Flow parameters through sluice gate in a dam in India

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ABSTRACT

Controlling the discharge through a gravity dam by means of sluice gate is quite common technique. Although extensive theoretical and experimental studies on discharge parameters are available, most of these studies reported sedimentation and river bed conditions resulting in reduced discharge through a dam, although limited research has focused on controlling and adjusting the discharge considering practical scenario. This study presents a simplified analytical model applied to a typical case study on a typical dam in western India which was used the lift irrigation technique for improving the discharge. The approach focuses on the parametric studies for predicting the variations in discharge ratio employing a range of geometrical parameters such as area and aspect ratio of the individual sluice gates and their total number. It was found that the discharge is largely affected by minor alteration in these parameters. A set of important conclusions was drawn from the entire study.

Key words: Analytical modeling, dam, discharge, flow, opening, ratio, sluice gates.

INTRODUCTION

Hydraulic structures have diversified applied functions such as flood control, distribution of stored water and most importantly providing constructive ecological conditions, for which the analytical aids available in daily operation are rare. A better prediction of the flow near the dam structures would be beneficial to optimum performance of all the tasks for which the dam is constructed.

Flow through a side sluice gate is governed by the equations of spatially varied flow with decreasing discharge. Sluice-gate discharges for various gate openings have been studied by numerous researchers. Henry (1950) studied the diffusion of submerged jet downstream to a normal sluice gate and developed a useful correlation for discharge coefficient under free and submerged flow conditions. This was later confirmed by Rajaratnam and Subramanya (1967). Panda (1981) and Tanwar (1984) related the discharge coefficient to the Froude number, the ratio of flow depth to the side sluice gate opening, and the ratio of tail water depth to the gate opening. In case of a normal sluice gate, the elementary discharge coefficient has been found to be a function of channel flow depth for free-flow conditions, while for the submerged flow condition, the ratio of crest width to gate opening is important. The latter is also applicable to a broad-crested sluice gate (Swamee et al., 1993). Swamee (1992) proposed relevant equations for both free and submerged flows as well as criteria for the submergence. The characteristics of a combined flow over weirs and below sluice gates of equal contraction are discussed by Abdel-Azim et al. (2002) using various geometrical combinations. The flow through rivers and resulting scouring was studied by Bhattacharya et al. (2003). The discharge characteristics of combined weirs and gate structure were studied as well. The study showed a major influence of flow and geometrical parameters on the discharge. The air-water interface in the channel was referred to as the free surface (Binder et al., 2009). Spulveda (2009) proposed various calibration methods for discharge coefficient of submerged sluice gates; a value of contraction coefficient as 0.611 was found to yield satisfactory results. Daneshmand et al. (2010) performed classical hydrodynamic analysis to arrive at specific solutions relevant to free surface flow. Water surface was found to be typically smooth for a freely emerging jet of
water from a sluice gate, and for submerged flow, the surface profile is usually quite rough (Goel et al., 2010). Mansoor (2014) classified sluice gates as normal, side and skew, depending on its alignment with channel axis. A sluice gate placed oblique to the flow direction was found to be more efficient. However, typical hydrological case studies conducted in India is rather limited (Basack et al., 2014).

The study focused on the Kawlewada dam located in Gondia district of Maharashtra and is a part of Dhapewada lift irrigation project, India. A sketch of the study area is shown in Figure 1. It is pragmatic that the Dhapewada lift irrigation project was not efficient due to reduction in the flow of the Wainganga river during the summer season (Goswami et al., 2017). To investigate the effectiveness of Dhapewada lift irrigation project in terms of discharge with the reduced flow and to maintain the ecological balance at the downstream side of the dam, the present study deals with a simplified analytical modelling approach, with relevant computation and interpretation.

The discharge through the dam was allowed through a series of rectangular sluice gates shown in Figures 2 and 3. The area, aspect ratio and number of gates have been varied and the resulting variations in the total downstream discharges are studied in detail.

**Analysis**

First of all, the net discharge through the sluice gates is calculated (see Figure 4) using the following correlation:

$$Q_{\text{gate}} = (a \times b \times N) \times V$$

(1)

where, $a$ and $b$ are lengths and width of the one gate opening and $N$ is the number of gates.
Figure 2: The Kawlewada dam: (a) Front View, (b) Top view, (c) Cross section view at point XX, and (d) Isometric view

All dimensions are in meters
The parameter $V$ is defined as (Rouse, 1967):

$$V = C_d \sqrt{2gy}$$  \hspace{1cm} (2)

where, $C_d$ is the coefficient of discharge, $g$ is the gravitational acceleration and $y$ is the gate opening. The parameter $C_d$ is given by (Rouse 1967):

$$C_d = \frac{C_c}{\sqrt{1 + C_c \times X_d}}$$  \hspace{1cm} (3)

where, $y$ is the gate opening and $C_c$ is the contraction coefficient.

