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# Velocity Distribution Downstream compound Weirs

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**ABSTRACT**

Weirs are the common and important structures which are used in controlling and measuring the flow in irrigation channel. This study carried out experimental runs to survey the velocity distributions in each vertical and longitudinal directions, downstream compound weirs. It uses compound sharp-crested weirs consisting of two triangular parts with different weir angles. All parameters, such as head over the weir, h, downstream water depth, $y_{tail}$, bed type, and the shape of the compound weir, which affect the velocity distribution were studied. Three weirs, 90/90, 90/120, and 90/150, two beds, sand and plastic, four heads, 6, 9, 12, and 15 cm, and three downstream depths, 10, 14, and 18 cm were used. The results show that the vertical and longitudinal velocity distributions increase with water head and with plastic bed case. The velocity distributions decrease for larger wide weir and higher downstream water depth.



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## INTRODUCTION

Applications of weir in measurement of discharge through large and small open channels in the field or in the laboratory remains an age old practice. Compound sharp-crested weirs are more commonly used due to their simplicity, easy maintenance, and good flow measurement precision. Many types of weirs more commonly used are the sharp weirs with a notch of rectangular and triangular shapes, used particularly where the coefficient of discharge $C_d$ starts from 0.55 in case of rectangular notch and 0.59 for the v- notch. These transactions are affected by viscosity and surface tension, roughness of the plate and weir shape. A weir that causes significant change of water level behind it, will give an accurate indication of the flow rate.

### *Background:*

A weir is built as an overflow structure perpendicular to an open channel axis to measure the discharge. There are mainly two types of weirs: sharp-crested weirs and broad-crested weirs. For a weir to be considered sharp crested, the top thickness of the crest and side plates should be between 1 and 2 mm. If the plates are thicker than specified, the plate edges need to be beveled to an angle of at least 45°; 60° is highly recommended for a V- notch, (Bos 1989). The overflow sheet or nappe should touch only the upstream faces of the crest and side plates and not cling to the downstream face of the weir. Regarding the flow of water over weirs, many studies have been reported in the literature such as Ackers et al. (1978), Bos (1989), Swamee et al. (1998), Borghei et al.(1999), Johnson (2000), Clemmens et al. (2001), and Aydin et al.(2002).

Effect of the downstream transition region of a flow measurement flume of rectangular compound cross section on flow properties and vertical velocity distribution in open-channel flow with rigid vegetation were studied by Mustafa Gogus et al (2013) and Changjun Zhu et al (2014). Also, experimental investigation on discharge coefficient for a combined broad crested weir-box culvert structure was studied by A. Guven et al (2013), J. Martínez (2005) carried out design and calibration of a compound sharp-crested weir and Anees Kadhum (2013) Study coefficient of discharge for a combined free flow over weir and under Gate for Multi Cases.

Flow equations for sharp-crested weirs are usually obtained by the mathematical integration of elemental flow strips over the nappe (Bos 1989). Each strip is considered an element with a different head. The triangular or V-notch sharp-crested weir is often used for flow measurement, particularly when accurate measurement of low flow rates is required. For triangular weirs, the flow equation is as follows (Henderson 1966):

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$$Q = \frac{8}{15} C_d \ h^{5/2} \sqrt{2g} \ \tan(\frac{\theta}{2}) \qquad (1)$$

Where; Q = discharge, $C_d$ = discharge coefficient, g = gravitational acceleration,

Kindsvater and Shen (USBR 1997) considered the surface tension and the viscous effects adding a correction factor to the head, so that the coefficient $C_d$ depended exclusively on the notch angle. Weirs are the common and important structures which are used in controlling and adjusting the flow in irrigation channel. Weirs widely used for flow measurements. Weirs, however, require to be cleaned and sediments removed periodically. Sluice gates are used extensively for flow control and water measurement for long time. One disadvantage of the sluice gates is they retain the floating materials. In order to maximize their advantages, weirs and gates can be combined together in one device, so that water could pass over the weir and below the gate simultaneously. Figure 1 shows this structure, this compound device create new hydraulic conditions in compression with weir or gate. Alhamid (1999) studied combined flow over V-notch weir and below contracted rectangular gate. Ferro (2000) reported the results of an investigation carried out to establish the stage discharge relationship for a flow simultaneously discharging over and under a sluice or a broad crested gate. Samani and Mazaheri (2007) presented a new physically based approach for estimating the stage discharge relationship of combined flow over the weir for semi submerged and fully submerged conditions.

