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Research on the impact of underground box culvert underpass construction on the pier of intercity railroad bridge

Ye Dan*

China Railway Engineering Design and Consulting Group Co.,Ltd., Beijing, China
ztzx_yd@126.com
**Corresponding author*

Abstract: *Taking the new underground box culvert underpassing the special bridge of Guangzhou-Qingdao Intercity Trans-Guangdong-Qingdao Expressway in the flooding remediation project around Guangzhou Vehicle Factory as an example, the impact of the underground box culvert proximity and underpassing construction process on the proximity pier of the special bridge at Huaian Station was studied. Firstly, the settlement values and lateral and longitudinal horizontal displacement values of the underpass pier at different construction stages were obtained by on-site monitoring. Subsequently, a numerical simulation model was established by PLAXIS 3D to further analyze the dynamic response law of the pier. Finally, the construction control standards and control measures for underground box culvert underpassing high speed railway bridges are proposed through parametric analysis of the excavation proximity and excavation depth of the underground box culvert. The research results show that during the construction of new underground box culvert underpass, the settlement and displacement conditions of the pier of Guangqing Intercity Bridge across Guangqing Expressway are within the specification limits, and in order to ensure the absolute safety and smoothness of train operation, it is suggested that the excavation depth of new underground box culvert underpass should be kept within 6 m, and the excavation proximity should be kept above 5 m when it exceeds 6 m.*

Keywords: *underground box culvert; underpass construction; railroad bridge; field monitoring; numerical simulation*

1. Introduction

With the development and improvement of China's comprehensive transportation system, road, railway and other transportation networks are constantly encrypted. Limited by pre-planning, economic base and land resources, more and more road lines and railway lines are close or even cross. For the high-speed railway bridge, the construction of the surrounding environment is very likely to cause uneven settlement of the bridge pier, and then lead to the dynamic irregularity of the track, which seriously affects the safe operation of high-speed railway [1-2]. Therefore, it is of great engineering significance to study the influence of surrounding environment construction on the bridge pier of high-speed railway.

At present, many scholars have conducted special studies on the dynamic response of bridge pier in the construction process of the surrounding environment [3-5]. Dong Liang et al. [6] studied the dynamic response of railway Bridges adjacent to coal mining by using numerical simulation methods, and considered the influence of pile loading mode and height on settlement deformation of pile foundation. Zhou Jimin [7] took the pile foundation group project of shield tunnel under viaduct as an example to study the influence law of shield tunneling under the bridge pile foundation by three-dimensional numerical simulation. Aiming at the influence of foundation pit dewatering on adjacent intercity railway Bridges, Meng Changjiang et al. [8] proposed a calculation method for the change of groundwater level near the high-speed railway piers in operation caused by foundation pit dewatering, and analyzed the settlement and safety factor changes of high-speed railway piers. However, the existing research results rarely involve the influence of underground box culverts on the pier of high-speed railway Bridges, and can not provide reference for the construction control standards of underground box culverts of underpass railway Bridges.

Based on this, the dynamic response rule of railway bridge pier in the process of underground box culvert construction is studied based on site monitoring and numerical analysis, and the construction control standard and control measures of high-speed railway Bridges under underground box culvert are discussed.

2. Engineering Background

The flooding renovation project around the factory area of Guangzhou Car Works is located in Ziwei Road, Huadu District, Guangzhou City. The underground box is planned to be built under the super bridge of Guangqing Expressway. As shown in Figure 1, the Angle between the new box culverts and Guangqing Intercity railway is 85°, and the underpass position is between pier No. 33 and pier No. 36 of Guangqing Intercity Railway. The bridge structure is 32 m simple supported beams, the pile foundation is rock-socked pile, and the pier height is about 25 m. The box culvert of the lower penetration section is a reinforced concrete structure, the size is width × height = 3.0m × 1.5m, the buried depth is about 3.0m, the design slope is 0.001, and the design flow rate is 1.5-1.7m /s. The soil layer where the foundation is located is clay layer, and its excavation and backfilling process will inevitably cause bad effects on the bridge pier.

