Flood control impact assessment of Tai'an Viaduct (across Panwen River) on Qingdao Lanzhou Expressway

Zhaozhen Wei*, Guanghui Wang2 and Lili Liu2
1 Scientific Research Department, Shandong Jiaotong University, Ji’nan, Shandong, 250357, China
2 Exploration and Design Department, Water Resources Research Institute of Shandong Province, Ji’nan, Shandong, 250357, China
*Corresponding author’s e-mail: weizhaozhen@sdjtu.edu.cn

Abstract. This paper introduces the bridge design and the basic situation of the river channel. Through the calculation of the design flood, backwater, scouring and silting at the bridge site, the paper analyzes and demonstrates the rationality of the construction project from the aspects of the relationship and influence with the relevant planning, the adaptability with the existing flood control standards and management requirements, the impact on the flood safety and appropriate stability, the impact on the existing flood control projects and the flood control and emergency rescue.

1. Introduction
The total length of reconstruction and expansion project of Laiwu Tai'an section of Qing-lan expressway is 63.802km (newly built 43.22km, widened 20.582km). The recommended route scheme starts from the south of Xigang village, Yanzhuang Town, Gangcheng District, Laiwu City. The construction of Yanzhuang junction connects with Beijing Shanghai Expressway, connects with the Ji Tai highway under construction and Tai Xin expressway, and then widens and reconstructs Taishan Xincheng expressway, and ends at Taishan junction interchange of G3 Jingtai Expressway, and connects with the left end of Taian Liaocheng section of Qinglan Expressway under construction.

1.1. Overview of proposed bridge design
Tai'an viaduct is a newly-built section, which crosses two rivers: Panwen River and comb river. It crosses the Panwen River in the northeast of Xiajiazhuang village, Taishan District, Tai'an City, with a total length of 4760.06m. Prestressed concrete (post tensioned) small box girder is used for the upper structure, which is simply supported and then continuous. Ribbed slab abutment is used for 0 abutment of substructure, column abutment is used for 160 abutment, column pier, and pile foundation is used for Pier and abutment.

The bridge site is located at stake No. 7+551 of the middle channel line of Panwen river. The drainage area above the bridge site section is 226.1km², and the angle between the pier layout direction and the flow direction is 7 °. The minimum design elevation of the beam bottom within the river channel is 132.786m.
1.2. Basic information of river course
The Panwen River originates from the west of the Mount Tai’s main peak, with a drainage area of 379km² and a length of 44km. Its upstream is Taohuayu, flows southwest to Xiaoxinzhuang and turns to the southeast and flows into Dahe Reservoir at Daxinzhuang with Chonghe River from the West at the same time. The drainage area above Dahe Reservoir is 84.53km². The larger tributaries are Mingtang River, Shuxi River, Nai River, Qili River and Kaiyuan River. Pan River flows into Muwen River in Beidian village.

1.3. Water conservancy planning and implementation arrangement
According to the flood control planning report of Tai’an City, Shandong Province (Shandong Tai’an water conservancy survey, design and Research Institute), the planning flood control standard of Panwen River at the crossing of Tai’an Viaduct (across the Panwen River) is based on the 50-year return period. Tai’an Viaduct (crossing the Panwen River) crosses the middle of the river channel with stake No.7+551, which is within the scope of planning and control. At present, the project planning of bridge crossing river channel has not been implemented.

At the bridge site, the width of the planned channel bottom is 200m, the elevation of the channel bottom is 120.14m, the slope is 1:2.5, and the longitudinal gradient of the river channel is 2.06 ‰. The top elevation of the dike is 125.44m.

2. Analysis and calculation of flood control evaluation

2.1. Flood control standard
The design flood standard of the proposed Tai’an Viaduct (across the Panwen River) is 100-year return period. According to the river regulation project planning, the design flood standard of Tai’an viaduct crossing the Panwen River is 50-year return period.

2.2. Design discharge and design flood level
The design flood with a return period of 50 years at the bridge site adopts the planning results, and the design peak discharge is 2437 m³/s. There is no planning result for the 100-year return design flood, which is 2823.7 m³/s after calculation.

