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## FLOW THROUGH NON-COPLANAR VERTICAL ORIFICE

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**Abstract:** An orifice is an opening provided in the vertical wall or horizontal bottom of a vessel or tank or a channel so that the fluid can discharge freely under atmospheric conditions. In the present investigations, flow through the stepped vertical orifice is experimentally determined and its analysis is carried out. The flow through the different orifices working under different relative heads (with overall head being maintained constant) is analysed and the discharge coefficient for the stepped orifice is determined. The relevance of the present research carried out with respect to inclined weir, researched by the authors is highlighted. The importance of this type of Non-coplanar vertical Rectangular slots wherein the relative orifices do not share the same plane is emphasized. The discharge coefficient for the Non-coplanar vertical Rectangular slots is found to vary within an acceptable percentage deviation from the mean coefficient of discharge. The experimental head-discharge plot also indicates the validity of the research work with most of the experimental values falling on the proposed equation for the flow through the Non-coplanar vertical Rectangular slots.

### I. INTRODUCTION

An Orifice is an opening having closed perimeter, made in the walls or the bottom of a tank or a vessel or a channel containing fluid, through which the fluid may be discharged. Depending on size, the orifice may be classified as small and large orifices. In case of small orifices, the velocity distribution is assumed to be uniform over its vertical height as the height of the orifice is deemed to be small relative to the head on which the orifice is discharging. Whereas, in case of large orifices, the velocity is assumed to vary with the vertical axis as the height of the orifice is relatively larger compared to the head on which it is discharging. Few researchers have attempted flow through multiple slots. Mefford presented a discussion of recent designs and construction methods for fishways using multiple-slot baffles (1). Prabhata K. Swamee et.al. worked on the rectangular slots resulting from sluice gates on raised edges (2). Shesha Prakash and Shivapur worked on inclined rectangular slots. They considered the flow through rectangular slots as combined effect of flow through horizontal and vertical slots (3). However, the theoretical equation resulting out of this resolution of inclined flow as horizontal and vertical components was not experimentally verified. The horizontal or vertical components behave as flow through the respective slots do not happen in single plane but is to be treated as non-coplanar slots. To obtain an experimental analysis carried out on flow through inclined sharp crested weirs by Shesha prakash and Shivapur is simulated to the combined effect of flow through small vertical and horizontal orifices (4, 5, 6, 7, 8, 9), Shesha Prakash et.al. (10, 11, 12, 13, 14, 15, 16, 17, 18). In this paper, it is attempted to experimentally find the flow through such varying Non-coplanar vertical Rectangular slots as large orifice.

### II. MATHEMATICAL FORMULATION

Consider the flow through the stepped vertical orifice as shown in Fig. 1. Consider a rectangular strip of height  $dh$  at a depth  $h$  from the free surface.

Velocity of flow through the strip =  $\sqrt{2gh_x}$

From discharge continuity equation, Discharge through the strip =  $dq = Ldh\sqrt{2gh_x}$

Total discharge is given by  $q = \int_a^h L\sqrt{2gh_x} dh$

$$\text{Or } q = \frac{2}{3} C_d L \sqrt{2g} \left[ h^{\frac{3}{2}} - a^{\frac{3}{2}} \right]$$

(flows above  $a$ )

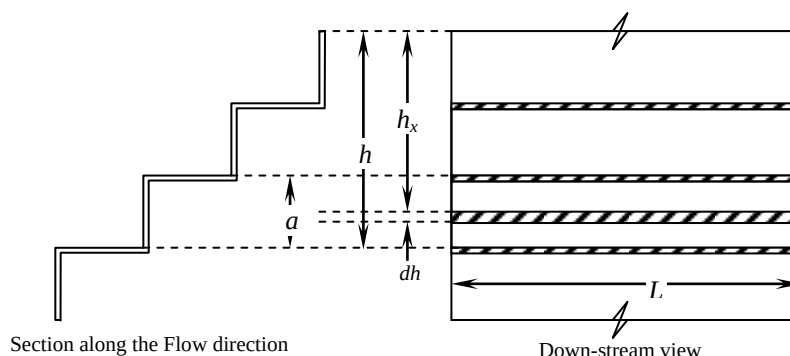


Fig. 1 Sketch of the Stepped Vertical Orifice

Where  $C_d$  is the coefficient of discharge for the vertical orifice,  $L$  is the length of the vertical orifice and  $a$  is the height of the large vertical orifice.

