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HYDRAULIC SIMULATION IN WATER ENVIRONMENT HARNESSING FOR TIDAL RIVER NETWORK

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Abstract: Based on the Saint-Venant equations, a 1-D river network numerical model has been developed, in which a junction control method for water level is used. In order to improve the computational stability and accuracy, the Preissmann's four points implicit difference scheme is used in the model. Owing to the hydraulic structure such as the water gate exited in rivers, the discharge formulas of different kind of hydraulic structures are adopted and its continuity equations are discretized to the same form as that of Saint Venant equations, which are convenient for solving the equation groups as one unity. The model has been applied to hydraulic simulation in water environment harnessing for Zhangjiagang River Network that is a typical tidal River Network. The results can be provided as design basis for engineering.

Key words: Water environment harnessing, Tidal river network, Junction control method, 1-D numerical model

1. INTRODUCTION

In the lower reaches of the Yangtze River, River Network is normally affected by the runoff and the tide in common. Zhang Jiagang River Network is such a typical tidal River Network,which is mainly consisted of Chao Dong Wei Gang River, Yi Gan River, Er Gan River and You Che Gang River, intaking from south to north into the Yangtze River. Those rivers are mainly connected by South Heng Tao River, East Heng River, Gu Dou Gang River, Xin Shi River, Xin Feng River and Bai Zhi Gang River. The East Heng River, Gu Dou Gang River and Xin Shi River pass through the Zhang Jia Gang city zone (See Fig.1). With the increment of water demand to industry and agriculture as well as the raising of mankind's requirement for environment, water environmental problem especially in urban area is increasingly attentive. Plenty of works have been made such as decreasing the discharge of polluted water and handling sewage. In fact, it also is an available approach that the clean water drawn from the Yangtze River is used to displace the sewage and make the water quality of river course in urban clean as soon as possible. In this method, it is asked to renovate the existing waterways and manage scientifically the flash-locks according to the tidal level changing. Therefore it is necessary to study the plan and the control of tidal river network system.

Then, a 1-D river network numerical model is presented. In this model, different kinds of discharge formulas are adopted for the diversity of hydraulic structures in rivers such as the water gates, but the continuity equations are discreted the same form as that of Saint Venant equations, which are convenient for solving the equation groups as one unity. In order to improve the computational stability and accuracy the Preissmann's four points implicit difference scheme is used. In addition, a junction control method on water level for 1-D model is established (Zhu, Zhang and Mao, 1995). The water level and discharge of 1-D model are obtained by solving the irregular spare matrix equations and utilizing the transforms of the single river finite-difference equations. Application of the 1-D model to the

Zhang Jia Gang River network has been carried out. The results of hydraulic simulation including several cases can be provided as basis for water environment harnessing.

2. THE RIVER NETWORK MODEL

As mentioned above, a junction control method for water level is established in the model. So all those river junctions' water level are obtained by solving a irregular matrix equation, and then the water level at all single river nodes are gotten by the solution algorithm for the single river. This model is applicable to all river network types.

2.1 GOVERING EQUATIONS

Generally varied unsteady flow in an open channel can be described mathematically by the well-known Saint-Venant equations. These equations are written as follows.

Continuity equation:

$$\frac{\partial Q}{\partial x} + B_w \frac{\partial Z}{\partial t} = q \tag{1}$$

Momentum equation:

$$\frac{\partial Q}{\partial t} + 2u\frac{\partial Q}{\partial x} + (gA - Bu^2)\frac{\partial Z}{\partial x} - u^2\frac{\partial A}{\partial x} + g\frac{n^2|u|Q}{R^{4/3}} = 0 \tag{2}$$

where t=time; A=cross-sectional area; Q=discharge; q=lateral flow; Z=water surface level; B= water surface width; R=hydraulic radius; u = water velocity; g=gravitational acceleration; n= Manning roughness coefficient;