The published materials about the flow over the compound weirs are mostly related to the investigations on discharge coefficient for it. There are a no studies concerning the velocity distributions in vertical and longitudinal directions downstream the compound weirs. In this backdrop, this study surveys the velocity distributions in each vertical and longitudinal directions downstream the compound weirs, and presents its results in the forms of curves to show the velocity distributions in vertical and longitudinal directions, for different beds, water heads, downstream water depth, and different weirs.

***Experimental Apparatus:***

The experimental work of this study was conducted in a flume located at the Hydraulics Research Institute (HRI) experimental hall of the National Water Research Center, Egypt. The flume channel is 21 m long, 0.6 m wide, 0.5 m deep, and the side walls along the entire length of the flume were made of brick. The flume is associated with a steel wooden gate with an orifice with a rectangular shape, also has movable downstream gate is located at the end of the flume. Centrifugal pump driven by induction motor to re-circulated the flow from an underground reservoir to the flume. Electromagnetic current meter was used for measuring the velocities in each vertical and longitudinal directions, and the discharge was measured using flow meter. The weir models were made of steel with a 0.02 m thick 0.3 m height and 0.6 m width. Compound sharp-crested weirs consisting of two triangular parts with different weir angles were used changing the upper weir angle as 90, 120, and 150 degrees, refer as 90/90, 90/120, and 90/150 respectively, Fig. 1. The tested upstream water heads have values of 6, 9, 12, and 15 cm measured from the compound weir vertex, while the values of weir downstream water depths, $y_{tail}$ varied as 10, 14, and 18 cm. Sand and plastic flume beds were used in the this study experimental program.

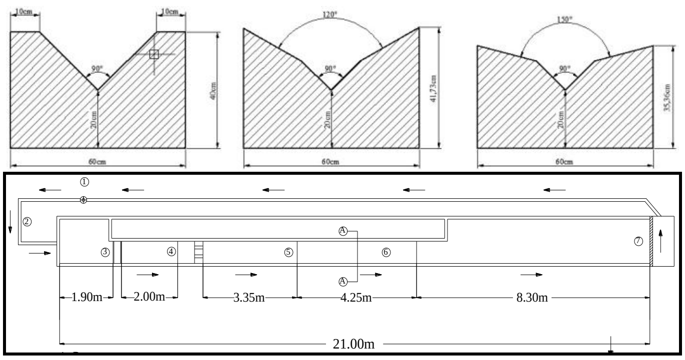


**Fig. 1:** Experimental Apparatus.

***Experimental Work:***

The experimental work consists of two main sets of experiments. The first set consists of twenty four runs using plastic bed, for different heads, $h$, different downstream water depths, $y_{tail}$, and different weir models. The second set also, consists of twenty four runs using sand bed for different pervious parameters, as summarized in the following Tables 1 and 2. The velocities were measured at depths function of the downstream depth as 0.2 $y_{tail}$, 0.4 $y_{tail}$, 0.6 $y_{tail}$, and 0.8 $y_{tail}$ from the water surface.

***Experimental Procedure:***

1- Place the specific weir plate which is to be tested first, using plastic bed. Ensure that the square edge of the weir faces upstream.

2- Start the pump and slowly open the flume regulating valve until the water level reaches the crest of the weir and measure the water level to determine the datum level.

3- Adjust the flume regulating valve to give the first required head level of approximately 6 cm. Measure the flow rate using the flow meter, and the velocity distributions in each vertical and longitudinal directions were surveyed by the electromagnetic current meter. In the vertical direction, velocities were measured at depths of 0.2 $y_{tail}$ , 0.4 $y_{tail}$ , 0.6 $y_{tail}$ , and 0.8 $y_{tail}$ from

