

Comparison and analysis of calculation of Bridge backwater based on Mike21 hydrodynamic model

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Abstract: The construction of bridges and other structures across the river will affect the flood discharge capacity and local water potential of the river. Based on Navier-Stokes equation of MIKE21FM hydrodynamic module, this paper carries out two-dimensional numerical simulation of part of Shixi River. By optimizing the grid near the piers to reduce the difference brought by the terrain generalized grid of the real river, it simulates and analyzes the length of the curve of yong-high and Yong-water under different flood frequencies, the Nash-Sutcliffe efficiency coefficient and relative error analysis are used to verify the rationality of the results. The simulation results can accurately reflect the real changes of river water level, It provides a theoretical basis for flood impact analysis.

1 Introduction

At present, scholars at home and abroad have made fruitful research achievements on the impact of Bridges across rivers on river regime and accumulated a lot of engineering experience. They proposed the empirical formula of bridge yong Shui under different working conditions^[1], which has been widely applied in engineering due to its simple form and easy application. With the development of computer technology, the limitations of traditional empirical formulas are gradually revealed, and numerical simulation is developing towards precision and visualization. Mike21, as a bidimensional simulation tool for rivers and lakes, has been widely used and studied in China^[2-5].

Pingshan River is a first-grade tributary of Danshui River, one of the five rivers in Shenzhen. Shixi River is a first-grade tributary of Pingshan River, located in the northeast of Pingshan River basin, originating from Bijia Mountain in Huizhou (elevation 717.5m), and flowing into the main stream of Pingshan River from Tugang Ling downstream. The river length is 12.328km, with an average specific drop of 11.7‰, and the basin area is 23.33km², among which the basin area in Shenzhen is 5.83km². The upper part of Shixi River is located in Daya Bay District, Huizhou, which is known as Shitou River locally. It originates from The Bijia Mountain (elevation 717.5m) bordering Shenhui. From east to west, it flows through Tangheng and Tangbu before entering The territory of Shenzhen. Shitou River is located in Huizhou and has a tributary, about 3.0km in length, with a rainwater harvesting area of about 3.5km².

2 Model selection and model construction

2.1 Model Selection

The commonly used mathematical simulation software for the simulation and analysis of rivers and lakes include MIKE^[6], FLUENT, Hec-RAS^[7], etc., among which MIKE software has been widely applied in flood submergence, water quality analysis of water sources, and flood discharge capacity of river channels, and has accumulated a lot of engineering experience^[8-10].

MIKE21FM model developed by the Danish institute of hydraulic to Saint Venant equations as the basic control equation of the hydrodynamic module is based on the numerical solution of two-dimensional shallow water equation, the integral along the depth of incompressible Reynolds averaged Navier - Stokes equations, can be used to simulate the water level and flow of all kinds of force to produce change, space discrete finite volume method is used to calculate area, has the very good conservation of nature, can accurately process rapids, discontinuous solution.

2.2 Model building

2.2.1. Model calculation range

In order to better study the terrain conditions of the reach, this paper derived the data based on the measured terrain data and combined with Arcgis software elements turning

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points, applied the unstructured grid to process the channel, and interpolated the nearby scattered points through the interpolation method of adjacent points.

2.2.2. Generalizations of main river structures

This simulation area involved a total of the Shixi River Bridge at stake 0+235 and the Shixi River Bridge at stake

0+936.29. Considering that the two bridges are not under water, the generalization of the bridge is changed to the generalization of the bridge piers. The road bridge has a width of 9m and a total of 4 piers. The Shixi River Bridge has a width of 18m and a total of 8 piers, each of which has 4 piers. The distance between single-row piers is 20m.

