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FLOOD ROUTING MODELS IN CONFLUENT AND DIVIDING CHANNELS *

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Abstract: By introducing a water depth connecting formula, the hydraulic equations in the dividing channel system were coupled and the relation of discharge distribution between the branches of the dividing channels can be yielded. In this manner, a numerical model for the confluent channels was established to study the variation of backwater effects with the parameters in the channel junction. The meeting of flood peaks in the mainstream and tributary can be analyzed with this model. The flood peak meeting is found to be a major factor for the extremely high water level in the mainstream during the 1998 Yangtze River flood. Subsequently the variations of discharge distribution and water level with channel parameters between each branch in this system were studied as well. As a result, flood evolution caused by Jingjiang River shortcut and sediment deposition in the entrance of dividing channels of the Yangtze River may be qualitatively elucidated. It is suggested to be an effective measure for flood mitigation to enhance regulation capability of reservoirs available upstream of the tributaries and harness branch entrance channels.

Key words: confluent channels; dividing channels; backwater effect; flood peak meeting; the Yangtze River

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Introduction

The confluent channels together with dividing channels are called channel junctions in hydraulics, which are the most common phenomena in natural water systems and open channels. Many works have been carried out since Taylor[1] studied the flow characters of channel junctions. The representative researches aiming at one-dimensional characters in confluent channels are: Ramamurthy[2] (1988) investigated the backwater effects in confluent channels with right confluent angles; Ni Jin-ren[3] (1992) inspected the relations of backwater effect with the confluent ratio and confluent angle; Hsu[4] (1998) examined the water depth ratio, flow detached area and contract coefficients in right angle confluent channels; Hsu[5] (1998) considered cases

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with confluent angles of 30°, 45° and 60° respectively based on the previous research, and came to the conclusion that the depth ratio increases with the confluent angle, lateral inflow and the Froude number at downstream end of the mainstream. As there are many parameters in a confluent channel system, certain simplification should be made to facilitate analyzing the backwater effects in the confluent channels. The discharge distribution problem in the dividing channels seems to be easier, but it has not been solved entirely yet, especially for the rule of discharge distribution. Available studies on this issue are: Lakshmana[6] (1966) investigated the relation of discharge distribution ratio with the Froude number downstream, channel lengths and channel widths; Ramamurthy[7,8] (1988, 1990) found the relation of discharge distribution with the water depth ratio and Froude number; Chen Li[9] (2001) proposed a simple formula to calculate the discharge distribution ratio in dividing channel.

According to the actual circumstances of the Yangtze River flood disasters, the most serious problem for confluent channels is the flood peak meeting, which characterizes the floods in 1998 and previous history record (Ji Xue-wu 1999[10], Li An-tian 1999[11]). On the other hand, the discharge distribution remains a fundamental problem in discrepancy. Ji Xue-wu (1999)[10] pointed out that the shortcut of Jingjiang River reduces its dividing channels discharge and increases the discharge and waterlevel in the mainstream. On the contrary, Duan Wen-zhong (2001)[12] deemed that the shortcut of Jingjiang River cut down the waterlevel in the mainstream. Hence, it is still open to the people in hydraulic community whether the shortcut of Jingjiang River is favorable for the flood prevention of the Yangtze River or not.

In the present paper a numerical model is established to study the backwater effects of the confluent channel, in which the flow is assumed unsteady and the bed resistance and slope are nonzero. The flood peak meeting of confluent channels in the Yangtze River is further discussed. It is found that the flood peak meeting is a crucial factor responsible for the high waterlevel during 1998's Yangtze River flood. By introducing a water depth connecting equation, the variation of discharge distribution and waterlevel with channel parameters can be analyzed, and the cause for the water movement change induced by the Jingjiang River shortcut and sediments deposition in the dividing rivers of the Yangtze River can be qualitatively explained.

1 Models and Validation

1.1 Confluent channel model

Figure 1 shows a confluent model, in which *ABCD* is the confluent unit, Q_1 and Q_2 the upstream discharges of the mainstream and branch, respectively; Q_3 the discharge downstream the confluent unit, θ the confluent angle, B_1 and B_2 the river widths for the mainstream and branch, respectively. The length of the confluent unit is $\Delta l = B_2/\sin\theta$. Both the cross-sections of the mainstream and branch are assumed to be rectangular. The water depth that near section *AB* upstream the mainstream, near section *BC* upstream the branch, and near section *CD* downstream the mainstream is h_1, h_2 and h_3, respectively. To study the variation of backwater effects with confluent angle, one-dimensional *Saint-Venant* equations with source terms are adopted as follows:

$$\frac{\partial Q}{\partial x} + B\frac{\partial y}{\partial t} = q_l, \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) = -gA\left(\frac{\partial y}{\partial x} + S_f\right) + q_l u_q, \quad (2)$$

where Q is the mean discharge of the cross-section (m^3/s), y waterlevel (m), A the wetted cross-sectional area (m^2), B the river width, x the distance along the channel, q_l denotes the lateral discharge in unit width (m^2/s), u_q the lateral velocity component in the mainstream flow direction (m/s), g the gravitational acceleration. In Eq. (2) values of q_l and u_q are 0 in the river units except for confluent unit.