**Table 1:** First set of experimental runs outline, for plastic bed.

| First Set | Run No. | h (cm) V-notch | $Y_{tail\ (cm)}$ | First Set | Run No. | $h_{u.s}$ (cm) V-notch | $Y_{tail\ (cm)}$ |
|---|---|---|---|---|---|---|---|
| V 90/120 Plastic | 1 | 6 | 10 | V 90/150 plastic | 13 | 12 | 10 |
| | 2 | 6 | 14 | | 14 | 12 | 14 |
| | | | | | 15 | 12 | 18 |
| | 3 | 6 | 18 | | 16 | 15 | 10 |
| | 4 | 9 | 10 | | 17 | 15 | 14 |
| | 5 | 9 | 14 | | 18 | 15 | 18 |
| | 6 | 9 | 18 | V 90/90 Plastic | 43 | 12 | 10 |
| | 7 | 12 | 10 | | 44 | 12 | 14 |
| | 8 | 12 | 14 | | 45 | 12 | 18 |
| | 9 | 12 | 18 | | 46 | 15 | 10 |
| | 10 | 15 | 10 | | 47 | 15 | 14 |
| | 11 | 15 | 14 | | 48 | 15 | 18 |
| | 12 | 15 | 18 | | | | |

**Table 2:** Second set of experimental runs outline, for sand bed.

| Second Set | Run No. | Upstream head h (cm) | $Y_{tail\ (cm)}$ | Second Set | Run No. | Upstream head h (cm) | $Y_{tail\ (cm)}$ |
|---|---|---|---|---|---|---|---|
| V 90/150 Sand | 1 | 6 | 10 | V 90/120 Sand | 13 | 12 | 10 |
| | 2 | 6 | 14 | | 14 | 12 | 14 |
| | 3 | 6 | 18 | | 15 | 12 | 18 |
| | 4 | 9 | 10 | | 16 | 15 | 10 |
| | 5 | 9 | 14 | | 17 | 15 | 14 |
| | 6 | 9 | 18 | | 18 | 15 | 18 |
| | 7 | 12 | 10 | V 90/90 Sand | 19 | 12 | 10 |
| | 8 | 12 | 14 | | 20 | 12 | 14 |
| | 9 | 12 | 18 | | 21 | 12 | 18 |
| | 10 | 15 | 10 | | 22 | 15 | 10 |
| | 11 | 15 | 14 | | 23 | 15 | 14 |
| | 12 | 15 | 18 | | 24 | 15 | 18 |

the free surface, at different longitudinal sections, 2.5, 3.6, 5, 6.25, 7.5, 10, and 12.5 times of the weir height, $X/H$ for different downstream water depths, $y_{tail}$ , which may take values of 10, 14, and 18 cm. The downstream depth may be adjusted by the downstream gate is located at the end of the flume.

4- Increase the flow by opening the flume regulating valve to set up heads above the datum level in steps of approximately 3.0 cm until the regulating valve is fully open. At each condition measure the flow rate and observe the shape of the nappe, and the velocity distributions in each vertical and longitudinal directions are measured.

5- Close the regulating valve, stop the pump and then replace the weir with the next weir to be tested. Repeat the test procedure.

6- The above procedures are repeated for using sad bed.

## RESULTS AND DISCUSSION

First of all, the flume was calibrated through measuring the discharge coefficient, $C_d$ . Fig.2 shows that the discharge coefficient for different weirs are consistent with literature work. The coefficient of discharge, $C_d$ , was calculated as;

$$C_d = \frac{Q_{act}}{Q_{th}} \tag{2}$$

Where; $Q_{act}$ is the actual discharge, which was measured in each run, and $Q_{th}$ is the theoretical discharge, which was calculated through the following concluded formula;

$$Q_{th} = \frac{8}{15}\tan(\frac{\theta_1}{2})h^{2.5}\sqrt{2g} \quad \text{for } h \prec h_1 \tag{3}$$

$$Q_{th} = \frac{8}{15}\tan\left(\frac{\theta_1}{2}\right)h_1^{2.5}\sqrt{2g} + 2\sqrt{2g}\left(\frac{2}{3}h_1(h-h_1)^{1.5}\tan(\frac{\theta_1}{2}) + \frac{4}{15}(h-h_1)^{2.5}\tan\frac{\theta_2}{2}\right)$$

for $h_1 \prec h \prec h_2$ (4)

where: $\theta_1$ is the compound weir lower part angle, $\theta_2$ is the compound weir upper part angle, $h_1$ is the height of the lower part, $h_1$ is the upper part height, and $h$ is the head over the compound weir vertex.

