Study on Flow Conditions for Navigation in Entrance Area and Connection Reach Downstream of the Lock of a New Hub

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Abstract: The entrance area and approach channel downstream of the lock of a new hub are located on the concave bank of a narrow river section with poor flow conditions for navigation. This paper studies their flow conditions for navigation at all levels of flow rate through the combination of the overall physical fixed bed model test and the remotely controlled self-propelled model ship, and finally puts forward a recommended scheme meeting the navigation requirement for reference in similar works by means of removal of the deflecting area downstream of the power station, dredging of the side shoal on the left bank and changes in the layout of the navigable wall.

1. Introduction
The primary function of the new hub is shipping, accompanied by power generation, improvement of the urban water environment and the integrated transportation system and other tasks. The normal storage level of the reservoir is 252.50 m and the corresponding storage capacity is 38 million m³. The power station has an installed capacity of 21 MW and an annual power output of 94.6 million kW·h for 4505 annual utilization hours. The hub consists of a power station, a flood discharge and scouring sluice, a lock and a joint dam on the right bank from left to right, with a total length of 404.00 m. The new lock is of Grade IV, with an effective dimension of 140 m×23 m×3.5 m (effective length of lock chamber × clear width × minimum water depth of threshold). The representative design ship type is a 500 t dry bulk carrier. The highest navigable water level downstream is the corresponding downstream level at the flood frequency of 33.3%, namely 254.64 m, and the lowest navigable water level is 245.70 m.

2 Model design
The overall physical model of the new hub ranges from about 1.5 km upstream of its dam axis to 2.6 km downstream of the dam axis. The total length of the simulated river section is about 4.1 km. The model is designed to be geometrically normal according to the criteria of similar gravity, flow continuity and resistance [1], both the plane scale and the vertical scale of which are 100. The river section where the new hub is located is an inland waterway of Grade IV, which is navigable for 500 t transport ships. Therefore, a 500 t dry bulk carrier is selected as the test ship type. The geometric scale of the ship model is the same as that of the overall river model.

3 Design scheme

3.1 Engineering layout
The hub is composed of a lock on the right bank, a power plant on the left bank, an 11-hole flood
discharge and scouring sluice and other main buildings. The dam site is located in a relatively straight river channel and the sluice is arranged in the deep trough. The lock is set on the right bank and the power station on the left bank. The front edge of the upper lock head is set at the dam axis which is vertical to the lock axis. The lock is composed of upper and lower lock heads, a lock chamber and upstream and downstream approach channels which are arranged asymmetrically. The straight section of the approach channel upstream of the lock is about 330 m long and 46.0 m wide, including a 135 m navigation section, an adjustment section and a 140m berthing section. That of the approach channel downstream of the lock is 310 m long and 46.0 m wide, including a 138.2m navigation section, an adjustment section and a 140m berthing section. The entrance area and the connection reach downstream of the lock are located on the concave bank. The bed width is 160 m to 270 m. The length of the entrance area of the downstream approach channel is 2.5 times the length of the representative design ship type, namely 120 m. The connection reach is 180 m outside the entrance. The layout plan of the design scheme is shown in Figure 1.

### Table 1. Working condition of model test

| Test group | Test flow (m$^3$/s) | Tailgate water level (m) | Working condition | Hub opening mode |
|------------|---------------------|-------------------------|-------------------|-----------------|
| 1          | 155.7               | 246.12                  | The sluice is closed and the power station is generating power. | The power station has one center hole opened and the sluice is closed. |
| 2          | 467                 | 246.54                  | Test flow condition | The power station has 3 holes opened and the sluice is closed. |
| 3          | 1000                | 245.11                  | Joint dispatch of the power station and the sluice | The power station is operating at full capacity and holes 8#, 9# and 10# of the sluice are opened. |
| 4          | 2000                | 246.14                  | Test flow condition | The power station is operating at full capacity and holes 2#, 4#, 6# and 8# of the sluice are opened. |
| 5          | 3650                | 247.41                  | Test flow condition | Power station shutdown. sluice open for complete discharge. |
| 6          | 5360                | 249.36                  | Sluice open for complete discharge | Flood frequency 50%. power station shutdown. sluice open for complete discharge. |
| 7          | 6780                | 251.74                  | Sluice open for complete discharge | Flood frequency 33.3%. highest navigable flow. power station shutdown. sluice open for complete discharge. |

