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Centrifuge model study on geogrid reinforced soil walls with marginal backfills with and without chimney sand drain

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ABSTRACT

The objective of this paper is to investigate the performance of geogrid reinforced soil walls with panel facing using marginal backfill with and without chimney sand drain subjected to seepage. A series of centrifuge model tests were performed at 40 gravities using a 4.5 m radius large beam centrifuge facility available at IIT Bombay. The results revealed that a geogrid reinforced soil wall with low stiffness geogrid and without any chimney drain experienced a catastrophic failure due to excess pore water pressure that developed in the reinforced and backfill zones at the onset of seepage. In comparison, a soil wall reinforced with stiff geogrid layers was found to perform effectively even at the onset of seepage. Provision of chimney sand drain effectively decreased pore water pressure not only at the wall toe but also at mid-distance from toe of the wall and thereby resulted in enhancing the wall performance under the effect of seepage forces. However, a local piping failure was observed near the toe region of the wall. The observed centrifuge test results were further analysed by performing seepage and stability analyses to evaluate the effect of thickness of sand layer in a chimney drain. An increase in thickness of sand layer in chimney drain was found to improve the discharge values and thereby enhancing the factor of safety against piping near the toe region. Based on the analysis and interpretation of centrifuge test results, it can be concluded that marginal soil can be used as a backfill in reinforced soil walls provided, it has geogrid layers of adequate stiffness and/or proper chimney drain configuration.

1. Introduction

The backfill material is one of the key components of geosynthetic reinforced soil walls and slopes. Usually freely drainable and well graded granular materials are used for this purpose. Design guidelines proposed by AASHTO (2009) and FHWA (Berg et al., 2009) have stringent requirements for selecting backfill materials. According to them the maximum percentage of fines (i.e. passing 0.075 mm sieve) in the backfill should not exceed 15% and plasticity index should remain below 6% for walls and below 20% for slopes. The use of such backfill typically accounts for 40% of the total construction costs (Durukan and Tezcan, 1992). Recent study by Koerner and Koerner (2011) shows that the soil backfill take up as high as 50–75% of the total wall cost. The soils which do not fulfill these requirements have been termed as marginal soils, poorly drainable or low permeable backfills. However, NCMA (2009) guideline permits the use of backfill having up to 35% fines for carefully engineered structures with provision of suitable drainage system.

Most failures in reinforced soil walls and slopes happen due to the usage of marginal soils (Yoo and Jung, 2006; Koerner and Koerner, 2013). Hence, there are several concerns regarding the use of marginal soils as backfill. As the marginal fill has low permeability, infiltration causes the generation of positive pore water pressure. According to Koerner et al. (1998), without the provision of a proper drainage system, the total force against the wall would be twice as that of a properly drained reinforced soil fill. In addition to this, wetting of the soil can cause reduction in soil stiffness and strength as well as, a reduction in interfacial shear resistance. The creep deformation of the soil is also intensifies due to the wetting of the fill.

Koerner and Koerner (2013) provided the data base of 171 failed geosynthetic reinforced soil walls in which 44 cases had excessive

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deformation and in the remaining 127 cases, at least some part of wall had collapsed. Fine grained backfill was used in 61% of these walls and 91% of the walls were geogrid reinforced. It was concluded that the main reason for such that failures was improper drainage system behind the reinforced zone. Large deformations at the wall face, considerable vertical settlements as well as tension cracks at the top surface of the wall, aesthetics problems and also catastrophic failures have been reported in reinforced soil walls and slopes with marginal backfills. Hence, it was suggested that the drainage system and utilities should be shifted out of reinforced soil zone (i.e. back and bottom drainage system).

On the other hand, the lack of availability of well graded granular soil for backfill have resulted in increasing tendency of using locally available soils. Christopher and Stuglis (2005) reported the potential savings in the range of 20%–30% for replacing standard backfills with onsite marginal soils. Few studies have also shown excellent performance of geosynthetic reinforced soil walls and slopes constructed with poor drainage backfills even after subjecting to heavy rainfall or rising ground water condition (Mitchell and Zornberg, 1995; Raisinghani and Viswanadham, 2011; Tan et al., 2001; Tatsuoka and Yamauchi, 1986). The main inference drawn from these studies was regarding the use of nonwoven geotextile layer which facilitates internal drainage in the reinforced soil zone. Mitchell and Zornberg (1995) reported different case studies including full scale case studies and small scale tests of reinforced soil walls and slopes constructed with backfill material having poor drainage. They concluded that, geosynthetic reinforcements with high in-plane permeability (e.g. nonwoven geotextile) can effectively enhance the performance of reinforced soil walls with poor drainage backfills. On the other hand, the effectiveness of impermeable reinforcement layers (e.g. geogrids, woven geotextiles) in improving the behavior of reinforced soil walls with marginal backfill without any drainage system is questionable. Mitchell and Zornberg (1995) reported several case studies related to the unsuccessful application of impermeable elements in the reinforced soil walls with marginal backfill, however there are some cases clarifying the satisfactory performance of geogrid and woven geotextile reinforcement layers in stabilizing substandard backfills (Abu-Farsakh et al., 2006; Balakrishnan and Viswanadham., 2016b; Farrag et al., 2004; Portelinha et al., 2013, 2014; Riccio et al., 2014). The low tensile stiffness of nonwoven geotextiles has brought up the idea of using composite or hybrid elements to fulfill both requirements of stiffness and drainage (Raisinghani and Viswanadham, 2010, 2011). A simple example of composite element is a geogrid layer with nonwoven geotextile layers at top or bottom or on both sides. Provision of thin sand layers encapsulating geogrid layers has also been reported as a viable solution in reinforcing poor drainage backfills (Abdi and Arjomand, 2011; Abdi et al., 2009).

