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Performance evaluation of geogrid reinforced soil walls with marginal backfills through centrifuge model tests

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ABSTRACT

Marginal fill materials that do not follow the guidelines are used in constructional activities due to ease in its availability and economic benefits. But several cases of geogrid reinforced soil wall failures indicate the loss of interfacial shear resistance due to wetting of backfill as a possible reason. In the present study, centrifuge tests were performed on geogrid reinforced soil wall models with wrap-around facing using a 4.5 m radius large beam centrifuge facility available at IIT Bombay at 40 gravities. A marginal soil with 21% fines was chosen as backfill in the study. Two geogrid types of different stiffnesses were modelled based on scaling considerations and used in the study. The models were prepared at wet of optimum to simulate wet backfill conditions. The surface settlements of the models during centrifuge tests were monitored with the help of Linear Variable Differential Transformers (LVDTs). Digital Image Analysis (DIA) was performed on photographs of the front elevation of the model captured during flight, to obtain face movements and reinforcement strain distribution along geogrid layers during centrifuge tests. Interpretations of centrifuge model test results reveal that the soil wall reinforced with low stiffness geogrid layers was observed to deform excessively and undergo pullout failure along soil–geogrid interface. However, the provision of geogrid layers with higher stiffness limited the excessive outward deformations of geogrid reinforced soil walls with marginal backfills. Further, the effect of moulding water content and stiffness of the geogrid on the mobilization of pullout resistance was evaluated through pullout tests in the laboratory. Based on the observations made from pullout tests and centrifuge tests, provision of stiffer geogrids in geogrid reinforced soil walls was found to be one of the viable options to mitigate the problems posed by marginal backfills.

1. Introduction

A wide spectrum of fill materials is available and they are generally classified on the basis of gradation, plasticity, clay mineralogy and chemical composition. Selection of a fill type for a particular project depends on various factors such as strength and deformation requirements, availability and interaction with reinforcement. Grain size, plasticity, permeability, shear strength (under short term and long term conditions) and compaction characteristics are also evaluated to select a material as backfill. The fill material should be reasonably free from organic or other deleterious materials. The use of well graded, freely draining granular fill in reinforced soil wall is important to achieve good soil-reinforcement interaction and proper drainage. Koerner et al. (1998) recommends a backfill material which is completely free from fines. AASHTO (2009) allow a backfill material with less than 15% of fines passing No. 200 (0.075 mm) sieve and plasticity index not exceeding six.

But due to the ease in availability, on-site (or locally available) soils are widely used. They also result in saving 20–30% of cost compared to use of permeable or granular fill material (Christopher and Stuglis, 2005). Such soils do not follow the specifications and are termed as marginal soils, low permeable or poorly draining in literature by Mitchell and Zornberg (1995), Koerner et al. (1998), Christopher et al. (1998) and Raisinghani and Viswanadham (2010, 2011). The problems posed by marginal backfills have been a topic of study by these researchers. It was indicated by Koerner et al. (1998) that without drainage, the total force against the wall can be twice as that of a properly drained reinforced fill soil.

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The problems caused by marginal backfills were addressed by Christopher et al. (1998), Christopher and Stuglis (2005) and Koerner and Koerner (2011). The generation of positive pore water pressure during compaction, subsequent loading and surcharge were identified as the problems caused by fine grained soil fills when placed at wet of optimum. Raisinghani and Viswanadham (2011) reported increase in positive pore water pressures within the backfill and the reinforced zone of a slope reinforced with geogrid layers at the onset of seepage of water that led to catastrophic deformations and failure. Soils compacted at wet of optimum consolidates with time and those compacted at dry of optimum undergo compaction on wetting of the fill. Wetting of backfill soil due to ingress of rain water was identified as a problem for marginal soils placed at dry of optimum. Water level fluctuations, rapid drawdown conditions and seepage forces were listed as the main destabilizing forces in the poorly draining backfill. Excessive lateral deformation of wall, loss of shear resistance of the fill, vertical settlement of reinforced fill, cracking and aesthetics problems were also reported in walls that allowed high fines/high plasticity soils in the reinforced zone. Mitchell and Zornberg (1995), Koerner and Soong (2001), Koerner et al. (2005), Yoo and Jung (2006) and Hossain et al. (2012) have reported various geogrid reinforced soil wall failures. Case studies of wall failures have mentioned that the use of poor quality backfill (or marginal backfill) and lack of proper drainage measures are few of the major reasons for the wall failures. Koerner and Koerner (2013) had reported 171 cases of geosynthetic reinforced soil wall failures. Out of the reported geosynthetic reinforced soil wall failure cases, 65% were of 4–12 m height, 91% were geogrid reinforced, 86% failed in less than 4 years, 61% used silt/clay as backfill, 72% had poor compaction and 60% were due to presence of internal or external water.