### 3.2 Flow conditions for navigation in the entrance area and the connection reach

When the flow rate $Q \leq 1000$ m$^3$/s, the transverse velocity and longitudinal velocity are less than 0.30 m/s and 2.0 m/s respectively and flow conditions for navigation in the entrance area meet the specification. When $Q = 467$ m$^3$/s and $Q = 1000$ m$^3$/s, the maximum transverse velocity and longitudinal velocity in the connection reach are 0.55 m/s and 0.40 m/s, and 1.31 m/s and 1.13 m/s respectively, and it can be judged that the connection reach has better flow conditions according to basic requirements for flow conditions for navigation in the entrance area. With the increase of the flow rate, the flow velocity in the entrance area and the connection reach increases. When $Q \geq 2000$ m$^3$/s, the
maximum transverse velocity within 120m~300m from the entrance is 0.31 m/s ~0.67 m/s. When Q=6780 m³/s, the maximum transverse velocity in the entrance area and the connection reach are 0.33 m/s and 0.48 m/s respectively. In summary, when Q≥2000 m³/s, flow conditions for navigation in the entrance area do not meet the specification and the connection reach has poor flow conditions for navigation. According to ship test results, when Q=3650 m³/s, the down-bound ship has an increased drift angle and a wide track belt and drifts to the right of the route after exiting the entrance area under the influence of the flow and bend in the connection reach. Its maximum rudder angle and drift angle in the entrance area and the connection reach are -15.4° and 23.6° respectively. When Q=6780 m³/s, the oblique flow area moves downward and the drift angle of the ship starts to increase at the end of the connection reach. The maximum drift angle, 27°, occurs within 500 m~600 m from the embankment head. The maximum rudder angle and drift angle of the ship are -16.1° and 11.6° respectively in the entrance area and the connection reach.

Table 2. Variation of the maximum transverse velocity at the downstream entrance and connection areas in design scheme

| Flow rate (m³/s) | 155 | 467 | 1000 | 2000 |
|------------------|-----|-----|------|------|
|                  | Controlled discharge | Complete discharge |
| Distance from the entrance (m) |       |      |      |      | 3650 | 5360 | 6780 |
| 0                | 0.03 | 0.08 | 0.06 | 0.18 | 0.06 | 0.23 | 0.27 | 0.09 |
| 20               | 0.03 | 0.07 | 0.12 | 0.09 | 0.05 | 0.20 | 0.19 | 0.08 |
| 40               | 0.02 | 0.18 | 0.15 | 0.13 | 0.06 | 0.17 | 0.45 | 0.27 |
| 60               | 0.05 | 0.20 | 0.17 | 0.29 | 0.22 | 0.25 | 0.15 | 0.26 |
| 80               | 0.05 | 0.26 | 0.26 | 0.22 | 0.17 | 0.31 | 0.15 | 0.27 |
| 100              | 0.05 | 0.21 | 0.19 | 0.14 | 0.11 | 0.26 | 0.26 | 0.22 |
| 120              | 0.03 | 0.14 | 0.17 | 0.44 | 0.21 | 0.35 | 0.31 | 0.33 |
| 140              | 0.03 | 0.11 | 0.16 | 0.49 | 0.25 | 0.24 | 0.26 | 0.18 |
| 160              | 0.10 | 0.10 | 0.31 | 0.48 | 0.23 | 0.24 | 0.15 | 0.33 |
| 180              | 0.12 | 0.23 | 0.35 | 0.48 | 0.45 | 0.47 | 0.20 | 0.20 |
| 200              | 0.10 | 0.19 | 0.30 | 0.69 | 0.40 | 0.38 | 0.35 | 0.39 |
| 220              | 0.10 | 0.33 | 0.24 | 0.43 | 0.24 | 0.28 | 0.24 | 0.17 |
| 240              | 0.11 | 0.37 | 0.36 | 0.51 | 0.47 | 0.47 | 0.25 | 0.24 |
| 260              | 0.12 | 0.43 | 0.29 | 0.63 | 0.46 | 0.67 | 0.23 | 0.48 |
| 280              | 0.11 | 0.33 | 0.33 | 0.63 | 0.44 | 0.36 | 0.24 | 0.39 |
| 300              | 0.14 | 0.30 | 0.40 | 0.53 | 0.54 | 0.41 | 0.43 | 0.45 |