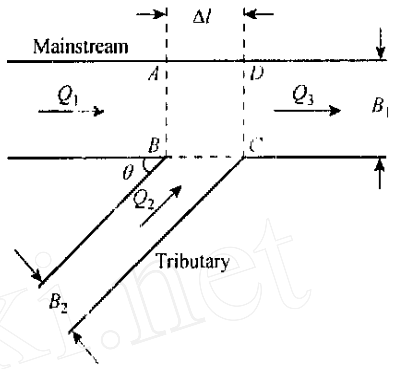

Fig. 1 Schematic of confluent channels model

Both the mainstream and branch are divided uniformly into one-dimensional mesh cells, of which the length is 1 km. The confluent river area is considered to be one grid unit. The conventional four-point partial implicit scheme is adopted to solve the above equations. The time step is 600 seconds.

1.2 Boundary and connecting conditions

Upstream boundary conditions: both mainstream and branch are $Q = f(t)$.

Downstream boundary condition: the relation between waterlevel and discharge, $Q = f(y)$, derived from *Manning* equation can be written as follows:

$$Q = \frac{\sqrt{S_0}}{n} \frac{(A/h)^{5/3}}{(\chi/h)^{2/3}}(y - z), \quad (3)$$

in which χ is the wetted perimeter (m), $\chi(y) = b + 2h$; b the bottom width of the cross-section (m), h the depth (m), $h(y) = y - z$, y waterlevel (m), z the height of the river bed (m), S_0 the river slope, n the *Manning* coefficient. Waterlevel y_2 at border BC of the confluent unit is regarded as the downstream condition of the branch, and its value is set to be the average of y_1 and y_3, upstream and downstream the confluent unit of the mainstream in the last time step.

1.3 Validation of the confluent model

Figures 2 and 3 provide the boundary conditions in the computation, the discharge courses at Yichang station of the Yangtze River and Changyang statiion of the Qingjiang River,

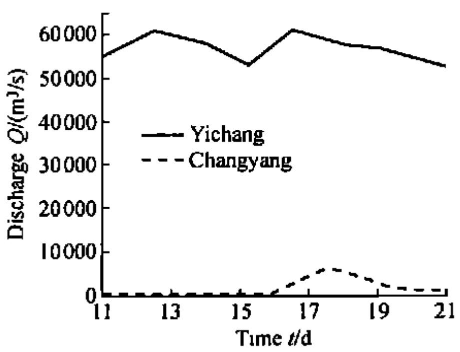

Fig.2 Discharge at Yichang and Changyang stations

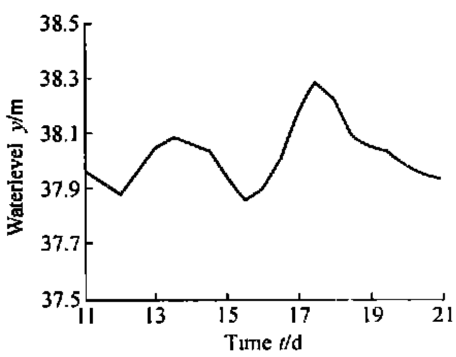

Fig.3 Waterlevel at Jianli station

and the waterlevel course at Jianli station of the Yangtze River , during the period from 11th to 21st August in 1998. *Manning* roughness coefficient is set to be 0.015. Fig. 4 and Fig. 5 show the comparison of the numerical simulation and observation for the waterlevel at Yichang and Shashi stations , respectively. It can be found from these two figures that the numerical results accord well with the observation.

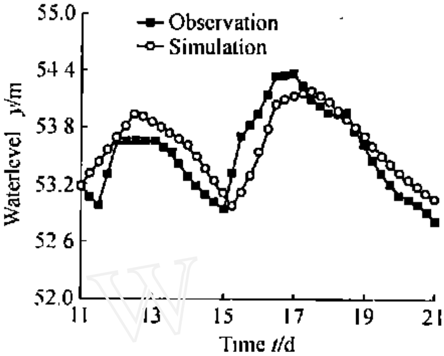

Fig. 4 Comparison of numerical and observation results for waterlevel at Yichang station

