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Technical Note

Effect of Opening Holes on the Hydraulic Performance for Crump Weir

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A B S T R A C T

Nowadays, developed and applied hydrology become very important thing in the life due to the wide verity advantages for the applications of this field. Hydraulic Structures such as crump weir are placed in channels to estimate or measure flow rate and flow control devices. In this study there is a new performance for crump weir which appears by adding opening holes in the model of crump weir. Opening holes are working as an energy dissipater and as an improver for the discharge coefficient (Cd). Where the discharge coefficient (Cd) is improved and recorded a higher values in comparison with conventional weir under the same laboratory conditions. The twenty-eight laboratory experiments were carried out using free flow in a horizontal channel of 12 m length, 0.5 m width and 0.35 m depth for a wide range of discharge. The experimental results indicated that Cd values increase by increasing the number opening holes in body of crumb weir. Thus; increasing the holes numbers from one to two and three holes) increase Cd value about (10, 11 and 13%), respectively as compared with traditional weirs without opening holes. On the other hand, The results revealed better flow behaviour for two holes model than one and three holes, the flow is more stable and the transition flow regime has less instabilities and Energy dissipation rate is the maximum. Thus; the weir crumb with three voids are not stable and it was not easy to localized it in the channel.

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1. INTRODUCTION

Weirs are one of the most common and simplest hydraulic structures that has been constructed in many centuries by hydraulic engineers. The weirs is used for different functions such as flow measurement, diversion, and water level management. Depending on the functions of weirs, they were implemented in various places like rivers, canals and reservoirs. Generally weirs are used for measuring discharge, avoiding flooding's, regulating the flow depth and improving the navigability of river [1].

Various types of weirs are appeared depending on the weirs' geometry, where one of the most interesting type of weirs is a broad crested weirs. Crump weir is a special type of broad crested weirs with a triangular profile [2]. It also known as flat V-triangular profile weir which is shown in Figure 1. So, Crump weir has many features such as straightforward structure, giving high precision in flow measurement. Also, It is comparatively insensitive to submerged conditions and ease of determination of flow curves for any width [3]. In addition to that, it has many advantages like the coefficient of discharges remains stable and constants through undrown condition; and moderately unresponsive to drowned condition [4]. Moreover the laboratory investigation found the stepped and unstepped weirs for steep slope channels which is having a high difference in head of water between upstream and downstream in order to find their efficiency for dissipating flow energy. Al-Talib found that stepped weirs are more efficient than unstepped weirs and the maximum energy dissipation ratio in stepped weirs was approximately 10% higher than in unstepped weirs [5].

On the other hands, Keller studied a standing inclined crest Crump weir, two models were tested of scales 1:10 and 1:3. It was concluded that for similar transversal crest grade, the weir acts like one half of flat-V weir at relatively large heads. At lower heads, the

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discharge coefficient value consequently decreases and the cross section of the flow converts asymmetrical. The amount of precipitation at the upstream of the channel affects very sensitive on the critical head. This kind of Crump weir must not be used for measuring flows in a straightforward channel with no related models study or a wide field's calibrations [6]. Razi, et al. studied the relationship between the rate of flow and upstream head over crump weir besides obtaining an approximate free surface profile in unsteady open channel flow [7].

One of the most effective issues that face the structure life span is the height of the hydraulic jump where increase or decrease the height away from (Y_c=1) which lead to collapse the structure or increase the sedmentation and decrease the flow rate. So, many researchers try to control the hydraulic jump value in order to mitigate the effect of increase or decrease the hydraulic jump [8]. In this research, Crump weir with one, two and three holes was applied for the first time to work as an energy dissipater and as a improver for the discharge coefficient (Cd). Where the discharge coefficient (Cd) is improved and recorded a higher values in comparison with traditional weir. The improvement in the weir body will make many changes in the weir performance. The objectives of this study is to investigate the effect of changes in the geometrical parameters of the crumb Weir on the discharge coefficient. Also studying the influence of the (geometrical and hydraulic) variables of crump weir on the rate of energy dissipation.

