Analysis of the Influence Relationship for the Earth Dam-Break Outflow Estimation Parameters

Liu Jie*[a], Xu Jiajun, He Hujun and Li Xuewei
School of Civil and Building Architecture Engineering College of Pan Zhihua University, No.10 Airport Road, PanZhihua, China

Keywords: Dam-Break, Breach Outflow, Breach Width, Breach Water Surface Velocity, Breach Water Depth.

Abstract: In order to exploration the relationship between breach hydrograph and other breach parameters, a series earth dam-break experimental with spatial breach overtopping tests were conducted in an 4m wide, 50m long and 2m high with glass side-walls flume at the State Key Laboratory of Hydraulics and Mountain River Engineering of Sichuan University. An industry camera and two digital video recorders were used to record the dam breach process, and the Large-Scale Particle Image Velocimetry (LSPIV) technique was introduced to measure water surface velocity of dam breach. The results showed that the dam breach process can be divided into two stages, the main feature of first stage was "headcut" while the second stage was "surface" erosion. The length rate of CSC and CS was approximately 0.85 at peaking discharge moment in the present study. The breach hydrograph may be the function of breach water width and breach water velocity. The breach water depth can be estimated by using $h_c(t) = z_w(t) + X_c(t)\tan\varphi - z_d$, and the breach depth at 100s was approximately equal to 13cm based on this formula. The time of breach peak discharge was nearly the same as the breach width reach the maximum. However, there was about 30s time lag for breach peak discharge relative to time of peak breach water surface velocity

1 INTRODUCTION

The earth dams have served mankind as hydropower generating industry, water supply, irrigation systems and flood control. If the inflow exceeds the storage capacity of the reservoir and/or the spillway design in the time of cloudburst, the dam-break may happen and the rushing flood would cause damage and disruption to people and economies. (Wang and Chen, 2010).

Over the past several decades, the model of estimating the earth dam failures discharge due to overtopping has been developed, mainly using mathematical techniques. Besides, many researchers attempted to find a general formula to describe the time history of breach hydrograph, since the hydrograph can be used to predict the downstream flood levels and discharges routing (Singh 1996; Hanson et al., 2005). Such formulas for dam breaching according to the basis of data from dozens of historic dam failures were called parameter method. The common parameters include reservoir volume, reservoir water depth, breach width, breach shape, breach water velocity and so on (Wu, 2011). The advantages of parameter method are quick and easy and can be used to estimate real-time discharge. For example, Coleman et al.(2002) proposed the concept of "curved section", which was the highest points of the inlet of breach channel (Coleman et al., 2002). In this cross-section, the hydrograph was related to the water height above the breach channel during dam failure process. However, the reservoir water level for all of Coleman's experiments were considered keeping constant during whole dam-break process. In other words, Coleman ignored the effects of the reservoir volume. Following Coleman's research, Al-Riffai (2014) conduct a series experiments to estimate the width of "curved section". Since the shape of "curved section" was not a straight line, Al-Riffai (2014) assumed the shape to be a circular, and then the distance ratio of curved line

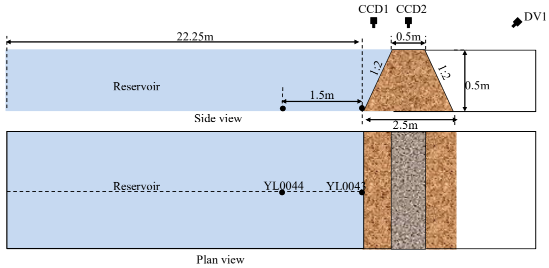
[a] https://orcid.org/0000-0003-0947-5590.
*Liu Jie(1986-), man, Doctor, Associate professor, Mainly engaged in dam-break and disaster research

