Test Study on Influence of a Sluice on Navigation of Ships

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Abstract. The navigation influenced by extension project of a sluice was researched in this paper. This sluice connected the inland river and outer river, and the hydraulic characteristics beside it were significant for ships’ passages. The test in this paper was conducted for simulating the flow patterns and hydraulic characteristics around this sluice. According to the test results, the flow velocities and flow patterns around approach channels of the inland river and the outer river in various conditions are given in this paper, including the maximum lateral flow velocity and the maximum reserved flow velocity. These data provided scientific bases for safe operation of the sluice and navigation channels. In addition, a guide wall was proposed to effectively reduce the lateral flow velocity.

1. Introduction
The construction of hydraulic projects will change the flow conditions of the original river while transforming nature for humans [1][2]. According to the existing results [3] ~ [5], the hydraulic characteristics around the sluice project should be researched, especially the navigation safety [6]. This is also one of the purposes of our research.

The hydro-junction described in this paper is composed of ship locks and control gates. The flow rate of the pumping station is 90m³/s and the total net width of the control gates is 20m. It belongs to the large II hydro-junction project and the project’s scale is relatively large.

In order to ensure the normal operation of the project and the safe navigation of ships, we suggested that in this test, the rationality of the design scheme needed to be verified, in particular, the impact on the normal operation of ship locks when the pump sluice was in drainage condition.

2. Test Model
The design of the model follows the “Code for normal hydraulics model investigation for hydropower & water resources” (DL/T5244-2010) and are processed with reference to the "Hydraulic Calculation Manual", "Model Test Measurement Technology" and past related scientific research.

2.1. Model design.
The model is designed according to the gravity similarity criterion. The model geometric scale is \( \lambda = 25 \) (prototype: model) and the corresponding physical scales (prototype: model) are:
Velocity scale: \( \lambda_v = \lambda_q^{1/2} = 5 \)
Flow rate scale: \( \lambda_q = \lambda_\ell^{5/2} = 3125 \)
Roughness scale: \( \lambda_n = \lambda_q^{1/6} = 1.71 \)
Water depth scale: \( \lambda_h = \lambda_q = 25 \)

The model was made of cement mortar and plexiglass. The accuracy is strictly controlled according to relevant test procedures. The roughness of the plexiglass is 0.008 to 0.009, and the similarity theory is 0.014 to 0.015, which is similar to the concrete roughness. The surface of cement mortar is about 0.011 to 0.012, which can basically match the similar requirements of resistance. The overall hydraulic model layout of the drainage pump is shown in Fig. 1.

![Fig. 1. Overall hydraulic model](image)

2.2. Measurements.
Measuring weirs are used in this test to maintain water levels. In the inland side, a channel is arranged to support water and measure its flow rate. The flow rate of each pump unit in the pumping station is measured by the control valve and glass rotor.

The water level is carried out by the vibrating meters and water level styluses. These two are verified by each other. The data of former one is collected by computer and the latter is read manually. The reading accuracy of the stylus can reach 0.02 mm.

The flow velocity is measured by opto-electronic flow meters. Data is collected by computers. For some measurement points, flow direction is measured by direction meters at the same time.

Tracers are used to show the flow pattern and high-performance cameras are used to record flow field images for analysis.

3. Results
According to the design data, the navigable water level of inland river is 1.8m-3.5m, and the navigable water level of river is 1.0m-4.0m. During the test, the maximum flow rate of the sluice gate was used to observe the lateral surface velocity of the water at the gate area of the inner and outer river approaches. The main test conditions are listed in Table 1.

| Condition No. | Water level of Inland River (m) | Water level of Outer River (m) | Flow Rate (m³/s) | Direction |
|---------------|---------------------------------|-------------------------------|------------------|-----------|
| 1             | 2.50                            | 1.44                          | 140              | Drainage  |
| 2             | 3.50                            | 1.44                          | 140              | Drainage  |
| 3             | 1.80                            | 1.44                          | 140              | Drainage  |
| 4             | 2.50                            | 3.12                          | 140              | Diversion |
| 5             | 3.50                            | 3.12                          | 140              | Diversion |
| 6             | 1.80                            | 3.12                          | 140              | Diversion |
| 7             | 1.80                            | 1.95                          | 140              | Diversion |
| 8             | 1.80                            | 2.50                          | 140              | Diversion |
3.1. Velocity at the gate area of navigation approach at inland side

3.1.1. lateral surface velocity
In condition 1, the inland water level is 2.5m and the drainage flow is 140m³/s, and the gate is partially opened. This operating condition is one of the common most unfavorable conditions. In this test, the right side of the inland river was observed to gradually contract in front of the approach gate and flowed toward the sluice at the head of the separation dike. There is an unequal angle between the local flow velocity near the head of the bank head and the axis of the approach channel. In the test, the velocity of the water surface at the gate area of the approach channel was mainly observed to analyze the influence of the floodgates on navigation. The flow pattern is shown in Fig. 2. In the test, the lateral flow velocity within the 20m in front of the dike is large. The maximum is about 0.37 m/s.

