ANALYSIS OF FLOW VARIETY ON A WELLGUARD BUOY REGULATED TIDAL GATE

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Abstrak— Backflow has been identified as one of the major problem that causing the ineficiency in urban drainage system. This is particularly true for urban located at the flood plain area. During high tide, backflow from the main water body may occured which caused the inadequacy drainage outfall. Thus, a drainage system should be installed with a tidal control gate to prevent from flash flood. This paper investigates the performance of a ball valve in a drainage system as a self-regulating tidal control gate. In this study, a prototype of drainage system was designed and constructed. It consists of three main components; open channel drainage, sump and floating ball mechanism. The experimental results show the different pattern of ball movements depends on the variety of inflow water. The floating ball mechanisms formed a sinusoidal wave mechanism. It is found that the possibilities of gate closing is about 41% during small flow, 5% for moderate flow and the gate is totally open during high flow. These results indicates that the employment of ball valve as a self-regulated tidal gate is not adequate to prevent flood.

Kata kunci— backflow, high tide, flash flood, tidal control gate, floating ball mechanism.

I. INTRODUCTION

Flood is mainly caused by heavy precipitation rain and tide level. Heavy precipitation rain in plain area causes high intensity of water flowing to downstream. Normally, 20 to 45% of the incident rainfall are unabsorbed and flow to the downstream, but under exceptional circumstances the unabsorbed water may rise up to 70% [1]. If high tides occur at the sea and water level at downstream increases occur simultaneusly, it cause overflow which leads to backflow at upstream area.

Backflow has been identified as one of the major problem causing the inefficiency in urban drainage. The phenomenon of urban flooding caused by surcharged water level in urban drainage system [2]. During high tide, backflow from the main water body occurred cause the inadequate drainage outfall. Under such situation, the water level in the main drainage channel may be lower than the water body as shown in Figure 1. Such drainage problems are more serious when the timing of high tides occurrence coincides with that of monsoon season.

Failure of drainage systems leads to urban flooding, therefore the implementation of a cooperative operation scheme for urban drainage system is needed [3]. Flooding in urban area is an inevitable problem for many cities in Asia region. Refference [4] is analysing drainage system together with the suggestion of alleviation scenarios to relieve flood problems, in example is feasibility study of applying real time control to urban drainage system to reduce flood problems. Urban flooding associated with extreme precipitation is a significant cause of disaster [5].

To prevent flood, drainage system is installed with a tidal control gate [6]. In recent years to meet the demand for municipal construction and flood, flood control structures have been built [7]. There are many type of tidal control gate valve. Penstock valve, flap gate valve, duckbill valve are among them.

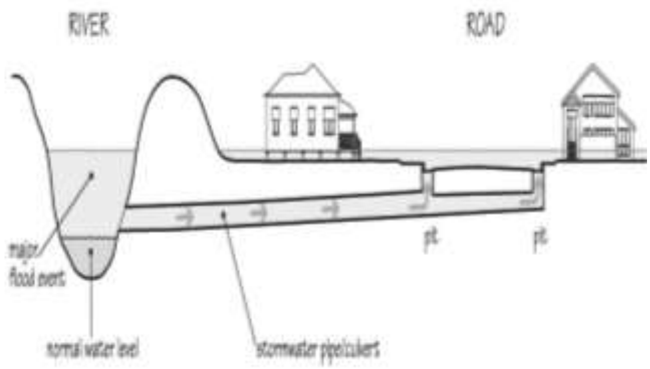

Figure 1. Backflow flooding concept [8]

The flap gate is widely used for tidal control gate system. However the drawback of conventional tidal gate only has one way check valve which only works under a significant different hydraulic head between upstream and downstream point [9]. Refference [10] states that specific research needs to include new technologies and strategies for the operation of drainage system.

In this experiment, a new gate systems which apply Archimedes principles of Buoyancy are proposed. To apply this principle of Buoyancy, the gate is provided with a ball-valve as a self-regulating tidal control gate.

