Application of Mathematical Model in Water Conservancy Project at Confluence Section

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Abstract. The new construction of the wading project at the confluence section, where the flow condition is rather complex, has definitely to take more influencing factors in consideration. In order to investigate quantitatively the effect of secondary flows on the transport of flow and sediment in a sharply curved channel, the landscape project at the Yibin reach was taken as an example, and the 2D Mathematical Model was used to simulate the distributions of flow factors. As the predicted project is located at the confluence of the Three Rivers, the left banks of the Minjiang River and the Yangtze River, the complexity of the inflow and outflow conditions was considered during the study, and different research schemes were compared. Result of this research can be valuable reference for similar projects.

1. Introduction

The construction of wading projects more or less affect the flooding and bed tendency of the river. In recent years, mathematical model, as one of the methods, has been used to analyze the impact of wading engineering. Shi Yingbiao[1], Zhang Wei[2], etc. conducted research on the influence of the river-crossing tunnel on the river channel through mathematical modelling. Ren Shasha[3], Wang Yunbo[4], etc. used mathematical model in schemes compassion for a channel improvement project. Ma Rongyong[5] studied the impact of bank protection projects on river flooding through mathematical modelling, and Shen Sunping[6] adopted a mathematical model to study the impact of bridge construction on the channel.

Due to topographical reason, the river flow conditions are complex at confluence sections, making it more relatively complicated in predicting construction of the wading project at these locations. In China, many cities are located aside the river convergence section. For example, Yibin is located where the Minjiang River and the Jinsha River flow together into the Yangtze River, Chongqing is at the confluence section of the Jialing River and the Yangtze River, Wuhan, the Han River and the Yangtze River, and Yueyang, the Yangtze River and the Dongting Lake. The Yibin River section is took as an example to demonstrate the influence of landscape engineering construction on the river variation with mathematical methods, and can be reference for the study of similar engineering issues afterwards.

2. General Description of Yibin River

The Yibin River is located in the upper reaches of the Yangtze River, where the Jinsha River, Minjiang River flow together into the Yangtze River, whose river bank are low hills, with the width of the valley not constant, and a curved river channel, the bed of which mainly are pebble with sand, is with good
flow impact resistance. Over the years, the location of the confluence, Hejiangmen is relatively stable, and so is the coastline of Yibin urban area. The inter-annual river bed erosion and sedimentation are basically balanced.

The channel of the Minjiang River in the section is a relatively curved, with the river width is about 300-400m in the flood period and 180-270m in the normal and dry period. At the beginning of the section, the Minjiang River and the Yangtze River intersect at an angle of 90°. The flood control embankment for riverside road is built on the right bank of the river at the beginning of the section.

The channel of the Jinsha River in the section is relatively straight and the river width is even. The width of the river during the flood period is about 240-320m, and the width of the river during the middle and dry period is about 180-230m. There are flood control embank for riverside road in the urban area on both banks.

The channel of the Yangtze River in the section has an inverted "S" shape. There are two reverse curves, namely, Baishawan and Daxikou. A wide convex bank is formed near the top of the curve and the river is notably widened. The width of the river during the flood period is about 350-650m; and the width of the river during the dry period is about 25-400m, rather wide beaches are formed along the river.

The proposed landscape project in Yibin City is located on the left bank of the Minjiang River and the Yangtze River in the Yibin River Section, including landscape greening, roads and bridges and flood control embankments. The total length of the project is about 4km. as shown in Figure 1.

3. Model establishment

In order to analysis the influence of the predicted wading project on the river channel at the river confluence, the HELIU-2 model, which is independently originated by the CRSRI river research institute, is used to modelling and analyzing the river section, and the model is calculated using the finite volume method.

The topographic map of the Jinsha River section in the calculation is based on the 1/10000 channel measured on March 2008, and the Minjiang River section adopted the topographic map of October 2011, and the topographic map on January 2014 is used for the lower Yangtze River section. The body-bound orthogonal curve grid of river boundary is adopted in meshing, the number of grid nodes is 285×96, the grid spacing at water flow direction is 13~80m, and the grid spacing vertical to water flow direction is 7~40m. The grid of the proposed project is densified, with an average grid size of 13m×7m. The grid layout of the calculated river reach is shown as in Figure 2.