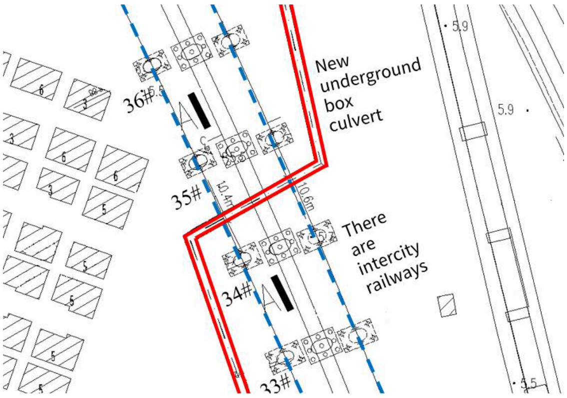

Figure 1. Schematic diagram of the position relationship between underground box culvert and railway bridge

3. On-site monitoring

3.1. Monitoring scheme Settings

Figure 2. Schematic diagram of site monitoring and measuring point layout of bridge pier

The dynamic response of pier of railway bridge during the construction of underground box culvert is analyzed by field monitoring and measurement. The monitoring contents mainly include settlement displacement of pier No. 33 to No. 36, transverse horizontal deformation along the bridge, longitudinal horizontal deformation in the cross section direction and inclined deformation. Among them, according to the Code for Railway Engineering Measurement (TB 10101-2018) [9], the settlement observation is measured by high-precision level, the tilt of pier column is measured wirelessly by dipmeter, the horizontal and longitudinal displacement of pier top is monitored by total station, and the horizontal displacement measurement points in the upper row are arranged on the pier top surface. The bottom row horizontal displacement monitoring point and settlement monitoring point are located about 1m above the top surface of the cap, and the pier column measurement point layout is shown in Figure 2.

3.2. Analysis of monitoring results

Figure 3 shows the settlement and displacement change curve of pier No. 33 to 36 in the excavation stage of underground box culvert, underpass construction, backfill stage and post-construction observation stage. It can be found that the settlement value of adjacent pier is within the range of -5 mm. It meets the ±6 mm limit requirement stipulated in the Technical Regulations for Highway and Municipal Engineering Underpass High-speed Railway (TB10182-2017) [10]. Due to the short excavation time, no significant settlement occurred at each pier. The settlement mainly occurs in the underpass construction and backfill stage, among which, No. 34 and No. 35 pier are greatly affected by the underground box culvert construction, the pier settlement value of No. 34 pier after the completion of construction is -5.0mm, the pier settlement value of No. 35 pier after the completion of construction is -4.2mm, and the pier settlement tends to be stable after the end of backfill for a period of time; However, pier No. 33 and Pier No. 36, which are far away, are almost unaffected by construction and only have slight settlement, which tends to be stable after the completion of excavation.

