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INVESTIGATION OF THE UPSTREAM AND DOWNSTREAM SLOPE OF THE LONG-THROATED FLUMES ON THE DISCHARGE COEFFICIENT

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ABSTRACT

Long-throated flumes provide economical and flexible water measurement capabilities for a wide variety of open-channel flow situations. Primary advantages include minimal head loss, low construction cost, adaptability to a variety of channel types, and ability to measure wide ranges of flows with custom-designed structures. Discharge coefficient of long-throated depends on many parameters such as upstream and downstream slope, step height and throat length. In order to investigate the effects of these parameters on the values of discharge coefficient, in this study a series of laboratory experiments were carried out in a flow measurement flume of rectangular cross section.

The experiments carried out with different upstream and downstream slope, two step height (P = 7.62 and 15.62cm), constant throat width (w = 25cm) and throat length (L = 30.48cm). Eleven different models made of Plexiglas were tested in a horizontal flume for large range of discharges. The results of this study indicated the long-throated flume can be used for flow measurement with average of 1.6% flow measurement error. Also the results reveled that the decreasing of upstream slope and the increasing of downstream slope would caused the discharge coefficient is increased.

Keywords: flumes, water, flow, measurement, slope, upstream, downstream, step height, throat length.

1.0 INTRODUCTION

The most common structures used to measure flow in open channels operated by producing critical flow or flow at critical-depth through a control section of known dimensions under this flow condition, the discharge through the critical section is a function of the section shape and the upstream potential energy, as indicated by the water level upstream from the structures. By definition, the presence of critical flow in the control section prevents the downstream water level and flow conditions from affecting the flow through the critical section, and the discharge can be computed as a function of the measured upstream head. Sharp-crested weirs, broad-crested weirs, and a wide variety of flumes are examples of critical-flow devices. To apply a critical-flow device for flow measurement, one must define the particular relation between flow rate and upstream head, and the range over which it is applicable (Clemmens *et al.,* 2001).

These two issues present a significant problem for some critical-flow devices are:

The flow through the critical section of many of these devices is three- dimensional and cannot be easily analyzed with available one dimensional hydraulic theory. Therefore these devices must be calibrated with the aid of physical models, laboratory tests, or complex three-dimensional numerical modeling; laboratory calibration tests that determine empirical discharge coefficients are the most commonly used.

The discharge coefficients of many critical- flow devices vary widely when operating outside of a narrow rang of conditions. For example the discharge coefficients of sharp-crested weirs change significantly if tail water level exceeds the crest elevation of control section (i.e. the crest is submerged).

Studies of flow measuring structures in open channels, such as broad crested weirs and long throated flumes of different cross sections have been reported by various investigators (Bos, 1977; Bos, 1978; Bos and Reinink, 1981; Bos, Replogle and Clemmens, 1984). In all these studies theoretical analyses were followed by experimental investigations to obtain relations between hydraulic and geometric parameters.

1.1. Long-throated flume

The term long-throated flume describes a broad family of critical-flow flumes and used to measure open-channel flows. A variety of specific configurations are possible depending on the type of approach channel, the shape of the throat section, the location of the gauging station, and the use or lack of a diverging transition section(Wahl *et al.,* 2000). Figure-1 shows the general longitudinal profile of flow through a long-throated flume. The subscripts 1 and 2 refer to conditions in the approach and tail water channels, respectively, and the subscript c will refer to conditions at the critical section. In this Figure Q is discharge, v is the flow velocity, p is the step height, y is the water depth, and h is the step referenced head; H is the total energy head and ΔH is the energy loss across the flume.

The hydraulic theory for predicting discharge through long-throated flumes has resulted from over a century of development. The first laboratory and theoretical studies on critical-depth flumes were made by Belanger in 1849 and by Bazin in 1896 (ref. Clemmens *et al.,* 2001). Theoretical predictions of flow were investigated by Ackers and Harrison (1963) and further by Replogle (1975) (ref. Clemmens *et al.,* 2001). Bos *et al.,* (1984) described the theory for determining discharge through these flumes. The head-discharge equations for a flow measurement flume of rectangular cross section were derived by Al-Khatib (1989) and herein only the final results are presented:

$$Q = \frac{2}{3} C_d b \left(\frac{2}{3} g \right)^{\frac{1}{2}} . H_1^{\frac{3}{2}} \qquad (1)$$

Where Q = volume rate of flow; *Cd* = characteristic discharge coefficient, b = bottom width of the control section; g = acceleration due to gravity; *H*1 = the total energy head at the head measurement-section.

