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Breach Flow Hydrograph Due to Washoutof Fuseplug in an Earthen Dam

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Abstract: The computation of hydrograph of breach flow passing through a fuse plug depends on the geometry of fuseplug, the properties of fuse plug fill materials,capacity of the reservoir and the incoming flow to the reservoir. The experiments are carried out with adopted fuse plug geometry. But the soil fills and incoming discharge to the reservoir were varied. The non-dimensional breach flow hydrograph are plotted with scale parameters q_{wp} and t_{wp}, the peak breach flow intensity (q_{wp})and time to breach that peak value (t_{wp}) for all the runs respectively. These scales are correlated with average inflow to the reservoir (q_{in}),fuseplug height (H_D), soil resisting velocity (V_{SR}) and surface area of the reservoir (A_s). The values of exponent 'n' for the fitted curves of the recession limbs of the normalized hydrographs varies from 0.5 for type-A soil to l.0 for type-D soil. A more reasonable value of 'n' is 0.65 which makes the fitted curve more acceptable. This study supports an approach which can be used to compute breach flow hydrograph.

Key words: Fuse plug · Hydrograph · Scale parameters

INTRODUCTION

Dams play a major role in managing surface water resources in a planned way to bring economic development of a nation. Among the various types of dams constructed around the globe, the earthen dams are the most common type and constitute the vast majority of dams.

The earthen dams are more susceptible to failure [1-3]. The causes may be due to improper design, excessive sedimentation of reservoir, adoption of erroneous reservoir operational rules, or due to unexpected flash flood [4, 5]. The main cause of the failure of an earthen dam is due to overtopping of artificially stored reservoir water. When dam fails, large quantity of stored water is released causing disaster in the downstream region. Hence,fuseplug is provided to protect the dam against catastrophic failure due to overtopping. Fuse plug, a pre-defined breach section, works as a safety valve for an earthen dam [6, 7]. The height of fuseplug is the difference between maximum reservoir level (MRL) and full reservoir level (FRL). ln an eventuality of failure of crest gates to operate in time, it also serves as an emergency outlet. This is provided intentionally to be washed out during high flood and to be reconstructed after the passage of flood. When water overtop over the fuseplug section,the flow that takes place is a weir type flow. The changing morphology of fuse plug with time of breach controls the breach flow. To estimate breach flow (Q_w), the reservoir water level,the height and location of crest of the weir formed due to erosion of soil from fuseplug surface are essential which is practically not possible to measure in the field [8-10]. So the experiments are carried out in a controlled environment with a physical model of fuse plug in the Hydraulic Laboratory,University College of Engineering, Burla, Odisha, lndia.

Experlmental Setup and Data Acqulsltlon: The flume used for the experiments is a tilting flume of 15 m long, 0.6m wide and 0.6m in height. The model of fuse plug was made in wood with a trapezoidal breach section at the centre. The fuse plug used for experiment is of the following dimensions: H_D=Height of fuse plug = 20cm, B_{ft} = Top width of fuse plug= 40cm, B_{fb}, = Bottom width of fuseplug = l6.88cm, L_{LB} = longitudinal Base length of fuse plug = l.l5m, L_{LT} = Longitudinal Top length of fuse plug = l5cm. The slopes of upstream and downstream faces othefuse plug = l(V): 2.5 (H).

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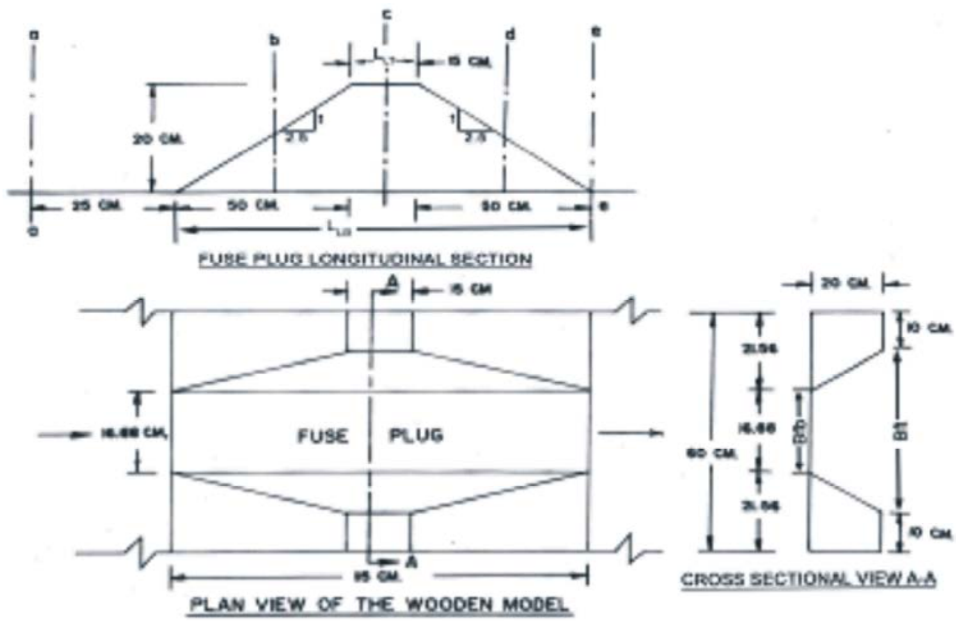

