Geotextiles and Geomembranes 29 (2011) 588–595

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

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

Technical note

Pullout tests conducted on clay reinforced with geogrid encapsulated in thin layers of sand

M.R. Abdi [a,*], M.A. Arjomand [b]

[a] Faculty of Civil Engineering, KNT University, P.O.B. 15875-4416, Tehran, Iran
[b] Faculty of Civil Engineering, Shahid Rajaee University, Tehran, Iran

ARTICLE INFO

Article history:
Received 18 September 2010
Received in revised form
19 March 2011
Accepted 1 April 2011
Available online 2 May 2011

Keywords:
Clay
Sand
Geogrid
Encapsulation
Pullout
Resistance

ABSTRACT

The interaction between reinforcement and backfill materials is a significant factor for analysis and design of reinforced earth structures which is simplified as pullout or direct shear resistance. This paper presents the results of pullout tests aimed at studying the interaction of clays reinforced with geogrids embedded in thin layers of sand. Pullout tests were conducted after modification of the large direct shear apparatus. Samples were prepared at optimum moisture content and maximum dry densities obtained from standard Proctor compaction tests. Tests were conducted on clay–geogrid, sand–geogrid and clay–sand–geogrid samples. A unidirectional geogrid with sand layer thicknesses of 6, 10 and 14 mm were used. Results revealed that encapsulating geogrids in thin layers of sand under pullout conditions enhances pullout resistance of reinforced clay. For the clay–sand–geogrid samples an optimum sand layer thickness of 10 mm was determined, resulting in maximum pullout resistance which increased with increasing confining pressure. The optimum sand layer thickness was the same for all the normal pressures investigated. For sandy soils the passive earth pressure offered the most pullout resistance, whereas for clayey soils, it was replaced by frictional resistance. It is anticipated that provision of thin sand layers will provide horizontal drainage preventing pore pressure built up in clay backfills on saturation.

1. Introduction

Throughout the world there is an increasing demand for geotechnical structures which are more economical and environmentally acceptable. To reduce the negative environmental effects caused by aggregate extraction and to save costs, there is a tendency to use local cohesive soils as construction materials. If the properties of these materials do not fulfill the geotechnical requirements, their engineering behavior can be modified using chemical additives (i.e. lime or cement) or they can be reinforced by inclusions. Geosynthetics have been used in geotechnical engineering for the past three decades because of speed of construction, flexibility, durability, use of local soils rather than imported material, and cost effectiveness. Their use is well established for the purpose of material separation and filters (Faure et al., 2006; Liu and Chu, 2006; Wu et al., 2006) and as reinforcement for improving the stability of embankments and walls (Bathurst et al., 2005; Skinner and Rowe, 2005; Varsuo et al., 2005; Hufenus et al., 2006; Nouri et al., 2006; Chen et al., 2007; Bergado and Teerawattanasuk, 2008; Li and Rowe, 2008; Sieira et al., 2009; Palmeira, 2009).

Cohesive soils being one of the most abundant and cheapest construction materials, their use can be extended by improving its engineering performance by incorporation of reinforcing elements. The main function of these elements is to redistribute stresses within the soil mass in order to enhance the internal stability of reinforced soil structures. The inclusions undergo tensile strains as they transfer loads from unstable portions of the soil mass into stable zones. Thus, a safe and economic design of soil reinforcement requires a good understanding of interaction mechanisms that develop between the soil and the reinforcement (Giroud, 1986; Bergado et al., 1991; Touahamia et al., 2002). The interactions can be simplified as soil sliding in direct shear over the reinforcement and pullout of reinforcement from the soil (Jewell et al., 1984). The pullout mechanism has been investigated by full-scale and laboratory model tests and numerical analysis (Goodhue et al., 2001; Sugimoto and Alagiyawanna, 2003; Desai and El-Hoseiny, 2005; Moraci and Gioffre', 2006). These studies mostly investigated geosynthetic/granular soil interactions. Few researches have been done to evaluate the interactions between cohesive soils and the geosynthetics (Bergado et al., 1991; Keller, 1995; Almohd et al., 2006; Abdi et al., 2009).

* Corresponding author. Tel.: +098 21 88770006; fax: +98 21 88779476.
E-mail addresses: abdi@kntu.ac.ir (M.R. Abdi), ma.arjomand@gmail.com (M.A. Arjomand).

0266-1144/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.geotexmem.2011.04.004