In recent years long-throated flumes have become the measurement device of choice for most applications (Reclamation, 1997), superseding Parshall flumes and other traditional devices. These older devices were laboratory-calibrated, because the flow through their control sections is curvilinear. In contrast, streamlines are essentially parallel in the control sections of long-throated flumes, making them amenable to analysis using straightforward hydraulic theory.

Significant advantages of long-throated flumes include (Wahl *et al.,* 2000):

- Choice of throat shapes allows a wide range of discharges to be measured with good precision;
- Minimal head loss needed to maintain critical flow conditions in the throat of the flume; and
- Economical construction and adaptability to varying site conditions.

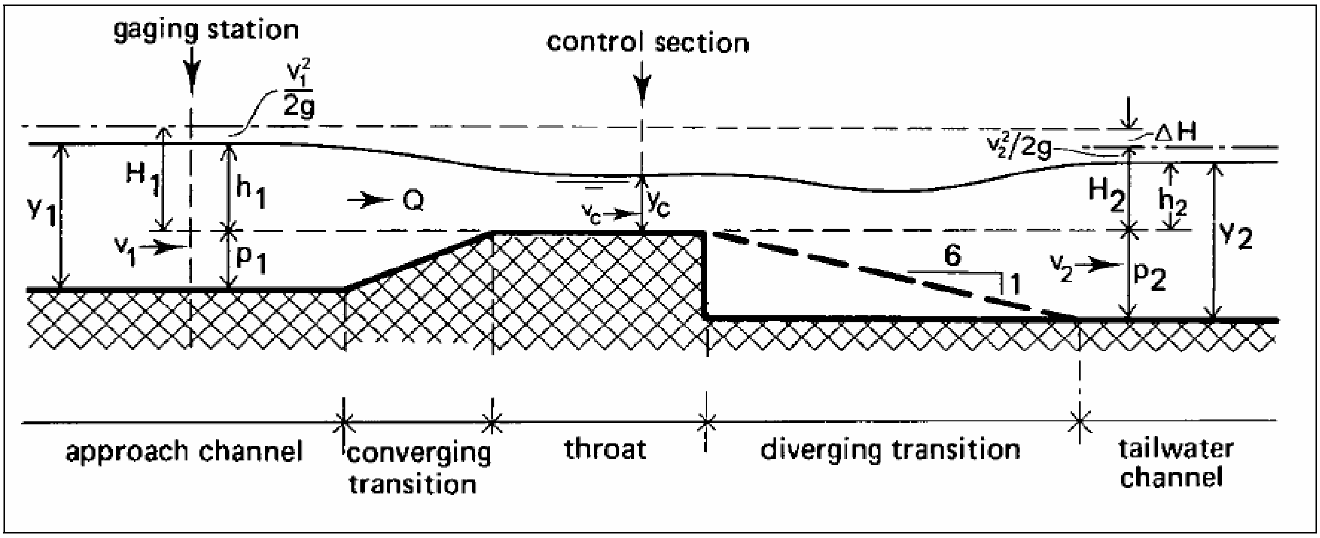

Figure-1. Longitudinal Profile of a long-throated flume.

2.0 MATERIALS AND METHODS

2.1. Experimental setup

In order to achieve the objective of this study a physical model is considered. Thus all series of experiments were conducted in a glass-walled horizontal flume 12.0 m long, 0.25 m wide and 0.50 m deep in the Hydraulic Laboratory at the Water and Science Collage of Shahid Chamran University, Ahwaz, Iran. Figure-2 shows the plan view of the hydraulic laboratory and the flume which used in this research. Long-throated flumes were manufactured from glass and placed at the distance of 2m from the upstream of the main flume system (the test section in Figure-2). In order to dissipating of the inflow energy, first flow passed through **flow dissipater area**, then traveled about 2 m to the test section.

