ERODABLE DAM BREACHING PATTERNS DUE TO OVERTOPPING

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Dedicated to my beloved father and mother and my family

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ABSTRACT

There have been numerous studies on dam breaching that have been carried out for a long time, but this area still needs further investigation. Dams which have failed due to breach mechanism have caused disastrous effects to the downstream area, such as loss of lives, property damages, economic and environmental damages. This is due to the complex process of breaching which involves many factors such as cohesiveness of the embankment material, the height of the dam and the slope of the embankment dam. Hence, the aim of this study was to investigate the breach patterns and breach grows when breaching takes place. Besides, this study is also focused on the breach hydrograph that is produced after the failure of embankment. The embankment dam of 0.1m was tested in 11m length and 0.6m width channel. The equation used to measure the outflow discharge was $Q = 8/15\ (C_d)(2g)^{0.5} \tan(\theta/2)\ (h)^{2.5}$. Different embankment parameters were considered, i.e. the embankment materials (coarse and medium sand), the inflow rates (Q_1 = 0.6 m^3/s, Q_2 = 0.9 m^3/s and Q_3 = 1.2 m^3/s) and the slope of the embankment dam (1V:2H and 1V:3H). Most of the embankment dam tested showed that vertical erosion occurred first until a certain point before lateral action took place. Higher inflow rate produced higher peak outflow and shorter peak time. Besides, higher inflow rate flushed away all the embankment materials towards downstream and formed a wedge shape at the end of the process, as observed from the side view. For different embankment slopes used, the flatter slopes prolonged the erosion process about 7.7 % and also reduced the peak outflow value of about 15.8 %. Different grain sizes of soil were also used in the tests and it proved that the smaller grain size of soil reduced the peak outflow value (6.5%) and prolonged the peak time about 13.3%. Process of dam breach is clearly influenced by the embankment material, the embankment slope and the inflow rate.

ABSTRAK

Terdapat banyak kajian mengenai kepecahan empangan yang telah dijalankan untuk sekian masa yang lama, tetapi bidang ini masih memerlukan siasatan yang lanjut. Empangan yang telah gagal kerana mekanisma pemecahan telah menyebabkan kesan bencana di kawasan hiliran, seperti kehilangan nyawa, kerosakan harta benda, dan kemusnahan ekonomi dan alam sekitar. Ini kerana proses pemecahan yang kompleks dan melibatkan banyak faktor seperti kesepaduan bahan tambak, ketinggian empangan dan cerun tambak empangan. Oleh itu, tujuan kajian ini adalah untuk menyiasat corak dan penjalaran pemecahan apabila kepecahan empangan berlaku. Selain itu, kajian ini juga memberi fokus kepada hidrograf pemecahan yang dihasilkan selepas kegagalan tambak. Tambak empangan setinggi 0.1 m telah diuji salurannya sepanjang 11 m dan 0.6 m lebar. Persamaan yang telah digunakan untuk mengukur pelepasan aliran keluar adalah. Q = 8/15 $(C_d)(2g)^{0.5}$ tan $(\theta/2)$ $(h)^{2.5}$. Parameter tambak yang berbeza telah diambil kira, iaitu bahan-bahan tambak (pasir kasar dan sederhana), kadar aliran masuk (Q_1 = 0.6 m^3/s, Q_2 = 0.9 m^3/s dan Q_3 = 1.2 m^3/s) dan cerun empangan tambak (1V: 2H dan 1V: 3H). Kebanyakan empangan tambak yang telah diuji menunjukkan bahawa hakisan menegak berlaku dahulu sehingga satu titik tertentu sebelum tindakan sisi berlaku. Kadar aliran masuk yang lebih tinggi menghasilkan puncak aliran keluar yang lebih tinggi dan puncak waktu yang lebih pendek. Selain itu, kadar aliran masuk yang lebih tinggi menghanyutkan segala bahan tambak ke arah hilir dan membentuk satu bentuk baji pada akhir proses, sebagaimana yang diperhatikan dari sudut sisi. Bagi cerun tambak yang berbeza, cerun mendatar melambatkan proses hakisan kira-kira 7.7%, dan juga mengurangkan nilai puncak aliran keluar kira-kira 15.8%. Saiz butiran tanah yang berbeza juga telah digunakan dalam ujian dan ianya terbukti bahawa saiz butiran tanah yang lebih kecil mengurangkan nilai puncak aliran keluar (6.5%) dan memanjangkan masa puncak kira-kira 13.3%. Proses kepecahan empangan jelasnya dipengaruhi oleh bahan tambak, cerun tambak dan kadar aliran masuk.

