Engineering Geology 209 (2016) 70–81

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Modeling lateral enlargement in dam breaches using slope stability analysis based on circular slip mode

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ARTICLE INFO

Article history:
Received 27 December 2015
Received in revised form 24 April 2016
Accepted 26 April 2016
Available online 1 May 2016

Keywords:
dam breach
geotechnical analysis
circular slip surface
the effective versus total stress analysis
DBS-IWHR
Yigong Barrier Lake

ABSTRACT

Evaluation of breach flood of landslide or artificial dams is usually performed by combining the hydraulic modeling of the breach flow and geotechnical analysis of the breach channel stability. This paper is a continuation of the previous work, which mainly focused on the hydraulic aspects of a dam breach flood. Efforts have been made to improve the related slope stability analysis approach that traditionally adopts a simple wedge failure mode. The improvements includes a vertical cut at the slope toe due to soil erosion, an approach to determine the critical slip surface, the effective and total stress methods dealing with different dam materials, and a procedure to model the stepped failures of the breach bank due to continuous toe cutting. Using VBA programming, an Excel spreadsheet entitled DBS-IWHR has been developed to perform the stability analysis. This spreadsheet has been incorporated into another spreadsheet entitled DB-IWHR for the calculation of the flood hydrograph. The developed model has been tested by back analysis of the Yigong landslide dam breached at the Tibetan Plateau in China in 2000 with a flood peak of 94,013 m^3/s. The calculated results of the final breach base level and the peak discharge are in good agreement with the field data. Further, the results are shown to be insensitive to the variations in the geotechnical parameters used in the model.

1. Introduction

For safety control, it is important to estimate the flood due to the breach of natural or artificial dams (ASCE/EWRI Task Committee 2011). For this type of estimation, a dam breach analytical model usually combines hydraulic and geological approaches. The flow discharge passing through the breach opening is usually determined by the broad crested weir flow formula. As the base of the breach is cut deep to a certain elevation, the banks on both sides of the channel may collapse, resulting in a wider channel. This is known as lateral enlargement. For this type of dam breach analysis, as a preliminary approach, the planar wedge failure mode is usually used in the slope stability analysis (e.g., Fread, 1988). The process of 'cut and collapse' cycle continues until the reservoir water is depleted.

In this study, the authors' research group had the opportunity to examine the documented field monitored information of the draining process of the Tangjiashan barrier lake. Based on an in-depth back analysis of the monitored data, Chen et al. (2015) proposed improvements to the existing dam breach analytical methods. These improvements enable the dam breach flood analysis to be less sensitive to the input parameters. It can also be performed using a simple coded Excel 2013 spreadsheet, namely DB-IWHR. Due to the limitation of space, the earlier paper (Chen et al., 2015) mainly focused on the hydraulic aspects of the improved method. The present paper provides the details on the modeling of lateral enlargement of a breach during a dam breach process.

Since the slope stability analysis contains tedious procedures (e.g., modeling of a vertical toe cutting and stepped collapsing, searching for the critical slip surface and applying a total stress analysis method), a spreadsheet for computing the lateral enlargement process, namely, the DBS-IWHR, in conjunction with the DB-IWHR, has been developed. This spreadsheet enables the practitioners to carry out their routine stability analyses on predicting the dam breach flood. It is available for downloading at the website: http://www.geoeng.iwhr.com/geoeng/download.htm.

The developed method is applied in the back analysis of a gigantic landslide dam breach that occurred in Yigong in the Tibet Plateau in 2000 with a flood peak of 94,013 m^3/s.

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http://dx.doi.org/10.1016/j.enggeo.2016.04.027
0013-7952/

