Experimental Study of Height and Surface Roughness Effects of Crump Weirs on Over Flow Characteristics

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Abstract:

In the different fields of hydraulics, environmental, irrigation, and chemical engineering, weirs are the most widely used hydraulic structures as flow measuring and flow control devices in open Channels. Conventional rectangular, triangular, and trapezoidal weirs are among the oldest weirs. The concern of this paper is to study the effect of height and surface roughness(that coming from different of construction materials)of crump weirs on discharge coefficients (C_d) under different flow conditions.

This work was conducted in experimental flume by using three sizes of crump weir and three types of surface roughness. The obtained results show that C_d values will increase with increasing flow rate as well as with decreasing in crump height; an increase in surface roughness of crump weir can makes great reduction in C_d value. (The water level to weir height) h/P effect on C_d values increase with increasing in crump weir height. An empirical relation was obtained to estimate the coefficient of discharge C_d under different height and surface roughness of crump weirs.

Key words: weir, roughness, surface, flow.

الخلاصة:

في مختلف حقول الهندسة الهيدروليكيه والبيئيه وهندسة الري والهندسة الكيميائية، تعتبر السدود الغاطسة من اكثر المنشأت الهيدروليكية استخداما لقياس التصريف والسيطرة على الجريان في القنوات المفتوحه . السدود الغاطسة المستطيلة ،المثلثة, او الشبه المنحرف من الاشكال والانواع المتعارف عليه كثيرا والمستخدمة منذ القدم . في هذا البحث تم دراسة تأثير ارتفاع وخشونة السطح (الناتجه من استخدام مختلف المواد الانشائية في التنفيذ (للسدود العريضة) دمدم(الشكل على معامل التصريف (C_d) عند ظروف جريان مختلفة.

تضمن العمل إجراء تجارب مختبرية باستخدام ثلاث سدود بارتفاعات مختلفة ولكل موديل تم استخدام ثلاث انواع من الخشونة لسطح السد. بينت النتائج المستحصلة ان قيم معامل التصريف سوف تزداد بزيادة التصريف وتقل بنقصان ارتفاع السد، كذلك وجد ان زيادة خشونة السطح تعمل على نقصان واضح في قيم معامل التصريف (C_d) . ووجدت معادلة وضعية لتقدير قيم معامل التصريف للسدود C_dعلى قيم P/h (تاثير منسوب الماء الى ارتفاع السد) تحت ظروف جرى ان مختلفة.

الكلمات المفتاحية : السدود الغاطسة ، الخشونة ، السطح ، الجريان.

1.Introduction

Weirs are the most commonly used device in channels for flow measurement and flow regulation due to its simplicity. Conventional rectangular, triangular and trapezoidal weirs are among the most common oldest types of weirs, progress broad-crested weir, crump weirs (special type of broad crested weir)are started to use in hydraulic engineering. The advantages of the crump weir shape are the stable overflow pattern compared to sharp-crested weirs, the ease to pass floating debris and the simplicity of design. A form of weir with a precise triangular profile often used for discharge monitoring. The Crump section flat-vee weir is favored by hydrometrics' because of the accuracy and range of flow measurement, but is disliked by fisheries officers because it can present a barrier to fish migration. [Rickard *et.al.*2003].

It is very important to investigate the behavior of the flow over the crump weir. A few number of studies have been devoted to the flow over this type of weirs, [Bos ,1989] was the first to study the flow characteristics of trapezoidal profile weirs systematically. He conducted a series of experiments on these types of weirs with both upstream and downstream side slopes. The discharge coefficient was determined for free flow conditions using different discharge values.

[Kandaswamy and Rouse,1957] have done experimental investigations on terminal weirs and sills. The [U.S.B.R,1948] studied of crests for over fall dams. [Prakash. and Shivapur,2004] gave an expression for the discharge coefficient of the sharp-crested inclined inverted V-notch weir .

[Ganapathy *et. al*. 1964] established design curves for the variation of the discharge coefficient with the head and the skew angle. [Mohapatra ,1964] carried out an investigation to obtain the discharge coefficient for oblique terminal weirs. [Muralidhar,1965] conducted experiments on broad-crested skew weirs.

[Sarginson ,1972] had conducted investigations on circular weirs and showed that the discharge coefficient C_d was close to and usually larger than unity, and it is primarily a function of the ratio of upstream head to crest radius (H_W/R). [Ramamurthy et. al.1988] studied the flow characteristics of rectangular broad-crested weirs with vertical upstream walls under free flow and submerged flow conditions. The study was focused on examining the effects of rounding of the upstream top corner of the weir on flow surface profile, bed pressure profile, and discharge characteristics. Ramamurthy and Vo,1993] tried to improve the discharge coefficient by providing different upstream and downstream slopes for circular-crested weirs .[Keshava and Shesha ,1994,1996b] presented a general numerical optimization procedure to obtain the proportionality range for any sharp-crested weir to develop any type of head-discharge relationship. [Keshava and Shesha,1996a] presented a general algebraic optimization procedure to obtain the linear characteristics for an inverted semicircular weir. Chanson and Montes,1998] described experimentally the flow over circular weirs under different flow conditions that the overflow is characterized by nape adherence on the downstream cylinder face and over flow properties are significantly affected by the upstream flow conditions. [Liu *et. al*.,2002] investigate numerically and experimentally the flow over semicircular weir.

They found that most of the experimental works that have been performed towards the understanding of the flow characteristics over the weirs and also the determination of the coefficients of discharge under different flow conditions, without the consideration of the effect of surface roughness of the weir on flow properties. In this paper experimental work for a crump weir is performed, in order to find out the effect of height and surface roughness on discharge coefficient and flow characteristics over the weir and it can be considered as the first investigation on this type of weir (crump weir).

