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Laboratory Investigation to Study Breach Behavior of Embankments

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Abstract: *Dam failures cause loss of lives as well as massive damage to the structure. Overtopping failure of dams is the most frequent form of embankment failures as compared to other causes of failure. Therefore, it is necessary to analyze the breaching of embankment for the development of early warning system of people downstream of the embankment. To understand the breaching process, the essential breach parameters are breach initiation time, breach width, time to breach, shape of breach. Also, the soil characteristics of fill material influence the rate of breaching of embankment dams. Present study gives the results of seven tests conducted in a small flume using a wooden fuse plug model. For constant hydraulic conditions, the temporal variations of breaching process were observed and described in different phases of breach profile. It was analyzed that soil composition and degree of compaction were key factors in the breaching process. The constant hydraulic conditions and limited width of the flume are some limitations of the study.*

Keywords: *Fuse plug, Dam breach, Breach characteristics, Temporal variation, Degree of compaction.*

1. Introduction

A dam is a hydraulic structure constructed across a river to store water on its upstream sides with essential benefits to the society like water supply, irrigation, flood control, hydroelectric power generation. Earthen embankment dams have been built since early days of development and used throughout the world [1]. Now, there exist a lot of earthen dams small or large in the world. Along with their benefits, many dam failures have occurred in the past which results in not only loss of lives but also cause massive damage to environment and property. O'Connor and Bee [2] recognized that there was not only destructiveness but also large scale geographic change due to earthen dam failures. These dam failures, besides due to natural disasters have been reported on account of seepage, overtopping, piping and structural defects. From previous studies, it may be concluded that about one third of dam failures were caused by overtopping. The risk of overtopping for embankment dams can never be eliminated completely but can be reduced. So, it becomes essential to analyze the breaching of embankment for the development of early warning system.

2. Review of Literature

Dam failure may be occurred due to many reasons like differential settlements, seepage, overtopping rock slide or poor construction [3]. During the dam failure, the flooded water outflows through or over the dam to rise the discharge on downstream side of the dam. Fread [4] described that in case of dam failure, the magnitude of flow increases abruptly and the time requires for evacuation is very less than precipitation-runoff floods. There are different approaches in the literature, to analyze the breaching of dams which include, parametric modelling [5], case studies [6], [7], physical modelling [8] and experimental studies [1], [9]. Prediction of breach parameters is quite complex because it is difficult to determined various breach characteristics (breach width, formation time, shape of breach) simultaneously. Wahl [10] described the uncertainties in the prediction of embankment dam breach parameters. The different parameters like breach initiation, breach formation etc., can be determined by obtaining the influence of soil material and rate of erosion on the process of breaching during the failure of dam due to overtopping [11]. Wu [12] reviewed the different breach modelling methods and concluded that only a few researchers considered the effect of embankment erodibility in the breach modelling. The factors responsible for breaching of an embankment are properties of material used for embankment, geotechnical behavior and the hydraulic flow through the breach [13]. Also, it is not possible to determine these parameters practically in the field [14].

Among the very recent studies are the works of [7], [15], [16] and [1]. Interestingly, out of these three, [7] is a case study and author studied the pore water pressure and settlement of Alborz earth dam and predicted the future planning, [15] is a one-dimensional mathematical model study. [1] and [16] were experimental investigation in a small and large flume. Verma et al. [1] studied the erodibility process using a fuse plug model in a small flume. For the dam breach analysis, it is essential to conduct small scale or large scale tests which help to address many of the shortcomings identified in literature [17]. Further

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there should be correlation between laboratory tests and the realistic dam failures. In the present paper, the results of an experimental study of progressive breaching of embankment dams due to overtopping have been presented using a fuse plug model.

3. Description of Fuse Plug

Fuse plug is a temporary earthfill structure which is provided usually at the centre of the dam. It acts as a safety valve for the embankment dam. It was designed by considering the water surface level of the reservoir. During the high flood conditions, the fuse plug provides safe passage of water and washes out in a controlled manner without damaging the rest of the dam [18] and so behaves like an auxiliary spillway. As shown in Figure 1, it allows erosion of fill material in longitudinal as well as in vertical direction during overtopping and no erosion in lateral direction.

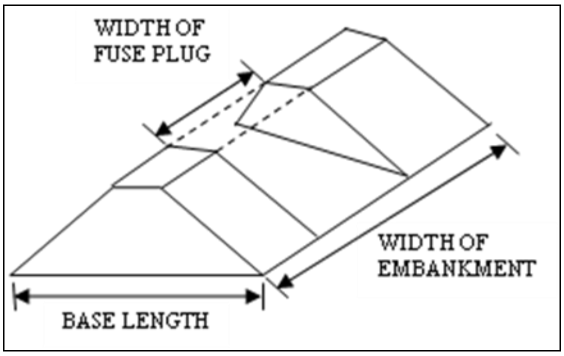

Figure 1: *Fuse Plug model*

Therefore, washout process occurs two dimensionally. A very few researchers studied and analyzed breach modelling using fuse plug. Recently Verma et al. [1] and Sahu et al. [9] studied the breaching of embankment using fuse pug.