The performance of a ball valve is investigated as a self-regulated tidal control gate during high tide condition. The effect of downstream water toward the floating ball system is also studied. A prototype of drainage system model with a scale of 1:10 is developed for the study. The prototype includes the floating ball with 0,11 m diameter and density of 362,13 kg/m^3.

II. METHODOLOGY

A prototype model of the drainage system is used to carry out the study. It is designed to simplify the actual condition of drainage system, tidal gate and water body. The model consists of an open channel drainage and sump with a floating ball mechanism in between them.

A. Open Channel Drainage

The open channel drainage model was designed to replicate the urban drainage system. It has 7,02 m length, 0,30 m wide and 0.60 m high as shown in Figure 2. The lenght is divided into two parts; the first part is 4,57 m and the second part is 2,44 m in lenght which connected by bolt. The slope of 1:500 is set by created a drop down of 0,009 and 0,005 m for each part respectively. To have the accurate value, the slope is set by using the levelling equipment.

Figure 2. Open channel drainage

The open shannel drainage system is equipped with a water flter as shown in Figure 3. The water filter is placed right after the inflow pipe to reduce the velocity and energy of the unsteady inflow water. Thus, the inflow water height are easily to measure.

Figure 3. Water filter

B. Sump Model

The sump model was designed to replace the water body in actual condition. It is designed with two parts; main body and gate system as shown in Figure 4. The main body used as replicate to the actual water body while the gate system is used to trap water and control the tidal level. This component is constructed using wood based material with one of the side is made of transparent fiberglass to form an aquarium-like box with 0,92 m deep. The transparant side of the sump creates to ease the observer study the ball performances.

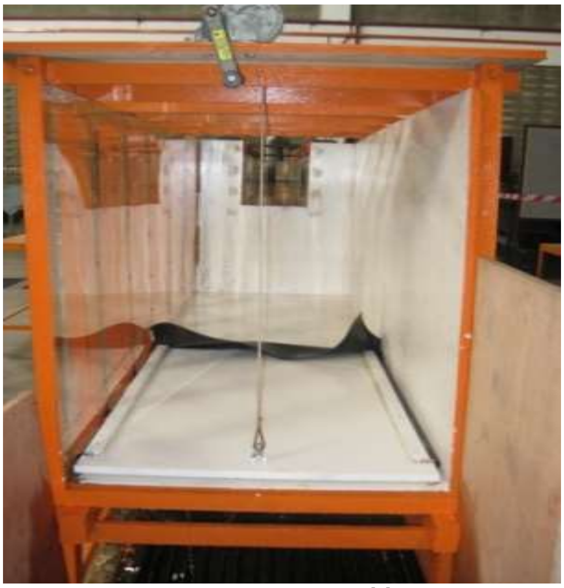

Figure 4. Sump model

The gate designed with a flap gate system with one side is fixed at the base of the sump while the other side is free. This free side is connected to a pulley crane to control the tides water level. Addition of rubbers which covers the gate is used to block the minor water flowing through the spaces.

C. Floating Ball Mechanism

The floating ball mechanism was designed as self-regulating tidal control gate. It is made by fiberglass and divided into two section, upper and lower section and placed at the edge of the drain as shown in Figure 5.

Figure 5. Floating ball mechanism

The upper section has a cube shape with the size of 0,20×0,20×0,22 m. As the channel has a 0,30 m width while the floating ball mechanism only has 0,10 m of inflow space, then the excessive constriction lane is formed right before the intersection. This section is functionated as a drainage water reciever with a 11,4 cm diameter of a circular hole at the bottom. This hole is connect to the lower section.