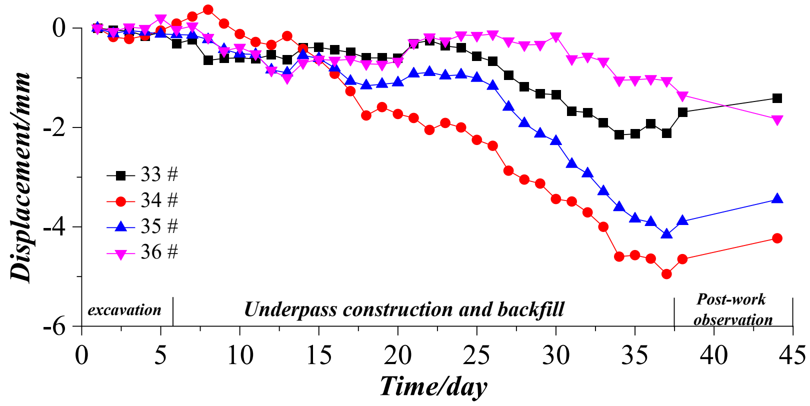

Figure 3. Settlement and displacement change curve of pier

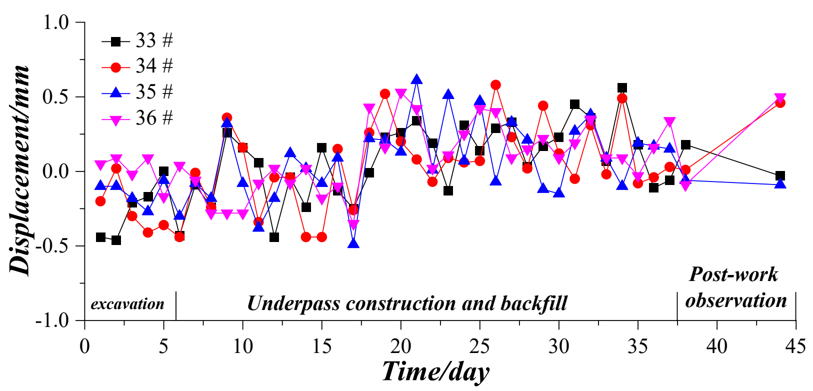

Figure 4. Change curve of pier horizontal displacement

The change curves of lateral and longitudinal horizontal displacement of pier No. 33 to 36 in the excavation stage of underground box culvert, underpass construction and backfill stage and post-construction observation stage are shown in FIG. 4 and FIG. 5 respectively. The positive value of horizontal deformation indicates that it points to the large mileage side of the railway, and the negative value points to the small mileage side. The result of longitudinal horizontal deformation is positive, indicating that it points to the left side of the railway (towards large mileage), and negative, indicating

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that it points to the right side of the railway. According to the comprehensive analysis of FIG. 4 and FIG. 5, it can be seen that the construction of underground box culverts has a small influence on the deformation of the embankment, and the horizontal and longitudinal horizontal displace are both less than 1 mm, which meets the limit value of ±3mm stipulated in the Technical Regulations of Highway and Municipal Engineering Underpassing High-speed Railway (TB10182-2017) [10]. Among them, the transverse horizontal displacement and longitudinal horizontal displacement of the pier mainly occur in the underpass and construction backfill stage, and the closer to the construction road, the greater the deformation impact of the pier.

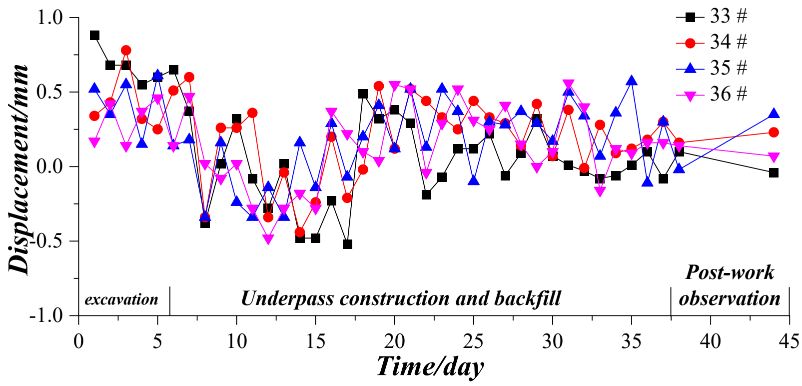

Figure 5. Change curve of longitudinal horizontal displacement of pier

4. Numerical Analysis

4.1. Establishment of finite element model

The dynamic response of high speed railway bridge pier during the construction of underground box culverts is further analyzed by using PLAXIS 3D, a general geotechnical finite element analysis software. PLAXIS 3D software can be used in the analysis of many geotechnical problems, the division of various finite element grids and the simulation of construction processes [11]. The length, width and height of the finite element model are set to 160 m, 120 m and 56 m respectively according to the project scope and evaluation needs, while avoiding the influence of boundary effect. Among them, bridge pier, cap and pile are assumed to be linear elastic structure, and only the influence of elastic modulus is considered. The soil mass is simplified into 4 horizontal strata from top to bottom, and the modified MoHR-Coulomb model is used to simulate its constitutive behavior. Solid elements were used to simulate the bridge cap, pile elements were used to simulate the bored pile, the vertical load transmitted to the top of the bridge cap was realized by surface load, plate elements were used to simulate the steel plate protection, and beam elements were used to simulate the support. In addition, the boundary around the finite element model adopts horizontal constraints, and the bottom boundary adopts vertical constraints. The finite element calculation model is shown in Figure 6, and the geological parameters of the soil layer are shown in Table 1.

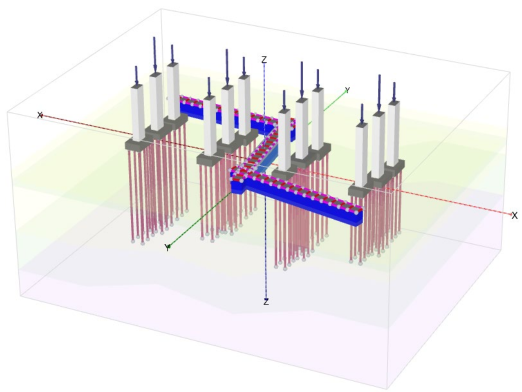

Figure 6. Finite element calculation model

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Table 1 :Geological parameters of soil layer