Fig. 1: Fuse plug model in plan and sectional View
The Photographs at Different Sequences of Breaching of a Fuse Plug for a Test Run

Table 1: Type of Soils Used for the Fill of Fuse Plug

Type of soil	d_{50} (mm)	ϕ (degree)	C (KPA)	Y_b (gm/cc)	w % (OMC)	Remark
A	0.51	21	43.16	2.19	10	Soil collected from near
B	0.40	22	17.66	2.02	11	by area of UCE, Burla
C	0.60	27	13.73	2.12	12.5	
D	0.46	26	10.75	2.22	10.5	

The trapezoidal breach Section having side slope θ = 60° was considered based on the historical dam failure cases due to overtopping of reservoir water reported [11]. Figure-l shows the detailed plan, longitudinal section and cross-section of the fuse plug adopted for experiment.

ln the experiments different types of soils were used as fuse plug fill materials.The properties of soil used in the experiments are shown in Table-l.

Preparation of Fuse Plug Model: The wooden fuse plug model block was fitted inside the flume at a distance 6.0m from the inlet of the flume. The open trapezoidal fuse plug section was filled with soil by compacting, layer by layer, at its OMC till the fuse plug model dimensions were achieved [12-14]. The water level (h_w), bed level (h_c) at different longitudinal section, as shown in Figure -l were recorded manually with respect to time using point gauges by five persons referring to a common digital clock. From these basic data other data are computed.

The photographs at different sequences of breaching of a fuse plug for a test run are shown in the Figure- 2a to 2f to demonstrate the erosion of soil by breach flow from a broad crested type of weir [15-17]. The crest height of weir and its location goes on changing with time. ln Figure 2a the fuse plug is about to be overtopped by reservoir water, in figure-2b, water just overtopped, where as in Figure 2c and 2d the weir type of flow is clearly visible and in the Figure-2e, it shows the breaching process has come to an end phase and finally in Figure-2f it shows the complete washout of fuse plug.

Breach Flow Hydrograph: The plotted graph of breach discharge with time is known as breach flow hydrograph [18, 19].

The study regarding breach hydrograph is essential for the management of flow downstream of the reservoir. The procedure to this approach suggested is explained in the following paragraph. ln flgure-3 the longitudinal profile of the fuse plug during its wash out process is shown.

The head of water over the crest of the sediment bed as shown in the Figure-3 during fuse plug breach is noted as (h_u). This is the difference between reservoir water level (h_{wr}) and the height of crest of sediment bed profile