***Velocity Distributions at the Compound Weir downstream:***

The velocity distributions were measured by the electromagnetic current meter, downstream the compound weir. The vertical velocities were measured at depths of 0.2 $y_{tail}$ , 0.4 $y_{tail}$ , 0.6 $y_{tail}$ , 0.8 $y_{tail}$ from the water surface. These velocity distributions were measured at different distances downstream the weir, $X$ = 50, 75, 100, 125, 150, 200, and 250 cm. The

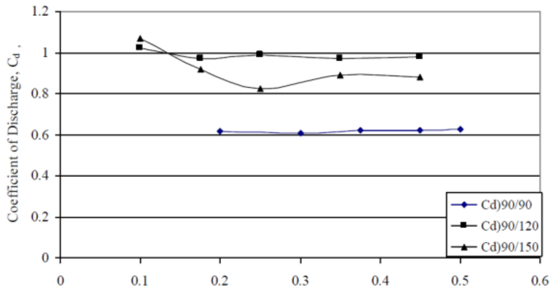


**Fig. 2:** Coefficient of Discharge for different weir models.

Effect of water heads $h$, downstream water depths $y_{tail}$ , beds (sand and plastic), and weir models on the velocity distributions in each vertical and longitudinal directions were studied.

It was found that, the vertical velocity distributions downstream the compound weir have the same trend at different distances from the weir, $X$ . Figs.3 and 4 are examples for downstream water depth, $y_{tail}$ = 14 cm, upstream water head $h = 12$ cm, sand bed, and for 90/120 weir model. Fig.3. represents the vertical velocity distributions at different longitudinal distances as a ratio of the weir height, $H$ , i.e. at $X/H$ of 2.5, 3.75, 5, 6.25, 7.5, 10, and 12.5. Fig.4 shows the longitudinal variations in velocity values at different water depths. The figures show that, the variations in the velocity values at different distances is due to the non uniformity of flow at the weir downstream. The difference in the velocity values at the same depth, decreases as the downstream distance, $X$ increases, and the flow will be uniform after $X/H$ = 12.5.

Figs.5 shows the velocity distributions in the vertical direction at different heads, for longitudinal distance, $X$ = 125 cm, $y_{tail}$ = 14 cm, sand bed, and 90/120 weir model. Fig.6 shows the longitudinal velocity distributions for the same parameter values. The upstream water head was measured as function of the total compound weir height, $h/H$ . The values of $h/H$ were taken as 0.36, 0.45, 0.60, and 0.75. It was found that, as the upstream water head,

$h$ increases the velocity values at different depths increases. For example; changing $h$ from 6 to 12 cm the velocity at 0.6 $y_{tail}$ from the water surface increases from 0.056 to 0.007 m/s.

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Also, changing the weir model affecting the vertical and longitudinal velocity distributions downstream it. This study found that, for $y_{tail}$ = 14 cm, $h$ = 12 cm, and sand bed, increasing the upper part angle, $\theta_2$ the velocity values in the vertical direction decreases, Figs.7 and 8. This is due to increasing the flow area as a result of increasing the upper part angle, $\theta_2$ . So, 90/90 weir model gives velocity values more than 90/120, and 90/150 models for $h$ = 12 cm, $y_{tail}$ = 14 cm, and sand bed.

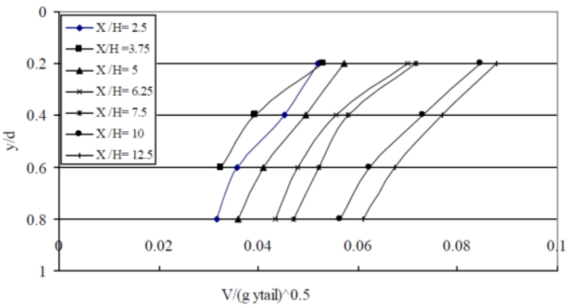


**Fig. 3:** Vertical Velocity Distribution at different distances down stream the weir, for ytail = 14 cm, h=12 cm, sand bed, and for 90/120 weir.

