Experimental Study on the River Engineering Model of Shuangliu Bridge across Yangtze River in Wuhan

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Abstract. Shuangliu Bridge across Yangtze River in Wuhan was the key control project of Xingang Expressway. It was the way to cross the river for the construction of Xingang Expressway. The bridge was located at the junction of the exit of Yejiazhou River Section and the entrance of Tuanfeng River Section. The upstream was 26.5 kilometers from Yangluo Expressway Bridge of Yangtze River, and the downstream was 21 kilometers from Huanggang Bridge of Yangtze River. Based on analysis of evolution of riverbed and the experiment of river engineering model, not only evolution rules of a river channel of the section at the bridge site after the application of the Three Gorges Reservoir were specially studied, but also the change rules before and after the construction of the bridge were also studied such as the damming at the upstream section of the bridge site, the current velocity and flow direction of the upper and lower reaches, the discharge of the single wide at the bridge site, and the distributary ratio of a branch channel of the lower reaches of the Tuanfeng River, etc. It showed the two bridge schemes had no great influence on river regime and flood control of engineering reach, and a double-tower cable-stayed bridge was better than a three-tower cable-stayed bridge. The results can be adopted or referenced to designing project.

1. Introduction

In order to carry out a series of national strategies such as the Yangtze River Economic Belt and quicken the construction of the shipping center in the middle reaches of the Yangtze River, the Shuangliu Bridge across Yangtze River was planned to build at the junction of the exit of the Yejiazhou reach and the import of the Tuanfeng reach. The upstream of the bridge site was 26.5 kilometers from Yangluo Expressway Bridge of Yangtze River, and the downstream was 21 kilometers from Huanggang Bridge of Yangtze River. The bridge had two schemes: a double-tower cable-stayed bridge and a three-tower cable-stayed bridge. In the scheme of the double-tower cable-stayed bridge, 8 bridge piers were arranged, of which pier 5#, pier 6# were the main span and the distance of the span is 820m. The three-tower cable-stayed bridge scheme had 5 bridge piers, of which pier 2#-pier 4# were two main spans and the distance of the span is 570m\textsuperscript{[1]}.

In order to analyze the influence on the river regime, the flood control of different bridge schemes, an analysis of riverbed evolution and a test of a physical model of river engineer were carried out. It showed that the two bridge schemes had no great influence on river regime and flood control of engineering reach, and a double-tower cable-stayed bridge was better than a three-tower cable-stayed bridge.
2. The near river regime of the reach at the bridge site and the change of scouring and silting of the section

2.1. The near river regime of the reach at the bridge site
The upstream origin of the reach of the bridge site was at Baima Town, the downstream end of it is Huangbaishan at the exit of Tuanfeng Reach, and it consisted of Yejiazhou Reach with a micro-bend transition and Tuanfeng Reach with a double-braided reach. The left branch was about 18.3km long, with the water of Jushui River into the sink, the curvature of the reach was 2.22. The Yejiazhou Reach was 28.2 km from Yangluo to Niji. The plane swing of the reach was restricted by natural mountains and rock spurs, and the plane position of the mainstream was relatively stable. The Tuanfeng Reach was narrow at both ends and open in the middle, and the river regime was controlled by the nodes of Niji and Huangbaishan in the intake and exit sections of the riverway[2].

The evolution analysis of river bed showed that the plane position and mainstream trend of the Yejiazhou Reach had been relatively stable since the integration of Mouezhou bank in the middle of the river turned into a micro-bend single river pattern. Since the water storing of the three Gorges Project, the Yejiazhou Reach had shown a general trend of scouring development, but restricted by the stable boundary conditions of both sides of the strait, the overall pattern of the river regime in the reach had been stable in recent years, and the river regime pattern of a single bend would not change in a short period of time. Since 1980's, the Tuanfeng reach had maintained the pattern of two branches and one continent, and the right branch is the dominant one. With the implementation of a series of revetment projects, the collapse and retreat of the shoreline of Dongcaozhou in the channel had slowed down, and the overall river regime was relatively stable. It was expected that the river pattern of the right main and left branch of the Tuanfeng reach would not be reversed with the operation of the three Gorges Project.

