Journal of Engineering and Development, Vol. 16, No.3, Sep. 2012 ISSN 1813- 7822

Effect of Channel Slope on Energy Dissipation of Flow for Single Step Broad –Crested Weirs

Sahad Salim Elyass
Assist. Lecturer
Technical College / Mosul

ABSTRACT

The effect of channel bed slope on energy dissipation of flow for single step Broad– Crested Weir was studied experimentally under free flow conditions. Five weir models were manufactured and tested , and one hundred twenty one experiments were conducted in a laboratory horizontal channel of 12m length, 0.5m width and 0.45m depth for a wide range of discharge. The experimental results showed that water surface profiles were smooth and continuous and had a descending trend from the point of measurement taking the shape of the weir with a steep drop near the downstream face of the weir. It was found that for the same ratio (P/P1) the channel slope effect (S) was inversely proportional on the energy dissipation. In addition, the effect of (He/P) did not appear when (P/P1 =1&1.2), while in the other weirs appeared. An empirical non-dimensional relation was obtained to determine the energy dissipation ratio in terms (He/p), (P/P1), (S) and (Fr_2) with high correlation coefficient.

تأثير ميل القناة على تبديد طاقة الجريان فوق الهدارات ذات القمة العريضة مفردة الدرجة

ملخص

يتناول هذا البحث دراسة تأثير ميل قعر القناة على تبديد طاقة الجريان فوق الهدارات ذات القمة الدائرية العريضة مفردة التدرج تحت حالات الجريان الحر مختبريا. ولتحقيق الغرض أعلاه تم إنشاء واختبار خمسة نماذج منها، و إجراء مائة وعشرون تجربة في قناة مختبرية أفقية ذات طول (12 م) وعرض (0.5 م) وعمق (0.45 م) ولمدى واسع من التصاريف. لقد أثبتت النتائج المختبرية بان أشكال سطح الماء الجانبية كانت سلسة انسيابية ومستمرة بالانخفاض من نقطة القياس أخذتا شكل الهدار ثم تهبط هبوطا شديدا بالقرب من مؤخر الهدار. ميل القناة (S) كان تأثيره يتناسب عكسيا على تبديد طاقة الجريان لنفس حالات (P/P1) . لم يظهر تأثير (He/P) لحالات (P/P1 =1&1.2) بينما كان له تأثير واضح في للنماذج الأخرى من الهدارات.تم استنباط علاقة وضعية لا بعدية بدلالة (He/p) ، (P/P1) ، (S) ، (Fr_2) وبمعامل ارتباط عالي.

INTRODUCTION:

The increasing need for storage of water calls for intensive efforts on the part of hydraulic engineers to develop express methods of weir design and construction. Water impounded behind dams, weirs, barrages and other major hydraulic structures is needed for irrigation, human needs and more recently for industrial purposes. [1]

Broad crested weirs are low cost and simple overflow structures widely used for flow measurements in field and laboratory channels. Moreover, these weirs have an advantage compared with other flow structures because of their high range of discharge and modular limit. [2]

Previous investigations on the characteristics of flow over broad-crested weirs were based on experimental measurements to obtain empirical equations for the estimation of discharge coefficients [9].

In recent years, the characteristics of flow over round–nosed broad crested weirs, step broad crested weirs and drops have attracted the attention of many investigators to obtain empirical equations for the estimation of discharge coefficients. [3];[4], Based on the boundary layer theory. [5]. [6] investigated in a laboratory study the stepped and non-stepped weirs in order to find their efficiency for dissipating flow energy. [7] Studied experimentally flow characteristics and energy dissipation over step round broad – crested weirs. A new performance was added to the weir, by making it as an energy dissipater and the experimental results of this study showed that energy dissipater increased up to 46%. Furthermore, the discharge coefficient C_d improved and got higher values in comparison with traditional weirs and [8] presented a method for predicting both subcritical and supercritical flow characteristics over drops. He also derived an empirical relation to estimate the relative energy loss.

Therefore, in this investigation, the main objective is to study the effect of channel slope on energy dissipation of flow for single step broad – crested weirs.

ENERGY DISSIPATION RATIO, E %

Apply energy equations between section (1) and section (2) in Fig. (1) .We gets:

$$E_1 = P_1 + H + \frac{V_1^2}{2g} \qquad \text{.. (1)}$$

$$E_2 = P_2 + h + \frac{V_2^2}{2g} \qquad \text{.. (2)}$$

$$\Delta E\% = \frac{E_1 - E_2}{E_1} * 100\ \% \qquad \text{.. (3)}$$

DIMENSIONAL ANALYSIS

The broad crested models were based on the following assumptions: flow upstream of weir is steady, sub-critical and two dimensional; the effect of flow surface tension is neglected. For rectangular broad crested weir assuming the critical flow on the weir, crest [10]
For a free flow over a single step broad–crested weir with rounded upstream corner, a functional relationship can be taking all the above parameters and written as follows.(see Fig(1)) :

$$f_1(E\%,\ q\ ,H_e, P, P_1, \mathrm{L}, \mathrm{L}_1, \mathrm{W}, R, \nu, g, \mathrm{S}) = 0 \quad \ldots\ldots\ldots (4)$$

Since, L; L_1,W , and R are fixed in this study then equation (4) can be rewritten as :-

$$f_2(E\%,\ q\ ,H_e, P, P_1, \nu, g, \mathrm{S}) = 0 \quad \ldots\ldots\ldots (5)$$

Using Buckingham Pi-theorem and after certain permissible manipulations, Eq. (5) becomes:

$$E\% = f_3\left(\frac{\mathrm{H_e}}{\mathrm{P}}, \frac{\mathrm{P}}{P_1}, R_e, \mathrm{F_{r_2}}, \mathrm{S}\right) \quad \ldots\ldots\ldots (6)$$

R_e = Reynolds number, and
Fr_2 = Froude number.