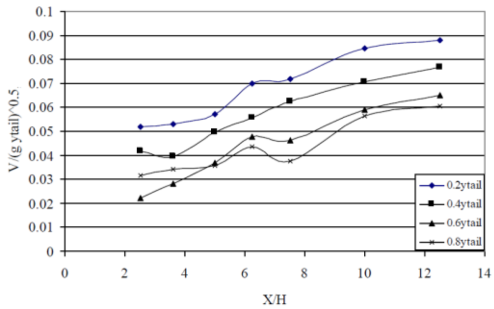


**Fig. 4:** Longitudenal Velocity Distribution at different Depths, for ytail = 14 cm, h=12 cm, sand bed, and for 90/120 weir.

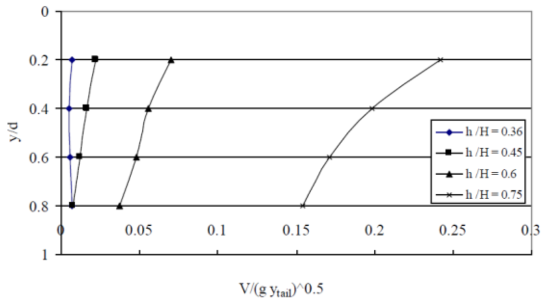


**Fig. 5:** Vertical Velocity at Different Water Heads, for X = 125 cm, ytai l = 14 cm, sand bed, and 90/120 weir.

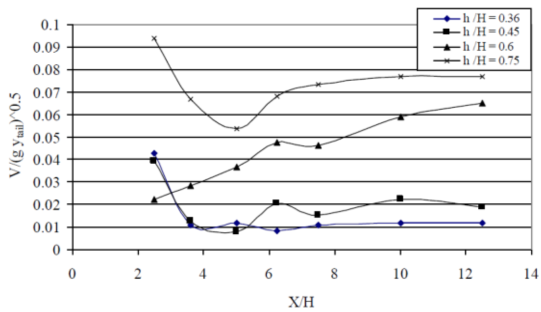


**Fig. 6:** Longitudinal Velocity Distribution at different Heads for X = 125 cm, ytai l = 14 cm, sand bed, and 90/120 weir.

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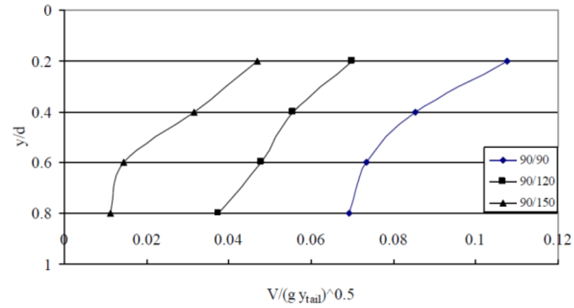


**Fig. 7:** Vertical Velocity Distribution for Different Compound weir models, for ytai l= 14 cm, h = 12 cm, and sand bed.

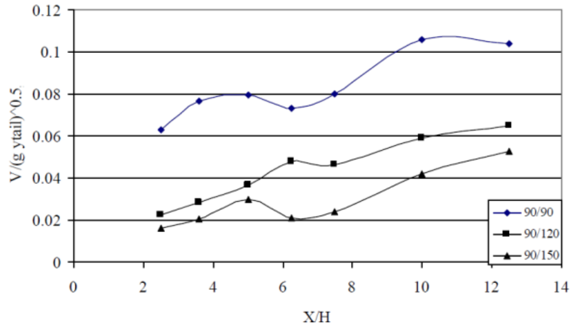


**Fig. 8:** Longitudinal Velocity Distribution for Different weir, for ytail = 14 cm, h = 12 cm, and sand bed.

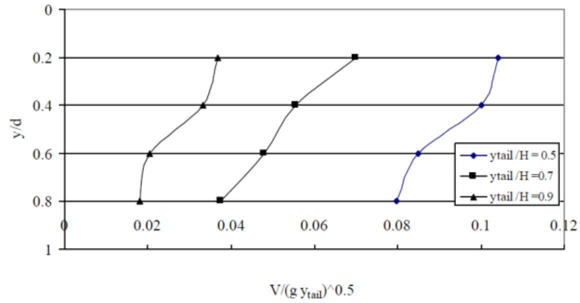


**Fig. 9:** Vertical Velocity Distribution at Different Downstream water depths, for h = 12 cm, sand bed, and 90/120 weir.

