Geotextiles and Geomembranes 29 (2011) 567–580

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

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

Centrifuge model study on low permeable slope reinforced by hybrid geosynthetics

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ARTICLE INFO

Article history:
Received 27 October 2010
Received in revised form
31 May 2011
Accepted 17 July 2011
Available online 10 August 2011

Keywords:
Geosynthetics
Low permeable soils
Reinforced slopes
Hybrid Geosynthetics
Seepage
Centrifuge modeling

ABSTRACT

The objective of this paper is to study the performance of hybrid geosynthetic reinforced slopes, with permeable geosynthetic as one of its components, for low permeable backfill slopes subjected to seepage. Four centrifuge tests have been performed to study the behavior of hybrid geosynthetic reinforced slopes subjected to seepage, keeping the model slope height and vertical spacing of geosynthetic reinforcement layers constant. Centrifuge model tests were performed on 2V:1H slopes at 30 gravities. One unreinforced, one model geogrid reinforced and two hybrid geosynthetic reinforced slope models with varying number of hybrid geosynthetic layers were tested. The effect of raising ground water table was simulated by using a seepage flow simulator during the flight. Surface movements and pore water pressure profiles for the slope models were monitored using displacement transducers and pore pressure transducers during centrifuge tests. Markers glued on to geosynthetic layers were digitized to arrive at displacement vectors at the onset of raising ground water table. Further, strain distribution along the geosynthetic reinforcement layers and reinforcement peak strain distribution have been determined using digital image analysis technique. The discharge for the performed model tests is determined by performing seepage analysis. It was confirmed by the centrifuge tests that the hybrid geosynthetics increases the stability of low permeable slope subjected to water table rise. The hybrid geosynthetic layers in the bottom half of the slope height play a major role in the dissipation of pore water pressure.

1. Introduction

Geosynthetic reinforced soil walls and slopes are being widely used because of their low cost, flexibility and simple construction techniques. The backfill material forms one of the major constituents of a geosynthetic reinforced soil wall and slope and accounts for 30–40% of their cost. Granular backfill with good permeability characteristics is the preferred material for constructing reinforced soil walls and slopes. Zornberg and Leshchinsky (2003) evaluated the design criteria put forth by agencies worldwide for geosynthetic reinforced soil structures. A vast variation exists between the design procedures adopted in various countries. AASHTO (2002) (American Association of State Highway and Transportation Officials) permits the use of 0–15% fines whereas NCMA (National Concrete Masonry Association, 1997), permits fines up to 35% for carefully engineered structures. Most of the geosynthetic reinforced soil walls are conservatively designed using soils with low percentage of fines in the reinforced zone as per the design criteria put forth by various agencies worldwide. However the lack of availability of such backfill at construction site and high transportation costs involved in importing such material has often led to the use of locally available low permeable soil as backfill material for constructing geosynthetic reinforced slopes and walls. Use of backfill with relatively low permeability may lead to a situation where the wall, initially designed to work under drained conditions, is actually working under undrained conditions. In this case, excess pore water pressures are generated within the soil mass which may reduce the strength of the soil, particularly at the soil-reinforcement interface (Lee and Bobet, 2005; Sandri, 2005). Cases have been reported about failure of reinforced soil walls constructed with relatively low permeability and investigations have revealed that the use of backfill with relatively high percentage fines coupled with insufficient precautions considered for drainage were the prominent reasons (Yoo and Jung, 2006). The economic advantage of a geosynthetic reinforced structure is completely eliminated by the need of such a select fill within the reinforced zone, with the cost of the fill depending on its availability. The potential savings for replacing conventional backfill

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0266-1144/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.geotexmem.2011.07.003

materials with soils having relatively high percentage of fines could be in the range of 20–30% of current reinforced soil wall costs (Christopher and Stuglis, 2005). However, to avoid performance related issues in the form of excessive deformation and/or actual collapse, the reinforced soil walls must be designed with adequate drainage precautions for reducing pore water pressures. Hence the need to explore the potential use of locally available low permeable backfill has arisen. Abdi and Arjomand (2011) reported that the provision of thin sand layers as a drainage layer prevents pore pressure built up in clay backfills on saturation. Further based on pullout test results, it was reported that the encapsulation of geogrids with thin sand layers improves the response of clay by way of interfacial interaction.

Nonwoven geosynthetics, due to their highly porous structure, has received wide acceptance as a drainage material for various geotechnical applications. The in-plane flow characteristics of these geosynthetics within fine grained soils have been studied by Koerner and Sankey (1982), Ghosh and Yasuhara (2004), Ling et al. (1993), Hara et al. (2007), Raisinghani and Viswanadham (2010) and Raisinghani (2011). The application of nonwoven geosynthetics as an effective reinforcing element for reinforced soil structures with silty clay/clayey backfills has also been demonstrated by Fourie and Fabian (1987), Tatsuoka and Yamauchi (1986), Porbaha and Goodings (1996), Yasuhara et al. (2001, 2002) and Guler and Ocbe (2003). However, the low tensile stiffness and higher elongation characteristics of nonwoven geotextiles has restricted its use as a reinforcing material. Geogrids have been successfully used for tensile reinforcement but lack drainage ability essential for soils having low permeability. The combination of geogrid with adequate opening sizes and suitable nonwoven geotextile, can cater the need of both drainage and reinforcement requirement (referred herein as hybrid geosynthetic) in reinforced walls and slopes constructed with soils having relatively low permeability. The applications of hybrid geosynthetics formed with combination of some other geosynthetics have been prevalent in areas of landfill construction, road construction, soft ground improvement, etc. Very recently, Khosravi et al. (2011) studied the application of hybrid geosynthetics to control the uplift pressure in a filter drainage system under the canal lining through small-scale physical model tests in the laboratory.