2.2 THE FINITE-DIFFERENCE EQUATIONS

In a single river without branch, the finite-difference equations for one river segment from node (i) to (i+1) are obtained by using Preissmann's four-point implicit difference scheme. For each river segment, there are two equations, which are written as

$$C_i Z_i^{j+1} + C_i Z_{i+1}^{j+1} - Q_i^{j+1} + Q_{i+1}^{j+1} = D_i \tag{3}$$

$$E_i Q_i^{j+1} + G_i Q_{i+1}^{j+1} - F_i Z_i^{j+1} + I_i Z_{i+1}^{j+1} = H_i \tag{4}$$

where $C_i = B_{wi+1/2}^{j}\frac{\Delta x_i}{2\theta\Delta t}$; $D_i = \frac{(1-\theta)}{\theta}(Q_i^j - Q_{i+1}^j) + C_i(Z_i^j + Z_{i+1}^j) + q_i\frac{\Delta x_i}{\theta}$;

$$E_i = \frac{\Delta x_i}{2\theta\Delta t} - 2u_{i+1/2}^j + \frac{g\Delta x_i}{2\theta}\left(\frac{n^2|u|}{R^{4/3}}\right)_i^j ;\quad F_i = I_i = (gA - Bu^2)_{i+1/2}^j = gA_{i+1/2}^j - B_{i+1/2}^j\cdot(u_{i+1/2}^2)^j ;$$

$$G_i = \frac{\Delta x_i}{2\theta\Delta t} + 2u_{i+1/2}^j + \frac{g\Delta x_i}{2\theta}\left(\frac{n^2|u|}{R^{4/3}}\right)_{i+1}^j ;$$

$$H_i = \frac{\Delta x_i}{2\theta\Delta t}(Q_i^j + Q_{i+1}^j) + \frac{2(1-\theta)}{\theta}u_{i+1/2}^j(Q_i^j - Q_{i+1}^j) + \frac{(1-\theta)}{\theta}(gA - Bu^2)_{i+1/2}^j(Z_i^j - Z_{i+1}^j) + \frac{\Delta x_i}{\theta}\left(u^2\frac{\partial A}{\partial x}\right)_{i+1/2}^j .$$

2.3 BOUNDARY CONDITION

At the inlet or outlet, the known boundary values such as the discharges $Q(t)$ or the water elevations are prescribed with time.

The Saint-Venant is not satisfying because of the sharply change of water elevation in the place of the hydraulic structures,. However, the flows on the two sides of hydraulic structure are still kept conservation and the continuity equation can be written as follows.

$$-Q_i^{j+1} + Q_{i+1}^{j+1} = 0 \tag{5}$$

Where i is denoted as the upstream sides of hydro-structure and i+1 is denoted as the downstream sides.

On the other hand, the discharge formulas of the hydro-structure can be derived as follows.

$$\Delta Q = \frac{\partial Q}{\partial z_i}\Delta z_i + \frac{\partial Q}{\partial z_{i+1}}\Delta z_{i+1} \tag{6}$$

Such as weir formulas (Xu, Hu and Xue,1990), when the water level of the upstream sides of hydro-structure is more higher, then the equation (6) is expressed as:

$$Q_i^{j+1} - \left[\frac{\partial(B_o\sigma\varepsilon m\sqrt{2g}H_o^{\frac{3}{2}})_i}{\partial z_i}\right]^j Z_i^{j+1} - \left[\frac{\partial(B_o\sigma\varepsilon m\sqrt{2g}H_o^{\frac{3}{2}})_i}{\partial z_{i+1}}\right]^j Z_{i+1}^{j+1} = H'_i \tag{6'a}$$

$$H'_i = \left[B_o\sigma\varepsilon m\sqrt{2g}H_o^{\frac{3}{2}}\right]_i^j - \left[\frac{\partial(B_o\sigma\varepsilon m\sqrt{2g}H_o^{\frac{3}{2}})_i}{\partial z_i}\right]^j z_i^j - \left[\frac{\partial(B_o\sigma\varepsilon m\sqrt{2g}H_o^{\frac{3}{2}})_i}{\partial z_{i+1}}\right]^j z_{i+1}^j 。$$