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LIST OF SYMBOLS

B	-	Breach width
B_w	-	Breach width due to dam breach
Y	-	Water depth before dam breach
v	-	Flow velocity
g	-	Acceleration due to gravity
t	-	Time of breach
Q_b	-	Outlet discharge after dam breach
h_e	-	Erosion depth
C_d	-	Discharge coefficient
h	-	Height of water at the notch area
Lp	-	Length in the prototype
Lm	-	Length in the model
θ	-	Angle of notch
h	-	Head above bottom of notch

CHAPTER 1

INTRODUCTION

1.1 Introduction

Dams are purposely constructed for water irrigation, flood control, hydroelectricity, water supply, and recreational improvement. Dams can be divided and classified in different ways, namely sizes, filling materials, shapes, and purposes. The main factors that must be considered before constructing the dams are topographic and geologic characteristics (Singh, 1996). The construction of dams must comply with regulations and design specifications to prevent failures.

Recently, a dam failure has been discussed all over the world. Failure of Aznalcollar tailings pond dam in Spain for example, caused ecological damage due to the toxic material that spilled into the river system (Coleman *et al.*, 2002). Failure of dam to release the reserved water in the reservoir to the downstream area not only affecting the people living at downstream area, but also affects socio-economy activity, destruction of power plant, damage of properties, damage of bridges and so on.

In Malaysia, such scenario rarely occurred since the use of concrete dam, which has higher strength and less eroded compared to earth embankment dam. However, overtopping is an unexpected scenario that may occur due to heavy torrential rain, increasing of population and others. Hence, the study on the dam breach failure should be carried out to reduce all the effects related to dam failure. Besides, an in-depth study on dam breaching is needed to contribute or upgrade the numerical tools which are used to predict the time to peak and peak outflow related to the failure.

In order to reduce the effects of dam breach, many protections have been implemented. Chanson (2009) listed down several protection systems such as concrete overtopping protection systems, timber cribs, sheetpiles, riprap and gabions, reinforced earth, and minimum energy loss weirs.

1.2 Breach Parameters

In analyzing breaching of a dam, breach parameters involved are breach depth, breach width and breach side slope. The detail on the geometry of dam breach can be described in Figure 1.1, where h_b = breach height, h_w= water level, and B = breach width. Meanwhile, the breach depth is defined as the breach height, measured as the distance from the dam's crest to a certain height or breach invert. The extension of the breach depth usually occurs in a vertical way. In turn, breach width is defined as the top, lower or average width of the breach which depends on each model (Atallah, 2002). On the other hand, Wahl (1998) stated that the breach side slope factor is referred as Z in Figure 1.1. The side slope is usually in a ratio of 1V:ZH. The final shape of breach would be the output of the breach side slope, breach width or a combination of breach side slope and breach width.

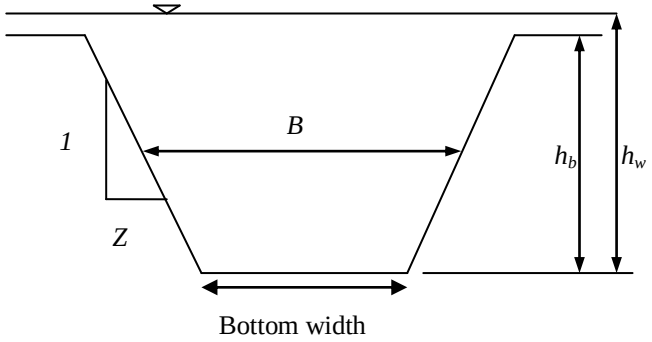

Figure 1.1 Parameters of dam breach (Wahl, 1998)

Breach initiation time begins with the flow over the dam which initiates the warning for the dam failure. At this phase, the outflow of the dam is not very severe. Hence, the dam is not failed yet. Breach formation time is defined in many ways by the researchers. However, Wahl (1998) stated that the definition from various researchers has similar meaning as DAMBRK, which is ' *The time of failure used in DAMBRK is the duration of time between the first breaching of the upstream face of the dam until the breach is fully formed ...*'. This phase usually deals with the progressive of outflow through the dam which cannot be stopped, unlike the breach initiation time.

