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The Hydraulic Investigation of Perforated-Cylindrical-Intake Structure

Niayesh Fendereski[1]*, Mohsen Masoudian[2], Esmaeil Kordi[3], Klaus Röttcher[4], Mohammad Gharahgezlou[5]

[1]*Faculty of Agricultural Engineering, Sari Agricultural Sciences and Natural Resources University, Sari, Iran*
[2]*Assistant prof., Water Engineering Faculty, University of Agricultural and Natural Resources, Iran*
[3]*Member of ASCE, Gorgan, Iran.*
[4]*Prof., Faculty of Civil Engineering, Ostfalia University of Applied Sciences, Campus Suderburg, Germany*
[5]*Young Researchers and Elite Club, Sari Branch, Islamic Azad University, Sari, Iran*

*Corresponding author's Email: niayesh.mirfendreski@gmail.com

ABSTRACT: Water surface level regulation and deviation of a constant value of discharge into the side channel, is the basis of the intake systems in irrigation channels, considering the main discharge rate fluctuates during the seasons. Hence, the necessity to design a structure which can control the consequences of discharge fluctuation in main channel and divert the constant value of demand water flow is more recognizable. The perforated-cylindrical-intake instrument is a new model of regulator-intake function, includes a free overflow on a cylindrical weir associated with intake element that can fulfil the main objective of a regulator and an intake devices, simultaneously. This research firstly, examined the different geometric conditions of the structure and determined the best one, then, tried to investigate the hydraulic function, operation method and the correlation of the intake discharge and upstream flow depth versus the discharge of the main channel in various condition of the structure based on an experimental work. The results show that in wide range of discharge variation in the main channel, the intake discharge variation were not considerable, also, it would be possible to measure and control the intake discharge precisely, installing a counter and a valve at the side channel.

Key words: Cylindrical weir-gate; Over-under flow; Intake; Orifice.

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INTRODUCTION

Instability of water demand in downstream flow or the lack of required water supply at the source, lead to flowing discharge variation at irrigation channels and fluctuation in water level; on the other hand, in order to divert a specific amount of water of the main to the side channel, the water level needed to be stable (Amiri Takaldani, 2011). Therefore, the intake structure designed, in irrigation channels, which consists of two different parts, water level regulation (located in main channels) and intake (located in the beginning of side channels).

Regarding to the importance of intake systems' role in water distribution, it can be said that the success probability of each channel is dependent upon the operation of these structures; and to provide the downstream water demand, various structures to control and regulate the flow, are getting employed, that different characteristics of the project such as physical conditions, designing and operating considerations and costs, affect their selection. Hence, a new device, perforated-cylindrical-intake structure, has been introduced, includes a free overflow on a cylindrical weir associated with intake component. The mentioned device can satisfy the main goal of a water surface regulator and an intake devices, simultaneously, to provide a given diverted flow discharge rate (in an acceptable tolerance), in a relatively broad range of the main discharge rate of open channel, with considering a slight tolerance of the upstream flow depth. Figure 1 shows a general view of the cylindrical weir, outlet pipe and orifices.

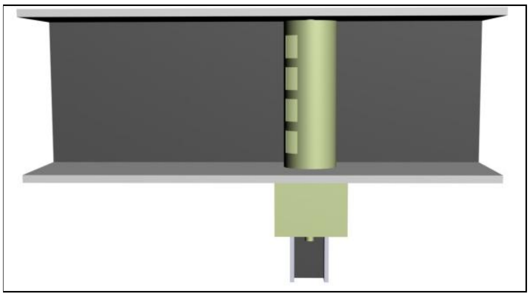

Figure 1. Schematic diagram of body, outlet pipe and orifices in main and side channels