4 Optimization scheme

4.1 Engineering layout and test results and analysis in optimization scheme 1

4.1.1 Engineering layout
Test results of the design scheme show that the downstream entrance area has strong oblique flow and its flow conditions for navigation cannot meet the specification. The design scheme needs to be optimized [2-6]. According to the analysis, main reasons for the non-conformance of flow conditions for navigation in the downstream entrance area and connection reach to the requirements include: Firstly, the influence of the river regime downstream of the power station, due to which water flows obliquely and concentrates on the right bank after discharge from the power station. Secondly, the high terrain of the side shoal on the left bank downstream of the hub, resulting in a narrow cross-section of the entrance area. Therefore, it is planned to remove the deflecting area on the left bank downstream of the power station and dredge the side shoal on the left bank at the bend downstream of the hub to
243.00 m.

**Figure 1. Project layout in optimized scheme 1**

4.1.2 Test results and analysis

Flow conditions for navigation in the entrance area meet the specification under the condition of $155.7 \text{ m}^3/\text{s} \leq Q \leq 6780 \text{ m}^3/\text{s}$.

The connection reach has good flow conditions for navigation when the transverse flow velocity is within $0.3 \text{ m/s}$ and the longitudinal velocity is within $2.0 \text{ m/s}$ under the condition of $155.7 \text{ m}^3/\text{s} \leq Q \leq 1000 \text{ m}^3/\text{s}$ and $5360 \text{ m}^3/\text{s} \leq Q \leq 6780 \text{ m}^3/\text{s}$.

With the increase of the flow rate, when $Q=2000 \text{ m}^3/\text{s}$ (controlled discharge), the maximum transverse velocity and longitudinal velocity are $0.44 \text{ m/s}$ and $1.41 \text{ m/s}$ respectively within $220 \text{ m}~300 \text{ m}$ from the entrance and the angle between the route and the water flow is $14.9^\circ~19.5^\circ$. Compared with the maximum transverse velocity ($0.69 \text{ m/s}$) and longitudinal velocity ($2.21 \text{ m/s}$) in the design scheme, they are reduced by $0.25 \text{ m/s}$ and $0.80 \text{ m/s}$ respectively. When $Q=2000 \text{ m}^3/\text{s}$ (complete discharge), the maximum transverse velocity and longitudinal velocity are $0.51 \text{ m/s}$ and $1.43 \text{ m/s}$ in the connection reach within $240 \text{ m}~300 \text{ m}$ from the entrance and the angle between the route and the water flow is $14.2^\circ~20.3^\circ$. Compared with the maximum transverse velocity ($0.54 \text{ m/s}$) and longitudinal velocity ($1.71 \text{ m/s}$) in the design scheme, they are reduced by $0.03 \text{ m/s}$ and $0.28 \text{ m/s}$ respectively. When $Q=3650 \text{ m}^3/\text{s}$, the maximum transverse velocity and longitudinal velocity are $0.47 \text{ m/s}$ and $1.53 \text{ m/s}$ in the connection reach within $280 \text{ m}~300 \text{ m}$ from the entrance, both of which occur on the left of the channel at $300 \text{ m}$ from the entrance, and the angle between the route and the water flow is $14^\circ~22.4^\circ$. Compared with the maximum transverse velocity ($0.67 \text{ m/s}$) and longitudinal velocity ($2.12 \text{ m/s}$) in the design scheme, they are reduced by $0.20 \text{ m/s}$ and $0.58 \text{ m/s}$ respectively.

According to results of the ship maneuvering test, the down-bound ship still faces difficulties at the end of the connection reach and in the downstream bended section. Affected by both the oblique flow and the bend, it drifts greatly to the right after exiting the connection each, which is not greatly improved in comparison with the design scheme.

