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Experimental Studies on the Formation of Air-core inside the Drop Shaft

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Abstract. In this study, the drainage efficiency of the multi-stage intake structure, which transports flood to the underground storage, was investigated from the laboratory experiments. The multi-stage intake structure was designed based on the tangential intake and the steps on the bed were purposes to decrease the energy of approaching flow. The experimental results show that the maximum water depth was effectively decreased in the entrance of the drop shaft. The measurements results of the air core width in the drop shaft show that the flow was stably drained without the choking. Furthermore, the air core width tends to increase with the Froude number, and these results indicate that the multi-stage intake structure is applicable to convey the approaching flow with relatively high velocity.

1. Introduction

Urban inundation damage is increasing due to climate change and rapid urbanization. These urban environment change leads to the decrease of reservoir capacity of the river basin and the lack of drainage capacity in urban areas. Drainage pumping station and detention pond have been previously used to prevent flooding as major measures to secure drainage capacity in urban areas. Recently, however, the deep-underground tunnel and underground detention pond are emerging as the most effective flood prevention measures. In the aforementioned drainage systems, the drop shaft, which is an inlet of the underground tunnel, has the greatest influence on the discharging efficiency. Thus, it is important to analyse the flow characteristics in the drop shaft to increase the discharge efficiency.

For the efficient drainage system, the shape of intake structure is important to increase flowrate to the drop shaft. The intake structure can be classified as tangential, screw, and spiral inlets [1]. Several researches [2, 3, 4] conducted laboratory experiments to suggest the optimal design of the tangential intake structure. Furthermore, [5] reported the design guideline for a tangential inlet based on the hydraulic stabilities. In case of the spiral inlet, [6] presented the efficient design for the intake structure, and [7] suggested the theoretical formula for the free surface profile along the intake wall. Due to the relatively high cost of

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the spiral inlet, [8] suggested using the screw type intake structure, and [9] reported the design criterion.

Previous researches attempted to suggest several designs for the intake structure to enhance the drainage efficiency in the drop shaft. In this study, a new intake structure was designed based on the tangential intake incorporating the multi-stage channel bed. Thus, the laboratory experiments were conducted to test the drainage efficiency of the new intake structure. The water surface change in the approach channel and the inlet of drop shaft were measured in various flow conditions. Furthermore, the width of air core in the drop shaft was measured using the conductivity sensor, which measured the thickness of water flowing along the drop shaft wall. From the measurements, performance of the intake structure was assessed by the water level increase and air core size.

2. Experimental setup

The laboratory channel is consisted with an approach channel, an intake structure, and a drop shaft as shown in Fig. 1. The approach channel has 0.2 m width and 1.35 m long, and the flow is transported to the intake structure along the channel. The intake structure was designed to mitigate the energy by incorporating the multi-stage bathymetry based on the tangential intake. Fig. 2 shows the multi-stage intake structure, in which the channel bed has steps to decrease the energy of approach flow. The channel width in the intake structure is gradually decreased to the entrance of drop shaft. The diameter of the vertical shaft is 0.12 m. In this channel, drainage efficiency was evaluated by the measurements which were the elevation in the approach channel and the intake structure. The width of the water at the drop shaft wall was also measured to evaluate whether the sufficient air core is obtained or not.

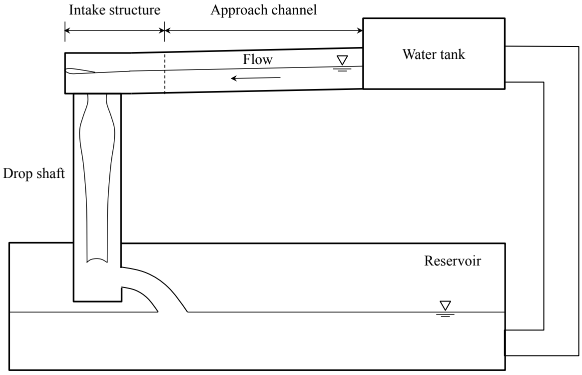
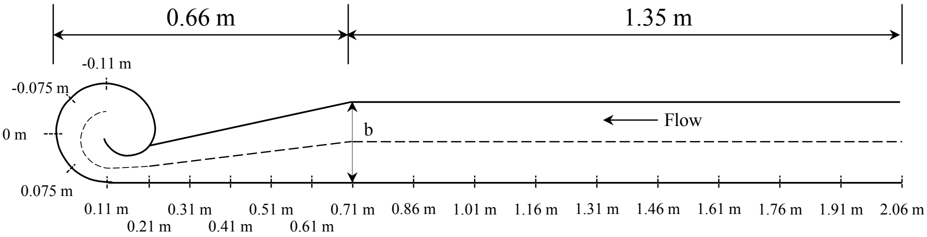