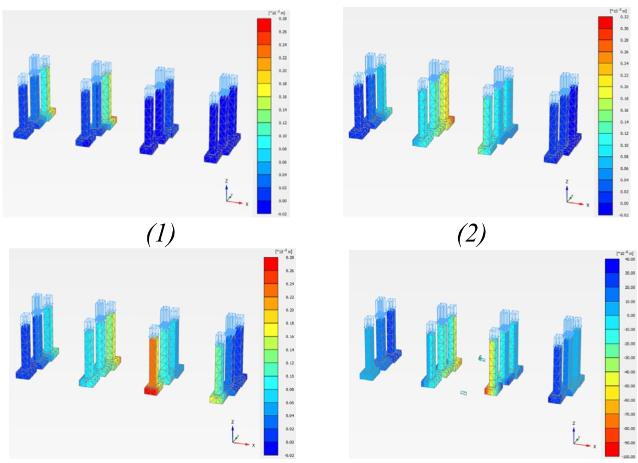
Geotechnical designation	c/kPa	φ/°	E_s/Mpa	Basic bearing capacity/kPa	Side friction resistance/kPa
Miscellaneous fill	18.4	15.6	4.6	-	40
Silty clay	23	24	9	180	60
Gravelly sand	1	35	20	300	80
limestone	500	35	22000	1000	120

4.2. Finite element calculation conditions

According to the actual construction sequence of underground box culverts, this numerical analysis is divided into initial ground stress field simulation, Guangqing intercity railway simulation, underground box culvert road excavation of large mileage excavation construction, underpass excavation construction, small mileage excavation construction and backfilling of different stages on the deformation of existing railway Bridges. At the beginning of each stage, the initial ground stress of the soil mass is calculated first, and the subsequent construction process is carried out on the basis of the ground stress distribution obtained in the previous calculation step. In addition, in order to discuss the construction control standard of the underground box culvert underpass high-speed railway bridge, the distance near the pier and the excavation depth of the underpass section are parameterized.

4.3. Analysis of calculation results

According to the finite element software PLAXIS, a three-dimensional model was established for calculation and analysis. Figure 7 shows the impact of additional settlement deformation on the pier top of the bridge that passes through Guangqing intercity railway under the flooding renovation project around the plant area of Guangzhou Rolling Stock Works. When the underground box culvert passes through the Guangqing intercity railway construction, the pier top of the bridge will produce a small displacement. The excavation conditions of the underpass section of pier No. 34 and the vertical additional displacement of the top of pier No. 35 in the excavation of large-mileage foundation pit are the largest, about 4.4mm, which is also consistent with the field monitoring results. It can be considered that the numerical simulation method adopted in this paper has good reliability. In different construction stages, the impact of underground box culvert underpass construction on each sub-pier is different. In the construction stage of large-mileage excavation, it mainly affects the right pier of pier No. 36 and 35, in the construction stage of large-mileage excavation, it mainly affects the right pier of pier No. 36 and 35, and the opposite pier of pier No. 35 and 34. It is suggested that the settlement monitoring of the sub-piers on both sides of the underpass pier should be strengthened during the underpass construction of the underground box culvert.



(1) (2) (3) (4)

(1) Excavation construction of large mileage foundation pit ,(2) excavation construction of foundation pit in the lower penetration section,(3) Small mileage foundation pit excavation construction ,(4) backfill

Figure 7. Cloud map of pier roof settlement at different construction stages

FIG. 8 and FIG. 9 are cloud maps of lateral horizontal displacement and longitudinal horizontal

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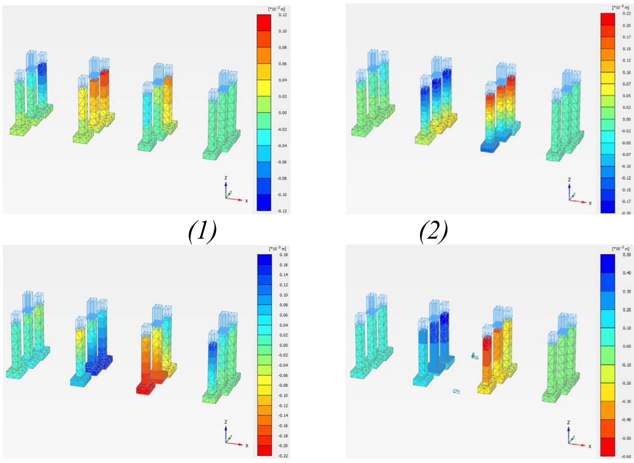
displacement changes of each pier top at different construction stages of the underground box culvert. Because the constraint effect of the superstructure on the pier was not considered in the numerical simulation, the calculated value was larger than the actual displacement value, and the horizontal horizontal displacement reached 1.5mm and the vertical horizontal displacement reached 1.3mm, but it was still within the limit of the specification. The variation law of the horizontal displacement of each pier is basically the same as that of the settlement in the whole construction process, and the maximum horizontal deformation and longitudinal horizontal deformation occur in the excavation stage of the foundation pit in the lower penetration section. Based on the settlement, horizontal displacement and longitudinal displacement of bridge piers, it can be seen that the influence of road underpass construction on railway bridge is limited, and the bridge structure is always in a safe state.