Whereas, the Equation (8) can be written as:

$$Q_{i+1}^{j+1} - \left[\frac{\partial(B_o\sigma\varepsilon m\sqrt{2g}H_o^{\frac{3}{2}})_{i+1}}{\partial z_i}\right]^j Z_i^{j+1} + \left[\frac{\partial(B_o\sigma\varepsilon m\sqrt{2g}H_o^{\frac{3}{2}})_{i+1}}{\partial z_{i+1}}\right]^j Z_{i+1}^{j+1} = H''_i \tag{6'b}$$

$$H''_i = -\left[B_o\sigma\varepsilon m\sqrt{2g}H_o^{\frac{3}{2}}\right]_{i+1}^j + \left[\frac{\partial(B_o\sigma\varepsilon m\sqrt{2g}H_o^{\frac{3}{2}})_{i+1}}{\partial z_i}\right]^j z_i^j + \left[\frac{\partial(B_o\sigma\varepsilon m\sqrt{2g}H_o^{\frac{3}{2}})_{i+1}}{\partial z_{i+1}}\right]^j z_{i+1}^j 。$$

Where B_o=weir width; σ=submergence coefficient; ε=side contraction coefficient; m=discharge coefficient; H_0=head of the higher water level; h_s=head of the lower water level.

2.4 TRANSFORMS OF THE FINITE-DIFFERENCE EQUATIONS

Every single river is divided into several river segments and every segment has the two equations (3) and (4). The variables, Z_i^{n+1} and Q_i^{n+1}, are overlapped at the cross section between every two segments and can be expressed by the boundary variables of every single river. The forms transformed as follows:

$$Q_i = f_1(z_i, z_{num+1}) \quad (i=\text{num, num-1, ……,1}) \tag{7}$$

$$Q_{i+1} = f_2(z_{i+1}, z_1) \quad (i=\text{1, 2, 3……,num}) \tag{8}$$

Hydraulic conditions at the river junction of river network may be described by equations of mass and energy conservation. Assuming no change in storage volume and energy, the continuity equation and the energy equation can be approximated as (Akan and Yen,1981)

$$\left[\sum_{I=1}^{NR} Q_I\right]_K = 0 \tag{9}$$

$$Z_{in} = Z_{out}, \tag{10}$$

where K= the K-th river junction; NR=the number of single rivers connecting to the K-th junction; Q_I=the inlet or outlet discharge at corresponding junction. in and out stand for any one of the incoming and outflow rivers, respectively.

If there are M river junctions in a river networks, utilizing the equation (3)-(4) or (6)-(7), equation (9)-(10) and considering the boundary conditions, the control equations for junctions' water level can be written in matrix notation as

$$[A]\{Z\} = \{B\} \tag{11}$$

where $[A]$ is the M×M coefficient matrix, $\{B\}$ is a vector of intercept values, $[A]$ and $\{B\}$ can be obtained through equation (9), and $\{Z\}$ is the vector of unknowns(all junctions' water level). Solving the equations (10), the water level of all river junctions can be gotten, then all single river's boundary conditions are known. Finally, by the single river equation (3)-(4) or (6)-(7), Z^{n+1} and Q^{n+1} at all nodes are obtained.

3. MODEL APPLICATION TO THE ZHANG JIA GANG RIVER NETWORK

3.1 COMPUTATIONAL RANGE AND PARAMETERS

The computational region covers the most rivers of the Zhang Jiang Gang River network. That includes Yi Gan river, Chao Chong Wei Gang River, South Heng Tao River, East Heng River, Xin Si River, Gu Dou Gang River, Xin Shi River, Xin Sha River, Gao Bei Tang River, Bai Zhi Gang River, Hua Yuan Pang River, Xin Feng River, He Xin Heng Tao River, Yue Lai Hneg Tao River, Fan Gang River and Da Zha River (see Fig.1, The doted lines are denoted to the new rivers dredged in future). The total length of this part is about 84 km. This river network which consist of 57 interior rivers and 32 river junctions, is such an example that adopts the model above. These river segments vary from 20 m to 300 m in length and the time step Δt is set to be 5s.

