Breaching of Earthen Dams due to Washout of Fuse Plug

[1]Deepak Kr. Verma and [2]Vikas Garg

[1]Assistant Professor, Civil Engineering, U.I.E.T., Maharshi Dayanand University, Rohtak
[2]Associate Professor in Civil Engineering, Central University of Haryana Mahendergarh

ARTICLE DETAILS

Article History
Published Online: 10 December 2018

Keywords
Fuse plug, dam breach, breach characteristics, temporal variations, embankment profile.

ABSTRACT

Failure of embankments due to overflowing is the major cause for the embankment dam as compared to other types of failure. Failure of a dam causes major losses huge damage to infrastructure and surrounding area; it has drawn more attention to researchers. It is to analyze the breach mechanism to forecast the infrastructure damage and to develop early warning systems. The geotechnical and flow characteristics influence the rate of breaching. The temporal variations of embankment profile and different functional parameters as initiation of breach, breach depth, total time to embankment failure, are necessary to understand the breaching process. In the present study, a total of eight tests were conducted on earthen dam model by using a fuse plug model. Limited fuse plugs and small-scale tests on a small flume are some limitations of the present work.

1. Introduction

Earthen dams are commonly constructed since early days of human civilization for different purposes. However, earthen dams are highly vulnerable to failure due to overtopping, piping, seeping, foundation defects. As the earthen dams are constructed by erodible materials so the failure of these dams, under high flood conditions, occurs due to flow of water inside the body of dam. Due to flow, erosion takes place and a hole occurs inside the dam. The failure of dam causes loss of lives and massive damage to infra structures. Previous studies (Costa, 1985 and Loukela, 1993) reveal that most of the earthen dam failures occurred in the past due to overtopping. It is difficult to eradicate completely the risk of overtopping but the evacuation time of warning time can be establish by analyzing the breach behavior of earthen dams. In the present paper an experimental study using a fuse plug model was described to obtain the different breach parameters before and during the process of overtopping.

2. Review of literature

Singh (1996) compiled the database of different dams that had failed in the past. He also classified the different methods of dam breach analysis. There are different approaches to analyze the breaching of embankments and were critically reviewed by Wahl (2007). These methods were critically described by Wu (ASCE, EWAI, 2011). Broadly differently breach modelling methods were grouped under three categories as parametric models, simplified and detailed physical models. Dam breach modelling, parametric or physical, were based on statistically regression equations or case studies. These models did not consider the impact of embankment material, hydraulic condition, and also scouring rate during the overtopping which are the important factors. Different parameters were determined breach conditions like beginning of breach time, breaking time, time to crack formation (Jhonson et al., 2011). Further it was required to perform experiments at different field tests which help to overcome the limitations to be identified in the earlier work (Colemn, 2004). Recently Jhao (2014) also done experiments on breaching on embankment and Verma et al. (2014) used a fuse plug as an auxiliary spillway and investigated the temporal variation of breach parameters in a small flume.

Fuse Plug Model

Fuse plug is an integral part of earthen dams. It washes out under flood conditions, in a controlled manner without damaging the rest of the body of dam (CWC, 1989). It also provides additional discharge capacity and acts as an auxillary spillway. The fuse plug does not permit lateral erosion of dam (Verma et al., 2017) and it allows 2D breach development (Figure 1). Recently Verma (2014), Sahu et al. (2013) and Schomocker et al. (2009) used the fuse plug models for analyzing the breaching of earthen dams.

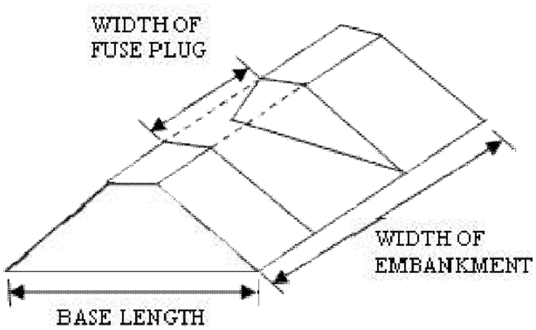


Figure 1: Fuse Plug model

3. Experimental Programme

A total of eight tests were conducted in a small recirculating glass flume in the Hydraulics laboratory. The flume was having dimensions of 4.5 m x 0.57 m x 0.57 m (Figure 2).In all tests a fuse plug model was used to study the breach behaviour of earthen dams during overtopping.

