layer of water and two layers of confined water.

1.3 Grouting pre-reinforcement scheme

The shield tunnel underground crossing the railway box culvert, through setting three grouting holes on the top and setting DN25 radial grouting pipe in the radial direction to grout pre-reinforcement the vault. The grouting tube length is 5.5 m, the grout diffusion radius is designed with 0.5 m ,and grouting time should be controlled less than 5 m from the excavation surface. Slurry apply PO. 42.5 ordinary Portland cement and the grouting pressure is 0.5 Mpa. Grouting pre-reinforcement scheme is shown in figure 2.

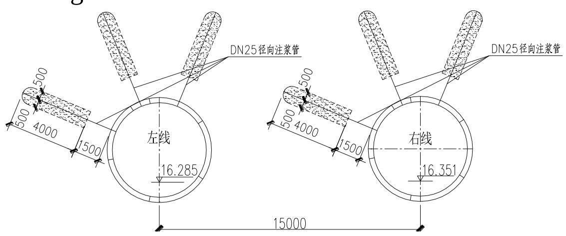


Fig.2 The measure of grouting pre-reinforcement (unit: mm）

2 Numerical analysis model is established

2.1 Model size and mesh

This paper use the method of the definition of linear gradient in the MIDAS/GTS software (length) ,through inputting the length of the initial cell line and the end of the cell line, according to a linear interpolation, automatically set the node position, makes the grid surrounding railway box culvert and shield tunnel relatively intensive and the border grid relatively sparse.To guarantee the calculation accuracy at the same time, also ensure the calculation efficiency. Calculation model for regional aspect is 260m×144m×40m. The finite element mesh model is shown in figure 3.

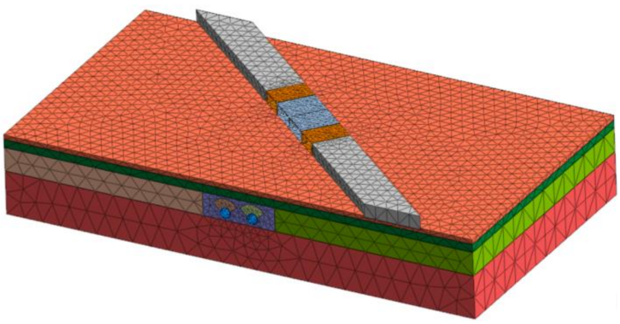


Fig.3 FEM mesh of calculation model（unit:m）

2.2 Setting model material parameter

The model of the foundation soil selects Mohr Coulomb constitutive model, with entity unit established, the specific value accordings to the corresponding geological exploration report data, see table 1. The bridge structure, shield shell and lining segment use elastic constitutive model. The bridge structure and lining segment are established by entity units and the shield shell applys plate unit. Part of the physical mechanical parameters of the structure are shown in table 2.

Table 1. Physical and mechanical parameters of ground

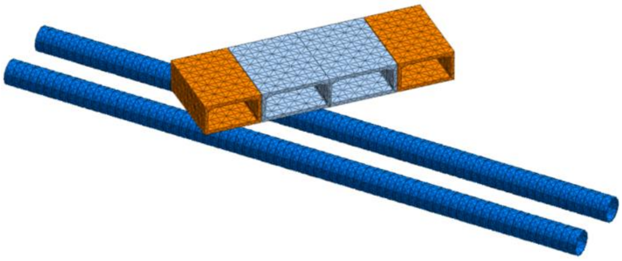
Geotechnical category	thickness /m	Elastic modulus/MPa	Poisson's ratio	Gravity density / kN/m³	Cohesive force / kN/m²	Friction Angle /°
filled earth	2.63	23	0.34	18.2	18	25
silty soil	4.4	26	0.36	19.7	20	25
medium-coarse sand、 pebble	2.6	40	0.27	21.2	0	40
silty clay	8.6	26	0.31	20.2	32	27
sand-gravel layers	—	74	0.24	19.7	0	45

Table 2. Parameters of model structure

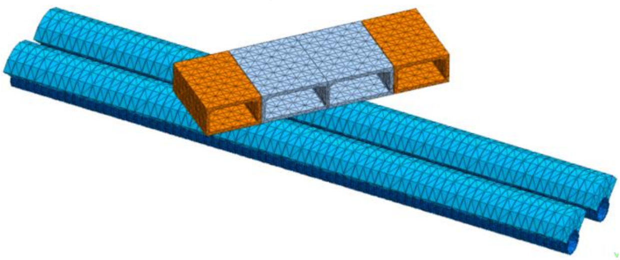
Name	Gravity density（kN/m3）	Poisson's ratio	Elastic modulus/（Gpa）
Bridge structure	25	0.3	30
shield segment	25	0.2	34.5
grouting layer	22	0.28	12
shield	78	0.3	210

2.3 Calculation scheme

According to the design requirements, before the shield tunnel across the railway box culvert bridge, through the arrangement of the radial grouting pipe grouting pre-reinforcement of shield tunnel. To evaluate the grouting reinforcement effect, the numerical simulation aims at two kinds of schemes, namely the scheme 1, regardless of the grouting reinforcement measures; Scheme 2, consider the grouting reinforcement measures, as shown in figure 4.