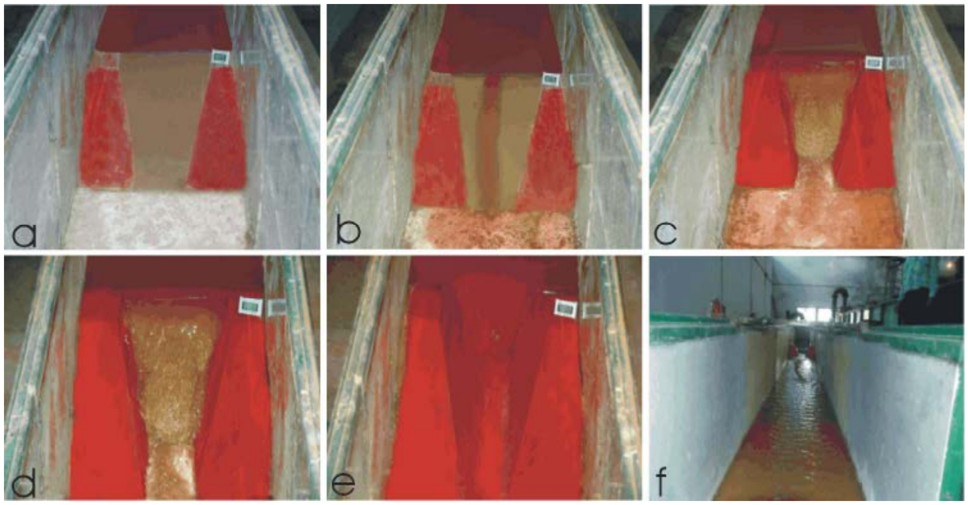

Fig. 2a: Flow of water to the reservoir Before overtopping the fuse plug model
Fig. 2b: Flow of water on fuse plug crest after overtopping
Fig. 2c: Vertical cut in the downstream face of fuse plug along with receding of toe erosion in upward direction
Fig. 2d: Vertical of the breach of fuse plug and spillway type crest formation is seen.
Fig. 2e: Reduction in reservoir water level and total breaching process comes to final stage.
Fig. 2f: Flow of reservoir water after the completion of breaching process

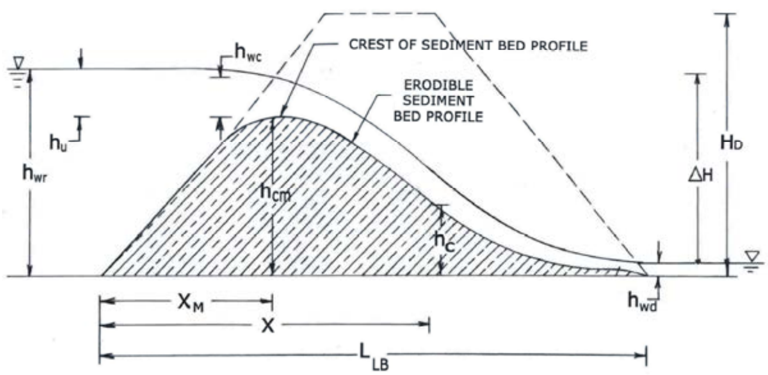

Fig. 3: Definition sketch for the scales X_m, L_{LB} and h_{cm}.

(h_{cm}) as: $h_u = h_{wr} - h_{cm}$.

The breach discharge (Q_w) flowing over fuse plug is computed from the governing equation of continuity of flow as follows:

$$Q_W - Q_{in} = A_s \frac{dh_{wr}}{dt} \quad (1)$$

where,

Q_{in} = lnflow discharge in to the reservoir, which is kept constant throughout the experiment and is measured after completion of breaching of the fuse plug.

A_s = Water Surface area in the reservoir (constant in the present case as flume is prismatic), $\frac{dh_{wr}}{dt}$ = Rate of water level variation in the reservoir.

ln the above Equation (l), Q_{in}, is a known quantity and is constant through out the experiment. This is measured at the end of the experiment with a sharp crested rectangular were placed across the Pucca ground channel which collects water from the flume.The water level variation ($\frac{dh_{wr}}{dt}$) in the reservoir can be obtained from the measured water surface (h_{wr}) with time. Thus the outflow discharge Q_w can be computed.