Limited field studies have been performed to assess the behavior of reinforced soil walls with substandard backfills (Benjamim et al., 2007; Farrag et al., 2004; Juran et al., 1990; Portelinha et al., 2013, 2014; Riccio et al., 2014; Santos et al., 2013, 2014; Yang et al., 2012). Different types of geosynthetics including geogrids, woven and nonwoven geotextiles were used in these studies. Farrag et al. (2004) reported the stress and strain behavior of a full scale geogrid reinforced soil test wall constructed with silty-clay backfill over a soft foundation. In this study, the locus of maximum geogrid loads did not correspond to the theoretical Rankine failure surface and varied according to the geogrid rigidity. The application of woven and nonwoven geotextiles as reinforcement in retaining walls was reported in different field test studies (Benjamim et al., 2007; Portelinha et al., 2013, 2014).

Field studies or full scale tests require large costs and considerable time to monitor the behavior. Moreover, several parameters (such as, complexity of structure construction and its instrumentation, accuracy of the instruments, measurement errors, etc.) affect the accuracy of the results. Centrifuge modelling is a viable solution to overcome these limitations in research activities. Centrifuge modelling of geotextile reinforced cohesive soil walls and slopes were conducted by Porbaha and Goodings (1996). They studied the effects of different parameters including the length of the reinforcement, rigid and firm foundation, and different wall and slope angles. Chen et al. (2007a, 2007b) studied the behavior of geotextile reinforced soil walls subjected to varying g-levels. They used clayey soil very close to its liquid limit to simulate wet state due to poor drainage conditions after several days of heavy rainfall. They studied the effect of the reinforcement spacing and the length. It was found that for a given reinforcement spacing there is a critical reinforcement length value beyond which, no further improvement can be attained. A series of centrifuge model tests were performed to study the behavior of geotextile reinforced cohesive soil slopes at increasing g-level by Hu et al. (2010). A silty clay soil compacted at optimum moisture content was used for thestudy. They studied the mechanism of reinforcement by considering the effects of the slope inclination and reinforcement length on the model behavior. It was concluded that the geotextile reinforcement increased the thickness of shear zone and changed the position of the shear zone. Raisinghani and Viswanadham (2011) reported the results of centrifuge model tests on low permeable soil slopes reinforced with and without hybrid geosynthetics (i.e. combination of one layer of non-woven geotextile and one layer of geogrid layer). They concluded that hybrid geosynthetics increase the stability of marginal slopes. It was also noted that hybrid geosynthetic layers at the bottom of the slope played a major role in dissipation of pore water pressure. Performance of geogrid reinforced soil walls with marginal backfills could be enhanced by using high stiffness geogrid layers. This was evaluated through centrifuge model tests were evaluated (Balakrishnan and Viswanadham, 2016a) onthree wrap-around facing wall models tested at 40 gravities.

Numerical modelling techniques have also been utilized by researchers to study the performance of geosynthetic reinforced soil walls and slopes with marginal backfills. In generally, there are two general approaches in numerical modelling, i.e. limit equilibrium analysis (Bhattacherjee and Viswanadham, 2015; Iryo and Rowe, 2005a, b; Thuo et al., 2015) and finite element analysis (Helwany et al., 1999; Liu et al., 2009; Riccio et al., 2014).

The primary cause of failure in reinforced soil walls with marginal backfill could be attributed to the lack of proper drainage system especially at the back and the bottom of the reinforced soil zone (Koerner and Koerner, 2013). NCMA guideline also permits the use of backfills with fines up to 35% only when proper back and base drainage system, named as chimney drain, is provided for the reinforced soil wall. The chimney drain consists of uniformly graded coarse aggregate having thickness ranging from 400 to 600 mm both in horizontal and vertical directions (Das, 2008). Nevertheless, the effect of providing chimney drain on the behavior of the geogrid reinforced soil walls is limited since there is no document issuing the exact function of the chimney drain through field tests or physical model tests. Therefore, this paper aims primarily to gain knowledge on the use of the chimney sand drain in enhancing the behavior of the geogrid reinforced soil walls with marginal backfill. Additionally, the effect of geogrid stiffness in improving the reinforced soil wall behavior was examined to ascertain the effect of increasing global reinforcement stiffness to mitigate deformation and stability problems of reinforced soil walls with marginal backfills. The present study focuses on the deformation characteristics of three geogrid reinforced soil retaining walls with precast panel facing and marginal backfill soil (both in reinforced and backfill zones) through centrifuge model tests at 40 gravities. Precast panel

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