

# Application of 2D Hydraulics Model on Bridge Sluice and Scour Calculation

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**Abstract.** This article takes ZhuLong River in Zibo City as an example, using MIKE 21 two-dimensional mathematical model to simulate the influence of the bridge of flood control. The method of local topography and local roughness correction is used to generalize the piers in engineering. This article simulates the flushing and scouring process of bridges under a flood of 100 years. The results show that the MIKE 21 numerical model can simulate the complex terrain better, and the relative deviation in the process of model validation are all less than 1%. The backwater height and scour depth of the bridge are all within a reasonable range. Therefore, for a bridge with important flood control tasks in complex terrain river, it is suggested to use mathematical model to calculate the backwater value, so as to get more reasonable calculation results, and provide the basis analysis and calculation for flood control impact assessment.

## 1. Introduction

After the bridge project is built in the river course, the hydrological situation of the original river course is affected to a certain extent. It is mainly characterized by a circular local sluice area upstream of the piers and a ribbon deceleration area downstream of the piers. Due to the high flow velocity of the river channels, the pier has a certain pick-flow effect, which increases the flow velocity across the downstream of piers. Affected by the effect of piers in the river way on the water flow, there will be a phenomenon of stagnant water in the upstream of the bridge site. Scouring and sedimentation will occur in the river channel downstream of the bridge site.

At present, there are mainly empirical formula method for calculating the water loss and erosion in front of the bridge, including numerical calculation method and hydraulic model method. Due to the experience formula has the advantages of simple form, less parameter and convenient application, the empirical formula method is generally adopted in the project. With the progress of modern computer technology and numerical methods, hydrodynamic numerical model has been widely used. In the process of application, the hydrodynamic numerical model has been continuously improved. It is gradually to the direction of precision and visualization, there are FVCOM, EFDC, MIKE as the core of the representative model. MIKE 21 numerical model can simulate better complex terrain.

In this article, a case study of Zhulong River in Zibo city was conducted. This article use the MIKE 21 model establish a two-dimensional hydrodynamic model of 0.34 km long channel in Zhulong River. This model simulates the water level changes and river erosion siltation situation before and after the bridge construction, and compared with the design value, so as to provide a reference for the evaluation of flood control of the bridge.

## 2. MIKE 21 model



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MIKE 21 is a two-dimensional numerical model developed by the Danish Hydraulic Institute to simulate rivers, lakes, estuaries, bays, coasts and oceans with multiple modules of hydrodynamics, convection and diffusion, water quality and sediment Water, waves, sediment and environment. MIKE 21 uses drag theory to calculate the effect of piers in a subgrid structure. The drag force is calculated using the Morrison formula based on fluid mechanics:

$$F = \frac{1}{2} \rho_w a C_D A_e V^2 \quad (1)$$

Where:  $F$  is the drag force;  $\rho_w$  is the water density;  $a$  is the streamline coefficient;  $C_D$  is the drag coefficient;  $A_e$  is the water holding area; and  $V$  is the flow rate.

In MIKE 21, the pier angle is set according to the direction of the vertical section of the bridge projected from the projection of the project. The angle is clockwise in degrees. The circular section in the model needs to be set with height and diameter. The rectangular section needs to be set high and length and width.

### 3. Case Analysis

#### 3.1. Project Overview

The research object of this article is Yumin Road Crossing East Zhulong River Bridge Project. It is located in the area of Zibo High-Tech Industrial Development Zone. It is one of the important bridges on Yumin Road. The Yumin Bridge is a medium-sized bridge. The designed flood control standard is 100 years. The Yumin Bridge is 53 m in length, and the angle is 90 °. The satellite image of the study area is shown in Figure.1.



Figure.1. Bridge location

#### 3.2. Division of Network Iatex and Terrain Data Processing in the Model Range

Based on the measured terrain data of 1:100, the 2D hydrodynamic model of river is established by MIKE 21. The computation range is about 150 m upstream and downstream upstream of the bridge site, and the total length is 300 m. The triangular mesh is used in the model, and the total number of triangular mesh is 9635. The edge length of the grid is 1~10 m, and the model calculation grid is shown in Figure.2.

The mathematical model of terrain data from the piggy bank reconstruction project in the CAD map topographic data. Due to the lower terrain elevation of CAD drawings and smaller rivers, it may lead to relative errors. This model use distance inverse interpolation, the original terrain data is processed to obtain the terrain data at each grid node. The interpolation of the river after the topography as shown in Figure.3.

#### 3.3. Boundary Condition

For all conditions of the simulated river section, the operating conditions are calculated according to a constant flow. The upstream boundary of the flow inlet and the downstream boundary of the water table are set according to flood conditions of 100-year-long piers provided by hydrological calculation. The

upstream flow boundary takes the estimated flow rate of the most upstream pier to be  $170 \text{ m}^3/\text{s}$  and the downstream water level boundary extends linearly from the water level at the most downstream pier to the model exit boundary. The calculated downstream exit water level is 26.05 m.