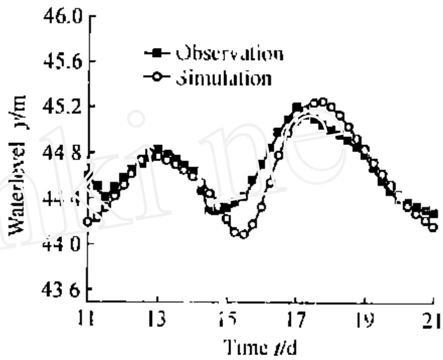

Fig. 5 Comparison of numerical and observation results for waterlevel at Shashi station

1.4 Dividing channel model

Figure 6 is a sketch for the dividing channel model with bed height difference , in which *AB* is the mainstream , *B* is the crotch through which the water in the mainstream flows into branches *BC* and *BD*; *C* and *D* are the downstream ends of the branches , respectively. The difference between the two branch beds at point *B* is Δz. The bed of branch *BC* is connected to mainstream *AB*. *ab* , *bc* and *bd* are steady water surface line in channel *AB* , *BC* and *BD* , respectively.

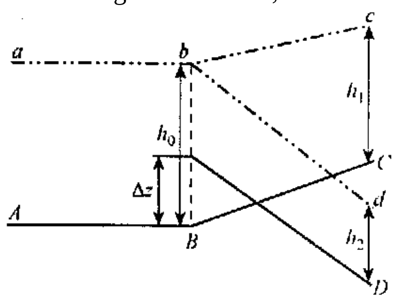

Fig. 6 Dividing channels model with discordant beds

To begin with , the governing equations in hydraulics we may utilize later are listed below. The continuous equation in steady state can be written as

$$Q_1 + Q_2 = Q_0 , \qquad (4)$$

where Q_0 , Q_1 and Q_2 are the steady discharge values for the mainstream and branch *BC* and *BD* , respectively. According to the steady gradually varying flow theory[13] in open channels , *Manning* equations at bound *C* and *D* can be expressed by

$$Q_1 = \frac{B_1}{n_1} \sqrt{i_1 - (1 - Fr_1^2)\, h_{1s_1}}\, h_1^{5/3} , \quad Q_2 = \frac{B_2}{n_2} \sqrt{i_2 - (1 - Fr_2^2)\, h_{2s_2}}\, h_2^{5/3} , \qquad (5a, b)$$

in which i_1 , i_2 , h_{1s_1} , h_{2s_2} , s_1 , s_2 , Fr_1 , Fr_2 , n_1 , n_2 , B_1 , B_2 , h_1 , h_2 , J_{f1} and J_{f2} are the bed slopes , depth slopes at downstream ends , flowing directions and Froude numbers , roughness coefficients , river widths , depths at downstream ends and friction slopes for channel *BC* and *BD* , respectively. *Fr* is the Froude number defined by $Fr^2 = Q^2/(B^2 g h^3)$.

In dividing channels *ABCD* , there are three equations (seen in Eqs. (4) and (5a ,b)) , but the number of the parameters (Q_1, Q_2, h_{1s_1} and h_{2s_2}) is four. A depth connecting equation is further introduced in this paper according to the geometrical characters of the dividing channels. Thus, the number of equations and variables are kept the same. From Fig.6 we can find such a geometrical relation as follows:

$$h_0 = h_1 - \alpha_1 L_1 h_{1s_1} = h_2 - \alpha_2 L_2 h_{2s_2} + \Delta z, \tag{6}$$

where h_0 is the depth at crotch B, L_1 and L_2 are the river lengths for channel BC and BD, respectively. Parameters α_1 and α_2 are defined as the correctional factors for the average depth gradients along the distance of channel BC and BD, respectively; $\alpha_1 = \overline{h}_{s_1}/h_{1s_1}$, $\alpha_2 = \overline{h}_{s_2}/h_{2s_2}$; $\overline{h}_{s_1}$ together with $\overline{h}_{s_2}$ are average depth gradients along the distance for channel BC and BD, respectively; $\overline{h}_{s_1} = (h_1 - h_0)/L_1$, $\overline{h}_{s_2} = [h_2 - (h_0 - \Delta z)]/L_2$.