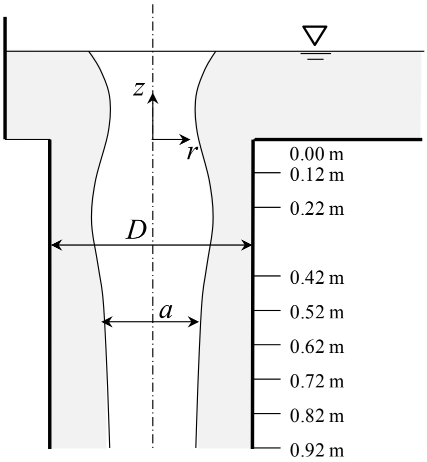
Fig. 1. Schematics of the experimental channel.

Fig. 2. Photos of multi-stage intake structure.

Fig. 3 shows the measurement points for analysis of water depth and air core change by various flow conditions. The water depth was measured using a capacitance-type wave gauge in both the approach channel and the intake structure. In the entrance of the drop shaft, tape rulers were used due to difficulties of measuring using the wave gauge. The width of air core in the vertical shaft wall, which denotes a, was measured using the conductivity sensor, in which the signal of conductivity sensor shows high value in the water and abruptly decreases in the air. Using the sensor, the air core width (a) was measured at 8 points in the vertical shaft. Table 1 shows the experimental conditions, of which b is the approach channel width and y_1 is the water depth at $x = 0.6$ m. The tangential intake has a purpose to transform a subcritical flow to a vertical shaft flow [1]. Thus, the flow condition in the approach channel was controlled to have stably subcritical flow (Fr < 1).



a) Water level measurements



b) Air core measurements

Fig. 3. Descriptions of the measurement points in the approach channel and the drop shaft.

Table 1. Experimental conditions.

Case	Q **(m³/s)**	y_1 **(m)**	**Fr**	y_1**/b**
Q04	0.004	0.133	0.131	0.667
Q07	0.007	0.201	0.116	1.005
Q09	0.009	0.268	0.109	1.339
Q13	0.013	0.334	0.105	1.671
Q16	0.016	0.411	0.099	2.054

3. Experimental results

3.1. Water depth measurements

The water depth was compared in various flow conditions, and Fig. 4 shows the water depth along the center of channel. The water depth steadily increases by increasing the flowrate, and the water depth doesn't increase in the intake structure ($x < 0.71$ m) in spite of decrease of the channel width. In a curved channel, a standing wave can be appeared due to the velocity increase [10], and the previous research [11] reported that the maximum water level may occur within the vertical shaft. However, in this channel, the water depth increase by a standing wave was not observed in the vertical shaft. From these results, the intake structure incorporating the multi-stage is capable to stable conveyance of the rainwater in the flood.

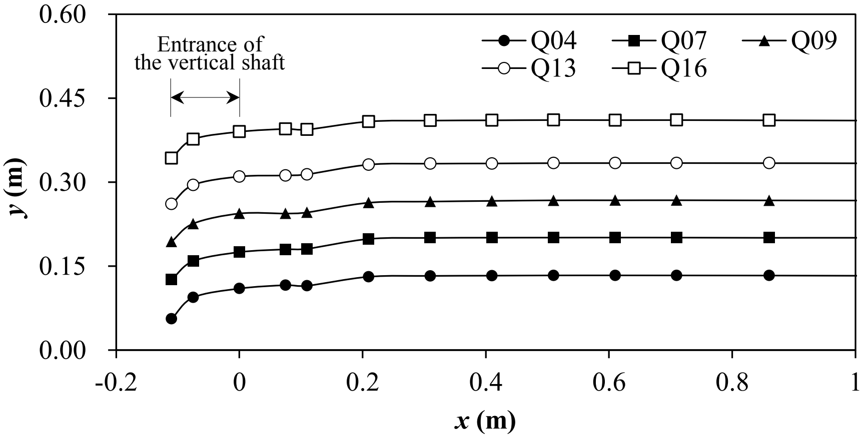


Fig. 4. Measurements of the water level by changing the flowrate.