2. Experimental Setup and Procedure

The experiments were conducted in a horizontal rectangular flatbed flume 17.0 m long, 0.5m wide and 0.5m height. The flume has glass-sided walls and smooth galvanized flatbed. A rectangular sharp-crested weir 35cm height and 30cm width was fixed at 3.7m downstream from the flume inlet, the weir was calibrated and used as a measuring device for the actual flow. This experimental setup is shown in Figure(2).

The flume was provided with various screens upstream and downstream of the sharp-crested weir in order to improve the approach flow. Three different sizes with heights (P=10cm,15cm,20cm) ,(large angle α= 26.5°, small angle β =11.3°) were used as a crump weir models. For each type of crump three types of surface roughness were used. The first one was a smooth PVC , the second one is coated with a uniform sand D_{50} =0.72 mm (D_{50}=is the sieve diameter in which 50% of material are finer), while the third is covered by gravel of D_{50}= 3.6 mm .Nine models where used to conduct the experimental work with bed horizontal distances(a=30.6, 26.5, 40.1)cm,(b=75, 50, 100)cm as shown in

Figure (1). In each run the selected model was inserted along the width of the flume at a distance 7.6m downstream from the sharp weir, then the pump started at desired flow rate and after the flow stability was achieved the water surface level upstream and above the weir model were measured using point gauge. The rate of the supplied flow at each experiment was controlled by an electrical board and measured by the sharp-crested weir. Figure(3) shows the water profile above the crump weir for roughness type (3) and P=15cm . For each type of the crump weir a series of tests under different flow rates were conducted. A total of 45 runs were conducted at the experimental work.

3. Theoretical Aspects:

Weirs are elevated hydraulic structures used to measure flow and/or to control the water elevation at outflows from basins and channels[Chin,2006]. The crump weir has a triangular profile as is shown in Figure 1. There are two different types of flow conditions: the modular flow condition, and the non-modular flow condition.

Modular Flow occurs when the weir operates under owned, with high downstream water level low Figure (4). In this condition, the upstream head is not affected by the downstream head; therefore it is possible to determine the flow rate by taking a single measurement of upstream head [John *et,al.*,1982].

$$Qm = C_{d}.\sqrt{g}.b.H_0^{\frac{3}{2}} \qquad \text{.........(1)}$$

Where:

Q_m = Flow rate for modular flow (m^3/s)

C_d = Modular discharge coefficient

g = Gravity (m/s^2)

b = Breadth of weir (m). b = 0.5 m

H_o = Total Head upstream of weir crest (m).

H_1 = Total Head downstream of weir crest (m).and

$$H = y + \frac{v^2}{2g} \qquad \text{.........(2)}$$

While ,modular flow occurs when the weir operates drowned, with high downstream water level. Figure (5). In this condition, a single measurement of upstream head is not adequate to determine the actual flow because the upstream head is affected by changes in the downstream head. Then, a dimensionless reduction factor is required to correct the non modular flow: $f = Q/Q_m$,

where Q = Flow rate for Non-Modular Flow (m^3/s),C_d is the discharge coefficient. It equals unity for an ideal flow condition. By using the Eq.1 and data obtained from the experimental work the values of C_d for each weir under different rates of flow has been calculated in order to explore the effect of height and surface roughness of crump weir on the value of the C_d.

4. Effect of Discharge, Height of Weir and Surface Roughness on C_d

To illustrate the variation of C_d values with the discharge, the values of C_d are plotted against the unit discharge for different weir heights under the same surface roughness as shown in Figures(6, 7 and 8) . It's evident from these Figures that there is an increase in C_d values with the increase of the rate of the flow. These Figures show also, that the C_d values vary inversely with the weir height. To find out the effect of weir surface roughness on C_d, the values of C_d are plotted as a function of the discharge for the same height of the weir but under different surface roughness as shown in Figures (9, 10 and 11).

These figures show that the C_d values are decreases with the increase in surface roughness and this attributed to the fact that an increasing in roughness of surface will lead to increase in the head of the water, and according to Eq.1: if the discharge has fixed at constant value, any increase in water level value will result in a reduction in C_d value.

To clarify numerically the effect of discharge, weir height and surface roughness on C_d value, the percentage of changes in C_d values with the percentage increase in discharge, weir height, and surface roughness were calculated as shown in Tables 1, 2, and 3,respectively.

Table 1 shows that an increase in the discharge of (3.1904 %) led to an increase in the C_d value of (1.8867, 2.0571, 2.7195) % for weirs heights10 cm, 15 and 20 cm, respectively for smooth surface weirs. While for those weirs coated by sand of D_{50}=0.72 mm the rates of the increase in C_d were 1.9042% , 1.9172%, 2.5418% and for weirs coated by gravel D_{50}=3.6 mm the rates of increase in C_d were 2.0509%, 2.0972%,2.5557%.

Table 2 shows the rate of decrease in C_d value due to increase in weir height. Generally, it seems that an increase in weir height from 10 cm to 15cm (50%increase) make a reduction in C_d value about 32.51 %. While an increase in weir height from10 cm to 20 cm (100% increase) reduce C_d values about47.96 % .

Table 3 shows that for the same weir and under equal flow rate an increase in surface roughness of the weir from D_{50}= 0mm (PVC) to D_{50}= 0.72 mm makes a reduction in C_d value around 1.81%(as an average value), while an increase from D_{50}= 0mm to 3.6 mm makes a reduction about 3.64% . Generally this means that an increase in surface roughness of weir make a slight reduction in C_d values.

