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Model test research on effect of flow accelerating-board in a pumping station

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Abstract. Generally, the sedimentation in the forebay of pumping station may result in bad flow patterns, which will decrease efficiency of pump device and cause the vibration of pump house and units, or other safety problems. To research the improvement of this impact in an actual project, a physical model test was established for the original scheme of one pumping station. One part of results show that the flow velocity in the channel of regulating-pool is low under the high-water level condition, and it’s easy to cause the sedimentation in the regulating-pool. According to this problem, we propose a flow accelerating-board scheme for the regulating-pool. The final results show that this scheme could effectively increase the flow velocity at the bottom and reduce the sedimentation in the regulating-pool. Although the hydraulic loss of regulating-pool increased, it could be able to satisfy the design requirements.

1. Introduction

The forebay of pumping station is an important hydraulic structure which connects the channel and the inlet channel. In order to provide good flow conditions for the water pump, the flow in the forebay should be such as that the velocity distribution is uniform, the water flow is smooth and there are no vortices in the forebay[1][2][3]. The actual observation and later theoretical studies have shown that the bad forebay caused recirculation, vortex, disturbance of water intake and deterioration of water pump suction conditions, the efficiency of the pump units decreased, the vibration of the pumping station and the units start-up difficulties, cavitation and noise[4]. In the pumping station with large sediment concentration, the adverse hydraulic conditions in forebay can also cause the sedimentation or erosion at the bottom of forebay. Therefore, it is important to improve the efficiency of pump and prevent the sedimentation by improving the flow patterns in the forebay of pumping station through some necessary measurement[5].

In this paper, there is a regulation-pool in front of the forebay, the partition wall in the regulation-pool is setting up to guide the water to enter the forebay easily. The flow velocity in the channel flow is low under the high water level condition, and it’s easy to cause the sedimentation in the regulating-pool. So, it’s necessary to make further modification of the regulating-pool under the condition of ensuring the head loss to meet the design requirements, to increase the flow velocity at the bottom of the channel.
flow and inhibit the sedimentation in the regulating-pool. According to the model test results of the pumping station, the scheme of adding the flow accelerating-board in the regulating-pool was put forward to verify the feasibility of increasing flow velocity at the bottom of the channel flow and suppressing the sedimentation in the regulating-pool.

2. Model foundation

2.1. General situation of the pumping station
A pumping station is an important part of the upper reaches Huangpu River water source connected pipe project. The original design: through two water pipes to supply water to two regulating-pools, the effective volume of a single pool is about 10000m³, the elevation of the bottom is 1.00m (the elevation of the ground outside the pumping station is 4.50m), set up partition wall in the regulating-pool. Each regulating-pool corresponding to a forebay, and supply water to four pumps. Intake sump is setting up to each pump alone which is separated by partition wall, the width and length of intake sump are 5.0m and 17.8m respectively, the elevation of the Intake sump bottom is 7.00m, the intake sump link up with the regulating-pool through inclined floor of the forebay. The planar graph of the pumping station is shown in Fig.1.

![Fig.1 The planar graph of the pumping station](image)

2.2. Model design
The physical model of the pump station adopts the whole normal hydraulic model, and it’s designed according to gravity similarity criterion. Considering the requirements of the flow at drag square area and the choice of the model pump, choose $\lambda = 10$ as the linear scale for the model. The similarity scales of other physical quantities are shown in Table 1.
### Table 1. The scale of the model.

| Scale Type       | Value |
|------------------|-------|
| Gradient scale   | 1     |
| Angle scale      | 1     |
| Velocity scale   | 3.16  |
| Flow scale       | 316.23|
| Roughness scale  | 1.47  |

The forebay and intake sump of the pumping station are made of concrete, and the roughness is 0.013~0.014, the roughness of the model is 0.009~0.010. The sidewall of the model is made of pure cement, and the roughness is 0.010. The regulating-pool and intake sump of the model are made of organic glass and plastic, and the roughness is about 0.009. The roughness of the model generally satisfies the similar requirements of roughness.

### 3. Analysis of test results.

#### 3.1. The original scheme.

The original scheme selects designed operating conditions of pumping station as the test condition (the water supply scale of the pumping station is 2.4 million m³/d), six units are running, and the flow of each pump is 4.954 m³/s. The test conditions are shown in Table 2.