4. Experimental Programme

Seven tests on two fuse plug models were conducted in a recirculating water flume (Figure 2) for studying the breaching of an earth embankment, in the Hydraulics research laboratory of Civil Engineering Department at M.M. Engineering College, Mullana, Ambala (India).

4.1 Experimental Set Up

The different tests were conducted using a glass water flume, a wooden fuse plug model, soil of different composition, a compaction roller and other essential standard laboratory devices. The flume dimensions were 4.5 m x 0.57 m x 0.57 m.A reservoir of dimensions 1.00 m x 1.00 m x 0.85 m was used as water reservoir and another tank of same dimensions was used as a sump tank. A water circulating channel was used of dimensions 4.85 m long, 0.57 m wide and 0.85 m deep which was attached with sump tank (Figure 2).The walls and bottom of flume were made of glass to allow lateral observation of the model during the tests. The soil properties were determined in the Soil Mechanics laboratory before the construction of embankment. The two digital cameras were used to record the process of the tests. To obtain water elevations and temporal variation of longitudinal and cross-sections of embankment as the tests proceeded, a pointer gauge with a rolling carriage, placed on the side walls of the flume, was employed. For constructing the embankment models, different proportions of sand, silt and clay were used.

4.2 Soil Properties

Soil properties of embankment material were determined in the Soil Mechanics laboratory. The optimum moisture content, dry density and water content for each soil were determined and the results have been shown in Table 1.

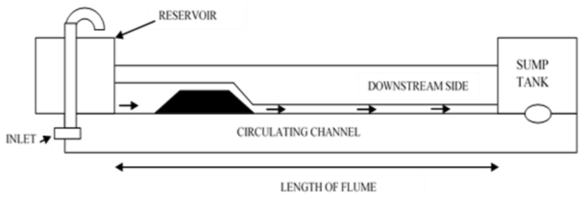

Figure2: *Line diagram of flume*

Table 1: *Properties of soil used for different test*

Test no.	Coarse Grained Soil (% age)	Fine Grained Soil (% age)	Maximum Dry Densitygm/cc
1	38	62	1.625
2	89	11	
3	85	15	1.925
4	95	5	1.902
5	93	7	1.88
6	80	20	1.86
7	76	24	1.87

5. Experimental Procedure

The wooden material was used for fabricating the fuse plug model and painted to avid seepage. For different tests the location of model inside the flume was same for all tests. The dimensions of the model used in the present study are presented in table 2 and Figure 3 (a) and (b).

Table 2: *Dimensions of fuse plug model*

Dimensions of fuse plug model		Values (cm)
Width of fuse plug (B_f)		32.5
Longitudinal length of model, L	Top length (Crest) (L_{ft})	20
	Base length (L_{fb})	120
Height (H_f)		25
Slope		1 V: 2 H

Figure 3(a): *Fuse plug model*

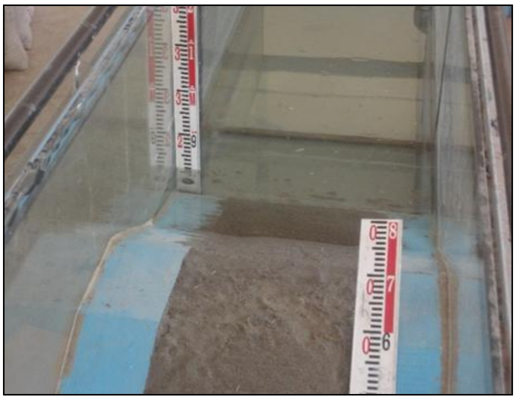

Figure 3(b): *Model with fill material*

5.1 Embankment Construction

The height and width of the fuse plug were restricted as per the dimensions of the model and flume. To reduce the seepage, a layer of pure clay was used at the toe onupstream side the model. The material was filled in 5 layers in the fuse plug model. The soil mixed with optimum moisture content filled in the flume and then the soil is compacted with hand operated roller. Different embankment models were made with mixes of locally available soils in different proportions. After constructing the embankment, an extension time of 24 - 48 hours was provided for uniformity of material. To facilitate observations of the development of breach, a grid of horizontal and vertical line was drawn on the glass sidewalls of the flume. The sump tank as well as water circulation channel were filled up to specified level so that circulation of water could be maintained through the reservoir tank and flume. During the filling of water in reservoir tank, the inflow was controlled by the head regulator attached to the inflow pipe and rate of inflow was measured with the help of a piezometer. The depth of water on the upstream of the fuse plug was measured at regular intervals of time by a pointer gauge mounted on a rolling carriage. To maintain uniformity for all the tests, the water on upstream side was filled upto a height of 22 cm. After filling the water on upstream side of embankment, it was retained about 20 hours for homogeneous saturation of embankment. Thereafter, the level of water on the upstream was increased and overtopping occurred. The breaching process of breach growth was videotaped with a high speed digital video camera (Fastec Imaging Inline Gigabyte Ethernet Camera) (Figure 4). The instant photographs were taken with two digital cameras. The procedure was repeated for different proportion of sand-silt-clay using two different fuse plug models.