If α_1 and α_2 are given, the number of unknown variables in Eqs. (4), (5a, b) and (6) equals to that of equations. Hence, a quadratic equation relating to Q_1 and Q_2 can be obtained

$$f(Q_2) = C_4 Q_2^4 + C_3 Q_2^3 + C_2 Q_2^2 + C_1 Q_2 + C_0, \tag{7}$$

where the coefficients are

$$C_4 = \alpha_2 L_2 n_2^2 g h_2^{-1/3} - \alpha_1 L_1 n_1^2 g h_1^{-1/3} - h_2 + h_1 - \Delta z, \quad C_3 = -2 Q_0 C_4,$$

$$C_2 = Q_0^2(\alpha_2 L_2 n_2^2 g h_2^{-1/3} - \alpha_1 L_1 n_1^2 g h_1^{-1/3} - h_2 + h_1 - \Delta z) + (\alpha_1 L_1 n_1^2 g h_1^{-1/3} - \alpha_2 L_2 i_2 - h_2 + h_1 - \Delta z) B_2^2 g h_2^3 + (\alpha_1 L_1 i_1 - \alpha_2 L_2 n_2^2 g h_2^{-1/3} + h_2 - h_1 + \Delta z) B_1^2 g h_1^3,$$

$$C_1 = 2 Q_0 B_2^2 g h_2^3 (\alpha_2 L_2 i_2 - \alpha_1 L_1 n_1^2 g h_1^{-1/3} - h_2 + h_1 - \Delta z),$$

$$C_0 = B_1^2 B_2^2 g^2 h_1^3 h_2^3 (\alpha_2 L_2 i_2 - \alpha_1 L_1 i_1 - h_2 + h_1 - \Delta z) + Q_0^2 B_2^2 g h_2^3 (\alpha_1 L_1 n_1^2 g h_1^{-1/3} - \alpha_2 L_2 i_2 - h_2 + h_1 - \Delta z).$$

Usually, the flows in rivers are subcritical, namely, $Fr^2 \ll 1$. Assuming free boundary conditions are given downstream the branches, that is, the friction slopes are equal to bed slopes, $J_f = i$, the depths are defined as normal depths, and the correctional factors turn out $\alpha_1 = \alpha_2 = 1$. Hence the solutions in symmetric form can be rendered in the form as follows:

$$Q_1 = \frac{\frac{B_1}{n_1}\sqrt{i_1}}{\frac{B_1}{n_1}\sqrt{i_1} + \frac{B_2}{n_2}\sqrt{i_2}} Q_0, \quad Q_2 = \frac{\frac{B_2}{n_2}\sqrt{i_2}}{\frac{B_1}{n_1}\sqrt{i_1} + \frac{B_2}{n_2}\sqrt{i_2}} Q_0, \quad \frac{Q_1}{Q_2} = \frac{\frac{B_1}{n_1}\sqrt{i_1}}{\frac{B_2}{n_2}\sqrt{i_2}}. \tag{8}$$

By above-mentioned three equations, the discharge distributions are found to be dependent on the geometrical factors (river widths, roughness coefficients and bed slopes) and independent of the river lengths, while free boundary conditions are imposed downstream.

2 The Application of Confluent Channel Model in Flood Peak Meeting

2.1 Backwater effects

According to the Taylor's definitions, the depth ratio $R_h = h_1/h_3$ and discharge ratio $R_q = Q_1/Q_3$ are taken to scale the backwater effects and the confluent ratio, respectively. In this paper the relation between parameters R_h, R_q, θ, and width ratio B_1/B_2 is discussed. It seems to be much more complicated to study the overall relation of R_h and the others. Therefore, we prefer to fix the flow Froude number Fr_3 downstream the mainstream for the sake of simplicity.

Parameters are chosen as follows: confluent angle θ varying from 30°, 60°, 90°, 120° to 150°, and confluent ratio R_q varying from 0.1, 0.3, 0.5, 0.7 to 0.9. The downstream discharge of mainstream Q_3 and width of mainstream are fixed at 10000 m^3/s and B_1 = 1000 *m*, respectively. The width of the branch B_2 varies from 500, 750, 1000, 1250 to 1500 m. *Manning* coefficient and bottom slope are 0.02 and 6E-5 respectively in both mainstream and branch.

2.2 Variation of depth ratio R_h with confluent angle θ

The relation of R_h and θ is related with R_q or B_2. Therefore, when considering this relation, either R_q or B_2 should be fixed.

Figure 7 shows the variation of depth ratio R_h with confluent angle θ, while the confluent ratio R_q is fixed. In Fig. 7(a) R_q is 0.1, and R_h increases remarkably with θ, which means that the backwater effects are enlarged with the confluent angle. In Fig. 7(b) R_q is 0.7, and R_h alters gently, which means weak backwater effects as the lateral inflow discharge is small.