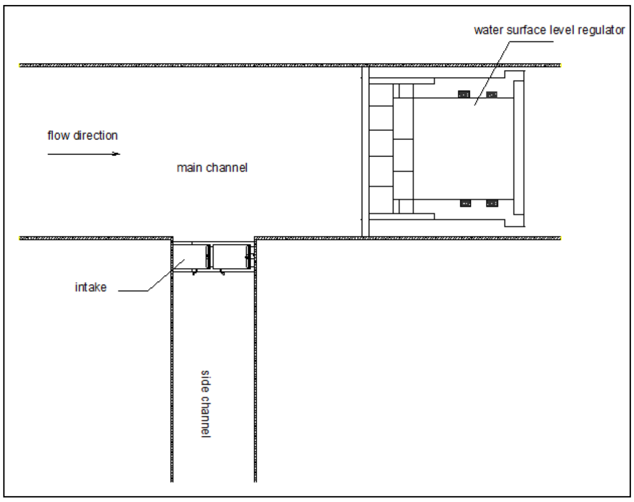

Figure 2. Location of current regulator and intake structures in irrigation channels

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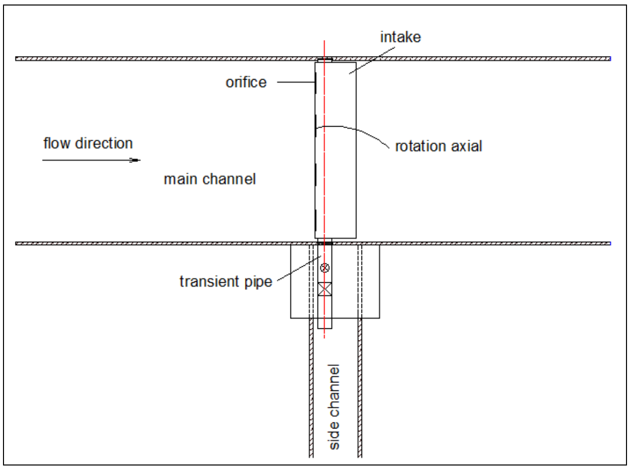

Figure 3. Location of perforated-cylindrical-intake in channels

The most obvious characteristic of the mentioned device compared to current structures, is an individual device with 2 functions, simultaneously. Against the common intake structures which are located in the edge of the side channel, its cylindrical body is installed in main channel where the side channel is exactly attached in, and make the orifices to be located in front of the flow, the transient pipe which is connected to the cylindrical body, on the side channel. Figures 2 and 3 shows the location of common regulator and intake structures, and the perforated-cylindrical-intake in channels, respectively.

The hydraulic of the mentioned structure can be separated into different parts, including cylindrical weir-gate as water level regulator and orifices which diverts the water flow. Literature review indicates that, major of the previous investigations were conducted on different aspect of cylindrical weir-gate. Gharahgezlu et al. (2010), studied the hydraulic of cylindrical weirs and combined model of weir-gate and their functions, then concluded that the discharge coefficient of cylindrical structures is higher than the other structures and H/p(ratio of the upstream flow depth to weir height) is the main parameter in discharge coefficient of combined model of weir-gate. Gharahgezlu et al. (2011) investigated the discharge coefficient of combined model of cylindrical weir-gate in low amount of discharge and showed that H/a (ratio of the upstream flow depth to gate opening amount) and H/p (ratio of the upstream flow depth to weir height) affect the discharge coefficient, and an increase of each parameter result discharge coefficient increasing. In a constant value of H/p, the rise of diameter, led to the increasing of discharge coefficient, whereas, in a constant value of H/a, the diameter rising, led to the decrease of discharge coefficient. Masoudian et al. (2012) in an experimental investigation of discharge coefficient of cylindrical weir-gate in high amount of discharge, deduced that, in a constant value of H/p, increasing of gate opening amount led to discharge coefficient reduction and in a constant value of H/a, with diameter decreasing, the discharge coefficient rises. Also, the discharge coefficient of cylindrical weir-gate was varied between 0.75-1.05. Gharahgezlu et al. (2013) based on experimental work, reported that the overflow has influence on underflow in combined model of weir-gate and led to 1-25 percent of discharge coefficient reduction comparing to the gate model. Masoudian et al. (2012) indicated that discharge coefficient of gate decreases with increasing of gate opening amount, in a constant value of H/p. Severi et al. (2012) examined the impact of structure position on perpendicular direction on discharge coefficient of cylindrical weir- gate. The results showed the maximum and minimum discharge coefficient has been observed respectively, in the cylindrical weir and cylindrical gate. Also, by converting the structure from cylindrical weir-gate to cylindrical gate, the curves depicted amount of against and have reduced suddenly, which this progress was due to decreasing the amount of back water and remarkable decreasing in upstream depth.