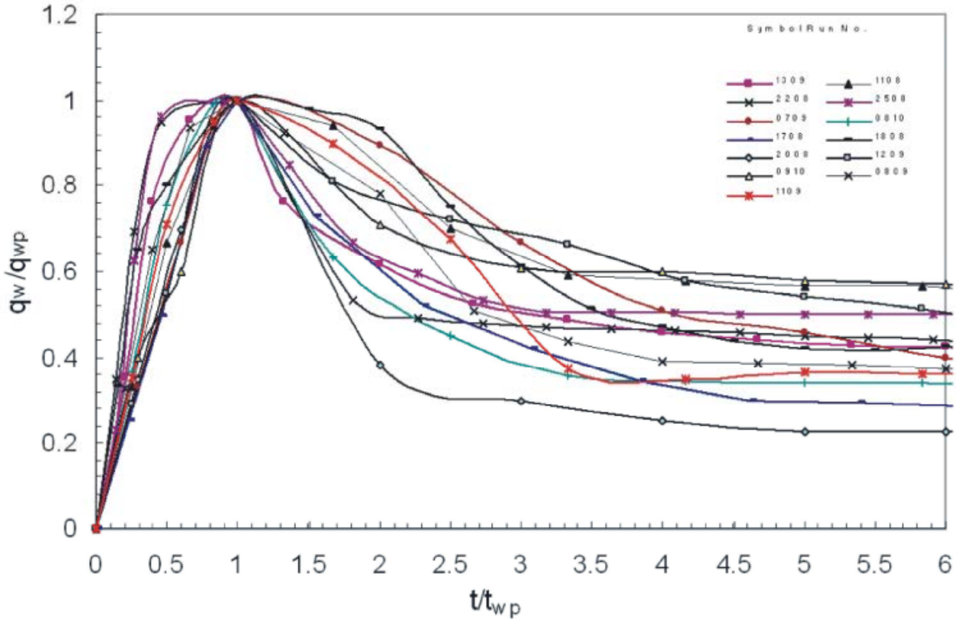

Fig. 4: Normalized breach hydrograph

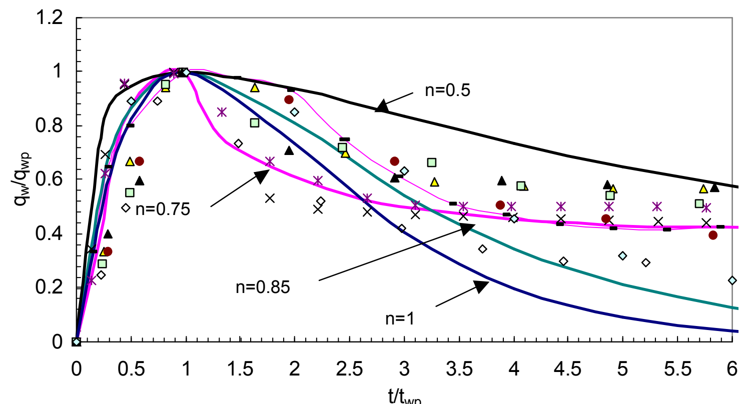

Fig. 5: Normalized breach hydrograph with exponent value of "n" for different soil used as the fuse plug fill

Variation of Water Diseharge Lntensity with Time: The discharge intensity (q_w) is equal to breach discharge (Q_w) at any given time of breach divided by the average width (B_{fb}) of breach section [20]. The normalized (q_w) is obtained by dividing its peak value q_{wp} which is plotted against the normalised time as shown in Figure- 4 for all the runs with different types of soil fill used in the fuse plug. The nature of these graphs are almost have a common features like a steep rising limb,a peak and mild slope receding limb. The equation which fits this nature of graph is as follows with variation in 'n' values.

$$\frac{q_w}{q_{wp}} = \left(\frac{t}{t_{wp}}\right)^n \exp\left\{1-\left(\frac{t}{t_{wp}}\right)^n\right\} \quad (2)$$

The value of 'n' is obtained by trial and error method of fitting the curve. The values of exponent 'n' are varying as 0.5, 0.75. 0.85 and 1.0. The normalized hydrograph with 'n' value equal to 0.85 passes through most of the experimcntal data which is shown in the Figure-5.The scales used to normalize the graphs are q_{wp} and $t_{wp.}$ So to obtain the breach hydrograph for any given situation these scales are to be determined flrst. The scale q_{wp} is plotted against inflow discharge in a dimensionless form for all the types of soils used in the present fuse plug model as shown in Figure -6. lt may be observed that the variation of q_{wp} with q_{in} is as depicted in equation-3.

$$\frac{q_{wp}}{\sqrt{gH^3_D}} = \left(\frac{gq_{in}}{V^3_{SR}}\right)^{0.5256} \times 0.0024 \quad (3)$$

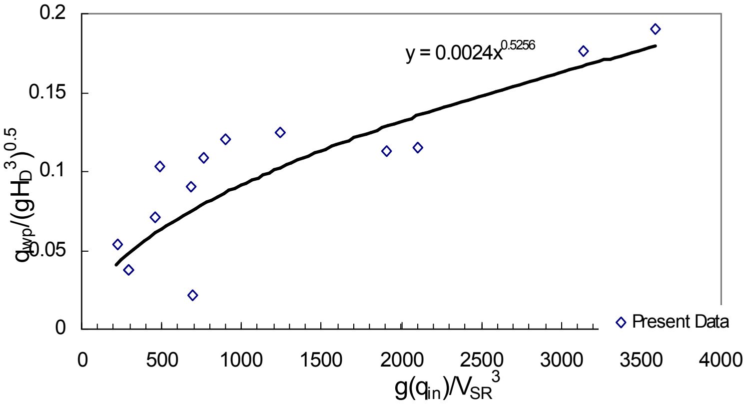

Fig. 6: Variation of non-dimensional outflow discharge scale (q_{wp}) with average inflow discharge intensity and soil resisting velocity (V_{SR})