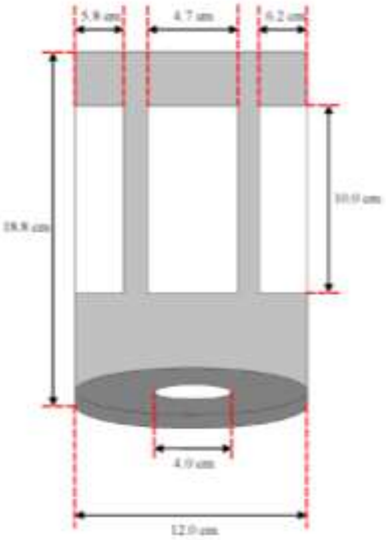

Figure 6. Cross Section Of The Floating Ball Mechanism

The lower section constructed with a tube shape. It has 0,12 m diameter and 0,188 m of height. There are three valve at the side and a hole at the bottom of the tube to aloow water pass to the water body. The lower section is shown in Figure 6.

Figure 7. Point measurement

The ball which placed at the lower section, has a significant role for the gate system. The floating ball performance depends on the ball characteristic. For this experiment, the ball has 0,11 m diameter with the volume of $7{,}16\times10^{-4}$ m^3 and 0,259 kg of the mass. This ball is designed to have density 362,13 kg/m^3 which is one third of the water density.

The floating ball mechanism is equiped with a point measurement. It is an apparatus used to measure the ball movement. It is divided into two parts, a ruler and a point gauge. This tool is placed right above the floating ball mechanism as shown in Figure 7.

D. Tidal Level

Generally there are two types of tidal level; they are low and high tide condition. During Low tide condition (Figure 8), the ball setting is completely floated to provide a maximum clearance between the ball surface and the top edge of drainage sump. The drainage water from the municipal catchment would be discharged into the water body system effectively.

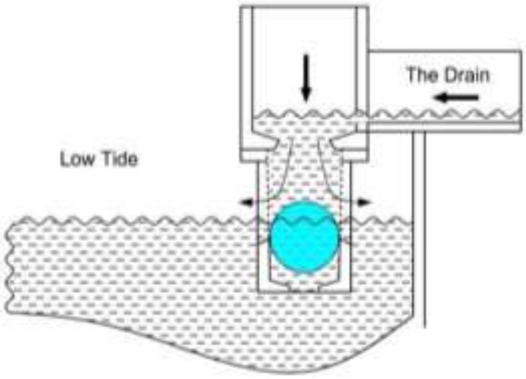

Figure 8. Low tide condition

Whereas at high tide condition (Figure 9), the ball setting will automatically close and stay closed during high tide thereby protecting from the backflow. The objective of this experiment is to have the floating ball mechanism remain closed on the high tide condition. The automatic setting of this floating ball mechanism is strongly depends on the hydrological characteristics of the drainage channel and the water body.

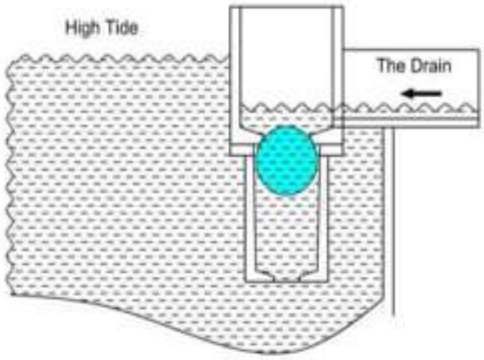

Figure 9. High tide condition

E. Experimental Procedure

The experimental procedure is explained by Figure 10. First step, prepare all the equipment to run the experiment because hydraulical experiments need fast action and respond as the water flow may change significantly in a short time.

