Test research on flow patterns at intake area of a pumping station

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Abstract. This paper focuses on the problem of the flow pattern in the inlet area of a drainage pumping station for its safety. Limited to the restrictions on terrain conditions and surrounding constructions, this pumping station was designed with a compact layout which could not followed by regular standards. The small size may affect the hydraulic conditions at the intake of this pumping station, which in turn will affect the safe operation of the project. Therefore, in order to ensure whether the pumping station works stably, it is necessary to conduct an intensive study on the flow pattern at the intake area of this pumping station via a model test. Research shows that the original design may bring hydraulic problems. In the test, we found intermittent suction vortexes in the inlet area. This hydraulic phenomenon should be avoided in the inlet area of pump stations. In this case, it is proposed to reduce the elevation of the water intake system to increase the depth of submergence. According to the test results, harmful vortexes disappeared and the water flow became smoother in all operating conditions after adopting improvement measures. This shows that the proposal is effective and makes the project safer.

1. Introduction

Generally, urban rainwater pumping stations are limited by land conditions, device networks, existing buildings, construction conditions, etc., that designers usually have to minimize the floor area and reduce the impact on surrounding environment. These factors make drainage pumping station inlet and outlet buildings are difficult to follow the pumping station design specifications which requires good hydraulic conditions [1]. Due to the small building size, a bad hydraulic phenomenon, the air-entraining vortex, is easy to happen [2] at inlet buildings of pumping stations. It may seriously impact the safety and efficiency of pumps in running process [3]. For example, the efficiency of a pump to decrease by about 15% if only about 1% (volume ratio) of air is inhaled via the vortex. Sometimes it even causes damage to the unit. So, it is common to take appropriate improvement measures [4][5] to avoid undesirable hydraulic phenomena caused by the small floor area and building size, thus ensuring safe and efficient operation of the pumping station.

In this paper, the pumping station we studied here is locate in the core area of a megacity of China. the overall arrangement of this pumping station is relatively compact. The volume of forebay of the rainwater pump room is small. When the pump starts to work, the water surface of forebay may fluctuate excessively, thus damaging the pump unit. Therefore, it is necessary to perform a model test of this pumping station to observe the fluctuation of water surface in forebay at pump starts-up and to
analyze the flow patterns in the intake building. The results can provide a scientific basis for the operation of the pumping station.

2. Physical Model
According to the engineering data, the physical model includes a portion of the rainwater pipes, intake gate wells, intake progressive box, forebay, intake flow channels, and pump units and so on. The picture of the test model is in Figure 1.

2.1. Model design
This model test was conducted according ‘Specifications for normal hydraulic model test’ (SL155-2012) published by the Ministry of Water Resources, People's Republic of China. Other elements not covered by above standards followed ‘Design code for pumping station’ (GB/T50265-2010), ‘Specification for design of drainage/pumping station in municipality’ (DGJ08-22-2003), ‘Hydraulic calculation manual’, and ‘Measurement techniques for model test’ as well as previous scientific research results and test methods.

Considering the test content and conditions, $L_p$, the linear scale for the pumping station, was selected as 8 (prototype/model). Some important parameters could be calculated from $L_p$.

Flow velocity scale: $v_p = L_p^{0.5} = 2.83$

Flow rate scale: $Q_p = L_p^{2.5} = 181.02$

Time scale: $t_p = L_p^{0.5} = 2.83$

Roughness scale: $\lambda_p = L_p^{1/6} = 1.414$

2.2. Manufacture and measurement
The prototype inlet pipes, inlet gate well, inlet progressive box and forebay were all made of reinforced concrete with roughness rate of $0.013 \sim 0.014$. The inlet gate well, progressive box and forebay in the model were all made of pure cement with roughness rate of $0.010$. The inlet pipes were made of plastic pipe and plexiglass pipe and the inlet water channel section was made of plexiglass,
their roughness rate was in 0.008~0.009, which could basically match the requirements of similar roughness.

The flow rate of a single pump was measured by the electromagnetic flowmeter installed on the outlet pipe. The water level and flow rate were measured by φ8mm pressure-measuring pipe. The flow velocity was measured by photoelectric flowmeter, and the data was collected by computers, which could measure multi-point flow velocity at the same time.

3. Results
In the test, we first carried out preliminary verification of the original design. The purpose was to observe the flow patterns and analyze its reasons through both single pump start-up in low water level and full pumps operation test in high water level. Further, this could provide a basis for proposing reasonable engineering improvements.

3.1. Problems
In the single pump start-up condition, the original flow rate was 4.08m3/s and the water level of forebay was -2.87m (as shown in Figure 2(a)) before the unit turned on. When the pump started to work, the water level at the end of forebay instantly dropped about 0.4m (as shown in Figure 2(b)) and resulting in a certain range of fluctuation (as shown in Figure 2(c)). By the pump running, we did not observe a significant recovery or stability of the water level in forebay. After the pump started running, there was always a surface vortex in front of the flow channel inlet (as shown in Figure 2(d)), with an air-entraining vortex.

Figure 2. Flow patterns of water surface in single pump start-up condition

In the lowest water level and single pump operation condition, there was more obvious air-entraining vortex than above. As shown in Figure 3, the surface depression was clearly visible (in (a)) and the air-entraining vortex traced by stain was completely continuous (in (b)).
3.2. Modified plan
On the basis of keeping the main layout structure of the design scheme unchanged, the pump inlet flow patterns were improved by changing the local structure and adding appropriate engineering measures to ensure the safe and stable operation of pumps. The main purpose of the modification scheme test was to compare the effect of different engineering measures, and to select the improvement scheme with better flow patterns and relatively small hydraulic loss in the pumping station inlet system.

After careful comparison, the final adjustments were made as follows. (1) Increased inlet pipe diameter from 3m to 3.5m. (2) Added combination beams and diversion piers for flow correction measures in the intake gate well, including three beams, one diversion pier, and two short piers. (3) Other detailed changes. The main modified model is shown in Figure 4.

The inlet box flow was generally uniform after improvement. The water flow was horizontally averaged, forming a stagnant area in front of the pump. The vertical water flow was mainly adjusted downward by the combination beam, and the pump inlet flow was relatively smooth. According to long-time observation, a little depression in water surface could be found occasionally in front of the flow channel entrance, and there was no air-entraining vortex. The flow patterns in forebay is shown in Figure 5.
4. Conclusions.
In this paper, we conducted a model test to research the hydraulic problems of a compact pumping station. During the tests we found the air-entraining vortex, a hydraulic phenomenon that was detrimental to safe operation of the pumping station units. In order to solve this problem, we optimized the flow patterns via some reasonable local adjustments. From the results, we could see that the adjusted flow patterns were smoother and the air-entraining vortex disappeared. This showed that our program worked. Detailed plan includes setting up a diversion device, increasing the diameter of the pipe and combination beams, reducing the bottom elevation of the inlet tank and so on.

Limited by the article space, only some typical flow pictures and optimization methods are shown here. However, the success of the adjustment results is enough to prove the importance of the hydraulic test. Therefore, it is necessary and effective to conduct test analysis in future hydraulic engineering design. It can provide scientific basis for the safe and stable operation of the project.

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