Research on the Calculation Method of Navigable Effective Width of Two Bridges Near Layout

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Abstract: New-built bridges and old bridges in inland waterways near layout, the intersects angle that the normal direction of bridges axes and the flow direction is more than 5, it is an important issue that the navigable effective width is determined scientifically and reasonably to ensure the safety of ships and bridge. In this paper, navigable effective clearance width of two bridges as a whole are calculated based on channel conditions and pier layout, which calculate the navigable effective width in the channel direction by oblique projection, determine the turbulence width by physical model test, graphics and compare. Finally, taking the Lijiatuo Yangtze River second bridge project in Chongqing as an example, the scientific and rationality of this method is verified, which can provide reference for the determination of navigable effective clearance width of similar bridges in the future.

1 Introduction

With the implementation of the national strategy of the Yangtze River Economic Zone and the Comprehensive Three-dimensional Transportation Corridor Planning of the Yangtze River Economic Zone (2014-2020), there are more bridges crossing the trunk stream of Changjiang River and their distribution density is high. By the end of 2018, nearly 130 bridges cross the trunk stream of Changjiang River from Hejiangmen to the Yangtze Estuary, there is a bridge with an average of 20 kilometers. The bridges group have been basically formed, especially in the main urban areas of Chongqing, Wuhan and Nanjing. The new round of comprehensive three-dimensional transportation corridor planning for the Changjiang River Economic Zone is being studied and compiled. It is predicted that by 2035, the number of bridges across the Changjiang River main waterway will still increase significantly. According to the investigation, the better locations of the trunk stream of Changjiang River have been basically exhausted. Therefore, the situation of building bridges nearing layout will increase, and the bridge waters area belong to the navigation restricted section of ships. The influence of wind and current and the turbulence of piers on the lateral drift of ships will increase the probability of collision between ships and bridges [1]. Studying the calculation method of the navigable effective width of bridges is of great significance for the design of bridges navigable holes and the safety of ships navigation and bridges.

2 Calculating Method of Navigable Effective Clearance Width of Single Bridge

2.1 Navigable Effective Clearance Width of Bridge

According to the provisions of Navigation standards of inland waterway (GB50139-2014) Fig. 5.2.2 navigation effective clearance diagram and other relevant standards, Navigable effective clearance of bridge is the inner space of two piers of bridge navigable holes, and the minimum clearance width perpendicular to the axis direction of waterway, which can typical ship type or typical fleet pass safely the bridge navigable holes, excluding the anti-collision facilities of pier and the turbulence width[2]. The main influencing factors are channel grade, typical ship type, flow velocity, the intersection angle between the normal direction of bridge axis and flow direction, pier and so on.

2.2 Calculation of Navigable Effective Clearance Width

The calculation method of navigable effective clearance width of bridge is the same between Navigation standard of inland waterway and Navigation Standard of the trunk stream of Changjiang River, which is determined whether the intersection angle between the normal direction of bridge axis and the flow direction is greater than 5º. When the angle of intersection is less than 5º, the navigable effective clearance width of the bridge is

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calculated by the method of Appendix C in the standard, and shall not be less than the value specified in the table. When the angle of intersection is greater than 5, the navigation effective clearance width needs to calculate the effective width after oblique projection, which is determined according to the magnitude of the transverse velocity. When the transverse velocity is greater than 0.3m/s, the navigable effective clearance width should be increased on the basis of the values specified in the table. The added value should be selected according to the corresponding transverse velocity in the standard appendix. When the transverse velocity is greater than 0.8m/s, piers shall not be installed in the navigable waters or across the river [2] [4]. The specific formulas are as follows.

$$\boldsymbol{B_0}=\boldsymbol{B}_{\mathrm{Skew}}\times\cos\theta-\boldsymbol{L}\times\sin\theta \tag{1}$$

$\boldsymbol{B_0}$ is the navigable effective clearance width projected along the orthogonal direction of waterway, $\boldsymbol{B}_{\mathrm{Skew}}$ is the navigable effective clearance width along axes of bridge for navigable holes, L is the length of pier, and θ is the angle of intersection between the normal direction of bridge axis and the flow direction.