Reynolds number will have very large values and hence its effect will be very little, therefore, R_e can be dropped and Eq. (6) can be rewritten as:

$$E\% = f_4\left(\frac{\mathrm{H_e}}{\mathrm{P}}, \frac{\mathrm{P}}{P_1}, \mathrm{S}\ , \mathrm{F_{r_2}}\right) \quad \ldots\ldots\ldots (7)$$

EXPERIMENTAL SET- UP AND PROCEDURE:

THE FLUME

The experimental works of this study was carried out in a rectangular flume having a working length of 12 m with a cross section 0.5 m wide and 0.45 m depth. The sidewalls were of toughened glass with a number of Perspex panels incorporated. The flume bed was supported by steel under frame to permit accurate alignment .Two movable carriages equipped with point gauges were mounted on the rails for the measurements of vertical elevation at the top of channel sides. The channel was pivoted with jacking station for normal inclination

Water was circulated through the channel by an electrically driven centrifugal pump. .The flume was equipped with a downstream storage concrete tank from which the water drained by a pump through return pipe and supplied the water to a stilling inlet tank via which the water was gently passed to the flume .Discharge was measured by a pre-calibrated triangular sharp-crested weir installed in the inlet of the channel (Picture 1)

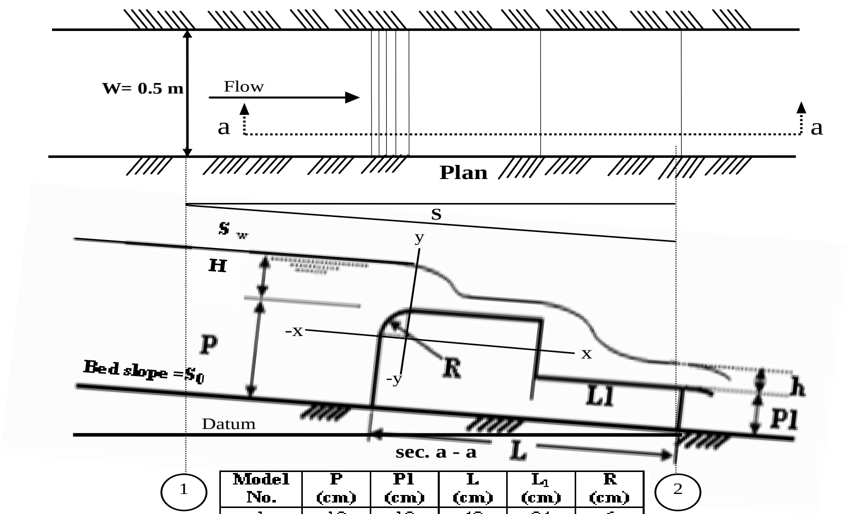
Picture (1) General view of the labroatory

CONSTRUCTION AND OPERATION OF WEIR MODELS:

Five weir models were manufactured and tested, in which the D/S crest height and angle channel slope were varied. These models can be classified into four groups based on the variation of channel slope (S) [group (1,2,3 and 4)(S = 0 , 0.001, 0.002 and 0.004)] . Each group included the testing of five models based on the variation of D/S weir height (P1) [model No.(1,2,3,4 and 5)(P1=(12,10,8,6 and 4 cm)] . Testing details are shown in table (1) and fig.(1). All models were manufactured from thermo-stone and well polished to smooth surfaces. To ensure stability and uniformity of water surface levels, models were placed on the bed of the flume at a distance 3.5 m D/S the flume inlet. The procedures started to supply different discharges over the weir models and all measurements were conducted at the centerline of the flume. In each test, the measurements along the weir models were conducted under the free flow conditions. In addition, free-falling nape at D/S step of models was fully aerated to prevent ventilation.

Table (1) Details of the tested weir models:

