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THE CHANGES OF FLOW PROFILE DUE TO THE CONSTRUCTION OF CYLINDRICAL STRUCTURE AS A HYDRAULIC CONTROL STRUCTURE IN OPEN CHANNEL

M. R. M, Adib[1], A. N. Azrin[1], T. Wardah[2] and A. Junaidah[2]
[1]Department of Water and Environmental Engineering, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia
[2]Flood Marine Excellence Centre, Institute for Infrastructure Engineering & Sustainable Management, Faculty of Civil Engineering, Universiti Technology Malaysia
E-Mail: adib@uthm.edu.my

ABSTRACT

Construction of hydraulic control structures is generally aimed to control the velocity of water flow in open channels. Controlled velocity water flow in open channels very important to reduce the hydrodynamic forces in the flow to be able to erode the banks of the canal and structure. This study focuses on changes of the flow profile and the specific energy that occurs in an open channel structure as a result of the construction of cylindrical hydraulic control structures and to obtain the effectiveness of cylindrical structure. A cylindrical structure with a diameter of 0.3 meters constructed in the middle of an open channel structure measuring 10 meters long and 0.3 meters wide. The effectiveness of the cylindrical structure derived from the results of two different conditions studied. case 1, the opening in the surface of the cylindrical structure at a distance of 50 mm from the base of the structure at the upstream of the channel, while in the case 2 openings are positioned at a distance of 50 mm from the surface of the cylindrical structure at upstream of the open channel. As the consequence, the higher the opening on cylindrical structure at upstream channel which in case 2 more effective in controlling the flow in open channel. This is because the structure able to withstand greater upstream flow of up to 0.004m^3/s compared to case 1 were only able to withstand until 0.002m^3/s. In addition, case 2 is able to reduce the specific energy flow in the downstream channel by 21% and sub critical transition flow occurred at downstream. This structure also able to withstand water without causing flooding the upstream channel until 14.42s. Based on the overall results of the laboratory testing, the structure capable to control the flow in open channels and also can reduce the flow of energy that occurs in the downstream.

Keywords: cylindrical shape structure, flow profile, specific energy.

INTRODUCTION

Open channel flow occurs when the fluid flows only partially full of solids border due to gravity. In open channel flow, fluid flow has a free surface, and liquids are not under pressure other than atmospheric (Chow *et. al.,* 1959). Some open channel flow occurs naturally as a river and usually have an irregular cross-section. Open channel flow can also occur in artificial channels such as flume and canal. This channel has a cross section such as rectangular, triangular or trapezoidal. Open channel flow can also occur in the channel if the channel is not full flowing (Giles *et. al.,* 1994).

Hydrodynamic force is the power of water and movement it seeks to erode the river banks. This causes the river to the next large deposits exist in the riverbed (Xinkui, 1993). Thus, the hydraulic control structures like sluice gate and the energy dissipated structure built on an open channel to control this problem. Various hydraulic structures built successfully operate properly. However, only some of which achieve the objectives of construction and cost-effective (Lewin *et. al.,* 2001).

CYLINDRICAL SHAPE HYDRAULIC CONTROL STRUCTURE

Hydraulic control structures constructed to reduce the hydrodynamic forces on the banks of the river (Julien *et. al.,* 1994). Force of water movement and capable erode the river banks called hydrodynamic force (Xin Li, 2013). This causes the river becomes wide and form sediment at the bottom of the river. The river became shallow and not capable to retain a high volume of water. Construction of hydraulic control structure capable to reduce the hydrodynamic force of the water where the water can be controlled as a result of friction that occurs between water and the surface of hydraulic control structure (Novak *et. al.,* 2006). Cylindrical shape hydraulic control structure capable to retain water at the center of the structure before being discharged to the downstream of the open channel.

Cylindrical shape hydraulic control structure constructed to overcome the problems that occur in open channels. The structure constructed in an open channel structure located at the Water Resource Laboratory, Faculty of Civil and Environmental Engineering. The cylindrical hydraulic control structure was constructed in the center of an open channel structure which is at a distance of 5 meters from upstream. Hydraulic control structure used in this study is a cylindrical structure with a diameter of 0.3 meters and has two openings that were placed oppositely. Both openings are in same size of 0.1 meters long and 0.05 meters broad. The opening position is 0.05 meters from the base of the structure while the other is 0.05 meters from the surface of the structure. Figure-1 shows the design of an open channel model structure and the placement of the cylindrical hydraulic control structure.