Full scale tests were carried out by Guler and Ocbe (2003), Benjamim et al. (2007), Yang et al. (2009), Huang et al. (2010), Stuglis (2010) and Riccio et al. (2014). But full scale model tests involve cost and time for monitoring the response of the structure. Portelinha et al. (2013) discussed the loss of matric suction in reduced scale geotextile reinforced soil wall models backfilled with marginal soil. Centrifuge model studies on geosynthetic reinforced soil walls with marginal backfills were carried out by Porbaha and Goodings (1994) and Porbaha and Goodings (1996, 1997). Nonwoven geotextile was used as the reinforcing element in these cases. Greater resistance to development of tension cracks by an increase in reinforcement length was reported by Porbaha and Goodings (1994). It was observed by Porbaha and Goodings (1996) that on inclusion of geotextile reinforcement layers, the failure mode changed from overturning to rotational sliding. Longer reinforcement lengths were found to increase the failure height of wall and the failure surface was restricted to the reinforced zone. It was observed that reinforcement length should be greater than 75% of wall height to accommodate tension cracks within the reinforced zone. The effectiveness of various combinations of reinforcement lengths and spacing in alleviating the deformations of geogrid reinforced walls with very wet clayey backfill was assessed by Chen et al. (2007) through centrifuge model tests. Chen et al. (2007) conducted centrifuge tests on geogrid reinforced soil walls by increasing gravity level in increments gradually. It was found that increasing reinforcement lengths above a critical value will not improve the performance of wall for a given reinforcement spacing. The influence of reinforcement geometrical arrangement and variable spacing, with single reinforcement type was discussed by Ho and Rowe (1996), Rowe and Ho (1996, 1997, 1998), Helwany et al. (1999) and Liu et al. (2009). Hatami et al. (2001) carried out finite element studies on wrap-around faced reinforced soil walls with non-uniform reinforcement stiffness. It was observed that reduction in stiffness of reinforcement layers laid at smaller spacing is preferable in controlling the face movements compared to stiffer reinforcement layers at larger spacing. It was also concluded that reduction in length of every alternating reinforcement layer by 50%, while maintaining the stiffness is also an economic solution.

The soil-geosynthetic interface properties are important in the design and performance of geogrid reinforced retaining walls. The interface properties are determined either by direct shear tests or pullout tests. The interaction mechanisms between marginal backfill and geogrid have been investigated through pullout tests by Sridharan et al. (1991), Bergado et al. (1992), Farrag and Griffin (1993), Abdi and Arjomand (2011), Chen and Wu (2012), Esmaili et al. (2014) and Hatami and Esmaili (2014). The frictional resistance along the soil–geogrid interface was observed to decrease with increase in moisture content. The pullout resistance or interfacial shear resistance, which is a function of frictional resistance, was also found to decrease with increase in moisture content of soil. Chen and Wu (2012) had reported 50% reduction in pullout resistance with increase in degree of saturation of silty sand up to 94%. The loss of matric suction as a result of wetting was found to reduce soil shear strength and soil-reinforcement interface shear strength by Hatami and Esmaili (2014).

In general, marginal fills when placed at their maximum dry unit weight and optimum moisture content exhibits greater stability due to the presence of matric suction. Geogrid reinforced soil walls backfilled with marginal fills can undergo immediate failures if there is a reduction in frictional bond interaction along soil–geogrid reinforcement layers. Negligence in strictly adhering to the guidelines is a reason for majority of reinforced soil wall failures. The non-uniform arrangement of reinforcement in geogrid reinforced soil walls, i.e. in terms of length, spacing and stiffness, find practical applications when cost-effective solutions are sought after. The influence of reinforcement length, stiffness and spacing on uniformly reinforced soil walls has been well documented in literature. Decrease in reinforcement spacing alleviates wall deformations. But spacing cannot be reduced than a minimum value as it involves more reinforcement material, cost and time. The minimum reinforcement length ratio recommended by Berg et al. (2009) and AASHTO (2009) is 0.7 for the static stability of reinforced soil walls. The influence of non-uniform reinforcement stiffness on deformation behaviour of geosynthetic reinforced soil walls with granular backfills has been addressed by Hatami et al. (2001) and Huang et al. (2010).

However, the knowledge pertinent to the evaluation of the performance of geogrid reinforced soil walls with marginal backfills, especially at a desired or constant gravity level during centrifuge tests is limited. Hence this forms the research motivation behind the study with a special emphasis in evolving viable options for improving the performance of geogrid reinforced soil walls with marginal backfills. This paper also highlights the demonstration of a test setup developed at the Indian Institute of Technology Bombay for evaluating the performance of geogrid reinforced soil wall at a constant gravity level or a desired gravity level in a centrifuge. In the present study, deformation behaviour of geogrid reinforced soil walls with marginal backfill is evaluated through centrifuge model tests at 40 gravities An attempt has also been made to improve the deformation behaviour of geogrid reinforced soil walls by replacing geogrid reinforcement with higher stiffness (referred as stronger geogrid layers) in the upper half zone of wall and wholly. The reinforcement stiffness was varied and the reinforcement length and spacing were kept constant in the present study. The backfill was compacted at wet of optimum (OMC+5) to simulate wet backfill because sudden failures arise due to poor quality control while placement of the fill and due to improper drainage measures. The influence of moulding water content and geogrid type on interfacial shear resistance was investigated through a short series