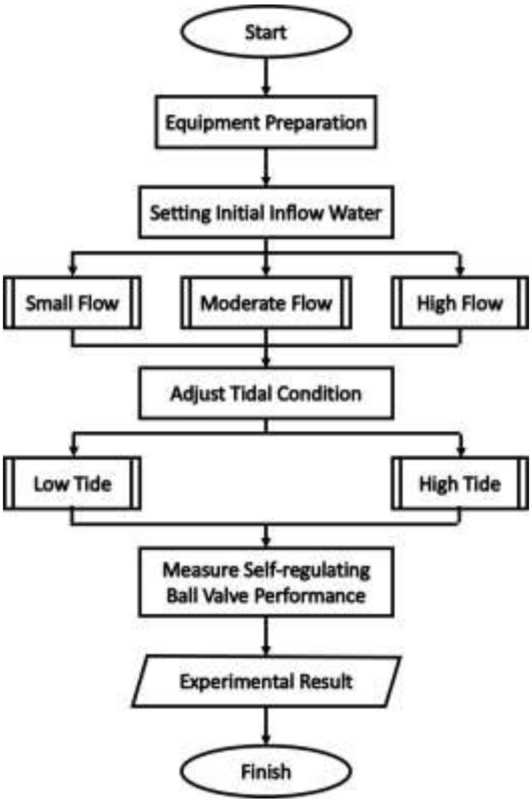

Figure 10. Experimental procedure

The experiment start with setting the inflow water. There are three criteria proposed, which are small flow, moderate flow and high flow. The inflow water assumed as small flow when $Y_1 \leq 0{,}04$ m; moderate flow $0{,}04 \text{ m} < Y_1 < 0{,}05$ m; and high flow $Y_1 \geq 0{,}05$ m. Then, the initial inflow water depth (Y_1) value is set respectively from small to high flow. The Y_1 valueis recorded once the flow are stable in the low tide condition.

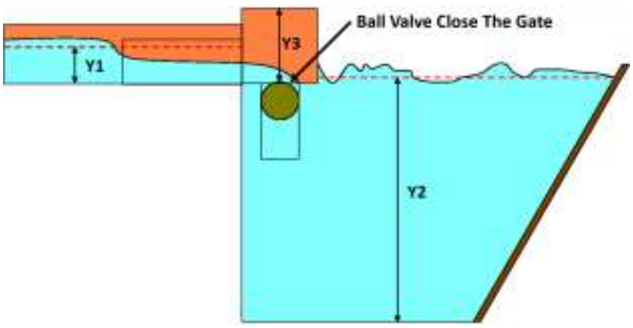

Figure 11. Cross-section of the high tide condition

After the inflow water is in a stable condition, then adjust the flap gate by lifting it slowly. This act will create high tide condition. The water body will rise slowly and lift the floating ball mechanism. It is set until the water body level (Y_2) is enough to submerge the ball. Then, record the Y_2 value.

Once this condition fulfilled, measure the self-regulating ball position (Y_3) immediately. Repeat the procedures with different inflow water. The Y_1, Y_2 and Y_3 value are ilustrated by Figure 11.

III. RESULTS AND DISCUSSIONS

The investigation focuses on the floating ball performance during high tide condition. The results is listed as the ball movement through difference of inflow water.

A. The Performance of Floating Ball

The main objective of this experiment is to analyze the performance of the ball valve as the self-regulating tidal gate. The performance is indicated by the capability of the ball valve to close the gate system. This is to ensure that water from the downstream can't reach upsteam area. Thus it can prevent plain area from flood.

The movement of the ball valve is determine by Y_3 value. The tidal gate system is considered close when 95% of the ball submerge by the downstream water as shown in Figure 10. Theoretically Y_3 value needed to close the gate is ±0,095 m.

The Y_3 value related to the Y_1 + backwater is shown in Figure 12. The graph is divided the inflow water into three conditions. They are small flow, moderate flow and high flow. The ball movement is slightly formed a sinusoidal wave. This turbulance movements mean that the gate can't close properly. The ball move up and down simultaneously.