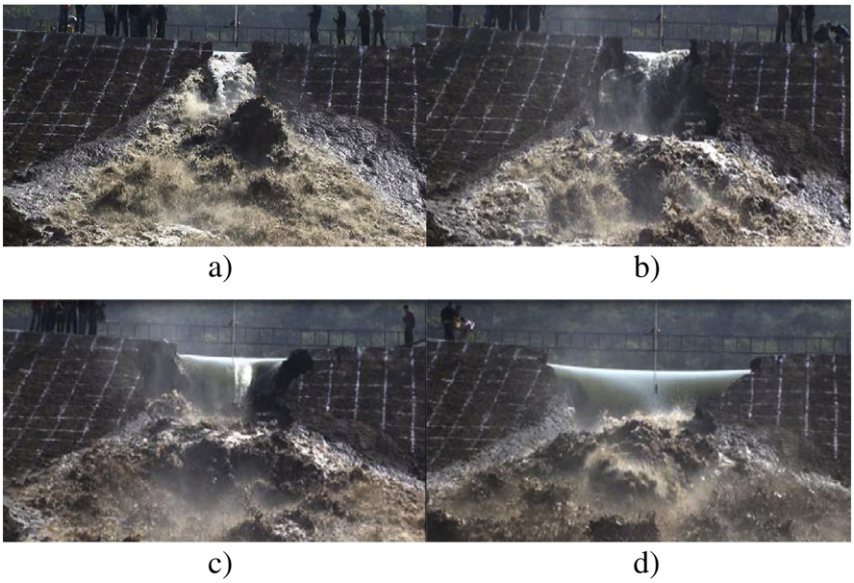

Fig. 1. The enlargement process of a model dam in different elapsed times: (a) 210s; (b) 360s; (c) 480s; (d) 520s (Zhang et al., 2009, courtesy by Shengshui Chen).

2. Modeling lateral enlargement

2.1. Lateral enlargement of breached bank due to slope instability

The continuous enlargement of a dam breach opening is a phenomenon commonly observed in the field and laboratories. For example, Liu et al. (2010) reported that during the breach of the landslide dam at the Tangjiashan barrier lake, the width of the channel was enlarged from 7 m to 150 m. Fig. 1 shows the enlargement process during the breaching process of a 9.7 m high model dam (Zhang et al., 2009). Further, for the same model dam, Fig. 2 catches the instant of 360 s, shown as Fig. 1(b) in the previous pictures, when a slump of soil fell down, the red dotted lines clearly show the landslide process of the dam breach.

2.2. Discussion on previous work

In most of the existing dam breach analytical methods, the lateral enlargement of the channel is modeled using slope stability analysis methods. In these methods, a planar wedge failure mode is used in which the slip surface is assumed to be a straight line (Fread, 1988; Osman and Thorne, 1988; Singh and Scarlatos, 1988; Peviani, 1999; Mohamed, 2002; Zhu, 2006; D'Eliso, 2007; Huang, 2008; Wang et al., 2008; Morris et al., 2009b; Chang and Zhang, 2010; Viero et al., 2013; Wu, 2013; Dou et al., 2014; Peng et al., 2014). The necessary analytical details that should be considered include: (1) a vertical cut at the slope toe, (2) the approach to determining the critical slip surface, (3) appropriate consideration of the pore water pressure in the failed slope, and (4) the procedure to model the stepped failures of the breach bank due to continuous toe cutting. The method proposed by Osman and Thorne (1988) appears to have considered most of the aforementioned details, especially the vertical cut at the toe, and has therefore encountered wide applications (Huang, 2008; Wang et al., 2008; Morris et al., 2009a, b).

Apart from these aspects, it should also be noted that the geotechnical profession has a long history of assessing the stability of a slope by circular or more generalized shaped failure surfaces (Bishop, 1955; Morgenstern and Price, 1965). It is also noted that the pore water pressure or phreatic line in the dam body is invariably ignored in all the existing methods.

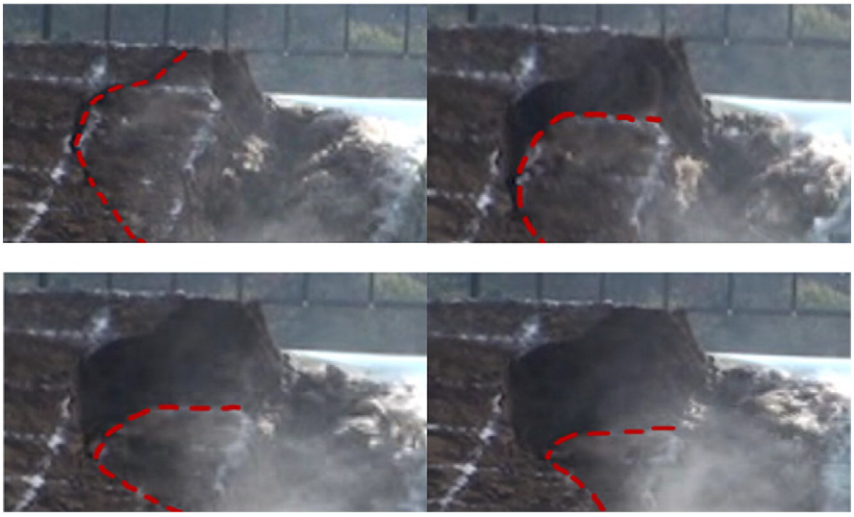

Fig. 2. The detailed landslide process happened in the right bank of the breach at 360 s shown in Fig. 1(b) (Zhang et al., 2009, courtesy by Shengshui Chen).