Model No.	P/P1	S	Run No.	He(cm)	Range of Flow Rate q (cm²/sec)	Fr_2	Range of E%
1	1	0	1 - 7	7.01 - 11.34	271.29 - 594.99	1.32 - 1.23	2.33 - 1.92
		0.001	8-13	5.17 - 10.72	208.68 - 558.71	1.42 - 1.01	4.46 - 4.14
		0.002	14-19	5.26 - 11.36	189.06 - 612.59	1.16 - 1.06	6.61 - 5.9
		0.004	20-25	5.37 - 11.61	198.62 - 643.99	1.18 - 1.08	10.86 - 9.01
2	1.2	0	26 - 31	4.34 - 11.57	138.51 - 623.31	1.91 - 1.35	10.84 - 9.62
		0.001	32 - 37	5.57 - 11.04	205.51 -584.58	2.15 - 1.64	8.7 - 7.86
		0.002	38 - 43	5.47 - 11.27	203.21 -616.15	2.13 - 1.52	9.67 - 9.07
		0.004	44 - 49	5.58 - 11.52	213.48 -647.73	2.17 - 1.67	13.26 - 11.67
3	1.5	0	50 - 55	4.95 - 10.5	170.61 -540.77	1.79 - 1.3	20.57 - 16.27
		0.001	56 - 61	5.57 -11.47	206.93 -623.31	2.33 - 1.89	14.45 - 10.73
		0.002	62 - 67	5.47 - 11.17	203.93 -612.59	2.3 - 1.83	17.15 - 13.23
		0.004	68 - 73	4.75 -11.61	167.38 -659.87	2.21 - 1.78	24.32 - 16.8
4	2	0	74 - 79	4.24 - 11.59	136.23 -637.78	1.61 - 1.29	35.62 - 25.7
		0.001	80 - 85	4.32 - 11.83	143.1 -662.1	1.64 - 1.3	36.68 - 26.66
		0.002	86 - 91	5.78 - 11.17	224.84 -617.58	1.93 - 1.76	31.45 - 22.38
		0.004	92 - 97	5.89 - 11.63	237.34 -674.85	1.92 - 1.77	34.34 - 24.1
5	3	0	98 - 103	4.85 - 11.37	165.78 -616.15	1.52 - 1.31	48.08 - 35.37
		0.001	104 - 109	5.57 - 10.83	208.68 -575.65	2.19 - 1.86	34.48 - 29.79
		0.002	110 - 115	6.51 - 10.85	268.28 -586.65	2.17 - 1.96	37.67 - 28.96
		0.004	116 - 121	5.06 - 10.86	186.65 -599.89	2.47 - 2.01	42.22 - 30.75



Model No.	P (cm)	Pl (cm)	L (cm)	L_1 (cm)	R (cm)
1	12	12	48	24	6
2	12	10	48	24	6
3	12	8	48	24	6
4	12	6	48	24	6
5	12	4	48	24	6

Figure (1) Locations of grid points for the water head measurements

RESULTS AND DISCUSSION

The experimental results of measurements of water surface profiles along the centerline of the channel show a descending trend from the point of measurement taking the shape of the weir with a steep drop near the downstream face of the weir. Figures. (2,3&4) show the center line water surface profiles of Y versus X for all test runs of weir model No.(3) [P/P1=1.5 , S = 0001., 0.002 & 0.004] , where Y is the depth of flow above the crest and X is the horizontal distance measured from the upstream of the crest . Also figure (5) represents three dimensional flow water for (P/P1=1.5 , S=0.004 and q=167.38 cm^2/s).

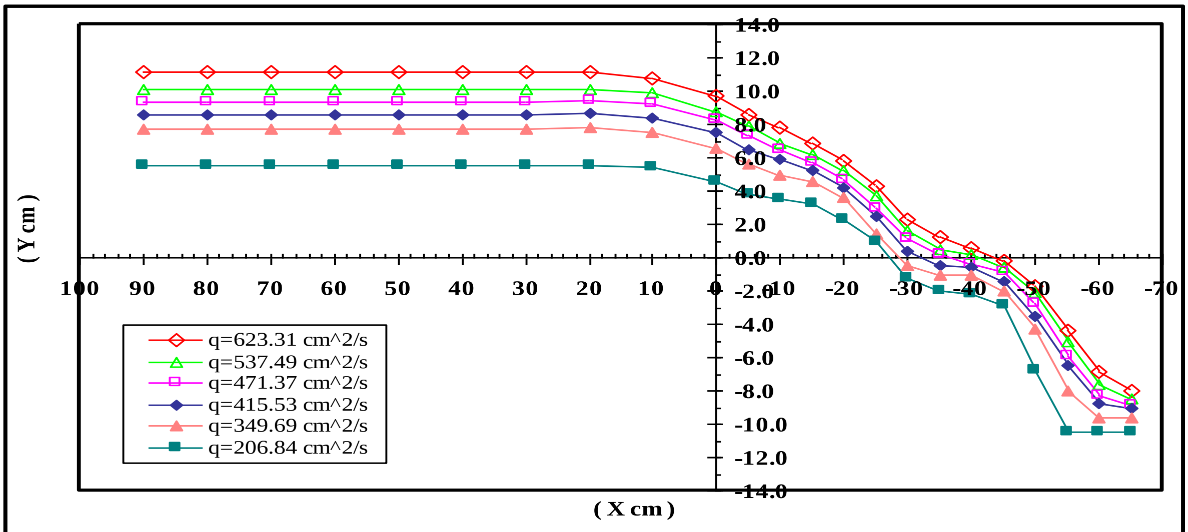


Figure (2) Variation of Y with X for all test runs of weir with (P/P1=1.5 and S=0.001)