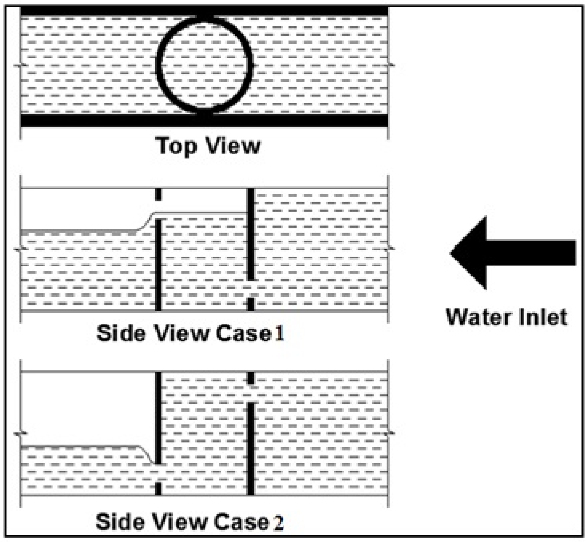

Figure-1. Plan of an open channel model structure and the position of the hydraulic cylinder control structure.

In this study, the type of flow that occurs in the downstream channel is determined by the Froude Number and the Reynolds Number. Froude Number is the ratio of inertial forces to gravitational forces, while the Reynolds Number is the ratio of inertial forces to fluid viscosity. The type of flow can be determined from the Froude Number are, critical flow, sub critical flow and super critical flow (Chanson, 2004). Froude Number can be determined using the following formula (Ab Aziz, 2007):

$$Fr = \frac{v}{\sqrt{gL}} \quad (1)$$

Fr is the Froude number; v is a velocity (m/s); g is the gravitational force (9.81m/s^2); and L is length of open channel structure. Number Reynolds produce different types of flows with Froude number. Type flow resulting from Reynolds number is laminar flow, transition flow and turbulent flow (Thomas, 1995). Reynolds number is determined using the following equation (Ab Aziz, 2007):

$$Re = \frac{vL}{\mu} \quad (2)$$

Re is the Reynolds number; v is a velocity (m/s); L is length of open channel structure; and μ is water viscosity (1.002 x 10^{-3}). Specific energy changes that occur between the upstream and downstream channels are also determined in this study. Specific energy is defined as energy and water per weight of water is measured in units of meters distance (Ab Aziz, 2007). For uniform flow, specific energy remained unchanged from one side to the other side. While the flow is not uniform, specific energy decreases or increases along the channel (Giles *et. al.,* 1994). Specific energy is determined as (Subramanya *et. al.*, 1997), :

$$E = y + \alpha\frac{v^2}{2g} \quad (3)$$

$$E = y + \frac{q^2}{2gy^2} \quad (4)$$

$$E = y + \frac{Q^2}{2gA^2} \quad (5)$$

in this study, equation 5 was used, where E is the specific energy (m); y is the depth of water (m); Q is the flow rate (m^3/s); g is the gravitational force (9.81m/s^2); and A is the area of open channel structure (m^2).

CASE STUDY

Cylindrical hydraulic control structures constructed in the open channel at a distance of 5 meters from the upstream channel in two (2) cases that's been established. case 1, the position of the opening is at a distance of 50 mm from the base of the cylindrical structure while for case 2, the opening is located at a distance of 50 mm from the surface of cylindrical structure. The data collected during this testing were (1) upstream flow rate, (2) the depth of water in the upstream channel, (3) the water depth in the downstream, (4) water retention time and also (5) time for water to move a distance of 1 meter.

Water retention time is taken when the water touched the bottom of a cylindrical structure until water comes out of the hydraulic control structure. Duration of water retention time in upstream channels demonstrate the ability of the structure in flood control that occur in the upstream channel as a result of the construction of a cylindrical hydraulic control structure. Duration of water to at distance of 1 meter in the downstream channel was recorded to facilitate the calculation for a flow velocity in the downstream channel to establish the flow rate at the downstream.

