

Effect of Increase of Momentum on Discharge Characteristics of Broad-Crested Weirs

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SUMMARY The effect of placing a rotating cylinder at the top upstream corner of a broad-crested weir having vertical faces is investigated experimentally. The discharge capacity of the weir is shown to improve significantly by the installation of such a device. Analysis of experimental data has resulted in a method of calculation of the increase in discharge for different diameters and speeds of rotation of the cylindrical roller.

1 INTRODUCTION

It is known (Rouse, 1950) that the discharge coefficient of a broad-crested weir with a rounded upstream corner is less than the theoretical value primarily on account of the deceleration of the flow at the crest due to the formation of the boundary layer. One would therefore expect that the discharge coefficient should increase - and probably even exceed the theoretical value - if the momentum of the liquid in the vicinity of the crest is increased. Such an increase in discharge coefficient would be of great practical significance; one could then design weirs and barrages across rivers with smaller afflux, thereby reducing the extent of submergence upstream. Further the total height of the diversion structure is reduced as a consequence and guide banks and afflux bunds can be designed to be of smaller height.

If a cylindrical roller is placed in the upstream corner of the weir for the entire width of the weir as shown in Figure 1 and is rotated mechanically it

- B Width of the weir, flume;
C Coefficient of Discharge used in the equation
 $Q_0 = K_1 K_2 C_B \sqrt{g} h^{3/2}$;
g Gravitational Acceleration,
h Head over the weir;
 K_1 Correction factor for effects of viscosity and surface tension;
 K_2 Correction factor for effect of curvature of flow;
L Length of weir crest in flow direction;
N Speed of rotation of roller;
 Q_0 Discharge over weir under a head h when the roller is rotating;
r Radius of cylindrical roller;
R Reynolds Number $\frac{g^{1/2} h^{3/2}}{\nu}$;
u Velocity at a height y from the crest;
W Height of the weir;
 W_1 Weber Number $\frac{\rho g h^2}{\sigma}$;
x Distance from the downstream end of the weir;
y Distance of any point from top of crest;
 y_1 Distance of water surface from top of crest;
 ν Kinematic viscosity of the liquid;
 ρ Mass density of the liquid;
 σ Surface tension of the liquid;

3 EXPERIMENTAL SET-UP AND PROCEDURE

3.1 Experimental Set-Up

The experiments were carried out in the Hydraulics Laboratory of the Civil Engineering Department at the University of Roorkee. In all the tests the width of the weir was made equal to the width of the channel, i.e., only suppressed weirs were tested. Two different heights and three different crest-lengths of weirs were used. Both the weir faces were kept vertical.

The experiments were conducted in a fixed bed masonry flume 1.0 m wide, 10.75 m long and 0.60 m deep. The width of the flume was reduced to 0.42 m in order to get a higher discharge intensity and to enable fixing of the cylinder easily. Water was supplied to the flume from a constant head tank and the discharge measured with the help of a calibrated orifice meter fitted in the supply line.

A portion of the test weir around the cylindrical roller was built of steel to ensure the correct geometry in the vicinity of the roller; see Figure 1. The rest of the weir was built of brick masonry and finished smooth with cement mortar. Ventilation

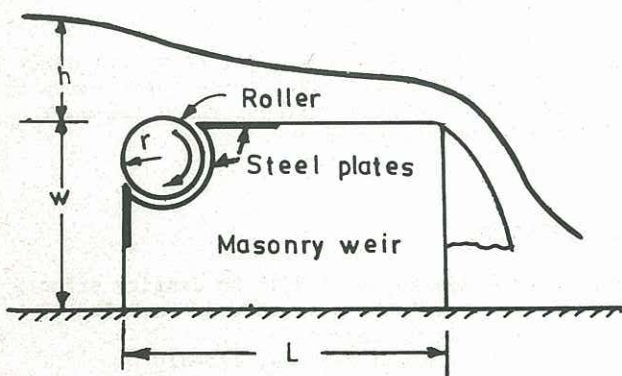


Figure 1 Diagrammatic Sketch of Weir with Roller

accelerates the liquid near the crest. Hence one may expect that such a device will increase the discharge coefficient of the weir. An experimental study was carried out by the authors to investigate the order of increase in discharge due to such increased momentum and the results of this study are reported in this paper.

