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EXPERIMENTAL INVESTIGATION OF THE FAILURE MECHANISM OF THE ZONED COHESIVE EARTHFILL DAMS

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Abstract — *Earthfill dams are the common manmade hydraulic structures constructed all over the world. Breaching of an earthfill dam can leads to catastrophic damage to downstream communities, substantial loss of life, environmental damages, and momentous property damages. This research paper aims to investigate the breach pattern of the zoned cohesive earthfill dams due to overtopping. Two small-scale laboratory experiments with different mode of initiation of breaching process, flat crest top level and an initial pilot channel erected at middle of crest were conducted. The dimensions of placed model were, 12 inches crest width, 30 inches crest length, 20 inch crest height, and 1:2 upstream and downstream side slopes. The results indicated that headcut erosion has a vital role in the breach development process of cohesive zoned embankments. The breach cross section has almost a trapezoidal shape. The final breach section width reached to the full width of the dam in case of flat top crest level test while it was confined to the middle of the dam in case of test performed with initial pilot channel at middle of the crest. Also, the presence of relatively high cohesive soil in the central impervious core strongly slow down the breach growth process.*

***Keywords**-Breaching; Earthfill Dams; Headcut; Overtopping; Cohesive.*

1. INTRODUCTION

Structures like dams, levees, and dykes have been constructed as flood defence structures. Flood have been causing a lot of damage to the life and property of the people. Pakistan has been one of the major victims of these floods, affecting about 20 million peoples, over 1,980 reported deaths and nearly 2,946 injured in the 2010 floods reported as the wrost flood in the world after 1929. About 1.6 million homes were destroyed, and thousands of acres of crops and agricultural lands were damaged (NDMA-2010). Earthfill dams are the common type manmade hydraulic structures. These dams been helping to provide use water for electricity, irrigation, navigation, municipal and rural water supply, and flood control. However, these dams can withstand limited level of safety and are prone to decay owing to numerous triggering mechanisms particularly failure due to overtopping which causes erosion of dam materials and eventually results in complete failure of the dam[2]. The failure of these dams is very sensitive to materials, various forces impact, environmental factors, and other numerous factors that includes construction technique, geometry of embankment, composition of material, nature of embankment crest, reservoir extents, reservoir capacity, protective cover, and the mode of failure [3]. Water in large quantity is abruptly released when an earthfill dam is breached causing catastrophic damage to downstream communities, often leading to substantial loss of life, extensive economic loss, environmental damages, and momentous property damages.

Breaching is the predominant mechanism of earthfill dam failure. Breaching may be initiated by different causes including embankment overtopping, extreme waves impact and piping through the dam body or foundation [4]. The overtopping of water may result because of different reasons, such as an upstream dam failure or excessive rainfall, blockage of debris in outlet structures or spillway, crest settlement [5]. The geometry of breach is different depending on the failure mode (piping or overtopping), dam material (mixed, non-cohesive, or cohesive), and the dam type (non-homogeneous or homogeneous) [6]. The breach shape, breach size, and failure time depend on the material erodibility and outflow characteristics [7]. An understanding of failure mechanism and the major affecting parameters is of considerable interest for risk analysis, damage assessment, developing early warning systems, and evacuation plan. In water resources engineering and management, it is very important to understand and forecast these processes.

Thus, to provide additional knowledge to the existing knowledge in the respective field for assisting better understanding of the breach growth process, formation time, temporal evolution, and to acquire essential data for development of mathematical model, two small-scale laboratory tests were conducted in the Hydraulics Laboratory of the "University of Engineering & Technology, Peshawar, Pakistan".

2. Methodology

To accomplish the objectives of the current research work, a systematic stepwise procedure was adopted which comprises of laboratory soil test prior to placing of model embankment, adjustment of instruments for different measurements and videotaping of the breach process, placing of the dam model, and then commencement of the experiments.