2. EXPERIMENTAL WORK

2. 1. Model Description During the experimental part, four different models were be used to study the effect of crump weir geometric parameters on the discharge coefficient as shown in Figure 2. A model should not produce from the same materials as the prototype. Same in shape and the roughness of the original model, the model will usually be satisfactory [9]. The sheets wood were cut in inclined upstream faces slope with angle (27°) and downstream slope angle is (11°), these angels of the weir crump body is considered the ideal one [10] and the voids produced by CNC (Computer Numerical Controlled) machine. This drawings, to cut the wood sheets into the desired shapes. machine uses computer commands, based on CAD- After cutting, the sheets are assembled and pasted together by silicon and other pasting materials to form the crump weir model as shown in Figure 3. Each model was fixed cruelly to the flume bed using two screws and enough silicon rubber amounts in order to prevent movement and provide water tightness. The models were placed at the middle of the flume reach in order to confirm that uniform flow is developed, also to avoid the downstream impacts. The dimension of models are (0.05) m width and the height from the base to the upper point in the crest of crump weir is (0.12) m as shown in Figure (2).

2. 2. Flume of Experimentation In this study, a rectangular open channel flume with (10) m length, (8) cm width and the water could reach to (40) cm depth was used to perform all the experiments. The flume walls are made from acrylic glass to provide visual observation, while the bed is made from stainless steel. An electrical control unit is placed at the flume upstream to operate the facilities like the pump and the slope changing system. The Flume is provided with a digital flow meter for discharge measurement. In addition, a point gauge is implemented for measuring water depth. At the entrance of the flume, there is a vertical sluice gate to raise the water level in the flume during submerged flow conditions to form the hydraulic jump while downstream gate is placed at the end of the channel to control water depth as Shown in Figure 3.

2. 3. Test Procedure All the experiments were performed with a flume slope equal to zero (flat). After fixing each model at the middle part of flume section as shown in Figure 5, the point gauge apparatuses were used to measure the crest level of the model. The bed level reading were also recorded. The experiments conducted for discharges ranging from (9 to 31) l/s. Test procedure will be presented for the following main topics of this research:

2. 3. 1. Discharge Measurement (Q) During the experimental work, a digital flow meter flow provided in the flume for measuring discharge. The flow ratio per width unit in any event used as:

Figure 1. Crump weir [11]

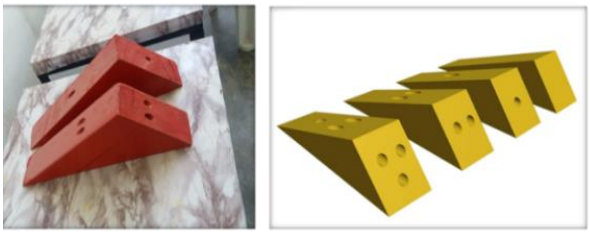


Figure 2. Physical models of crump weir for crest height 12cm

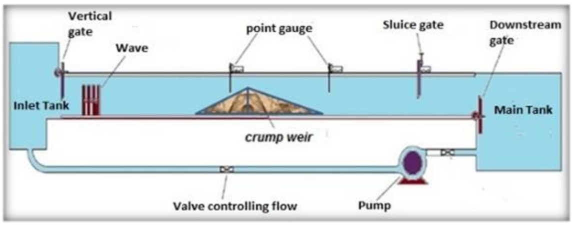


Figure 3. Sketch of the experimental flume

$$q=Q/(b) \tag{1}$$

whereas (b) is the width of the channel.

2. 3. 2. Froude Number (F_r) The ratio of inertia force and gravity force is known as Froude Number, (F_r) and its formula is written as following:

$$F_r = \frac{q}{\sqrt{9.8*} \sqrt[2]{y_1{}^3}} \tag{2}$$

Froude Number is used to investigate the flow regimes limits.

2. 3. 3. Discharge Coefficient (Cd) Water levels upstream the models were measured by the point gauge described. For all the tested configurations, water levels were measured for the 8 runs at a distance more than 10 times the head of water above the crump weir crest (H).

In the present research modular flow condition is used during all experimental work and the discharge coefficient of the crump weir was measured using the following equation [12].

$$Q = C_d \, B \, H^{1.5} \sqrt{g} \tag{3}$$

B = the weir width = 0.08 m , H= Head of water above crump weir crest (m).