Naeemi et al. (2008), studied the usual intake systems being used in irrigation channels and recommended a new device, check intake. Balouchi and zeynivand (2012) examined the effects of hydraulic and geometric parameters like length and width of the orifice, on discharge coefficient of combined model of rectangular weir-gate, then presented a formula to estimate the discharge coefficient. Shirdeli and Shafaee bajestan (2006), in an experimental work, investigated the submerged rectangular orifices hydraulic behaviour. They express a correlation for discharge coefficient.

In this paper, initially, different geometric conditions of the structure have been described and the best one has been determined, after that, tried to examine the hydraulic function, operation method and the correlation of the intake discharge and upstream flow depth versus the discharge of the main channel in various condition of the structure based on an experimental work.

MATERIALS AND METHODS

The structure operation's analyze were presented in two separated section, in the current paper. At first, using the general concepts hypothesis of flow and geometry, the primary shape of the mentioned structure and different parts of it, have been extracted, then, the hydraulic function of the intake has been introduced and studied using the various index such as intake discharge and upstream flow depth variation trend against the variation of main channel discharge. According to that, three different hydraulic conditions of weir, weir-gate and gate are possible, experiments for them defined and had been done.

The experiments were conducted in a recirculating tilting rectangular-flume with smooth glass side walls with 0.30 (m) width, 11 (m) length and 0.7 (m) depth and a constant slope 0.0001, in hydraulic lab of Ostfalia University (Fig 4). The PVC pipes were used to construct the perforated-cylindrical weir experimental models. The diameter of 120 (mm) was investigated for the studied shape. Four rectangular orifices were embedded on the cylinder with 30 (mm) width and 15 (mm) length (Fig 5).

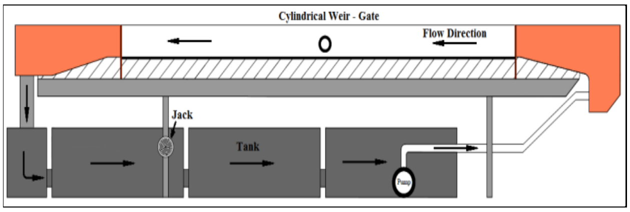

Figure 4. Sketch of flume and location of the cylindrical intake

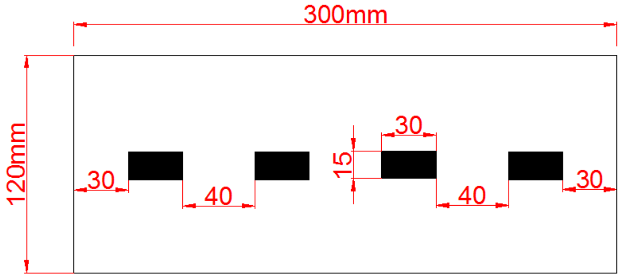

Figure 5. Dimension and position of the orifices on the surface of the cylindrical model