Jie, L., Jiajun, X., Hujun, H. and Xuewei, L.
Analysis of the Influence Relationship for the Earth Dam-Break Outflow Estimation Parameters.
DOI: 10.5220/0011950300003536
In *Proceedings of the 3rd International Symposium on Water, Ecology and Environment (ISWEE 2022)*, pages 150-155
ISBN: 978-989-758-639-2; ISSN: 2975-9439

and straight line and how the "curved section" influence the breach discharge was discussed (Al-Riffai, 2014). Walder et al. (2015) employed the photogrammetric method to measure the "curved section" shape, believing the vertical cross section was a parabolic, and obtained a discharge estimating formula that based on area of "curved section"(Walder et al., 2015). Liu et al. (2021) used LSPIV technology to measure the surface velocity of "curved section", analysing the effects of different vertical velocity profile approximation and suspended sediment concentration (Liu et al., 2021). However, very few work have carried to investigation the relationship between breach hydrograph and other breach parameters, especially whether the peak time for those parameters are synchronized. In order to better understanding this relationship, a series earth dam-break experimental with spatial breach overtopping tests were conducted, and the focus of this paper was to analyse the experiments data and provides the research basis for the following manuscript.

2 EXPERIMENTAL SETUP

The experiments flume was built in *Jiang'an* campus of Sichuan University, and the scale was 4m in width, 2 m in height and 40 m in length with a concrete bed. The flume side walls were built using bricks and concrete with glass view windows at the middle centre. The model dam was an isosceles trapezoid homogenous sand dam, with the 0.05 m depth initial breach through the middle of dam crest. The dam height is 50 cm, top width is 50 cm and the bottom width is 250cm. Two pressure transducers labeled Y0043, Y0044 were deployed to measure the time history of water depth along the flume. In addition, two industrial cameras labeled CCD1 and CCD2, and one high speed digital cameras labeled DV1 were used to record the dam break process. The schematic views of the whole flume and the photo image of experiment field were shown as Figure 1. The inflow to the reservoir was supplied by two symmetry channel and measured with a Sharp-crested weir at upstream of reservoir after all the equipment were ready. The inflow discharge stabilized quickly until the water level rail up to 40cm and then maintained at a relatively constant flow of about 0.00167m3/s for all tests. Once the upstream water level reaches and overtops the dam crest, the dam breach process commences. In order to obtain the water surface velocity based on LS-PIV technology, the scraps of paper with 1cm by 1cm in size and white in colour were throw into reservoir as tracers to visualize the flow pattern when the test begins.



(a)Schematic view of whole experiment field

(b) The photo image of whole experiment field

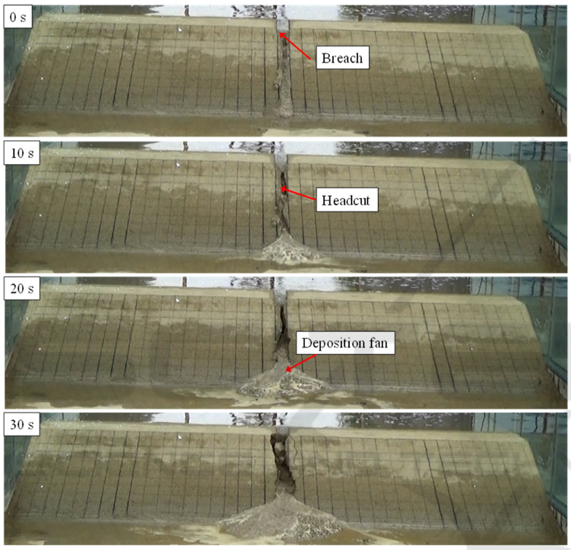
Figure 1: The schematic views of the whole flume and the photo image of experiment field

