Explore on Application of Two-Dimensional Hydraulics Model in Flood Impact Assessment of the New Century Bridge

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Abstract. The New Century Bridge will be built across Xiliao River. The construction of the bridge increases the complexity of water flow condition of Xiliao River. By establishing the mathematical model and adopting the form of finite element mesh dissection, the distribution of the maximum depth of flood water, the maximum flow velocity and the highest water level for flood in front of the dam and bridge are simulated before and after the bridge built to judge flow pattern effectively. By establishing a numerical model of flow pattern, which plays a decisive role for bridge abutment protective, depth of the pile foundation and pile caps, and has the greatest impact for next structure optimization of the bridge.

1. Introduction
The New Century Bridge is located in northeast of Tongliao city, total length of 528 m, in the east-west direction. The bridge road level is urban arterial road, security structure design is A class. The standard of flood control of designing is “a once-in-a-century”. The flow rate is 1910 m³/s and the design flood level is 184.0 m [1-2].

In order to analysis accurately the water flow distribution of the backwater effect and the velocity change and so on before and after the completion of new century bridge, using two-dimensional hydraulics model, the calculation of backwater is analyzed. The calculation software is Mike21 software which is developed by DHI company.

Calculation process mainly includes the determination of calculation range, Mesh division, the determination of the initial boundary value conditions, model parameter rate, the calculation of backwater, and so on[3].

2. Analysis and Calculation of Backwater Influence

2.1. Two-dimensional Water Flow Model

2.1.1. Basic form
The two-dimensional unsteady flow equation is used in two-dimensional hydraulics model. [3] The equation is consist of water flow continuity equation and momentum equation. Its specific form is as follows:
\[
\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = q, \tag{1.1}
\]

\[
\frac{\partial (hu)}{\partial t} + \frac{\partial (hu^2)}{\partial x} + \frac{\partial (huv)}{\partial y} + gh \frac{\partial Z}{\partial x} + g \frac{n^3 u u^2 + v^2}{h^{1/3}} = 0, \tag{1.2}
\]

\[
\frac{\partial (hv)}{\partial t} + \frac{\partial (huv)}{\partial x} + \frac{\partial (hv^2)}{\partial y} + gh \frac{\partial Z}{\partial y} + g \frac{n^3 v v^2 + u^2}{h^{1/3}} = 0, \tag{1.3}
\]

where
- \( h \) - water depth (m);
- \( z \) – water level (m);
- \( u, v \) – average horizontal velocity component along vertical in x, y direction (m/s);
- \( g \) - gravity acceleration (m/s²);
- \( n \) - roughness;
- \( q \) - source sink term (m/s).

2.1.2. Definite conditions of model
The finite volume method is used to solve discrete solutions of two-dimensional unsteady flow equation. Definite conditions includes the initial conditions and the boundary conditions[4].

The initial conditions of the two-dimensional unsteady flow model includes the velocity and the water level. The initial conditions are determined, firstly according to the physical condition of the problem such as hydrostatic or uniform flow, and secondly according to the observation data. Due to the data of observation point is only partial data, we need to estimate the losing space value by the interpolation method.

When the grid cell edge is the calculating domain boundary or entity boundary (e.g., engineering building), the numerical flux calculation becomes a Riemann boundary problem.

2.2. Determination of Calculation Range and Mesh Division [5]

2.2.1. Calculation range
The water-tightness part of The New Century Bridge is approach span part of 1 ~ 14 bridge abutment and approach bridge. The length range of this calculation is the river reach from upper reaches 3.3 km to 1.3 km lower reaches of the bridge, total length of 4.6 km. The width range is river main channel and floodplain between the embankment on both banks of Xiliao River, with a total area of 4.77 km² [2]. The paper of mathematical model simulation scope and river topographic distribution, Fig. 1.

![The New Century Bridge](image-url)
2.2.2. Topographic data and mesh division

We measured the topographic data within the scope of river reach from 3.3 km upstream to 3.3 downstream of The New Century Bridge as the basis data of subdivision of this project area. In order to compare the changes of flow pattern for reach before and after the bridge built, the Mesh division of completely consistent is adopted. Only when the mesh elevation is valued, the mesh topography where the bridge abutment and the approach span are will be processed separately.

In order to accurately simulate the situation of diaphragm of the bridge, each bridge abutment is generally changed into the rectangle which is completely consistent with the abutments form, the area around the bridge abutment is encrypting processed. We will set 7452 nodes in calculation scope and 14594 units of Mesh division. The average area of mesh units is 327 m², the largest area of mesh units is 1254 m², and the minimum area of mesh units is 1.06 m².

2.3. Determination of Boundary Conditions and Initial Conditions

The upper boundary condition of two-dimensional water flow model uses flow boundary, and the lower boundary condition uses water flow boundary. Therefore “a once-in-a-century” flow rate of 1910 m³/s is used in the upper boundary condition, and “a once-in-a-century” water level of 183.62 m is used in lower boundary condition [3]. The initial water level of “a once-in-a-century” in the calculation scope is 183.62 m, and the initial condition of flow velocity is 0 m/s.