Also, In order to divert flow into cylinder (connection of main to the side channel), a pipe with diameter of 30 (mm) were used. Discharge rate covers a range of 0.3-48 (lit/s). Experiments were conducted on initial Froude and Reynolds numbers in ranges of $0.1<Fr1<0.45$ and $1600<Re_{up}<200000$, respectively. The diverted discharge Q_i rate was measured using volumetric approach. Main channel discharge rate Q_m was measured by a triangular weir, and the water surface level was recorded using a liminimeter with ± 0.1(mm) accuracy. The total discharge, Q_t was obtained by Eq. 1:

$$\mathbf{Q_t = (Q_m + Q_i)} \qquad (1)$$

$$\mathbf{Qi = \left(\frac{\forall}{T}\right)} \qquad (2)$$

Where, Q_t= total discharge rate (m^3/s),∀= measured diverted volume (m^3/s) and T = recorded time. The following Eq. (3) was used to determine main channel discharge rate through the triangular weir.

$$\mathbf{Q_m = \frac{8}{15} C_d \sqrt{2g}.tg\frac{\theta}{2} H_m^{2.5}} \qquad (3)$$

Where, H_w= head of water over the weir (m). The following equation is used for Cd (-) prediction (Eq. 4).

$$\mathbf{C_d = 0.00034H_w + 0.6} \qquad (4)$$

Figure 6 shows the model installed in the laboratory flume, in different positions of the structure.

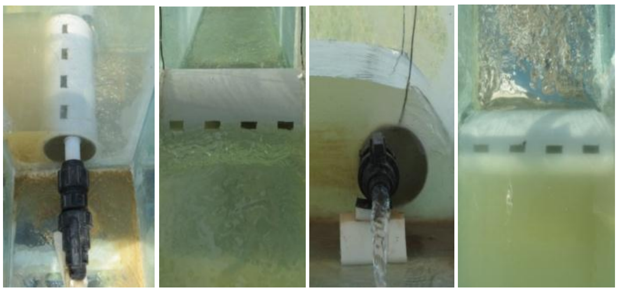

Figure 6. The intake model installed into the laboratory flume in different position

RESULTS AND DISCUSSION

Geometry of the proposed device

Figure 7 shows a schematic sketch of the studied regulator-intake device components and their positions. To create the investigated conditions, including overflow, over-under flow and under flow (weir, gate and weir-gate), the cylinder can rotates on the central axis of intake pipe (Figure 8). However, the amount of opening height, for the over-under and under flow conditions, depends on cylinder diameter D (mm), intake diameter D_i (mm), position of the intake pipe on the cylinder perimeter and the embedded orifices location on cylinder as compared to intake pipe.

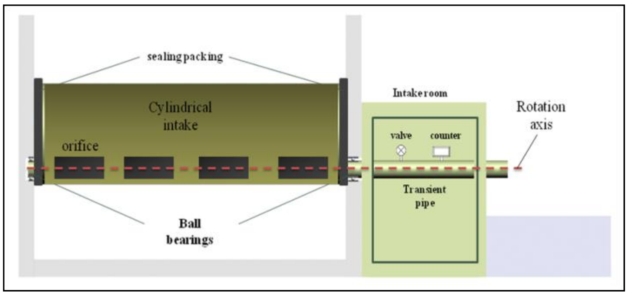

Figure 7. The schematic design of the studied device

To find the maximum domain of opening height variation in a constant cylinder diameter, the intake pipe should be abutted on the cylinder internal perimeter. Based on geometric analysis, the position of orifices should be corresponded to the nearest point to the position of the intake pipe that results in obtaining the maximum domain of opening height variation, as shown in Figures 8 and 9. This figure exhibits the probable different functions of the cylinder positioned into the main open canal and the optimized locations for device components of orifices, rotation axis and outlet pipe, that embedded on the cylinder perimeter. For the over flow and underflow conditions, the upper and lower sides of the rectangular orifice position on the crest of the cylinder and abut on the line perpendicular to bed main channel, respectively.