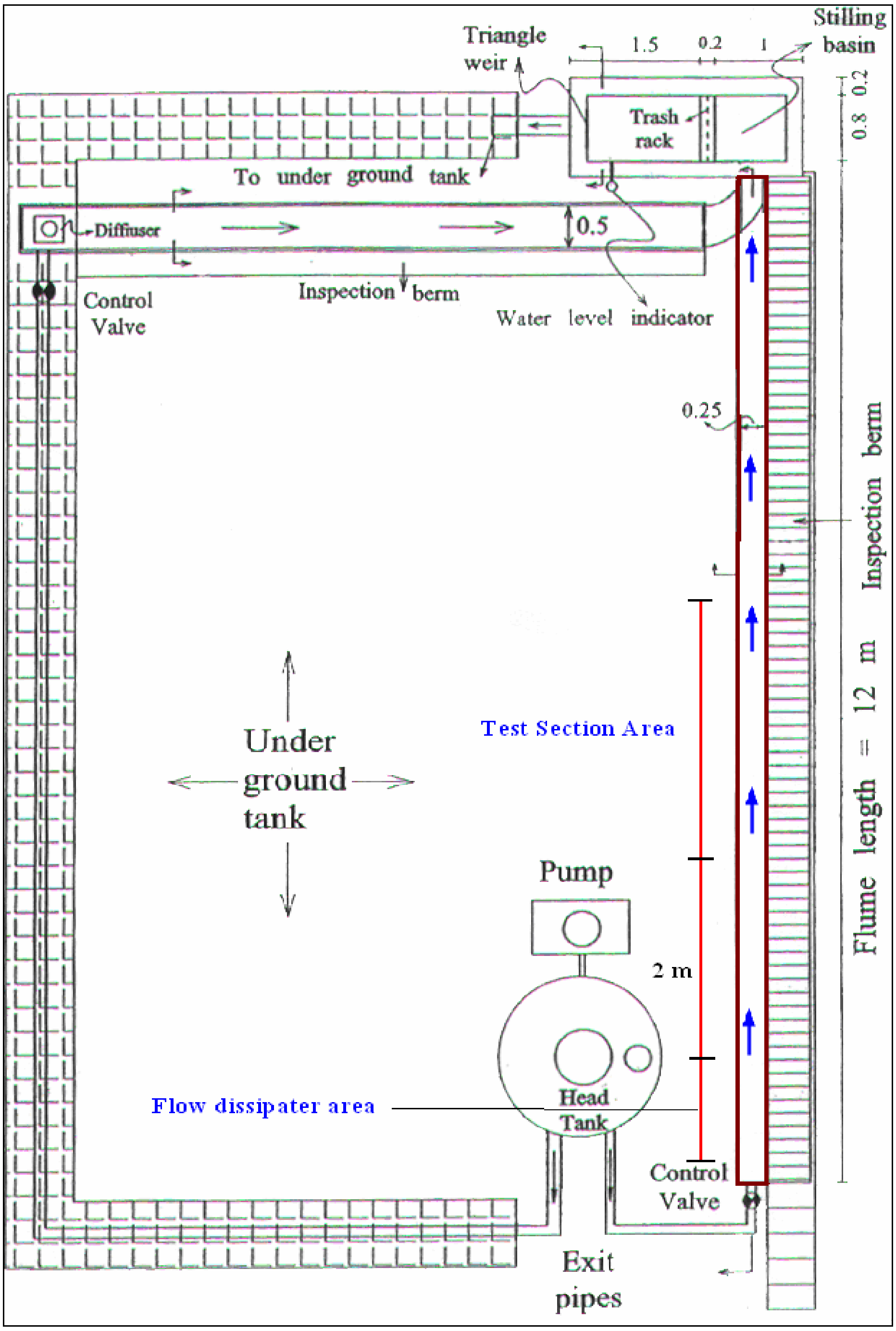

Figure-2. The plan view of hydraulic laboratory and main flume.

For each test, the upstream step-referenced head on the flume was measured using a point gage (estimated measurement uncertainty ± 0.1 mm), and the discharge through the flume was determined using the triangular weir (53 degree). The tail water levels relative to the step elevation were also recorded.

2.2. Test flumes

For carry out of experiments 11 kind of flumes were used. Long-throated flumes were constructed in the test section (Figure-2) and operated at a range of flow rates. Table-1 summarizes the dimensions of the tested flumes. The tested flumes shared several characteristics. All utilized rectangular-shaped approach, throat, and tail water sections. The throat width (w) and the length of the throat section (L) were held constant at 25 cm and 30.48 cm respectively for all flumes. The principal differences between the different tested flumes were the step height, upstream and downstream slope. The upstream slope was 1:1, 2:1 and 3:1. The downstream slope was 6:1, 10:1 and vertical. Also the step height was 7.62 cm and 15.24 cm.