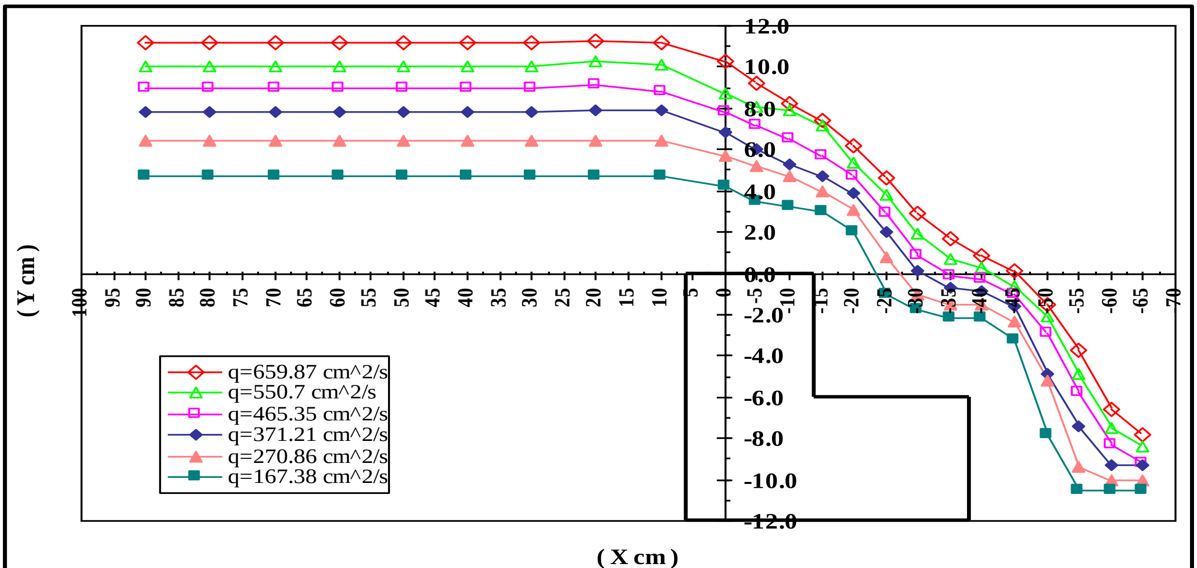


Figure (4) Variation of Y with X for all test runs of weir with (P/P1=1.5 and S=0.004)