2. 3. 4. Critical Depth (y_c) The critical depth is the most important criteria for critical flow of a rectangular open channel. The depth of water at the critical is computed at the critical section by Chow [13].

$$y_c = \sqrt[3]{\frac{q^2}{g}} \tag{4}$$

where y_c is the depth of water at the critical section, g is the gravitational acceleration and q is the flow rate per breadth unit.

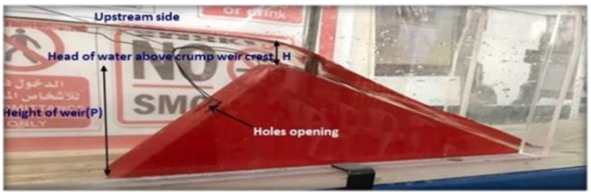


Figure 4. Flow over crump weir model

Figure 5. Flow over crump weir in condition of two open holes

2. 3. 5. Dissipated Energy (ΔE) In order to prevent erosion and scouring in downstream (D/S) ends of weirs, the hydraulic energy should be dissipated [14]. Energy dissipation rate can be obtained by calculating the energies upstream and downstream the crump weir.

$$\Delta E = \left(\frac{E_u - E_d}{E_u}\right) \tag{5}$$

where ΔE is the energy dissipation rate, E_u is the energy upstream the crump weir and E_d is the energy downstream the crump weir.

The energy upstream the spillway is computed at the critical section by Chow [13].

$$E_u = H + \frac{3}{2} y_c \tag{6}$$

where E_u is the maximum energy at the weir crest, H is the weir height, and y_c is the depth of water at the critical section.

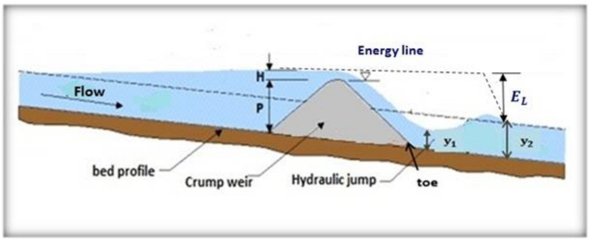
The residual energy downstream the crump weir can be calculated if the depth of water downstream the weir (y_1: clear water depth) is measured. If the hydraulic jump location is close to the crump weir toe depth after the hydraulic jump (y_2) to calculate [15].

$$\frac{y_2}{y_1} = \frac{1}{2}\left[-1 + \sqrt{1 + 8F_r{}^2}\right] \tag{7}$$

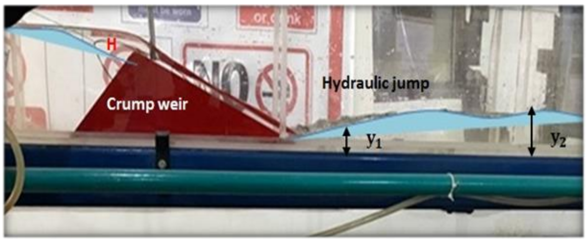
where y_1 is the depth of water before hydraulic jump, (y_2) is depth of water after the location of hydraulic jump. While If the hydraulic jump location is crump weir toe, y_1 is measured directly [16]. After getting the value of y_1, residual energy downstream of weir can calculate by following expression:

$$E_d = y_1 + \alpha \, \frac{U^2}{2g} \tag{8}$$

where y_1 is the clear water depth downstream the spillway, α is the kinetic energy correction coefficient, [17] suggested that α= 1.1, U is the mean velocity = Q/A, Q is the discharge, A is the cross-sectional area of the flowing water, and g is the gravitational acceleration. Figure 6 depicts a definition sketch for this method.



(A)



(B)

Figure 6. (A): Sketch of hydraulic jump method (Theoretical sketch), (B): Sketch of hydraulic jump method (The model in reality)

2. 3. 6. Length of Hydraulic Jump (Lj) In spite of hydraulic jump is studied since two hundred years, the reaction between the entrapped air and turbulent flow structures are still not fully understood [18]. The length of jump is measured by graded ruler fixed to the sidewall of the flume, and the depths before and after the hydraulic jump were measured by point gauge on the other.