2.1 Soil laboratory tests

Essential laboratory tests were conducted to acquire necessary soil parameters. The tests carried out are specific gravity, atterberg limits, soil gradation, and proctor compaction test. Figure 2.1 provides the illustration of the various soil test conducted to obtain the different soil parameters. Results of the laboratory tests are given in the Table 2.1. The soil gradation curve is given in the Figure 2.2.

(a) (b) (c)

Figure 2.1. Laboratory tests of the selected soil samples (a) specific gravity test, (b) sieve analysis test, (c) standard proctor compaction test

Table 2.1. Summary of the soil parameters

Parameter	Symbol	Core Material	Fill Material	Unit
Specific Gravity	Gs	2.61	2.69	---
Optimum Moisture Content	w_{omc}	16.5	18.4	%
Maximum Dry Density	γd_{max}	114.5	106.2	lb/ft^3

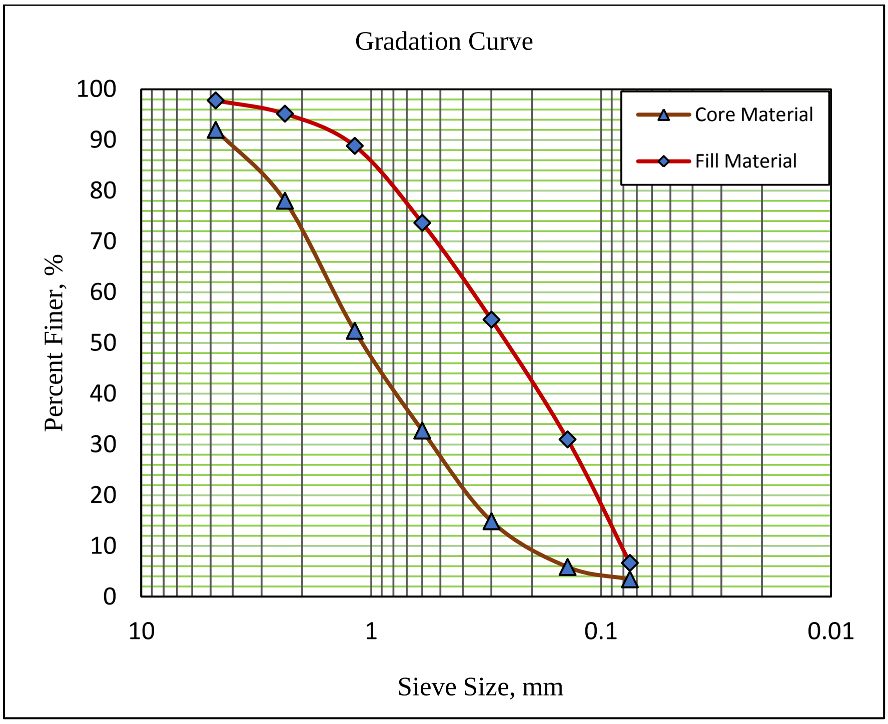
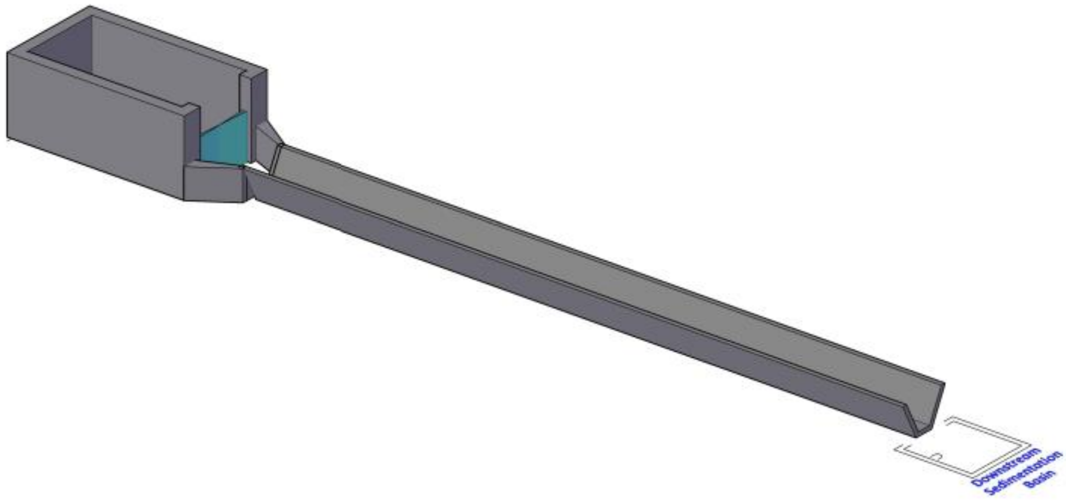