2 NOTATION

The following symbols are adopted in this paper:

holes were provided in all the weirs to aerate the nappe. The cylinder of the required diameter was provided to the full width of the flume at the top upstream corner of the weir, such that the roller was flush with the horizontal and vertical faces of the weir. The cylinder was taken out through the side walls and housed in two well lubricated bearings. A pulley was mounted at one end of the roller and driven by a variable speed electric motor. Two different diameters of rollers, viz 30 mm and 60 mm were used during this study.

3.2. Experimental Procedure

A weir of the required dimension was built at a distance of 1.95 m from the downstream end of the flume. A certain discharge was allowed into the flume and this was measured with the help of the orifice meter. For a particular discharge measurements were taken for no roller rotation as well as with four different roller speeds of 1000, 2000, 3000 and 4000 RPM. The measurements included the water surface profile on the crest and upstream, as well as velocity distribution at the centre of cross section of the crest with a Prandtl tube. The measurements were repeated for other discharges and subsequently with different weirs.

4 ANALYSIS OF DATA

4.1 Typical Water Surface Profiles

The water surface profiles at different speeds for a particular discharge are shown for one of the weirs tested in Figure 2. These profiles are typical of the water surface profiles obtained at other discharges and for other weirs. It may be seen from Figure 2 that, with increase in speed of rotation,

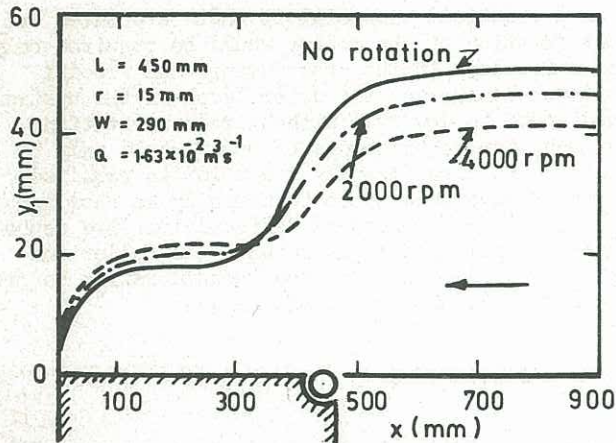


Figure 2 Typical Water Surface Profiles

there is a general lowering of the water level upstream of the weir; on the weir crest itself the trend is roughly reversed indicating that the critical depth section is closer to the downstream end of the crest at higher speeds.

4.2 Typical Velocity Profiles

The velocity distribution at the centre of the crest at different roller speeds is shown in Figure 3 for one weir at a particular discharge. The effect of the roller rotation on the velocity distribution is clearly seen in this figure. There is a considerable increase in velocity at small distances from the crest and the increase is larger at larger speeds; this increase in velocity diminishes at large distances from the crest. To maintain the same discharge (note that the discharge was held constant during these runs) the increase in velocity