![Fig. 2. Flow pattern of inland side in condition 1](image)

Working condition 2, 3 are similar as working condition 1. The maximum lateral surface velocity measured in the test is shown in Table 2.

| Condition No. | Water level of Inland River (m) | Flow Rate of Drainage (m³/s) | Max Lateral Surface Velocity (m/s) |
|---------------|---------------------------------|-------------------------------|----------------------------------|
| 1             | 2.50                            | 140                           | 0.37                             |
| 2             | 3.50                            | 140                           | 0.25                             |
| 3             | 1.80                            | 140                           | 0.42                             |

3.1.2. Recirculation flow velocity
In condition 4, the inland water level is 2.5m and the diversion flow rate is 140m³/s. After the water flows out to the bank, the left side gradually spreads to the side of the approach channel. A recirculation zone is formed at the portal area of the inland navigation channel. The flow pattern is shown in Fig. 3.
In this test, a maximum reflux flow rate of 0.35 m/s is measured, which is less than the allowable reflux flow rate for navigation. Due to the gradual diffusion of the mainstream, the horizontal velocity of the water surface in the portal area is relatively small, which has no significant impact on navigation. The maximum reflux flow velocities in the approach gate area in working condition 5 and 6 are listed in Table 3.

Table 3. Max reflux velocity in gate area of approach channel at inland side

| Condition No. | Water level of Inland River (m) | Flow Rate of Drainage (m³/s) | Max reflux Velocity (m/s) |
|---------------|---------------------------------|-----------------------------|--------------------------|
| 4             | 2.50                            | 140                         | 0.35                     |
| 5             | 3.50                            | 140                         | 0.28                     |
| 6             | 1.80                            | 140                         | 0.39                     |

3.2. Velocity at the gate area of navigation approach at outer side.

3.2.1. Lateral surface velocity

In condition 7, the river water level is 1.95m and the diversion flow rate is 140m³/s. The flow regime observed during the test is basically the same as it in the inland side. Fig. 4 shows the flow pattern at the entrance gate of approach channel. In the test, the maximum horizontal flow velocity at water surface in the entrance gate area is 0.41 m/s.

Table 4 Max lateral surface velocity at outer side

| Condition No. | Water level of Outer River (m) | Flow Rate of Diversion (m³/s) | Max Lateral Surface Velocity (m/s) |
|---------------|--------------------------------|------------------------------|-----------------------------------|
| 7             | 1.95                           | 140                          | 0.41                              |
| 8             | 2.50                           | 140                          | 0.35                              |
3.2.2. **Recirculation flow velocity**

Similar in the inland side, the maximum reflux velocity at the entrance gate area of approach channel at the outer side is 0.42 m/s, which is slightly larger than the allowable return velocity. Fig. 5 shows its flow pattern in condition 11.

![Fig. 5. Flow pattern at outer side in condition 11](image)

The horizontal flow velocity caused by the mainstream is relatively small, which has no significant impact on navigation. The maximum flow rate of return flow 12-15 is shown in Table 5.

| Condition No. | Water level of Inland River (m) | Flow Rate of Drainage (m³/s) | Max reflux Velocity (m/s) |
|---------------|---------------------------------|------------------------------|---------------------------|
| 11            | 1.00                            | 140                          | 0.52                      |
| 12            | 1.44                            | 140                          | 0.40                      |
| 13            | 1.95                            | 140                          | 0.36                      |
| 14            | 3.12                            | 140                          | 0.30                      |
| 15            | 4.00                            | 140                          | 0.25                      |

### Table 5 Max reflux velocity in gate area of approach channel at outer side

3.3. **The safe flow rate and the guide wall**

Through the gate control to properly reduce the sluice drainage flow, flow velocity can be reduced at the approach channel’ gate area. In this test, the flow rate was gradually reduced at the same water level in order to observe the flow pattern at the approach channel and finally obtain the safe flow matching the allowable lateral velocity. Table 6 and Table 7 show the allowable flow rate in allowable lateral velocity 0.3m/s and 0.25m/s.

| Lateral Velocity: 0.3m/s | Inland side | Outer side |
|--------------------------|-------------|------------|
| Inland water level (m)   | 3.50 3.00   | 2.70 2.50 1.80 |
| Allowable flow rate (m³/s) | 160 140 120 110 95 | 170 150 140 115 100 |

| Lateral Velocity: 0.25m/s | Inland side | Outer side |
|--------------------------|-------------|------------|
| Inland water level (m)   | 3.50 3.00   | 2.70 2.50 1.80 |
| Allowable flow rate (m³/s) | 140 120 100 90 80 | 150 130 120 95 85 |

In the test, it was observed that adding a guide wall at the head of the bank could effectively reduce the lateral surface velocity at the gate area of the approach channel. By comparison, the length is suitable for 20m. When the length is less than 20m, its effect is significantly reduced.
4. Conclusions
It could be seen from this test that the flow rate through the sluice would affect the water flow velocity and flow pattern of approach channels. In this test, the lateral flow velocity of the approach channel area was used as a control index to study the navigation safety under different working conditions. The results showed that adopting the sluice controlling operation or adding guide wall could significantly reduce the adverse effects of sluice operation on navigation. According to the test data, the flow rate corresponding to the allowable lateral flow velocity was analyzed, which provided an important reference and effective improvement for the safe operation of the project.

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