Because of the inconsistency between the flow direction of the current and the ship's route, the current will have a cross-flow effect on the ship and push the ship off the scheduled route [5]. For the bridge area waters, the transverse flow will occur when the normal direction of the bridge axis intersects with the flow direction. The larger the intersection angle is, the greater the transverse velocity is, and the larger the transverse drift of the ship caused by the transverse flow force is. In addition to meeting the standard requirements, the navigable effective clearance width of bridges should be comprehensively analyzed according to the trend of the waterway in the bridge area waters and whether there are special vessels (fleets) navigable or not. the navigable effective clearance width should be appropriately increased When necessary [6].

3 Calculation Method of Navigable Effective clearance Width of Two Bridges Near Layout

3.1 Navigable Effective clearance Width

When the distance between the New-built bridge and adjacent bridge in inland waterway cannot meet the requirements of Navigation standards of inland waterway, the navigation holes of the two bridges should correspond and be arranged close to each other, and the distance between the adjacent edges of the two bridges should be no more than 50m [2]. Under the above circumstances, the navigable effective clearance width cannot be calculated only according to the new-built bridge. The ship is a rigid body. Referring to Table 3.0.2-1 of Navigation standards of inland waterway, the total length of a 300 tons vessel is 55 m on the Class V waterway, that is, more than 50 m. When the axes of two parallel bridges are not perpendicular to the flow direction and the angle of intersection is greater than 5º, the ship's central axis is not parallel to the normal direction of the axes of the two bridges which passing through the bridge area water for a single ship or fleet of no less than 300 tons. When the ship passes through the first bridge, it will synchronously pass through the bridges near the layout. Therefore, the effective clearance width of the navigable hole of the new bridge cannot be used as the criterion for judging whether the navigable conditions of the channel are affected. According to the ship maneuvering characteristics and industry experience, the navigable effective clearance width between the two bridges near layout should be determined by considering the oblique projection of the two bridges as a whole, and by means of graphic comparison of the turbulent width and the position of the two piers.

Because the turbulent width of pier is related to many factors such as inflow conditions (flow velocity, flow direction, water depth), pier type, scour, river type (such as straight, bending or bifurcation), etc. [7] [8], when there is turbulent flow near pier in water, the turbulent width needs to be determined by simulation test.

$$\boldsymbol{B}=\boldsymbol{B_0}-\mathbf{b_1}-\mathbf{b_2} \tag{2}$$

Among them, B is the navigable effective clearance width, and b1 and b2 are the turbulent width of the two piers respectively.

3.2 Calculation of Navigable Effective Clearance Width

Taking the total length between the piers of the two bridges as L, according to the oblique projection calculation method and formula (1), the navigable effective clearance width B′is calculated that projected along the orthogonal direction of the channel,. When there are obstructive turbulence near the piers of the two bridges, the turbulence width is determined by simulation test [9].

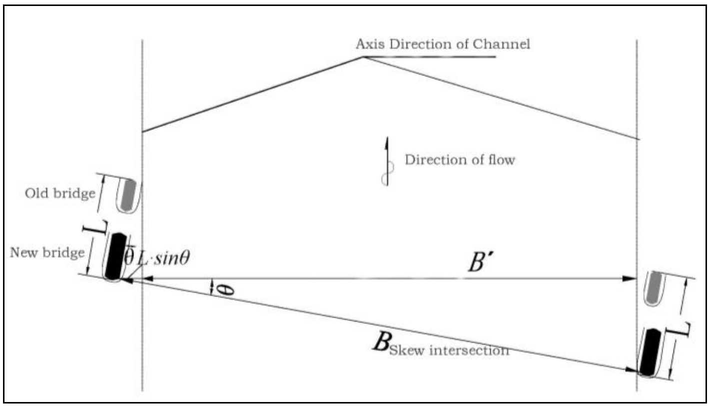

Figure 1. Schematic diagram of calculation method for navigable Effective clearance of two bridges near layout

Considering that the navigable effective clearance width calculated by oblique projection may overlap with the turbulence width at the pier, the position relationship between the turbulence width and the tangent line along the channel direction and the two piers is compared by graphical method from the point of view of calculation rationality, and the minimum width after deducting the most adverse influence is taken as the navigable effective clearance width [10-11], which is calculated concretely. The calculation method is shown in Figure 1.