3.2. Air-core in the dropshaft

The vortex flow, which occurs at the intake of the drop shaft, flows along the wall of vertical shaft with air. The air core in the drop shaft enhances the drainage efficiency by mitigating choking and sustaining flowing area. In this study, an experimental study on the air core that discharges the air to prevent choking and maintain discharge effect was carried out. Fig. 5 shows the vertical change of the air core width (a) in the vertical shaft. The results show that the flow conveyance was stably maintained in every flow conditions without choking even though the air core width decreases by the increase of flowrate. By increasing the flowrate, the air core width decreases at the upper part of the vertical shaft. Fig. 6 shows the maximum and the minimum values of the dimensionless air core width by changing the flow conditions. The minimum air core width decrease more rapidly than the maximum width according to the flow rate increase. In case of Case Q16, the portion of the minimum air core width decreases to 19.2% from 36.3% of the vertical shaft diameter. In contrast, the air core width increases with the Froude number, which indicates that the multi-stage intake structure stably transport the approach flow with relatively high velocity.

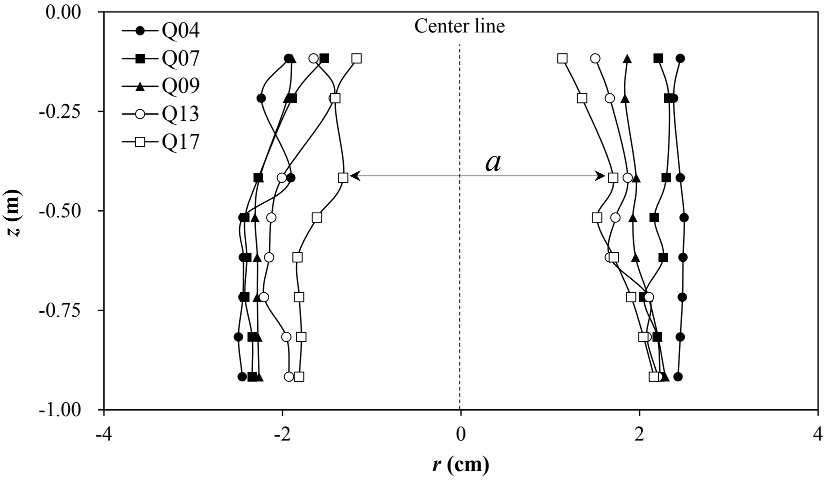


Fig. 5. Measurements of the water level by changing the flowrate.

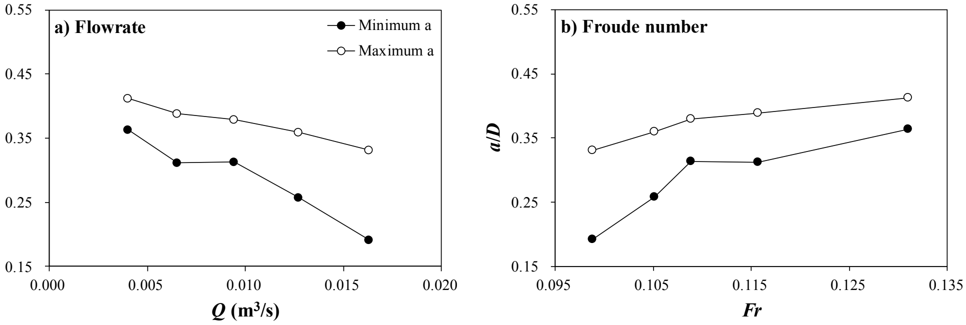


Fig. 6. The air core width change by the flowrate and the Froude number.

4. Conclusions

In this study, the laboratory experiments were conducted to investigate the drainage efficiency of the tangential inlet with the multi-stage structure. The drainage efficiency was evaluated by the measurements, which are the water depth in the intake structure and the air core width in the vertical shaft. From the water depth measurements, the approach flow was stably transported in the intake structure without the standing wave, which occurs at the sharply curved channle. Thus, the height of guide wall is not necessary to increase in the intake structure due to the maximum water level occurrence. The air core width decreases by the flowrate increase, and the portion of the minimum air core width decreases to 19.2%. However, the choking in the vertical shaft was not occurred in every flow conditions. Furthermore, the air core width tends to increase with the Froude number. These results show that the multi-stage intake structure is applicable to convey the approaching flow with relatively high velocity.

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