Figure 8 gives the variation of depth ratio R_h with angle θ, while the river width of the branch B_2 is fixed. In Fig. 8(a) B_2 is 500 m, and R_h amplifies with θ remarkably, which represents serious backwater effects. In Fig. 8(b) B_2 is 1000 m, and R_h varies mildly, which

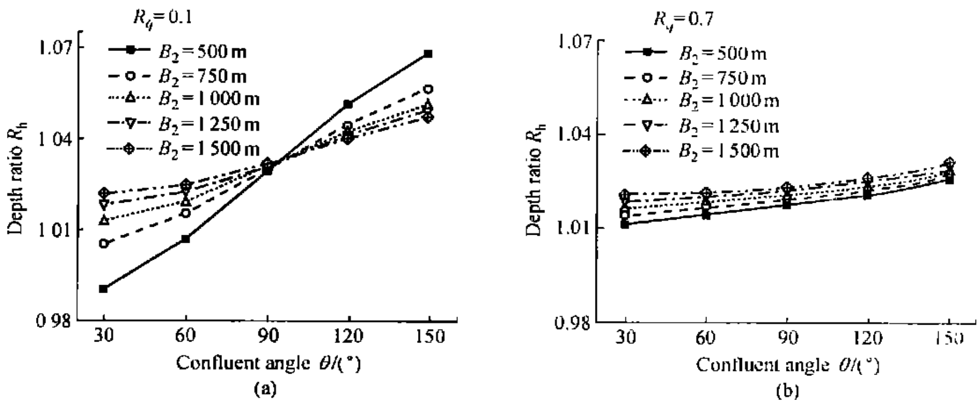

Fig. 7 Relations of depth ratio and confluent angle with confluent ratio fixed

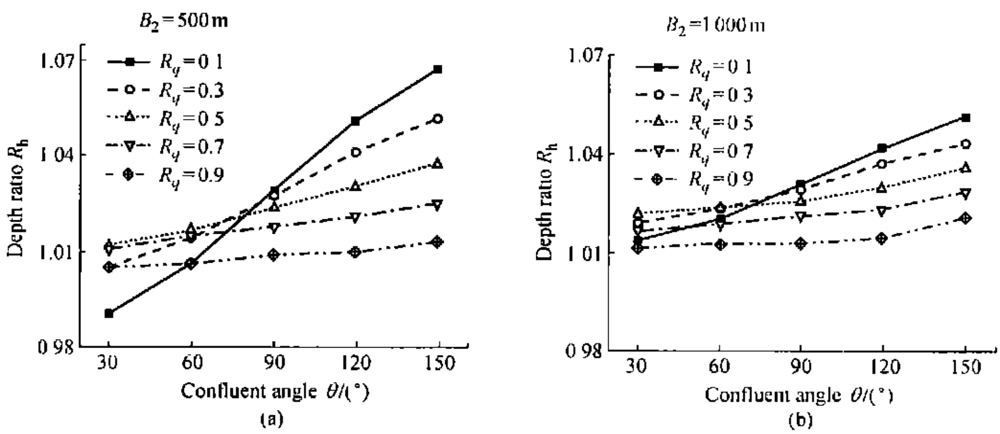

Fig. 8 Relations of depth ratio and confluent angle with branch width fixed

means weak backwater effects as the lateral inflow velocity is small.

We may conclude that, as the confluent angle θ increases, the momentum income from the branch river is enhanced, and then the backwater effect amplifies; as the branch river width reduces, the velocity of the branch river flow grows, and then the backwater effect amplifies.

2.3 Variation of depth ratio R_h with confluent ratio R_q

Figure 9 shows the variation of depth ratio R_h with confluent ratio R_q, while the branch river widths B_2 are 500 m and 1 000 m in Figs. 9(a) and 9(b), respectively. As θ is larger than 90°, R_h goes down with R_q. The slopes of curves in these figures decline with B_2. It indicates that the velocity of the lateral inflow lessens and the backwater effects diminish. For the case that θ is less than 90°, along with the increase of R_q, the depth ratios enlarge at first and then reduce. We can explain it by the following reason: as the lateral discharge is increasing, the discharge upstream the mainstream reduces, which causes R_h to drop.

Figure 10 presents the variation of depth ratio R_h with the confluent ratio R_q, while the confluent angles θ are 30° and 120° respectively in Fig. 10(a) and Fig. 10(b). For θ is larger that 90°, R_h decreases with R_q. In Fig. 10(a) θ is less than 90°, along with the increase of R_q, R_h