3 OBSERVATION AND DISCUSSION

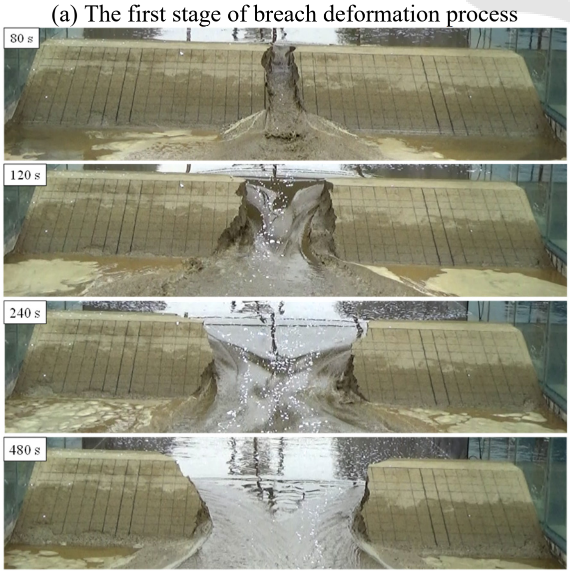
3.1 Dam Breaching Process

Snapshots of the breach development in the idealized dam are captured and presented in Figure 2. The starting time of dam-break was defined as the water flows through the initial breach channel and reached the dam toe (Figure 2(0s)). In the early stage of dam failure, since the discharge was too small, the most of water was permeated into dam and the sand can't be moved far away, the initial breach flow resulted in sheet and rill erosion in downstream slope, a large amount of sand accumulate at the toe of dam and formed a deposition fan. This phenomenon would last until the time of 50s. During this stage, the depth erosion was faster than width erosion at downstream but at crest the depth erosion and width erosion was nearly the same (Figure 2(30s)). Observations from other researcher's laboratory experiments and case studies suggest that the earth dam breaching mechanism for the typical overtopping erosion model relay on dam material and compaction, which is head-cut erosion for cohesive earth dam while progressive surface erosion for non-cohesive dam, but there are no strict definition for the transition point between surface erosion and head-cut (Hanson et al., 2005).

Referring this definition, the head-cut was the main feature for the stage of 0s~50s of our experiments. Erosion further advanced form downstream slope to upstream, resulting the dam crest width decreasing. The breach side wall mass failure often interdicted breach flow. When the head-cut sheet advanced to the water line on the upstream slope of the dam, the breach outflow increased significantly. From this moment, the breach inlet enlarge rapidly, a large amount of water swarmed into breach, the carrying sand ability enhances, the breach erosion model was changed from "head-cut" into "surface" erosion (Figure 2(80s~480s)). Therefore, the breach erosion model is not only related to the material and compaction, but also be related to breach outflow.



(a) The first stage of breach deformation process



(b) The second stage of breach deformation process

Figure 2: The breach deformation process of two stages

3.2 The Parameters of Breach Outflow Estimation

Many researchers attempted to investigation the common parameters to quantify the breach outflow. According to Coleman, the best cross-section for calculate real-time discharge is at the "curve section" (Coleman et al., 2002). Generally, the breach discharge can be defined as $Q_{out}=\bar{A}\bar{V}$ ($\bar{A}$ was average cross-section area, $\bar{V}$ was average water velocity). While the average cross-section can be express as $\bar{A}=\bar{B}\bar{h}$ ($\bar{B}$ was average length of breach width, $\bar{h}$ was average breach water depth), and the average water surface was often the function of water surface velocity. Therefore, the breach discharge can be estimated as $Q_{out}=\bar{B}\bar{h}\cdot f(u_{surf})$ (u_{surf} was the water surface velocity)(Mahmoud et al., 2022).

3.2.1 The Length of "Curve Section"

The length of "curve section" was difficult to measure directly since its irregular shape (Figure 3). One of the common methods was using other distance to replace it. For example, the dash line in Figure was the "curve section"(CS), which can be replaced by the dot dash line or solid line. The dot dash line was the chord of "curve section"(CSC), the solid line was breach water width at initial breach inlet position(IB). The location of dash line and dot dash line moving upstream but the solid line stood still during whole dam-break process.