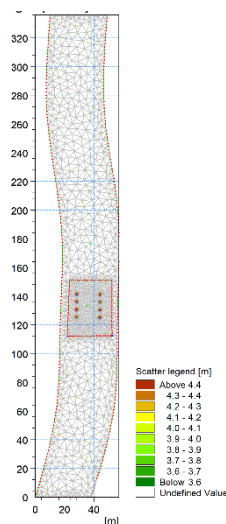


Fig.2. Mesh map of river model

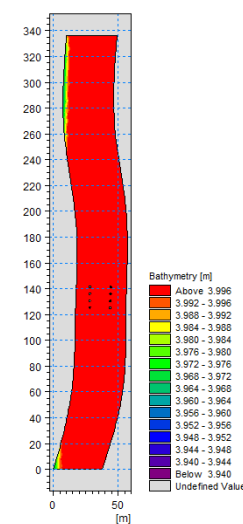


Fig.3. Topographic map of Yumin bridge

### 3.4. Model parameters

According to the "Handbook of Hydraulics Calculation" and the situation of the lining material and the cross-section of the river way, the river way adopts the compound trapezoidal section and the canal bottom adopts the cast-in-place concrete lining with a roughness of 0.017, but the roughness of the river bottom is 0.022. Interlocking prefabricated concrete block slope protection is adopted because the roughness not only depends on the surface smoothness of the prefabricated interlocking concrete block, but also depends on the laying flatness of the interlock prefabricated concrete block slope protection with a roughness of 0.017.

According to the Geological Prospecting Report, the sediment in the study riverbed surface is mainly coarse and coarse sand. The sediment diameter of the riverbed is between 0.1 to 10 mm. Due to the lack of further detailed sediment grading data and sediment particle size distribution information, in the mathematical model of water and sediment, considering the riverbed coarsening, the representative particle size of sediment is selected as  $d_{80} = 1 \text{ mm}$ .

### 3.5. Model verification

Due to the lack of measured flood water level data, this hydrological analysis cites the design flood discharge results in "Zibo High-tech Industrial Development Zone Flood Control and Waterlogging Planning" and uses the results as the verification data of the model. As can be seen from Figure.4, the deviation of the water level calculation results is generally within  $\pm 0.1\text{m}$ , the maximum deviation is 0.03m, and the relative deviation is less than 1%, which meets the simulation calculation requirements. Overall, taking into account the project focus is to calculate changes in water level before and after the project, the calculated deviation is acceptable.

## 4. Numerical Simulation Results Analysis

### 4.1. One flood per 100 years

In this article, the Yumin bridge and bridge section model established the river boundary and bridge piers as the boundary of solid-wall, and set the inlet condition of the model as the flow boundary near the actual water head and the boundary condition of the downstream river outlet as the water level

condition. According to the distribution of flow velocity in Fig.5, before the construction of the bridge, the flow velocity at the entrance of the river way is larger, and the local flow velocity is more than 2 m/s, which is related to the local topography of this section. Other parts of the flow rate is generally between 0.5-2 m/s. After the bridge is built, the flow velocity of the waterway where the piers are located is relatively large, and the local flow velocity is more than 2.5 m/s, which is not only related to the effective flood discharge area occupied by the bridge piers, but also to the local topography of the river. The other part of the flow rate is generally between 1.5 ~ 2.5 m/s.

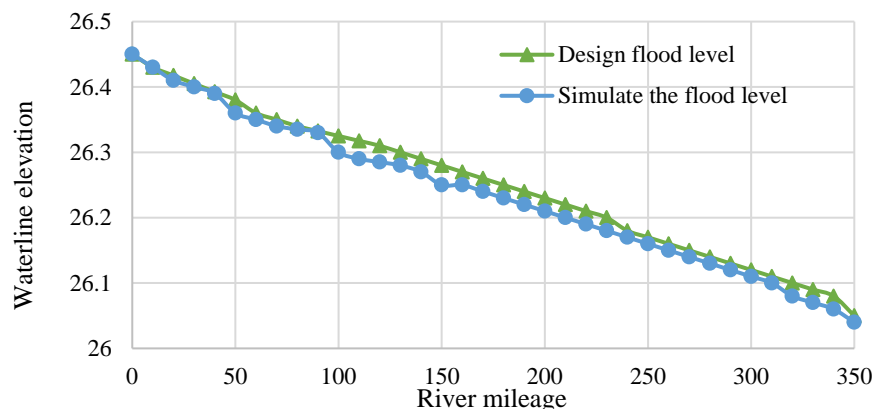


Figure.4. Waterline verification results

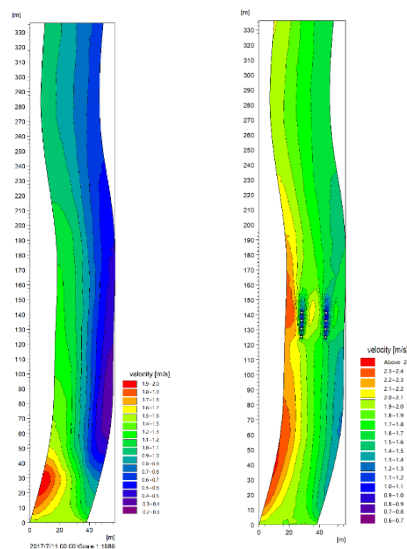


Figure.5. Fore and later of the bridge piers near the water flow velocity distribution

The Yumin Bridge section 100 a flood case, fore and later of the project along the water level changes as shown in Figure.6. As can be seen from the figure, the phenomenon of slush water produced by Yumin Bridge is obvious. The overall sluice water height is not large. The maximum sluice water height is 0.045m, but the slug length is relatively large, which is similar to that of two rows of piers Water blocking effect.

