Effectiveness Using Circular Fibre Steel Flap Gate As a Control Structure Towards the Hydraulic Characteristics in Open Channel

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Abstract. Hydraulic control gate structure plays an important role in regulating the flow of water in river, canal or water reservoir. One of the most appropriate structures in term of resolving the problem of flood occured is the construction of circular fibre steel flap gate. Therefore, an experiment has been conducted by using an open channel model at laboratory. In this case, hydraulic jump and backwater were the method to determined the hydraulic characteristics of circular fibre steel flap gate in an open channel model. From the experiment, the opening angle of flap gate can receive discharges with the highest flow rate of 0.035 m³/s with opening angle was 47°. The type of jump that occurs at the slope of 1/200 for a distance of 5.0 m is a standing jump or undulating wave. The height of the backwater can be identified based on the differences of specific force which is specific force before jump, \( F_1 \) and specific force after jump, \( F_2 \) from the formation of backwater. Based on the research conducted, the tendency of incident backwater wave occurred was high in every distance of water control location from water inlet is flap slope and the slope of 1/300 which is 0.84 m/s and 0.75 m/s of celerity in open channel model.

Keywords: Circular fibre steel flap gate, hydraulic jump, backwater, opening angle, flooding.

1. Introduction
Hydraulic engineering is the application of the principles of fluid mechanics to manage the problem by gathering, storing, controlling, transportation, settings, measurements and water consumption [1]. Hydraulics is also a scientific study that related to the flow of a fluid including the flow which through the closed channels (pipes) and the area of open channel. Open channel can be defined as a channel that flow with a free surface of the boundary surface vulnerable into air [2].

Flap gates is a convenient system can be mounted on the end of sewer or above the wall of drain which is to allow the water stream only in one direction [3]. Top hinged flap gates is a water control structure that is used in tidal structure to prevent flooding in the shore areas due to high tide of sea water or surge flooding to allow water flow into the sea during high tides [4]. Therefore the effectiveness of a control gate structure can be determined against the characteristics of hydraulic, hydraulic jump and backwater that acting on the structure.

2. Hydraulic Characteristics
Tidal control gates can be interpreted as an opening which allows water flows through it in only one direction [5]. The circular fibre steel flap gate is one of the various type (Figure-1). Furthermore, the advantages of the circular fibre steel flap gate over the rest are their easily measured and controlled flow, their simple design, high flow discharge coefficient and their less expensive costs in large scales [6]. Nevertheless, the characteristic of...
Fiber reinforced plastics (FRP) is similar with fibre steel since they have excellent durability and water or corrosion resistance [7]. Hydraulic assessment on the control flap gate was to study the pattern of the pressure distribution on the flap gate [8]. The difference between static force and real energy was increasing as soon as the gate opened. This reduction is due to the power that based on the fact which water comes out under the gate has zero atmospheric pressure (Figure-2) [9].

![Figure 1. Fibre steel flap gate modeling.](image1)

Hydraulic jump occurs when there is a friction between the upstream and downstream of a channel. They form transiently when deeper fluid gets pushed into a shallower and stagnant body of fluid [10]. Besides that, hydraulic jump also can be occurring when the supercritical flow met subcritical flow at a sufficient depth. Hydraulic jumps can also occur as steady phenomenon (in the lab frame) when a super-critical fluid (Fr > 1) transitions to sub-critical (Fr < 1) [11]. Hydraulic jumps have been extensively studied because of their frequent occurrence in nature and their use as energy dissipators in outlet works of hydraulic structures [12]. Two types of depth \( y_1 \) and \( y_2 \) is called as a depth classifiers ratio (Figure-3). The incidents of hydraulic jump are reviewed by using the principles of momentum.
Backwater is an increase level of water greater than normal (Figure-4). However, differences in circumstances of hydraulic system able to change normal conditions of water movement that causes the water move in the opposite direction [13]. The amount of backwater caused by piers depends mainly on their geometric shape, their position in the stream, the flow rate and the amount of channel blockage [14]. Under the backwater effect of a hydraulic structure, downstream river course can have a flowless regime in which ponding can occur [15]. This is the case especially when there is a channel with very mild slope, an irrigation channel affected by gate operations or a diversion weir on the downstream of a dam [15].