MODEL DEVELOPMENT AT OPEN CHANNEL STRUCTURE

This study was conducted in the laboratory. The material used for the cylindrical hydraulic structure must be light, easy to handle and also non-permanent structure. Cylindrical structure was built in an open channel at a distance of 5 meters from the upstream, case 1 positioned the opening in the upstream channel at a distance of 50 mm from the base of the cylindrical structure, and 50 mm from the surface of the cylindrical structure in the downstream channel. Case 2 have different opening positions from case 1. Opening position for case 2 is at a distance of 50 mm from the upper surface of the cylindrical structure while at the downstream channel, the opening is at a distance of 50 mm from the base of the cylinder surface. Figure-2 shows the installation of

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cylindrical shape hydraulic control structure in the center of the open channel structure.

Figure-2. Installation of cylindrical shape hydraulic control structure at the middle of open channel structure.

PERFORMANCE INDICATOR

The data obtained was analyzed for changes in open channel flow profile effects of the construction of a cylindrical shaped hydraulic control structure. Flow rate in both cases was fixed, the comparison between the two cases can be figured out. Based on the data that's been recorded, the specific energy changes that occurred in the downstream of the open channel, was generated from the calculation of the upstream and downstream channels using equation 5. Table-1 shows the result for case 1 and Table-2 show the result for case 2.

Table-1. Result for case 1.

Upstream Flow Rate (m^3/s)	0.001	0.002
Depth of Water at Upstream (m)	0.333	0.375
	0.340	0.376
	0.330	0.375
Upstream Velocity (m/s)	3.333×10^{-4}	6.667×10^{-4}
Time Of Water Retain (s)	13.54	8.33
Downstream Flow Rate (m^3/s)	0.258	0.309
Depth of Water at Downstream (m)	0.015	0.020
	0.020	0.023
	0.021	0.025
Downstream Velocity (m/s)	0.086	0.103

Through experiments conducted, only two (2) of the flow rate which could only be carried out for case 1, 0.001 m^3/s and 0.002 m^3/s. This is due to structural failure when the flow 0.003 m^3/s was flowing. Failure happens when the cylindrical structure was no longer able to bear the flow rate in the upstream channel and caused the water to overflow at upstream of the open channel structure. The swift flow in the upstream channel caused water retention faster than the water that comes out of the structure.

The maximum height measured by water retained in the cylindrical structure was 0.34 meters. No backwater or hydraulic jump occurred in downstream open channel impact of the construction of cylindrical structure. The type of flow that occurs in the downstream channel is sub-critical flow transition. Froude numbers obtained is less than 1, while the Reynolds number is between 500 until 12500. The maximum height in the downstream channel obtained is 0.025 m. Figure-3 shows the position the depth of water in the upstream and downstream channels observed.

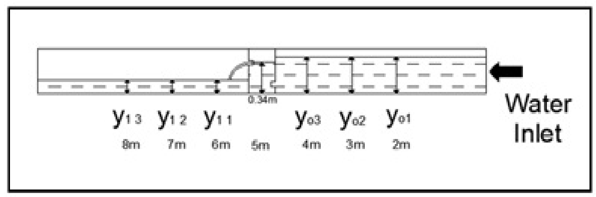

Figure-3. Position the depth of water in the upstream and downstream channels observed for case 1.

Table-2 shows the experimental data obtained from case 2. The maximum flow obtained in the upstream channel is 0.004 m^3/s. Structural failure occurs when the flow rate of more than 0.004 m^3/m flowed. Failure faced by the same structure as in case 1, which the structure is no longer able to retain water and causes overflow in the upstream of the channel.

Table-2. Result for case 2.

