Study on Upstream and Downstream Flow Characteristics of the Curved Branching River based on Qingshan Junction

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Abstract. Most of China's inland waterway construction started in the 1960s. With the increase of inland water transportation, inland water conservancy hubs need to be upgraded, especially in the complex terrain - curved branching river to establish navigation buildings to ensure navigation, improve transport capacity is extremely important. This paper studies the navigable flow conditions in the mouth area of the typical curved branching river of Qingshan Junction, explores the characteristics of the peer flow of the curved branching river, and puts forward an analysis model of the flow movement characteristics of the curved branching river, which can effectively improve the navigable flow conditions in the mouth area of the curved branching river and enrich the model base and knowledge base of the curved branching river. It has very important practical significance and engineering value for shipping safety and waterway management.

Keywords: The curved and branching river, transverse circulation, characteristic analysis, water flow characteristics flow condition.

1. Introduction

With the improvement of China's comprehensive national strength, the construction of China's ports and waterways has tended to saturation state, but the construction of inland waterways mostly happened in the 1960s, so many inland water conservancy hubs are facing the demand for upgrading, especially the water conservancy hubs built on complex terrain - curved branching rivers. Similarly, the construction of power generation buildings and navigation buildings in hydraulic engineering is increasing, while the construction of navigation buildings in the complex terrain - curved branching river is relatively weak. The flow condition of the curved branching river is relatively complex, and the flow is not only affected by the centrifugal force of the curved river, but also easily affected by the branching of the river. There are many existing studies on the curved river and branching river, but most of them are on a single bend or a single branching river, while relatively few studies on the situation of the curved branching river. The research on this aspect is not perfect enough, so this paper studies the navigable flow conditions in the mouth area of the curved branching river, explores the characteristics of the peer flow of the curved branching river, and proposes effective measures to improve the navigable flow conditions in the mouth area of the curved branching river, which is of great practical significance and engineering value for guaranteeing navigation and improving transport capacity.

2. Research Status at Home and Abroad

The main methods to study the flow in curved reach include theoretical analysis, physical model test and numerical simulation. In 1986, the British river flood control facilities carried out long-term experimental studies on open channel flow and bend flow respectively, and obtained a large number of test data, which provided detailed reference for further research on bend flow [1]. Kyong et al. built an "S" shaped curve model in the Korea Institute of Building Technology, studied the hydraulic characteristics of the curve flow through experiments, and conducted an in-depth study on the mixing effect of sediment in the continuous curve flow. They found that the lateral and longitudinal mixing effects were closely related to the generation, development and evolution of the curve circulation. Boxall carried out a curve flow test in the curve model, and selected model sand with a particle size of 0.85mm to make a trapezoidal moving bed model. Through the model test, he studied the curve flow characteristics and the scouring effect on the bed sand, and summarized the basic characteristics of the curve flow.

There have been many studies on bifurcated river channels. Taylor studied the relationship between bifurcated ratio and water depth ratio through experiments [2]. Grace et al. studied the variation law of diverging ratio under different main and branch width ratios and different branch angles [3]. In addition, Law, Ramamurthy et al. conducted qualitative research on the distributive sediment separation ratio through the bifurcated flume from the perspective of energy, combined with generalized model test and theoretical analysis. Wang Weifeng studied the evolution mechanism of the edge beach and the low beach at the bar head in the curved branching channel, as well as the turbulent characteristics of the flow in the curved branching channel [4]. Gu Li built a physical model test system for straight branching channels, and systematically investigated the effects of different branching channel width ratios and upstream flow on the distribution of turbulent kinetic energy in branching channels [5]. CAI Guozheng, Tang Cunben et al. tested and analyzed the hydraulic characteristics, excavation forms, regulation methods and channel flow patterns of Fenhan type rapids through model tests and combined with engineering practice experience. On this basis, they summarized the regulation principles of Fenhan type rapids[6]. Yu Xinming et al. established a two-dimensional planar flow mathematical model suitable for the simulation of bifurcated river channels by using the finite element method. Combined with the Baguazhou branch of Nanjing, the flow velocity distribution, water surface line and diversion ratio were verified and calculated[7].Cao Yi established a two-dimensional finite element mathematical model of mean water depth, and verified that the mathematical model was in good agreement with the physical model and could be used for numerical calculation. By analyzing the numerical simulation results of flow conditions in the gate area, it is found that the length of backflow area is negatively correlated with the cross-flow intensity, and the longer the backflow area is, the weaker the cross-flow intensity is. The numerical simulation results further verify that the measures such as leveling the riverbed, sealing the gap of the diversion pier and partially widening the channel can effectively reduce the transverse velocity in the mouth area[8].The Tianjin Institute of Water Transport Engineering Science of the Ministry of Communications has developed and studied a novel and ideal diversion building - diversion pier, which has been successfully applied to avionics hubs such as Dayuandu and Zhuzhou of Xiangjiang River, opening up a new way to weaken the oblique flow in the entrance area of the approach channel and solve the problem of navigation conditions [9-11].