Tabel-1. Tested flumes and relative information for each kind of them.

Flumes	Range of discharges tested (m^3/s)	Approach channel Froude number	Throat width, *w* (m)	Throat length, *L* (m)	D.S. slope	U.S. slope	Step height
C	6.87-50.16	0.16-0.35	0.25	0.3048	Vertical	3:1	7.62
D	7-43.28	0.16-0.37	0.25	0.3048	6:1	1:1	7.62
E	7.08-50.16	0.16-0.36	0.25	0.3048	6:1	2:1	7.62
F	8.87-44.24	0.18-0.33	0.25	0.3048	6:1	3:1	7.62
G	9.11-46.98	0.11-0.26	0.25	0.3048	10:1	2:1	7.62
H	10.46-47.98	0.13-0.26	0.25	0.3048	Vertical	1:1	15.24
I	7.65-48.4	0.08-0.28	0.25	0.3048	Vertical	2:1	15.24
J	7.43-51.9	0.10-0.28	0.25	0.3048	Vertical	3:1	15.24
L	10.73-43.28	0.37-0.22	0.25	0.3048	6:1	2:1	15.24
M	13.65-45.92	0.26-0.36	0.25	0.3048	10:1	3:1	15.24
N	4.90-43.28	0.05-0.22	0.25	0.3048	10:1	2:1	15.24

2.3. Experimental procedure

In this study, the experiment setup is not a scaled physical model for a specific flume in the field. The experiments carried out with different discharges. For this purpose the entrance valve on the inlet pipe was opened. For a selected model type a range of discharges which could be obtained from the constant-head storage tank of laboratory were examined. Depth of the flow above the crest level at approach channel was measured (h1) when the tail water gate of the flume was fully open (free flow measurements). At that moment, depth of the flow in the tail water channel above the crest elevation was. Figure-3 shows Flumes G in operation.

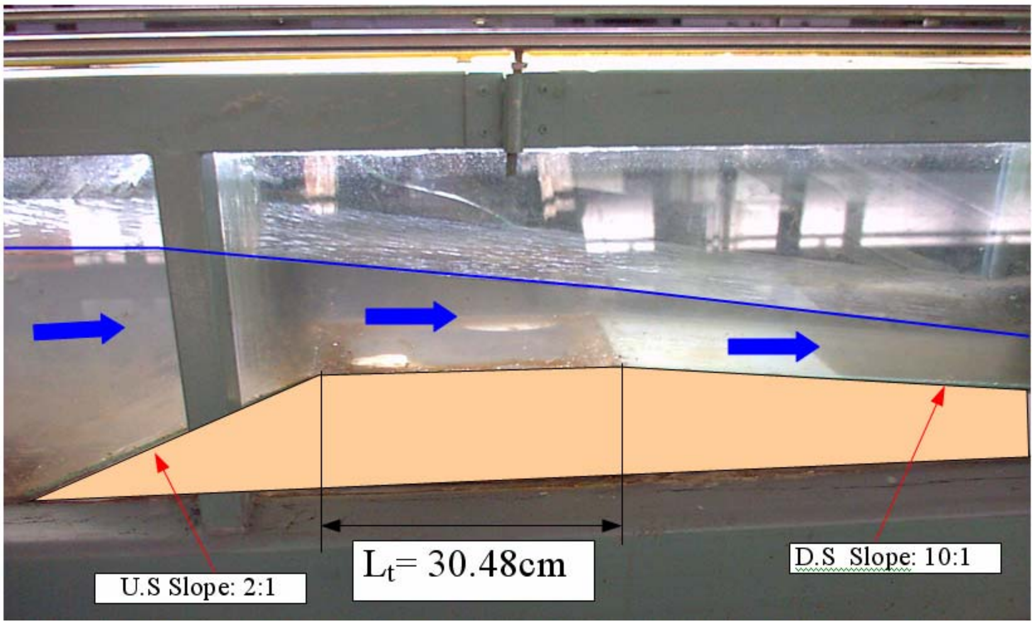

Figure-3. Longitudinal view looking at flume G, operating at a flow rate of 10 lit/s.

