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Discharge characteristics of orifice spillway under oblique approach flow

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ABSTRACT

Orifice type spillways are provided in the dam at lower level for facilitation in flushing of the sediment from the reservoir in addition to spilling the flood water. However, in most of the hydraulic structures, particularly in the earthen and rockfill dams, the spillway is not a part of the dam and it is provided on either of the banks of the river which results in oblique approach flow to the spillway that likely to affect the discharging capacity of the spillway. Presented in this paper is an experimental study for discharge characteristics of orifice type spillway under straight and oblique approach flow. Analysis of data indicates that discharge through the spillway decreases with increase of obliquity of the flow. The effect of the obliquity has been quantified and discharge equations for one, two and three simultaneous opening of the bays have been proposed.

1. Introduction

Provision of orifice spillway at lower level in the dam facilitates the flushing of the sediment downstream of the dam. The orifice type spillways have been widely recognized as the most appropriate especially for run-of-the river projects for handling both flood releases and flushing of sediment. The orifice spillway would be operated for un-gated condition for flushing the sediment from the reservoir with low reservoir water levels. However, it would be operated with gated condition for regulation of flow [9].

The spillway operates as free overflow spillway for lower discharges, whereas for higher discharges the flow through the spillway is governed by the orifice flow. Generally, the orifice flow condition requires head over the crest in excess of about 1.5–1.7G_o, where G_0 is the height of the orifice opening. A definition sketch of an orifice type spillway is shown in Fig. 1.

Flow through a bay of the orifice spillway may be written as [9]

$$Q = C_d L G_0 \sqrt{2gH_c} \quad (1)$$

where C_d is the coefficient of discharge, L is the width of bay, g is the acceleration due to gravity, and H_c is the head over the center line of orifice and equal to $H - G_0/2$, where H is the head over the spillway crest. The following equation relates C_d with the parameter ratio of operating H and design head H_d in the range of $H/H_d = 0.8$–1.33 [9].

$$C_d = 0.148 + 0.945(H/H_d) - 0.326(H/H_d)^2 \quad (2)$$

Several studies have been carried out for underflow through the gated and side orifices in channels [2–8,13–16]. Mazumdar and Roy [12] carried out an experimental analysis on orifice flow in a gated spillway. They introduced pressure correction factor as a function of both head and gate openings which reduced substantially the discrepancy between experimental values of discharge and theoretical values. Bhajantri et al. [1] investigated the hydraulic characteristics of flow over spillway crest profile by simulating the velocity distribution, pressure distribution and discharge characteristics using a finite volume based numerical model. They described the formulation and development of a numerical model based on weakly compressible flow equations for flow over spillway.

Most of the studies available in the literature deal with discharge characteristics of orifice type spillway under normal (straight) flow condition. However, in most of the hydraulic structures, particularly in the earthen and rockfill dams, the spillway is not a part of the dam and it is provided on either of the banks of the river. Thus approach flow to the spillway is oblique and that will affect the discharging capacity of the spillway. Presented in this paper, an experimental study related to discharge characteristics of orifice type spillway under straight and oblique approach flow, which have not been taken up earlier.

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Nomenclature

C_d	coefficient of discharge
Fr	Froude number
G_0	spillway gate opening, m
g	acceleration due to gravity, m/s^2
H	head over spillway crest, m
H_c	head over the center line of orifice, m
H_d	design head, m
L	width of bay, m
Q	spillway discharge, m^3/s
Re	Reynolds number
r	radius of approach flow, m
V	approach velocity, m/s
y	depth of approach flow, m
ρ	mass density, kg/m^3
μ	viscosity, (N s)/m^2

2. Dimensional analysis for C_d

Probable variables affecting the coefficient of discharge C_d for orifice type spillway are width of each bay L, G_0, H_c, radius of approach flow r, depth of approach flow y, approach velocity V, mass density ρ, viscosity μ, and acceleration due to gravity g. The functional relationship for C_d may thus be written as

$$C_d = f_1(L, G_0, H_c, r, V, y, \rho, \mu, g) \tag{3}$$

Taking ρ, V and H_c as the repeating variables, the functional relationship for C_d in terms of non-dimensional parameters may, thus be written as

$$C_d = f_2\left(\frac{H_c}{L}, \frac{H_c}{G_0}, \frac{H_c}{r}, \frac{H_c}{y}, \frac{\rho V y}{\mu}, \frac{V}{\sqrt{gy}}\right) \tag{4}$$