Figure 4: *Complete set up for experimentation*

5.2 Breach Flow Characteristics

Breach flow characteristics as breach initiation, breach formation, time to breach are important for downstream reservoir pathway. For a fuse plug, these characteristics depend upon the incoming flow to the reservoir, properties of fill material of fuse plug, geometry of fuse plug and capacity of reservoir. Different parameters which were essential for determining the wash out process of the fuse plug model is shown in Figure 5.

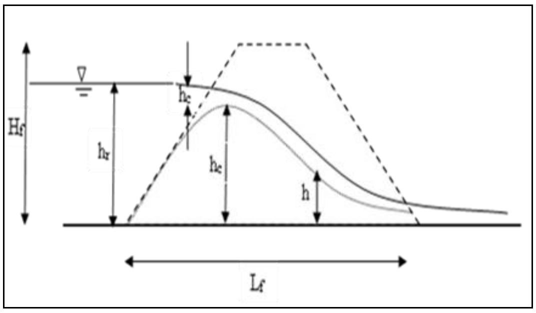

Figure 5: *Different flow parameters*

The water level above the crest of fuse plug (h_{cf}) was determined by taking the difference between water level in the reservoir (h_r) and height of crest of sediment (h_{cs}). The temporal variations of embankment profile and breach characteristics were observed during the overtopping for all tests. The breach parameters of embankment as breach width (b_w) and depth (b_d) were observed during the experiment at short intervals of time using point gauges.

6. Results and Discussion

As the water flows over the crest of embankment, the erosion occurs start from the toe of downstream face.

For both cohesive and non-cohesive soils, the embankment profile was different.

6.1 Embankment profile evolution

The results of 2 tests are taken for describing water surface profile through channel. Test 1 & 7 were considered here. In all 4 tests, the time period starting from breach initiation to breach formation. For cohesive soil as shown in figure 6 (a), the headcut widens and rate of erosion largely affected by cohesion of soil and the slope of headcut steepens. So, the soil material influences the rate of erosion and the influence may vary several orders of magnitude.

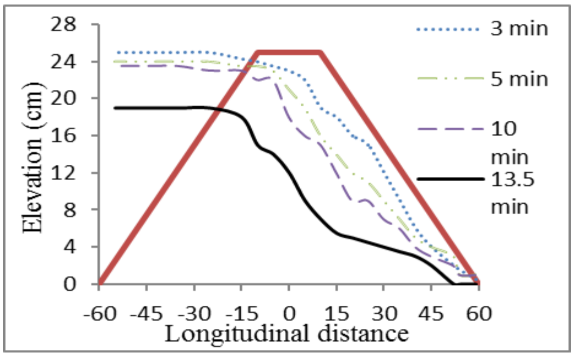

Figure 6(a): *Water surface profile for different time interval (test 1)*

For non-cohesive soil as shown in figure 6(b), the slope of water surface remains almost constant with the steep erosion of downstream face. From the literature, the slope of eroding headcut is equal to static friction angle.

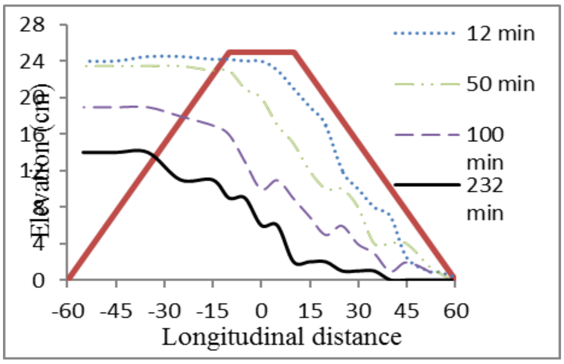

Figure 6(b): *Water surface profile for different time interval (test 7)*

7. Summary and Conclusion

In this study, the results of an experimental work conducted in a small flume using a fuse plug model are described. Seven tests, were analysed for overtopping failure of embankments.

For non-cohesive soil, the progressive erosion occurs and the results indicates that with the passage of time the breach discharge increases abruptly and decreases as the breach widens. The breach width at the top is more than the bottom, except for test 7 which concludes the trapezoidal shape of breach. These results correlate the data given in the literature. Moreover, it is concluded that the breach shape is independent of soil composition, but time-to-breach increases for the different tests by keeping the other parameters constant. So, breach characteristics depend upon soil composition. Also, degree of compaction reduces the time to breach as in test 4 and 5. It concludes that lateral widening of fuse plug model helps in flow of water in controlled manner and increase the evacuation time. The water surface profile of different tests indicates that for non-cohesive soil the breaching progresses gradually but in case of cohesive soil, it is steep erosion (headcutting) rather than progressive.

The constant hydraulic conditions for all tests and limited width of the flume used for the tests are some limitations of this study. Rather than the results of the study will be useful for designing embankments and developing evacuation plans.

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