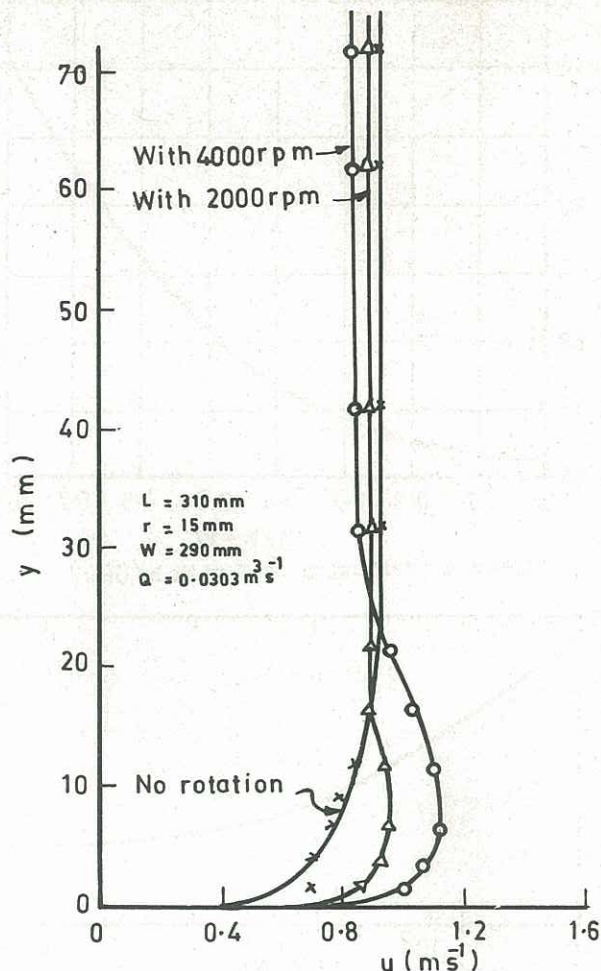


Figure 3 Typical Velocity Profiles on Weir Crest

at small values of y has to be offset by a decrease in velocity at very large values of y . Such a decrease is also clearly discernible in Figure 3. But it is the increase in velocity at small values of y which is really significant and is responsible for the smaller heads—see in Figure 2—at larger speeds, thus proving the premise that increase of momentum close to the crest ought to improve the discharging capacity of the weir.

4.3 Discharge Relation for no Rotation of Roller

As per Ranga Raju and Asawa (1977) the discharge over a broad-crested weir with a sharp upstream corner can be obtained from the equation

$$Q_0 = K_1 K_2 C B \sqrt{g} h^{3/2} \quad (1)$$

The parameter C accounts for the velocity of approach and was evaluated theoretically as a function of $h/(w+h)$ and the relationship is shown in Figure 4. Based on the analysis of a vast amount of data from different sources and using different liquids the parameter K_1 was related to $R^2 W_1^6$ as shown in Figure 5; the value of K_1 is unity at $R^2 W_1^6$ greater than 10^3 . They also proposed a relation between K_2 and h/L for sharp-cornered weirs; obviously the variation of K_2 with h/L would be different for a weir with a cylindrical roller placed at its upstream end.

It was assumed in the present analysis that Figure 4 and 5 are applicable to the present case also. Accordingly K_2 was evaluated for all the data (for no rotation of the roller) from (1) and the variation of K_2 with h/L is shown in Figure 6. There