5. Variation of C_d with (h/P)

The dimensional analysis for the variables affecting C_d value of weirs [19] shows that the value (h/p) (Where h is the head of the water above the weir ,P is the height of the weir), has a greatest influence on C_d value. The calculated values of h/P are plotted against the C_d values for each weir and for each surface roughness's as shown in Figures (12,13 and 14). These figures show that C_d value increases with increasing in h/P values for all cases. Also it's evident from these figures that the gradient of the curve fit the points are decrease with increase in weir height, this means that the effect of h/P on C_d values will increase with the increase in weir height. The data obtained from the experimental work are used to obtain a general empirical equation to calculate the discharge coefficients of circular crested weirs under different surface roughness. The nonlinear regression analysis is used for this purpose. The obtained equation was in the following form.

$$C_d = 0.62(\frac{h}{p})^{0.53} + 0.68(\frac{p}{D50})^{0.33} \quad \text{.........(3)}$$

For limitation: 10 > P > 20 , 0.1 > H > 0.54

6. Effect of weir height and surface roughness on head of water above the weir

In order to find the rate of change in the head of water above the crump weir under different conditions the values of h are plotted against the rate of the flow for each height of the weir and for each surface roughness as shown in Figures (15, 16, and 17). From principle of continuity equation, for constant width channels the depth of flow increase with increase in the discharge. These figures clearly show this point. Generally an increase in weir height from 10 cm to 20 cm leads to an increase in h value. This means that under the same rate of the flow large height make high level than small one.

To explain the effect of surface roughness on water head the values of h are plotted against discharge for different roughness values and weir heights as shown in Figure 18. For height P=10cm as an example, its clear from the Figure that there is an increases in h values with increase in roughness of the weir surface and this attributed to restricting action of surface roughness to the following flow.

To illustrate the rate of effect of surface roughness on head of water behind the crump weir the percentage of increase in h values were calculated for each crump weir as shown in Table 4.

Table 4 shows that the effect of increase in surface roughness on h values are large for small weirs than large ones, the rate was (3.906-3.937)% to (0.910-1.184)% for weir height 10 cm and (0.555- 3.333)% to (2.982—2.999)% for weir height 15cm, and (0.545-3.454)% to (1.890-1.221)% for weir height 20 cm.

7. Conclusions

Based on the analysis of the experimental observations, the following conclusions were made:

- There is an increase in C_d values with the increase in the flow rate, an increase in discharge(319.04 %) led to increase in C_d value (188.67, 205.71, 271.95) % for weirs heights 10 cm, 15 and 20 cm, respectively for smooth surface weirs. While for weir coated by sand of D_{50}=0.72 mm the rates of the increase in C_d were 190.42% , 191.72%, 254.18% and for weirs coated by gravel D_{50}=3.6 mm the rates of increase in C_d were 205.09% , 209.72%,255.57%.
- There is an increasing in C_d values with the decrease in the weir height under the same surface roughness. It was found that an increase in weir height from 10 cm to 15cm (50% increase) make a reduction in C_d value about 32.51 % .While an increase in weir height from 10 cm to 20 cm (100% increase) reduce C_d values about 47.96 %.
- C_d values decreases with the increase in the surface roughness. Results show that for the same weir height under equal flow rate .An increase in the surface roughness of the weir from D٠ =٥.mm (PVC) to D٠,٧٢ =٥.mm makes a reduction in C_d value around 1.81%(as an average value), while an increase from D =٥٠ ٠mm to 3.6 mm makes a reduction about 3.64%.
- The effect of h/P on C_d values will increase with the increase in weir height.
- For the same discharge the head of the water increases with increase in weir height. The result shows that an increase in height of the weir from 10 cm to 20cm leads to an increase in the h value around 71.8%.
- The effect of increase of surface roughness on h values will be more on small heights of the crump weir than large ones, the rates were (3.906-3.937) to (0.910-1.184) for weir height 10 cm and (0.555- 3.333) to (2.982—2.999) for weir height 15cm, and (0.545-3.454) to (1.890-1.221) for weir height 20 cm.

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Table 1: The percentage of increase of the C_d with percentage of increase of discharge

Coated D_{50}= 3.6mm		CoatedD_{50}= 0.72mm		Smooth(PVC)		% increase in q	q $m^3/s/m$	Weir Height (cm)
% increase in C_{d3} values	***C_{d3}	% increase in C_{d2} values	**C_{d2}	% increase in C_{d1} values	*C_{d1}			
	C_{d1-3}		C_{d1-2}		C_{d1-1}			P_1=10
	0.2406		0.2628		0.2765		0.021	
35.86	0.3269	29.61	0.3380	29.47	0.3580	42.81	0.030	
69.03	0.4067	55.21	0.4079	50.09	0.4150	76.19	0.037	
116.62	0.5212	88.62	0.4957	75.76	0.4860	119.04	0.046	
155.81	0.6155	122.98	0.5860	109.90	0.5804	166.66	0.056	
184.58	0.6847	158.82	0.6802	136.78	0.6547	209.52	0.065	
205.09	0.7435	190.42	0.7685	188.67	0.7982	319.04	0.088	
	C_{d2-3}		C_{d2-2}		C_{d2-1}			P_2=15
	0.1619		0.1645		0.1672		0.021	
37.72	0.2230	37.23	0.2259	38.33	0.2313	42.81	0.030	
68.80	0.2740	66.16	0.2744	68.68	0.2787	76.19	0.037	
102.92	0.3309	100.67	0.3334	105.89	0.3359	119.04	0.046	
139.94	0.3920	139.45	0.3939	146.17	0.3999	166.66	0.056	
173.39	0.4411	169.42	0.4432	182.44	0.4572	209.52	0.065	
209.72	0.4723	191.71	0.5029	217.46	0.5308	319.04	0.088	
	C_{d3-3}		C_{d3-2}		C_{d3-1}			P_3=20
	0.1260		0.1277		0.1300		0.021	
34.12	0.1690	33.9	0.1711	40.00	0.1820	42.81	0.030	
58.57	0.2398	56.38	0.2366	61.78	0.2350	76.19	0.037	
96.58	0.2414	91.86	0.2514	97.46	0.2567	119.04	0.046	
148.41	0.3004	143.06	0.3104	153.46	0.3295	166.66	0.056	
150.19	0.3102	146.38	0.3223	166.30	0.3462	209.52	0.065	
255.57	0.4014	254.18	0.4523	276.76	0.4898	319.04	0.088	