The design flood level at the bridge site is calculated according to Xie Cai formula and Manning formula:

\[ Q = AC\sqrt{Ri} \]  \hspace{1cm} (1)

\[ C = \frac{1}{n} R^{\frac{1}{6}} \]  \hspace{1cm} (2)

Where: A-cross section area of water discharge, m²;
R-hydraulic radius, m;
C-chezy coefficient;
N-channel roughness, taken as 0.03;
i-longitudinal slope gradient of river.

| Table 1. Design flood results above Taian Viaduct (Panwen River) |
|----------------------|-------------------------------------------------|
| Design frequency    | 2% | 1% |
| Design peak discharge(m³/s) | 2437 | 2823.7 |
| Design flood level(m)   | 123.61 | 123.93 |

2.3. Backwater analysis and calculation
After the completion of Tai’an Viaduct (across the Panwen River), due to the water blocking effect of the bridge pier, the flood discharge conditions of the river channel at the bridge site will change, and
the cross-section water area will be reduced, resulting in a certain backwater level in the upstream of the bridge. The bridge has 4 rows of piers in the current river channel with 6 piers in each row, and 7 rows of piers with 6 piers in each row are arranged in the section of the planned river channel. The angle between the arrangement direction of the pier and the flow direction is $7^\circ$, and the diameter of the pier is 2.0m.

Backwater calculation is carried out with the following formulas[2]:

$$\Delta Z_m = \eta \left( V_M^2 - V_T^2 \right)$$

$$L_y = \frac{2\Delta Z_m}{I_0}$$

Where: $\Delta Z_m$- maximum backwater height in front of the bridge, m;
Ly- total length of backwater curve, m;
$\eta$- water resistance coefficient, obtained by looking up the table;
$V_M$ -average velocity under the bridge, M / S;
$V_T$- average velocity of cross section, M / S;
$I_0$- water surface gradient.

The backwater calculation results are shown in Table 2.

| Design frequency | 2%   | 1%   |
|------------------|------|------|
| Design peak discharge(m$^3$/s) | 2437.0 | 2823.7 |
| Design flood level(m) | 123.61 | 123.93 |
| Discharge area of natural river(m$^2$) | 724.10 | 793.91 |
| Retarding area(m$^2$) | 48.94 | 53.46 |
| Ratio of retarding area to total area | 6.759 | 6.734 |
| Average velocity of cross section(m/s) | 3.36 | 3.55 |
| Average velocity under bridge(m/s) | 3.48 | 3.68 |
| Backwater height(m) | 0.042 | 0.046 |
| Backwater length(m) | 40.47 | 45.09 |
| Bridge water level(m) | 123.65 | 123.98 |

2.4. Scour calculation

The riverbed of the current section is silty clay, and the riverbed scouring is calculated as cohesive soil. The calculation results are shown in Table 3.

| Design frequency | 2% | 1% |
|------------------|----|----|
| General scour(m) | 1.22 | 1.33 |
| Local scour(m)   | 0.81 | 0.86 |
| Total(m)         | 2.03 | 2.19 |

3. Comprehensive evaluation of flood control

3.1. Relationship with relevant planning and impact analysis

The proposed Taian Viaduct (crossing the Panwen River) is located at stake No. 7 + 551 of the middle line of Panwen River. The river channel has been listed in the flood control planning report of Tai'an City in Shandong Province (Shandong Tai'an Water Conservancy Survey, Design and Research Institute). The bridge site is within the scope of planning and control. At present, the project planning for the bridge crossing the river channel has not been implemented. The bridge construction will increase the difficulty of planning implementation. According to the information provided by the bridge design department, the total length of the bridge is 4760.06m, and the width of the river channel
along the bridge direction at the planned section bridge site is 226.5m, and the length of the bridge meets the requirements of the width of the estuary.

3.2. Analysis of adaptability with existing flood control standards, relevant technologies and management requirements

The proposed Tai'an Viaduct (crossing the Panwen River) is designed according to 100-year flood control standard. The flood control standard of the river channel where the bridge is located is 50-year flood control, and the flood standard of the bridge is higher than that of the river channel. Therefore, the flood standard of the bridge is appropriate.

According to the specification requirements, the clearance under the bridge should not be less than 4.5m when crossing the highway of class III and below. According to the bridge layout scheme, the clear heights of the left and right banks of the bridge bottom within the river channel of the planned section are 7.491m and 7.346m respectively, which meet the requirements of specifications and standards.

According to the requirements of relevant documents, the included angle between the axis of piers in the same group and the flow direction should not be greater than 10º for bridges crossing general flood control and drainage channels. The direction of crossing the river is 90º, and the angle between pier layout direction and flow direction is 7º, which meets the requirements of the specification. There is no navigation requirement for Panwen River.

3.3. Impact analysis on flood safety

According to the requirements of relevant documents, "the water blocking ratio of bridges should not be greater than 10% when crossing rivers without embankments. In general, the percentage of water blocking area should not be greater than 9% when crossing other rivers with embankments. "The maximum backwater height of river sections crossing mountainous areas should be controlled within 0.10m". There are embankments on the planning section of Panwen River at the bridge site. When Tai'an Viaduct (crossing the Panwen River) has a 50-year return period and a 100-year return period flood, the water blocking ratio of the planning section is lower than 9%, and the backwater height is lower than 0.10m, which meets the requirements.