Figure 2.2. Sieve analysis curve

2.2 Layout of the channel

The experimental work has been performed in the channel having trapezoidal cross section. Figure 1 illustrates the layout of the channel. To the channel system, an upstream storage basin and downstream sedimentation basin were connected. The water was continuously recirculated through pump from underground reservoir into the upstream storage tank and then applied through inlet gate and from sedimentation basin back into the underground reservoir.



Storage basin

Figure 2.3. Illustration of layout of the channel

2.3. Model design

To satisfy the channel limitations, selection of the model various parameters was based on the data collected from previous research work, ICOLD and USBR embankment dam recommendations. The model different parameters are given in the Table 2.2 and is shown in the Figure 2.4.

Experimental reach

Storage basin

Sedimentation basin

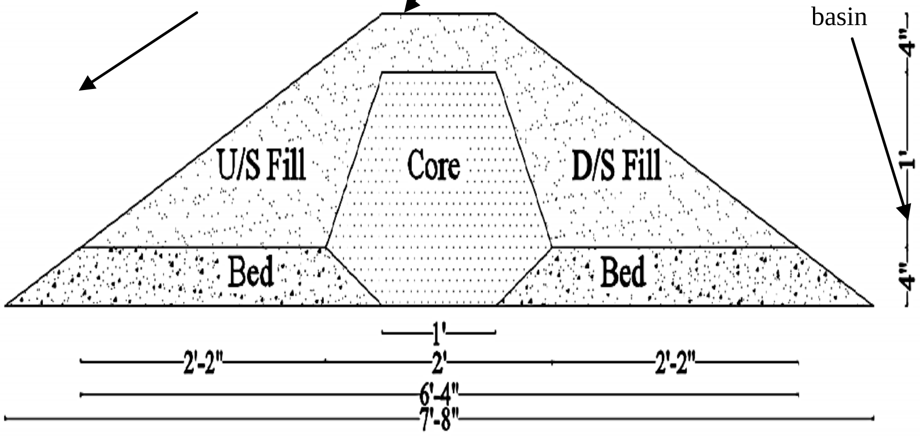


Figure 2.4. Cross-section of the tested earthfill dam model

2.3. Placement of the models

The earthfill dam models were constructed in the channel by placing the soil in loose horizontal layers. The model was placed in four layers. A hand compactor was used for compaction of each loose layer. Each layer was compacted almost to half of its initial thickness. After compaction of each layer, soil samples were collected and tested in the soil mechanics laboratory to obtain the achieved dry density and moisture content. Figure 2.5 provides the illustration of the placed model in the channel.

3. Rate of erosion

The erosion rate of earthfill dams can be significantly altered by the degree of compaction, nature of the soil, and amount of contained water contents. The high compaction level results in low erosion rate and elongates the failure time. By increasing the percent compaction of standard proctor compaction from 95% to 102%, reduced the erosion rate by half. Similarly, by increasing water content and compaction effort for the same soil has significantly altered the rate of erosion of the small-scale embankment models. [8] proposed a model describing headcut migration depending on hydraulic stresses, shear strength, and soil erodibility factor.

$$\varepsilon = \zeta\,(\tau_e - \tau_{es}) \tag{1}$$

Where
$\varepsilon = erosion\ rate$
$\zeta = coefficient\ of\ erodibility$
$\tau_e = effective\ stress$
$\tau_{ec} = Excess\ shear\ stress$