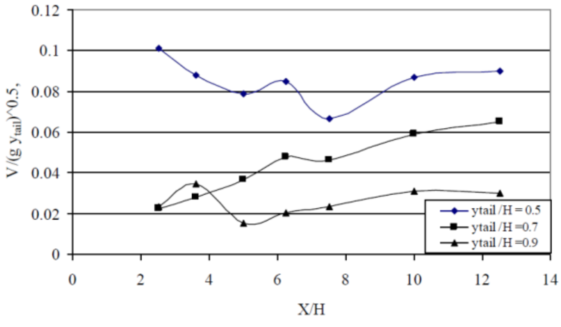


**Fig. 10:** Lonitudinal Velocity Distribution at different Downstream water Depths, for h = 12 cm, sand bed, and 90/120 weir.

Several experimental runs were carried out to study the effect of the downstream water depth, $y_{tail}$ on the vertical and longitudinal velocity distributions. All other parameters have constant values, i.e. $h$ = 12 cm, sand bed, and 90/120 weir model. The velocity in vertical and longitudinal directions decreases as the downstream water depth, $y_{tail}$ increases, Figs.9 and 10. This result is because the flow area increases, which results in decreasing in the velocity.

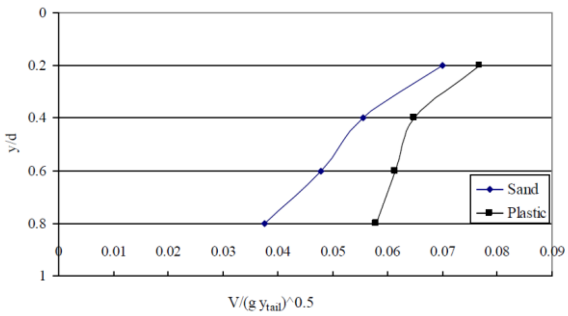


**Fig. 11**: Vertical Velocity Distribution for different beds, for h = 12 cm, ytail = 14 cm, and 90/120 weir.

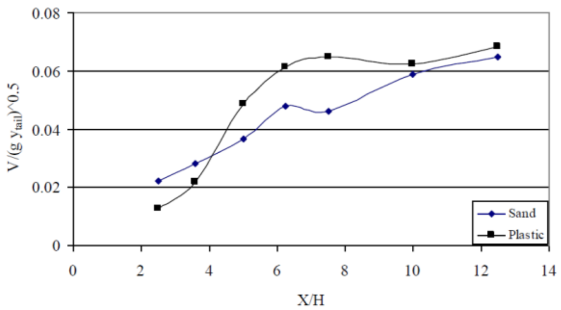


**Fig. 12:** Longitudinal Velocity Distribution for Different Beds for h = 12 cm, ytai l = 14 cm, and 90/120 weir.

On the other hand, the effect of the bed materials on the velocity distributions in the vertical and longitudinal direction were studied for $h$ = 12 cm, $y_{tail}$ = 14 cm, and 90/120 weir model. Figs 11 and 12 show that, the velocity in the two directions have more values in case of plastic bed than sand bed. The difference in the velocity values are large near the bed and decrease near the free surface. The reason of this result is that, the plastic bed has less friction than the sand bed.

From the analysis of the obtained results, this study found that the velocity distributions in vertical and longitudinal directions, downstream compound weirs are varied with the variation of the upstream water head, the downstream water depth, the compound weir model, and the bed materials.

***Conclusions:***

In this study, a series of laboratory experimental runs were conducted in order to investigate the effect of upstream water head, weir downstream water depth, bed material, and the weir model on the downstream velocity distributions in vertical and longitudinal directions. The following conclusions are obtained:

The discharge coefficient, $C_d$ values obtained from the experimental runs performed on the compound weirs has have the same values of the pervious studies.

Increasing the upstream water head results in increasing the downstream velocities at vertical and longitudinal directions.

Oppositely, the velocities downstream the weir decrease as the downstream water depth increase.

Also, as the weir model with upper part angle increases, the velocities decreases in their values.

It was found that, the flume plastic bed gives larger velocities than sand bed.

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