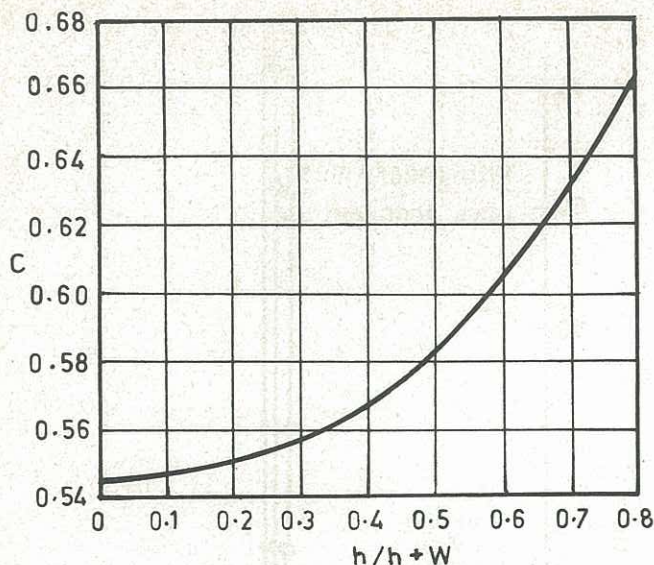


Figure 4 Variation of C with $h/(h+W)$

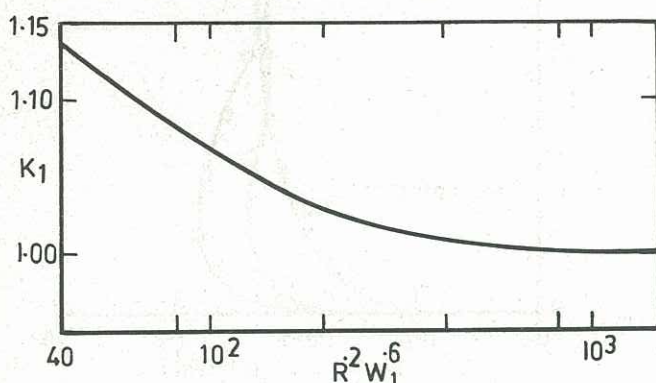


Figure 5 Correction for effects of viscosity and surface tension

exists a unique relation between these parameters independent of the size of the roller etc. Because of the absence of separation at the upstream corner in the present case, the value of K_2 is larger than for sharp-cornered weirs as shown in Figure 6. The scatter of data on Figure 6 suggests a possible

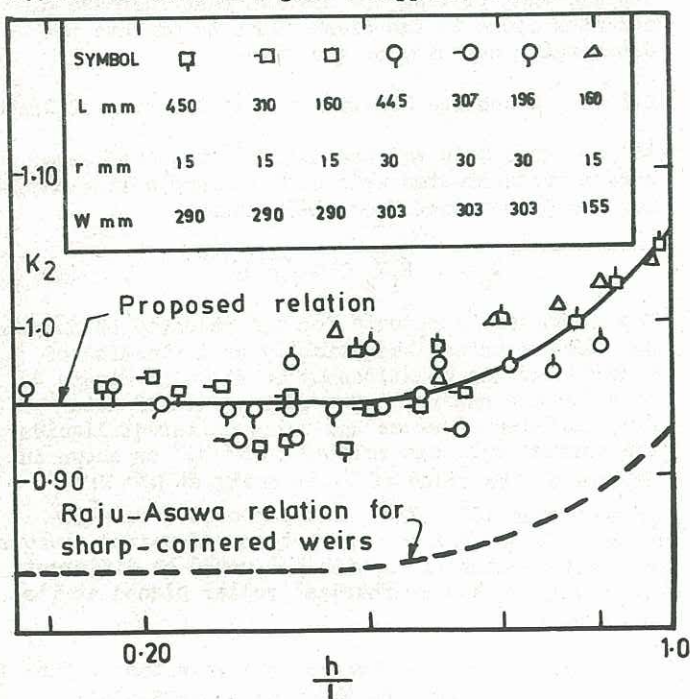


Figure 6 Variation of K_2 with h/L

error of less than ± 5 per cent in the discharge computed by this method.

4.4 Increase in Discharge due to Rotation:

The functional relation for discharge Q under rotation may be written as

$$Q = f(Q_0, N, r, g, h), \quad (2)$$

By dimensional analysis the above equation may be reduced to

$$\frac{Q}{Q_0} = f_1 \left(\frac{h}{r}, N \sqrt{\frac{r}{g}} \right), \quad (3)$$

if it is recognised that the parameter Q_0/Nr^2 has no physical significance and may thus be dropped.

The values of Q at the measured head h were calculated using (1) and Figures 4, 5 and 6. All the data were then plotted in accordance with (3). Contours of $N\sqrt{r/g}$ could be drawn on this figure despite some scatter as shown in Figure 7; the scatter may partly be attributed to the errors in the estimation of Q_0 . Figure 7 indicates that the increase in discharge is substantial at low h/r and high $N\sqrt{r/g}$ values. It is noteworthy that at high speeds and low h/r values an increase in discharge of the order of 50 per cent may be achieved by roller rotation.

From a practical viewpoint it must be pointed out that rotation of the roller would be required only for a few days in the year during peak floods; at lower discharges the water level in the upstream pool would be low even without roller rotation. As such, the requirements of power would only be nominal and significantly the power is required during floods when there is normally no shortage of hydropower. Practical difficulties like deposition of silt in the gap between the roller and the weir would, however, need consideration before the device is adopted in the field.

5 CONCLUSIONS

It has been shown that additional momentum supplied by having a rotating cylinder at the upstream corner of a broad-crested weir causes a favourable modification in the velocity profile over the weir crest resulting in an improved discharging capacity of the weir. The increase in discharge is shown to be considerable at high speeds of rotation and at low values of the ratio of head over the weir to the cylinder radius.