3. Model development at open channel structure
This research had been prepared to ensure the experiment work smoothly. In this studies, the preparation of experiment is focusing on the laboratory test to analyzes the impact of backwater, hydraulic jump and hydraulic characteristic by using circular fiber steel flap gate as a control gate. During the experiment, the suitable slope surface can be determined.

The first stage that involved in this research is to find out the comprehensive understanding of the title given by literature review. The literature review that could be considered on this research is based on the principle of backwater flow, open channel concept, celerity toward flap gate in open channel, hydraulic jump and hydraulic characteristic.

Therefore, the preparation for the laboratory test must be find out and will be handle the measurements of the parameter of depth before and after jump occur, time of wave in one cycle and opening slope during experiment. The data collected from the laboratory test will be analyzed.

3.1 Structure model
Installation of the fibre steel flap gate can be described based on the prototype model and the function of the flap gate can be illustrate on (Figure-5).
Water control gate that had been studied is a circular gate made of fibre steel reinforced material which has a hinge at the top. The dimensions of the control gate is shown (Figure-6). These circular flap gate provides greater water control due to the area in certain circumstances. As a result, opening force exerted on the flap gate was smaller [16].

A wave that generate from backwater can define the velocity of celerity. There are some major formulas that are used compatible with the velocity of the celerity. Celerity is defined which involve of backwater wave toward the control gate such as:

\[ C = \frac{L}{t} \]  \hspace{1cm} (1)

Where C and L is represent celerity of wave and length of the wave from crest to the crest, and t is the cycle time from crest wave to the another crest wave.

Specific force before and after jump that occur during the experiment based on the discharges value that is manipulated variation which is:

\[ F_{1,2} = A_{1,2} h_{1,2} + \frac{q^2}{gA_{1,2}} \]  \hspace{1cm} (2)
Where \( F \) and \( A \) is represent specific force and area of the circular gate, and \( h \) is the depth of the centroid point from surface to the base. However, \( Q \) and \( g \) represent discharge of the flow and gravity. (1 represent for before jump and 2 for after jump).

Specific energy is defined as energy flow per unit Joule Newton in any section of the channel calculated as the vertical distance between channel base and energy line. The equations involved are:

\[
E = y + \frac{g^2}{2gy^2} \tag{3}
\]

Where \( E \) and \( y \) represent specific energy and depth of surface water to the base. Beside that, \( g \) and \( q \) represent gravity and discharge per width of the channel.

\[\text{Figure 7. Schematic diagram of circular fibre steel flap gate.}\]

### 3.2 Hydraulics performance

From experiment conducted, experiment data in raw represent basic parameter which been discussed in structure model. Raw data in schedule manner in Microsoft Excel for easier process of analysis shape as graphic graph. Any raw data from experiment that has been done will be compile using excel formula to analyse the graphic graph.

Therefore, from the data result. Distinctions in terms of the slope will be identified. The values of 16 different flow rates in between \(0.005 \text{ m}^3/\text{s}\) and \(0.035 \text{ m}^3/\text{s}\) were determined in this experiment with distance of control gate from water inlet in 5.0 m. Every flow rates will be test using different slope of channel which is flat, 1/300, 1/200 and 1/100.

### 3.3 Slope of flap gate

Figure-8 indicates that the relationship between opening angle of gate with discharge. Therefore, at the maximum discharge the highest opening angle of circular flap gate from the upstream channel was 47°. In brief, the opening angle of gates obtained within the range of 14.4° and 47°. The slope of zero indicates a greater value of opening angle compared to the others.
From the graph clearly shows that the greater opening of angle when the flow rate imposed higher. Hence, the slope gradient can influence the opening circular gate. This problem due to the mass and fibre steel flap gate balancing weight besides water pressure exerted on flap gate.