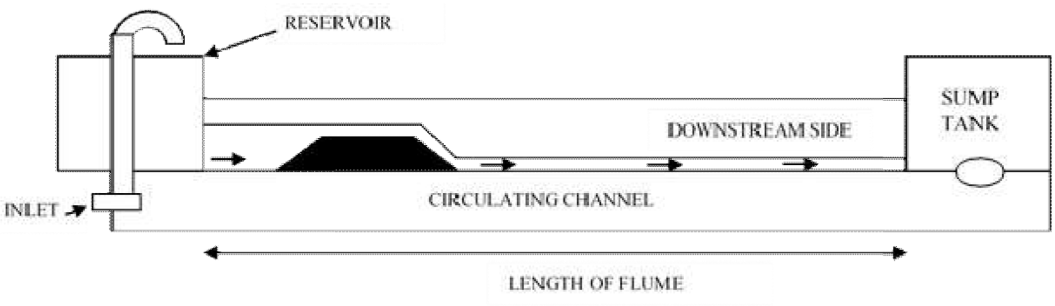


Figure 2: Line diagram of flume

Table 1: Dimensions of fuse plug model

Fuse plug model Dimensions		**Values (cm)**
Model width (B_f)		14.6
Longitudinal length of model, L	Top length (Crest) (L_{ft})	20
	Base length(L_{fb})	120
Height (H_f)		25
Slope		1V : 2 H

Description of fuse plug model

The fuse plug was fabricated using the wooden material and polished before placing in the flume to avoid seepage (Figure 3). The dimensions of fuse plug model are tabulated in table 1.

Figure 3: Fuse plug model

4. Experimental Set Up

For studying the different tests, a fuse plug model, soil of different proportions, a compaction roller along with essential standard laboratory devices were used. A high-speed digital video camera (Figure 4) and digital cameras were also used for observing the temporal variation of breach growth. The properties of different proportion of material were calculated by performing experiments in the Soil Mechanics laboratory (Table 2).

Table 2: Properties of soil use for different tests

Test Number	1	2	3	4	5	6	7	8
Coarse grained soil (% age)	38	89	85	95	93	80	76	72
Fine grained soil (%age)	62	11	15	5	7	20	24	28
Maximum dry density (gm/cc)	1.625		1.925	1.902	1.88	1.86	1.87	1.85

5. Experimental Procedure

All tests were performed by placing the fuseplug model inside the flume at a same position. The fill material mixed at optimum moisture content before placing in the flume.

Earthen dam with fuseplug

The fill material was filled in five compacted layers. To maintain the uniformity of embankment material, a sufficient time of 24-48 hours was provided. On the upstream side of dam model, clay layer was laid to reduce seepage and the water was filled on upstream side upto the specified level by controlling the inflow with head regulator attached to inflow pipe. Pointer guage was used to for measuring readings at temporal variation. Water depth was taken upto a height of 22 cm on the upstream side of the model. Water was collected and retained for the one day for considering homogenous saturation of embankment.

Figure 4: Experimental Set up

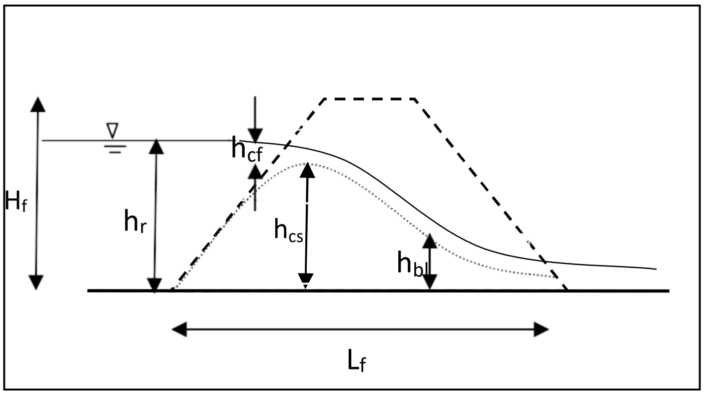


Figure 5: Different flow parameters

Breach flow Characteristics

Breach flow characteristics depends upon the incoming flow to the reservoir, material used in fuse plug, geometry of fuse plug and capacity of reservoir. Different parameters were considered in the fuse plug model is shown in Figure 5.

Instant photographs and videos were taken for overtopping the model. The different time durations were observed during the overtopping process. With the passage of time, reading were noted for different the water level in reservoir (hr) and crest sediment height (hcs) was observed. The water level above the crest (hcf) during the breaching process was calculated as hcf = hr – hcs. The temporal variations of breach flow characteristics were studied by plotting the graphs.

6. Results and Discussion

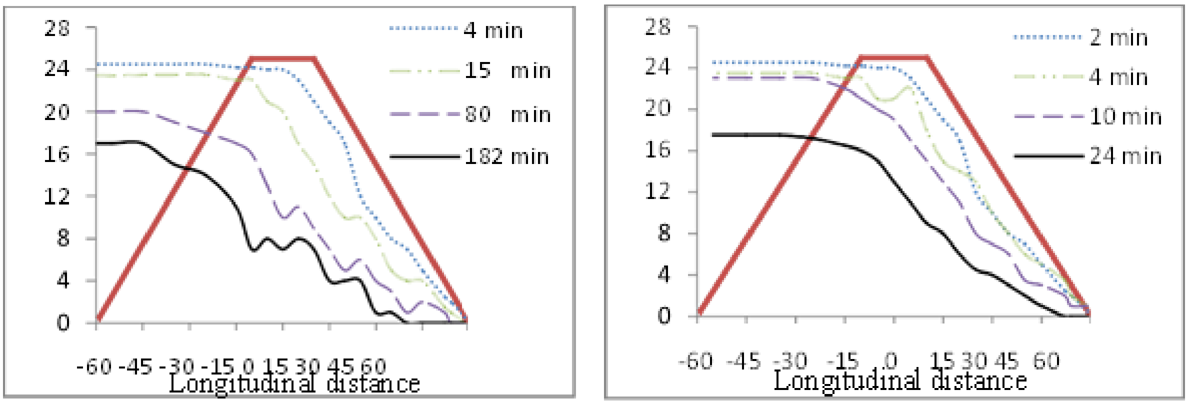
As the water flows over the crest of embankment, the scouring at different rate for cohesive and non-cohesive soils. This work has been carried out by the different researchers(Coleman et al., 2002, Hunt et al., 2005; Hanson et al., 2005) and they describe the whole process in different phases.

