

Experimental study on hydraulic characteristic around trash rack of a pumping station

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Abstract. This paper focuses on flow pattern around trash rack of intake of a pumping station project. This pumping station undertake the task of supplying up to 3,500,000 m³ water per day for a megacity. Considering the large flow rate, high lift, multi-pipe supply and long-time operation in this water conveyance pumping station, we built a physical model test to measure the flow velocity and observe the flow pattern to verify the reasonability of preliminary design. In this test, we set 3 layers of current meters around each trash rack of intake in reservoir to collect the flow velocity. Furthermore, we design 2 operating conditions of 9 pumps to observe the change of flow pattern. Finally, we found the velocity data were in a normal range under 2 different operating conditions of the 9 pump units.

1. Introduction

pumping station is one of the principal projects in urban water-supply system [1]. It affords water from reservoir to supply network pipes. Generally, a pumping station contains several main parts [2] and their safety, stability and efficiency should be well ensured. In this paper, we pay attention on a large pumping station served for a megacity. This pumping station support people with water up to 3.5 million cubic metre per day. Standing on this large scale, some flow characteristics should be carefully considered [1]. In most hydraulic project, engineers usually set trash racks between reservoir and intake pipe to prevent solids from entering the intake pipe [4]. To quantitatively analysis the flow pattern around trash racks [5][6] in this pumping station, we designed a physical model test to collect data and observe. Fig. 1 shows the general plan of this project. In figure, the reservoir is located at the northern part of whole map and the 3 circles in reservoir on map are the heads of intake pipes which are connected to forebays.



