Experiment and Simulation On Earthen Embankment Breach

Sanit Wongsa*

1Department of Civil Technology Education, King Mongkut’s University of Technology Thonburi (KMUTT), Bangkok, Thailand
Email:* sanit.won@kmutt.ac.th

Received **** 2015

Abstract

Many studies of earthen embankment failure from overtopping flow have been conducted in various aspects. Most of them focused on the mechanism of breach, depth and width of erosion, and breach hydrograph. The studied results as obtained either from both physical and numerical modelling and/or coupling techniques. The aim of this research is to study the effect of breach mechanism a physical hydraulic model under three types (overtopping, beneath structure and piping hole). Fixed embankment slopes, with scale 1:8.5 were employed in this study. It was found that the piping hole case at the toe of embankment was the most severe damage. The iRIC Nays2D numerical model shows a performance of simulated results in both water flow and breach morphological characteristics, therefore, indicating that the model simulation is reasonable

Keywords

Embankment breach; Characteristics of Failure; Overtopping; Beneath Structure; Piping Hole

1. Introduction

Earthen embankments, including dikes and dams, are of large benefit to people all over the world. Most of the earthen embankments were built up of cohesive soil and/or impervious soil. In the case of flood protection, permanent or temporality embankments were often used for protecting restricted area from a flood water level of some magnitude. However, as flood disaster is a natural phenomenon which is unpredictable, sometime, the flood level might be higher than the embankment height and overtopping flow would then occur. However, embankments could also give human lives and properties high risks to some extend for their failures due to overtopping, piping and other factors. The result of overtopping flow is the erosion on the embankment surface and the scour at the toe. No matter how the embankment was compacted well at the construction phase, gradual decreases in its strength due to weathering effects and negligence of proper maintenance and increase in soil moisture during flood event were unavoidable. These two effects became the prominent causes of the embankment failure.

*Corresponding author.

How to cite this paper: Wongsa, S. (2015) Experiment and Simulation On Embankment Breach. Journal of Geoscience and Environment, *, **. http://dx.doi.org/10.4236/gep.2015.****
Physical model is a useful and popular tool to investigate the breaching process in the embankment and has been applied by the former researchers ([1], [2]) in the laboratory, however, the scale limitations increase the uncertainty of the breaching development and the result distortions have been generated. In the meantime, researchers use prototype data analyses and conduct the real embankment breach tests in the field to get insights into the mechanism of breach development. But the data collected from prototype are usually not complete.

Severity of the embankment breach depended also on the overtopping flow discharge. In the study of cohesive embankment breach by many researchers ([3], [4], [5]), it was indicated that breach mechanism consists of 2 processes, the surface erosion and the headcut erosion. The width of the breach was assumed to be dynamically controlled by two parameters; the critical depth at the entrance to the breach channel and the stability slope of the embankment materials. The breach width, as expanding on both sides, would form a trapezoidal section. This concept of breach channel development has been adopted for formulating most of numerical models available presently. Even though inconsistency with real events when applied to the cases where breach location occurred near uneroded wall of a hydraulic structure. Examples of such embankment breach included the failure Bang Chom Sri regulator in Thailand [6]. Many comparative studies on the embankment failure which occurred in laboratory and real embankment scale breach by numerical model [7], [8]. It was found that under the same overtopping flow conditions, the embankment erosion which occurred near the regulator was compared well. Hence, it is the purpose of this study to investigate the embankment breach beneath hydraulic structures from a physical model in which the breaching under three different condition. The results may be used for developing the guidelines for protecting hydraulic structures from failures due to embankment breaching and flood protection. The observed data can also be analyzed for using in the development and validation of a numerical model for simulating the embankment breaching process.

2. Material and Methods

2.1. Experiment Setup

![Figure 1. Experiments setup flume, embankment and instruments.](image)

Table 1. Properties soil mixture used for the Experiment.

| Soil Properties | Items | Values | Items | Values |
|-----------------|-------|--------|-------|--------|
|                 | Specific Gravity, Gs | 2.87   | Friction Angle, $\phi$ | 17 |
|                 | Liquid Limit, LL%   | 51     | Cohesion, c          | 17 |
|                 | Plastic Limit, PL%  | 24     | Total Weight of Soil | 14.7 |
|                 | Plastic Index, PI   | 27     | Initial Void Ratio  | 0.89 |
|                 | $C_c$              | 29.7   | Initial Coeff. of Permeability | $5.1\times10^6$ |
|                 | $C_u$              | 2.6    | Type                | SW-SC |

The re-circulating flow basin, as shown in Figure 1, 3 types of experiments, (overtopping, beneath structure and piping hole) were conducted in the flume of 15.50 m x 1.50 m x 1.50m of King Mongkut’s University of Technology Thonburi (KMUTT), Thailand. The discharge that can be supplied at 4 constant discharges of 4.14, 7.78,
11.59 and 16.48 l/s, control flow discharge by using 4 pumps. Two sidewall of the flume were made up of concrete block, and the transit zone was built with gravel and measured flow discharge by V-notch weir. The embankments are built on non-erodible flume bed, 0.48m thick of soil mixture (SW-SC). In order to know the material properties, several standard geotechnical tests were performed on the soils and on the mixtures (Table 1), with the average grain size and density were 1.70 mm, and 14.70 kN/m³, respectively. Before the start of each experiment, the earthen embankment will be soaked for 2 hours. The surface erosion began immediately after the embankment overtopped. Two video cameras were used for recording the breaching process.