3.4. Analysis of influence on river regime stability

According to the calculation and analysis of pier scour, when the planning section of Tai'an Viaduct (across the Panwen River) encounters a 50-year return period flood, the general scour depth of the channel is 1.22m, and the local scour depth is 0.81m; when the 100-year return period flood occurs in Tai'an Viaduct (across the Panwen River), the general scour depth is 1.33m, and the local scour depth is 0.86m.

Due to the general scouring and local scouring, scouring is formed in the riverbed near the bridge site, and due to the change of flow regime, the effective flow area is reduced, and the velocity under the bridge and the nearshore velocity are increased, resulting in scouring on the bank slope near the bridge site, which has a certain impact on the stability of the river regime.

3.5. Impact analysis on existing flood control works

According to the bridge design scheme, the river channel where the bridge crosses is planned with dike, and the planning section has no pier arranged on the embankment slope, which meets the requirements of relevant specifications.

There is no sluice project and no masonry project in the upstream and downstream of the proposed bridge.

3.6. Analysis of the impact on flood control and rescue

There is no flood control channel on the top of the left and right bank of the proposed Tai'an Viaduct (crossing Panwen River). The minimum clear height of the existing beam bottom is 9.860m, and the
minimum clear height of the planned beam bottom is 7.346m. According to the regulations, the clearance under the bridge shall not be less than 4.5 m in general, therefore, the clear height of the bridge beam bottom meets the relevant requirements of flood control and emergency rescue and daily engineering management.

3.7. Analysis of the impact on the legal rights and interests of the third party

The main task of Panwen River is flood control. There is no water source nearby the bridge for protection. There is no water intake in the upstream and downstream, and there is no wharf and other buildings. Therefore, the construction of the bridge will not affect the legitimate rights and interests of the third party. Taking soil from river channel will reduce the buried depth of bridge piers, which has a great impact on the stability of the bridge. Therefore, the bridge management department and the river management department should delimit the no soil sampling area in the upstream and downstream of the bridge.

4. Conclusion

Tai'an Viaduct (crossing the Panwen River) is designed according to the standard of 100-year return flood, and the flood standard is appropriate.

The proposed bridge will cross the river by means of overpass. The minimum clear height of the beam bottom on the left and right banks at the top of the planned section of Tai'an Viaduct (across the Panwen River) is 7.491m and 7.346m respectively, and the clearance meets the relevant requirements of flood control and emergency rescue and daily engineering management.

The piers are arranged in the cross-section of the river channel, which causes water blocking, makes the water level in front of the bridge rise, and has a certain backwater length, which has a certain impact on the local flow of the river, and has an impact on the overall flood discharge of the river channel, but the impact is small. The water blocking ratio is less than 9% and backwater height is less than 0.10 m in Tai'an Viaduct (crossing the Panwen River), meeting the requirements of relevant documents.

There are no sluices, irrigation and drainage stations and diversion and drainage culverts within the backwater curve of the bridge site, which has no impact on the legitimate water rights and interests of the third party.

Acknowledgments

Found project: Shandong Jiaotong University Doctoral Research Fund (NO: BS201901059), Key projects of Art Science in Shandong Province (NO: QN202008265)

References

[1] Huo M, Li C.F. (2014) Technical Standard of Highway Engineering. China Communications Press Co.,LTD. Beijing.
[2] Wang P.Q, Wu Y.M. (2020) Key Technical Framework and Application of Flood Control Assessment of Crossing Bridges. China Rural Water and Hydropower, 10: 41-47, 53.
[3] Aristeidis K, Vasiliki K. (2019) Evaluation of the post-fire erosion and flood control works in the area of Cassandra (Chalkidiki, North Greece). Journal of Forestry Research, 30(6): 2387-2387.
[4] Chen C. F., Liu H.F. (2019) Flood control evaluation of rainwater pipeline into river in road engineering. Water Resources Planning and Design, 5: 54-56, 60.
[5] Yu G.Q., Li C.C. (2018) Analysis on the contents of flood control evaluation report and flood impact assessment report of road engineering rainwater pipeline into river. Water Resources Development Research, 4: 38-40, 64.
[6] Chai Z.K., Luo J.J. (2018) Practice and Thinking on the reform of flood impact assessment and approval system for non flood control construction projects. China Water Resources, 3: 37-40.