The redistribution of stresses within a reinforced soil mass as well as the deformation response of the structure depends on the shear strength properties of the soil, the tensile properties of the reinforcement, and the stress transfer mechanism taking place at soil/reinforcement interface. Thus, performance of reinforced earth structures depends on the mobilization of interfacial shearing resistance between soil and reinforcement. This criterion eliminates the use of fine grained soils in reinforced soil structures. Considering the distribution of induced interfacial shear stresses in the soil around the reinforcement, it has been shown that provision of a thin layer of frictional material around the reinforcement can mobilize full interfacial shear resistance (Sridharan et al., 1991; Unnikrishnan et al., 2002; Abdi et al., 2009). Unnikrishnan et al. (2002) reported that provision of thin layers of high quality sand around the reinforcement is effective in improving the strength and deformation behavior of reinforced clay. Abdi et al. (2009) also reported significant improvements in the response of clay soils through interfacial enhancement by encapsulating geogrids in thin layers of sand. The improvements were attributed to the more effective interaction and interlocking of sand particles within the geogrid apertures. They also stated that provision of thin sand layers can provide horizontal drainage paths in case of the backfill becoming saturated thus preventing pore pressure build up. In this regard, Zornberg and Kang (2004) reported that drainage capacity provides an increased pullout resistance by dissipating shear-induced pore pressures. Rowe and Taechakumthorn (2008) also reported that the use of prefabricated vertical drains (PVD) accelerated the excess pore pressure dissipation and eliminated the post-construction pore pressure build up. Raisinghani and Viswanadham (in press) evaluating the permeability characteristics of geosynthetic layers used with low permeability soils found that this characteristics is significantly improved with the provision of sand cushions and an increase in its thickness. Yin et al. (2008) studying the interaction of geosynthetics with fine tailings in pullout tests, reported that the interaction characteristics are influenced by tailings particle size, density, moisture content and vertical load.

In the current study by modifying large direct shear apparatus, pullout tests have been conducted on samples of clay reinforced with geogrids encapsulated in thin layers of sand. The main purpose of the study was to investigate the interactions under pullout conditions and to compare with the results from direct shear tests. It is hoped that this will extend the use of clays as a backfill material, lead to saving costs, prevent over use of granular resources, prevent pore pressure build up and reduce negative environmental impacts.

2. Materials and experimental program

2.1. Soils

Two soils were used in this study for the preparation of the samples. Kaolinite was used as the clay soil and Firozkoh sand was selected as the granular material. The soils' physical characteristics, shear strength parameters, and placement conditions were determined according to appropriate ASTM standards and are summarized in Table 1. According to Unified Soil Classification System (USCS), kaolinite was classified as CL and sand as SW. Their shear strength parameters were determined by direct shear tests using the same dry density and moisture content as specimens prepared for pullout tests.

Table 1
Soils characteristics.

Clay		Sand	
USCS	CL	USCS	SM
Liquid Limit	53 (%)	D_{10}	0.4
Plastic Limit	33 (%)	D_{30}	1.3
Plasticity index	20 (%)	D_{60}	2.5
Specific Gravity	2.73	Uniformity Coefficient	6.25
OMC	23 (%)	Coefficient of curvature	1.69
MDD	1550 (kg/m^3)	OMC	4 (%)
Cohesion	23.2 (kN/m^2)	MDD	1600 (kg/m^3)
Angle of Friction	10°	Angle of Friction	33.7°

USCS: Unified Soil Classification System, OMC: Optimum Moisture Content, MDD: Max. Dry Density.

2.2. Geogrid

A uniaxial geogrid coated with PVC and manufactured by Huesker Synthetic Gmbh and commercialized as FORTRAC 80/30-20 was used as reinforcement. The geogrid has a rectangular mesh configuration with 30 × 20 mm internal openings and thickness of 2 mm. The interface shear strength properties obtained by conducting modified direct shear tests together with the geogrid characteristics provided by the manufacturer are listed in Table 2.

2.3. Pullout box

The large direct shear apparatus (i.e. 300 × 300 × 200 mm) was modified for conducting pullout tests, schematically shown on Fig. 1. As shown, the shear box was placed within an outer larger box to which the geogrid was clamped. The normal pressure was applied through a rigid plate covering the whole surface area of the sample. Considering the width and the length of the shear box, this ensured a uniform distribution of normal pressure on the sample and the need for using an inflated air bag was alleviated. In order to eliminate friction at the interface of the shear box and the outer larger box, as well as the outer box and the machine frame, steel balls were used. By applying horizontal force to the outer box by an electro-hydraulically controlled motor, the geogrid was put in tension and tended to be pulled out of the sample. To reduce friction along the frontal face of the box as it has been shown by many investigators including Palmeira (1987), Alfaro et al. (1995), and Sugimoto et al. (2001) to significantly affect the results, PVC sleeves were used. ASTM D:6706 (ASTM 2001a) prescribes that the box thickness should exceed 20 times the D_{85} of the soil or 6 times the maximum soil particle size and its length should exceed 5 times the maximum size of the geogrid apertures. Considering that the maximum sand particle size and the geogrid aperture were 6 and 30 mm respectively, the minimum requirements specified by ASTM D:6706 were satisfied.

2.4. Specimen preparation

Pullout tests were conducted on 300 × 300 × 200 mm samples of clay–geogrid (CG), sand–geogrid (SG) and clay–sand–geogrid

Table 2
Interfacial properties of geogrid and its characteristics.

Geogrid	Interfacial ϕ with sand (Deg.)	Interfacial ϕ with clay (Deg.)	Interfacial C with clay (kN/m^2)
FORTRAC	38.2	18.3	17.0

Description	Symbol/Value
Raw material	PET
Coating	PVC
Ultimate longitudinal tensile strength (T_{ult})	80 (kN/m)
Ultimate lateral tensile strength (T_{ult})	30 (kN/m)
Longitudinal strain at T_{ult}	13%
Lateral strain at T_{ult}	11%
Ratio of geogrid solid area/total area (α_{ds})	10%