*C_{d1-1}:discharge coefficient for P_1=10cm, smooth PVC.
C_{d1-2}:discharge coefficient for P_1=10cm, CoatedD_{50}= 0.72mm.
C_{d1-3}:discharge coefficient for P_1=10cm, CoatedD_{50}= 3.6 mm.
**C_{d2-1}:discharge coefficient for P_2=20cm, smooth PVC.
C_{d2-2}:discharge coefficient for P_2=20cm, CoatedD_{50}= 0.72mm.
C_{d2-3}:discharge coefficient for P_2=20cm, CoatedD_{50}= 3.6 mm.
***C_{d3-1}:discharge coefficient for P_3=30cm, smooth PVC.
C_{d3-2}:discharge coefficient for P_3=30cm, CoatedD_{50}= 0.72mm.
C_{d3-3}:discharge coefficient for P_3=30cm, CoatedD_{50}= 3.6 mm.

Table 2: The percentage of decrease of the C_d values with the increase of the weir height

P=20cm(increase 100%)		P=15cm(increase 50%)		P=10cm	Unit discharge $q(m^3/s/m)$	
Percentage increase $(C_{d3}-C_{d1}/C_{d1})$ *100%	$C_{d3(1,2,3)}$	Percentage increase $(C_{d2}-C_{d1}/C_{d1})$ *100%	$C_{d2(1,2,3)}$	$C_{d1(1,2,3)}$		D_{50}(mm)
-52.98	0.1300	-39.52	0.1672	0.2765	0.021	D_{50}=0
-49.16	0.1820	-35.39	0.2313	0.3580	0.030	
-47.37	0.2350	-32.84	0.2787	0.4150	0.037	
-47.18	0.2567	-31.88	0.3359	0.4860	0.046	
-45.22	0.3295	-31.09	0.3999	0.5804	0.056	
-43.12	0.3462	-30.50	0.4572	0.6547	0.065	
-38.63	0.4898	-30.16	0.5308	0.7982	0.088	
						D_{50}=0.72
-51.40	0.1277	-37.40	0.1645	0.2628	0.021	
-49.37	0.1711	-34.16	0.2259	0.3380	0.030	
-49.23	0.2366	-32.74	0.2744	0.4079	0.037	
-49.21	0.2514	-32.72	0.3334	0.4957	0.046	
-47.03	0.3104	-32.71	0.3939	0.5860	0.056	
-42.61	0.3223	-32.64	0.4432	0.6802	0.065	
-41.14	0.4523	-32.56	0.5029	0.7685	0.088	
						D_{50}=3.6
-48.63	0.1260	-32.70	0.1619	0.2406	0.021	
-48.30	0.1690	-31.78	0.2230	0.3269	0.030	
-43.03	0.2398	-31.62	0.2740	0.4067	0.037	
-41.68	0.2414	-30.57	0.3309	0.5212	0.046	
-41.49	0.3004	-30.31	0.3920	0.6155	0.056	
-41.21	0.3102	-30.27	0.4411	0.6847	0.065	
-40.01	0.4014	-29.21	0.4723	0.7435	0.088	
-47.96		-32.51	average			

Table 3: The percentage of decrease in Cd values with increase in weir roughness.

Coated D_{50}= 3.6mm		Coated D_{50}= 0.72mm		PVC	Unit discharge $q(m^3/s)$	Weir height (cm)
$(C_{d3}-C_{d1}/C_{d1})$ *100%	$C_{d3(1,2,3)}$	$(C_{d2}-C_{d1}/C_{d1})$ *100%	$C_{d2(1,2,3)}$	$C_{d1(1,2,3)}$		
-12.98	0.2406	- 5.95	0.2628	0.2765	0.021	P_1=10
-8.68	0.3269	-5.58	0.3380	0.3580	0.030	
-8.00	0.4067	-1.9	0.4079	0.4150	0.037	
-7.24	0.5212	-1.7	0.4957	0.4860	0.046	
-6.04	0.6155	-0.96	0.5860	0.5804	0.056	
-4.58	0.6847	-0.89	0.6802	0.6547	0.065	
-3.85	0.7435	-0.72	0.7685	0.7982	0.088	
						P_2=15
-3.58	0.1619	-2.61	0.1645	0.1672	0.021	
-3.16	0.2230	-2.33	0.2259	0.2313	0.030	
-1.98	0.2740	-1.74	0.2744	0.2787	0.037	
-1.48	0.3309	-1.54	0.3334	0.3359	0.046	
-1.67	0.3920	-1.50	0.3939	0.3999	0.056	
-1.52	0.4411	-1.06	0.4432	0.4572	0.065	
-1.22	0.4723	-0.25	0.5029	0.5308	0.088	
						P_3=20
-3.07	0.1260	-1.76	0.1277	0.1300	0.021	
-3.14	0.1690	-1.98	0.1711	0.1820	0.030	
-1.04	0.2398	-1.68	0.2366	0.2350	0.037	
-0.96	0.2414	-1.56	0.2514	0.2567	0.046	
-0.83	0.3004	-0.79	0.3104	0.3295	0.056	
-0.73	0.3102	-0.90	0.3223	0.3462	0.065	
-0.69	0.4014	-0.65	0.4523	0.4898	0.088	
-3.64		-1.81	Average			

Table 4: The percentage of increase in h values with the increase in weir roughness.