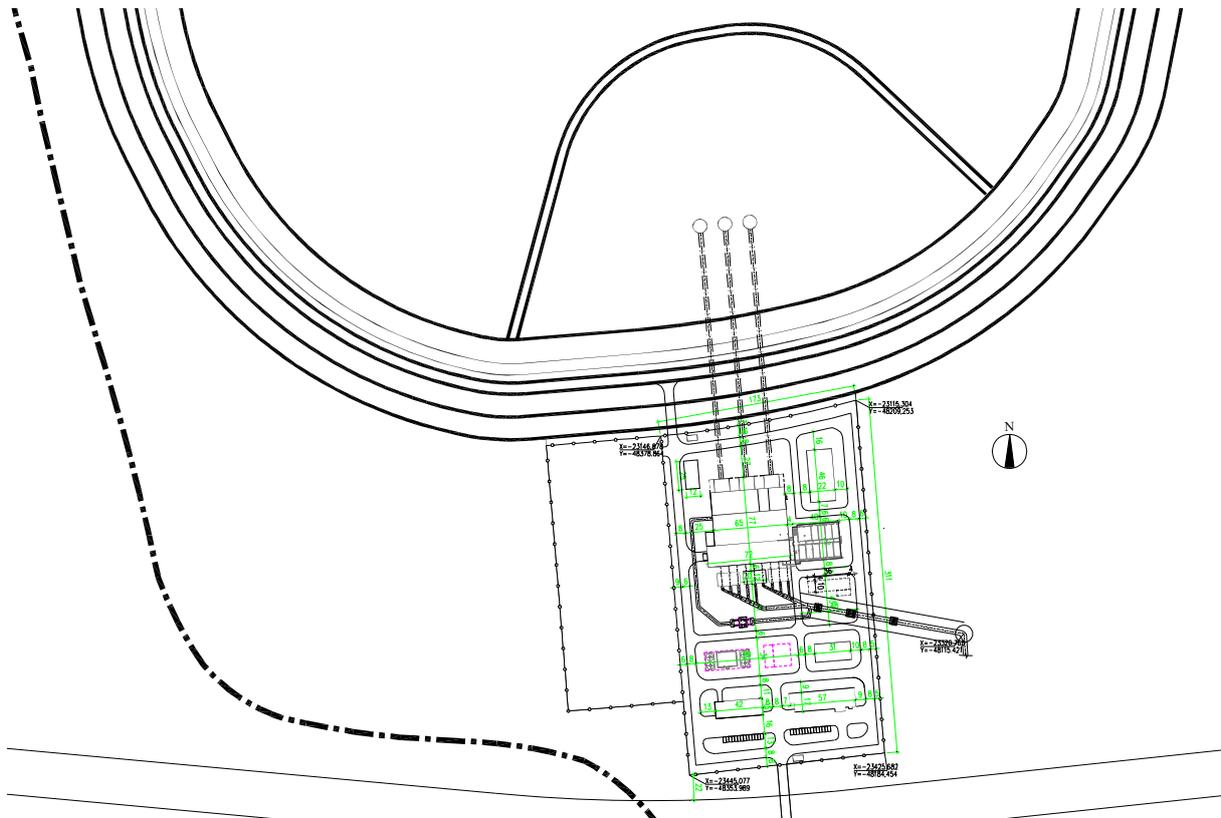


Fig. 1 Layout plan

2. Model design

The entire process of this model test was based on the national standard *Specification for normal hydraulic model test* (SL155-2012) published by The Ministry of Water Resource of People's Republic of China. Other unaccomplished matter was conducted referring to *Design code for pumping station* (GB/T 50265-2010), *Specification for design of drainage pumping station in municipality* (DGJ08-22-2003), and related experience.

2.1 Key parameters and materials of model

This model test research must contain the location of intake in reservoir, setup of gravitational intake pipe, size of entrance well, reasonability of setting bottom sill in forebay, flow pattern around bell mouths of pumps. Therefore, we had to scientifically select parameters of the hydraulic model to fit the geometry similarity, movement similarity and dynamic similarity.

The geometry scale of this physical model was determined to 10 To fit flow pattern and pump type. Accordingly, other physical scales were as follows:

$$\text{Velocity scale: } \lambda_v = \lambda_l^{1/2} = 10^{1/2} = 3.16$$

$$\text{Flow rate scale: } \lambda_Q = \lambda_l^{5/2} = 10^{5/2} = 316.23$$

$$\text{Roughness scale: } \lambda_n = \lambda_l^{1/6} = 10^{1/6} = 1.47$$

Pump type was based on the simulation requirements. After comparisons, we selected 150ZLDB vertical mixed-flow pump in test.

Roughness and materials. The forebay and intake sump of pumping station in prototype were made of concrete. The roughness was 0.013~0.014. In test, the overflow surface was carefully made of pure cement (roughness 0.010) which basically satisfied the roughness scale.

The roughness of steel penstock in prototype was 0.011~0.012. After converted by roughness scale,

it was 0.00748~0.00816 in test. According to related experience, the PMMA (polymethylmethacrylate, roughness close to 0.009) could match with a little large. By this, the route head loss would be a little larger and it is safer for engineering.

For observation, intake sump of pumping station was made of transparent PMMA.

Hydraulic model test system. Hydraulic model test system was an opened self-circulation device. It contained most parts of model and occupied around 800 m². Figure 1 shows the sketch of physical model.

Fig. 2 shows the entire physical model of this test.



Fig.2 Physical model

2.2 Measurement

In test, measurements for flow rate, pressure, water level, flow velocity and like were conducted by advanced measuring instruments. Simultaneously compared with traditional measuring method, the accuracy of measurement data could be guaranteed.

Flow rate. The flow rate of every single pump was measured by the ultrasonic flowmeter installed on outlet pipe. Meanwhile, we set measuring weir for comparison. The thin-wall weir was set in backwater channel to check the entire flow rate of all operating pumps.

Water level (pressure). The water level of typical sections in reservoir, intake pipe, forebay and intake sump was collected by the water level transmitter and recorded by computers. The piezometric tubes were set in appropriate positions to verify the digital data.