To sum up, there have been a lot of studies on the flow dynamics of curved branching channels. Meanwhile, scholars at home and abroad have also done a lot of research on the flow velocity distribution of curved channels and the flow movement law of branching channels, and have achieved remarkable results. However, few scholars have combined curved channels with branching channels. There are relatively few research results on the flow characteristics of curved branching river.

3. Construction of Flow Characteristic Model of Curved Branching River

The transverse circulation information of water flow collected around the curved river channel of Qingshan Junction includes: the force of water flow along the concave bank, the force of water flow along the convex bank and the force of water flow moving downward; The vertical gradient of water surface is obtained in real time when the water flow passes through the branch river, and the main water flow relative to the main branch river and the main branch force generated by the water flow to the main branch river are determined.

According to the obtained lateral circulation information, main water flow and main branching force, the curved flow movement characteristic model when water flows through the curved branching channel is as follows:

$$G = A\cos(w+q) + k \quad (1)$$

Where G is the movement characteristic of the curved water flow, A is the number of times the river bends, w is the force of the water flow along the concave bank, q is the force of the water flow along the convex bank, and k is the force of the water flow moving downward.

Further, the movement characteristic model of curved branching flow is as follows:

$$F = (A\cos(w+q) + k) \times \frac{v}{p} \quad (2)$$

Where, F is the movement characteristic of the curved branching water flow, v is the main water flow, and p is the main branching force.

When a water flow passes through multiple sub-branches, the sub-bifurcation force of the water flow relative to multiple sub-branches and the sub-bifurcation force of the water flow to the sub-bifurcation can be obtained in real time, and the movement model of the curved branching water flow can be optimized:

$$m = \begin{Bmatrix} l_1 & \cdots & l_i \\ r_1 & \cdots & r_i \end{Bmatrix} \quad (3)$$

Where, m is the matrix of secondary water flow and secondary branching force, l is the secondary water flow, r is the secondary branching force, and i is the i sub-branching force. Then the optimized curved branching flow movement characteristic model is as follows:

$$E = \left((A\cos(w+q)+k)\times\frac{v}{p}\right) \Big/ \sum_i \begin{Bmatrix} l_1 & \cdots & l_i \\ r_1 & \cdots & r_i \end{Bmatrix} \quad (4)$$

Where E is the movement characteristic of the optimized curved branching flow.

After obtaining the transverse slope of the water flow, the position of the maximum force of the water flow passing through the curved branch river can be calculated by using the optimized model of the curved branch flow movement characteristics.

4. Study on Upstream and Downstream Flow Characteristics of Qingshan Junction

4.1 Test and Analysis of Upstream Flow Conditions

The size of the upstream main waterway is 2.0m x 60m x 480m (water depth x double-line navigation width x bending radius).

Several typical working conditions were selected to carry out the flow field measurement of the upstream main channel and the ship model navigation test. Through the analysis of the simulation results, the main situation is as follows:

(1) Flow rate Q=2200m3/s

When the flow rate Q=2200m^3 /s, Youcha power station overflows 600m^3 /s, and the drainage gate is completely closed. In the upper channel, the flow velocity is 0.3-1.2m /s. The flow velocity is small, and the sailing flow condition is good (figures 1). During the normal storage stage of the upper channel, the flow velocity of the upper reach increases with the increase of the flow.