Upstream Flow Rate (m^3/s)	0.001	0.002	0.003	0.004
Depth of Water at Upstream (m)	0.335	0.362	0.360	0.390
	0.335	0.362	0.375	0.390
	0.335	0.362	0.375	0.390
Upstream Velocity (m/s)	3.333×10^{-4}	6.667×10^{-4}	1.000×10^{-3}	1.333×10^{-3}
Time Of Water Retain (s)	14.42	10.35	5.49	3.24
Downstream Flow Rate (m^3/s)	0.948	1.200	1.776	2.940
Depth of Water at Downstream (m)	0.007	0.015	0.022	0.030
	0.007	0.020	0.033	0.040
	0.021	0.030	0.035	0.040
Downstream Velocity (m/s)	0.316	0.400	0.592	0.980

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Figure-4 shows the position of water depth of case 2 depth upstream and downstream channels observed. Based on figures, the water levels that retained in cylindrical structure was 0.09m compared to case 1 that able to retain water up to 0.34m. Factors affected the water level in the structure was the position of the openings at cylindrical structure. The higher level of the exit opening caused the water retention in the structure higher. It caused the water needed to be at a high level to get out from the structure.

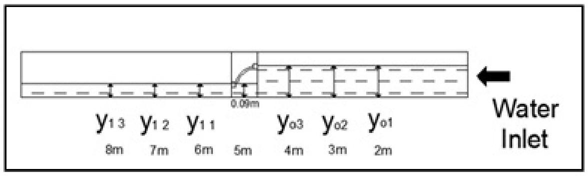

Figure-4. Position the depth of water in the upstream and downstream channels observed for case 2.

Hydraulic jump and back water also did not occur in the downstream channel for Case 2. Type of flow that occurs in the downstream channel was transition sub-critical flow. This caused the Froude Number obtained less than 1, while the Reynolds Number between 500 to 12500. The structure capable to prevent the occurrence of a hydraulic jump and also back water because the sub-critical flow transition occurred at the downstream of the channel. This shows the specific energy of the water was too small to allow hydraulic jump and back water take place in the downstream of an open channel.

FLOW PROFILE STUDY

This study has two (2) different case where each case has different opening positions. There are two (2) flow rate for case 1, while case 2 there are four (4) flow rate. Graph was built to show the relationship found in this study. Figure-5 shows the comparison for case 1 and case 2 between the velocity of flow in the downstream and upstream flow rate.

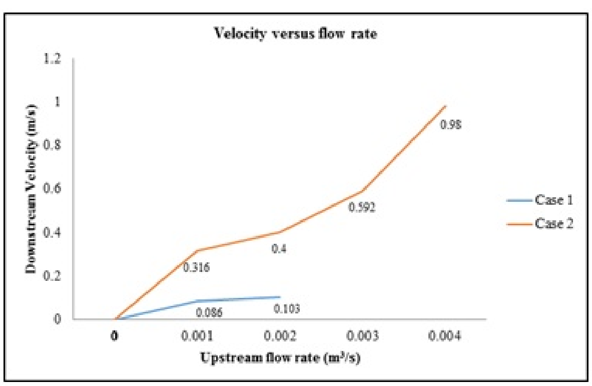

Figure-5. Comparison for case 1 and case 2 between the velocity of flow in the downstream and upstream flow rate.

The graph shows the velocity increases when the flow increases. The highest velocity obtained in this testing was 0.980 m/s in case 2 at flow rate 0.004 m^3/. The difference of velocity between case 1 and case 2 at discharge 0.001 m^3/s was 0.230 m/s. From this graph, it shows that the higher the flow rate in the upstream channel, the greater the velocity of flow in the downstream occurred.

Figure-6 shows the comparison for case 1 and case 2 between the retention time and upstream flow rate. The graph shows a decrease in time when the flow rate increases. Case 2 retained water longer compared to case 1. Case 2 able to bear a greater flow rate until 0.004 m^3/s with water retention time 14.42s.

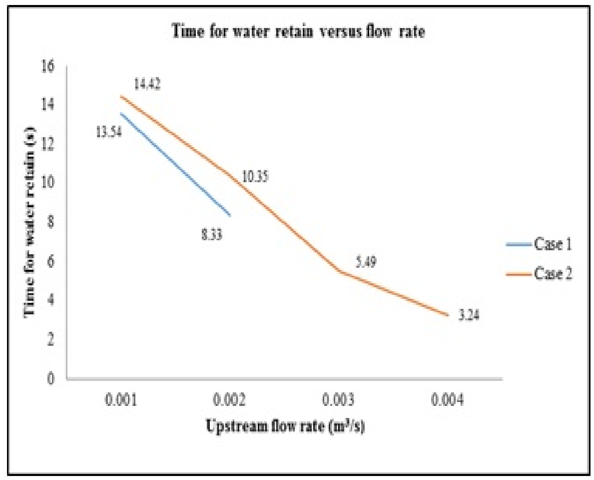

Figure-6. Shows the relationship between the retention time and upstream flow rate.