#### 4.2. Erosion and Sedimentation Numerical Simulation of Riverbed

This simulation uses the basic planar two-dimensional shallow water equation and the mathematical model for sediment transport. The simulation results will include both natural and general scouring of

the channel, excluding local scour caused by the three-dimensional water flow. In this simulation, a flood event of 100 years was used and the simulation duration was 24 hours. During this period, the general scouring near the piers has basically finished. According to the construction of nearby river water conservancy projects, flood peak lasted generally within 24 hours, so taking the calculation of 24 hours is reasonable. According to the construction of nearby river water conservancy projects, the surface sediment of the riverbed is coarse sand, and the particle size of sediment in the mathematical model is 1 mm.

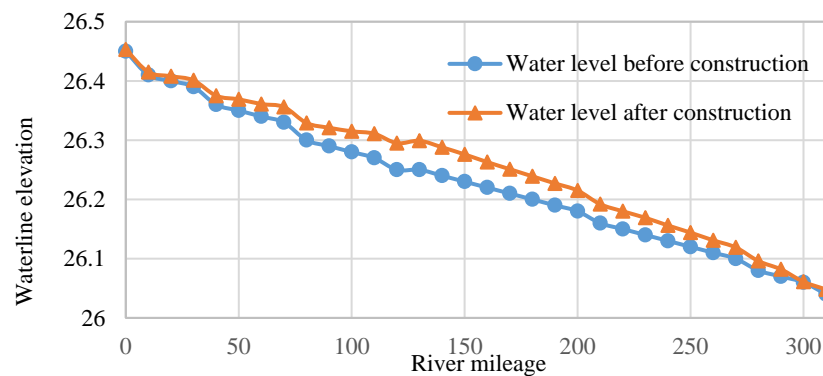


Figure.6 Fore and later of the project changes in water level

Due to the small slope of the calculated section of the river and the small flow velocity value of the river, the sediment transport rate of the river channel is small. From Figure.7, the maximum value is about  $0.05 \text{ m}^3 / (\text{s} \cdot \text{m})$ . The numerical simulation shows that the scour that will appear in this section is not very obvious. In addition, there is a artificial protective bottom in this section and the scouring can not be formed. There is a high risk of scouring downstream of the river bed and river banks on both sides of the bottom of the basement, and protection needs to be strengthened. The riverbed where the project is located is a case of flood and erosion deposition in a flood of 100 years as shown in Figure.8. It can be seen from the simulation results that the maximum depth of riverbed erosion at the pier is about 1.45 m.

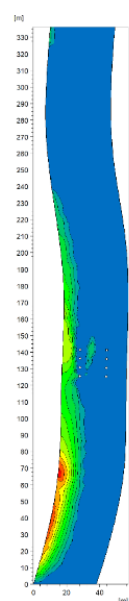


Figure.7.Sediment distribution

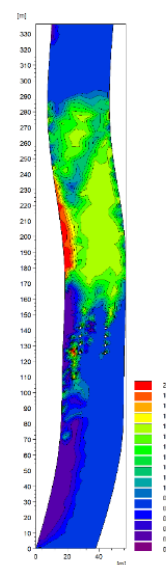


Figure.8. Erosion distribution of the riverbed

## 5. Conclusion

The MIKE 21 numerical model can simulate the complex terrain well. The relative deviation of the model during the calibration and verification is less than 1%. After the completion of the Yumin Bridge, the flow pattern and flow potential of the bridge under the bridge have changed before the construction. The change of the water flow conditions will also make some changes in the slope shape of the upper and lower reaches of the bridge along the river. The decrease of water area, the velocity of the under-bridge and the increase of the velocity of the near shore flow cause the erosion of the slope around the bridge site. Therefore, it has a certain unfavorable effect on the stability of the river and the safety of the slope. The upper reaches of the bridge will have slow sedimentation due to the stagnant water, resulting in the decrease of sediment carrying capacity and the siltation of upstream backwater. However, there is a dynamic balance between water and sediment deposition and erosion, and the riverbed is basically stable, but the overall flow regime of the river channel will not change.

Therefore, for projects under complex terrain conditions or bridges with important flood control tasks in the river, it is suggested to use mathematical models to calculate the water quality in order to obtain more reasonable calculation results and provide basis for flood control impact assessment.

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