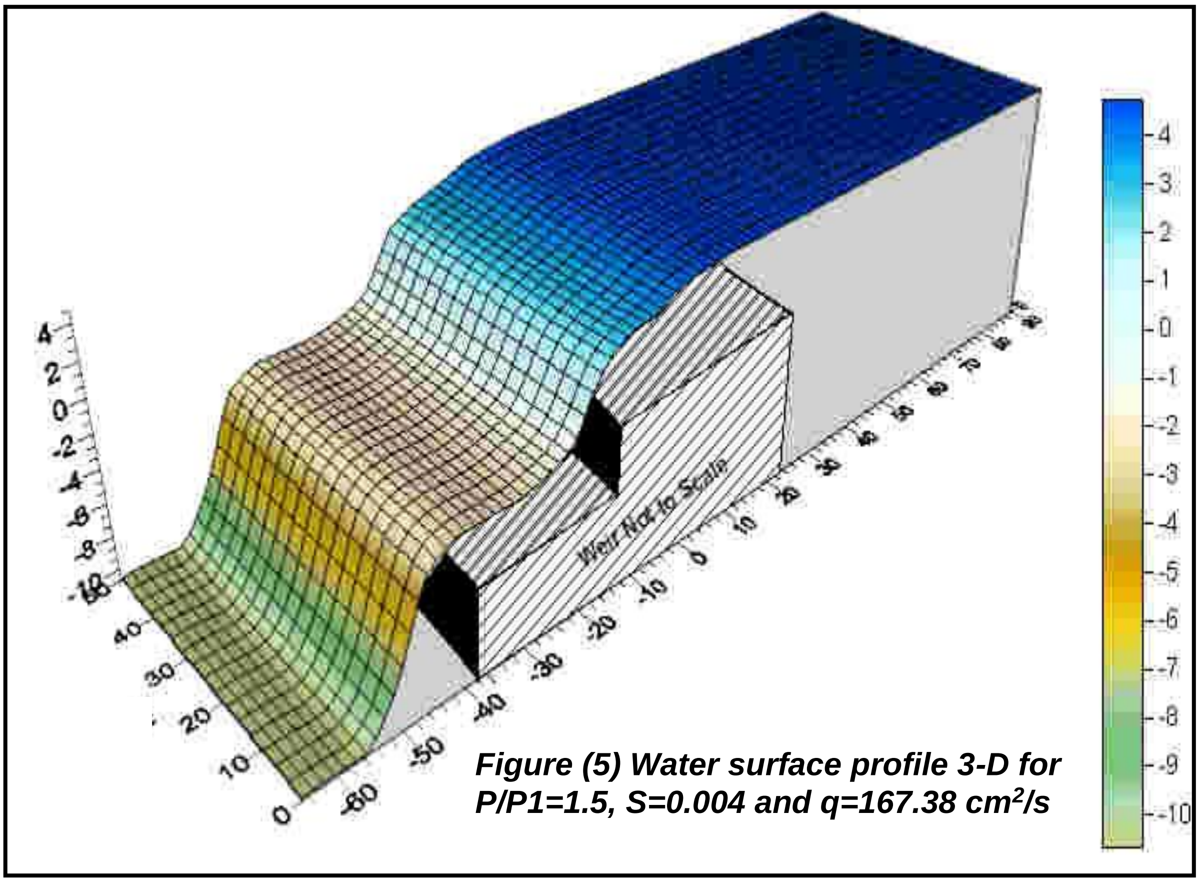


Figure (5) Water surface profile 3-D for P/P1=1.5, S=0.004 and q=167.38 cm^2/s

Figure (6) represents the relation between (He/P) with (E %) for all slopes which showed that when (S=0 and 0.001) there was not any effect of (He/P) on (E %) because the variation of energy head U/S the weir was very little. The effect of (He/P) on (E %) started when the (S=0.002) and became more obvious at the (S=0.004) depending on the reverse effect to increase the slope on decreasing the energy dissipation . Figure (7) explains the relationship between (He/P) with (E %) for different slopes. The effect (P/P1) began to appear with little effect at (S=0, 0.001, and 0.002) but did not exceed about 2% while in the case of (S=0.004) the reverse effect obviously appeared and the difference in (E %) ratio was more than 3%. Figure (8) explains the clear effect of (He/P) on (E %) for all slopes .The (E %) reached between the first and the last reading to about 6%. In figure (9) , the effect of reverse slopes on (E %) started to vanish gradually. However, the larger reverse effect of (He/P) on (E %) and the difference between the first and last reading reached to nearly 15%. However, in figure (10) when (P/P1=3) for the (S=0.001, 0.002, 0.003 and 0.004) the effect of the slope decreased clearly in this figure and showed the larger reversed effect when (S=0) and that was reasonable because of decreasing the flow velocity in D/S causing an increment in ratio of (E %). At figures (11,12) when (S=0 and 0.001) respectively there was not any effect of the (E %) for (P/P1=1, 1.2 and 1.5). While (P/P1=2 and 3) were seen , closely effective in energy dissipation due to starting the effect of slope obviously more than the effect of (P/P1) .In figures (13&14) the effect of (He/P) on (E %) when (P/P1=1 and 1.2) did not appear for the same reason as in figures (11 & 12) , but when (P/P1=1.5) the effect of (He/p) became larger for (S=0.004) compared with (S=0.002) , and the difference between the first and last reading was 7.52 % . Also the conditions of (P/P1=2 & 3) were as same as of figures (11 &12). Figure (15) indicated the relation between the different slopes and energy dissipation ratio and the effect of reverse slope revealed on energy dissipation.

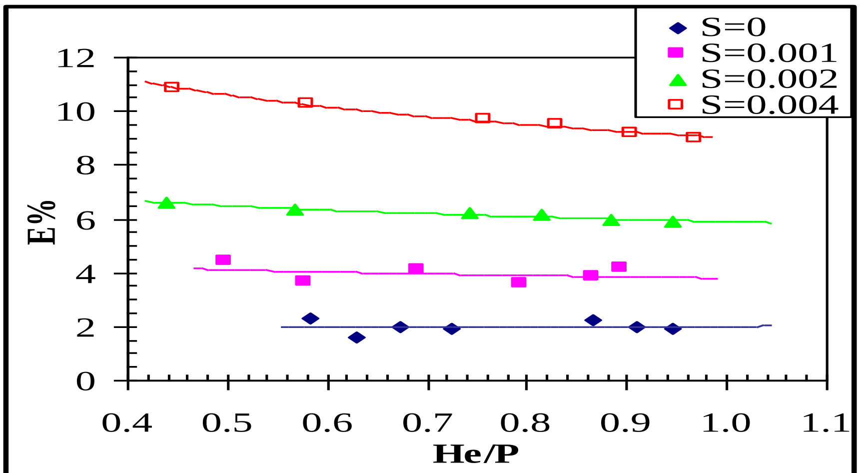


Fig. (6) Variation of E% with He/P for weirs of P/P1=1.