3.0 RESULTS AND DISCUSSIONS

All of the measured and calculated quantities from the experiments conducted in the course of this study were given by Asare (2006). In the following sections results of experiments were analyzed and summarized:

3.1. Flow measurement error

For each test flow, the measured upstream head was used to compute the flow through the structure using the analytically determined flume rating equation, and this result was compared to the actual discharge as determined by the weir. Figure-4 shows the relationship between measurement discharge by weir (Q_m) and total energy at upstream (H1) for 11 type of long-throated flumes which used in this study. Figure-5 shows the flow measurement error (flume rating compared to actual discharge) as a function of the actual discharge. This Figure shows that the flow measurement error is generally in the range of ± 20%. The average of flow measurement error of long-throated flume with rectangular cross section was achieved 1.4%. The average error indicates this structure has high accuracy for measurement of passing flow through long-throated flow.

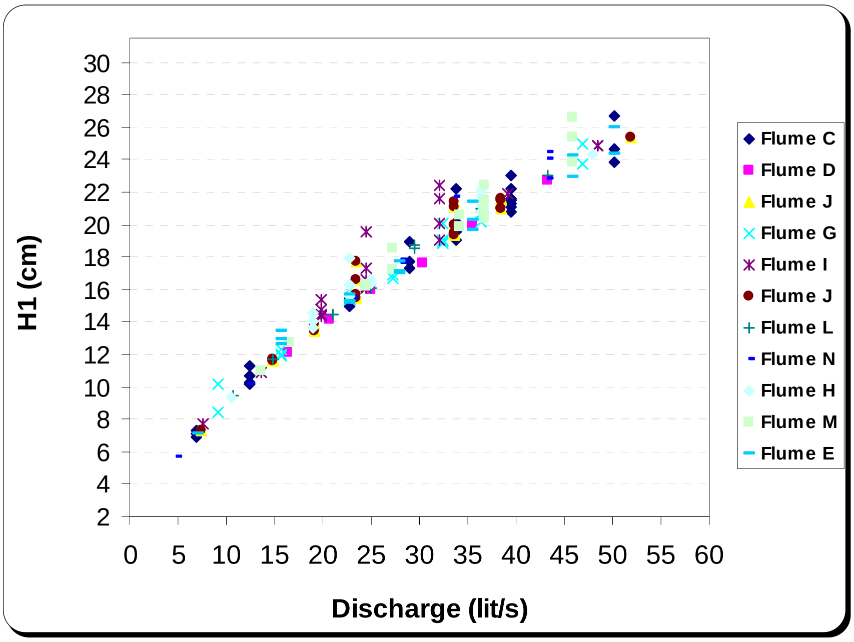

Figure- 4. The relationship between measurement discharge by weir (Q) and depth of the flow above the crest level at approach channel (H1).

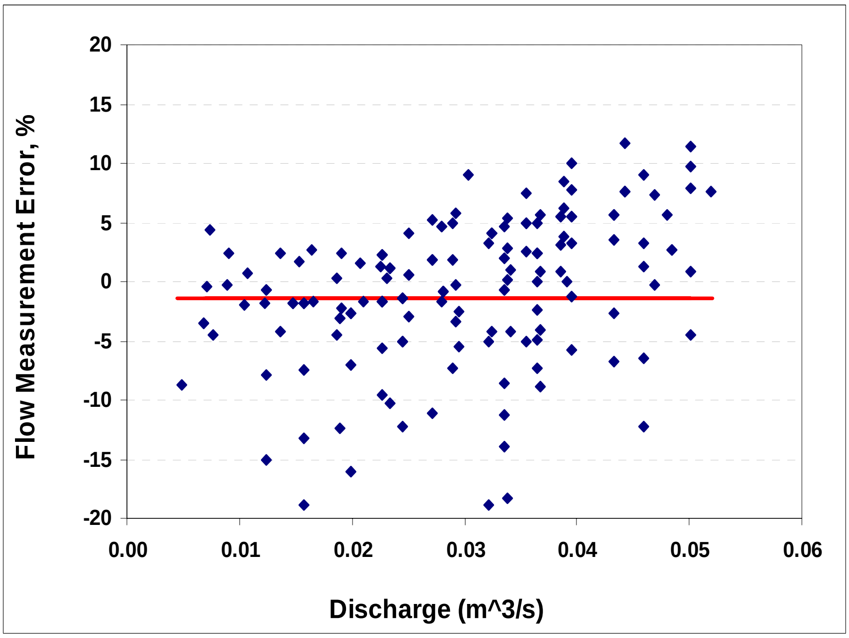

Figure- 5. Flow measurement errors as a function of actual discharge.