Non-dimensionalising the above equation, we get

$$q = \frac{2}{3} C_d L \sqrt{2g} \left[ \left( \frac{h}{L} \right)^{\frac{3}{2}} - \left( \frac{h-a}{L} \right)^{\frac{3}{2}} \right] L^{\frac{3}{2}}$$

$$Q = \left[ H^{\frac{3}{2}} - H_a^{\frac{3}{2}} \right] \dots 01$$

$$Q = \frac{q}{\frac{2}{3} C_d L^{\frac{5}{2}} \sqrt{2g}} \text{ and } H = \frac{h}{L}; H_a = \frac{h-a}{L}$$

Where

Flow through the stepped weir is given by

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 \dots 02$$

$$Q_a = \frac{q_a}{\frac{2}{3} L^{\frac{5}{2}} \sqrt{2g}}$$

### III. EXPERIMENTS

Experiments were carried on stepped vertical orifice fixed normal to the flow direction. The experimental channel is rectangular in section and having dimensions 0.28m wide, 0.45m deep and of 11.5m length. The channel is constructed of Perspex sheet and has smooth walls and bed to reduce the boundary frictional force with nearly horizontal bed. It is connected to a constant Head tank of dimensions 1.5mx1.2mx1.5m. The Non-coplanar vertical Rectangular slots is made of 8mm Flexy glass with a thickness of 1 mm at perimeter of the orifice and a 45° chamfer given on downstream side to get a springing nappe. The experimental set up is shown in Fig. 2. Water is supplied to the channel by an inlet valve provided on supply pipe. Overhead tank is provided with overflow arrangement to maintain constant head. Smooth, undisturbed, steady-uniform flow was obtained by making the water to flow through graded aggregates and the surface waves were dampened by tying gunny bags at the surface near the tank. The head over the weir is measured using an electronic point gauge placed in piezometer located at a distance of about 1.40m on upstream of Non-coplanar vertical Rectangular slots. A collecting tank of size 1.465m length, 1.495m breadth, and of 1.5m depth is provided with a piezometer. Water after running through the experimental setup is collected in an underground sump from which it is re-circulated by pump by lifting it back to the overhead tank.

In the present study, the conventional method of volumetric discharge measurement is used, which increases the accuracy of the work. The measurements are done through electronic gauge which automatically detects the water level and records the gauge reading. The volumetric measurement is done through self-regulated timer for a fixed rise of water level automated through sensors.



(a) End View



(b) Close up view

Fig. 2 Experimental Setup of the Stepped Vertical Orifice

### IV. PROCEDURE:

The step by step procedure followed for experimentation is as follows.

1. A sharp crested stepped vertical orifice was installed at a height 'z'.
2. The crest reading was taken by electronic gauge when the water was in verge of flowing past the weir crest.
3. The discharge in the channel was controlled by the valve provided on supply pipe.

4. When flow attained a steady-uniform condition, the head over the weir crest ' $h$ ' was measured through the electronic point gauge.
  5. For 100 mm, 200 mm, 300 mm and 400 mm rise of water level in collecting tank time in seconds was recorded. (To eliminate the human error in piezometric readings in the collecting tank, time was auto-recorded by an electronic timer, for the above interval of water rise in the tank and averaged, by considering the cumulative volume and the accumulated time).
  6. After having varied the discharge uniformly with a near constant increments in channel using a control gate of supply pipe, the steps 4 and 5 was repeated.
  7. Head readings were taken for both rising head and falling head for more accuracy.
- The present investigation was carried out on the range of variables shown in Table1.

Table1. Range of variables studied

| Particulars                                | Maximum | Minimum |
|--------------------------------------------|---------|---------|
| Actual discharge ( $\text{m}^3/\text{s}$ ) | 0.0202  | 0.0039  |
| Head over the crest (m)                    | 0.1597  | 0.0500  |
| No. of runs                                | 12      | 10      |

## V. ANALYSIS OF RESULTS:

Table 2 shows the experimental values tabulated with the discharge computations. Fig. 3 shows the plot of head-discharge for flow through the stepped vertical orifice. The values are non-dimensionalised so that the obtained result is more generic in nature. The estimated discharge is obtained from using the average coefficient of discharge 0.85 determined through experiments in Eq. 1. The perfect agreement of theoretical and actual discharge in Fig. 3 validates the theory, experiments and analysis. Fig. 4 shows the variation of coefficient of discharge with non-dimensional head and it is found to vary within +1% and -0.43% from the mean coefficient of discharge. It is also observed that the coefficient of discharge is increasing with the increase in head.