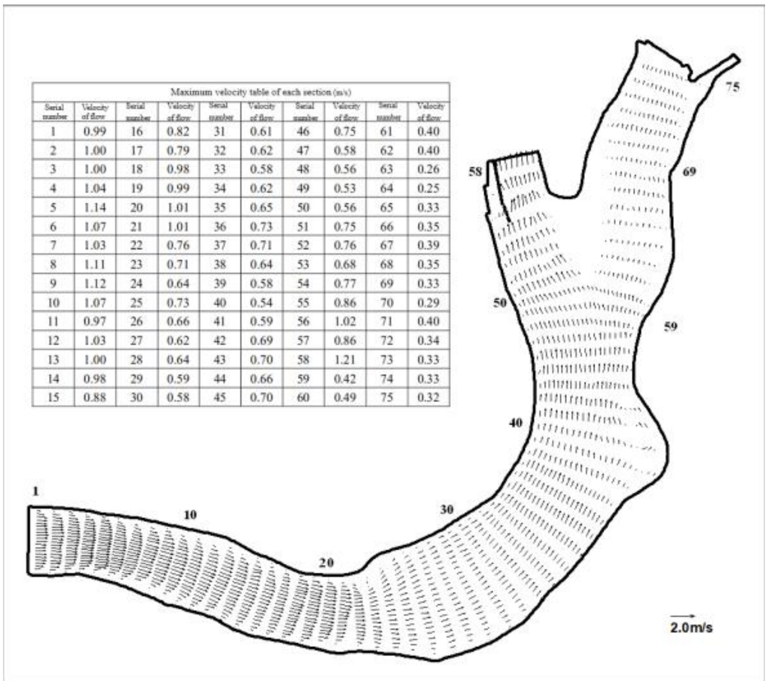
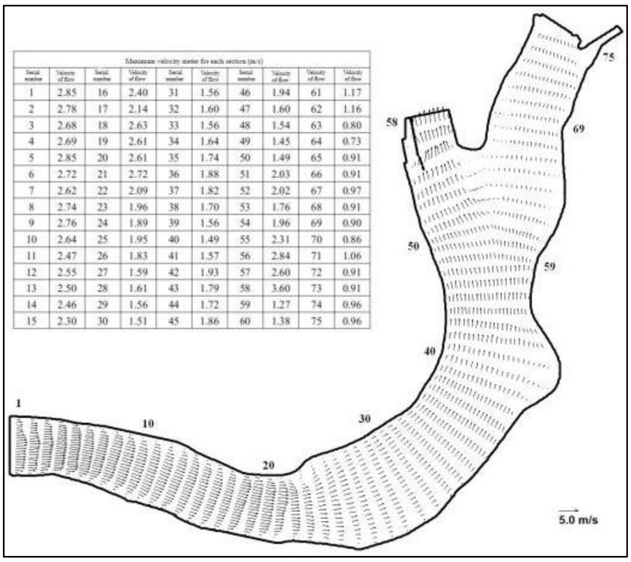


Figure. 1. Upstream flow field diagram of the hub (Q=2200m³/s).

(2) Flow rate Q≥8910m3/s

The flow velocity in the upper reaches of the river increases with the increase of the flow. Due to the change of the channel section and the backwater effect of the junction dam, the flow velocity gradually decreases along the route. Under different flow conditions, the flow velocity decreases from 2.5-3.5m /s near the Zhoujia River to 1.8-2.5m /s near the dry estuary (figure 2).



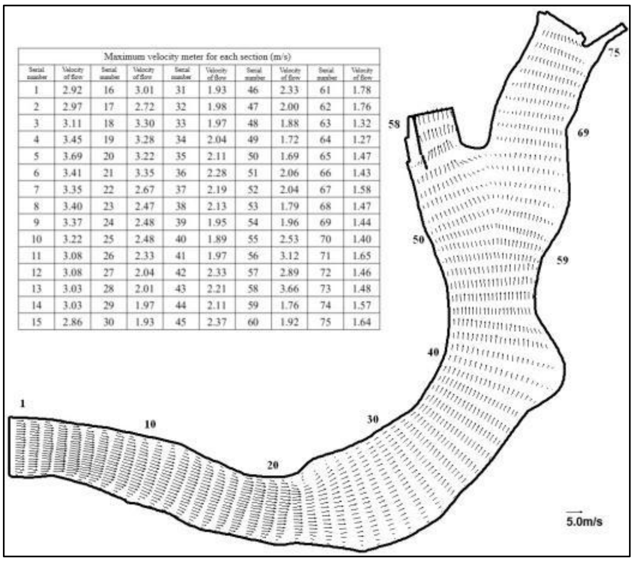


Figure. 2. Upstream flow field diagram of the hub (Q=8910m³/s，On the left) and (Q=14200m³/s，On the right).