Table 3. Variation of the maximum transverse velocity at the downstream entrance and connection areas in optimized scheme 1

| Flow rate (m$^3$/s) | 155 | 467 | 1000 | 2000 | 3650 | 5360 | 6780 |
|---------------------|-----|-----|------|------|------|------|------|
| Distance from the entrance (m) |     |     |      |      |      |      |      |
| 0                   | 0.02 | 0.12 | 0.04 | 0.04 | 0.19 | 0.06 | 0.05 |
| 20                  | 0.02 | 0.05 | 0.02 | 0.04 | 0.17 | 0.09 | 0.06 |
| 40                  | 0.01 | 0.07 | 0.04 | 0.02 | 0.19 | 0.08 | 0.06 |
| 60                  | 0.02 | 0.11 | 0.06 | 0.05 | 0.14 | 0.07 | 0.06 |
| 80                  | 0.02 | 0.13 | 0.08 | 0.09 | 0.11 | 0.07 | 0.06 |


|    |   |   |   |   |   |
|----|---|---|---|---|---|
| 100| 0.03 | 0.13 | 0.07 | 0.12 | 0.07 |
| 120| 0.02 | 0.11 | 0.13 | 0.11 | 0.12 |
| 140| 0.02 | 0.07 | 0.19 | 0.18 | 0.08 |
| 160| 0.07 | 0.05 | 0.24 | 0.24 | 0.14 |
| 180| 0.08 | 0.12 | 0.27 | 0.28 | 0.29 |
| 200| 0.07 | 0.15 | 0.27 | 0.3 | 0.19 |
| 220| 0.05 | 0.16 | 0.27 | 0.35 | 0.34 |
| 240| 0.06 | 0.19 | 0.27 | 0.39 | 0.38 |
| 260| 0.05 | 0.23 | 0.27 | 0.4 | 0.48 |
| 280| 0.05 | 0.27 | 0.27 | 0.42 | 0.49 |
| 300| 0.06 | 0.29 | 0.29 | 0.44 | 0.54 |

### 4.2 Engineering layout and test results and analysis in optimization scheme 2

#### (1) Engineering layout

Test results of the design scheme show that the downstream entrance area has strong oblique flow and its flow conditions for navigation cannot meet the specification. The design scheme needs to be optimized. Main reasons for the non-conformance of flow conditions for navigation in the downstream entrance area and connection reach to the requirements, as mentioned above, include: Firstly, the influence of the river regime downstream of the power station, due to which water flows obliquely and concentrates on the right bank after discharge from the power station. Secondly, the high terrain of the side shoal on the left bank downstream of the hub, resulting in a narrow cross-section of the entrance area.

Therefore, it is planned to remove the deflecting area on the left bank downstream of the power station, adjust the layout of the navigable wall downstream of the lock, making them symmetrical to the upstream, and meanwhile adjust the route. The engineering layout is shown in Figure 2.

#### (2) Test results and analysis

Flow conditions for navigation in the entrance area meet the specification under the condition of $1000 \text{ m}^3/\text{s} \leq Q \leq 3650 \text{ m}^3/\text{s}$.

When $Q=2000 \text{ m}^3/\text{s}$ (complete discharge), the transverse velocity on the left of the channel in the connection reach within 220 m~300 m from the entrance is greater than 0.30 m/s; the maximum transverse velocity and longitudinal velocity are 0.37 m/s and 1.64 m/s. Compared with the maximum transverse velocity (0.54 m/s) and longitudinal velocity (1.71 m/s) in the design scheme, they are reduced by 0.17 m/s and 0.07 m/s respectively. When $Q=2000 \text{ m}^3/\text{s}$ (controlled discharge) and holes 2#, 4#, 6# and 8# of the sluice are opened, the maximum transverse velocity in the connection reach is 0.40 m/s, which occurs on the left of the channel at the end of the connection reach, and the maximum longitudinal velocity is 1.63 m/s. Compared with the maximum transverse velocity (0.69 m/s) and longitudinal velocity (2.21 m/s) in the design scheme, they are reduced by 0.29 m/s and 0.58 m/s respectively.

When $Q=3650 \text{ m}^3/\text{s}$ (complete discharge), the maximum transverse velocity and longitudinal velocity are 0.38 m/s and 1.47 m/s in the connection reach within 240 m~300 m from the entrance, both of which occur on the left of the channel at 280 m~300 m from the entrance. Compared with the maximum transverse velocity (0.67 m/s) and longitudinal velocity (2.12 m/s) in the design scheme, they are reduced by 0.29 m/s and 0.65 m/s respectively.