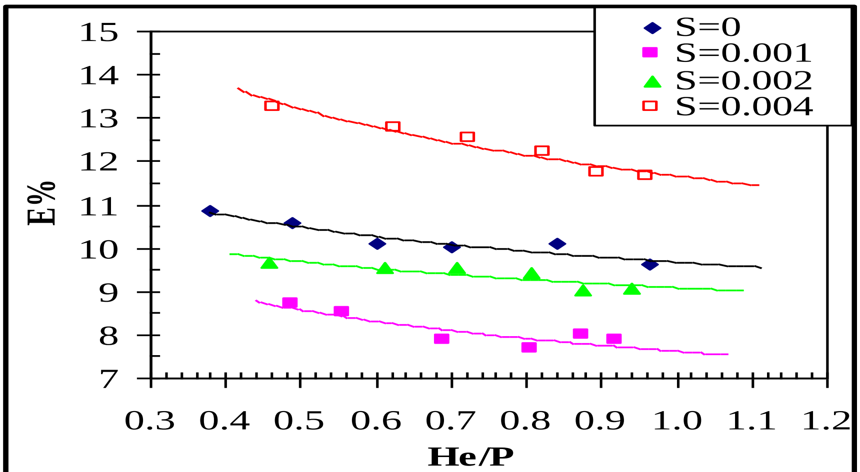


Fig. (7) Variation of E% with He/P for weirs of P/P1=1.2

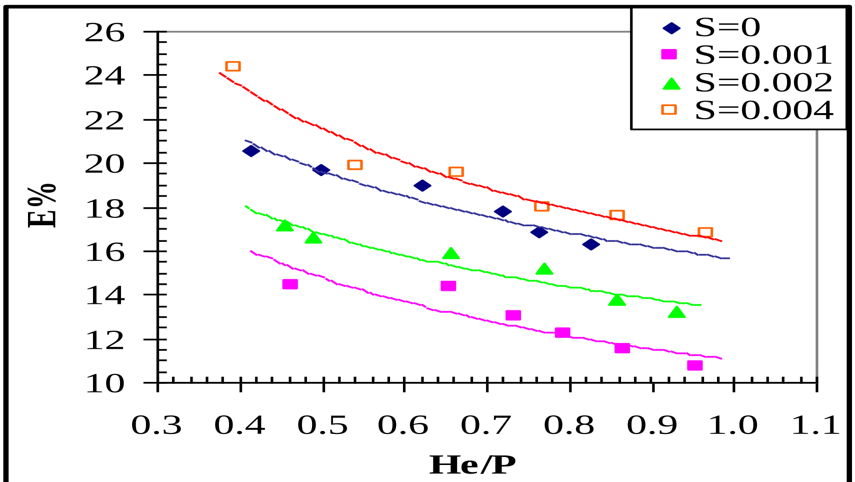


Fig. (8) Variation of E% with He/P for weirs of P/P1=1.5

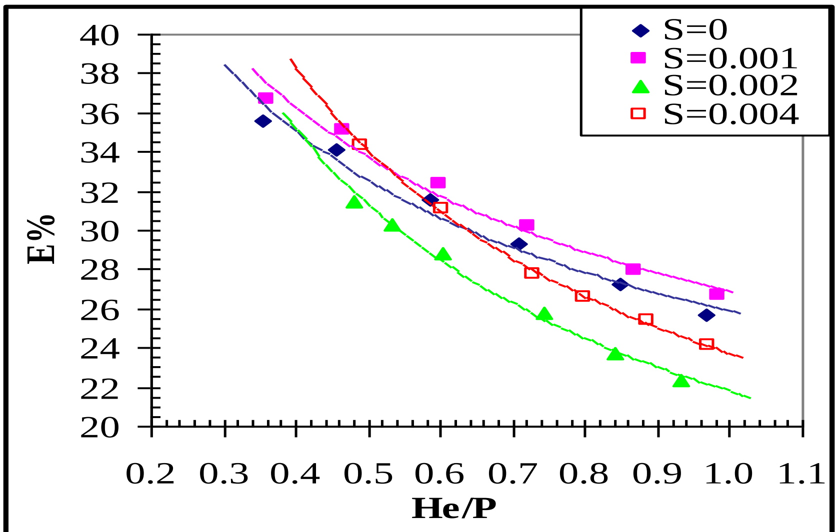


Fig. (9) Variation of E% with He/P for weirs of P/P1=2

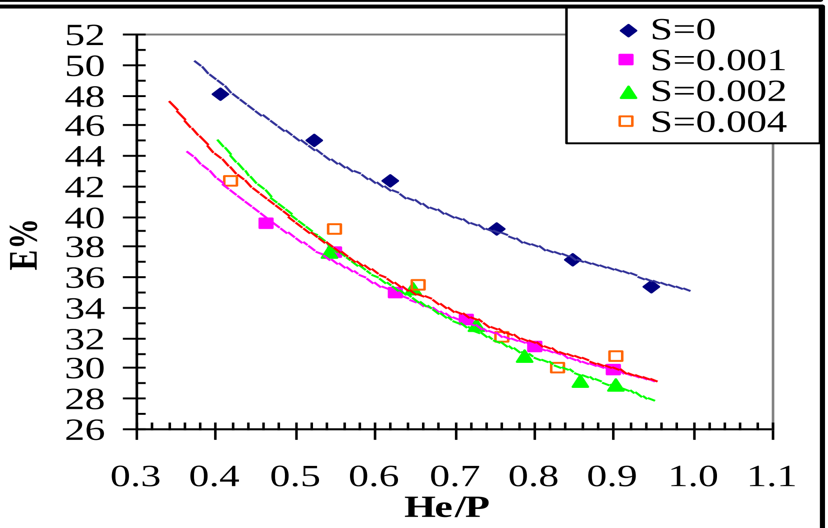


Fig. (10) Variation of E% with He/P for weirs of P/P1=3

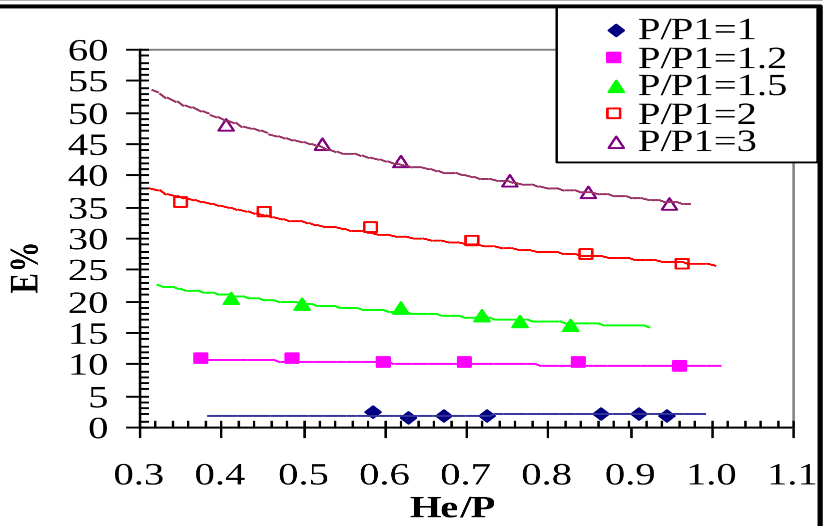


Fig. (11) Variation of E%. with He/P for weirs of S=0 .

