Study on Pier Scouring of Qingyi River Bridge in Jingxian County

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Abstract. Pier scouring, the main cause of bridge washout, has always been a research topic concerned by scholars both domestic and abroad. By taking the Qingyi River Bridge on Dinghuang Highway in Jingxian County as an example, in this paper, the pier scouring depth calculated by the current equations of Pier Scouring calculation, the results are verified by using the method of generalized model test. It shows that the results of physical model test is basically consistent with the theoretical calculation, which are relatively safe.

1. Introduction
Washout, the serious natural disaster faced by bridges all over the world, which cause damage to bridges is far more than earthquakes and typhoons do [1-4]. The State Transportation Administration of New York and Texas A&M University counted 1,502 bridge damage cases in the United States from 1966 to 2005. In the cases, 58% of bridge damage was caused by scouring [5-7], as shown in Figure 1.

Therefore, the study of bridge pier scouring not only has great academic value, but also engineering benefits. This study takes Qingyi River Bridge of Dinghuang Highway in Jingxian County as an example.

![Figure 1. Bridge Damage Statistics in the United States.](image-url)
2. Project overview
Qingyi River is the Primary tributary of the Yangtze River. The Qingyi River Bridge on Dinghuang Highway is located in Dingjaqiao Town. The bridge was started in 2007 and completed in 2009. The bridge length is 600 meters. The adopt double-row cylindrical piers was adopted, as shown in Figure 2.

![Qingyi River Bridge](image1)

![Test Model of the Bridge piers](image2)

Figure 2. The entity figure of Qingyi River Bridge and the generalized model diagram of the piers

3. Equations for pier scouring calculation
After the completion of the bridge, besides the natural evolution of the river bed, there are also river bed scouring caused by interfere flow and sediment movement. They work at the same time, making the scouring process very complicated. At present, the maximum piers scouring depth was divide into three independent parts: scouring caused by natural evolution, general scouring and local scouring, assuming that they occur successively. They can be calculated separately and then added as the maximum piers scouring depth, which refers to the addition of these three parts of scouring. The scouring caused by the natural evolution is usually very slight, often considered in the calculation of general scouring.

In recent years, many studies have been carried out on pier scouring, especially the local scouring. According to incomplete statistics, scholars both domestic and abroad have compiled and published more than 50 equations for calculating local scour depth of piers from different ways and assumptions. In this paper, three equations are used respectively.

3.1 Equation of Chinese Specification
In 1965, equation (65-1) and (65-2) for calculating local scour of piers were formulated in China. After that, base on the experiences and conclusions from supplementary experiments, the equations were modified and became the equation JTJ062-1991. In this paper, modified (65-2) and (65-1) equation recommended in the Hydrological Specifications for Survey and Design of Highway Engineering (JTG C30-2015) are used [8].

\[ v \leq v_0 \]

\[ h_b = K_v \xi \eta_2 B_1^{0.6} (v - v_0') \]  \hspace{1cm} (1)

\[ v > v_0 \]

\[ h_b = K_v \xi \eta_1 B_1^{0.6} (v - v_0') \left( \frac{v - v_0'}{v_0 - v_0'} \right)^{n_1} \]  \hspace{1cm} (2)
3.2 Scouring equation recommended by current specification of the United States

In September 1988, the Federal Highway Administration (FHWA) issued a technical report T5/4023 entitled "Bridge Scouring", and also an analysis named "Interim Method for Bridge Scour Evaluation". In 2003, a panel headed by E.V. Richardson published "Bridge Scour Evaluation in the United States", which introduced the contents about bridge scour forecast and river stability estimation recommended by FHWA.

The equation for local scour recommended by the Bulletin of American Hydraulic Engineering (HEC-18) is as follows [9]:

\[
\frac{h_b}{h} = 2.0K_fK_2'K_3K_4 \left( \frac{b}{f} \right)^{0.65} F_r^{0.43}
\] (3)

3.3 Equation of Soviet Specification

With bed load

\[
h_b = \left( h_0 + 0.014 \frac{v-v_0}{\omega} \right) K_\omega K_2
\] (4)

Without bed load

\[
h_b = h_0 \left( \frac{v-v_0'}{v_0'-v_0} \right)^{3/4} K_\omega K_2
\] (5)

Based on the water level and flow data of Qingyi River in typical year 1983 and 1998 and the above three equations. The scouring depths calculated are shown in the following table.