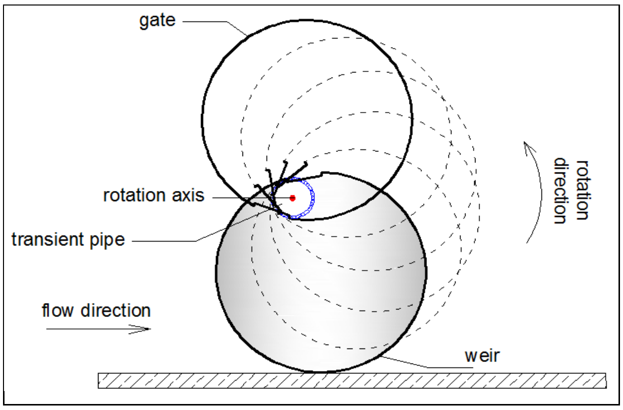

Figure 8. Probable different functions of cylinder positioned into the channel and the optimized location for components of orifices, rotation axis and outlet pipe, embedded on the cylinder perimeter

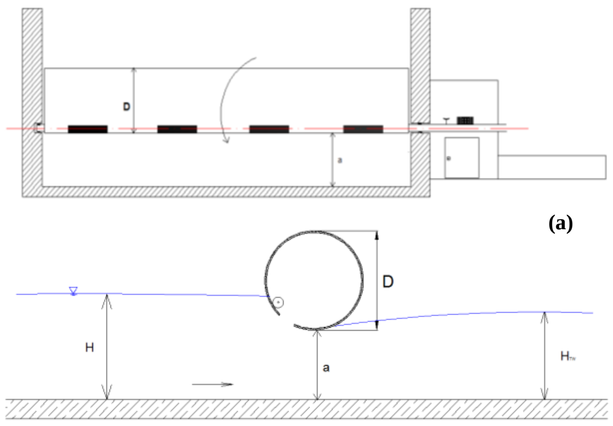

Figure 9 (a)

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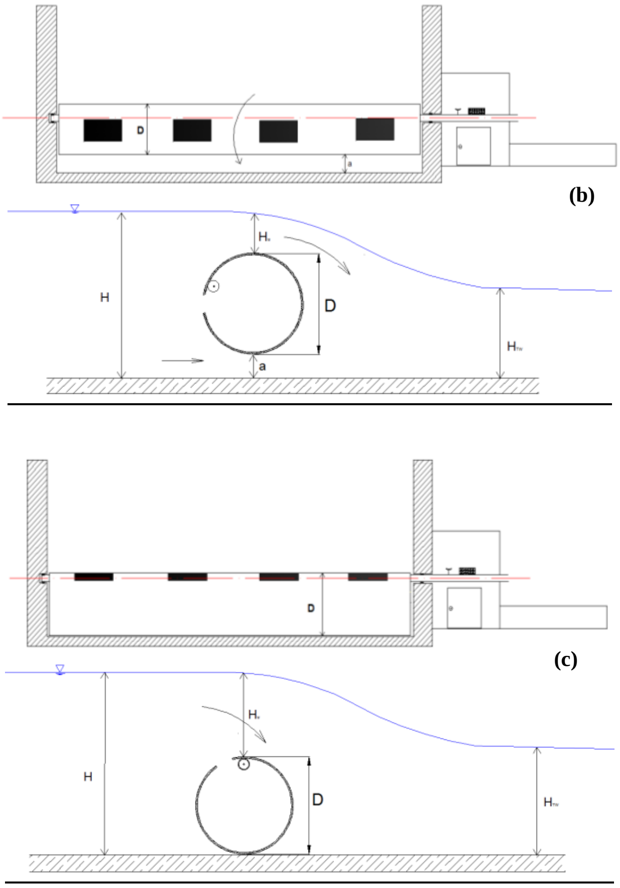


Figure 9. Cylindrical gate (a), Cylindrical weir-gate (b), Cylindrical weir (c)

Relevant calculations

Based on Phi Buckingham theorem, cylinder diameter, intake diameter and orifice dimensions are effective factors on the intake discharge rate. In the following part, the relevant calculations and used assumptions to determine these parameters for set-up installation are presented. Table 1 shows the calculated factors to setup the physical model and experimental work design.