In both optimization schemes 1 and 2 for the downstream area of the hub, flow conditions for navigation in the entrance area meet the specification when $Q \leq 3650 \text{ m}^3/\text{s}$. When $Q=2000 \text{ m}^3/\text{s}$ and $Q=3650 \text{ m}^3/\text{s}$, both the transverse velocity and the longitudinal velocity in the connection reach are reduced to different extents in comparison with the design scheme. However, flow conditions for navigation are poor according to the navigation of the ship model. Further optimization and improvement are required.
5 Recommended scheme
According to results of the model test for the entrance area and connection reach downstream of the hub under optimization schemes 1 and 2, the connection reach has poor flow conditions for navigation when the flow rate $Q \geq 2000$ m$^3$/s (controlled discharge) downstream of the lock.

According to the analysis in combination with the flow field study under optimization schemes 1 and 2, the main reason for the non-conformance of navigation conditions in the downstream connection reach to the requirement is the narrow cross-section in the entrance area and the connection reach. Therefore, we combine engineering measures in optimization schemes 1 and 2 to further expand the cross-section in the entrance area and the connection reach, including:

Firstly, removal of the deflecting area and the side shoal on the left bank downstream of the power station.
Secondly, adjustment of the layout of the navigable wall downstream of the lock and the cross-section of the river bed to increase the discharge area in the entrance area and the connection reach and reduce the flow velocity in the entrance area.

(1) Engineering layout
Engineering measures for optimization of the downstream of the hub: removal of the deflecting area on the left bank downstream of the power station. Dredging of the side shoal on the left bank at the bend downstream of the hub to 243.00 m. Adjustment of the layout of the navigable wall downstream of the lock, and adjustment of the route. The engineering layout is shown in Figure 2.

![Figure 2. Project layout in recommendation scheme](image)

(2) Test results and analysis
When $155.7$ m$^3$/s$\leq Q \leq 6780$ m$^3$/s, the transverse velocity and longitudinal velocity are less than 0.3 m/s and 2.0 m/s respectively and flow conditions for navigation in the entrance area meet the specification.

When $155.7$ m$^3$/s$\leq Q \leq 3650$ m$^3$/s and $Q=6780$ m$^3$/s, the transverse velocity and longitudinal velocity in the connection reach are less than 0.3 m/s and 2.0 m/s respectively, and the connection reach has good flow conditions for navigation. When $Q=5360$ m$^3$/s, the maximum transverse velocity and longitudinal velocity are 0.35 m/s and 1.21 m/s respectively, both of which occur at the end of the connection reach and on the left of the channel at 300 m from the entrance.

According to results of the ship maneuvering test, when $Q=1000$ m$^3$/s, the downstream entrance area and bend channel can meet the requirement of two-way navigation. When $Q=2000$ m$^3$/s (controlled discharge) and $Q=3,650$ m$^3$/s, the upbound ship can go smoothly. However, affected by the flow and the bend in the connection reach and the oblique flow on the right, the down-bound ship has a gradually increased drift angle and drifts towards the right to the upbound channel. According to the ship model test, the down-bound ship adopts the navigation pattern of "hanging", i.e. navigates along the left sideline of the design channel after exiting the entrance, and can keep its position on the left of...
the center line without occupying the upbound channel. The requirement of two-way navigation can be met. When $Q=5360 \text{ m}^3/\text{s}$ and $Q=6780 \text{ m}^3/\text{s}$, the ship can enter and exit the entrance area and navigate in the connection reach smoothly, but the down-bound ship still needs to pass through the entrance area and the connection reach with the navigation pattern of "hanging" after exiting the entrance and can keep its position on the left of the center line. The requirement of two-way navigation can be met.

Table 4. Variation of the maximum transverse velocity at the downstream entrance and connection areas in recommendation scheme

