Geotextiles and Geomembranes 42 (2014) 15–24

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

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

Improving piping resistance using randomly distributed fibers

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ARTICLE INFO

Article history:
Received 8 February 2013
Received in revised form
31 August 2013
Accepted 16 December 2013
Available online 4 January 2014

Keywords:
Piping
Seepage
Randomly reinforcement
Fiber
Hydraulic gradient

ABSTRACT

Piping is a problem that commonly occurs downstream of hydraulic structures under the influence of upward seepage. Piping is considered as the main mechanism of hydraulic structures failures. In this work an experimental program was set for determining the seepage velocity and piping resistance for unreinforced and randomly reinforced silty sand samples. Two types of fiber were used for preparing the reinforced samples. The experimental tests were carried out for different fiber contents (0.5, 0.75, 1.0 and 1.25%) and fiber lengths (5, 25 and 35 mm) under different hydraulic heads. Discharge velocity and seepage velocity of water flow through unreinforced and reinforced samples were calculated and compared with unreinforced sample. The results show that the inclusion of fibers reduced the seepage velocity, increased the piping resistance and increased the critical hydraulic gradient hence, considerably delaying the occurrence of piping. Furthermore, the amounts of increase in the piping resistance and hydraulic gradient are functions of percent and length of fibers.

1. Introduction

As the water flows through the soil there is a transfer of energy to the soil skeleton. This causes a seepage forces to act on the skeleton. When the flow of water is upwards and if the hydraulic gradient is high enough the resultant body force could be zero. The value of hydraulic gradient corresponding to zero body force is called the critical hydraulic gradient (i_c). In this case the contact force between particles of soil will be zero and soil will have no strength. This leads to erosion of soil. This phenomenon is known as piping. The actual word 'piping' refers to the development of channels which develop at the downstream side of the structure where the flow lines converge and high seepage pressures occur (Sellmeijer, 1988). Ojha et al. (2003) stated that piping is a form of seepage erosion and involves the development of subsurface channels in which soil particles are transported through the porous medium.

Sherard et al. (1984) indicated that the piping of loose soils is a common problem in downstream of earth embankments under the influence of upward seepage. Foster et al. (2000) reported that about 1.5% of embankment failures are resulted from the occurrence of piping. Ubilla et al. (2008) reported that the main reason for the failure of the levees and flood walls protecting New Orleans, Louisiana and the surrounding area during Hurricane Katrina can be the occurrence of piping. Das and Viswanadham (2010) suggested that the piping failure is synonymous with sand boiling or quick sand condition. Some researchers such as Foster et al. (2000) and Ojha et al. (2003) indicated that piping erosion occurs in structures that are made up of loose soil with relatively high permeability. Hydraulic structures should be protected against piping using appropriate techniques (e.g., sheet piling, impervious clay blanket, filters, etc). Reinforcing soil with randomly distributed fibers can help improve the soil properties and protect against piping. Soil reinforcement is an effective technique for improving the mechanical behavior of soils. Reinforcement of soil achieved by either inclusion of strips, bars, grids etc within a soil mass in a preferred direction or mixing discrete fibers randomly with a soil mass. The use of randomly distributed fibers for soil reinforcement has many advantages. The mixing of fibers with granular soil is relatively easy. Also, another main advantage of randomly distributed fibers is the maintenance of strength isotropy and the absence of potential planes of weakness that can develop parallel to oriented reinforcement (Maher and Gray, 1990). The history of this technique goes back to more than 3000 years ago when Babylonians used a mixture of soil and straw as a construction material for improving the behavior of soil (Jha and Mandal, 1988). From 1970s investigators studied the mechanical behavior of this kind of soil reinforcement through conducting appropriate tests (e.g., Lee et al. (1973), Gray and Ohashi (1983), Yetimoglu and Salbas

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0266-1144/$ – see front matter
http://dx.doi.org/10.1016/j.geotexmem.2013.12.005