2.2. iRIC Model
The iRIC Nay2D model has been used for simulate earthen embankment breach and its morphology. The shallow water equation of 2-D unsteady flow and sediment transport to calculate for water flow and morpodynamic of embankment breach, respectively [9].

3. Results and Discussion
3.1. Overtopping Case

Figure 2. The failure characteristics of the earthen embankment; overtopping case (at Q = 16.84 l/s).

The first surface erosion started to form a few minutes after the initial overtopping of the embankment. Almost simultaneously another larger headcut started to form at approximately mid-height of the embankment slope. The surface erosion characteristics observed in this case were more of detachment of lumped material than of individual particle detachment. This headcut was wider than the one at the toe and deepened vertically. Other smaller headcuts were also observed. As time progressed, predominant water path in the middle of the embankment was observed. The development of breach depth is presented in Figures 2 and 3. The embankment breach cross-section may be an approximate trapezoid. The data resembles an exponential curve. Once it reached the lower elevation, the breach widened and the material was eroded from the sides and from the upstream side. The breach remained stable after 130 minutes, the maximum breach depth and width were 0.26 and 1.12 m, respectively. Most of the time the flow remained attached to the headcut wall, except when mass erosion of the vertical wall became imminent. Figure 4 shows the time series of embankment erosion width, depth, and volume of soil. The water in the testing channel was gradually drained out through the circulated channel until it was dry. The breached channel dimensions and the scour and deposition profile on the embankment foundation on the downstream side were measured in details.

3.2. Beneath Structure Case

Figure 5. The failure characteristics of the earthen embankment; beneath structure case (at Q = 16.84 l/s).

After be soaked the embankment for 2 hours, the first erosion started to form a few minutes after the initial overtopping at the breach portion beneath embankment - structure, because of weakness at junctional between soil and concrete and/or structural joints. This breach portion was deeper than the overtopping case and deepened vertically. Other breach portion was not observed, because the water level drop at the upstream. As time progressed, predominant water path in the side of the embankment - structure was observed. The development
of breach depth is presented in Figures 5 and 6. The embankment breach cross-section may be an approximate rectangular. Once it reached the lower elevation, the breach widened and the material was eroded from the sides and from the upstream side. The breach remained stable after 120 minutes, the maximum breach depth and width were 0.36 and 0.57 m, respectively. Most of the time the flow remained attached to the headcut wall, except when mass erosion of the vertical wall became imminent. Figure 7 shows the time series of embankment erosion width, depth, and volume of soil. The water in the testing channel was gradually drained out through the circulated channel until it was dry. The breached sediment deposition with a fan shaped was observed.

3.3. Piping Hole Case

Figure 8. The failure characteristics of the earthen embankment; piping hole case (at Q = 16.84 l/s).

Piping and liquefaction may occur because of seepage or leakage flow through weak layers, structural joints, dead tree roots, and animal burrows in the embankment, without the necessity for the water level to have reached the full height of the embankment. As time progressed, predominant water path in the middle of the embankment was observed. The piping hole became wider faster than previous cases and the advance process took faster to reach the embankment crest. The lumped material simultaneously dropped, another larger headcut started to form at approximately mid-height of the embankment slope. The surface erosion characteristics observed in this case were observed. The development of breach depth is presented in Figures 8 - 10. The breach remained stable after 130 minutes, the maximum breach depth and width were 1.34 and 0.26 m, respectively. Excessive foundation seepage through permeable substrata is often accompanied by the formation of sand boils, which often look like miniature volcanoes ejecting water and sediment, and may result in piping failure if not controlled. High uplift pressure and saturation of foundation materials may give rise to slope instability and sliding failure. The piping failures caused by foundation defects are similar to those described in the preceding subsection, but the initial breaches may involve the whole height of the embankment. Sliding failures can form a large rupture much more rapidly than piping failures.

3.4. Model Simulation

The comparison of time series of breach width and depth between experiment measured data and simulated results from iRIC Nay2D model are shown in Figure 11. These results indicate well agreed between experiment data and this proposed model. Good performance of simulated results was observed in both water flow (flow field, flow vector) and breach morphological characteristics (breaching position, width, depth). Therefore, indicating that model simulation is reasonable.
Figure 3. The vertical displacement of embankment; overtopping Case

Figure 4. Time series of embankment erosion width, depth, and volume of soil of; overtopping case.

Figure 6. The vertical displacement of embankment; beneath structure Case
4. Conclusion

The embankment breach and failure characteristic were studied by using physical and numerical simulation, under 3 types of experiments, (overlapping, beneath structure and piping hole). The discharge that can be supplied at 4 constant discharges of 4.14, 7.78, 11.59 and 16.48 l/s. The results indicate that the breach types have an effect on the maximum breach width, depth and volume of eroded soil. It was found that the piping hole at the toe of embankment was the most severe damage. The iRIC Nays2D numerical model shows a performance of simulated results in both water flow and breach morphological characteristics, therefore, indicating that the model simulation is reasonable. The results can be used for developing the guidelines for protecting hy-
dualistic structures from failures due to embankment breaching and flood protection. However, it is important to conduct more large-scale laboratory experiments and field case studies to improve existing embankment breach models or develop new ones.

**Acknowledgements**

The authors would like to thank NRU - National Research University, Hydro and Agro Informatics Institute (HAI), PERDO and King Mongkut’s University of Technology Thonburi (KMUTT) for financial support in this study. I am also indebted to master and graduated students who involved the experiments.

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