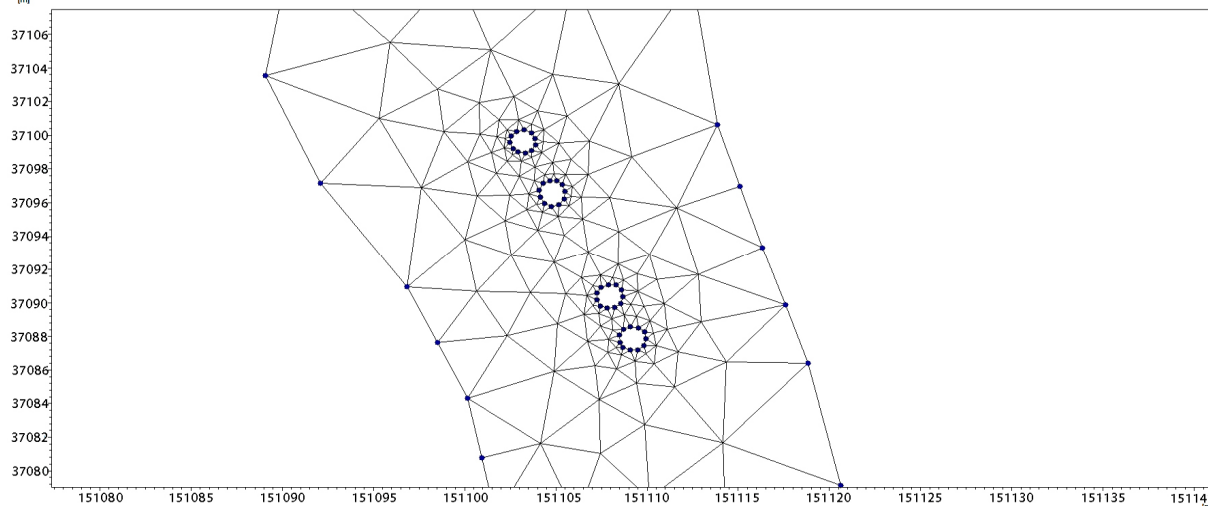


Fig.1 sketch map of Environment bridge

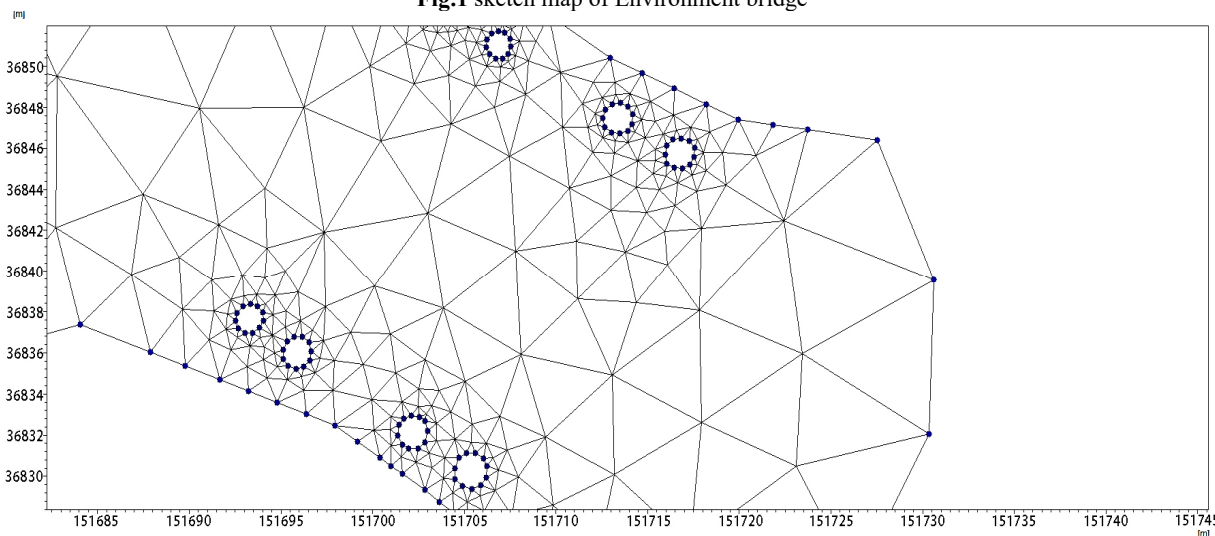


Fig.2 sketch map of Shixi River bridge

2.2.3 Boundary Condition Setting

The boundary condition of the model is the discharge-water level boundary condition. Taking the designed peak discharge of K2 + 144 section as the upper boundary of constant discharge, the once-in-20-year peak discharge of K2 + 144 section is 263.84 m³/s, and the once-in-50-year peak discharge of 318.93 m³/s, respectively, the lower boundary is the water level of K0 + 000 section corresponding to the flood peak discharge.