3. ANALYSIS OF DATA

3. 1. Discharge Coefficient Many factors effect on the discharge coefficient of crump weir, the effect of each onewill be discussed as following:

3. 1. 1. Influence of the Hydraulic Parameter H/P This parameter is very important in the discharge over Crump weirs studies because it represents the upstream head above the weir crest. From the data of Figure 7, it is obvious that the increasing of head over weir has a negative impact on Cd where Cd value increased with icreasing the holes number due to decrease the head over weir. The Cd increasing is due to flow behavior over the inlet, outlet, and side crests. In fact, the observation of the separate behavior of flow over these crests is difficult due to the interactive natural of flow. However; in general when the upstream head increases, more local submergence, nappe interaction and head loss occurs and that reducing the discharge capacity.

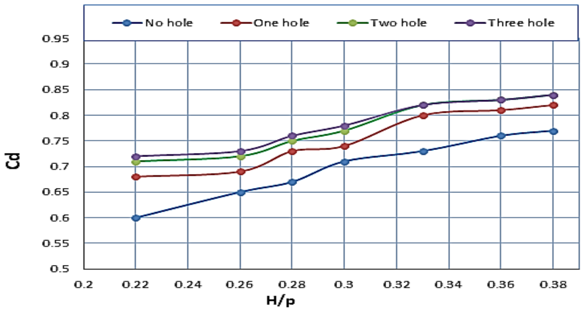


Figure 7. Effect of the hydraulic parameter H/P on Cd for the main models

3. 1. 2. Influence of Froude Number At the same crest height, discharge and upstream slope, the coefficient of discharge increases with increasing Froude number as shown clearly form the results of Figure 8.

3. 1. 3. Influence of Absolute Head A relationship between (Cd) and the absolute head (H) is a positive relation and increasing one of them will lead to increase the other one as shown clearly in Fiure 9. It is obvious from the figure below the changing in the discharge coefficient when using holes opening in weir models for a fixed upstream head Ho. All the five models lose their capacity as Ho increases.

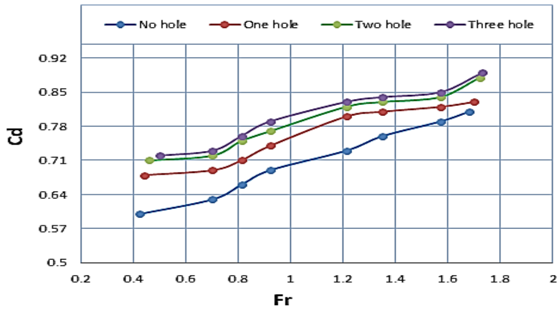


Figure 8. Variation of Cd versus F_r for four for the main models

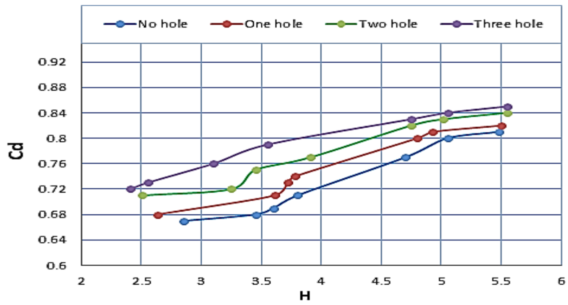


Figure 9. Variation of Cd vs. H

3. 1. 4. Energy Dissipation Figure 10 shows the relation between the Froude number and energy dissipation (ΔE) for different holes. It is observed that the energy losses decreases non-linear when number of opening holes to two and become increasing at three holes , It is evident from the figure that approximately 92, 97, 93% according to traditional weir of experimental data.

3. 2. Length of Hydraulic Jump Figure 11 illustrates the relation between hydraulic jump length (L_j) and the Froude number Fr for different holes. It is observed that relative length of the jump increases with increase in approach Froude number and number of holes of the crump weir.

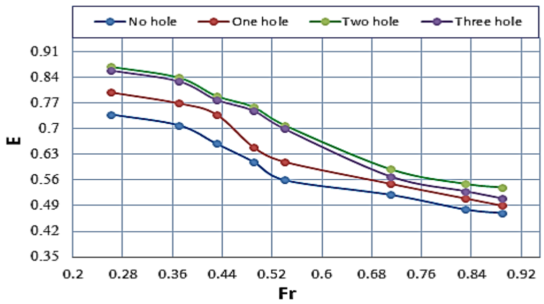


Figure 10. Variation of Energy Dissipation with approach Froude number.