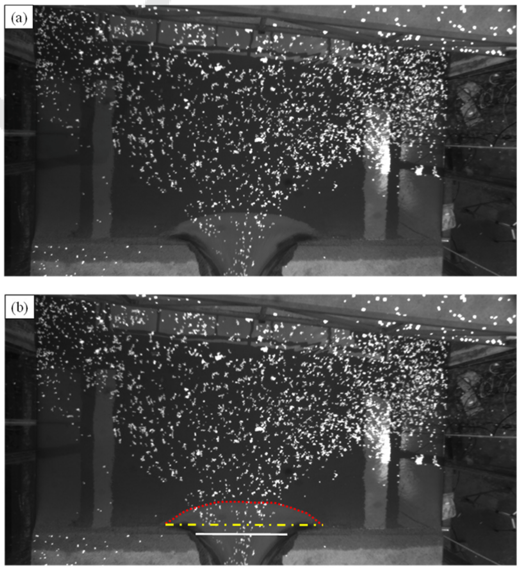


Figure 3: Sketch of different breach length location

Coleman's study showed the length of "curve section" was the function of time while not the sediment, the function was $L_* = 1.29\times10^{-3}(t_*)^{0.616}$ (L_* was dimensionless length, t_* was dimensionless time). For the present experiment, we measured the time history length of these three lines, and compared the experiments data with Coleman's function dada, which was shown Figure 4. It found that the calculated data fitting to the CSC data better than CS data and IB data before 120s. However, the calculated data separated a lot to all experiments data after 120s. This was because Coleman's formula was based on the condition of constant reservoir, which was not appropriate for present experiments. Comparison other three experiments data, the length of "curve section" was longest, the CSC was second long and the IB was shortest. At the beginning time and ending time of dam-break, the CS and CSC was the same length, while at other period the CS length was larger than CSC length. There were many investigators to estimate the length rate of CSC and CS. For example, Das's (1997, p. 89) study showed the rates were 0.46 and 0.67 for two dam-break experiments (Das et al., 1997). Walder et al.(2015, p. 6710) presented several dam failure test showing the rate may increase from 0.1to 0.5 as dam height decreasing (Walder et al., 2015). It was found that the rate was approximately 0.85 at peaking discharge moment in the present study. The profile of final breach was showed in Figure 5, In addition to these three sections, the length of other section form upstream to downstream was also different. Therefore, which section was most suitable for measuring the dam-break outflow? This is a long-term task that needs more work to confirm.

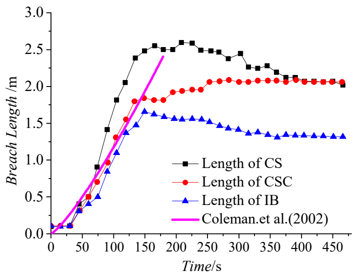
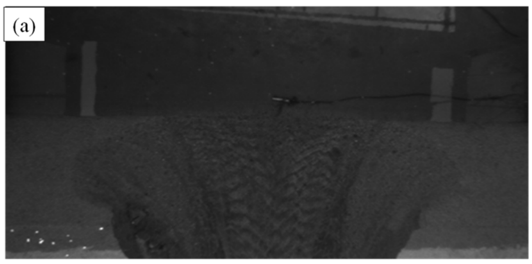


Figure 4: Comparison of breach length of different section and empirical formula



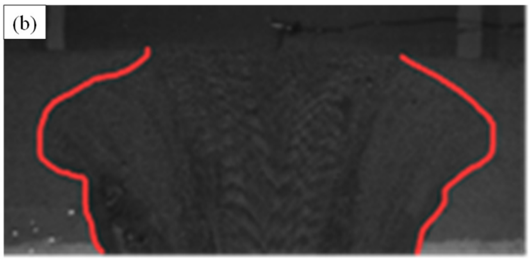


Figure 5: The profile for final breach

3.2.2 The Water Depth Estimation at "Control Section"

The location of the "control section" as a function of time, moved upstream during outflow rush out from dam breach, was recorded by using the video above the dam crest. The distance between every location and initial location can be measured by using photogrammetric method. As Figure 6 showed, the curvature of "control section" was decreasing when it moving upstream but the length was increasing.