2.4. Model Parameter Selection and Verification

According to the realities of the main channel and floodplain of river reach, the value range of roughness rate is from 0.025 to 0.055 [6].

| Section pile No | Water level of calculation | Water level of planning design | Remark                     |
|-----------------|---------------------------|-------------------------------|----------------------------|
| 0+037           | 184.27                    | 184.29                        | Downstream of Tonghuo Railway |
| 0+837           | 184.02                    | 183.99                        | Bridge site                 |
| 2+037           | 183.62                    | 183.62                        | Upstream of Khorchin bridge |

By comparison, two calculation results of water surface profile are closed and maximum difference of section average water level is 0.03 m. There are mainly two reasons: (1) the differences of the roughness values of local river; 2) the differences of the internal mechanism of two-dimensional water flow model. Thus, the parameter selection of the established a two-dimensional model is relatively reasonable, and can be applied to the simulation calculation and analysis of backwater.

2.5. Analysis of Flow Simulation Result

2.5.1. Analysis of current flow simulation result

According to the present situation interpolated the triangular mesh and the initial condition boundary condition and the parameters of model with constant rate, the maximum water level, the maximum water depth and the maximum velocity distribution of 100 year flood is calculated by simulating the current situation.
The water level of the river section at the bridge site of the 100 year flood occurred at 184.01m~184.03m as we can see from figure 3~figure 5, average water depth is 2.52m, maximum water depth is 3.61m, average velocity of cross section is 0.95m/s, local maximum velocity is 1.36m/s.

2.5.2. Analysis of future flow simulation result
According to the present situation and the parameters of model with constant rate, the maximum water level, the maximum water depth and the maximum velocity distribution of 100 year flood is calculated by simulating the current situation. Two-Dimensional Hydraulics Model results are shown in Figure 2 to Figure 4.

**Figure 2.** The highest level distribution diagram within the simulation diagram after the completion of the project (P=1%)

**Figure 3.** The maximum depth distribution diagram within the simulation diagram after the completion of the project (P=1%)
Figure 4. The maximum velocity distribution diagram within the simulation diagram after the completion of the project (P=1%) 

The water level of the river section at the bridge site of the 100 year flood occurred at 183.93m ~184.03m as we can see from figure 3~figure 5, average water depth is 2.58m, maximum water depth is 3.58m, average velocity of cross section is 1.52m/s, local maximum velocity is 4.15m/s.

2.6 Backwater and the Result of Flow Velocity Analysis

According to calculation results of two-dimensional water flow model, after the completion of The New Century Bridge, the change of the water level and flow rate of “a once-in-a-century” in river reach of the project are shown in table 1.

Table 1. Flood backwater calculation results of “a once-in-a-century” for The New Century Bridge

| Section pile No (m) | Before water level (m) | After water level (m) | Backwater Height (m) | Before Velocity (m/s) | After Velocity (m/s) | Velocity Variation (m/s) | Remark |
|---------------------|-----------------------|----------------------|----------------------|----------------------|----------------------|-------------------------|--------|
| 0+954               | 183.98                | 183.97               | -0.01                | 0.93                 | 0.94                 | 0.006                   | Downstream 100m |
| 0+884               | 184.00                | 183.98               | 0.06                 | 0.95                 | 0.92                 | -0.03                   | Downstream 30m |
| 0+012               | 184.27                | 184.32               | 0.05                 | 1.17                 | 1.15                 | -0.02                   | Upstream 808m (Tonghuo railway bridge) |
| 0-181               | 184.55                | 184.58               | 0.03                 | 0.62                 | 0.61                 | -0.01                   | Upstream 2000m |

From the results of table 1, after the completion of the bridge, abutments and bridge approach have influence on water level and flow velocity of river beach of the project.

(1) After the completion of the project, the water level of each section of upstream of bridge site is slightly higher than present situation. Section average water level of “a once-in-a-century” flood in upstream of bridge site at 30 m, 808 m, 2 km, and 3.3 km are increased 0.06 m, 0.05 m, 0.03 m, and
0.01 m respectively, and average flow velocity is decreased 0.03 m/s, 0.02 m/s, 0.01 m/s, and 0.003 m/s respectively.

(2) The section water level in the bridge downstream is slightly decreased. Section average water level of “a once-in-a-century” flood in downstream of bridge site at 30 m and 100 m are decreased 0.02 m and 0.01 m respectively, and average flow velocity is increased 0.02 m/s and 0.006 m/s respectively.

(3) After the completion of the project, the change of water level in the bridge site is lesser, but the flow velocity increases obviously. The average level of “a once-in-a-century” flood in the bridge site decreased 0.03 m and the average flow velocity increased by 0.57 m/s.

The comparison of water surface profile of the section status quo of the project and the completion of the project is shown in figure 5.

![Figure 5. Outcome comparison of water surface profile before and after building bridge](image)

3. References

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