Flow velocity. The flow velocity in typical sections should be measured to analysis the flow pattern in intake and supply construction. It was collected by the photoelectric current meter and recorded by computers.

Flow pattern observation. We set tracer material in water to take flow pattern pictures from high performance camera for further analysis.

3. Test conditions.

In reservoir, 3 trash racks were set between reservoir and intake pipes to prevent solids from entering the pipe. This device was used to protect the pipe. Behind the reservoir, every pipe was connected to 3 pumps via a forebay and used to delivery water from reservoir. In plan, these 9 pumps usually do not run together. In design, they were averagely divided to 3 group and each group should run independently to match up the need of water-supply system. However, the flow pattern and in front of trash rack and hydraulic loss would also be impacted by their type.

In this section, we are going to show the distribution of measuring points and the operating conditions of pump units.

3.1 Arrangement of flowmeters.

Above every trash rack, we set 3 layers of flowmeters in water to collect the flow velocity. Fig. 3 shows the position of flowmeters around every trash rack in reservoir.

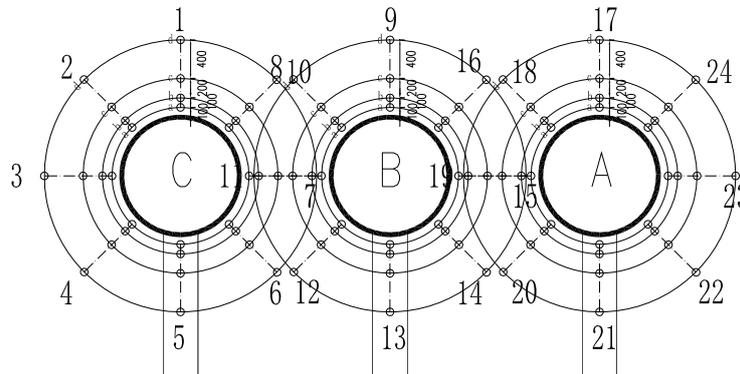


Fig. 3 position of flowmeters

As you seen in Fig. 3, we set 4 circles around each intake and the distance between these 4 circles and their intake were 1m, 2m, 3m, and 4m. In every circle, we set 8 vertical line for 3 layers to collect the flow velocity of bottom layer, middle layer and top layer. It meant there were 96 flowmeters around 3 trash racks.

3.2 Operating conditions of pumps.

In preliminary design of this project, 3 intake pipes were respectively followed by 3 forebays. Each forebay was connected by 1 pump-group (3 pumps). Due to the changing need of water-supply, the total 9 pumps were not designed to work together all the time. So, it is necessary to observe the flow pattern in different operating conditions.

Table 1. operating conditions of 9 pumps.

Operating condition	Water level in reservoir (m)	Flow (m ³ /s)	Working pump				Total	Spacing
			A	B	C			
1	-3.00	30.43	2	3	0	5	Accident working condition	
2	1.65	43.47	2	3	2	7	Low water level working condition	

4. Result.

Due to limited space of this paper, the data we are going to show you are few but typical.

Fig. 4, Fig. 5 and Fig. 6 are the data of flow velocity in top, middle and bottom layer, operating condition 1. In these 3 figures, it is obviously that the flow velocity increases with the distance between measuring point and trash rack decreases.

