Water Science and Engineering 2016, 9(2): 165−171

HOSTED BY ELSEVIER

Available online at www.sciencedirect.com

Water Science and Engineering

journal homepage: http://www.waterjournal.cn

Experimental study on piping in sandy gravel foundations considering effect of overlying clay

Shuang Wang [a,*], Jian-sheng Chen [b], Hai-qing He [a], Wen-zheng He [a]

[a] College of Civil and Transportation Engineering, Hohai University, Nanjing 210098, China
[b] College of Earth Sciences and Engineering, Hohai University, Nanjing 210098, China

Received 8 April 2015; accepted 10 August 2015
Available online 15 June 2016

Abstract

The influence of the overlying clay on the progression of piping in the sandy gravel foundation of water-retaining structures is often neglected. In order to study this influence, an experimental investigation was conducted on a laboratory-scale model. It was discovered that the critical hydraulic gradient and the area of the piping tunnel increase when the overlying clay thickens. With a thicker clay layer, erosion of the sandy gravel below the clay layer occurs later, but, once the erosion starts, the erosion rate is very high and the average velocity of water seeping through the cross-section of the sandy gravel increases rapidly due to the low deformability of the thick clay layer. Furthermore, it was found that the progression of piping is a complicated and iterative process involving erosion of fine particles, clogging of pores, and flushing of the clogged pores. Two types of erosion have been identified in the progression of piping: one causes the tunnel to advance upstream, and the other increases the depth of the tunnel. The results show that the overlying clay is an important factor when evaluating piping in sandy gravel foundations of water-retaining structures.

Keywords: Piping; Experimental model; Sandy gravel foundation; Overlying clay; Clog; Erosion rate

1. Introduction

Piping or tunnel erosion, defined as the hydraulic removal of subsurface soil, causing the formation of underground channels in natural landscapes (Boucher, 1990), is an important cause of dam failure. Recent comprehensive reviews by Foster et al. (2000a, 2000b) and Fell et al. (2003) showed that internal erosion and piping are the main causes of dam failure, with the proportion of dam failures caused by piping increasing from 43% before 1950 to 54% after 1950. In reanalyzing this survey data, Richards and Reddy (2008) determined that approximately 31% of all dam failures resulted from the piping mode of failure.

Since an embankment consists of different zones and materials, a wide range of parameters may influence initiation and continuation of an internal erosion process. The properties of materials, integrity of the structure, cross-sectional geometry of the dam embankment, and groundwater flow properties are some of the relevant parameters. Of the properties of materials, the grain size distribution and microstructure of the soil have significant influence on the potential of erosion, an issue that has been investigated by numerous researchers (Fannin and Moffat, 2006; Wan and Fell, 2008; Indraratna et al., 2011). It is generally accepted that broadly graded soils with flat slopes in the fine fraction and steep slopes in the coarse fraction and gap-graded granular soils are often internally unstable. Li (2008) proposed that the initiation of the internal erosion process was also influenced by the porosity of soil and grain shape. Al-Riffai and Nistor (2010) showed that the compaction of an earthfill dam model had a significant influence on internal erosion.

Bendahmane et al. (2008) performed a parametric study to examine the influence of three critical parameters (hydraulic

This work was supported by the 973 Program of China (Grant No. 2012CB417005) and the Postgraduate Research and Innovation Plan Project in Jiangsu Province (Grant No. CXZZ13_0243).
* Corresponding author.
E-mail address: wshwy.871112@163.com (Shuang Wang).
Peer review under responsibility of Hohai University.