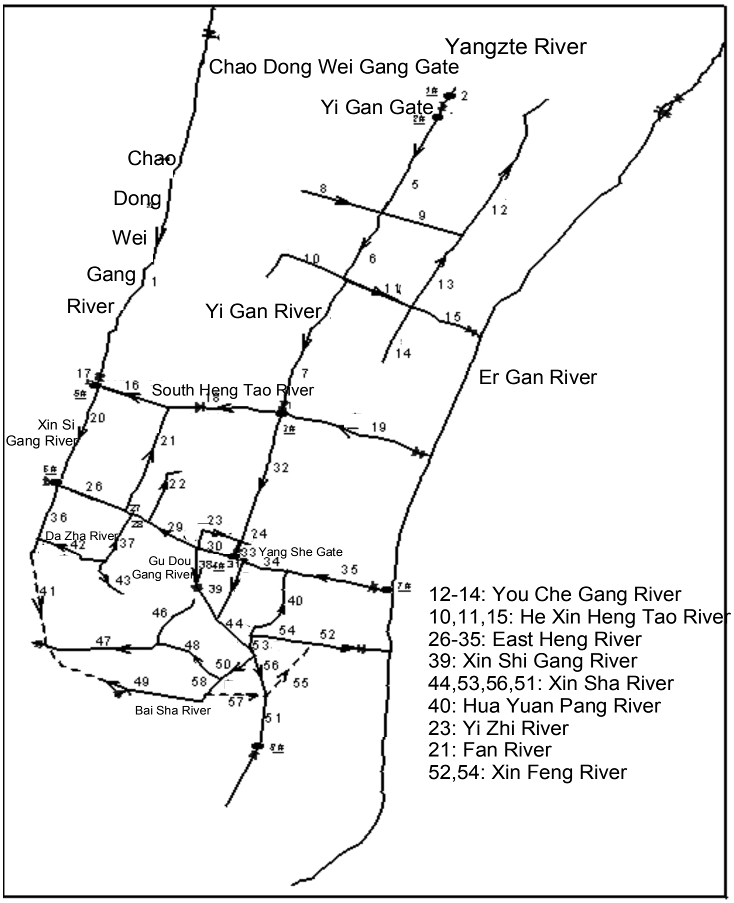
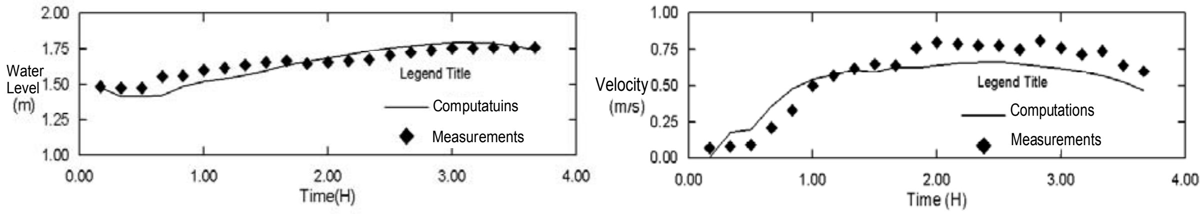