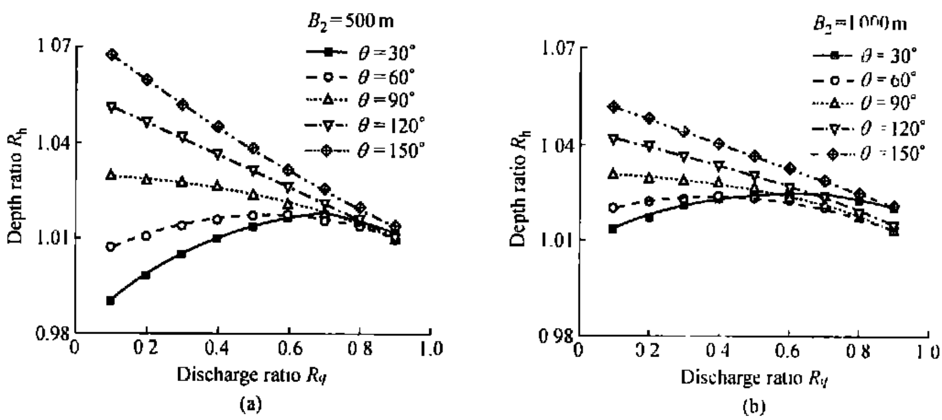

Fig. 9 Relations of depth ratio and confluent ratio with branch width fixed

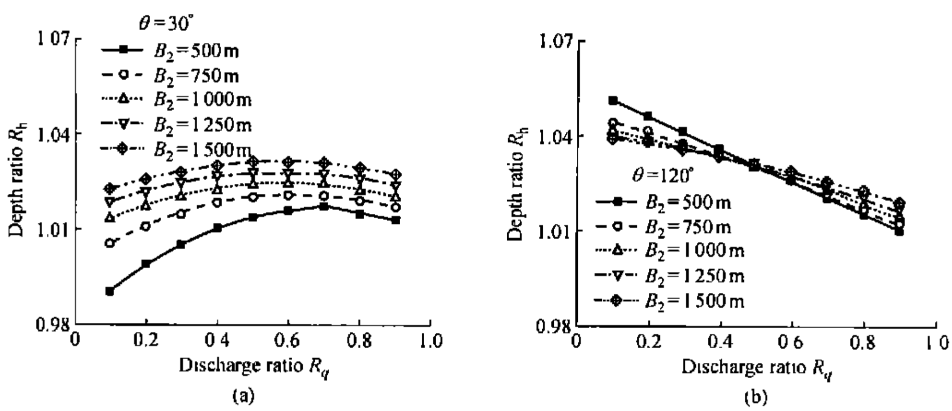

Fig. 10 Relations of depth ratio and confluent ratio with confluent angle fixed

grows at first and then reduces. It can be explained by the same reason as above.

Obviously, if the confluent angle θ is larger than 90°, the backwater effects become much more intensive. In addition, such effects become more apparent with the increase of the lateral inflow discharge and grow weaker with the increase of the branch river width.

2.4 Analysis of the flood peak meeting in confluent channels

Among all of the flood problems in confluent channels the flood peak meeting may be of the most significant one. It can be found by observation that the waterlevel of the whole Jiangjiang was much higher when the flood of the Yangtze River met that of Qingjiang River around 17th August in 1998.

The discharge course from the Yichang and Changyang station can be rendered as in Fig.2. Six cases are considered as follows: the flood of Changyang happens 4,3,2,1 days ahead of time or 1,2 days lag behind respectively. The waterlevel of flood peak in mainstream is carefully examined by comparison with observation. Fig. 11 shows the waterlevels at Shashi station. We can find from this figure that the meeting of the flood peaks of Changyang and Yichang stations on Aug 16th causes the high waterlevel in mainstream in Case 4; the peak meeting on Aug 13th in Case 1 invokes another high waterlevel in mainstream. As a matter of fact, the flood peak meeting in the Yangtze River on 17th August 1998 belongs to Case 4. Hence, we can infer that the high waterlevel during the Yangtze River flood period in 1998 is generated by the flood peak meeting in the confluent channels.

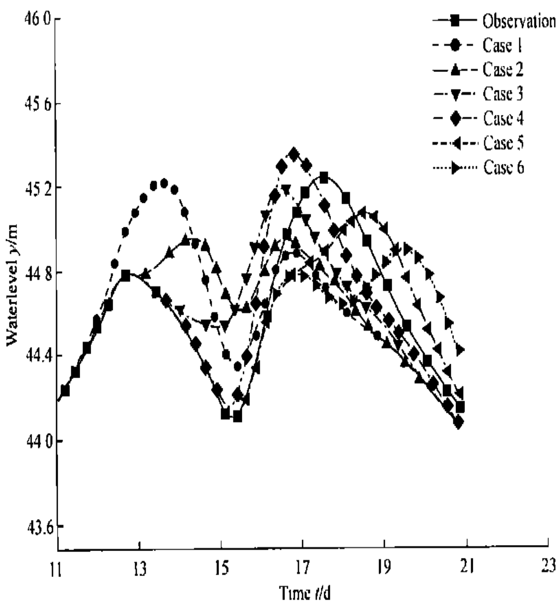

Fig. 11 Comparison of waterlevel at Shashi station under different discharge conditions of Qingjiang

Comparing the waterlevel peak among all of the cases at Shashi station, we find that the difference between the highest waterlevel (45.36 m) and the lowest (44.91 m) is 45 cm. *Huang* pointed out that the Geheyan reservoir stored 0.29 billion m^3 floods to reduce discharge peak by

4 200 m^3/s, and the waterlevel peak by 0.15 m at Shashi on 16th August[14]. The present model has obtained the reduced waterlevel peak 0.11 m, very close to the two previous results.

