Critical Hydraulic Gradient of Piping in Sand

Jianhong Zhang¹, Shubin Jiang¹, Qiusheng Wang², Yujing Hou² and Zuyu Chen²
1 State Key Laboratory of Hydroscience and Engineering, Tsinghua University, Beijing, China
2 China Institute of Water Resources and Hydropower Research, Beijing, China

ABSTRACT

The occurrence and development of piping in dikes is a very complex process due to complicated interactions between water and soil. This paper is based on a study of the physical modeling of piping in sand at 1 g and ng in a centrifuge. The main purpose of the study is to investigate the scaling law governing the centrifuge modeling of piping and also the critical hydraulic gradient when piping begins. A coarse sand with particle size of 3 - 5 mm and a fine sand with particle size of 0.25 - 0.50 mm were mixed at mass ratios of 4:1, 5:1 and 6:1 to prepare the three gap-graded sands used in tests. A series of permeability tests were performed to measure the critical hydraulic gradient which was in the range of from 0.227 to 0.276. The critical hydraulic gradient slightly increased with the fine-grain content. There was no sign of piping when the mass ratio was 4:1. Permeability tests were also carried out on a centrifuge using sand with mass ratios of 5:1 and 6:1. The centrifugal accelerations were set at 5 g and 10 g in order to ensure the Reynold’s number (Re) less than 10 in the models. Based on the experiments carried out at 5g, 10g, the critical hydraulic gradients were measured to be 0.20 to 0.23 in the centrifuge, basically consistent with the experiments at 1g. The scaling factor for seepage velocity is n while the scale of critical hydraulic gradient is approximately 1.

KEY WORDS: Dike; piping; centrifuge; scaling law.

INTRODUCTION

Darcy (1865) proposed the famous Darcy law governing seepage through soil, based on a series of experiments carried out at Dijon in France. Ever since then, great progress has been made associated with the movement of groundwater, the spread of heat and pollutant plumes (e.g. Bear 1972, Freeze and Cherry 1979, Zhang et al. 2001). The occurrence and development of piping in dikes is a very complex process due to the complicated interactions between water and soil. The mechanism of piping is still not well understood and requires more study effort.

To date, investigation of the flow and transport process in soils has used approaches such as laboratory column studies, full-scale field studies, theoretical and numerical simulations, and geotechnical centrifuge modeling. Among them, laboratory column study and geotechnical centrifuge modeling can provide valuable information on the fundamental process involved and the relevant mechanisms (e.g. Arulananand 1988, Cooke 1991, Cooke et al. 1991, Goforth et al. 1994, Taylor 1995, Zhang et al. 1998, Zhang et al. 2008, Zhang et al. 2009).

The scaling effect on seepage and hydraulic conductivity has been one of the topics of the European program NECER which gathered 11 centrifuge facilities (Physical modeling in environmental geotechnics, 2000). Singh and Gupta (2000) reported a study of hydraulic conductivity modelling of a silty soil at different compaction states by various conventional laboratory 1g tests and centrifuge tests. They concluded that hydraulic conductivity can be modelled adequately in the centrifuge and the permeability in centrifuge is n times of that in the prototype, in which n is the scale factor of a centrifuge model (Taylor 1995).

This paper presents a study of piping in sand both in laboratory and centrifuge. The main purpose of the study is to investigate the scaling law governing the centrifuge modeling of piping and also the critical hydraulic gradient when piping begins. Three gap-graded sands were used in the study. The permeability tests were carried out at 1 g, 5 g and 10 g to examine the effect of centrifugal acceleration on piping. The effect of sand composition on piping was also discussed.

CENTRIFUGE MODEL DEVELOPMENT

Materials

A coarse sand with particle size of 3 - 5 mm and a fine sand with particle size of 0.25 - 0.50 mm were mixed at various mass ratios of 4:1, 5:1 and 6:1 to prepare the three sands designated as sand A, sand B and sand C respectively. Fig. 1 illustrates the particle size distribution curves of the sands. Table 1 summarizes the properties of the tested sands.

It is known that a well-graded soil usually has a reasonable spread of particle size, represented by a smooth, concave particle size distribution curve. Quantitatively, a well graded soil should have a uniformity coefficient greater than 10 and a curvature coefficient in the range of 1 – 3 (Department of transport 1993, Powrie 2004). As shown in Fig. 1 and Table 1, particles between 0.45 – 3 mm are absent for sand A and