6 REFERENCES

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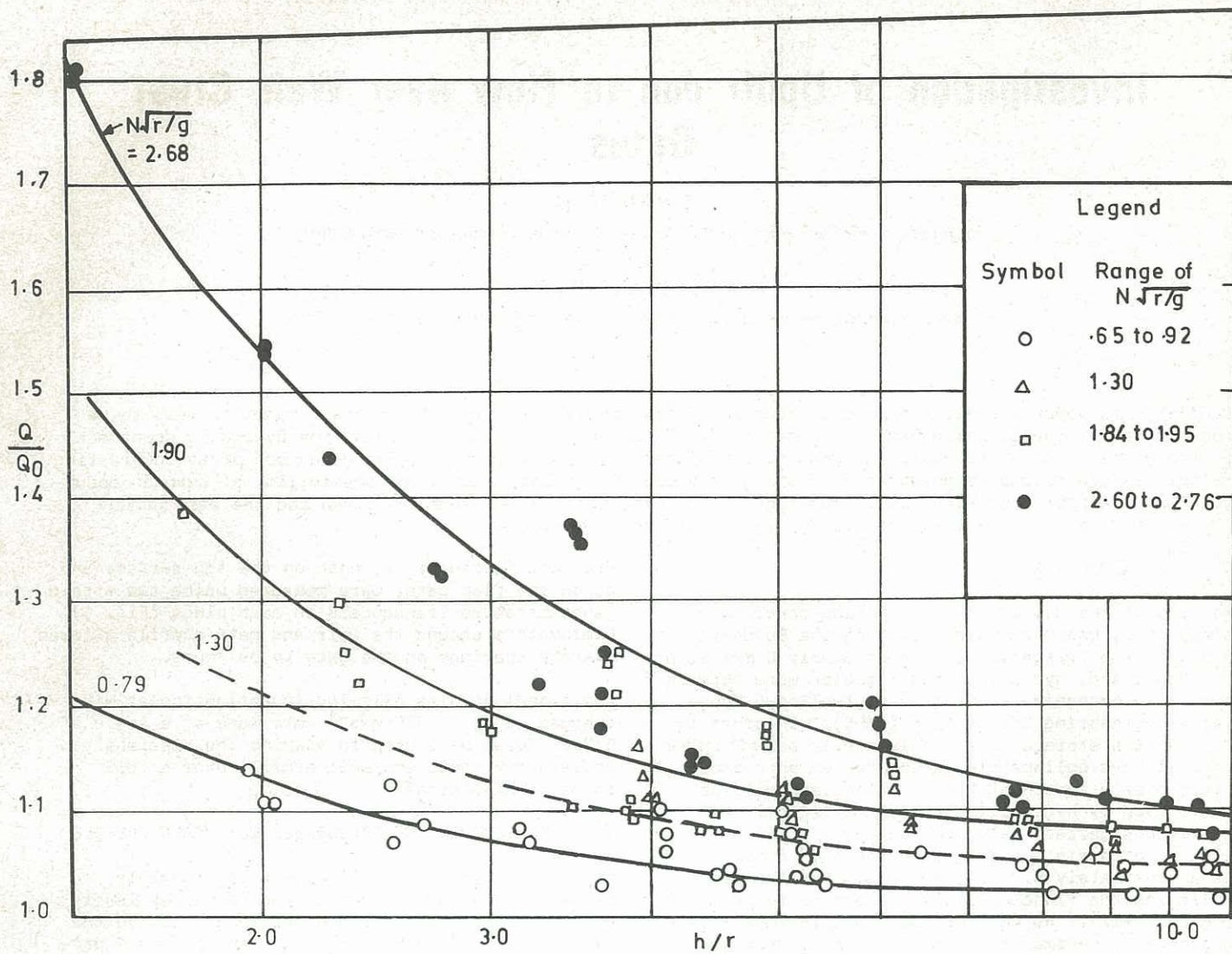


Figure 7 Variation of Q/Q_0 with h/r and $N\sqrt{r/g}$