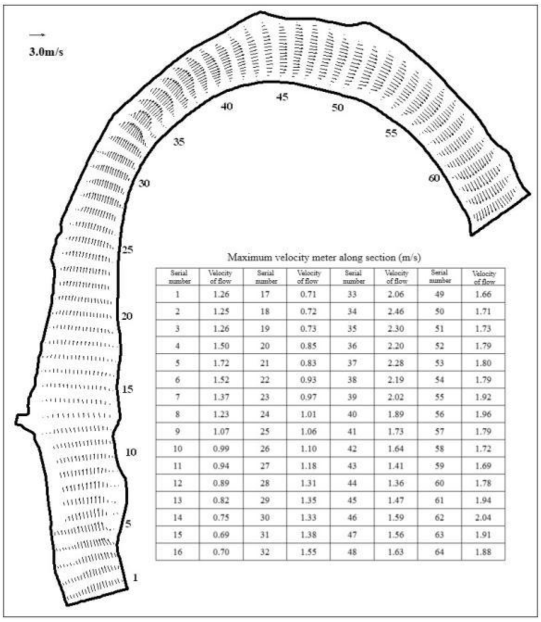
4.2 Test and Analysis of Downstream Flow Conditions

The downstream main channel size is 2.0m×60m×480m (water depth × double-line navigation width × bending radius), and the dredged bottom elevation is 37.0m. Typical working conditions were selected to carry out the flow field measurement of the downstream main channel and the ship model navigation test. Through the analysis of the simulation results, the main situation is as follows:

(1) Flow rate Q=2200m3/s

When the flow rate Q=2200m³/s, Youcha power station overflows 600m³/s, and the drainage gate is completely closed. The left branch sluice gate is partially opened to discharge 1600m³/s, the upstream normal water level, and the downstream tailgate control water level of 40.91m.

The design navigation width of the downstream channel is 60m, and the bottom elevation of the channel is 37.0m. In the bend below the Submersible bridge (Fujia River Beach), the channel excavation is close to 2.0m. When Q=2200m³/s, the flow rate in the local channel reaches 2.5m/s, and the plane layout of the local channel is not smooth with the flow direction (figure 3).

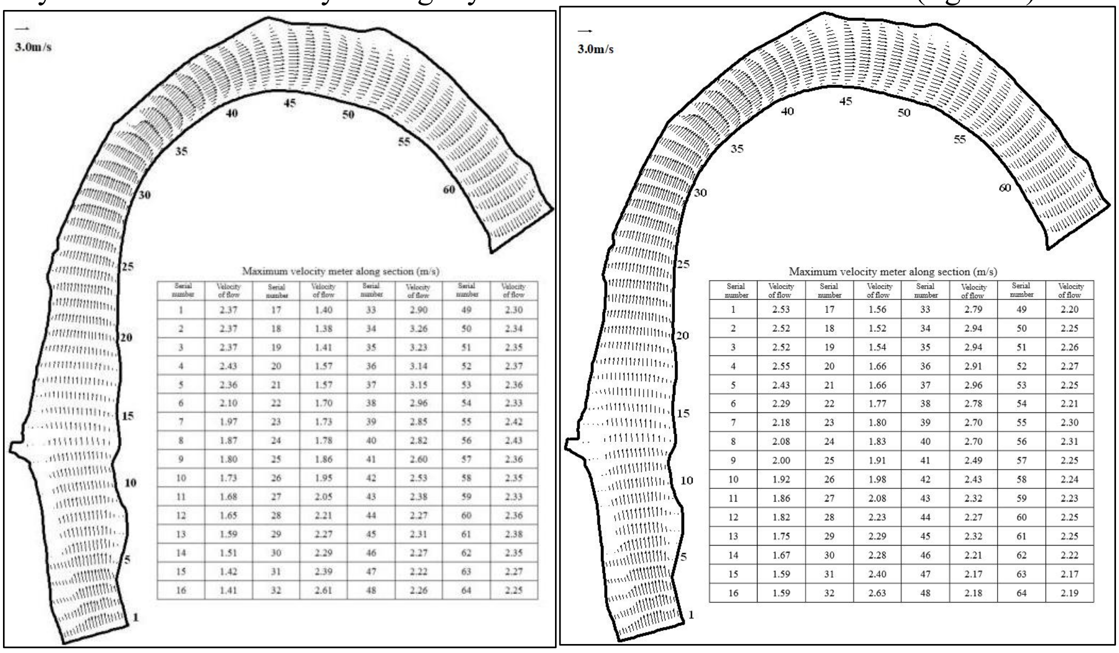


Serial number	Velocity of flow	Serial number	Velocity of flow	Serial number	Velocity of flow	Serial number	Velocity of flow
1	1.26	17	0.71	33	2.06	49	1.66
2	1.25	18	0.72	34	2.46	50	1.71
3	1.26	19	0.73	35	2.30	51	1.73
4	1.50	20	0.85	36	2.20	52	1.79
5	1.72	21	0.83	37	2.28	53	1.80
6	1.52	22	0.93	38	2.19	54	1.79
7	1.37	23	0.97	39	2.02	55	1.92
8	1.23	24	1.01	40	1.89	56	1.96
9	1.07	25	1.06	41	1.73	57	1.79
10	0.99	26	1.10	42	1.64	58	1.72
11	0.94	27	1.18	43	1.41	59	1.69
12	0.89	28	1.31	44	1.36	60	1.78
13	0.82	29	1.35	45	1.47	61	1.94
14	0.75	30	1.33	46	1.59	62	2.04
15	0.69	31	1.38	47	1.56	63	1.91
16	0.70	32	1.55	48	1.63	64	1.88

Figure. 3. Downstream flow field diagram of the hub (Q=2200m³/s).