2.2. Change of scouring and filling of the section at the bridge site for past years
According to the topography of the bridge site section since 2008-2016 (figure 1, the elevation datum is the 1985 national elevation datum), the profile of the section was relatively stable and a deflected "V" type, and the deep channel had always been located on the right side of the section. From 2008 to 2016, the left side of the section was scoured, and the deep groove on the right side was relatively stable within -7m, and the area of the section was relatively stable with a maximum variation of 5%.

![Figure 1: The change of the section at the bridge site for past years](image)

3. A design of the model of river engineer

3.1. A design of the model
The simulation range of the model test was from Baihu Town of the Yejiazhou Reach to Huangbai mountain at the exit of the Tuanfeng Reach, including the lower part of the Yejiazhou Reach and the whole Tuanfeng Reach, with a total length of about 40 km. The simulated river section consisted of the section with a micro-bend transition of the Yejiazhou river and the section of Tuanfeng River with
a double-braided channel of, and there was Jushui River into the entrance of the left branch at the branch channel of the Luohu Branch. The left branch was about 18.3 km long with.

The similarity conditions of the model design mainly included geometric similarity, similarity of water flow motion [3-4]. It was 400 in plane scale, 100 in vertical scale, 4.0 in variation rate of the model, and the plane collocation of the model was shown in figure2.

Fig. 2 The Plane collocation of model test

3.2. The calibration of the model

The calibration of the water level along the river, the velocity distribution of the cross-section and the ratio of the left and right branches was carried out in the model. The maximum error between the model and the prototype water level was 0.07m, the velocity error was generally less than 5%, and the ratio error between the left and the right branch of Tuanfeng River was less than 1.3%, which was within the allowable error range of the Code.

4. The experimental research and analysis of results

According to tasks and requirements of the test, tests of the two bridge-type scheme for Shuangliu Bridge across Yangtze River were carried out under four different frequency and hydrological conditions such as a design flux of flood control, a maximum navigable flux, a flat beach flux, a minimum navigable flux (The corresponding flux was shown in Table 1). The model was made by the topographic map of 1/10000 of the water channel as measured by Hydrographic Bureau of Yangtze River Water Conservancy Commission [5].

4.1. The change of the water level at the upstream of the bridge site

After the construction of the bridge, the bridge pier encroaches on the overpass area of part of the river channel and has the effect of the water blocking, the damming is generated within a certain distance in the upper reaches of the bridge. When the flux is 8540m$^3$/s-1-76100m$^3$/s$^{-1}$, the maximum height of the damming water level of the two-tower cable-stayed bridge is 5.7 cm after the bridge is built, and the maximum height of the damming water level of the three-tower cable-stayed bridge is 6.4cm. The
experimental results show when the flux is larger and the height of the water level is higher, the damming water is more extended and the value of the damming water level is more increased, and the influence range of the damming water level of different types of bridges is within 3500 m (Table 1). The influence of the three-tower cable-stayed bridge is slightly greater than that of the double-tower cable-stayed bridge in the upper reach of the bridge site. Because the position of the bridge is just in the narrow section, water will be dammed at the narrow section itself, and water will be prevented by the bridge pier, thus the damming height will be larger.

| The flux (m³/s) | 8540 (The minimum navigable flux) | 40000 (The flat beach flux) | 73600 (The maximum navigable flux) | 76100 (The design flux of flood control) |
|----------------|-----------------------------------|----------------------------|-----------------------------------|-----------------------------------------|
| The maximum height of hammering water (cm) | The double-tower cable-stayed bridge | 0.8 | 4.6 | 5.6 | 5.7 |
| | The three-tower cable-stayed bridge | 1.2 | 5.4 | 6.3 | 6.4 |

### 4.2. The change of the flow velocity and the flow direction of the upper and lower reaches of the bridge site

#### 4.2.1. The main flow line

After the construction of the bridge, the main line of the river near the bridge is right in the dry-water period, middle in the mid-water period and slightly left in the flood period. There is no obvious change in the position of the main streamlines of each bridge in comparison with that before the construction of the bridge.