Table 2. Computation of Discharge and Coefficient of discharge for the experimental values

| SN | Head over Orifice (h) |        | H      | Time for 1 m rise | $q_a$                 | ND       | $Q_{th}$ | $Q_{est}$ | $C_d$ |
|----|-----------------------|--------|--------|-------------------|-----------------------|----------|----------|-----------|-------|
|    | mm                    | m      | ND     | s                 | $\text{m}^3/\text{s}$ |          | ND       | ND        |       |
| 1  | 50.0                  | 0.0500 | 0.3333 | 565.60            | 3.87E-03              | 1.50E-01 | 1.80E-01 | 1.51E-01  | 0.84  |
| 2  | 71.7                  | 0.0717 | 0.4780 | 333.40            | 6.57E-03              | 2.55E-01 | 3.04E-01 | 2.55E-01  | 0.84  |
| 3  | 81.8                  | 0.0818 | 0.5453 | 273.65            | 8.00E-03              | 3.11E-01 | 3.72E-01 | 3.12E-01  | 0.84  |
| 4  | 83.0                  | 0.0830 | 0.5533 | 266.50            | 8.22E-03              | 3.19E-01 | 3.81E-01 | 3.19E-01  | 0.84  |
| 5  | 86.9                  | 0.0869 | 0.5793 | 248.15            | 8.82E-03              | 3.43E-01 | 4.08E-01 | 3.42E-01  | 0.84  |
| 6  | 94.2                  | 0.0942 | 0.6280 | 225.45            | 9.71E-03              | 3.77E-01 | 4.52E-01 | 3.79E-01  | 0.84  |
| 7  | 99.7                  | 0.0997 | 0.6647 | 207.35            | 1.06E-02              | 4.10E-01 | 4.89E-01 | 4.10E-01  | 0.84  |
| 8  | 100.3                 | 0.1003 | 0.6687 | 205.70            | 1.06E-02              | 4.14E-01 | 4.93E-01 | 4.14E-01  | 0.84  |
| 9  | 106.5                 | 0.1065 | 0.7100 | 188.70            | 1.16E-02              | 4.51E-01 | 5.39E-01 | 4.52E-01  | 0.84  |
| 10 | 108.8                 | 0.1088 | 0.7253 | 182.75            | 1.20E-02              | 4.66E-01 | 5.56E-01 | 4.67E-01  | 0.84  |
| 11 | 114.4                 | 0.1144 | 0.7627 | 169.85            | 1.29E-02              | 5.01E-01 | 6.00E-01 | 5.03E-01  | 0.84  |
| 12 | 118.4                 | 0.1184 | 0.7893 | 161.10            | 1.36E-02              | 5.28E-01 | 6.32E-01 | 5.30E-01  | 0.84  |
| 13 | 119.6                 | 0.1196 | 0.7973 | 158.35            | 1.38E-02              | 5.37E-01 | 6.42E-01 | 5.39E-01  | 0.84  |
| 14 | 122.6                 | 0.1226 | 0.8173 | 152.40            | 1.44E-02              | 5.58E-01 | 6.67E-01 | 5.59E-01  | 0.84  |
| 15 | 125.4                 | 0.1254 | 0.8360 | 147.55            | 1.48E-02              | 5.77E-01 | 6.90E-01 | 5.79E-01  | 0.84  |
| 16 | 130.2                 | 0.1302 | 0.8680 | 138.95            | 1.58E-02              | 6.12E-01 | 7.32E-01 | 6.14E-01  | 0.84  |
| 17 | 135.6                 | 0.1356 | 0.9040 | 131.40            | 1.67E-02              | 6.48E-01 | 7.75E-01 | 6.50E-01  | 0.84  |
| 18 | 138.7                 | 0.1387 | 0.9247 | 127.35            | 1.72E-02              | 6.68E-01 | 7.97E-01 | 6.69E-01  | 0.84  |
| 19 | 142.5                 | 0.1425 | 0.9500 | 122.80            | 1.78E-02              | 6.93E-01 | 8.23E-01 | 6.90E-01  | 0.84  |
| 20 | 145.1                 | 0.1451 | 0.9673 | 119.90            | 1.83E-02              | 7.10E-01 | 8.40E-01 | 7.04E-01  | 0.85  |
| 21 | 150.0                 | 0.1500 | 1.0000 | 116.28            | 1.88E-02              | 7.32E-01 | 8.70E-01 | 7.30E-01  | 0.84  |
| 22 | 152.9                 | 0.1529 | 1.0193 | 113.30            | 1.93E-02              | 7.51E-01 | 8.87E-01 | 7.45E-01  | 0.85  |
| 23 | 156.8                 | 0.1568 | 1.0453 | 110.85            | 1.98E-02              | 7.68E-01 | 9.10E-01 | 7.64E-01  | 0.84  |
| 24 | 159.7                 | 0.1597 | 1.0647 | 108.40            | 2.02E-02              | 7.85E-01 | 9.27E-01 | 7.77E-01  | 0.85  |