(2) Flow rate Q≥8910m3/s

In the downstream design channel, the flow velocity is high, reaching a maximum of 3.0m/s, and the plane layout of some waterways is slightly different from the flow direction (figure 4).



Serial number	Velocity of flow	Serial number	Velocity of flow	Serial number	Velocity of flow	Serial number	Velocity of flow
1	2.37	17	1.40	33	2.90	49	2.30
2	2.37	18	1.38	34	3.26	50	2.34
3	2.37	19	1.41	35	3.23	51	2.35
4	2.43	20	1.57	36	3.14	52	2.37
5	2.36	21	1.57	37	3.15	53	2.36
6	2.10	22	1.70	38	2.96	54	2.33
7	1.97	23	1.73	39	2.85	55	2.42
8	1.87	24	1.78	40	2.82	56	2.43
9	1.80	25	1.86	41	2.60	57	2.36
10	1.73	26	1.95	42	2.53	58	2.35
11	1.68	27	2.05	43	2.38	59	2.33
12	1.65	28	2.21	44	2.27	60	2.36
13	1.59	29	2.27	45	2.31	61	2.38
14	1.51	30	2.29	46	2.27	62	2.35
15	1.42	31	2.39	47	2.22	63	2.27
16	1.41	32	2.61	48	2.26	64	2.25

Serial number	Velocity of flow	Serial number	Velocity of flow	Serial number	Velocity of flow	Serial number	Velocity of flow
1	2.53	17	1.56	33	2.79	49	2.20
2	2.52	18	1.52	34	2.94	50	2.25
3	2.52	19	1.54	35	2.94	51	2.26
4	2.55	20	1.66	36	2.91	52	2.27
5	2.43	21	1.66	37	2.96	53	2.25
6	2.29	22	1.77	38	2.78	54	2.21
7	2.18	23	1.80	39	2.70	55	2.30
8	2.08	24	1.83	40	2.70	56	2.31
9	2.00	25	1.91	41	2.49	57	2.25
10	1.92	26	1.98	42	2.43	58	2.24
11	1.86	27	2.08	43	2.32	59	2.23
12	1.82	28	2.23	44	2.27	60	2.25
13	1.75	29	2.29	45	2.32	61	2.25
14	1.67	30	2.28	46	2.21	62	2.22
15	1.59	31	2.40	47	2.17	63	2.17
16	1.59	32	2.63	48	2.18	64	2.19

Figure . 4. Downstream flow field diagram of the hub (Q=8910m³/s，On the left) and (Q=14200m³/s，On the right).

The analysis shows that there are the following problems in the navigation conditions of the downstream channel:

1) When there is low water, the water flow returns to the channel, the flow velocity in the channel is large, and the plane arrangement of the local channel slightly crosses the direction of the water flow, forming the scissors water to the channel, which is difficult for the navigation of ships.

2) During the flood period, the flow velocity within the designed channel is relatively large, and the downstream channel is curved, and the plane layout of the local channel is not smooth with the flow direction, and the convex mouth on the left bank slope near the Submersible bridge forms bayonet, which makes it difficult for ships to enter the designed and planned route, and the navigation parameters such as ship drift distance and drift Angle will be larger.

3) It is suggested that the downstream channel should be widened, the left bank slope convex beak near the Submersible bridge should be cut off, and the plane layout of the route should be optimized.

5. Conclusion

In this paper, a model of the flow characteristics of curved branching river is proposed, which can automatically analyze the flow characteristics of curved branching river. By analyzing the flow motion characteristics of the curved branching river, the data can be provided to support the navigation of ships and ensure the safety of ships passing through the curved branching river. Combined with the model, the upstream and downstream flow conditions of Qingshan Junction are tested, and the potential problems in the downstream channel of Qingshan Junction are obtained through analysis, and optimization suggestions are put forward. With the deepening of the research on the pivotal flow characteristics of the curved branching reach, it can provide the basis for the development and management of the curved branching reach more efficiently.

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