Table 1. The determined factors to install the physical model and set up installation

Geometric characteristics		hydraulic characteristics	
W (m)	0.3	n (-)	0.009
S (-)	0.0001	Q (lit/s)	0.4-44
L (m)	11	dn_{max} (cm)	8.5
d(m)	0.7	dn_{min}(cm)	55
D (m)	0.12		
Wc (m)	0.3		
At	17.8		
Ao	4.45		
d (m)	0.03		
a (mm)	15		
b (mm)	30		

For discharge rate variation (0.4-44 lit/sec) the calculated values of maximum and minimum normal flow depths (dn_{max} and dn_{min}) were equal to 8.5 and 55 cm, respectively (Hosseini, 1382). The optimum height fluctuations of the cylinder can be determined as =1.75D, based on the relation proposed by (Hosseini, 1382), so the domain of applicable cylinder diameter, with considering the dn_{max} and dn_{min} factors, is equal to 5-31 cm. for present experimental work D=12cm was selected. The outlet diameter (intake) can be changed in the range of$[0.05D \leq d \leq 0.5D]$. For the experiments the ratio of $\left[\frac{d}{D}\right] = 0.25$ was selected (d= 3cm). Also, based on the law of continuity, diverted discharge rate q_i (lit/s) is equal to orifices discharge so, using the Eq. (5), q_i=0.6 (lit/s) and total orifice area A =17.8cm2. Area of each orifice (4 orifice are embedded on the perimeter of cylinder) is equal to 4.45cm^2.

$$\mathbf{q_i = A \times c\sqrt{2gH}} \qquad (5)$$

Where, q_i= diverted discharge rate (lit/s), A=cross section area (m2), C= orifice discharge coefficient =0.6, H=flow depth of the crest of cylinder that H_{max}= (D-d). The maximum domain of opening height variation, rotation angle from over-flow to under-flow conditions were equal to 0.088m and 158^o degree, respectively (Figure 10).

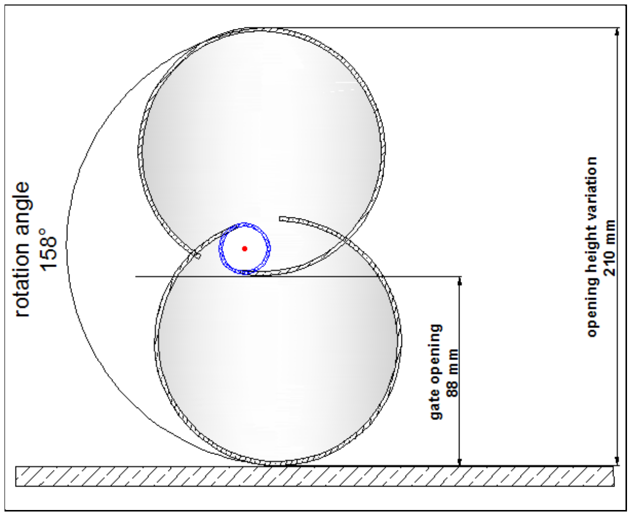


Figure 10. Domain of opening height variation of the cylindrical between 0 and 88 mm, D =12 cm.

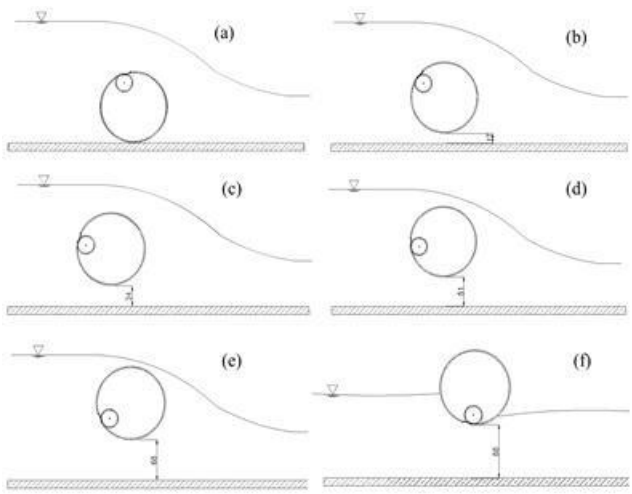


Figure 11. The studied flow conditions, (1) over-flow condition, opening height=0, (2) over-under flow condition, opening height=1.7 cm, (3) over-under flow condition, opening height=3.4 cm, (4) over-under flow condition, opening height=5.1 cm, (5) over-under flow condition, opening height=6.8 cm, (6) under flow condition, opening height=8.8 cm.