1.3 Background of the Study

The studies on dam breach have been carried out either by physical experimentation or numerical study. The physical experiment contributes in gaining the data at the laboratory instead of collecting the data at the breach location during the real event, which are dangerous for the researchers. Details from previous research on dam breach are explained in the Chapter 2. The investigations on the breached dam study have been carried out since 1980s. Researchers such as Temple and Hanson (2005), Visser (1998), Wahl (2004), Zhu *et al*., (2006) and some other

researchers who carried out physical experiments have contributed in understanding the breach process. They varied the parameters such as embankment slopes, embankment materials and compaction efforts in understanding the breach process. However, there are still lacking in data and understanding in upgrading the breach models.

Breach simulation and prediction are always associated with greatest uncertainties on aspects for forecasting of dam breach flooding. The uncertainty requires researchers to improve their knowledge on the dam breach. Most of the numerical modelling neglected some aspects such as the effect of slope protective layers, composite structure and other aspects. Hahn *et al.* (2000) also stated that majority of the models used simplication in the model, which does not cover all aspects in dam breach parameters. Wahl (2010) reviewed the numerical modelling and stated that the uncertainty is the prediction of the reservoir outflow hydrograph. Most of the numerical modelling neglected some aspects such as the effect of slope protective layers and composite structure. Besides, the understanding on the dam breach process is very poor and hence it needs to be improved. The lack of understanding in the dam breach process is contributed by the limited number of reported real dam failure events and limited number of available breach data.

1.4 Scope and Objectives of the Study

The study focuses on the breached embankment patterns due to overtopping, which is known as the most common mechanism of embankment failures. The material used to construct the dam in this study is homogeneous soil, where sand is used as the fill material. The notch is located at the middle of the embankment dam to initiate the breach process. This point is acted as the weak part of the embankment dam.

Hence, experimental study are carried out to understand the process of embankment failure and a detail observation on the process of breaching where the real cases of the breached dam usually occur. The objectives that need to be achieved at the end of the study are:

a) To investigate the flow characteristics of dam breaching due to overtopping.
b) To plot the patterns of dam of failure for different flow rates, sediment sizes and embankment slopes.
c) To determine the breached hydrograph for different flow rates, sediment sizes and embankment slopes.

1.5 Significance of the Study

The process of dam breaching is lacking in the data and understanding. Mathematical modelling, for example, assumed more simplistic breach morphology, oversimplification, and others. Besides, most models also neglect some of the criteria such as flow sediment transport, effect of dam slope protective layers, and so on. The previous studies have no fraction on the sediment sizes used as the embankment dam. Meanwhile, the present study used the fraction method with the range of 0.2 mm to 0.6 mm and 0.6 mm to 2.0 mm. Hence, the behaviour of breach pattern for different soil range can be observed.

While for experimental work, the available data are limited, leading to the lacking of understanding on the breaching problem. Besides, previous researchers have also recommended that the study should be carried out in detail as the room for discussion is still available. This is due to the fact that the breach process is a complex process affected by many factors such as embankment dam height,

embankment dam slope, embankment dam height, embankment materials, and others. Thus, it is hoped that the problems arise from the dam failures study can be handled and avoided to provide the best solution, and better flood prediction can be obtained. The experimental works carried out in this study contribute more in understanding the breach process, as well as contributing in the data for experimental and validation model or upgrading the mathematical modelling.

1.6 Summary

The thesis consists of five chapters and appendices. Chapter 2 is the compilation of the review on literature related to dam breach. The review covers previous studies on dam breach, together with the parameters influencing the breached dam, as well as those parameters related with the experimentation work. The reviews of previous research on dam breach are covered, which include the process of breach, causes of breach and breach widening accompanied by the breach hydrograph.

In Chapter 3, the discussion is about the methodology adapted in order to achieve the main aim of the study. The chapter also deals with the tests involved, either for geotechnical or hydraulics aspects. Chapter 4 discusses about the analysis of the experimental data. The analysis will cover the dimensional analysis, as well as similar analysis based on previous researchers, which include breach hydrograph, breach widening and breach growth. Chapter 5 draws the conclusions and recommendations for future research. References used in this study are presented at the end of this thesis.

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