3.2. The Effect of upstream slope of long-throated flume on the discharge coefficient (Cd)

In order to investigate of upstream slope of long-throated flume on the discharge coefficient (Cd), a comparison was made between calculated discharge coefficient of flume when the upstream slope of the flume was reduced from 1:1 to 2:1 and 3:1 at two same conditions as following:

The downstream slope was 6:1 and step height (p) was 7.62 cm (Flumes D, E and F).

The downstream slope was vertical and step height (p) was 15.24 cm (Flumes H, I and J)

Figures 6 and 7 show the discharge coefficient as a function of H1/L, where *H*1 is the energy head in the upstream of the flume and L is the throat length of the flume.

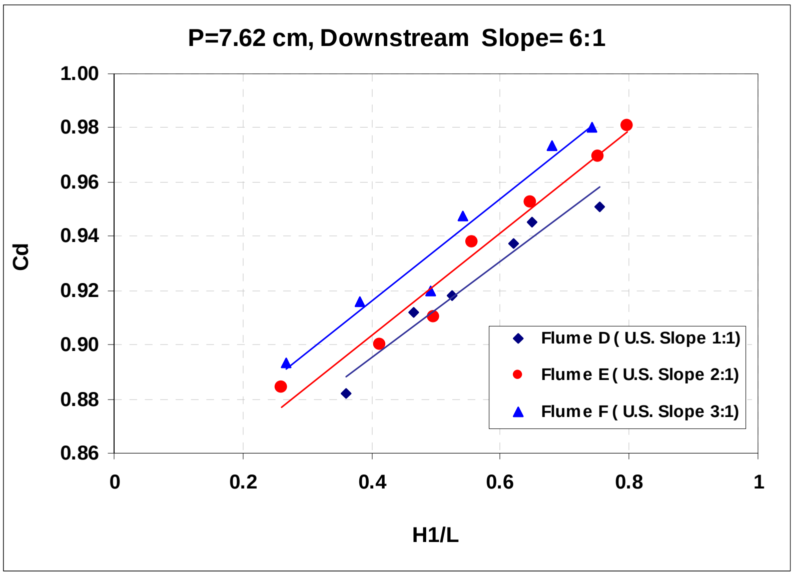

Figure- 6. Coefficient discharge of flumes D, E and F as a function of upstream slope and H1/L when step height (p) is 7.62 cm and downstream slope is 6:1

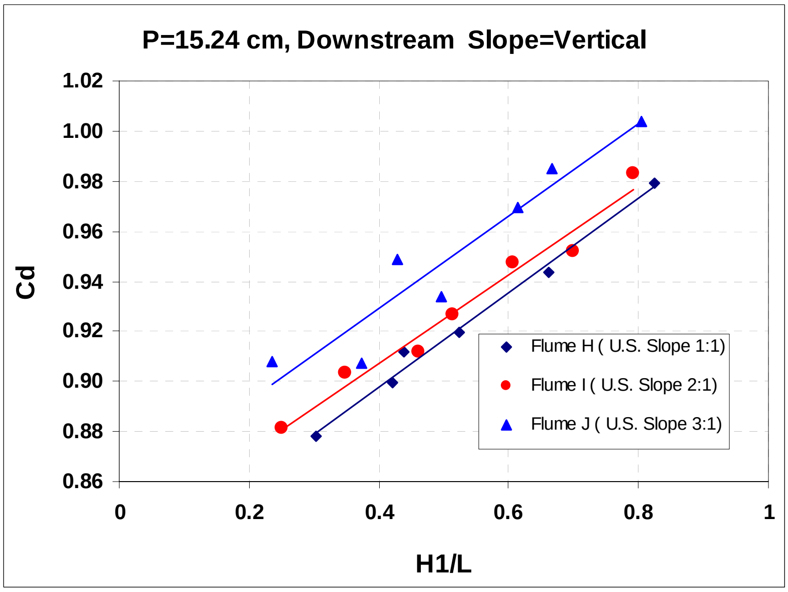

Figure- 7. Coefficient discharge of flumes H, I and J as a function of upstream slope and H1/L when step height (p) is 15.24 cm and downstream slope is vertical.