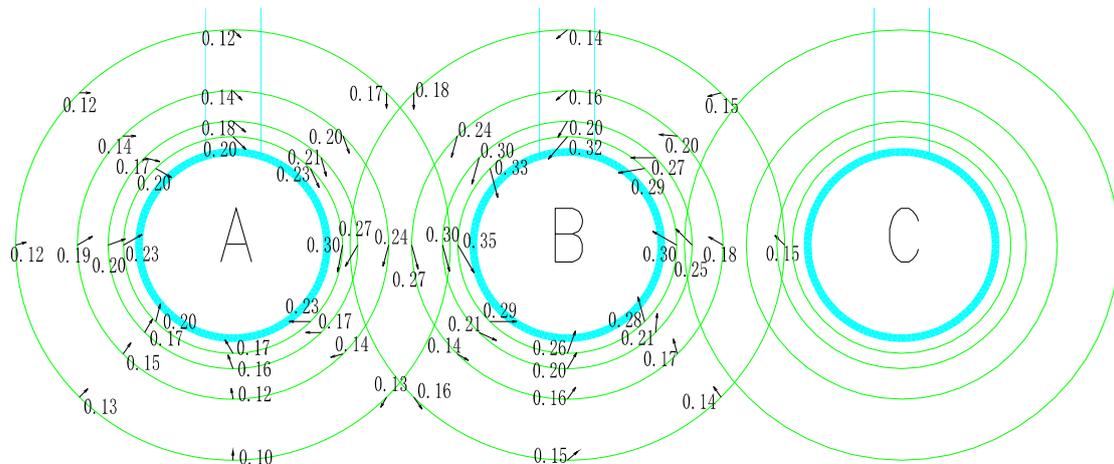


Fig. 4 Flow velocity in top layer, operating condition 1

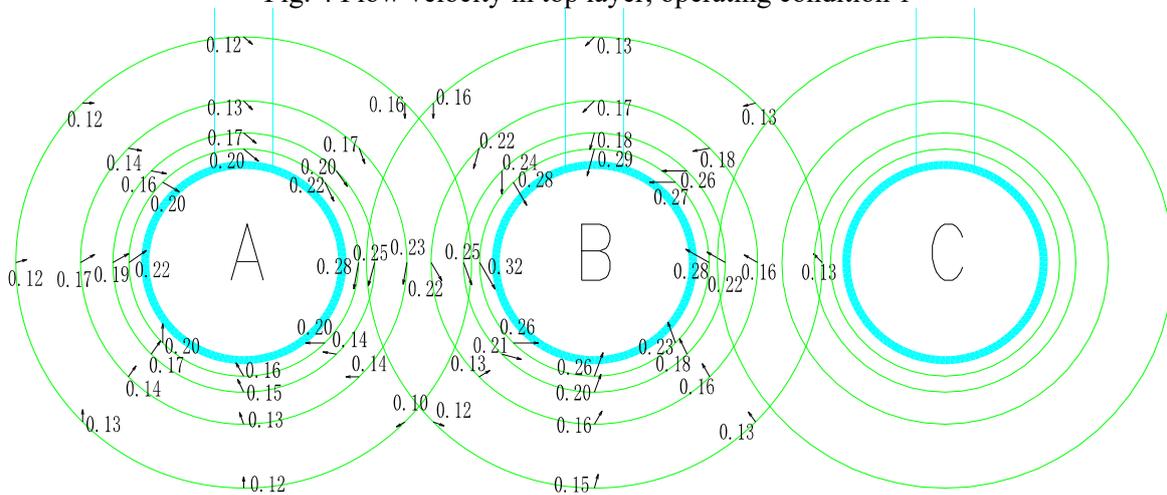


Fig. 5 Flow velocity in middle layer, operating condition 1

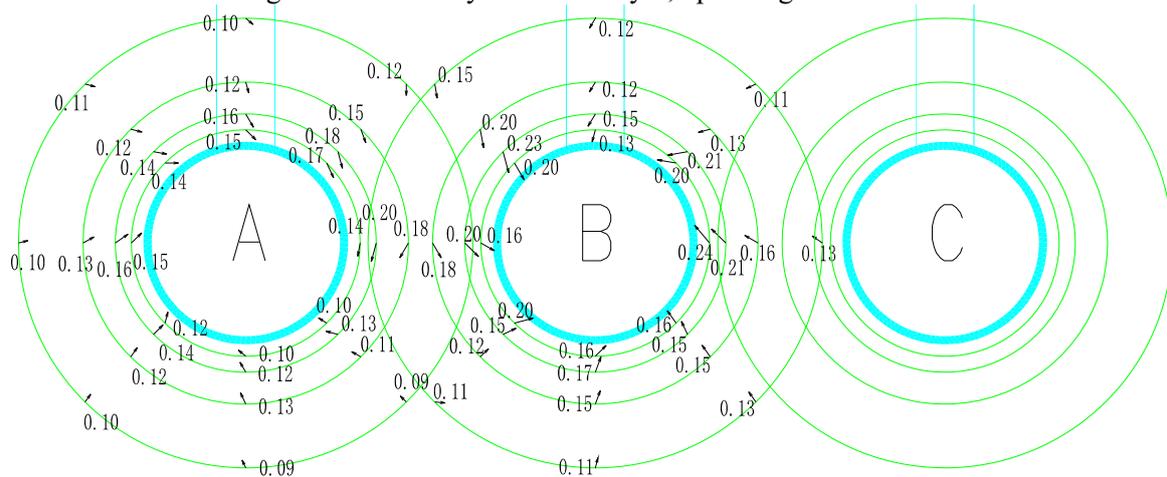


Fig. 6 Flow velocity in bottom layer, operating condition 1

According to these figures, the max flow velocity on top layer is 0.35 m/s, which is 0.03 m/s more than the max on middle layer. On bottom layer, the max velocity is 0.24 m/s. All the max data occur around intake B, which is followed by the max number of working pumps. In intake A or B, the rotational direction of vertex combined with every single flow direction is the same as it in following Fig. 7.

Fig. 7 and Fig. 8 shows the flow pattern in operating condition 1 and 2. Respectively to A-B-C, the number of working pumps are 2-3-0 in Fig. 7 and 2-3-2 in Fig. 8. The foam (used to instead solids in test) are mainly crowded above trash rack B and A in Fig. 7. This is because the pumps behind the pipe are working. In Fig. 8, due to the higher water level, the top flow velocity decreases. Compared with Fig. 7, the distribution of floating solids on water surface are more balanced in Fig. 8.



Fig. 7 Operating condition 1



Fig. 8 Operating condition 2

5. Conclusion