Eq. (4) may be modified in terms of Reynolds number and Froude number of the approach flow and be expressed as

$$C_d = f_2\left(\frac{H_c}{L}, \frac{H_c}{G_0}, \frac{H_c}{r}, \frac{H_c}{y}, \mathrm{Re} = \frac{\rho V y}{\mu}, \mathrm{Fr} = \frac{V}{\sqrt{gy}}\right) \tag{5}$$

An experimental study was carried out to investigate the effect of the identified non-dimensional parameters on the C_d.

3. Experimental program

3.1. Setup description

The experiment was carried out at the Hydraulic Laboratory of Department of Civil Engineering, Indian Institute of Technology Roorkee on an orifice type ogee spillway consisting of four bays each of 158.3 mm width and 250 mm height. Three piers of semi-circular nose and thickness 111.1 mm were provided. The profiles of upstream breast wall and upstream and downstream ogee are shown in Fig. 2.

A stilling basin of length 1166.7 mm is provided downstream of ogee profile for energy dissipation, which is followed by a rectangular channel of bed width 966.67 mm. The approach channel is rectangular in cross section with bed width 966.67 mm and follow circular path. The experiment was performed for three radii of the curved approach channel so that three oblique approach flow shall be generated. Various dimensions of the spillway is shown in Fig. 2, while Fig. 3 shows photographic view of the set-up. Water was supplied to the approach channel from a reservoir, in which water was fed by three 50 hp pumps. A pre-calibrated rectangular weir was installed downstream of channel for measurement of discharge passing through the spillway.

3.2. Procedure

The experiments were conducted for studying the discharging capacity of the orifice spillway for un-gated and orifice flow conditions under three different oblique approach flows, i.e., $r=\infty$ (straight approach), 2 m and 3.72 m. For each approach flow condition, measurements were taken for different combinations of single bay, two bays and three bays operation as given in Table 1 – a total nine combinations were studied.

For each run, discharge passing through the spillway using weir, water level upstream of the spillway in mid-stream and transverse distribution of approach flow at mid-depth and 1 m upstream of the spillway crest were measured. However, discharge passing through each bay was computed by measuring the three points velocities of flow over the crest using the Pitot tube and integrating it over the opening area of the orifice at the crest.

For each configuration of bays, the experiment was performed for various discharges ensuring orifice flow in the bay(s) by maintaining water level upstream of the spillway above the invert of the breast wall. The coefficient of discharge was computed using

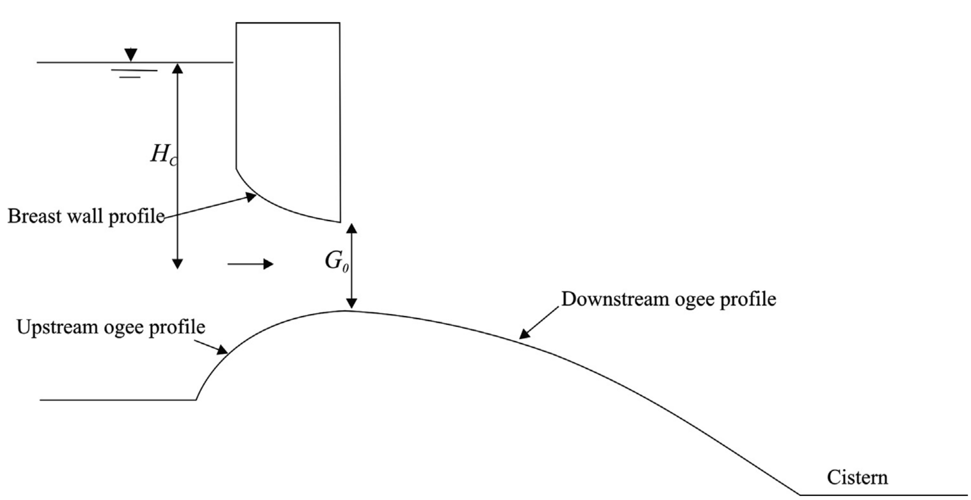

Fig. 1. Definition sketch of orifice type.