D_{50}=3.6mm		D_{50}=0.72mm		Smooth PVC	Unit discharge $q(m^3/s/m)$	Weir height (cm)
$(h_3- h_{1/} h_1)*100$ %	$h_3(m)$	$(h_2- h_{1/} h_1)*100$ %	$h_2(m)$	$h_1(m)$		
3.937	0.142	3.906	0.133	0.128	0.021	P_1=10
3.571	0.145	3.428	0.142	0.140	0.030	
3.448	0.150	3.068	0.148	0.145	0.037	
2.761	0.154	2.401	0.152	0.147	0.046	
2.061	0.156	1.666	0.151	0.150	0.056	
1.432	0.159	1.378	0.153	0.148	0.065	
1.184	0.162	0.910	0.160	0.157	0.088	
						P_2=15
3.333	0.186	0.555	0.181	0.180	0.021	
3.278	0.189	2.112	0.188	0.183	0.030	
3.174	0.195	2.116	0.193	0.189	0.037	
2.635	0.195	2.631	0.195	0.190	0.046	
2.990	0.200	2.880	0.198	0.202	0.056	
2.997	0.205	2.984	0.202	0.208	0.065	
2.999	0.227	2.982	0.210	0.232	0.088	
						P_3=20
3.454	0.232	0.545	0.230	0.220	0.021	
2.702	0.239	0.625	0.236	0.235	0.030	
1.887	0.241	1.265	0.240	0.237	0.037	
1.633	0.242	1.416	0.241	0.240	0.046	
1.439	0.245	1.826	0.244	0.242	0.056	
1.224	0.256	1.830	0.252	0.250	0.065	
1.221	0.258	1.890	0.255	0.253	0.088	

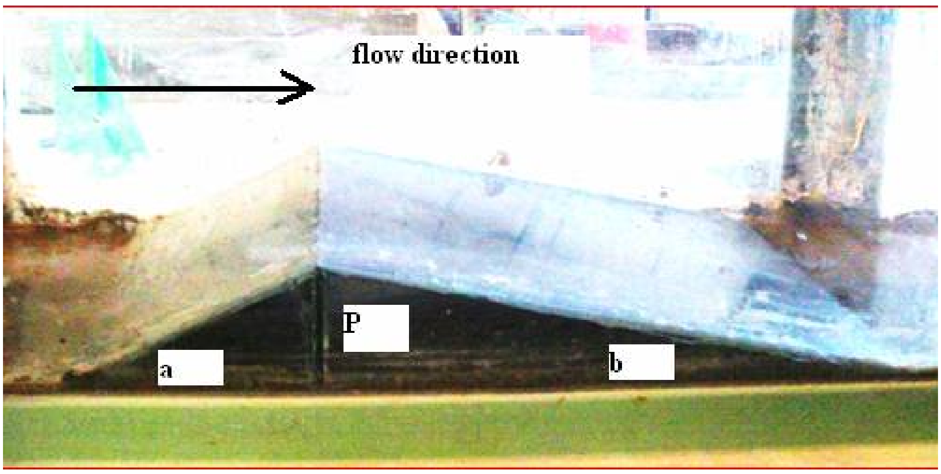

Figure 1: Schematic diagram of cramp weir model.

