Analysis of the Influence of Bridge Piers on River Flow—I
Computation of Bridge Crossing Choking

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Abstract. The analysis of the impact of pier backwaters is very important in bridge design. The composition of the bed sand across the river, the shape of the pier, the hydraulic gradient of the channel, and the water resistance of the pier all have an impact on the water level backwater height and backwater distance. Considering the actual situation of the project, the influence of piers on flood discharge is analysed and calculated by different backwater empirical formulas. The results show that the calculation results of the formulas are not far apart. Considering the most unfavourable situation, the calculation results of Cao Ruizhang formula of the Chinese Academy of Railway Sciences are selected as the final results. Combined with the analysis of water resistance, the construction of the project has little impact on the flood discharge of the river.

1. Introduction
The construction of the bridge piers reduces the water area under the bridge and hinders the flow of the river. When retaining the water, the water flow is compressed, causing energy loss in the water flow and making the upstream water surface of the building rise and causing backwater[1]. The research work on bridge pier backwaters was carried out very early. It has a history of about 160 years since the formula of bridge backwater proposed by D'Aubuisson [2,3] in 1840. Around 1950, the Soviet Union began promulgating bridge design specifications. In addition, countries in Europe and America also successively proposed backwater calculation formulas. After 1970, China's highway and railway systems began to engage in backwater analysis [4].

The newly-built bridge crossing the Fuhuan River, a tributary of the Yangtze River, has a width of about 900m and a total of 21 piers [5]; the construction of bridges, on the one hand, the river flow will erode the piers and affect the safety of the bridge, on the other hand, the water resistance of the bridge pier will hinder the flooding of the river, and the increase of the water level upstream of the pier will also affect the operation safety of other nearby wading structures. In this paper, empirical formula method is mainly used to analyse and calculate the backwater of bridge, which provides a theoretical basis for engineering design.
2. Calculation formulas

Because the empirical formula has the advantages of simple form, less parameters and easy application, it is widely used in the process of engineering design. In this paper, several representative backwater calculation formulas are selected for comparative analysis.

(1) Formula 1: Cao Ruizhang formula

The formula is obtained from the study of hydraulic model test data and field observation data, and the following simplified form is obtained through continuous improvement [6].

\[ \Delta Z = K \frac{V_q^2 - V_{0q}^2}{2g} \]  

Where: \( \Delta Z \) is the maximum backwater height (m); \( V_q \) is the average flow velocity of the cross section after the bridge is built, \( V_q = \frac{Q_s}{w_j} \) (m/s); \( V_{0q} \) is the average flow velocity of the cross section before the bridge is built, \( V_{0q} = \frac{Q_s}{w_0} \) (m/s); \( w_0 \) is the water passing area before the bridge is built (m²); \( w_j \) is the net water area under the bridge before scouring (m²); \( Q_s \) is the design flow rate (m³/s); \( k_p \) is the coefficient reflecting the decrease of the flow velocity under the bridge as the riverbed erosion section increases, \( k_p = 1/[1 + A(P - 1)] \); \( A \) is the particle size coefficient of the river bed; \( A = 0.5 \times d_{50}^{0.25} \); \( d_{50} \) is Median particle size (mm); \( P \) is the erosion coefficient; \( w \) is the cross-sectional area of the water required under the bridge (m²), \( w = \frac{Q_s}{V_s \cos \alpha} \);

\( V_s \) is the design flow rate, this report uses the average flow velocity of the channel (m/s); \( K \) is the backwater coefficient, \( K = 2/(V_q/V_{0q} - 1)^{0.5} \).

(2) Formula 2: Henderson formula

The formula was proposed by Henderson by analysing the local energy loss caused by the resistance of the bridge pier. The Bridge Research Institute of the Ministry of Railways of my country has verified the rationality of the parameter value based on a large number of field investigation data [4,7].

\[ \Delta Z = (1 + \eta) \frac{V_q^2 - V_{0q}^2}{2g} \]  

Figure 1. Cross section diagram of bridge [5].
\( \eta \) is a coefficient related to the shape of pier, which is 0.35 for rectangular pier, 0.18 for circular pier and 0.24 for both ends.

3. Formula 3: D'Aubuisson formula

The backwater formula proposed by D'Aubuisson is derived from the energy formula, which is a common empirical formula in foreign countries. Its simplified formula is as follows:\(^{[2,3]}\):

\[
\Delta Z = \eta \left( \nu_q^2 - \nu_{0q}^2 \right)
\]

(3)

In the formula: \( \eta \) is a coefficient related to the characteristics of the river channel and the ratio of the flow of the embankment and the design flow of the river bank, usually taking 0.05, 0.07, 0.1 and 0.15;

According to "Specifications for Survey and Design of Highway Bridge Site" (JTJ062-91), the maximum backwater distance \( L \) can be obtained by the following formula:

\[
L = \frac{2\Delta Z}{J}
\]

(4)

Where: \( \Delta Z \) is the maximum backwater height (m); \( J \) is the hydraulic gradient.