4. Model research and analysis of calculation results

The proposed project is located in the confluence of the three river. The rivers involved are Jinsha River, Minjiang River, and the Yangtze River. The design flood standard for the river reaches is 50 years. There are Pingshan Hydrological Station on Jinsha River, Gaochang Hydrological Station on Minjiang River, Hengjiang Hydrological Station on Hengjiang River, a tributary of Jinsha River, and Lizhuang

Figure 1. River map of Yibin reach.  Figure 2. Local grid mesh near the project.
Hydrological (Water level) Station on the Yangtze River in this section, which are all national basic network stations. Except the series of discharge data at Lizhuang Station is short, other hydrological stations have flow observation data for more than 50 years, which generally reflects the changes of water and sediment in the rivers involved in the proposed project in the Sanjiangkou area, and can be used as hydrological calculations for the river sections base stations. After analysis and calculation of the flood frequency, the design flood results of each station are shown in Table 1.

Table 1. Design flood parameter of each hydrological station.

| River          | Hydrological Station        | Statistical parameters | Flood Flow at Design Frequency (m³/s) |
|----------------|----------------------------|------------------------|--------------------------------------|
| Jinsa River    | Pingshan Station           | Mean Flood peak mean   | Cᵥ Cv/Cₛ 1% 2% 5% 10%                |
| Hengjiang River (tributary of Jinsha River) Below | Hengjiang River Statton   | 17500 0.32 4.5 36000 32700 28400 25200 |
| Hengjiang River confluenct point | Below                    | 3730 0.55 4.0 11300 9820 7840 6360 |
| Minjiang River | Gaochang Station           | 19100 0.28 5.0 36600 33600 29600 26400 |
| Yangtze River  | Lizhuang Station           | 20400 0.37 4.0 45400 41000 35100 30500 |
|                |                            | 33500 0.27 5.0 62800 57800 51000 45600 |

When evaluating the flood impact of newly-built wading projects in non-confluent river sections, different calculation conditions are usually selected for mathematical model calculation and analysis[7]. However, the inflow and outflow conditions of the confluenct river section are complex, as for the proposed project in this article, taking the 2% frequency flood condition as an example, the following situations are calculated and analyzed.

![Figure 3. Scheme of the Yibin reach.](source)

(1) When the inflow from the Minjiang River (Qₐ, the same below) reaches a 2% frequency flood flow, and the Yangtze River section downstream (Qₐ, the same below) also reaches a 2% frequency flood, and the Jinsha River's inflow (Qₐ, same as below) is Qₐ - Qₐ.

(2) When Qₐ = 2% frequency flood flow, and Qₐ ≠ 2% frequency flood flow. Then Qₐ and Qₐ are difficult to determine.

(3) When Qₐ = 2% frequency flood flow, and Qₐ = 2% frequency flood flow, then Qₐ = Qₐ - Qₐ.

(4) When Qₐ = 2% frequency flood flow, and Qₐ ≠ 2% frequency flood flow. Then Qₐ and Qₐ are difficult to determine.

(5) When only Qₐ = 2% frequency flood flow is determined, the combination of Qₐ and Qₐ is numerous and difficult to determine.

Therefore, considering that the proposed project is located on the left bank of the Minjiang and Yangtze River sections, and the control flood recurrence period in the project section is 50 years, this calculation is divided into two working cases (case 1 and case 2) to analyze of the project’s impact on flood speed. Case 1 is when the design flood inflow of the Minjiang River reaches the frequency of 2%
and 5%, and the Jinsha River inflow adopts the flow at measured Lizhuang Station minus the Minjiang inflow; Case 2 is when the design flood inflow of the Jinsha River reaches the 2% and 5% frequency and the inflow of Minjiang River adopts the measured flow at Lizhuang Station minus the inflow of Jinsha River. The calculated control water level at the end of the river reach is calculated with the 1D water flow model from Xiangjiaba to Zhuxi (See Table 2).

| Case Number | Flow frequency | Jinsha River inflow ($Q_B$) (m³/s) | Minjiang River inflow ($Q_A$) (m³/s) | Lizhuang Station measured flow ($Q_C$) (m³/s) | Control level at end of reach (m) |
|-------------|----------------|-----------------------------------|-------------------------------------|---------------------------------------------|----------------------------------|
| Case 1      | 1 2%           | 16800                             | 41000                               | 57800                                       | 276.64                           |
|             | 2 5%           | 15900                             | 35100                               | 51000                                       | 275.26                           |
| Case 2      | 3 2%           | 33600                             | 24200                               | 57800                                       | 276.64                           |
|             | 4 5%           | 29600                             | 21400                               | 51000                                       | 275.26                           |

Notes: Case 1: Jinsha River inflow=Lizhuang flow-Minjiang River inflow, Case 2: Minjiang River inflow=Lizhuang flow- Jinsha River inflow.