Anyhow, we may come to the conclusion that owing to commonly occurring flood peak meeting in the confluent channels, the storage capability of the reservoir should be large enough to cut down flood peak or avoid flood peak meeting.

3 Application of Dividing Channel Model to Flood Analysis in the Jingjiang River Area

Generally speaking, the downstream boundary conditions would not be free. Therefore, the correctional factors α_1 and α_2 and discharge distribution are not easy to be determined according to the previously mentioned method. Nevertheless, we may derive a number of equations in order to analyze the variation of discharge distribution with river geometrical factors. Differentiating the basic equations (4), (5a,b) and (6) with Fr neglected, we have

$$\mathrm{d}Q_1 = -\mathrm{d}Q_2, \tag{9}$$

$$\frac{\mathrm{d}Q_1}{Q_1} = \frac{\mathrm{d}B_1}{B_1} - \frac{\mathrm{d}n_1}{n_1} + \frac{1}{2}\frac{\mathrm{d}(i_1 - h_{1s_1})}{i_1 - h_{1s_1}} + \frac{5}{3}\frac{\mathrm{d}h_1}{h_1}, \tag{10}$$

$$\frac{\mathrm{d}Q_2}{Q_2} = \frac{\mathrm{d}B_2}{B_2} - \frac{\mathrm{d}n_2}{n_2} + \frac{1}{2}\frac{\mathrm{d}(i_2 - h_{2s_2})}{i_2 - h_{2s_2}} + \frac{5}{3}\frac{\mathrm{d}h_2}{h_2}, \tag{11}$$

$$\mathrm{d}h_1 - \alpha_1 L_1 \mathrm{d}h_{1s_1} - \alpha_1 h_{1s_1}\mathrm{d}L_1 = \mathrm{d}h_2 - \alpha_2 L_2 \mathrm{d}h_{2s_2} - \alpha_2 h_{2s_2}\mathrm{d}L_2 + \mathrm{d}\Delta z. \tag{12}$$

Under some hypothesis the variation of flow field parameters (Q_1, Q_2, h_{1s_1}, h_{2s_2} and h_0) with geometrical factors (B_1, n_1, i_1, L_1, B_2, n_2, i_2 and L_2) can be analyzed in detail. And the friction slope can be expressed by

$$J_\mathrm{f} = i - (1 - Fr^2)\frac{\mathrm{d}h}{\mathrm{d}s}. \tag{13}$$

With subcritical assumption, the Froude number should satisfy $Fr^2 \ll 1$ and can be neglected. According to the *Manning* equation, the friction slope J_f is always larger than 0, sequentially we have

$$i - \frac{\mathrm{d}h}{\mathrm{d}s} > 0. \tag{14}$$

3.1 Influences of the river lengths

Actually, the most typical case for the river length affecting the flow is the shortcut of a river. The shortcut in fact means that the river length is shortened, and then the slope is enlarged with the heights of its ends fixed. Typically assuming channel BC is shortcut, the following relations:

$$\mathrm{d}i_1 = -\frac{i_1}{L_1}\mathrm{d}L_1,\ \mathrm{d}n_1 = \mathrm{d}n_2 = \mathrm{d}B_1 = \mathrm{d}B_2 = \mathrm{d}h_1 = \mathrm{d}h_2 = \mathrm{d}i_2 = \mathrm{d}\Delta z = 0 \tag{15}$$

should be satisfied, from which Eq. (12) can be simplified as

$$-\alpha_1 L_1 \mathrm{d}h_{1s_1} + \alpha_1 L_1 \frac{h_{1s_1}}{i_1}\mathrm{d}i_1 = -\alpha_2 L_2 \mathrm{d}h_{2s_2}. \tag{16}$$

Combining Eqs. (9), (10), (11) and (16), we can obtain

$$\frac{\mathrm{d}h_{1s_1}}{\mathrm{d}i_1} = \left[1 + \frac{\alpha_1 L_1}{\alpha_2 L_2}\frac{Q_2}{Q_1}\frac{i_1 - h_{1s_1}}{i_2 - h_{2s_2}}\frac{h_{1s_1}}{i_1}\right]\left[1 + \frac{\alpha_1 L_1}{\alpha_2 L_2}\frac{Q_2}{Q_1}\frac{i_1 - h_{1s_1}}{i_2 - h_{2s_2}}\right]^{-1}, \tag{17}$$

$$\frac{\mathrm{d}h_0}{\mathrm{d}i_1} = \alpha_1 L_1\left(\frac{h_{1s_1}}{i_1} - 1\right)\left(1 + \frac{\alpha_1 L_1}{\alpha_2 L_2}\frac{Q_2}{Q_1}\frac{i_1 - h_{1s_1}}{i_2 - h_{2s_2}}\right)^{-1}, \tag{18}$$

$$\frac{\mathrm{d}Q_1}{\mathrm{d}i_1} = -\frac{1}{2}\frac{1}{\alpha_2 L_2}\frac{Q_2}{i_2 - h_{2s_2}}\frac{\mathrm{d}h_0}{\mathrm{d}i_1}. \tag{19}$$