3. Calculation conditions and parameter values

Similar to the scour calculation conditions of newly built bridge piers\(^{[5]}\), the calculation conditions for engineering backwater calculation still select two working conditions:

1. Case 1: 1996 type flood flow condition, the flow is 5570m\(^3\)/s;
2. Case 2: The combined conditions of the water level of the outer river in 1954 and the flow of the inland river in 5 years, the flow is 3200m\(^3\)/s.

The flood control design flood level corresponding to the two working conditions is 27.798m\(^{[5]}\).

According to engineering design data, \( d_{50} \) in formula (1) is 0.2mm; \( \eta \) in formula (2) is 0.24; \( \eta_1 \) in formula (3) is 0.15; hydraulic gradient \( J \) is 0.074 \( \% \).

4. Calculation results and analysis

Due to the construction of bridge piers in the river channel, the cross-sectional water area of the channel where the bridge is located is reduced by the compression of the bridge piers. The water resistance of the bridge piers causes the water level in front of the piers.

4.1. Analysis of water resistance of bridge pier

Table 1 is the water resistance achievement table of the cross-section of the proposed bridge. It can be seen from the table that when the water level of the cross section where the bridge is located is 27.798m, the water blocking area of the proposed project is 418m\(^2\), and the water blocking rate is 6.3%. Under the conditions of the 1996 type flood flow (case 1), after the bridge was built, the average velocity of the pier increased by 0.05m/s, and the velocity increased by 6.0%. Under the combined conditions of the water level of the outer river and the inflow of the river in five years in 1954 (case 2), after the bridge was built, the average velocity of the pier increased by 0.03m/s, and the velocity increased by 6.3%.

4.2. Analysis of backwater calculation results

According to formula (1) ~ formula (4), the local water situation of the proposed project under the two calculation conditions is shown in Table 2. It can be seen from the table that formula 1 (Cao Ruizhang formula) has the largest backwater calculation result and formula 3 (D'Aubuisson formula) has the smallest value. Considering the most unfavourable conditions, the backwater result is the maximum calculation result, which is the result of formula I. Therefore, under the conditions of the 1996 flood flow (case 1), after the project, the maximum upstream water height of the project is 1.6cm, and the maximum distance of the upstream water is 432m; under the condition of combination of external river
level and internal river 5-year return period discharge in 1954 (case 2), after the project, the maximum upstream water height of the project is 0.5cm, and the maximum upstream water distance is 135m.

Table 1. Achievements of water resistance of the section of the proposed bridge.

| Calculation conditions | Design flood |
|------------------------|--------------|
| Cross-sectional area   | Cross-sectional area (m²) 6668 |
| The area occupied by the project (m²) | 418 |
| Water resistance (%) | 6.3 |
| Before building the bridge (m) Before building the bridge (m/s) 872 | |
| Water surface width Width of water surface occupied by piers (m) | 55 |
| Percentage of occupied water width (%) | 6.3 |
| Before building the bridge (m/s) | 0.84 |
| Section average velocity | After building the bridge (m/s) 0.89 | |
| Velocity increment (m/s) Velocity increase (%) | 0.05 6.0 |
| Before building the bridge (m/s) | 0.48 |
| Case 1 | After building the bridge (m/s) 0.51 | |
| Section average velocity | Velocity increment (m/s) 0.03 | |
| Before building the bridge (m/s) | 0.48 |
| Case 2 | After building the bridge (m/s) 0.51 | |
| Section average velocity | Velocity increase (%) 6.3 | |

Note: A positive value indicates that the project is occupying the area of flood cross section, and a negative value indicates that the project increases the area of flood cross section.

Table 2. Statistics of local backwater in the project.

| Calculation conditions | Formula 1 | Formula 2 | Formula 3 | Maximum |
|------------------------|-----------|-----------|-----------|---------|
| Case 1 | Backwater height(cm) 1.6 | 1.5 | 1.4 | 1.6 |
| Backwater length(m) 432 | 405 | 378 | 432 |
| Backwater height(cm) 0.5 | 0.5 | 0.4 | 0.5 |
| Backwater length(m) 135 | 135 | 108 | 135 |

5. Conclusion

Based on the above analysis, when a cross-river bridge is built on the Fuhuan River, a tributary of the Yangtze River, the bridge pier occupies the channel flood cross-sectional area, resulting in the reduction of the flood discharge area of the river by 6.3%. At the same time, the velocity near the bridge pier increases, and the average velocity increases by about 0.05~0.03m/s. The maximum height of the channel backwater of the pier approaching the bridge is about 1.6cm, and the backwater length is within 432m upstream. There are no other water-related projects near the project. Therefore, although the construction of the bridge has an impact on the flood discharge of the river, on the whole, the influence of the project on the river flow is limited and the project is feasible.

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