3.4 Hydraulic jump

Figure-9 indicates that depth of flow versus specific energy with different slope of flat, 1/300, 1/200 and 1/100 for distance 5.0 m. For the critical depth flow and critical specific energy are also included for facilitate the process of analyzing the graph of the depth of flow and specific energy. For the flat gradient, energy curve line does not applicable at all flow rates. This is because the depth of flow does not reach the critical depth flow point, $y_c$. The value of specific energy to flow in point $y_1$ is the lowest compared to $y_0$ and $y_2$ value. Hence, the hydraulic jump has occurred at the depth of $y_1$ due to the undulating wave which Froude number is between $1.0 < Fr < 1.7$. Thus, less energy is required through a stream.

**Figure 8.** Opening angle versus slope gradient graph.

**Figure 9(a).** Graph Depth of Flow versus Specific Energy for flat slope.

**Figure 9(b).** Graph Depth of Flow versus Specific Energy for 1/300 slope.
Figure 9(c). Graph Depth of Flow versus Specific Energy for 1/200 slope.

Figure 9d). Graph Depth of Flow versus Specific Energy for 1/100 slope.

Meanwhile, different situation for the slope of 1/100 because flow rate 0.021 m$^3$/s and 0.035 m$^3$/s have made an energy curve line occurred. The value of specific energy to flow in point $y_1$ is the lowest compared to $y_0$ and $y_2$ value. Hence, the hydraulic jump has occurred at the depth of $y_1$ due to the oscillating jump which Froude number is between $2.5 < Fr < 4.5$. Thus, less energy is required through a stream.

3.5 **Celerity waves**

Figure-10 indicate that difference slope occurs at a distance of 5.0 m, which resulted the celerity wave but at slope of 1/300 wave shown consistently from the flow rate of 0.005 m$^3$/s to 0.035 m$^3$/s. A celerity wave in a consistent state at the beginning discharge for flat slope but then decline began in the flow rate of 0.029 m$^3$/s. However, the slope of 1/200 and 1/100 decreased starting at 0.021 m$^3$/s for slope 1/200 and for slope 1/100 is at 0.017 m$^3$/s of flow rate. Thus, on the distance of 5.0 m from the upstream was discovered that the slope 1/300 a celerity wave can be generated.

Figure 10. Graph Celerity versus Discharge on distance 5.0m.
3.6 Probability of backwater

The analysis of specific force was divided into two parts which are analyzed specific force before jump, $F_1$ and specific force after jump, $F_2$. The purpose of analyzed specific force was to review the probability of backwater wave occurring whether in weak or bumpy conditions.

![Figure 11. Specific force versus Discharge on different jump situation.](image)

Since the analysis has been performed, it is found at the distance of 5.0 m was a suitable location for built control gate from the upstream channel. Thus, at the maximum discharge which is 0.035 m$^3$/s, the comparison of the differences specific force before and after jump during the experiment can determined the depth of the wave can be generate which is 0.004 m$^3$.

4. Conclusion

Therefore, the location to be constructed the control gate in order to reduce the risk of hydraulic jump and backwater occurring in the upstream channel is at the distance of 5.0 m with the slope is less than 1/300. While, clearly stated that the opening angle is greater if the flow rate imposed even greater. It shows that the flap gate can receive discharges with the highest flow rate of 0.035 m$^3$/s with opening angle was 47°. The type of jump that occurs at the slope of 1/200 for a distance of 5.0 m is a standing jump or undulating wave due to the Froude number is between 1.0 <Fr <1.7. In additional, celerity wave can be generated only occur in the slope of 1/300 for this distance and cannot form the celerity wave for slope less than 1/300. Moreover, the differences of specific force before and after jump were 0.004 m$^3$ for a maximum flow rate of 0.035 m$^3$/s.

Acknowledgement

The authors gratefully acknowledge with sincere thanks to Zulhelmi Yunos and Rahmawati Abdullah who worked diligently and for their selfless and consistent efforts to get through this task. We also express our sincere appreciations and gratitudes to the Department of Water And Environmental Engineering, Faculty of Civil and Environmental Engineering, UTHM, for or allowing the experiments conducted in the laboratory and also provide guidance on the use of open channel structure to prevent errors from occur.

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