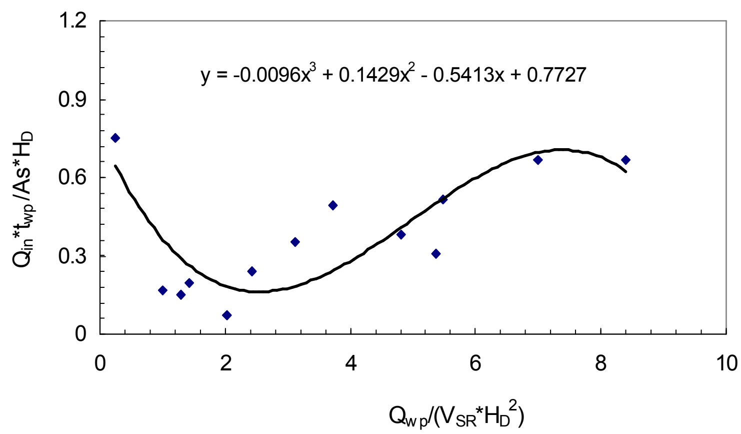

Fig. 7: Variation of non-dimensional time t_{wp} with non-dimensional Q_{wp}

To compute the outflow discharge at any time (t), it is essential to know the time scale parameter t_{wp}. The time of occurrence of peak discharge is nondimensionalised with Q_{in} and capacity of the reservoir (As, H_D)which is plotted against non-dimensional Q_{wp} of the form ($Q_{wp}/V_{SR}H_D^2$) ☻ as shown in Figure-7.The relation between them may be written as

$$\frac{Q_{in}t_{wp}}{Capacity} = -0.0096x^3 + 0.1429x^2 - 0.5413x + 0.7727 \qquad (4)$$

Capacity = A_s x H_D

$$Where, X = \left(\frac{Q_{wp}}{V_{SR}H_D^2}\right)$$

And $V_{SR,}$ The soil resisting velocity is given as follow.

$$V_{SR} = \sqrt{\frac{\Delta\rho}{\rho_w} g d_{50} \tan\phi + \frac{c}{\rho_w}}$$

An interesting observation may be marked in Figure -7 that t_{wp} is closely related to the peak discharge and Sediment resisting vclocity for a given capacity of the reservoir, inflow to the reservoir and height of fuse plug. This value initially decreases, reaches a minimum of the order of 0. 1 5 then gradually increases and may be constant there after.

CONCLUSION

The approach suggested for computation of breach flow hydrograph is a dimensionless analytical solution. The limitations of this study are the constant incoming discharge maintained to the reservoir and limited categories of soil taken as soil fill in side the fuse plug. Looking into the nature of the problem where system variables change dynamically,field measurements are impossible and the availability of supporting laboratory data is not much, the results presented can be used with an acceptable level of error.

Notations:

A_s : Reservoir Water surface plan area
B_{ft} : Top Width of fuse plug
B_{fb} : Bottom width of fuse plug
d_{50} : Median particle size of the soil
g : Acceleration due to gravity
h_c : Sediment bed height from bottom of the flume during breaching
h_{cm} : Crest height of erodible sediment profile
h_{wr} : Water surface at section-a which in the reservoir
h_{wd} : Downstream (near toe) water level from flume bed.
H_D : Height of fuse plug
h_u : Water head over the crest of the sediment bed.
L_{LB} : Longitudinal length at bottom of fuse plug
L_{LT} : Longitudinal Top length of Fuse Plug
n : Exponent
Q_{in} : Inflow discharge to the reservoir
Q_w : Breach water discharge
q_w : Outflow breach discharge intensity
q_{in} : Inflow discharge intensity
Q_{wp} : Peak breach water discharge
t : Time (in seconds, minutes and hours)
V_{SR} : Soil resisting velocity
X : Distance along the flow, from the origin of the fuse plug
X_{50} : The distance at which $h_c = 0.5h_{cm}$
X_m : Value of X at $h_c = h_{cm}$
ϕ : Angle of friction of the soil
σ : Standard deviation of a variable
γ_b : Bulk density of soil fill in fuse plug
ΔH : Difference in water level between upstream and downstream of the fuse plug
R_S : Density of sediment particle
ρ_w : Density of water

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