#### 4.2.2. The flow velocity

After the construction of the bridge, the distribution of the average flow velocity along the vertical line of the upstream and downstream reaches of the bridge is not obviously changed, and only the flow velocity is changed. When the flux is 76100 m³/s, the flow velocity of the 3-tower cable-stayed bridge is generally reduced by 4-17 cm/s, the double-tower cable-stayed bridge is reduced by 4-15 cm/s at the Section 5 of the downstream of the bridge, the three-tower cable-stayed bridge is generally increased by 4-18 cm/s, the double-tower cable-stayed bridge is increased by 4-15 cm/s at the Section 6 of the downstream of the bridge. The farther upstream or downstream, the velocity is more consistent before and after the bridge is built. The variation rules of velocity before and after the bridge at other levels is basically the same, such as the smaller the discharge is, the smaller the flow change is, and the larger the discharge is, the larger the influence range is, and the range of variation is the least and the range of influence is the shortest when the water flow is low water flux.

#### 4.2.3. The near-bank flow velocity

After the construction of the bridge, the near-bank flow velocity decreased within a certain range in the upper reaches of the bridge site, and the near-bank flow velocity increased somewhat in the lower reaches of the bridge site. When the flow flux is 76100 m³/s, the flow velocity at the Section 6 of the downstream of the double-tower cable-stayed bridge is 1.79 m/s where is 200 m from the edge of the right bank, and that of the three-tower cable-stayed bridge is 1.81 m/s, which is 0.07 m/s and 0.09 m/s higher than that before the construction of the bridge. At other stages of flux, the flux is the smaller, the increasing range of the near-bank flow velocity is the smaller.

#### 4.2.4. The flow direction

The flow direction of the bridge site section is larger at the left and right bank of the non-main flow area, generally from 10° to 15°, the maximum is 20°). In the main flow area, the navigation hole of the main span and the hole of the auxiliary navigation of the north span of the double-tower cable-stayed
bridge, and the navigation hole area of the two main span of the three-tower cable-stayed bridge is smaller than 5°. The bridge construction has little effect on the flow direction, and the changing range of is generally less than 5°. There is no obvious difference between the double-tower cable-stayed bridge and the three-tower cable-stayed bridge.

4.3. The change of the flux per unit width at section of the bridge site

The distribution of the flux of per unit width along the river width is basically the same before and after the construction of the bridge, and the position of the maximum flux of per unit width has not changed. The position of the maximum flux of per unit width of the double-tower cable-stayed bridge varies from Pier 5 to Pier 6 (the main span), and that of the three-tower cable-stayed bridge varies from Pier 3 to Pier 4 (the right main span). The results show that the change of the flux of per unit width of the double-tower cable-stayed bridge is relatively small, while that of the three-tower cable-stayed bridge is relatively larger.

4.4. The influence of the distributary flux ratio of the left and right branch at Tuanfeng Reach for the bridge construction

The results of the test show that the influence of the double-tower cable-stayed bridge on the distributary ratio of downstream section Tuanfeng Reach is slightly larger than that of the three-tower cable-stayed bridge. However, in general, the two bridge types have little effect on the distributary flux ratio of the channel, and have little effect on the evolution of the branch channel of Tuanfeng River.

5. Conclusions

(1) Based on the change of damming, velocity, flow direction and distributary flux ratio before and after the construction of the bridge, the study shows that the bridge has no great influence on the flood control of the river section of the bridge, and the two bridge types are basically feasible, among which the double-tower cable-stayed bridge type is superior to the three-tower cable-stayed bridge type.

(2) The deflection angle of the flow direction on the surface at the bridge site and nearby the main flow area is not generally more than 5 degrees. The bridge construction has little effect on the flow direction, and the range of change is usually less than 5°. There is no obvious difference between the double-tower cable-stayed bridge and the three-tower cable-stayed bridge in the angle of direction of flow direction.

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