Figure 4 shows the distribution diagram of the flow field in the calculated section, Figure 5 shows the contour map of the velocity change near the project after the project is constructed under two working cases, Table 3 shows the maximum value of the velocity change and the influence range of the velocity after the project is constructed. From the figures and tables, the following conclusions can be drawn.

(1) When the flood inflow from Minjiang River reaches 2% frequency flood (Option 1), the Minjiang River has a larger inflow, and the Jinsha River has a smaller inflow. The flow rushes out of the Minjiang River, thrusts towards the right bank of the Yangtze River (see Figure 4(a)). Downstream of the confluence, the mainstream will be deviated to the right bank. After the construction of the project, the flow velocity decreases in the upstream, downstream and nearby areas of the project, the amount will be 0.01~0.2m/s. The localized area of the project is affected by the blocking effect, and the flow velocity decreases greatly, the maximum reduction is 0.32m/s. At the sight-seeing platform and square, resulted from the narrowing of the channel, an increase in local velocity is observed. The velocity is increased from 0.01 to 0.15m/s and the maximum value is 0.21m/s. The influence of velocity is mainly concentrated in the range from 75m upstream to 600m downstream of the project (see Figure 5(a)).

(2) Compared with Option 1, under 2% frequency flood from the Jinsha River (Option 3) condition, when $Q_A < Q_B$, affected by the inflow of the Jinsha River, the mainstream after the confluence are basically centered. After the construction of the project, the velocity of the project upstream, downstream, and the vicinity of the project also showed a decreasing trend, and generally decreased by 0.01 to 0.2m/s, the maximum reduction of the velocity was 0.24m/s, which was 75% of Option 1; At sight-seeing platforms, squares, etc., the maximum increase in flow velocity is 0.17m/s, which is 81% of Option 1. Compared with Option 1, the area where the flow velocity increases at the mainstream aside the project of the Option 3 project changes, and the scope is smaller (see Figure 5(c)). Similarly, the discipline observed in option 4 and 2 are consistent with those of option 3 and 1.

(3) Compared within the cases, that is, comparison between option 1 and option 2, and between option 3 and option 4, all showed that, the smaller the incoming flow is, the greater the impact on the river flow velocity after the construction of project. As in Option 2, the velocity of the project area is generally reduced by 0.01~0.2m/s, the maximum value of the local velocity reduction local to the project is 0.39m/s, which is 1.2 times that of Option 1. In the sight-seeing platform and square, the maximum velocity increase is 0.26m/s, which is 1.2 times that of Option 1. The range of the flow velocity increase in the mainstream area in the outer channel of the project becomes larger, and the impact area is expanded to 80m upstream and to 610m downstream.
Through the above analysis, the following can be concluded:

5. Conclusion

Table 3. Maximum Flow Velocity Changes and Influence Range of Flow Field after the Construction of the Project.

| Case  | Option  | Velocity change value (m/s) | Velocity change range(m) |
|-------|---------|-----------------------------|---------------------------|
|       |         | Maximum deduction          | Upstream of the project   | Downstream project       |
|       |         | (m/s)                       |                           |                          |
| Case1 | Option 1| 0.21                        | -0.32                     | 75                       | 600                       |
|       | Option 2| 0.26                        | -0.39                     |                          |                          |
| Case2 | Option 3| 0.17                        | -0.24                     | 72                       | 550                       |
|       | Option 4| 0.20                        | -0.31                     |                          |                          |

5. Conclusion

Through the above analysis, the following can be concluded:
(1) The flow topography at the river confluence is complicated. When the proposed wading project is located near the confluence of the river, when using mathematical simulation method, it is necessary to consider the impact of the project on the channel discharge under different conditions of flow and diversion.

(2) Taking the proposed landscape project in the Yibin River section as an example, under two working cases, due to the water blocking effect of the revetment and other projects, the velocity is reduced near the project after the construction, and the velocity of the mainstream channel outer the project is increased. Meanwhile, because the project blocks the water and affects the cross-section area of the flood discharge, after the construction of the project, the impact of the project on the river flow velocity increases as the incoming flow decreases. During the modelling, the frequency of floods downstream the confluence remained unchanged, only the flow of the Minjiang and Jinsha rivers were changed. Since the proposed project is located on the left bank of the Minjiang River and the Yangtze River, the impact of flow changes in the Minjiang River flow is greater than that of the Jinsha River. Compare Option 3 with Option 1, and Option 4 with Option 2, it shows that when the Minjiang River inflow is less than that of Jinsha River, after the construction, the maximum velocity change and range of influence are relatively reduced.

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