Note: ND Non-Dimensional

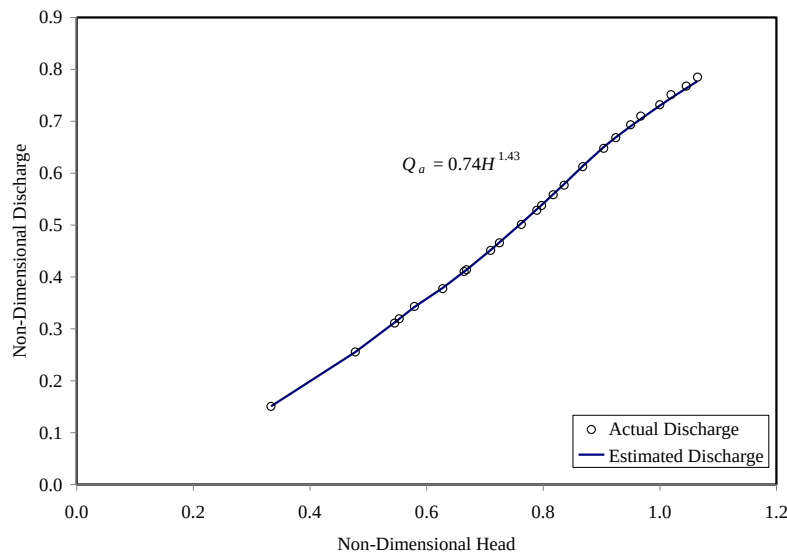


Fig. 3 Variation of Non-dimensionalised discharge with Non-dimensional head

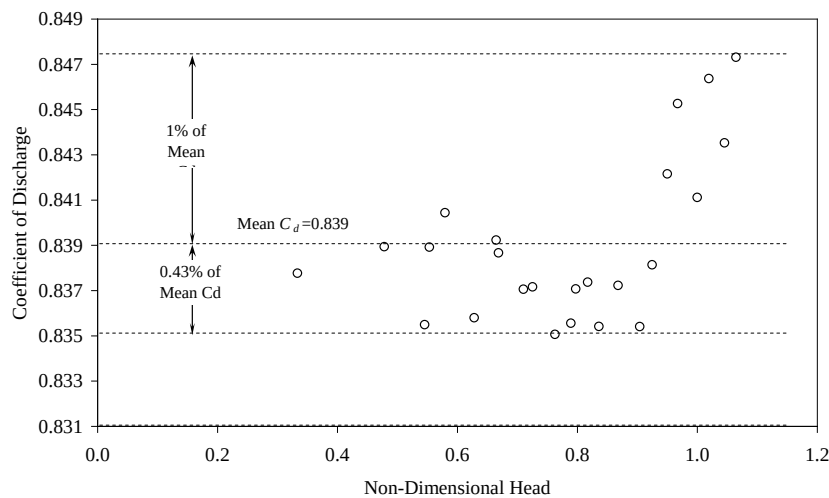


Fig. 4. Variation of Coefficient of discharge with Non-dimensional head

## VI. CONCLUSIONS

1. For the first time an attempt has been made to conduct an experiment for flow through **Non-coplanar vertical Rectangular slots**.
2. The coefficient of discharge is relatively very high at 0.839. This may be attributed to the variation of vertical slots relative positions or slots being not in the same plane.
3. It is also found that the variation of coefficient of discharge is within +1% and -0.43% from the mean coefficient of discharge.
4. The agreement of experimental values with the expected value of discharge validates the experiment, theory and analysis presented in this paper as explained in Introduction section.
5. The experimental values and analysis helps in the understanding of flow through inclined weirs, which has been researched in detail by the authors of this paper as explained in the Introduction section.

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