Figure 11 display the investigated flow conditions, including; (1) over-flow condition with an opening height=0, (2) over-under flow condition with an opening height=1.7 cm, (3) over-under flow condition with an opening height=3.4 cm, (4) over-under flow condition, opening height=5.1 cm, (5) over-under flow condition, opening height=6.8 cm and (6) under flow condition with an opening height=8.8 cm.

Experimental results

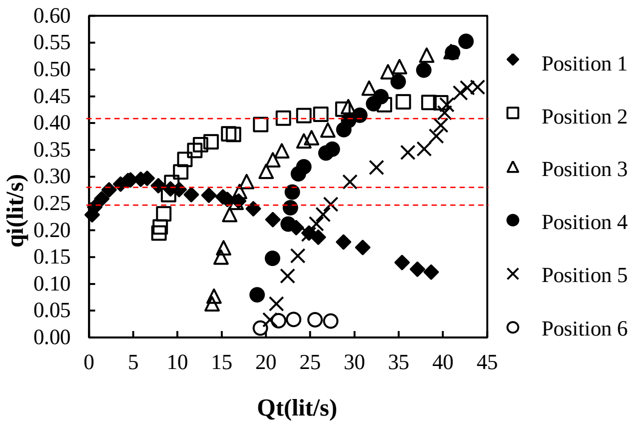
Graph 1 exhibits the variation of the intake discharge rate q_i (lit/s) against the total discharge Q_t(lit/s), for all the investigated conditions. Generally three different trends were observed for the conditions of overflow, under-overflow, and underflow. According to the Figure 11, in the first condition or overflow situation, with increasing the main discharge rate Q, the diverted discharge raises rapidly, peaks at q_i=0.295-Q=5.89lit/s and then decrease gradually. For the over flow condition, the values of 0.44 and 0.23 were observed for the measured main discharge and diverted discharge rates, indicates that about half of Q is diverted. A relatively flatted peak also can be found for this trend. However, in the lower main discharge rates, because of low velocity on the weir, much more path flow lines converge to the orifice, compared with the higher velocities on weir. For the conditions of 2, 3, 4, and 5, in which over-under flow situation was created, with increasing the opening height the initial main discharge grows. A similar trend was found for these conditions including a sharp ascent and then a moderate rise in experimental data for behavior of pair factors [Q-q_i] variation. However, with increasing the opening height, a growth in gradient of the second part of the trends can be observed (for conditions of 3, 4, and 5).

For the last condition (under-flow), a leveling off in variation of measured intake discharge data at q_i=0.03

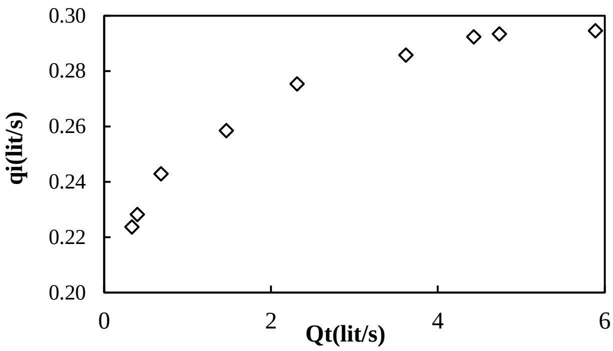
(lit/s) was seen (graph 1). In fact the value of diverted flow was independent from the discharge rate variation. It can stated that, a given diverted flow in a relatively wide range of the main discharge rate variation can be regulated that associates with a change in behavior of flow conditions from over-flow to over-under flow situations. For example, q_i=0.3 and q_i=0.27 can be controlled for the limits of $5 \leq Q \leq 30$ (lit/s) and $3 \leq Q \leq 29$ (lit/s) (based on the present experimental data). Also, the higher values of required intake discharge rates (0.31-0.44) can be diverted in the range of $10 \leq Q \leq 40$ (lit/s).