The upper, middle and lower curves in the Figures 6 and 7 are related to the upstream slope of 1:1, 2:1 and 3:1 respectively. With respect to the these Figures, it can say for a constant downstream slope and step height, any decrease in the upstream slope correspondingly leads to a decrease in the discharge coefficient. This is consistent with the hypothesis that decreases of upstream slope lead to the decrease of compression of the stream lines.

Therefore in order to maximize the discharge coefficient of long-throated flume i.e. increasing passing discharge through flume to the extent possible, it is advised to reduce the upstream slope of the flume.

3.3. The Effect of downstream slope of long-throated flume on the discharge coefficient (Cd)

In order to investigate of downstream slope of long-throated flume on the discharge coefficient (Cd), a comparison was made between calculated discharge coefficient of flumes when the upstream slope of the flume was changed and other parameters such as upstream slope and step height were constant as following:

The upstream slope was 3:1 and step height (p) was 7.62 cm (flumes C and F and flumes E and G).

The upstream slope was 2:1 and step height (p) is 15.24 cm (Flumes I, L and N and also J and M).

Figures 7 and 8 show the discharge coefficient as a function of H1/L for flumes of C and F and also flumes of E and G respectively.

Figures 9 and 10 show the discharge coefficient as a function of H1/L for flumes of I, L and N, and also for flumes of J and M respectively.

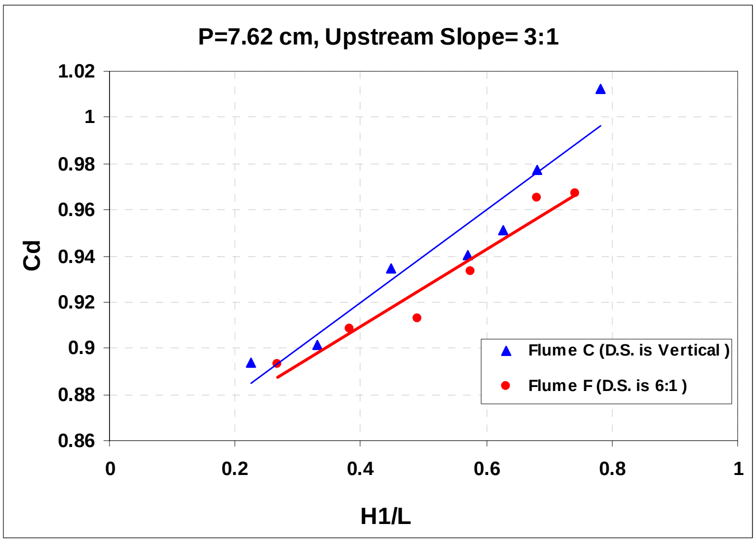

Figure-7. Coefficient discharge of flumes C and D as a function of downstream slope and H1/L when step height (p) is 7.62 cm and upstream slope is 3:1.

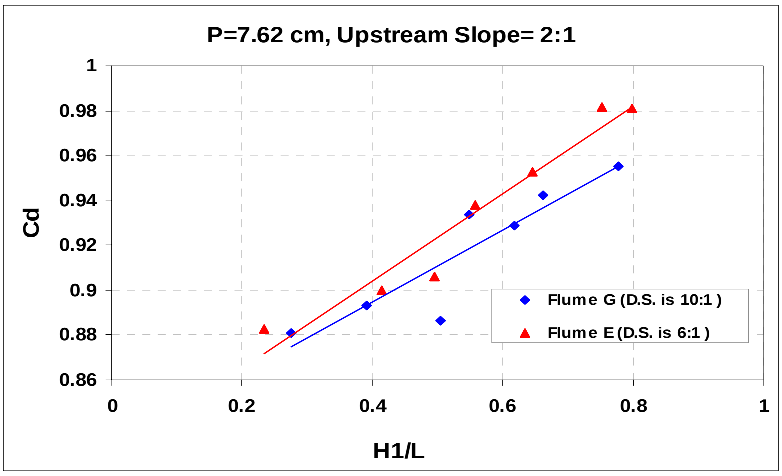

Figure- 8. Coefficient discharge of flumes G and E as a function of downstream slope and H1/L when step height (p) is 7.62cm and upstream slope is 2:1.