| Flow rate (m$^3$/s) | Distance from the entrance (m) | 155 | 467 | 1000 | 2000 |
|---------------------|--------------------------------|-----|-----|------|------|
|                     | 0                              | 0.15| 0.12| 0.18 | 0.03 | 0.03 | 0.02 | 0.04 | 0.02 |
|                     | 20                             | 0.11| 0.09| 0.14 | 0.03 | 0.04 | 0.02 | 0.03 | 0.02 |
|                     | 40                             | 0.07| 0.06| 0.1  | 0.02 | 0.05 | 0.03 | 0.01 | 0.02 |
|                     | 60                             | 0.05| 0.04| 0.09 | 0.02 | 0.06 | 0.05 | 0.04 | 0.04 |
|                     | 80                             | 0.04| 0.02| 0.11 | 0.04 | 0.07 | 0.04 | 0.05 | 0.07 |
|                     | 100                            | 0.04| 0.03| 0.13 | 0.05 | 0.09 | 0.06 | 0.04 | 0.06 |
|                     | 120                            | 0.04| 0.03| 0.15 | 0.03 | 0.11 | 0.09 | 0.01 | 0.02 |
|                     | 140                            | 0.04| 0.06| 0.16 | 0.06 | 0.12 | 0.08 | 0.06 | 0.05 |
|                     | 160                            | 0.03| 0.08| 0.16 | 0.07 | 0.12 | 0.06 | 0.09 | 0.04 |
|                     | 180                            | 0.04| 0.11| 0.18 | 0.09 | 0.14 | 0.04 | 0.09 | 0.01 |
|                     | 200                            | 0.04| 0.13| 0.19 | 0.1  | 0.15 | 0.03 | 0.12 | 0.05 |
|                     | 220                            | 0.05| 0.14| 0.19 | 0.11 | 0.15 | 0.05 | 0.17 | 0.08 |
|                     | 240                            | 0.05| 0.15| 0.18 | 0.13 | 0.17 | 0.08 | 0.21 | 0.11 |
|                     | 260                            | 0.05| 0.16| 0.18 | 0.14 | 0.2  | 0.13 | 0.24 | 0.15 |
|                     | 280                            | 0.05| 0.16| 0.18 | 0.14 | 0.23 | 0.17 | 0.28 | 0.18 |
|                     | 300                            | 0.06| 0.16| 0.17 | 0.14 | 0.26 | 0.22 | 0.35 | 0.24 |

6. Conclusion

(1) Flow conditions for navigation in the entrance area and the connection reach downstream of the lock of the new hub directly affect the navigation safety of ships. The transverse velocity in the entrance area and the connection reach downstream of the lock is high under the design scheme, threatening the safe navigation of ships. Therefore, engineering measures should be taken to improve flow conditions for navigation in the downstream entrance area so as to ensure safe entry and exit of ships into and from the entrance.

(2) In the recommended scheme, flow conditions for navigation in the downstream entrance area and connection reach are improved by means of removal of the deflecting area on the left bank downstream of the power station, dredging of the side shoal and adjustment of the layout of the navigable wall downstream of the lock. When $Q\leq 6780 \text{ m}^3/\text{s}$, flow conditions for navigation in the entrance area meet the specification, and according to the ship manoeuvering test, those in the connection reach basically meet the specification.

(3) For the new hub, especially the navigation-hampering section located on the concave bank and with a narrow cross-section in the entrance area and the connection reach downstream of the lock, engineering measures such as the combination of dredging of the side shoal and adjustment of the layout of the navigable wall can be taken to improve flow conditions for navigation in the entrance area and the connection reach so as to ensure safe navigation and smooth entry and exit of ships into and from the entrance and the main channel.

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Reference
[1] JTJ/T232—98,[S]Technical specifications for current and sediment simulation of inland river navigation channels and ports.
[2] Liu,D.,Huang,B.S.,Qiu,J.,etal. (2015) Experimental study on navigation flow condition for newly built second-line and third-line shiplocks of Feilaixia Water Control Projec. Water Resources and Hydropower Engineering, 46:58-60.
[3] Hao,P.Z., Li,B.H., Li,Y.B. (2000)Optimized Arrangement of Navigation Structures and Test & Study of Navigation Conditions of Dayuandu Junction[J]. Port & Waterway Engineering,10:29-33.
[4] Li,J.T.,Hao,P.Z.,Li,J.H. (2007)Optimization research on plan layout of Yuliang Hydro-junction Project of Youjiang River. Journal of Waterway and Harbor,28:348-353.
[5] Hao,P.Z.,Li,J., Xu,G.B.(2004)General Layout and Experimental Study on Navigable Condition Optimization of Navigation-Power Junction at Slightly Curved Braided Reach.Port & Waterway Engineering,11:66-69.
[6] Li,Y.B. (2004)Standard of navigable flow condition for connecting section outside navigation gate of navigation lock.Journal of Waterway and Harbor,2004(4):12-16.