3 Model simulation validation

The Shixi River has no measured runoff and flood data, so the design flood of every section in the basin is calculated by using the method of indirect derivation of

design flood from design rainstorm, methods Flood Analysis and calculation were carried out by using the method of comprehensive unit hydrograph and the method of inference formula in “the chart of rainstorm runoff check and calculation in Guangdong Province”; The difference between the two methods is less than 20% , so the synthetic unit hydrograph is used. Two methods are proposed for model validation, namely, the relative error value and Nash-Sutcliffe efficiency coefficient.

The relative error calculation formula:

$$RE_p = \frac{|q_t^{obs} - q_t^{sim}|}{H} \times 100\% \quad (1)$$

In the formula, q_t^{obs} is the measured value, m³/s and q_t^{sim} is the simulated value, m³/s. H is average water depth of section.

Nash-Sutcliffe efficiency coefficient formula:

$$R_{NS} = 1 - \frac{\sum_{t=1}^N (q_t^{obs} - q_t^{sim})^2}{\sum_{t=1}^N (q_t^{obs} - q_t^{-obs})^2} \quad (2)$$

In the formula, N is the number of data; q_t^{-obs} is the data mean; the rest of the symbols have the same meaning as before.

In order to test the rationality of the simulation results of this model, the design water level P = 5% flood peak

discharge is taken as an example, taking the design flood peak discharge of K2 + 144 section as the upper boundary of constant flow and the water level of K0 + 000 section corresponding to the flood peak discharge as the lower boundary, the results of water surface profile calculation are compared and analyzed to verify the rationality of the model. The results are shown in Table 1.

Table 1. Comparison of model simulation results and calculation results

Pile number	Location name	Design result/m	Simulation results/m	Error/m	Relative error/%	N-sCoefficient/R _{NS}
0+235.00	Environment bridge	29.630	29.458	0.172	3.59%	0.99
0+300.00		29.720	29.554	0.166	3.52%	
0+400.00		29.750	29.705	0.045	1.02%	
0+500.00		29.750	29.566	0.184	4.28%	
0+600.00		29.770	29.614	0.156	4.04%	
0+700.00		29.820	29.727	0.093	2.47%	
0+799.99		30.070	30.195	-0.125	3.21%	
0+899.99		29.920	29.861	0.059	1.75%	
0+936.29	Shixi River bridge	30.540	30.647	-0.107	2.56%	
0+999.99		30.700	30.599	0.101	2.36%	
1+038.18		31.050	30.904	0.146	3.60%	
1+099.98		31.030	31.013	0.017	0.44%	
1+199.99		31.010	31.127	-0.117	3.31%	
1+299.97		31.030	31.152	-0.122	3.72%	
1+399.97		31.150	31.17	-0.02	0.67%	
1+499.97		31.280	31.376	-0.096	3.36%	
1+599.97		31.790	31.875	-0.085	2.79%	
1+699.95		31.860	31.952	-0.092	3.27%	
1+799.95		32.060	32.118	-0.058	2.16%	
1+823.50		32.080	32.139	-0.059	2.23%	
1+899.94		32.570	32.593	-0.023	0.80%	
1+999.94	33.710	33.601	0.109	2.94%		
2+099.94	33.770	33.633	0.137	3.96%		
2+144.59	33.910	33.875	0.035	1.01%		

From the table, it can be seen that the result of the model is basically consistent with the river topography. The error between the result of the design water surface profile and the result of the simulation water surface profile is -0.125 ~ 0.184, and the Nakhi people efficiency coefficient is more than 0.8 in the verification process, the relative error is between 0.44% and 4.28%, which is less than 5%. The simulation error is small, and the model meets the verification precision. However, due to the lack of data in the river channel, it is inevitable that there will be some errors in the modeling process, resulting in the water surface line and design data can not fully coincide.

4 Calculation result of backwater

4.1 Empirical formula calculation result

Henderson's formula:

$$\Delta Z_M = (1 + \eta) \left(\frac{V_M^2}{2g} - \frac{\bar{V}^2}{2g} \right) \quad (3)$$

In the formula, ΔZ_M denotes the maximum backwater height before the bridge, m; η is the coefficient related to the shape of the pier, the rectangle pier is 0.35, the circle pier is 0.18. V_M is the average velocity under the bridge, m/s; \bar{V} is the average velocity of section, m/s. The formula is proposed by Henderson by analyzing the local energy loss caused by the pier resistance. The research Institute of Railway Bridge in China has verified the rationality of the parameter value of the formula based on a large number of field investigation data^[11].