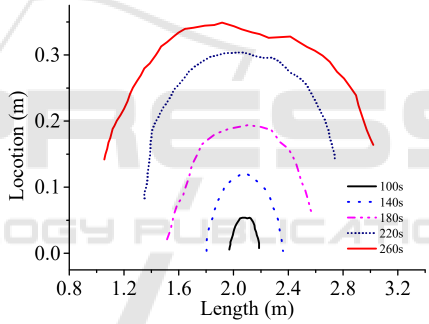


Figure 6: The location of "control section" moving upstream process

Following Walder's (2015) method, the flow depth at the "control section" was defined as follows:

$$h_c(t) = z_w(t) - z_c(t) \quad (1)$$

As Figure 7 showed, h_c was the water depth at the "control section", z_w was the water free surface elevation over the "control section", and z_c was the bottom elevation of the "control section", X_c was the distance form initial location to present location, φ was the upstream slope of the dam, z_d was the initial dam height. Among these parameters, z_d , z_w and X_c can be measured directly. For artificial earth dam, φ was usually a given factor, while it should be assumed for nature dam. Therefore, the equation 1 can be expressed as equation 2. Based on equation 2, the breach water depth was about 13cm at 100s. However, the equation 2 worked well in the early period of the second stage of dam break but not all: it failed when the breach water depth become too large.

$$h_c(t) = z_w(t) + X_c(t)\tan\varphi - z_d \quad (2)$$

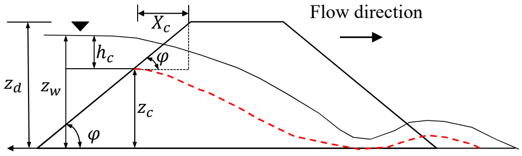


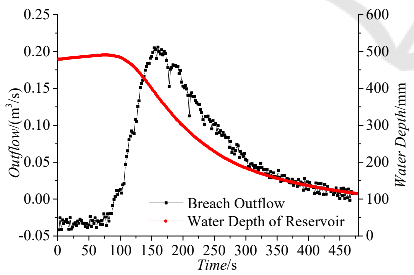
Figure 7: Sketch of the breach water depth estimation

3.2.3 Comparison Breach Hydrograph and Other Parameters

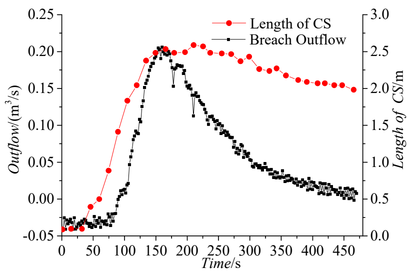
The breach discharge was the most important parameters for dam-break problem since it determines the downstream inundated area, which was often estimated using water volume balance of reservoir.

$$\frac{dW}{dt} = Q_{in} - Q_{out} \quad (2)$$

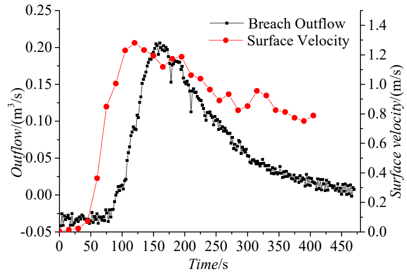
where Q_{in} was the inflow; Q_{out} was the breach discharge; W was the water volume of the upstream reservoir.



(a) Comparison breach hydrograph and water depth of reservoir



(b) Comparison breach hydrograph and breach length of "control section"



(c) Comparison breach hydrograph and water surface velocity

Figure 8: Comparison breach hydrograph and other parameters

In order to better understand the time correlation of breach discharge and other parameter such as reservoir water depth, breach width and breach water surface velocity, the breach hydrograph and these parameters were put together and showed in Figure 8a~c. According to equation 3, the discharge curve was derived from water depth of reservoir, and the peak discharge time would come out at maximum slope of reservoir water level curve, as shown in Figure 8a. Comparison of time history of dam breach discharge and the breach length of "control section", it can be found that when the length of "control section" reach the maximum, the discharge was also the maximum (Figure 8b). The water surface velocity at "control section" was measured by using LS-PIV technology, and there exist about 30s interval for peak water surface velocity to peak discharge (Figure 8c). Therefore, according to $Q_{out} = \bar{A}\bar{V}$ ($\bar{A}$ was average cross-section area, $\bar{V}$ was average water velocity), the contribution of cross-section area was larger than water velocity for dam breach outflow estimation.