### Table 2. The test conditions.

| Condition | The water level in the forebay (m) | The number of running units | The flow of forebay (m³/s) | Remarks                  |
|-----------|-----------------------------------|-----------------------------|---------------------------|--------------------------|
| 1         | 3.80                              |                             | 14.862                    | Designed normal water level |
| 2         | 1.80                              | 3                           | 14.862                    | Designed lowest water level |
| 3         | 5.80                              |                             | 14.862                    | Designed highest water level |

The test results of condition 1 show that the water flow from the regulating-pool into the forebay has to turn 9 times, due to the large number of channel flow and the narrow width, the flow velocity in the channel flow is large and the distribution is uneven, the main flow is on one side, and the local hydraulic loss is large at the corner. There is a very clear flow separation and a long narrow recirculation zone at the corner. In the regulating-pool, the partition wall area which is connected with the diffusion section of the forebay has a large range of retention region due to the large flow area. The flow patterns in the regulating-pool of condition 1 is shown in Fig.2, the velocity distribution in the regulating-pool is shown in Fig.3.
In the test of condition 2, it is observed that when the minimum water level is 1.80m in the forebay, the flow velocity in the channel flow is large due to the shallow water depth at the forebay intake.

The test results of condition 3 show that the hydraulic loss of the regulating-pool is reduced due to the increase of the water depth and the decrease of the flow velocity. The flow patterns in the regulating-pool and forebay is similar to condition 1.

The test results of the original scheme show that there is a large range of retention region at the corner, the distribution of the flow velocity in the channel flow is uneven, the main flow is on one side. It’s easy to cause the sedimentation in regulating-pool at the partition wall area which is connected with the diffusion section of the forebay due to the large flow area.

3.2. The flow accelerating-board scheme.

When the pumping station is running at the high water level, the flow velocity in the regulating-pool is significantly reduced. When the pumping station is running 3 units, the average flow velocity in the channel flow is about 0.34m/s, which is easy to cause the sedimentation in regulating-pool. Therefore, it is necessary to make further modification of the regulating pool under the condition of ensuring the hydraulic loss to meet the design requirements, to increase the flow velocity at the bottom of the channel flow and inhibit the sedimentation in regulating-pool.

The flow accelerating-board scheme is about to add boards in the regulating-pool, a expected bottom flow velocity can be obtained by arranging a sufficient number of boards in the channel flows and selecting a suitable bottom elevation. At the same time, the addition of flow accelerating-board will increase the local hydraulic loss in regulating-pool, the more number of the boards and the lower bottom elevation will increase the hydraulic loss. In the test, control the largest water surface falls is 0.20m, through the different orifice height, different number of boards and different layout, multi-program comparison, get a more reasonable layout of the flow accelerating-board. The layout of the flow
accelerating-board in the regulating-pool is shown in Fig.4 and Fig.5 (The elevation of the bottom of each board is 3.50m).

![Fig.4 The sectional drawing of the layout of the flow accelerating-board in the regulating-pool](image)

![Fig.5 The planar graph of the layout of the flow accelerating-board in the regulating-pool](image)

The flow accelerating-board scheme is plan to solve the sedimentation problem in the regulating-pool under the high water level operating condition, so we choose condition 3 to test. The results of the test show that when the boards are set up, the upstream flow shrink and dive before the board, and the bottom flow velocity gradually increased. In the area 5m downstream of the board, the main flow is in the lower part of the channel flow. As the increase of distance from the board, the main flow gradually spread up from the bottom, the bottom flow velocity has decreased and the upper flow velocity has increased. Until get to the next board, the upstream flow shrink and dive again, and the bottom flow velocity increased.

The velocity distribution in the regulating-pool of condition 3 is shown in Fig.6~Fig.8, It can be seen from the figures that the flow velocity at the bottom of each channel flow is large, and the flow velocity at the bottom of the channel flow is 0.45 m / s ~ 0.60m / s. The velocity is larger than the velocity without the flow accelerating-board (about 0.34 m / s), but the average velocity in the channel flow is slightly lower than the velocity under the designed normal water level condition.
Fig. 6 The velocity distribution at the bottom of condition 3

Fig. 7 The velocity distribution at the surface 1.5m distance from the bottom of condition 3
Fig. 8 The velocity distribution at the surface 3m distance from the bottom of condition 3

After setting the flow accelerating-board in the regulating-pool, because of the increase of the velocity at the bottom of the channel flow, the frictional hydraulic loss and the local hydraulic loss of the channel flow increase. The water surface has fallen 0.21m from the regulating-pool to the forebay of condition 3, basically meets the design requirements.

4. Conclusion

In this paper, a physical model test is established for a pumping station. The test results of the original scheme show that the flow in the regulating-pool is affected by the partition wall, and there is a recirculation zone at the corner. The distribution of velocity in the channel flow is uneven, and the main flow is on one side. In the regulating-pool, the partition wall area which is connected with the diffusion section of the forebay has a large range of retention region due to the large flow area, where the sedimentation is easy to occur.

According to the test results view of the original scheme, we propose a rectification scheme: the flow accelerating-board scheme. The test results show that this scheme can effectively increase the flow velocity at the bottom of the regulating-pool, and effectively reduce the sedimentation in the channel flow when the pumping station is running at high water level. Although the hydraulic loss of the regulating-pool is increased, but also meets the design requirements.

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