The maximum ratio of [Q/q_i] =0.57 was found for the first position (over-flow), with Q=0.377 and q_i=0.224 (graph 2).

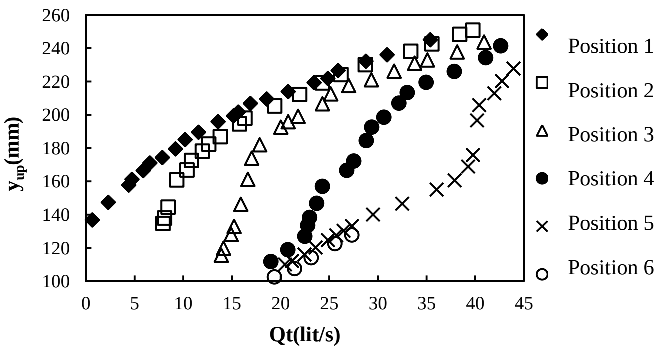
The main objective of a regulator-intake device is to provide a controlled intake discharge rate, in the wide range of the total discharge rate variation with a slight variation of upstream depth of flow that it demonstrated in the graph 3. According to the Figures (12), a general increasing trend can be found in variation of Q (1-43 lit/sec) with respect to the y_{up} (140-240 mm), for all the studied conditions. In another word, if the channel needs to provide the constant depth of 160 mm in variable discharges of main channel, the above goal could be reached, using the rotational ability of the structure and taking water in various hydraulic function of the intake (over flow, over-under flow and under flow). For instance, the results show that in the investigated conditions, in order to have the constant depth of 160 mm for discharge amount of 4.4 lit/s, over-flow condition with an opening height=0 (Fig 11(a)), can be used, and with increasing of discharge, for the amount of 9.37 lit/sec, with the rotation of the structure and creating the over-under flow condition with an opening height=1.7 cm (fig 11(b)), the extra amount of discharge passes under the gate and the normal depth of the channel will be constant. As well, the considerable note in graph 3 is wide range of discharge will be needed to reach to low amount of constant upstream flow depth rather than the high amount of constant upstream flow depth.



Graph 1. Variation of the diverted discharge rate q_i (lit/s) with respect to the total discharge Q_t(lit/s), for all the studied cases.



Graph 2. Variation of the maximum diverted discharge rate q_i (lit/s) with respect to the total discharge Qt (lit/s), for the case of position 1



Graph 3. Variation of the total discharge rate Qt (lit/s) with respect to the upstream flow depth y_{up} (mm), for all the studied cases.

CONCLUSION

This research presents an experimental study on flow hydraulic through a perforated-cylindrical-intake device that behaves as a water-surface-level regulator and intake instrument, simultaneously. This research examines the intake efficiency of the device, experimentally. Based on the results, with increasing the total discharge rate different trends in variation of upstream flow depth-intake discharge can be found. However, the investigated perforated-cylindrical-intake with rectangular orifice can satisfy the main target of the regulator-intake device, as to provide a given controlled diverted discharge, in the wide range of the total discharge rate associated with a slight variation of upstream depth of flow. Besides, With regard to the applicability of the proposed structure, it is suggested to investigate the precise dimensions of structure's diameter, the diameter of transient pipe, the area of orifices, etc. the effects of each orifice on the others can be observed and the optimised distance between each orifices, regards to the channels discharge variation, the structure's diameter and the orifices' dimension can be examined, also, the position of the orifices in one or multiple rows can be investigated.

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