Fig. 1 Map of the Zhang Jia Gang River Networks

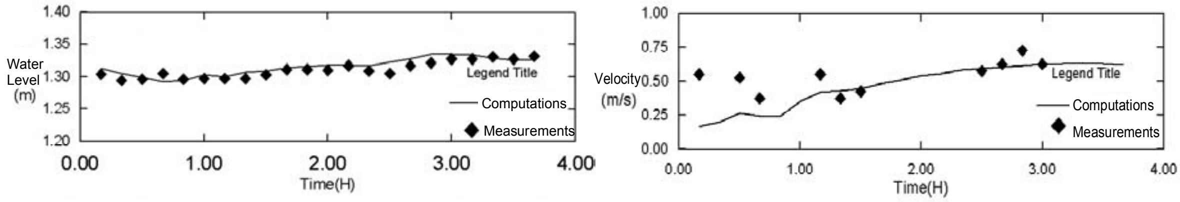
3.2 VERIFICATION OF MODEL

The data from field measurements on the present river networks, including the water levels and velocities of point 3# and point 4# in fig.1, are employed to verify the model offered above.

Fig. 2 and 3 demonstrate the comparisons of the field survey data and the computational results of the tidal level and the flow velocities. As shown in those figures, satisfactory agreements are obtained.



(a) 3#



(b) 4#

Fig. 2 Verification of water level and velocity at the point 3# and 4#

3.3 COMPUTATIONS AND ANALYSIS

3.3.1 Principles in water environment harnessing

On the ground of the principles, the clean water is drawn from the Yangtze River into Yi Gan River and Chao Dong Wei Gang River and the sewage is discharged into the Er Gan River from Xin Feng River and East Heng River. According to the analysis for the water environment of this area, it needs about 2509 thousand m^3 clean water drawn to replace the sewage and make the water quality attain the third criterion. On the other hand, the water level in the city zone can't be more than 3.8m for the limit of the navigation and the effluent.

3.3.2 Study case 1

In the old plan, the Yangse Gate will be moved from the present location to the north of point 3#. In order to decide whether the plan is rational, the discharge absorbed by the use of tidal level change is computed for the two cases (moving and not moving the gate). The computations are done in a closed river networks that Chao Dong Wei Gang Gate, both ends of South Heng Tao River and Dong Heng River, the south end of Xin Sha river are closed. The tidal level change in the inlet comes from field measurement from 23 to 24 July 2001.The results are showed in Table 1.

Table 1 Comparison of water level and discharge in different condition

Condition		Not to dredge the Yi Gan River						Dredge the Yi Gan River	
		Not to move the gate		Move the gate				from Yi Gan River and Chao Dong Wei Gang River	from Yi Gan River only
		from Yi Gan River and Chao Dong Wei Gang River	from Yi Gan River only	Gate width 6m		Gate width 10m			
Max water level of Yi Gan River	A(m)	5.003	4.99	5.256	5.256	5.077	5.066	5.026	5.026
	4#(m)	4.347	4.092	4.199	4.092	4.31	4.094	4.447	4.12
Discharge (thousand, m^3)	Yi Gan River	2159	2215	1835	1834	2099	21133	2469	2492
	Chao Dong Wei Gang River	889	0	898	0	892	0	883	0
	Total discharge	3085	2215	2732	1834	2992	2113.3	3353	2492

From the table, moving the Yang Se Gate to the new place will give rise to raise the water level and reduce the intake. The wastewater in the river network can't be displaced fully. So the Yang Se Gate should not be moved to the point 3#.

3.3.3 Study case 2

The second problem is to know the influence to discharge absorbed when the Yi Gan River is dredged deeper 1m. Two cases including dredging and no dredging are simulated and compared. The result shows that the volume of absorbed water is increased from 3085 thousand m^3 to 3353 thousand m^3 after dredging (see Table 1). The influence is remarkable.