4 SUMMARY AND CONCLUSIONS

This study presents the experimental investigation of the breach parameter relationship for earth dam failure due to overtopping. The experiment was conducted in a flume of 50m*4m*2m with an idealized earthen dam placed in the middle. According to experiments data, it showed that the dam breach process can be divided into two stages, the main feature of first stage was "head-cut" while the second stage was "surface" erosion. It was found that the length rate of CSC and CS was approximately 0.85 at peaking discharge moment in the present study. The breach water depth can be estimated by using $h_c(t) = z_w(t) + X_c(t)\tan\varphi - z_d$, and the based on this formula, the breach depth at 100s was approximately equal to 13cm. The peak time of discharge was nearly the same as maximum breach width time and maximum reservoir water depth decreasing slope time but delayed to peak water surface velocity time about 30s.

ACKNOWLEDGMENT

This research was jointly supported by the youth program of Sichuan Science foundation: Experimental study and numerical simulation of landslide surge superimposed in different stages of earth-rock dam break process (Grant No. 2022NSFSC1068), and the open project of key laboratory of scientific research projects of colleges and universities of Sichuan province (Grant No. SC_ FQWLY-2021-Y-03), the 2022 open project of failure mechanics engineering disaster prevention of key Lab of Sichuan Province: The investigation of the impact force of surge wave on dam and its damage mechanism research (Grant No. FMEDP202210), the 2022 open project of failure mechanics engineering disaster prevention of key Lab of Sichuan Province: Study on the rule and mechanism of dynamic crack propagation under blasting (Grant No. FMEDP202208).

REFERENCES

Al-Riffai, M., 2014. Experimental study of breach mechanics in overtopped noncohesive earthen embankments. PhD dissertation, Univ. of Ottawa, Ottawa, Ont., Canada.

Coleman, S. E., Andrews, D. P., and Webby, M. G.,2002. Overtopping breaching of noncohesive homogeneous embankments. Journal of Hydraulic Engineering-Asce, 128(9): 829-838.

Das, P. K., 1997. Breach erosion process of homogeneous earth fill dams and fuse plugs due to overtopping flow, Ph D thesis, Indian Inst.of Technol. Kanpur, Kanpur, India,.

Hanson, G. J., Cook, K. R., and Hunt, S. L., 2005. Physical modeling of overtopping erosion and breach formation of cohesive embankments.Trans. ASABE,48(5):1783-1794.

Liu, J., Xiao, H., Lin, P., Zhou, C., and Wang, W., 2021. Effect of vertical velocity profile approximations on estimates of dam breach discharge using surface velocities. Journal of Flood Risk Management, 14(3):1-13.

Mahmoud T. Ghonim, Magdy H. Mowafy et al.,2022. Investigating the peak outflow through a spatial embankment dam breach. Ain Shams Engineering Journal 13,101799

Singh, V. P., and Scarlatos, C. A.,1988. Analysis of gradual earth-damfailure. Journal of Hydraulic Engineering, 114(1): 21–42.

Wang J.C., Chen X.,2011. Study of a landslide surge disaster based on Pan Jiazheng calculation method of sliding velocity and surge. Hazard, 1:16–22.(in Chinese)

Wu W. M.,2011. Earthen Embankment Breaching. Journal of Hydraulic Engineering, 137:1549-1564.

Walder, J. S., Iverson, R. M., Godt, J. W., Logan, M., and Solovitz, S. A.,2015. Controls on the breach geometry and flood hydrograph during overtopping of noncohesive earthen dams. Water Resources Research,51(8): 6701-6724.