(1) (2) (3) (4)

(1) Excavation construction of large mileage foundation pit ,(2) excavation construction of foundation pit in the lower penetration section,(3) Small mileage foundation pit excavation construction ,(4) backfill

Figure 8. Cloud map of vertical horizontal displacement of pier top in different construction stages

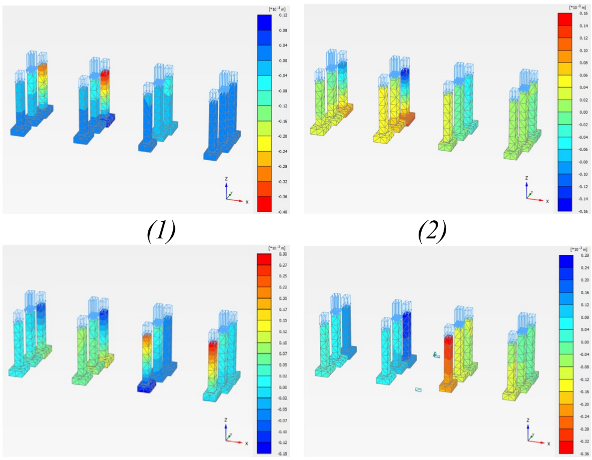


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Figure 9. Cloud map of vertical horizontal displacement of pier top at different construction stages

4.4. Parametric analysis

The construction control standards of underground box culverts under high-speed railway Bridges are discussed in order to set the distance of large and small excavation near piers as 2 m, 5 m, 10 m and 15 m, and the excavation depth of the underpass section as 6 m and 3 m. FIG. 10 and FIG. 11 show the variation curves of settlement and extreme horizontal displacement of bridge pier with proximity when the excavation depth is 6 m and 3 m, respectively.

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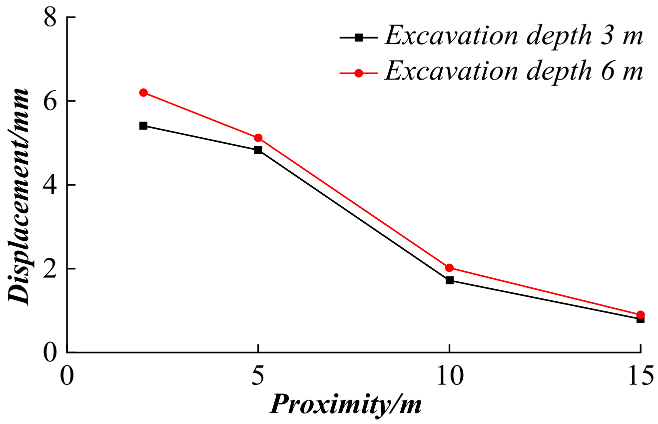

Figure 10. Variation curve of pier settlement value under different working conditions

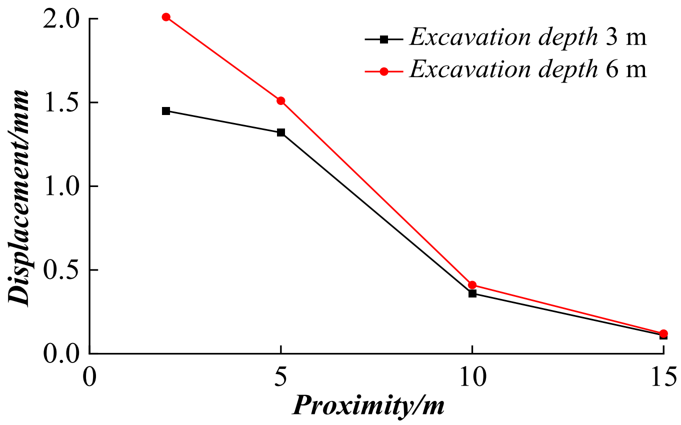

Figure 11. Variation curve of pier horizontal displacement under different working conditions