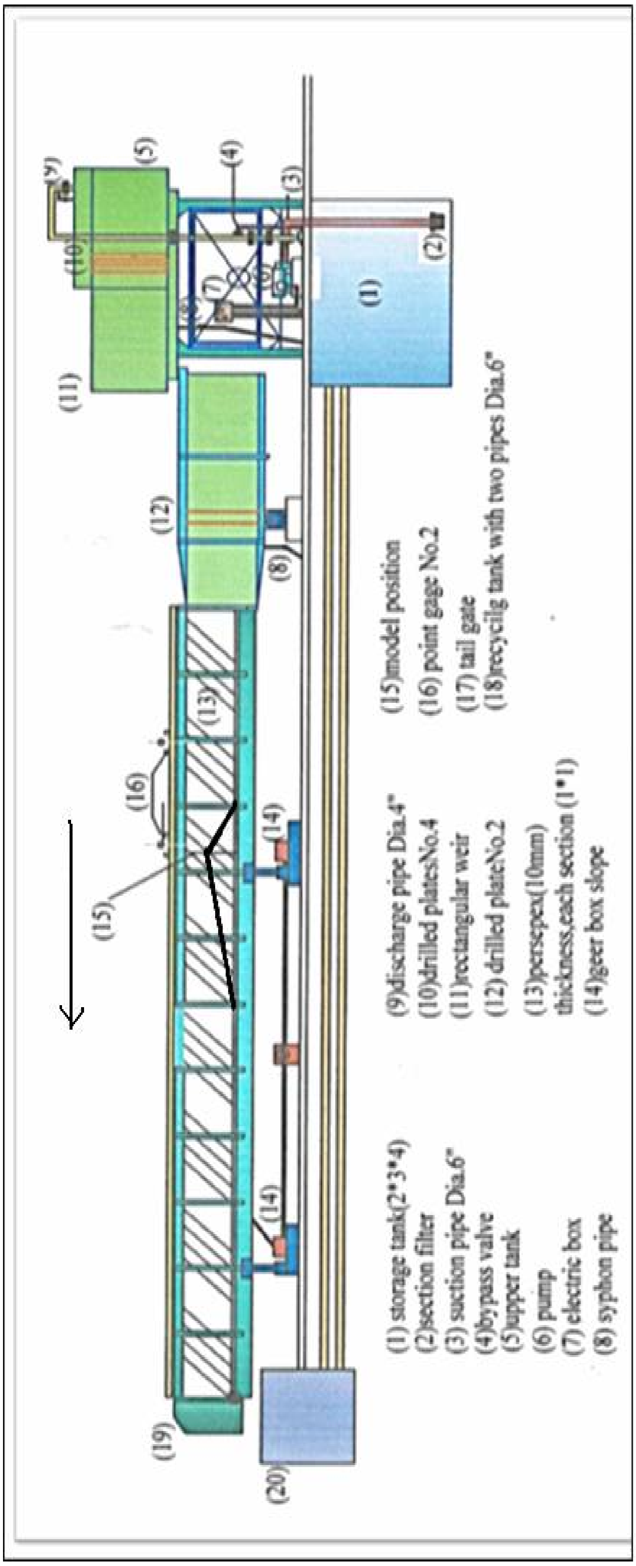

Figure2: Experimental setup used for conducting the experiments.

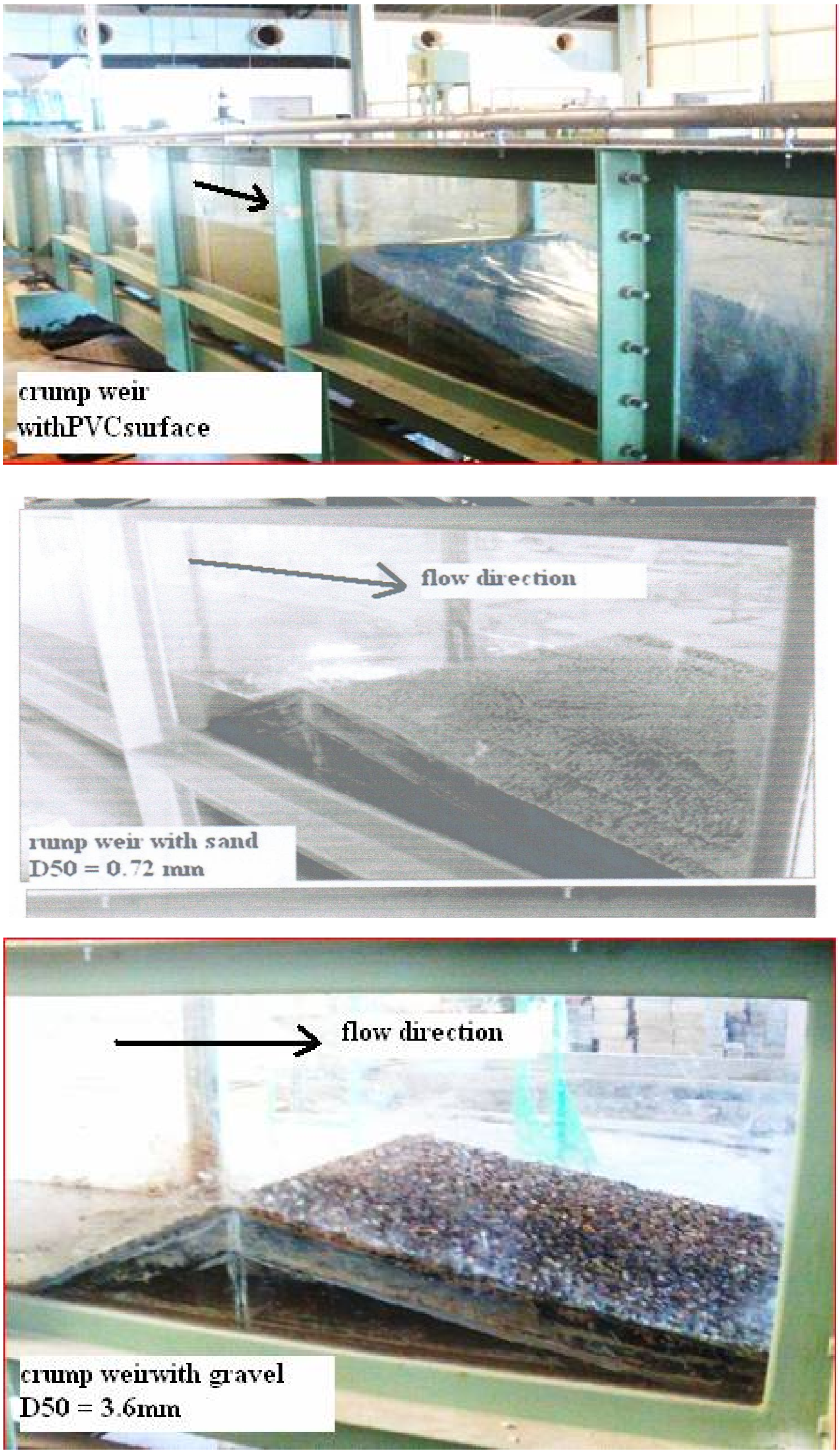

Figure.3: The flow over the Weir for three crump weir (height: 15 cm, PVC ,coated with sand D_{50} = 0.72 mm, coated with gravel D_{50} = 3.6mm).

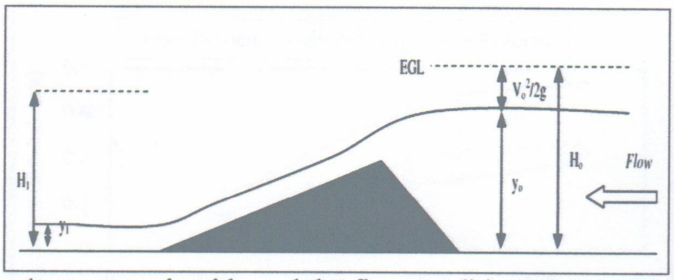

Figure4: crump weir with modular flow condition. [John et,al.,1982].