（a）Scheme 1



（b）Scheme 2

Fig.4 Calculation program of the numerical simulation

2.4 Shield tunnel construction process simulation

This article adopts the way of unit grid activation - passivation to simulate the shield tunnel dynamic excavation process,the numerical simulation of shield tunnel construction steps are as follows:

(1)Establish strata-shield tunnel-railway bridge box culvert three-dimensional numerical analysis model, calculate the initial stress field of the soil under gravity stress,and reset the displacement.

(2)"Activate" railway box culvert structure unit, calculate the distribution of stress field of railway box culvert after the completion of construction and reset the displacement.

(3)Define the shield tunnel construction steps, each ring soil excavation is 1.2 m.shield machine advances according to the following three stages of the construction, soil excavation, shield shell respectively to promote, the segment installation and shield tail grouting, stress release proportion was 30%, 30%, 40% by calculation.

(4)Circulate step (3) in turn,first construct the left line of the tunnel,after construct the right line of the tunnel,until the excavation is completed, in this paper, soil excavation and shield tunnel supporting has a total of 242 steps.

(5)Calculation and post-processing analysis results.

3 Monitoring point arrangement and deformation control standards

For further analysis of the influence of the subway shield tunnel construction on the deformation of the railway box culvert ,along the tunneling direction,set up three monitoring cross section in the central of the bridge and on both sides,the section 1, section 2, section 3.On monitoring sections,set up a monitoring station each interval of 2 m, and set up a monitoring station on left and right sides of settlement joint , each monitoring section has a total of 33 monitoring stations. Choose typical monitoring station to number, the typical spot located at the central and edge of the bridge, and two sides around the settlement joint , each monitoring section has a total of seven typical monitoring stations. Monitoring sections and typical monitoring point arrangement is shown in figure 5.

According to the engineering evaluation report, the control values of the railway box culvert structure settlement and differential settlement is+ 5 mm - 5 mm.During the shield crossing the railway bridge box culvert,the surveillance is strengthen, and the deflection of the bridge is observed in time.

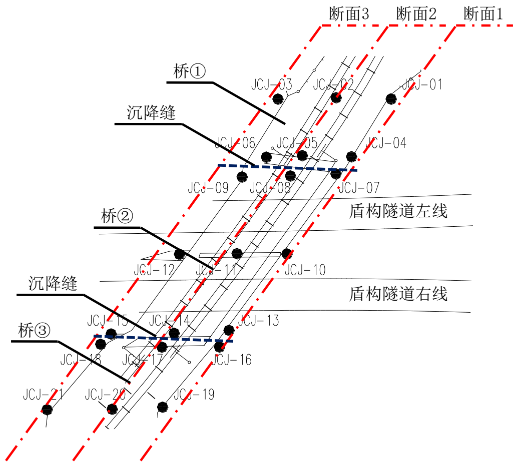
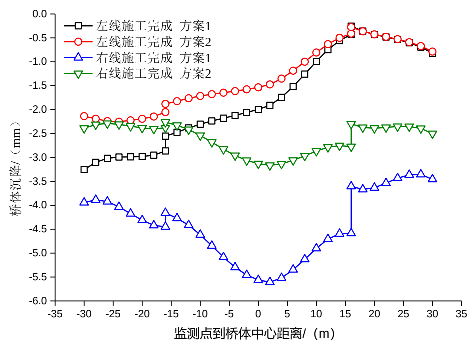