Fig. 1 shows an application of hybrid geosynthetics for a reinforced slope with low permeable backfill at the onset of raising ground water table due to infiltrating rain water. The use of a permeable geosynthetic layer in the form of a hybrid geosynthetic may help to lower phreatic surface and reduce generated pore water pressures by draining water in the plane of hybrid geosynthetics. Successful application of using such hybrid materials also termed as "geocomposites" for a pavement and behind a retaining wall has been reported by McKean and Inouye (2001). In both the cases, hybrid geosynthetic was used in preventing the water table from rising as a result of rainfall.

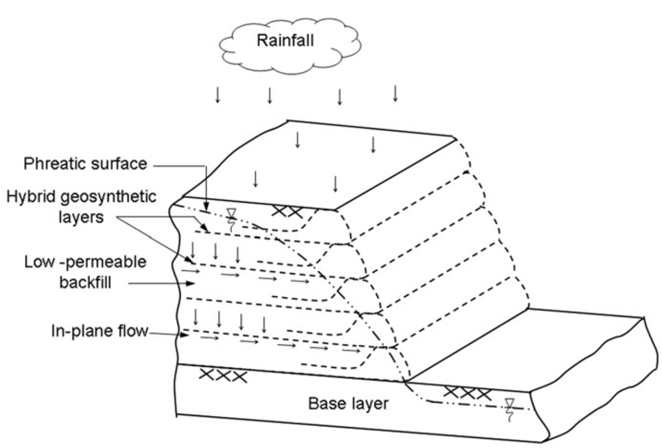

Fig. 1. Schematic representation of hybrid geosynthetic reinforced slope with low permeable backfill subjected to raising ground water table.

Chen et al. (2007) and Hu et al. (2010) performed centrifuge tests on geotextile reinforced cohesive soil slopes to investigate the deformation behavior and factors influencing the reinforcement mechanism. The seepage phenomenon in model slopes reinforced with and without reinforcement layers has been studied by Resnick and Znidarcic (1990), Hiro-oka et al. (2001) and Viswanadham and Raisinghani (2010). Analytical and numerical methods have also been reported by various researchers with an attempt to study the possible use of low permeable backfill for geosynthetic reinforced structures subjected to seepage (Iryo and Rowe, 2005; Liu et al. 2009; Tolooiyan et al. 2009). Viswanadham and Raisinghani (2010) presented a few centrifuge test results on the use of geocomposites for improving the stability of a low permeable slope. However limited physical model studies have been reported with respect to the use of hybrid geosynthetics in a reinforced slope constructed with low permeable backfill materials. In addition, comparison of excess pore water pressure generation with and without nonwoven geotextile component of hybrid geosynthetic layers on the stability and deformation behavior of reinforced slopes is limited.

This paper addresses the stability and deformation behavior of slopes reinforced with and without nonwoven geotextile component of hybrid geosynthetic layers with low permeable backfill, subjected to seepage. The performance of hybrid geosynthetic reinforced slopes has been evaluated by performing centrifuge tests on model slopes subjected to seepage. The model hybrid geosynthetic material used in the present study has been developed as per the modeling considerations for geosynthetics. The slope height, slope inclination, vertical spacing of reinforcement layers and the backfill soil type were kept constant. The effect of geosynthetic reinforcement, drainage component of hybrid geosynthetic and number of hybrid geosynthetic layers on the deformation of slope, pore water pressure distribution and reinforcement peak strain distribution with depth has been evaluated. Finally, stability and seepage analysis of the centrifuge models was carried out using SLOPE/W and SEEP/W software packages (Geo-Slope, 2007).

2. Scaling considerations for modeling of hybrid geosynthetics

Centrifuge modeling technique helps to achieve identical stress fields in both model and prototype. In order to replicate a prototype response in a small-scale centrifuge model, the scaling relationships for various physical factors that link the model behavior to that of the prototype, can be developed using dimensional analysis (Langhaar, 1951). The similitude condition for geosynthetic materials does not allow the direct use of commercially available prototype materials for the model. The model hybrid geosynthetic material used in the present study is a composite developed to serve the dual function of reinforcement and drainage and needs to be scaled down satisfying reinforcement and drainage functions. The selection criterion of the reinforcement component for forming the model hybrid geosynthetic material was based on scaling down the tensile load-strain behavior and the percentage open area f expressed in percentage is the ratio of area formed by grid opening sizes to area formed by grid opening sizes measured up to center of width of ribs. The expression for percentage open area can be written as $f = a_l a_t/[(a_l + b_l)(a_t + b_t)]$ (where, a_l and a_t are grid opening sizes in longitudinal and transverse directions and b_l and b_t