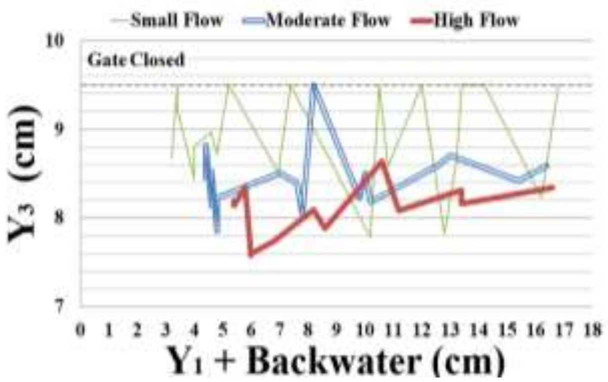

Figure 12. Performance of the floating ball mechanism related to inflow water

The results shows that for small flow condition there are 41% chances for the self-regulating ball valve to close the tidal control gate. For moderate flow condition this value decreased to only 5%. While for high flow condition, the gate can’t close the system. Overall, there is only 18% chances for the self-regulating ball valve to close the tidal control gate system.

This pattern occurs due to the effects from upstream and downstream water. From the analysis, found that buoyancy and hydrostatic forces act at downstream. These forces keep the ball buoyed when high tide condition. At upstream, there are other forces which is pushed the ball. These forces come from weight of water, orifice effect and weight of the ball itself.

Furthermore, the result also shows the increasing of upstream water level. It caused by the backwater from floating ball mechanisms as a hydraulic structure. The water flow from upstream will stuck here by the closure of gate system. Then, the backwater increased the upstream water level while the flow rates remain constant.

B. The Effect of Downstream Water

There are four forces acting on the floating ball which are the weight of water (W_W), weight of ball (W_b), buoyancy force (F_b) and hydrostatic force (F_h). Figure 13 clearly shows that the weight of water and ball are acting downward direction while the others forces are acting upward direction. From this condition, the equilibrium point is found when sum of these four forces are equal to zero as shown in equation:

$$F_h + F_b = W_W + W_b \quad (1)$$

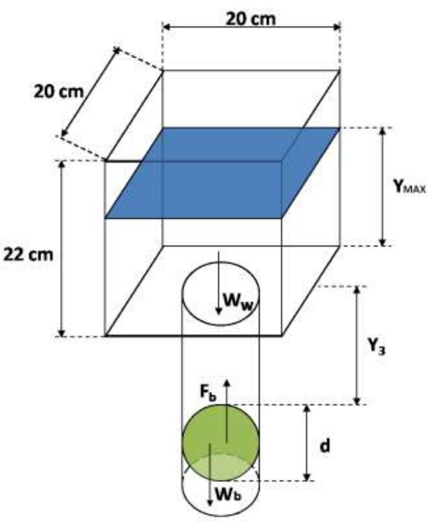

Figure 13. Acting forces to the floating ball mechanism

Hydrostatic force start acting on the ball once the water body has a higher level than the floating ball mechanism. This force is occured due to the downstram water pressure. The higher downstream water level, the higgher pressure to the gate system. The hydrostatic force are obtained by applying the hydrostatic presure equation in Equation (2). Figure 14 shows the graph about the incrasing of hydrostatic force value by the incrasing of downstream water level (Y_2).

$$F_h = \rho_{fluid}\, g\, V_{water\ above\ gate\ system} \quad (2)$$

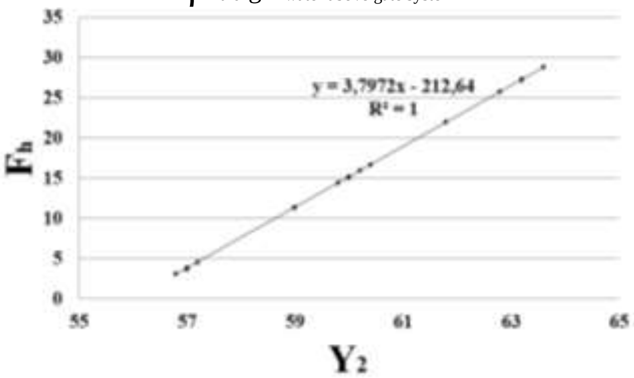

Figure 14. Hydrostatic forces acting on the ball valve

Buoyancy force is created by the difference of density between the floating ball mechanism and water. As density of the ball is lower than the water density, thus the ball will buoy up and creates an upward forces. The value of F_b is 6,7 N. It is calculated by using buoyancy equation:

$$F_b = \rho_{fluid}\, g\, V_{displaced\ fluid} \quad (3)$$

The weight of water is measure at its maximum level. From the experiment, the maximum height of water above floating ball mechanism (Y_1 + backwater) is 0,17 m. Then, the W_W is calculated by multiplying water volume inside the cube, water density (ρ_W) and gravitational force ($g = 9{,}81\ m/s^2$); and resulted with 66,7 N weight of the water above the floating ball mechanism. Whereas the weight of ball is simply calculated through its mass multiple by gravitational forces which resulted 2,54 N.

By considering all of these forces, the F_h needed to close the gate when the Y_{MAX} of 0,17 cm is 62,6 N. From the experiment, the actual maximum F_h reached is only 28,9 N. This value is around a half of the F_h needed to close the gate.

The experiment can achieve this value by raising the water body level (Y_2) until around 0,73 cm. However to fulfill this condition, the water at the downstream and upsetream are equally level. This condition must be avoided as it means very high flood occure at the downstream area. Figure 14 shows the theoretical versus actual F_h from the experiment.

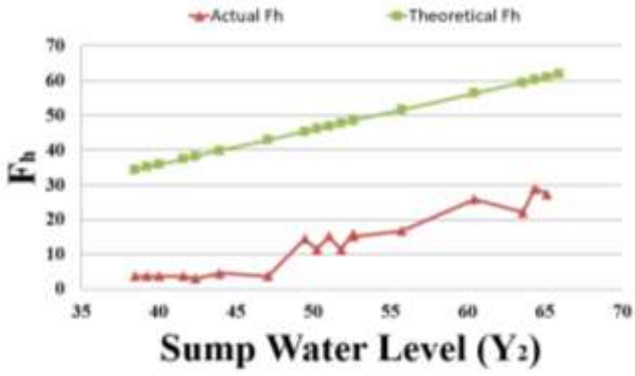

Figure 14. The actual vs theoretical F_h

There are another forces that keeps the gate open, which is the orifice effect. Orifice is a generator for main upstream forces. It is occured due to a constriction between the drainage model and the floating ball mechanism. While the uniform flow pass through this constriction, its depth will decrease as the velocity of the water rises. This act is creating turbulences to the water just before it knock the ball valve. Figure 15 shows the orifice effect.

Figure 15. Orifice effect

Additionally, the shape of ball for the gate also effect the movements. It sphere shape can.t deny the possibility for the ball to spin and rotate by forces from upstream water (Figure 16). This spinning sliced up the water and creates space for the ball valve to move downward and open the tidal control gate.

Figure 16: The ball spin and rotate due to upstream forces

IV. CONCLUSION

The movement of the floating ball mechanism as a self-regulating tidal gate has possibilities about 41% to close the gate system during small flow, 5% for moderate flow and totally open while high flow. From this result, the capability of the system to close and prevent upstream from flood is about 18%.

There are buoyancy force, hydrostatic force, weight of the ball and weight of water that act to the self-regulating tidal gate either from upstream and downstream water. These forces needs to be equal for the ball to close the tidal control gate system. From the experiment, the floating ball mechanism lack of hydrostatic force from downstream.

Besides, the orifice effect and the ball shape is also distract the ball performance. The orifice crates a turbulence just before the floating ball mechanism and added up some forces to the ball. While the sphere shape allows the ball valve to spin and rotate.

However, the building of a new hydrological structure such as the tidal control gate is required a good planning. Especially with the installment of the self-regulating tidal gate. It will have an impacs on the ecosystem such as sedimentation and reduction in aquatic organisms (Feng and Luo, 2010).

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