The backwater curve length is calculated as follows:

Backwater curve length:

$$L = \frac{2 \Delta Z_M}{I} \quad (4)$$

In the formula, I is the natural water surface ratio of the bridge section, and The shixi River Bridge is 1.3‰; Environmental Park Road bridge take 0.55‰.

Table 2. calculation value of backwater experience formula in front of bridge with different frequency

Name of bridge	Flood Frequency	Henderson's formula			Backwater curve length/m
		Pier shape	$(1+\eta)/2g$	Back-up water value/m	

Environment bridge	5%	Circular shape	0.06	0.15	545
	2%	Circular shape	0.06	0.22	800
Shixi River bridge	5%	Circular shape	0.06	0.33	508
	2%	Circular shape	0.06	0.41	631

4.2 Model calculation results

Table 3. calculation values of backwater model in front of bridge with different frequencies

Pile number	Location name	Flood level/m					
		River channel (No Bridge) /m		River channel (Bridge) /m		Back-up water value/m	
		P=2%	P=5%	P=2%	P=5%	P=2%	P=5%
0+235.00	Environment bridge	29.93	29.36	30.07	29.46		
0+300.00		29.97	29.40	30.22	29.55		
0+400.00		30.09	29.59	30.24	29.71	0.14	0.10
0+500.00		30.11	29.47	30.24	29.57	0.25	0.15
0+600.00		30.17	29.56	30.13	29.61	0.15	0.12
0+700.00		30.25	29.71	30.25	29.73	0.13	0.10
0+799.99		30.44	30.19	30.47	30.20	0.08	0.05
0+899.99		30.27	29.86	30.28	29.86	0.06	0.02
0+936.29		30.87	30.45	31.00	30.65	0.03	0.01
0+999.99		30.97	30.35	31.19	30.60	0.01	
1+038.18	Shixi River bridge	30.98	30.56	31.40	30.90	0.13	0.20
1+099.98		31.01	30.73	31.37	31.01	0.22	0.25
1+199.99		31.10	30.91	31.35	31.13	0.42	0.34
1+299.97		31.07	30.89	31.37	31.15	0.36	0.28
1+399.97		31.18	31.07	31.28	31.17	0.25	0.22
1+499.97		31.69	31.38	31.74	31.38	0.30	0.26
1+599.97		32.07	31.88	32.10	31.88	0.10	0.10
1+699.95		32.09	31.95	32.11	31.95	0.05	
1+799.95		32.27	32.12	32.29	32.12	0.03	
1+823.50		32.33	32.14	32.33	32.14	0.02	
1+899.94	32.90	32.59	32.90	32.59	0.02		
1+999.94	34.15	33.60	34.15	33.60			
2+099.94	34.21	33.63	34.21	33.63			
2+144.59	34.37	33.88	34.37	33.88			

From the above data, it can be seen that the bridge pier reduces the flow area under the bridge and causes the upper reaches of the bridge to Produce backwater. From Table 2 and Table 3, it can be seen that the back-up water value of the Environment Garden Road Bridge is 0.15 m once flood in 20 years through the empirical formula, the results are consistent with the model simulation. The back-up water value of the 50-year flood is 0.22 m, the model simulation result is 0.25 m, the back-up water value of the 20-year flood is 0.33 m, the model simulation result is 0.34 m, the 50-year back-up water value of the 50-year flood is 0.41 m, the result of the model is 0.42 m, and the result of the empirical formula is consistent with that of the model. According to the above data, the result of the model is slightly higher than that of the empirical formula, its error may be due to the lack of complex river terrain information, but its error is within the controllable range, the specific data as shown in the table above.

5 Conclusion

Taking some sections of the Shixi River as an example, the MIKE21 hydrodynamic model is established to simulate the flood-carrying capacity of the river under the flood frequency of $P = 2\%$ and $P = 5\%$, and the situation of the backwater of the two bridges in the river channel, compared with the calculated results of the empirical formula, the error of the model is reasonable, and its yong-gao value is within a reasonable range, which shows that the model is reliable and can reflect the influence of different frequency floods on the river course, at the same time, the model can clearly reflect the changes of water level, flow velocity and flow field near the bridge, and can provide technical support for engineering decision.

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