http://dx.doi.org/10.1016/j.wse.2016.06.001
1674-2370/

gradient, clay content, and confining pressure) on erosion mechanisms of clay and sand. Marot et al. (2009) discussed the effects of internal flows on a sand/kaolin mixture, in terms of the rate of erosion and the variation in permeability. Richards and Reddy (2010) designed a true triaxial piping apparatus for testing a wider variety of soils under a wider range of confining stresses, hydraulic gradients, and pore pressures. Maknoon and Mahdi (2010) studied the initiation of external suffusion caused by water level increases using a laboratory-scale model. Marot et al. (2010) and Sail et al. (2011) developed an experimental bench to study the initiation and progression of internal erosion and its consequences on the hydraulic and mechanical behavior of cohesionless soils. Moffat and Fannin (2011) and Moffat et al. (2011) studied the spatial and temporal progression of internal instability in four types of cohesionless soils with multi-stage seepage tests in a large permeameter and proposed a novel concept of a hydro-mechanical path in stress-gradient space. Zhang et al. (2012) presented new experimental data regarding the erosion rate during the process of a dam break caused by overtopping and examined three relevant parameters affecting the erosion rate: the length of the dam crest, the inner slope, and the dam composition. Marot et al. (2012) designed a specific centrifuge bench to study the scale effect in the suffusion experiment. Their study underlined the influence of specimen length on the critical suffusion hydraulic gradient and the rate of erosion. Luo et al. (2013) studied the suffusion failure mechanism in the case of a long-term large hydraulic head in a flood season. Chang and Zhang (2013) investigated the initiation and development of internal erosion and the effect of stress states on critical hydraulic gradients; they concluded that the initial hydraulic gradient under compression stress conditions generally increased with the shear stress ratio first and then decreased when the stress conditions approached failure.

Previous works have comprehensively studied the erosion process and erosion parameters, yet the in situ conditions of levees and their foundations were not considered completely. In a two-stratum foundation, the overlying clay layer on the sandy gravel was known as one of the fundamental factors that could contribute to the erosion of sandy gravel. In this study, a series of flume tests on the internally unstable sandy gravel foundation layer were carried out using a self-designed apparatus to study the progression of piping considering the effects of the overlying clay. Conditions were created as close as possible to real cases. Clay and sandy gravel were chosen as the overlying impervious layer and pervious layer materials, respectively. The constructed models were subjected to a gradual increase of the upstream water level.

2. Experimental method

2.1. Experimental apparatus

Fig. 1 shows the schematic representation of the experimental apparatus. The tank was made of transparent organic glass. The width, depth, and length of the tank were 30, 30, and 100 cm, respectively. An intake chamber with a length of 20 cm was built on the left side of the tank. Holes with similar diameters were arranged on the right wall of the intake chamber and a filter consisting of gravel was placed upstream of the soil sample. This filter was used to create a more uniform water pressure distribution on the upstream side of the soil sample. Seven piezometer tubes embedded at different locations in the soil sample were used to measure water level fluctuations. A pre-set outlet with a diameter of 5 cm was set on the right side of the glass cover-plate. It penetrated the clay layer, with one side fixed on the glass cover-plate, and the other side fixed on the surface of the sandy gravel soil sample. The outlet was connected to the downstream water tank by a plastic tube through which water and the eroded particles flowed and were collected. This experimental device allowed the measurement of the erosion rate, hydraulic parameters (water level, hydraulic gradient, and discharge), and geotechnical parameters (grain size distribution and porosity of the sandy gravel, and thickness of the overlying clay).

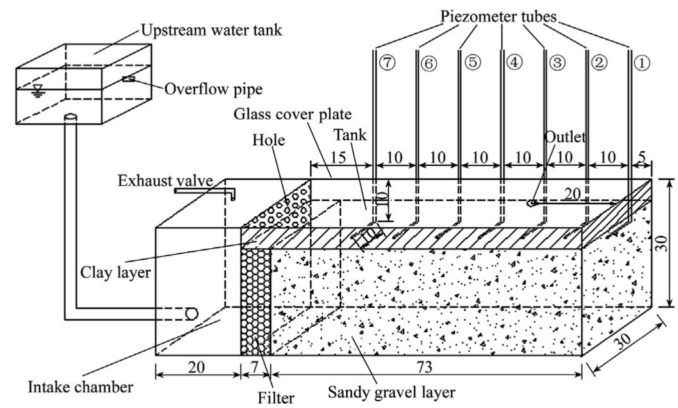

Fig. 1. Schematic representation of experimental apparatus (units: cm).

2.2. Experimental materials

The soil sample was a mixture of gravel with a diameter of 2−10 mm and sand with a diameter of less than 1 mm. The soil sample was gap-graded sandy gravel that could be considered internally unstable and was similar to “Sample A” in Skempton and Brogan (1994). The grain size distribution of the soil sample is shown in Fig. 2 (obtained using a sieve analysis). Soil sample properties and experimental conditions for three experiments are tabulated in Table 1.

2.3. Experimental procedure

The major stages of the experiments were as follows:

(1) Preparing the soil sample: First, moderate masses of dry sandy gravel and water were prepared and mixed completely. Then, the mixed soil sample was divided into several portions to be compacted in layers in the tank. Each layer, with a thickness of approximately 5 cm, was compacted to a predetermined density. At the same time, gravel was placed on