Overall, in both cases showed a reduction in time when the flow rate increases. The high at the time of water retained at upstream was at flow rate 0.001 m^3/s, for case 1 the value was 13.54s while for case 2 was 14.42s. The period of lowest water flow recorded show differences in both cases, case 1 the lowest time was 8.33s recorded at discharge 0.002 m^3/s. In case 2, the minimum time is 3.24s recorded on discharge 0.004 m^3/s. This problem occurs because of a rapid flow of water can reduce the water retention time in a cylindrical structure.

In addition, the graph of the relationship between depths of water in the downstream channel against the upstream flow rate was built. This graph shows an increase in the depth of the water in the downstream channels due to the flow in the upstream channel. Figure-7 shows the relationship between the depths of water in the downstream channel against the upstream flow rate for case 1.

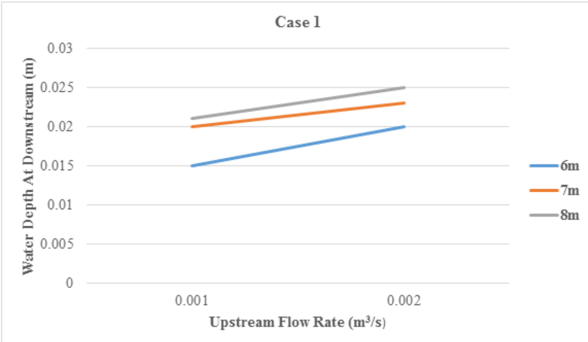

Figure-7. Relationship between the depths of water in the downstream channel against the upstream flow rate for case 1.

From the graph, the depth of the highest value recorded for case 1 at distance of 8 meters from the upstream. The highest value was 0.025m. The lowest value was recorded at distance of 6 meters from upstream channels. This shows, the greater the flow rate at upstream, the higher the water depth was recorded in the downstream channel. In case 2, the depth of water in downstream obtained was higher compare to case 1, because case 2 has higher flow rate than case 1. Figure-8 shows the relationship between the depths of water in the downstream channel against the upstream flow rate for case 2.

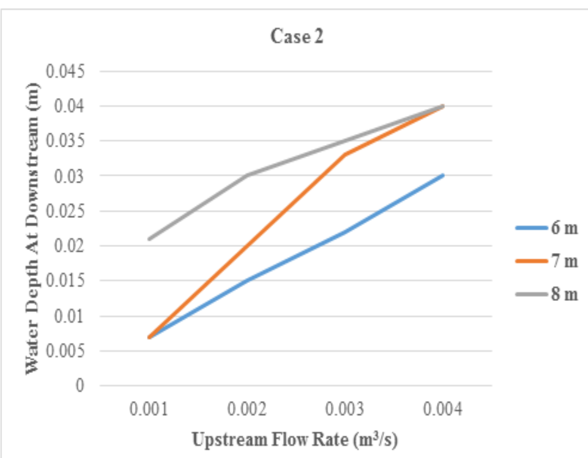

Figure-8. Shows the relationship between the depths of water in the downstream channel against the upstream flow rate for case 2.

The highest depth of water at downstream recorded for case 2 was 0.04 m. While the lowest value obtained was 0.007m. It shows the flow rate in the upstream channel plays an important role in controlling the depth of water that occurred at the downstream of an open channel. The high flow rate would give a higher depth in the downstream channel, especially at a distance of 8 meters from the upstream.

SPECIFIC ENERGY ANALYSIS

Changes in specific energy for the case 1 was shown in Table-3. The higher percentage different in specific energy recorded for case 1 was 94% while the lowest was 93%.

Table-3. Changes in specific energy for case 1.