(a) (b)

Figure 2.5. Illustration of the dam model placed in the channel (a) initial pilot channel provided at the middle of the crest (b) flat crest top level

4. Results and Discussions

Four stages were observed during the breaching process which are surface erosion, headcut formation and migration, lowering of the crest, and lateral erosion as shown in the Figure 2.6. Surface erosion initiates the breaching process with erosion of soil particles from downstream face near toe of the dam. The surface erosion results in formation of a headcut and ceases when it is fully developed. Then headcut erosion dominates the failure process. The headcut progresses toward the upstream of the embankment crest and continues to grow both in horizontal and vertical direction.

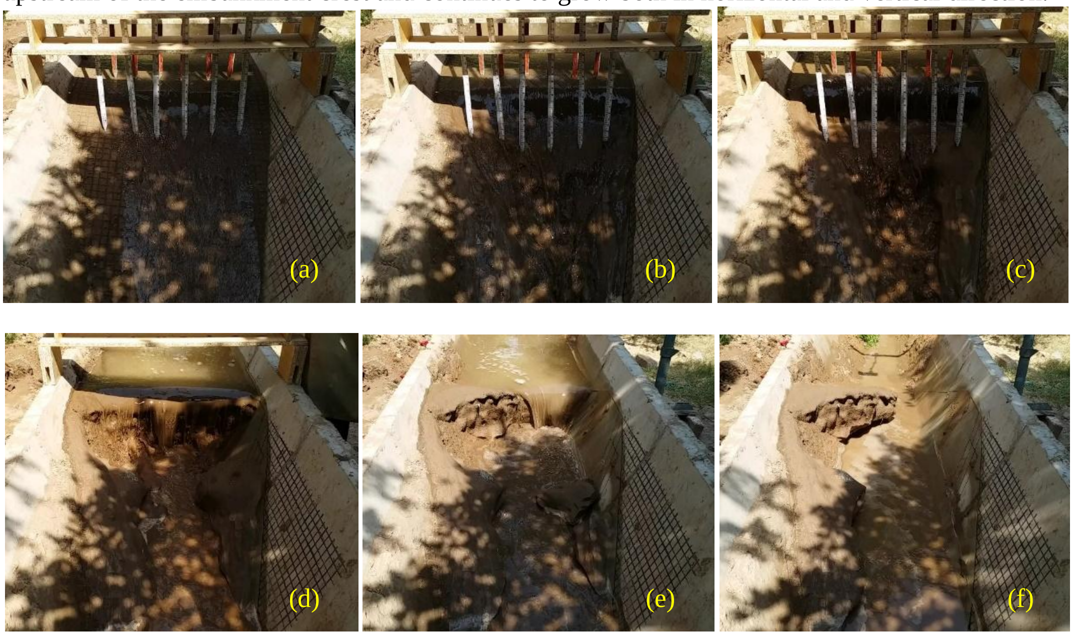


Figure 2.6. Breach development process (test 2): (a) rill and sheet erosion at t = *20 sec* (stage-1), (b) formation of headcut at t =*85 sec* (stage-2), (c) migration of headcut toward crest of embankment at t = *160 sec* (transition from stage -2 to stage -3), (d) erosion of crest and clay core at t = *330 sec* (stage-4) (e) headcut at upstream side (lowering of crest level) during stage-4 at t = *535 sec* (f) complete failure at t = *845 sec.*

5. Conclusion

1. For overtopping tests with flat crest top level, the erosion pattern is progressive comprised of initial rill and sheet erosion, formation and migration of headcut, lateral erosion, and lowering of the crest level.
2. For overtopping test with initial trench at middle of the crest, the breach section is confined to the middle of the embankment. This is because of the strong interlocking bond between the material of the adjacent layers.
3. Also, the presence of relatively high cohesive soil in the central impervious core strongly slow down the breach growth process.

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