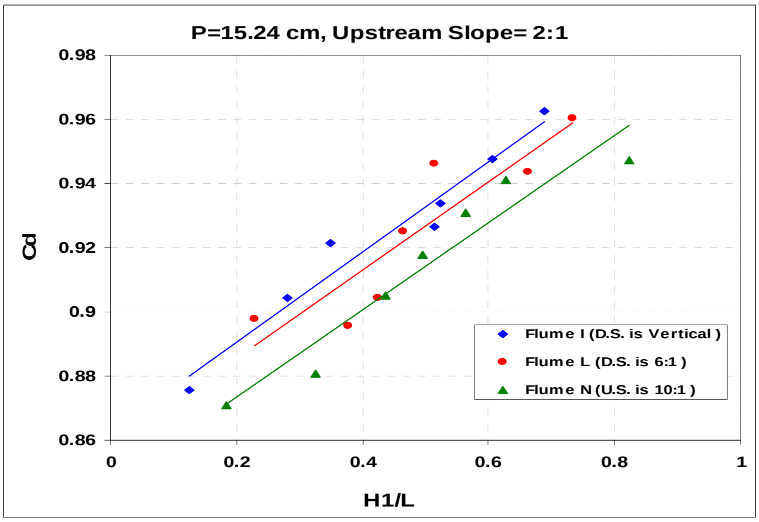

Figure- 9. Coefficient discharge of flumes I, L and N as a function of downstream slope and H1/L when step height (p) is 15.24 cm and upstream slope is 3:1.

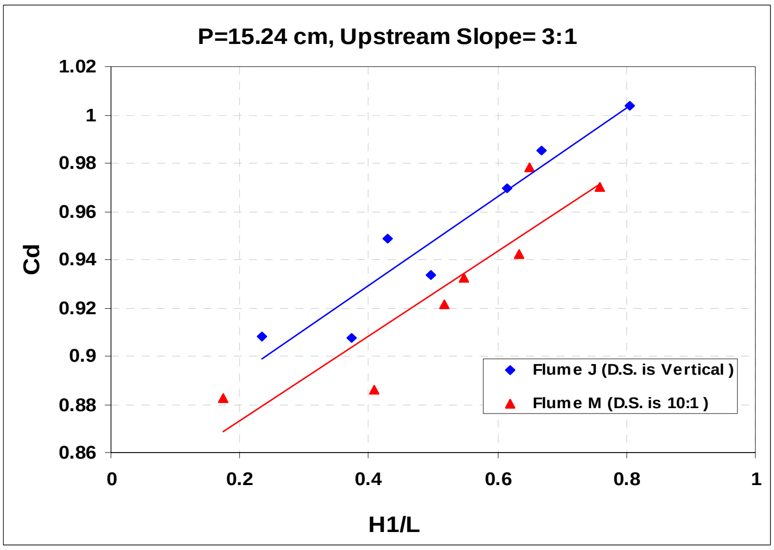

Figure -10. Coefficient discharge of flumes J and M as a function of downstream slope and H1/L when step height (p) is 7.62cm and upstream slope is 3:1.

With respect to the these Figures, it can say for a constant upstream slope and step height, any increasing in the downstream slope correspondingly leads to a increasing in the discharge coefficient. Therefore in order to increasing of the passing discharge through flume, it is better to increasing the downstream slope of the flume.

4.0 CONCLUSIONS

Long-throated flumes are a well-developed technology that provides economical and flexible water measurement capabilities for a wide variety of open-channel flow situations. The structures have low head loss requirements among other advantages (Wahl *et al.*, 2000).

The discharge coefficient of long-throated flume depends on the many parameters such as upstream and downstream slope. In this research in order to investigate the effects of these parameter different laboratory tests were conducted with 11 kind of long-throated flumes. Summarizing the findings derived from the different experiments is governed by following parameters:

- The flow measurement error.
- The effect of upstream slope of long-throated flume on its discharge coefficient.
- The effect of downstream slope of long-throated flume on its discharge coefficient.

The results of the present study revealed that the average flow measurement error was 1.6 %. With this respect, this structure can be used for flow measurement successfully.

The investigation of upstream slope show when the other parameters such as downstream slope and step height are constant, decreasing the upstream slope lead to the increasing the discharge coefficient.

Also the results of this study showed when the downstream slope is increased the discharge coefficient of flume increase.

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