Upstream Flow Rate, Q(m^3/s)	0.001	0.002
Upstream Specific Energy, E (m)	0.340	0.376
Downstream Flow Rate, Q (m^3/s)	0.0005	0.0008
Downstream Specific Energy, E (m)	0.021	0.026
Percent difference in specific energy (%)	94	93

Changes in specific energy for the case 2 shown in Table-4. Highest value changes recorded in this case 2 was 92% at flow rate 0.004 m^3/s. Although the specific energy reduces in Case 1 higher compare to case 2, case 2 still the best condition as the hydraulic structure because it can control flow and also can bear higher flow rate compared to case 1.

Table-4. Changes in specific energy for case 2.

Upstream Flow Rate, Q(m^3/s)	0.001	0.002	0.003	0.004
Upstream Specific Energy, E (m)	0.335	0.362	0.375	0.390
Downstream Flow Rate, Q (m^3/s)	0.0020	0.0036	0.0062	0.0118
Downstream Specific Energy, E (m)	0.026	0.038	0.053	0.089
Percent difference in specific energy (%)	92	90	86	77

Figure-9 shows the difference in specific energy that occurs in case 1 and case 2. There are only two (2) values for upstream flow rate for case 1, because the cylindrical structure was failed when 0.003 m^3/s flow rate was streamed to this structure. The comparison between the percentages of specific energy reduced at flow rate over than 0.002 $m^3/$ s cannot be made.

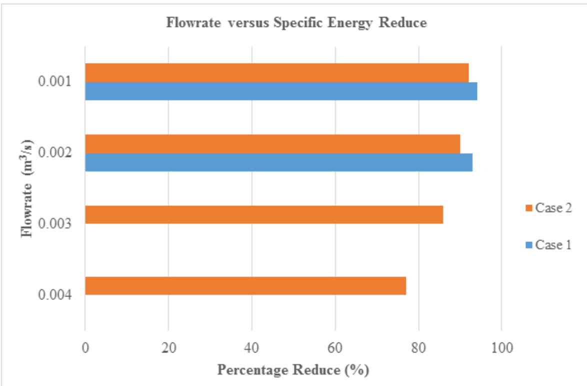

Figure-9. Comparison between case 1 and case 2 for the percentage difference of specific energy reduce.

CONCLUSIONS

Through laboratory testing that had been carried out, the change of flow profile in open channel effects of the construction of a cylindrical shape hydraulic control structure can be determined. The important parameter to be considered are the flow profile changes, changes in flow velocity and the water level in the upstream and downstream channels. Overall, the changes in the flow profile that occurred was, the flow rate increases in the downstream channel. However velocity showed the value added in the downstream channel, while the depth of water in the downstream channel is lower than the upstream channel. The relationship between the velocity of flow obtained in the downstream channels and discharge in upstream also can be establish to demonstrate the difference between case 1 and case 2.

This study was conducted to evaluate the changes that occur as a result of the construction of a cylindrical shape hydraulic control structure in the open channel. The resulting energy value of the upstream and downstream channels are also derived from calculations using the equations 3. Overall, the specific energy that occurs in an open channel for two cases show that, specific energy in an open channel downstream lower than in the upstream channel. Thus, the cylindrical structure is capable of reducing specific energy of water in open channels.

The effectiveness of the control structure of the hydraulic cylinder can be proved by the results of laboratory experiments carried out. Case 2 shows the situation better than case 1. Case 2 is able to bear a greater flow of 0.004 m^3/s while the case 1 is only able to accommodate flow of 0.002 m^3/s. In addition, the cylindrical structure on condition case 2 also can hold water in the upstream channel longer than case 1. This shows that the structure is capable of controlling the flood that will occur in the upstream channel because this structure can accommodate larger water flow and release it to downstream with shorter time.

In addition, case 2 also shows the change of specific energy in higher percentage even though the value is lower than case 1. The percentage of specific energy reduction in case 2 was 92%. Thus, the hydraulic control structure has a higher opening in the upper indicating the nature of the flow control structure is better than having a low opening position on the upper as well as to control the flood that will occur in the upstream channel.

Flow control structures come in a wide variety of types, sizes, processes and construction material. Flow control structure may be applied to a variety of situations but typically address bank erosion and protection. Flow control structures often constructed with material such as concrete and steel. Successful designs will accomplish engineering goal, cooperating with environmental issue especially habitat in water an also esthetics consideration.

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