Embankment profile

For cohesive and non-cohesive soil, test 1 and 7 were considered for describing water surface profile through channel. 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. 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 7 (a) and 7 (b) describes the temporal variation of embankment breach profile.

Figure 6 (a): Widening of breach

Figure 6 (b): Caveing in of sediment



7 (a) 7 (b)

Figure 7: Embankment profile for cohesive (a) and non-cohesive embankment (b)

Initially it was observed that detachment of downstream toe occurred for cohesive embankment (figure 7a). It occurred because of infiltration and subsequently increased magnitude of load of sediment on downstream side. This process took place as the earthen dam models were not fully saturated even after providing the extension time.

For non-cohesive soil, scouring occurred on the downstream side and also it was observed across the crest of the dam(Figure 7b). With continuous overtopping a narrow channel with nearly vertical banks was formed which steps forward to the crest of the model with steep of gentle gradient as shown in figure (7b) which was described by Walder and Godt (2015) as erosional cyclic steps.

7. Summary and Conclusions

Present study describes the experimental work in a small glass flume with fuse plug models for understanding the behavior of dams in breach during overtopping. Different tests were studied for cohesive and non-cohesive earthen embankment models. Due to overtopping of earth dams erosion rate is influenced and this influence may be of several orders of magnitude. Fuse plug plays an important role in the dam and reduces the chances of failure of dam. 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. During the experimental results it was observed that as the breach widened then the discharge of overtopping increases. Water surface profiles concludes the type of erosion for earthen models of different soil compositions. These 2D test are greatly helpful in determining the erosion process and also helps for the warning systems to be developed for making emergency action plans (EAP). but cannot describe the process breach widening in detail.

References

1. Costa, J. E. (1985). Floods from dam failures, Open-File Rep. No. 85-560, USGS., Denver, Colorado, 54. Central Water Commission, (1989). Report on Dam safety Activities in India, CWC Publication No. 47/89, I85, New Delhi, India.
2. Coleman, S. E., Andrews, D. P., and Webby, M. G. (2002). Overtopping breaching of noncohesive embankment dams, J. Hydraul. Eng., 128(9), 829–838.
3. Hanson, G. J., Cook, K. R., and Hunt, S. L. (2005). Physical modeling of overtopping erosion and breach formation of cohesive embankments, Trans. ASAE, 48(5), 1783–1794.
4. Hunt, S. L., Hanson, G. J., Cook, K. R. and Kadavy K.C., (2005). Breach widening observations from earthen embankment tests, Transactions of the ASAE Vol. 48(3): 1115−1120. 37.
5. Jhao, G., (2014). Breach growth in cohesive embankments due to overtopping", Ph.D. thesis, Delft University of Technology, ISBN: 97890-6562-3942 (online).

6. Johnson M., Mtalo F.W. and Lia, L., 2011. “How fill material affects the overtopping process for earthfill dams”, Hydro Review Worldwide.
7. Schmocker, L., Hock, E., Mayor, P.A. and Weitbrecht, V., (2009). Hydraulic model study of the fuse plug spillway at Hagneck canal, Switzerland, Journal of Hydraulic Engineering, Vol.139, Issue 8, 894– 904.
8. Verma, D., Setia, B. and Arora, V.K. (2017). Experimental study of breaching of an earthen dam using a fuse plug model, Interational Journal of Engineering, Vol. 30, , No. 4, 479-485.
9. Verma, D., Setia, B. and Arora, V.K. (2014). Mechanism of embankment dam breach, Published in Proceedings of the International Conference on Fluvial Hydraulics, EPFL, Switzerland, River Flow 2014, Retrieved from www.scopus.com.
10. Wahl, T.L., (1998), Prediction of embankment dam breach parameters: a literature review and needs assessment, Dam Safety Research Report DSO-98-004, U.S. Dept. of the Interior, Bureau of Reclamation, Denver, Colorado, July 1998.
11. Wahl, T.L., (2007). Uncertainty of Predictions of Embankment dam breach parameters, Journal of Hydraulic Engineering, Vol. 130, , Issue 5, 389-397.
12. Walder, J. and Godt, J.W. (2015). Controls on the flood hydrograph and breachgeometry during overtopping of noncohesive earthen dams, Water Resources Research, July 2015, DOI: 10.1002/2014WR016620.
13. Wu, W., (2011), “Earthen Embankment Breaching”, Journal of Hydraulic Engineering, ASCE/EWRI Task Committee on Dam/Levee breaching, doi: 10.1061/(ASCE) hy.1943-7900.0000498.