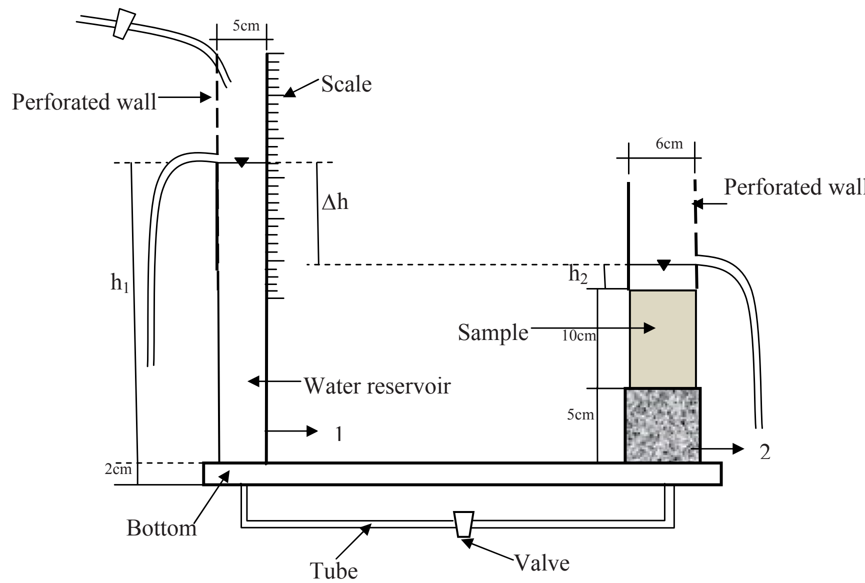

Fig. 1. Apparatus.

(2003), Yetimoglu et al. (2005), Consoli et al. (2007), Ahmad et al. (2010), Diambra et al. (2010) Lovisa et al. (2010), Edincliler and Ayhan (2010), Tang et al. (2010), Falorca and Pinto (2011), Plé and Lê (2012), Ibrahim et al. (2012) and Li and Zornberg (2013)). However, randomly reinforced soils have recently attracted attention of researchers as a method of improving soil against piping.

Furumoto et al. (2002) were the first researchers who proposed to increase the resistance against piping by using randomly reinforced soil. Sivakumar Babu and Vasudevan (2008) showed that for a soil reinforced with coir fibers. Increase in fiber content and fiber length increases the critical hydraulic gradient. Das et al. (2009) showed the influence of polyester fibers on piping behavior of fly ash as a fill material. Das and Viswanadham (2010) used two types of fiber with diameters 30 and 32 μm to investigate their influence on the piping resistance of a silty sand soil. They concluded that inclusion of fibers increases the piping resistance of soil.

2. Aim of this study

A review of the literature shows that the study of application of randomly reinforced soil with fibers for improving piping resistance in hydraulic structures is very limited. Furthermore, the previous studies on the applications of fiber reinforced soil for controlling piping have mainly used fibers of small diameter (in the range of μm) which would be difficult to implement in practical applications. Therefore, it was decided in this work to examine the possibility of using two types of polyester and polyethylene fiber with two relatively large diameters for improving piping resistance and controlling the seepage velocity of a sandy silty soil.

3. Apparatus

There is no standard test procedure available to measure the piping resistance of soils (Das et al., 2009). Skempton and Brogan (1994) designed and fabricated an apparatus for studying the phenomenon of piping in sandy gravel material. After that researchers such as Furumoto et al. (2002), Sivakumar Babu and Vasudevan (2008), Das et al. (2009) and Das and Viswanadham (2010) used an apparatus almost similar to the Skempton and Brogan's apparatus. In the present work, based on the considerations followed by previous researchers, a simple apparatus was designed and fabricated for conducting one dimensional piping test. The main function of this apparatus is to simulate the upward seepage through the soil sample. The cross section of the apparatus is shown in Fig. 1. This apparatus consists of two transparent cylinders with thickness of 5 mm that are placed on a Plexiglas base with thickness of 20 mm and connected to each other through a transparent tube with a valve. One of the cylinders with 50 mm diameter and 500 mm height is used for applying the desired hydraulic head and is called reservoir. A graduated scale is attached to the reservoir and is used for measuring the level of water. The wall of this cylinder is perforated at distances of 20 mm to help create various heads of water. The second cylinder consists of three sections. The first section is attached to the base and above it there is a perforated disc and a mesh on the disc. These accessories (perforated disc and mesh) are used to contain soil particles, to distribute the flow of water uniformly across the sample and to prevent from the downward migration of soil sample. The middle and top sections can be separated from each other. The dimensions of the middle section are 100 mm height and 50 mm diameter which is used as a mould for compacted soil sample. The top section has a diameter of 60 mm and its side is perforated to create the desired head of water on the soil sample. Therefore, in this

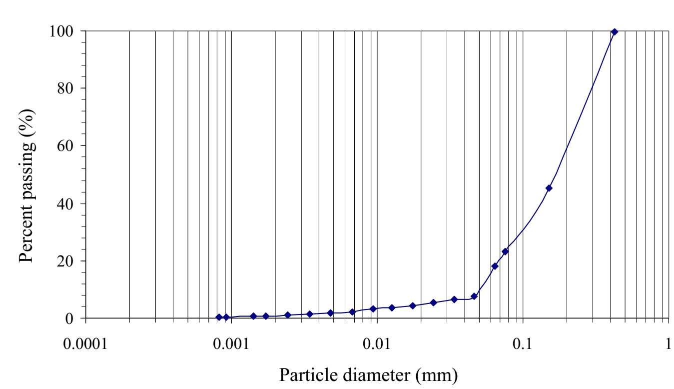

Fig. 2. Grain size distribution.