**RESULTS AND DISCUSSION**

The variation of the discharge ratio $R_Q$ is studied with respect to the area ratio $R_A$, the aspect ratio $a/b$ and the number of gates $N$. The range of variation of the input parameters has been presented in Table 1. The discharge ratio $R_Q$ and the area ratio $R_A$ are defined as:

$$R_Q = \frac{Q_{gate}}{Q_0}$$  \hspace{1cm} (4)

$$R_A = \frac{A_{gate}}{A_{dam}}$$  \hspace{1cm} (5)

$$A_{gate} = (a \times b \times N)$$  \hspace{1cm} (6)

$$A_{dam} = (L \times H)$$  \hspace{1cm} (7)

For the particular case, $L = \text{Length of dam} = 420$ m

$H = \text{Height of dam} = 30$ m
Table 1: Input parameters for case study.

<table>
<thead>
<tr>
<th>Area Ratio ($R_A$)</th>
<th>Aspect Ratio ($a/b$)</th>
<th>Number of Gates ($N$)</th>
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<tr>
<td>0.01</td>
<td>0.50</td>
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<td>0.75</td>
<td>10, 12, 14, 16, 18</td>
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<td>0.02</td>
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</table>

$Q_0$ = Net upstream discharge through the river without dam = 40.19×10³ m³/s (Goswami et al., 2017)

Considering value of $C_c$ to be 0.611, $a$ to be 10 meter and $y$ to be 0.4 meter (Goswami et al., 2017), value of $C_d$ is calculated and found as 0.6 using Eq. (3). Thus the velocity $V$ is found 8.40 m/s.

The variation of discharge ratio $R_Q$ with respect to aspect ratio $a/b$ for different values of $R_A$ and $N$ is shown in Figure 5. As observed that when the aspect ratio, area ratio and number of gates vary, it ranges $0 \leq a/b \leq 1.5, 1 \leq R_A \leq 5$ and $10 \leq N \leq 18$, respectively the discharge ratio varies from 0.35 to 2.6. It has also been observed that with an increase in aspect ratio, the parameter $R_Q$ increases linearly till a peak value is attained following a stabilizing trend. The peak value is observed to attain an aspect ratio of $a/b = 0.5$. Such observation may be justified by the fact that an optimization of the discharge yielded at this particular value of aspect ratio resulting from Equations (1), (2) and (3).

The variation of the discharge ratio $R_Q$ versus the area ratio $R_A$ for different values of $a/b$ and $N$ is shown in Figure 6. As observed, a linear trend of variation took place. A slight non-linear variation was also noted when the area ratio $R_A$ exceeds a value of 3, specifically for $N= 10$ and 12. The lines were observed to originate from origin and progressively diverged. Such pattern of variation may be justified by the fact that a progressively increasing area has initiated a linearly increasing discharge through the gate, as per Equation (1).

The variation of parameter $R_Q$ with respect to $N$ for different values of $a/b$ and $R_A$ are shown in Figure 7. As observed, the variation is linearly increasing commencing from the origin variation in the value of $a/b$ did not influence the divergence of the line significantly. Such trend is justified with the fact that increasing number of gates produced a proportionate rise in the discharge as per
Figure 5: Variation of discharge ratio with aspect ratio for numbers of gates: (a) 10, (b) 12, (c) 14, (d) 16 and (e) 18.

**Figure 5**: Variation of discharge ratio with aspect ratio for numbers of gates: (a) 10, (b) 12, (c) 14, (d) 16 and (e) 18.
Figure 6: Variation of discharge ratio with area ratio for different values of aspect ratio: (a) 0.50, (b) 0.75, (c) 1.00, (d) 1.25 and (e) 1.50.
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(a)

Number of gates, \( N \)

Discharge ratio, \( R_Q \) (10^{-3})

\( a/b : \)

- 0.5
- 0.75
- 1
- 1.25
- 1.5

\( R_A = 0.01 \)

(b)

Number of gates, \( N \)

Discharge ratio, \( R_Q \) (10^{-3})

\( a/b : \)

- 0.5
- 0.75
- 1
- 1.25
- 1.5

\( R_A = 0.02 \)

(c)

Number of gates, \( N \)

Discharge ratio, \( R_Q \) (10^{-3})

\( a/b : \)

- 0.5
- 0.75
- 1
- 1.25
- 1.5

\( R_A = 0.03 \)
The effectivity of sluice gates in controlling the discharge through a gravity dam has been investigated in this study by means of simplified analytical methodology. The model has been applied successfully to a specific case study at a site in western India and important observations were found therefrom.

The study reveals that the discharge ratio increases linearly with the aspect ratio till a peak value is attained and thereafter stabilises. The peak value was observed to occur $a/b = 0.5$. With respect to the area ratio and the number of gates, the discharge ratio increased fairly linearly commencing from the origin with progressive diverging trends.

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REFERENCES


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