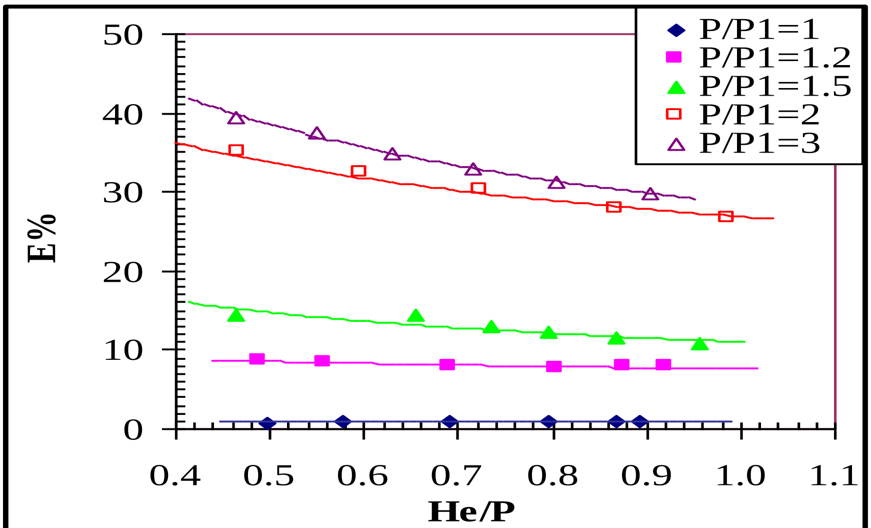


Fig. (12) Variation of E% with He/P for weirs of S= 0.001 .

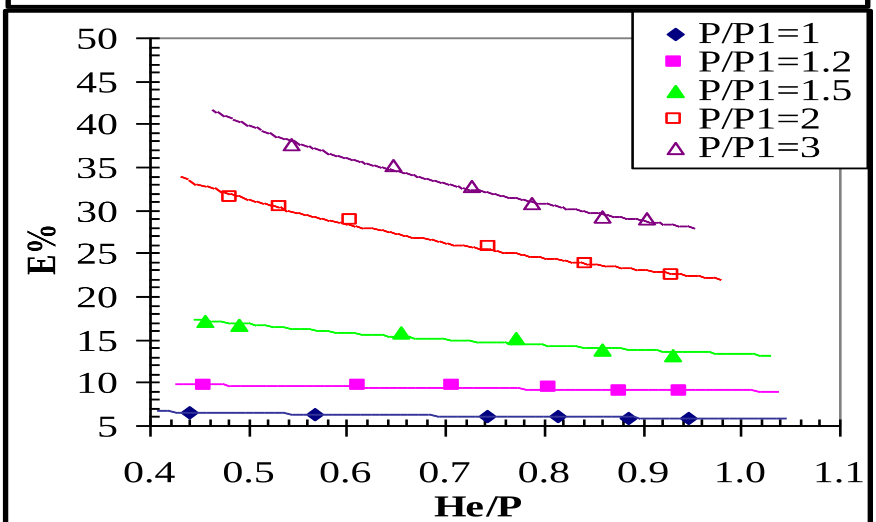


Fig. (13) Variation of E% With He/P for weirs of S=0.002

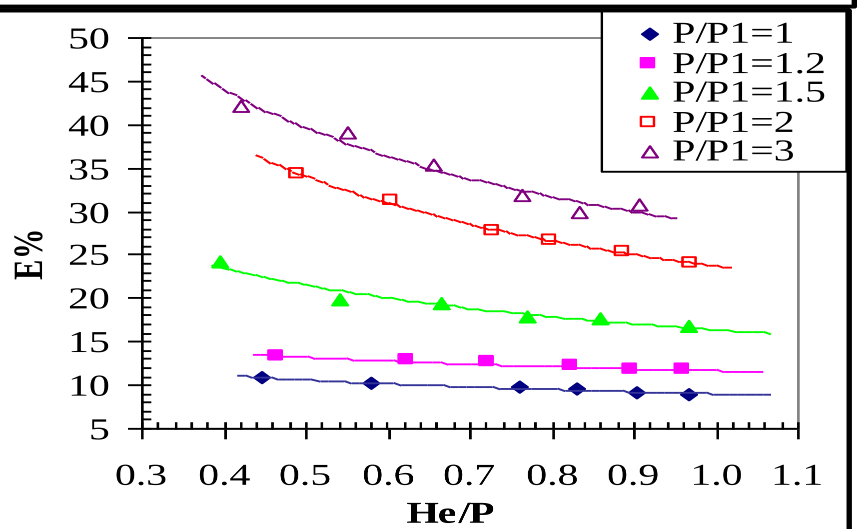


Fig. (14) Variation of E% with He/P for weirs of S= 0004 .

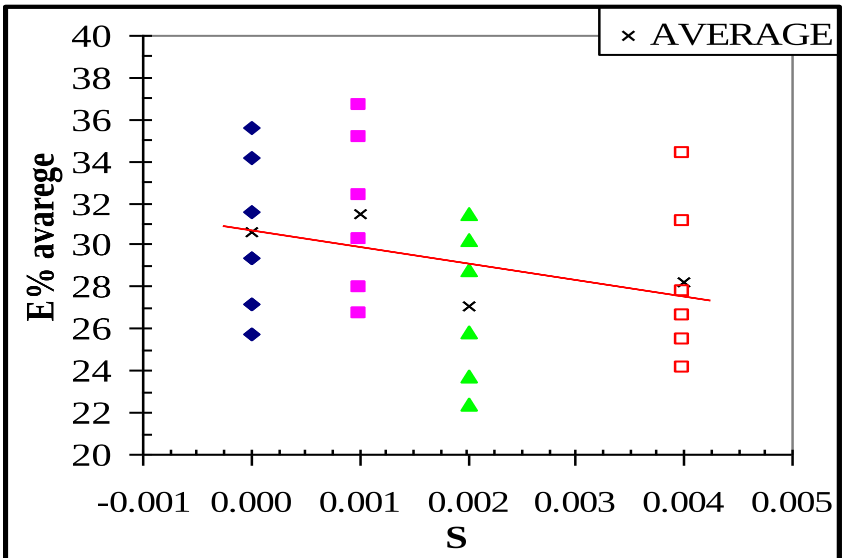


Fig. (15) Variation of E% avarege with S for weirs of P/P1=2.