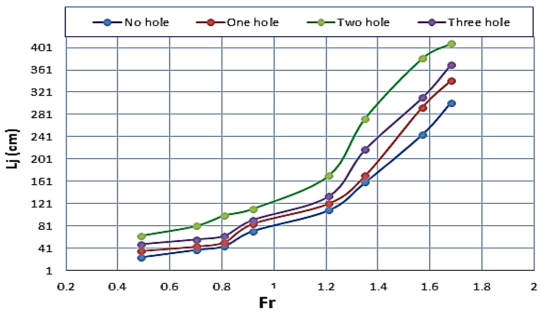


Figure 11. The relative hydraulic jump length with approach Froude number

4. CONCLUSIONS

In this research the following points have been concluded with the limitations of this study:

- The study is focus on the laboratory experiment that uses open channel flow model with a holes crump weir to determine the effect of holes on reduce the energy dissipater and as a improver for the discharge coefficient (Cd).
- For the same crest height and flow rate, Cd value increase by increasing holes opening in body of crumb weir. It notices that an increase in holes (from one, two and three holes) make an increase Cd value about (10, 11 and 13%), respectively as compared with traditional weirs, so it will reduce flood in the emergency condition this increasing in Cd value will be so worthy and we could adding screens on these holes to avoid clogging it.
- Discharge coefficient is affected insignificantly by increasing the holes numbers.
- The flow is more stable in the weir with two holes opening models, the transition flow regime has less instabilities.
- Energy dissipation is the maximum for the models with two holes opening in relatively low discharges. In high discharges, little differences between the tested configurations were observed.
- The weir crumb with three voids is not stable and it was not easy to place it in the channel.
- Finally, the best and the highest discharge coefficient and downstream hydraulic jump occur at crumb weir has two holes only and this condition considered more stability than the other conditions.

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چکیده

امروزه، توسعه و بکارگیری زمینه‌های هیدرولوژی، به دلیل مزیت‌های گسترده‌ای برای کاربرد این حوزه، از اهمیت بسیاری برخوردار است. سازه‌های هیدرولیکی از قبیل کراس پله در کانال‌ها برای تخمین یا اندازه‌گیری جریان و دستگاه‌های کنترل جریان قرار می‌گیرند. در این مطالعه یک عملکرد جدید برای پله‌ی فرو ریختگی وجود دارد که با افزودن سوراخ‌های باز در مدل نفوذ کریستالی ظاهر می‌شود. سوراخ‌های باز شدن به عنوان یک قطره دهنده انرژی و به عنوان یک بهبود برای ضریب تخلیه (Cd) کار می‌کنند؛ از آنجا که ضریب تخلیه (Cd) بهبود یافته است و مقادیر بالاتری را نسبت به معادله متعارف در شرایط آزمایشگاهی مشابه ثبت می‌کند. بیست و هشت آزمایش آزمایشگاهی با استفاده از جریان آزاد در کانال افقی ۱۲ متر طول، عرض ۰/۵ متر و عمق ۰/۳۵ متر برای طیف گسترده‌ای از تخلیه انجام شد. نتایج تجربی نشان داد که مقدار Cd با افزایش تعداد سوراخ‌های باز شدن در بدن موج میانی افزایش می‌یابد. بدین ترتیب؛ تعداد سوراخ‌ها از یک سوراخ به دو سوراخ و سه سوراخ به ترتیب در مقادیر Cd ۱۰٪، ۱۱٪ و ۱۳٪، در مقایسه با معابر سنتی بدون باز کردن حفره‌ها، افزایش می‌یابد. از سوی دیگر، نتایج نشان داد که رفتار جریان بهتر برای مدل دو سوراخ از یک و سه سوراخ، جریان پایدارتر است و رژیم جریان‌گذار دارای بی‌ثباتی کمتر است و میزان تلفات انرژی حداکثر است. در نتیجه، شکاف باریک با سه حفره پایدار نیست و برای محلی‌سازی در کانال آسان نیست.

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