3.3.4 Study case 3

Table 2 Comparison of time and discharge

Operating model		The time when closing gates		The total volume absorbed when closing gates			The time when the volume absorbed up to 2509 thousand m^3	The hours for absorb -ing water up to 2509 thousand m^3	The time as begin -ing to dewater	The time when the volume dewatered up to 2509 thousand m^3	The hours for dewater -ing
		Yi Gan River	Chao Dong Wei Gang River	Yi Gan River	Chao Dong Wei Gang River	The total volume of the two rivers left					
		(Hour)	(Hour)	(×1000 m^3)	(×1000 m^3)	(×1000 m^3)	(Hour)	(Hour)	(Hour)	(Hour)	(Hour)
Tidal 1	Open Chao Dong Wei Gang Gate	0	4.23	0	90.57	90.57	48.39	44.54	26.19	51.74	25.55
	Open Yi gan Gate	4.54	0	221.5	0	221.5	3.425	0	3.74	14.23	10.52
	Open two Gate	4.84	4.186	202.9	89.3	294.6	11.68	8.17	4.54	18.90	14.44
Tidal 2	Open Chao Dong Wei Gang Gate	0	4.29	0	61.38	61.36	56.75	52.64	35.21	60.125	24.91
	Open Yi gan Gate	4.503	0	148.9	0	148.91	10.108	11.81	4.49	18.05	13.56
	Open two Gate	4.502	4.075	147.03	59.9	208.4	31.9	28.33	9.92	32.96	23.04

The third case is to compute the spending time that clean water absorbed is up to 2509 thousand m^3 and the velocity in the rivers of city zone. There are 2 hydrometric boundary conditions each including 3 working states. The hydrometric boundary conditions are as follows: the tidal 1 measured from 23 to 24 July 2001 and the tidal 2 measured on 8 June 2001. The 3 states for operating Gate are as follows: the two gates comprised Chao Dong Wei Gang Gate and Yi Gan Gate are opened at the same time, only Chao Dong Wei Gang Gate is open and only Yi Gan Gate is opened. When the water level in Yangtse River is lower than that in river network, the two gates are closed and the water pumps begin to pump from Yangtse river, at the same time, the other two gates located at the east end of Xin Feng River and East Heng River are opened for dewatering. The results show in the table 2. The Figure illustrates that the discharge absorbed through tidal is much more and the time for pumping is more less when the two gates are opened at same time.

3.3.5 Study case 4

This part is to compute the velocities and discharges in three rivers crossing Zhang Jia Gang city zone. The hydrometric and operating conditions are the same as the above. In addition, the water level in city zone can't be exceeded to 3.8 m. Otherwise the two gates for drainage must be opened and one of gate in outlet be closed. The comparison of water level, velocity and discharge in different condition is show in table 3. From the results, the velocities and discharges are up to 0.1-0.20m/s and 10-20 m^3/s except in the Gu Dou Gang River that is beneficial to the water quality in city zone.

Table 3 Comparison of water level, velocity and discharge in different condition

	River	Tidal 1			Tidal 2		
		Two gates	Yi Gan Gate	Chao Dong Wei gang Gate	Two gateS	Yi Gan gate	Chao Dong Wei gang Gate
Max water level (m)	East Heng River	3.965	3.809	3.749	3.801	3.76	3.76
	Gu Dou Gang River	3.953	3.786	3.747	3.785	3.757	3.766
	Xin Shi River	3.956	3.79	3.746	3.777	3.765	3.768
Average velocity (m/s)	East Heng River	0.207	0.117	0.143	0.117	0.128	0.143
	Gu Dou Gang River	0.059	0.03	0.039	0.03	0.033	0.038
	Xin Shi River	0.226	0.149	0.104	0.149	0.114	0.104
Average discharge (thousand m^3)	East Heng River	239.53	130.68	139.7	130.68	128.84	141.06
	Gu Dou Gang River	44.69	20.2	23.52	20.2	20.29	23.51
	Xin Shi River	321.83	191.41	120.47	191.41	133.6	121.73

4. CONCLUSION

A 1-D river network model is established on a junction control method for water level and applied to the Zhang Jia Gang River networks, which is capable of predicting 1-D unsteady flow. Comparisons of computational results and field data demonstrate that the present model is efficient and applicable. The model can be applied to studing the environment-harnessing project in river networks.

Case studies show that the Yang She Gate should not be moved to the new location and the two gates for diversion should be open at same time so that more wastewater can be displaced by clean water. The results can be provided as design basis for project.

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