Empirical Expressions of Energy dissipation ratio (E %):

All experimental results of single step Broad–Crested Weirs were used as input data in a regression analysis computer program (SPSS-16.0) to obtain an empirical linear relation as below:

$$E\% = 9 - 16.5\left(\frac{He}{P}\right) + 16\left(\frac{P}{P1}\right) + 847\,(S) - 4.6\,(Fr_2) \quad .... \quad .... \quad .... \quad .(8)$$

With a correlation coefficient =0.95.The relation between E % values computed by Eq.(8) and values measured experimentally is plotted in Fig.(14) showed good agreements for all data of weirs.

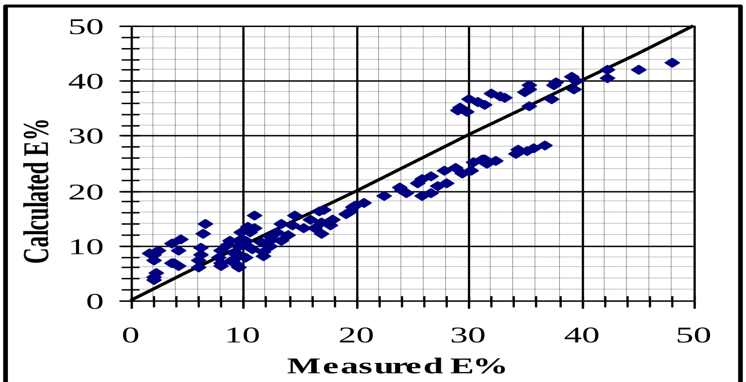


Fig. (16) Variation of measured E% and caculated E%

CONCLUSIONS:

Within the limits of the experimental data of the current study, the main following conclusions can be summarized as:

1- The channel slope was inversely proportional with the energy dissipation.
2- The effect of (He/P) did not appear when (P/P1 =1&1.2) for different slopes while in the others weirs appeared.
3- The maximum energy dissipation ratio was 12.71% for S=0, P/P1=3 between the range of flow rate (165.78 to 616.15 cm^2/sec).
4- An empirical non – dimensional relation was obtained to determine the energy dissipation ratio in terms (He/p) , (P/P1) , (S) and (Fr_2) with a high correlation coefficient R=0.95

NOTATION

The following symbols were used in this paper:

Symbols	Definitions
E %	energy dissipation ratio
f1 to f4	unctions
g	acceleration due to gravity (m/s^2)
H1	U/S head above crest(cm)
He	ffective upstream head above crest(cm)
h	D/S head (cm)
L	eir length (cm)
L1	length of D/S stepped weir (cm)
W	idth of weir (cm)
P	U/S weir height (cm)
P1	/S weir height (cm)
q	flow rate over the weir per unit width (m^2/s)
R	adius of the U/S corner of the weir (cm)
Re	Reynolds number
Fr_2	roude number at D/S
S	Bed slope of channel
υ	kinematics viscosity (m^2/s)
U/S	upstream weir
D/S	downstream weir

REFERENCES:

[1] Chilmeran, T. *Characteristics of flow over normal and oblique weirs with semicircular crest*. M. Sc. thesis, University of Mosul, Iraq.1996.

[2] Gogus, M., Defne , Z. and Ozkandemir,V., "**Broad-Crested Weirs with Rectangular Compound Cross Sections**", *Journal of Irrigation and Drainage Engineering*, Vol.132, No.3, June, PP.272-280,2006.

[3] Sarker, M .A. and Rhodes, D. G., "**Calculation of Free-Surface Profile over a Rectangular Broad-Crested Weir**", *Flow Measurement and Instrumentation*,Vol.15, Issue 4, August, PP.215-219.2004

[4] Gonzalez, C.A. and Chanson, H., "**Experimental Measurement of Velocity and Pressure Distribution on a Large Broad-Crested Weir**", *Flow Measurement and Instrumentation*, Vol. 18, Issue 3-4, June-August,PP.107-113,2007.

[5] Noori, B. M. and Juma ,I .A., "**Performance Improvement of Broad Crested Weirs**", *Journal of Al-Rafidain Eng.* / Mosul Unv,2009.vol.17,no.2,pp.95-107.

[6] Al-Talib, A. N. J. *Laboratory Study of Flow Energy Dissipation Using Stepped Weirs* M. Sc. Thesis, Engineering College, University of Mosul. Iraq.2007.

[7] Hussein H., Juma I. and Shareef S." **Flow Characteristics and Energy Dissipation Over Step Single Broad – Crested Weirs**",accepted in *Journal Al- Rafidain Engineering*, College of Engineering University of Mosul. Iraq,2009.

[8] Chamani, M.R.and Beirami, M. K.," **Flow Characteristics at Drops**", *Journal of Hydraulic Engineering*, ASCE , Vol. 128, No.8, PP.788-791,2002.

[9] Ackers, P.; White, W.R.; Perkins J. A. and Harrison, A J. M. , *Weirs and Flumes for Flow Measurement* , First Edition, John Wiley and Sons Co., Chicheestter , England, U. K.,1978.

[10] Boiten,W, "**Flow Measurement Structures**", *Flow Measurement and Instrumentation,* Vol.13, Issues 5-6, December, PP. 203-207, 2002.