Table 1. Comparisons of Three Equations for Pier Scouring

| Equation | 1983 yr | 1998 yr |
|----------|---------|---------|
| General Scour Depth (m) | Local Scour Depth (m) | Total Scour Depth (m) |
| Modified Equation (64-1) | 1.24 | / | / |
| Equation (65-2) | / | 3.56 | 4.80 |
| Equation HEC-18 | / | 3.12 | 4.36 |
| Equation of Soviet Specification | / | 3.83 | 5.07 |
| Average Total Scour Depth (m) | 4.74 | / | 5.43 |

Table 2. Water Level and Flow Data of Qingyi River in Typical Year 1983 and 1998

| Parameter | 1983 yr | 1998 yr |
|-----------|---------|---------|
| Rate of flow (m³/s) | Water lever (m) | Rate of flow (m³/s) | Water lever (m) |
| Value | 3719 | 2.69 | 4851 | 3.15 |

4. Generalized Model Experiment

To study the piers scour depth, a generalized model experiment, which started with a double-row pier of Qingyi River Bridge as the model sample, was carried out. The river bed under the Qingyi River Bridge is a non-uniform sandy river bed with a wide range of particle size distribution. According to the actual state and the similarity theory, the scale of 1:100 is determined. The median size of the sand is 16.5 mm. The experimental velocity and the water depth are in the range of 15-25 cm/s and 30-50 cm respectively.
The width of the channel is 2 m, and the length is 6 m. The inlet of this model is 8 m upstream of the test section, supplied by a centrifugal pump with a water supply flow of 800 m³/h. The flow rate can be adjusted by electromagnetic flowmeter and the water depth of the test section can be adjusted by tail gate. The details are shown in the following figure.

![Figure 3. Layout of the test channel](image)

The three-dimensional flow velocity around the pier was measured by using Acoustic Doppler (ADV), the depth and radius of the scour pit were measured by topographic instrument. In this experiment, the front pier is named 1 # pier and the back pier is named 2 # pier, the test data obtained are as follows:

| Group number | Velocity (cm/s) | δg | Maximum local scour depth(cm) | Radius of Scouring pit (cm) | Dune length (cm) | Maximum dune height (cm) |
|--------------|----------------|----|-------------------------------|-----------------------------|-----------------|--------------------------|
|              |                |    | 1#                            | 2#                          | 1#              | 2#                       | 1#                        | 2#                        |
| 3            | 17             | 3   | 1.8                           | 1.2                         | 6.3             | 5.3                      | 11.6                      | 10                        | 1.4                       | 1.3                       |
| 6            | 22             | 3   | 2.6                           | 1.8                         | 8.4             | 7.5                      | 18.5                      | 14.2                      | 2.2                       | 1.8                       |
| 4            | 17             | 4.3 | 1.8                           | 1.2                         | 6.2             | 5.3                      | 13.2                      | 10.1                      | 1.2                       | 1                         |
| 7            | 22             | 4.3 | 2.5                           | 1.8                         | 8.2             | 7.4                      | 18.5                      | 16.8                      | 1.8                       | 1.6                       |

According to the scale and the data of tables 1 and 2, it shows that the maximum scouring depth calculated by using these equations is relatively safe. In addition, when the velocity increases, the maximum local scour depth, the radius of scour pit, the length of sand dune and the maximum accumulation height increase tremendously, while the geometrical inhomogeneity coefficient of bed sand particles is constant. That it due to the increase of flow velocity increases the shear stress of flow, which aggravated the the scouring of local riverbed of bridge pier [10].

5. Conclusion

By taking Qingyi River Bridge as an example, the scouring depth was calculated and verified the results by using the generalized model experiment. The results show that:

The physical model experiment is basically consistent with the theoretical calculation, and the theoretical calculation results are relatively safe.

The scour depth calculated by using the Soviet equation is the largest, and the local scour depth calculated by using the equation HEC-18 is the smallest, meanwhile, the result calculated by using the
equation recommended in the Hydrological Specifications for Survey and Design of Highway Engineering is moderate and closest to the average value.

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