4 Example- Lijiatuo Yangtze River second bridge project in Chongqing

4.1 Basic situation of the project

The proposed Lijiatuo Yangtze River second Bridge in Chongqing is located at 676.8 km of the upper Yangtze River waterway. The recommended bridge location is located at the upper edge of the old Lijiatuo Yangtze River Bridge about 25 meters apart (the distance between the axes of the two bridges is about 52 meters, and the distance between the edges of the caps is about 15 meters). The upper and lower sections of the bridge location are Hujiatan and Lijiatuo curves respectively, and the project is in the transitional section between the two curves. The maximum angle between the normal direction of the axes of the proposed bridge and the flow direction is about 12°, the maximum lateral velocity is 0.48 m/s, and the navigation environment is complex.

The main span of navigation holes of the old Lijiatuo Yangtze River Bridge is 444 m, and the net span along the axes of the bridge is 435m. Regarding the proposed construction of Chongqing Lijiatuo Yangtze River second bridge, the design unit first proposed the scheme of double-tower cable-stayed bridge with 447 m main span of navigable holes. The net span along the axes of the bridge is 435m. The two piers of navigable holes are aligned with the inner side of the two piers of the navigable holes of the old Lijiatuo Yangtze River Bridge. The maximum angle of intersection between the normal direction of bridge axis and the flow direction is 10º.

4.2 Physical Model Test

Because the location of bridges and the turbulence width of piers in complex river sections must be determined by simulation test, the fixed-bed physical model test is carried out for the two bridge sections. According to the characteristics of water and sediment movement, riverbed scouring and silting law, test target, site and facilities of the proposed bridge section, the 1:150 normal model of the bridge section is established. The upstream and downstream of the bridge axis are simulated to be about 4.5 km and 3.5 km respectively, totaling about 8 km in length.

In order to better simulate the navigation flow conditions and their changes before and after the construction of the Lijiatuo Yangtze River second bridge in Chongqing, taking into account the river regime conditions, flow-gradient combination, navigation hydraulics indexes of ships, water level support, channel maintenance and the proposed bridge span, the model test conditions are determined as follows.

Table 1. Table of test operating

Serial umber	Flow(m^3/s)	Tailgate water level(m)	Remarks
1	8720	168.51	Average annual flow
2	25000	177.42	Perennial flood
3	35600	182.47	P=50% flood
4	44100	186.41	P=20% flood
5	49700	188.76	P=10% flood
6	54500	190.54	P=5% flood

Through physical model tests, the effects of turbulence on the main piers of navigable holes of the old Lijiatuo Yangtze River Bridge and two bridges under different flow levels are observed and compared, as shown in figs. 2 and 3. When there is only the old Lijiatuo Yangtze River Bridge, the maximum turbulence width caused by the inner side of the left and right main piers are about 5m and 6m respectively. When the two bridges coexist, due to mutual influence, the maximum turbulence width caused by the inner side of the left and right main piers of the existing Lijiatuo Yangtze River Bridge are about 5m and 8m, respectively; the maximum turbulence width caused by the inner side of the left and right main piers of the Chongqing Lijiatuo Yangtze River second bridge are about 6m and 9m, respectively.

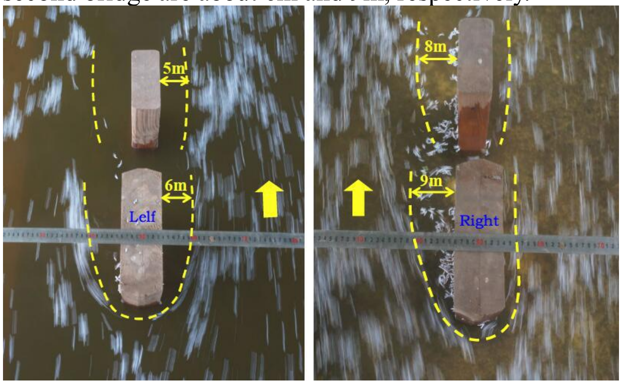

Figure 2. Photos of turbulence model test of main piers of two bridges (main span 447m)

4.3 Calculation of Navigable Effective Clearance Width

According to formula 1, the projection calculation results of navigation effective clearance width of the old Lijiatuo Yangtze River Bridge are as follows:

$B_{0old\ bridge}$=435×cos10º-27×sin10º=423.7m

After considering the turbulence width, the navigable effective clearance width is calculated according to formula 2 as follows:

B=423.7-5-6=412.7m

Similarly, when two bridges coexist, the results of oblique projection of navigable effective clearance width are as follows:

$B_{0\ scheme\ 1}$=435×cos10º-85×sin10º=413.6m

By comparing the position relationship between the turbulence width and the tangent of the two piers along the channel, it can be seen that the navigable effective clearance width of the two bridges when they coexist is as follows:

$B_{scheme\ 1}$=413.6-5-9=399.6m

Thus, although the newly built Lijiatuo Yangtze River second bridge and the old Lijiatuo Yangtze River bridge in Chongqing are located near the opposite orifice and parallel to the inner side of the piers, the navigable effective clearance width of the two bridges when they coexist is still reduced to a certain extent due to the 10º intersection angle between the axes of the bridge and the flow direction. In the river section with complex navigation environment, the span arrangement of the new bridge is not suitable to reduce the effective clearance width of the original navigation. Therefore, the span of Lijiatuo Yangtze River second bridge needs to be enlarged.

4.4 Bridge Span Increasing Scheme (Main Span 454m)

The left main pier is aligned with the inner side of the old bridge and the right main pier is moved 7m to the right for the scheme 2 after the bridge span is enlarged. Physical model tests show that the maximum turbulence width caused by the inner side of the left and right main piers of the old Lijiatuo Yangtze River Bridge are about 5m and 5m respectively, and the maximum turbulence width caused by the inner side of the left and right main piers of the Lijiatuo Yangtze River second bridge are about 6m and 6m respectively, as shown in Figure 3.

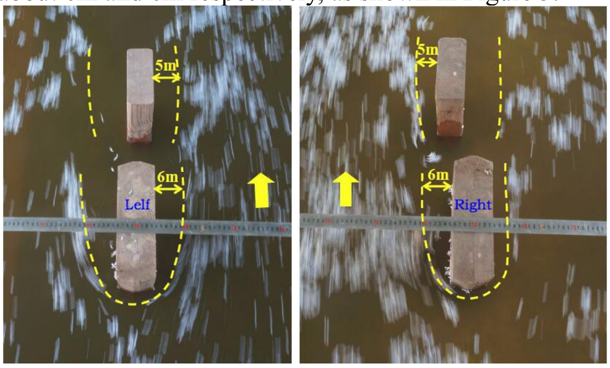

Figure 3. Photos of turbulence model test of main piers of two bridges (main span 454m)

For scheme 2, through oblique projection and graphic comparison, when the two bridges coexist, the navigation effective clearance width is limited mainly by the two main piers of the old Lijiatuo Yangtze River Bridge and their turbulence width, as shown in Fig. 4. Therefore, in the case of scheme 2, the navigable effective clearance width of the two bridges is 412.7m when they coexist.

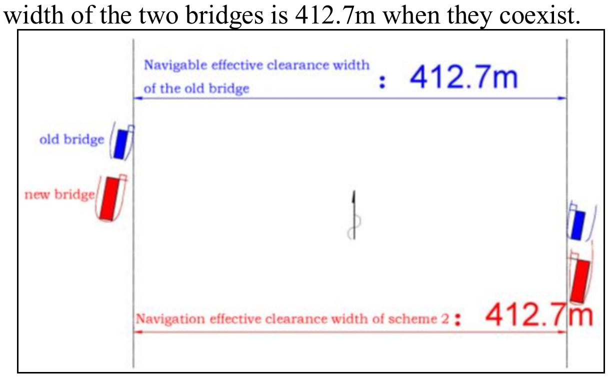

Figure 4. Computational method of oblique projection and graphic comparison

5 Conclusion

Through oblique projection and graphic comparison method, this paper calculates and analyses the navigable effective clearance width of the two bridges whose normal direction of the bridge axis intersects with the flow direction, and which are close to the layout. Taking the Lijiatuo Yangtze River second bridge project in Chongqing as an example, the specific calculation method is introduced in detail, which can provide reference for similar bridge construction in determining the navigable effective clearance width.

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