From the above equations, we have

$$\frac{\mathrm{d}h_{1s_1}}{\mathrm{d}i_1} > 0, \quad \frac{\mathrm{d}h_0}{\mathrm{d}i_1} < 0, \quad \frac{\mathrm{d}Q_1}{\mathrm{d}i_1} > 0. \tag{20}$$

It can be found from the above three equations that the depth of the mainstream declines and the discharge of channel BC increases with the shortcut of channel BC.

3.2 Influences of the river widths

If the width of channel BC is changed only, we have

$$\mathrm{d}h_1 = \mathrm{d}h_2 = \mathrm{d}n_1 = \mathrm{d}n_2 = \mathrm{d}i_1 = \mathrm{d}i_2 = \mathrm{d}B_2 = \mathrm{d}\Delta z = 0,\ \mathrm{d}B_1 \neq 0. \tag{21}$$

Repeating the previously stated steps, we have

$$\frac{\mathrm{d}h_{1s_1}}{\mathrm{d}B_1} > 0, \quad \frac{\mathrm{d}h_0}{\mathrm{d}B_1} < 0, \quad \frac{\mathrm{d}Q_1}{\mathrm{d}B_1} > 0. \tag{22}$$

Accordingly, the depth of mainstream drops and the discharge of channel BC rises with the width of the channel BC.

3.3 Influences of the bed heights

If the beds of dividing channels changed only, then we have

$$\mathrm{d}h_1 = \mathrm{d}h_2 = \mathrm{d}n_1 = \mathrm{d}n_2 = \mathrm{d}i_1 = \mathrm{d}i_2 = \mathrm{d}B_1 = \mathrm{d}B_2 = 0,\ \mathrm{d}\Delta z \neq 0. \tag{23}$$

Repeating the previously stated steps, we have

$$\frac{\mathrm{d}h_{1s_1}}{\mathrm{d}\Delta z} < 0, \quad \frac{\mathrm{d}h_0}{\mathrm{d}\Delta z} > 0, \quad \frac{\mathrm{d}Q_1}{\mathrm{d}\Delta z} < 0. \tag{24}$$

Therefore, it can be concluded that if the bed of channel BD rises as compared to that of channel BC, the depth of mainstream increases and the discharge of channel BD reduces.

3.4 Application to flood analysis in Jingjiang river area

The above conclusions are helpful for analyzing the influences of Jingjiang area natural and anthropogenic evolutions on the Yangtze River floods.

1) Because of the sediments deposition in the dividing rivers there, the height of its beds is raised and its cross-section reduced. The former conclusions 3.2 and 3.3 imply that such evolution may increase the discharge and waterlevel of the Jingjiang River, and thus aggravate the flood disaster in the Yangtze River.

2) The Jingjiang River has been shortcut by nature and human being, then its bed slope becomes more steep. From the conclusions 3.1, we know that this change may increase the discharge of Jingjiang River and decrease its waterlevel, which evidently may facilitate to regulate the flood disaster in the Yangtze River.

4 Conclusions

In the present paper, we have established numerical models for confluent and dividing channels. The models validated by comparison with observation have been successfully applied in the analysis of the Yangtze River flood in 1998 and flood regulation in the Jingjiang Area. We may conclude that

1) The dependence of backwater effects on confluent channel parameters is acquired with the Froude number Fr_3 downstream the mainstream fixed. Meanwhile, owing to commonly occurring flood peak meeting in confluent channels, building reservoir with large capacity is an effective measurement to avoid the flood disasters at present.

2) For either of the two branches in the dividing channels, the river length reduction, width widening and river bed scouring may reduce the waterlevel in the mainstream, and increase the discharge. The sediments deposition in the dividing rivers of Jingjiang River may result in the bed height rising and cross-section diminishing. These changes may increase the discharge and waterlevel of the Jingjiang River, and thus aggravate the flood disaster in the Yangtze River. The Jingjiang River was shortcut by nature and human activity, then its bed slope becomes steeper, which leads to the increase of discharge in Jingjiang River and decrease of waterlevel. Consequently, such evolution of channel facilitates to regulate the flood in the Yangtze River.

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