In this paper, we showed our research about flow pattern around trash racks of a pumping station via an entire model test. By collected data and observation, we found that in various working conditions of pumps, the flow velocity could always be kept in a normal range whether the distribution of floating solids on water surface was crowded or discrete. Finally, the max flow velocity always occurred around the intake which was followed by the max number of working pumps.

Acknowledgement

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References

- [1] W.M. Liu, Z.K. Jin, Y. Zheng. Numerical modeling and hydraulic optimization for large water pumping station [J] *Water and Wastewater Engineering*, 2009, 35(6).
- [2] Z.X. Du, X. Chu, H. Yang and J. Qian. Design of large-scale pumping stations in South-to-North Water Transfer East Route Project [J]. *Advances in Science and Technology*. 2003, 23(5).
- [3] J.G. Feng, X.S. Wang, H.W. Tong and Y.L. Chen. Improving of the flow patterns in forebays of the large urban water supply pumping stations [J]. *Water and Wastewater Engineering*, 2010, 36(11):51-54.
- [4] D.P. Sun, W.Z. Yan, P.T. Wang. Hydraulic Characteristics and Habitus Optimization for the Large Inlet Conduit System [J]. *Journal of Basic Science and Engineering*, 2011, 19(1):9-19.
- [5] S.K. Sun, H.T. Liu, Z.Z. Li, C.Y. Sun. Study on velocity distribution behind the trashrack in lateral intake/outlet of pumped storage power station [J]. *Journal of Hydraulic Engineering*, 2007, 38(11): 1329-1335.
- [6] X.P. Gao, J.B. Zhang, F. Ye, H.F. Song. Numerical simulation of trash rack for a pumped storage plant [J]. *Water Resource and Hydropower Engineering*. 2005, 36(2): 61-63.