Fig.5 Monitoring points of railway box culvert

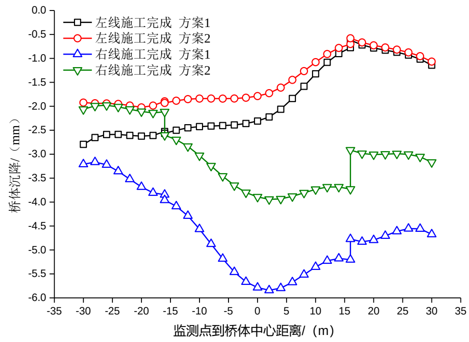
4 Calculation results and analysis

4.1The response analysis of the railway box culvert section settlement

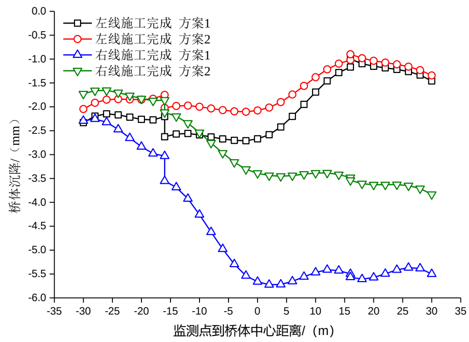
The curve of the railway box culvert section settlement is shown in figure 6. Analysis of diagram 6 shows:the most affected area of the subway shield tunnel construction on the railway box culvert is bridge (2) ,the maximum settlement occurred in the central of the bridge (2), without adopting grouting pre-reinforcement measures, the bridge's largest settlement is about 5.8 mm, which can not meet the requirement of the project.After adopting grouting pre-reinforcement measures, the bridge's largest settlement is about 4.0mm,which satisfy the engineering requirement, grouting pre-reinforcement can be controlled to some extent settlement of the bridge.Between left and right sides of the settlement joint exists the obvious settlement difference,without using grouting reinforcement scheme, maximum differential settlement is about 1.3 mm, after grouting pre-reinforcement scheme, maximum differential settlement is about 1 mm,the track above the adjacent box culvert cannot occur synchronous settlement due to the existence of the settlement joint , easy to affect the operation safety of the train.Adopting grouting pre-reinforcement measures, can to a certain extent, reduce the differential settlement on both sides of the settlement joint.



（a）cross-section 1



（b）cross-section 2

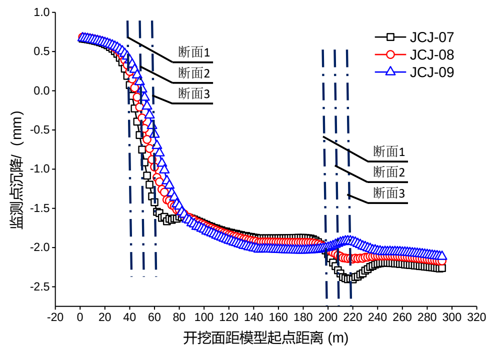


（c）cross-section 3

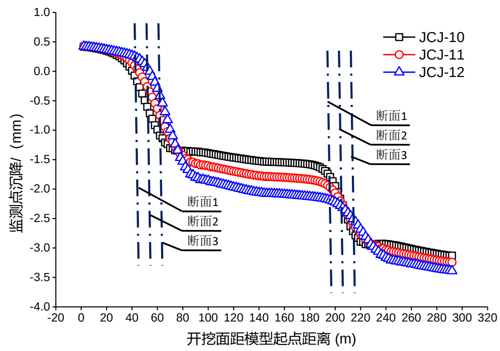
Fig.6 Settlement curve of the bridge cross-section

4.2 The time history response analysis of the railway box culvert settlement

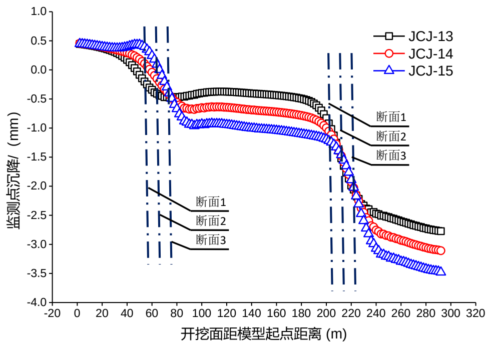
The span of the railway box culvert (2) is larger, and is the main area crossed by the shield tunnel, so the impact is the largest.Thus, this article mainly analysis the time history response of the bridge (2) settlement.The curves of the time history response of the bridge (2) setttlement are shown in figure 7.Analysis of the diagram 7 shows that the process of the left line of shield tunnel construction has greatest influence to monitoring JCJ - 07-09, impact on the spot JCJ - 10 ~ 12, smaller influence on spot JCJ - 13 ~ 15;the process of the right line of shield tunnel construction has greatest influence to monitoring JCJ -13-15, impact on the spot JCJ - 10 ~ 12, smaller influence on spot JCJ -07 ~ 09.In the processs of Shield tunnel underneath passing the railway box culvert., the impact of subsidence monitoring longitudinal interval is about 3D before monitoring to 3D after monitoring(D is the shield tunnel diameter).When the excavation surface is located below the monitoring spot, the bridge sedimentation rate is the fastest.



（a）Monitoring Point JCJ-07~09



（b）Monitoring Point JCJ-10~12



（c）Monitoring Point JCJ-13~15

Fig.7 Time-history subsidence curves of the railway box culvert ②

5 Conclusion

Through the research of geological conditions, construction technology, working steps for the typical range of Beijing subway underneath passing the railway bridge box culvert. The main conclusions include the following three points:

(1) In the processs of Shield tunnel underneath passing the railway box culvert., the impact of subsidence monitoring longitudinal interval is about 3D before monitoring to 3D after monitoring(D is the shield tunnel diameter).When the excavation surface is located below the monitoring spot, the bridge sedimentation rate is the fastest.

(2) In the processs of Shield tunnel underneath passing the railway box culvert., the box culvert on both sides of the settlement joint can appear larger differential settlement,cause the uneven settlement of the upper track of the bridge, easy to cause an effect to the operating safety of the train above the bridge.

(3) Before the shield tunnel cross the railway box culvert, grouting pre-reinforcement the vault of shield tunnel can to some extent control of the bridge settlement and the differential settlement between the left and right sides of the settlement joint.

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