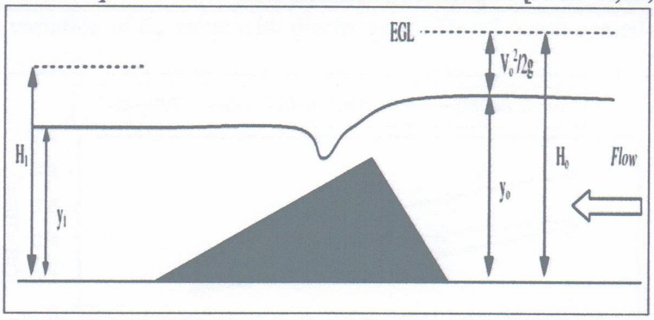

Figure5: crump weir with non-modular flow condition. [John et,al.,1982].

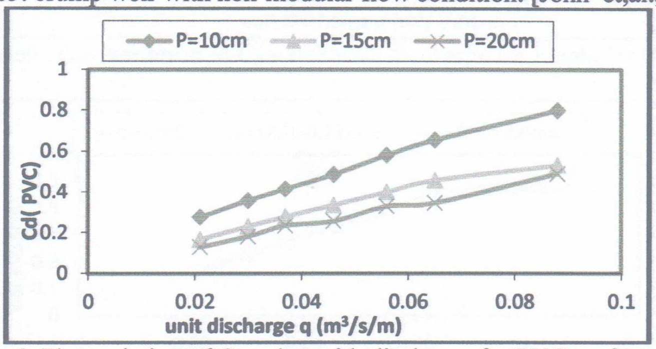

Figure6 :The variation of C_d value with discharge for PVC surface weir.

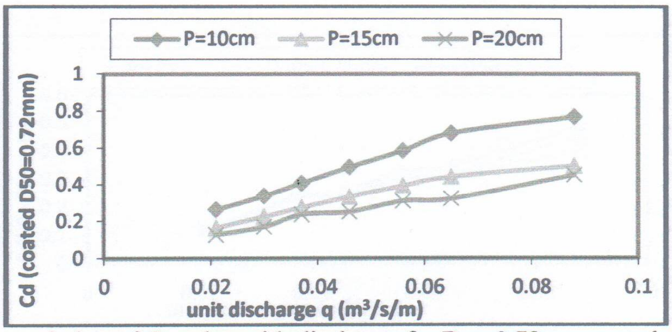

Figure7 :The variation of C_d value with discharge for D_{50}=0.72mm coated surface weir.

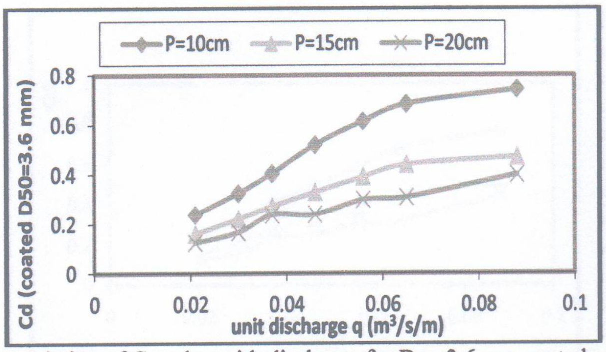

Figure8:The variation of C_d value with discharge for D_{50}=3.6 mm coated surface weir.

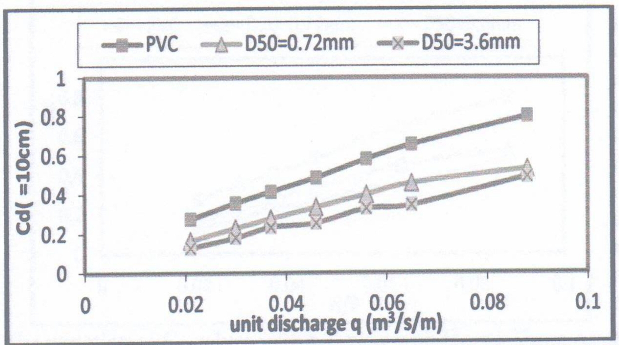

Figure9 :The variation of C_d value with discharge for height P=10cm.

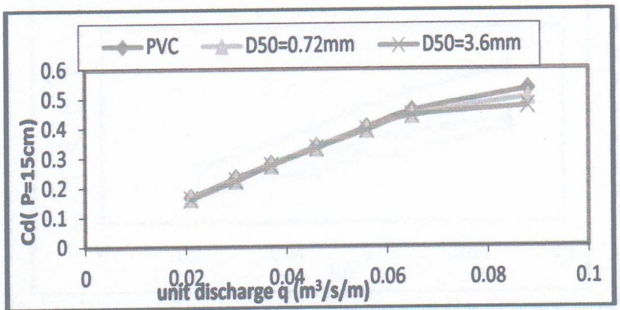

Figure10 :The variation of C_d value with discharge for height P=15cm.

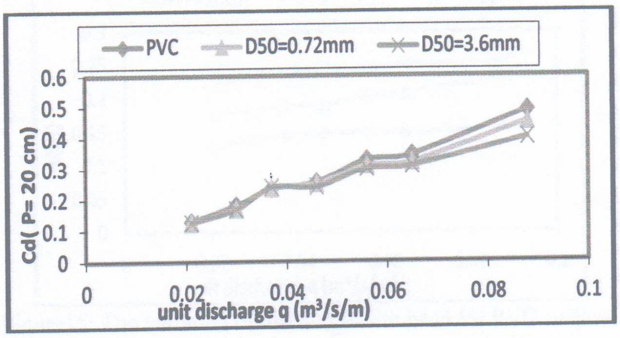

Figure11 :The variation of C_d value with discharge for height P=20cm.