As can be seen from FIG. 10 and FIG. 11, with the increase of excavation depth, the smaller the distance between adjacent piers, the greater the extreme value of settlement and horizontal displacement of bridge pier. When the excavation depth is 3 m, all excavation proximity can ensure that the settlement and horizontal displacement values of each pier are within the allowable range of the code. When the excavation depth is 6 m, the excavation proximity distance of 5m, 10m and 15m can ensure that the settlement and horizontal displacement value of each pier are within the allowable range of the code, and the settlement value and horizontal displacement value of the pier under the proximity distance of 2 m can reach the standard limit. Therefore, based on the site monitoring and numerical simulation results, combined with the complexity of site construction, environmental vibration and train operation, it is suggested that the excavation depth should be kept within 6 m during the construction of underground box culverts, and the excavation proximity should be kept above 5 m when the excavation exceeds 6 m.

5. Conclusion

In this paper, the impact of the construction process of the underground box culvert under the flood control project around the factory of Guangzhou Car Works on the adjacent pier is studied in combination with field monitoring and numerical simulation. The research results are as follows:

(1) Through site monitoring, it is known that the settlement of the pier mainly occurs in the construction and backfill stage, and with the construction process continues to increase, and tends to be stable after the completion of backfill, and the horizontal displacement and vertical horizontal displacement also occur in this stage. In addition, the settlement and deformation of the pier are related to the construction distance, the closer the distance from the construction road, the greater the

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deformation impact of the pier.

(2) Through numerical simulation, it can be seen that the settlement and horizontal displacement of each pier change in the whole construction process is basically the same, and all occur in the excavation stage of the underpass section. Based on the results of on-site monitoring and numerical calculation, the settlement and displacement conditions of the pier are all within the standard limits.

(3) According to the parametric analysis, it is suggested that the excavation depth of the new underground box culvert should be kept within 6 m during the construction process, and the excavation proximity should be kept above 5 m when the excavation exceeds 6 m.

References

[1] CHEN Zhaowei, ZHAI Wanming. Control threshold of pier settlement in high-speed railways based on train vibrations[J]. Journal of Traffic and Transportation Engineering, 2022, 22(02): 136-147.

[2] GONG Xunqiang, WANG Hongyu, LU Tieding, et al. A Settlement Curve Prediction Method of High-speed Railway Bridge Pier Based on RLM-MC[J]. Journal of the China Railway Society, 2022, 44(10): 142-149.

[3] JIANG Xiaorui, HUANG Jie, LI Nan. Discussion on Construction Control Technology and Standard of Intercity-railway Undercrossing Existing High-speed Railway by Open-cut Tunnel[J]. Railway Standard Design, 2020, 64(06): 104-111.

[4] LI Shizhong. Influence of Beijing-Hangzhou Grand Canal's Newly Excavated Waterway on Bridge Pier of High Speed Railway[J]. Railway Engineering, 2020, 60(08): 33-36.

[5] WANG Guodong, WANG Zhijie, DUAN Mingming, et al. Research on the construction influence and protection of railway tunnel crossing beneath the pier of existing continuous rigid frame bridge[J]. Journal of Railway Science and Engineering, 2017, 14(11): 2399-2406.

[6] DONG Liang, SU Yonghua, YUAN Lei. Influence of Ground Surcharge and Unloading on Settlement of Railway Bridge Pier[J]. Railway Engineering, 2019, 59(05): 51-55.

[7] ZHOU Jimin. Construction technology and environmental impact prediction for a shield tunnel under a viaduct pile foundation group[J]. Modern Tunnelling Technology, 2016, 3(1): 165-172.

[8] MENG Changjiang, XIONG Dasheng, ZHAO Haisu, et al. Assessment of effect of dewatering of excavations on nearby piers of operating high-speed railways[J]. Chinese Journal of Geotechnical Engineering, 36(S2): 265-268.

[9] TB 10101-2018, Specification for railway engineering survey[S].

[10] TB 10182-2017, Technical regulations for highway and municipal engineering underpass high speed railway[S].

[11] LI Yuan-xun, ZHU Yan-peng, YE Shuai-hua, et al. Skewness distribution patterns of surface settlement considering overload effect[J]. Chinese Journal of Geotechnical Engineering, 2021, 17(S2): 840-847.