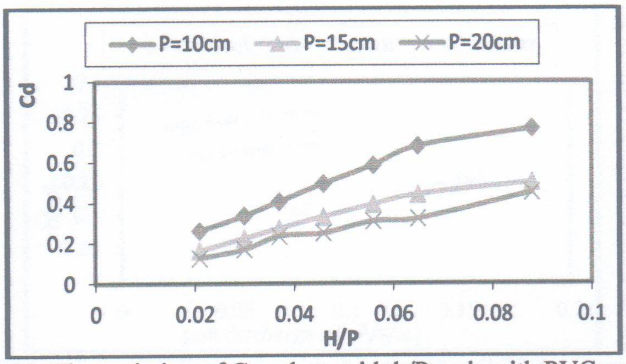

Figure12: The variation of C_d values with h/P weir with PVC surface.

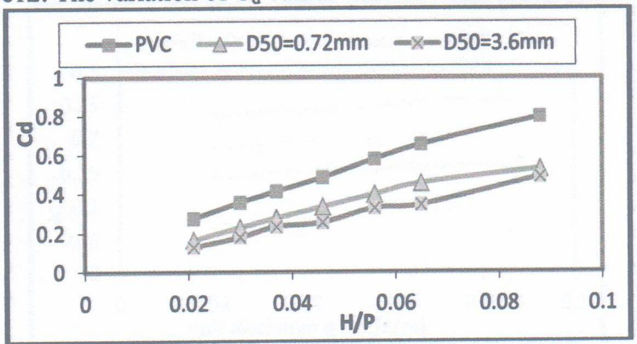

Figure13: The variation of C_d values with h/P weir with D_{50}=0.72mm coated surface.

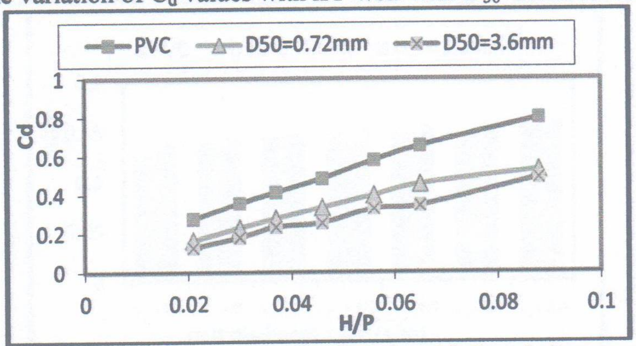

Figure14: The variation of C_d values with h/P weir with D_{50}=3.6 mm coated surface.

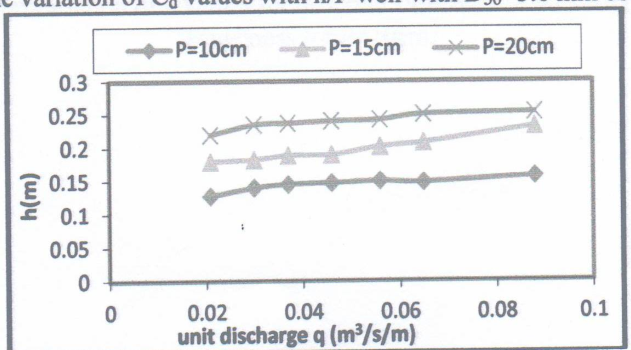

Figure15: The variation of discharge with head for PVC surface.

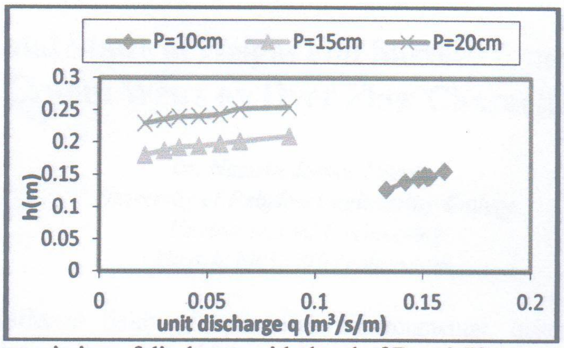

Figure16: The variation of discharge with head of D_{50}=0.72 mm coated surface.

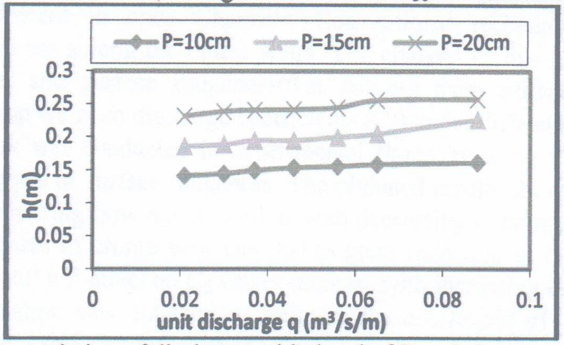

Figure17: The variation of discharge with head of D_{50}=3.6 mm coated surface.

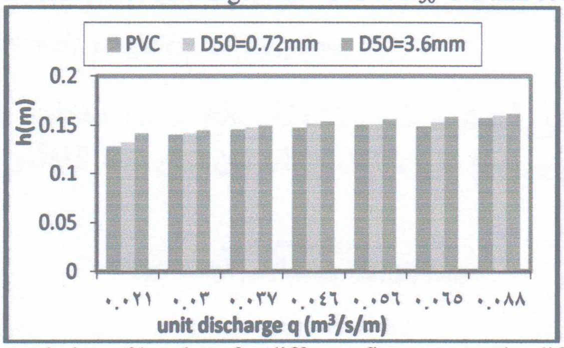

Figure18: The variation of h values for different flow rates at the different surface roughness for P=10cm.