HOSTED BY
ELSEVIER

CrossMark

Available online at www.sciencedirect.com

ScienceDirect

Soils and Foundations 57 (2017) 1045–1058

SOILS AND FOUNDATIONS

www.elsevier.com/locate/sandf

Experimental and PIV evaluation of grain size and distribution on soil–geogrid interactions in pullout test

M.R. Abdi *, H. Mirzaeifar

Faculty of Civil Engineering, K.N.Toosi University of Technology, Tehran, Iran

Received 15 January 2017; received in revised form 28 July 2017; accepted 25 August 2017
Available online 10 November 2017

Abstract

Due to complexity and a variety of influential factors, interactions at the soil-reinforcement interface are still not fully understood. In current research, pullout tests are conducted to evaluate the grain size and distribution effects on interactions at the soil–geogrid interface and particle displacements during pullout. Large scale pullout tests (i.e. 100 × 60 × 60 cm) were carried out using three granular soils with different grain size and distributions reinforced with an HDPE geogrid subjected to $\sigma_n = 25$, 50 and 100 kPa. Digital images were captured during tests and processed using particle image velocimetry (PIV) together with three dimensional finite element analysis using ABAQUS. The results showed that the pullout forces and the shear zone thickness substantially increase with increase in grain size, that particles close to the ribs displace in a circular manner and that strain distributions become more symmetrical. The results of finite element analysis also showed close agreement with the test results.

Keywords: Pullout; Geogrid; PIV; Shear zone; Grain size and distribution

1. Introduction

Investigating the soil–geogrid interactions will lead to a better understanding of the behavior of reinforced soil structures and result in more efficient and economic designs. Researchers have mainly concentrated on the macro-mechanic interactions, focussing their investigations on the effects of soil type, moisture content, normal pressure, type and length of geogrid, box dimension, sleeve length, load rate, creep, and the safety factor, etc. (Bergado et al., 1987; Palmeria and Milligan, 1989; Moraci and Gioffrè, 2006; Chen et al., 2007, 2011, 2014; Abdi et al., 2009; Palmeira, 2009; Abdi and Arjomand, 2011; Miyata and Bathurst, 2012; Ahmadi and Hajialilue-Bonab (2012); Abdi and Zandieh, 2014; Touahmia, 2014; Mosallanezhad et al., 2015; Choudhary and Krishna, 2016; Sadat Taghavi and Mosallanezhad, 2016; Mosallanezhad et al., 2016; Eun et al., 2017). However, a limited number of investigations have been conducted to evaluate micro-mechanic interactions. Sugimoto et al. (2001) adopted non-destructive X-ray radiography to examine sand behavior during geogrid pullout. They observed through X-ray radiography that lead shots in the entire area moved towards the front face and sand particles above and below the geogrid at about 300 mm from the front face move towards the front face with some angle to the geogrid. Giang et al. (2010) investigated the effects of transverse ribs and the dilatancy characteristics of sand around different geogrids in pullout tests. They used PIV to study the dilatancy mechanism and shear strain distribution and reported that transverse elements push soil particles in front, causing deformation in a curved shape. Zhou et al. (2012) studied soil particle movements around

Peer review under responsibility of The Japanese Geotechnical Society.
* Corresponding author.
E-mail addresses: abdi@kntu.ac.ir (M.R. Abdi), h.mirzaeifar@dena.kntu.ac.ir (H. Mirzaeifar).

https://doi.org/10.1016/j.sandf.2017.08.030
0038-0806/

Nomenclature

A_L	geogrid aperture longitudinal length
A_T	geogrid aperture transverse length
B_t	thickness of geogrid transverse element
B_w	width of geogrid transverse element
Cc	coefficient of curvature
Cu	uniformity coefficient
DIC	Digital Image Correlation
D_r	Relative density
D_{50}	average diameter of soil
$HDPE$	high-density polyethylene
L	geogrid length resisting pullout force
$LVDT$	linear variable differential transformers
GW	well-graded gravel
P	pull out resistance
PIV	particle image velocimetry
Rt	thickness of the element between two nodes
SP	poorly-graded sand
SW	well-graded sand
$USCS$	Unified Soil Classification System
σ_n	normal pressure
μ	apparent coefficient of friction
$\mu_{s\text{-}s}$	soil–soil interaction
$\mu_{s\text{-}g}$	soil–geogrid interaction
$\gamma_{d\ min}$	minimum dry unit weight
$\gamma_{d\ max}$	maximum dry unit weight
ν	Poisson's ratio
ψ	dilatancy angle
φ	internal friction angle

geogrid transverse elements in pullout tests using a combination of a microscope and a camera and showed that sand particles in front of transverse ribs rotate during pullout. Tatari (2014) adopted a non-intrusive modelling technique for the pullout test using transparent soil in conjunction with laser imaging and reported that the mobilization interaction zone controls the pullout mechanics. Bathurst and Ezzein (2015) used transparent granular particles as soil and digital image correlation (DIC) to measure the complete displacement of reinforcement and to target particles seeded in the surrounding soil during pullout tests. They employed a novel combination of technologies to observe and measure the behavior of the entire embedded area of a geogrid during pullout test. Ferreira and Zornberg (2015) utilized 3D transparent pullout testing device along with DIC technique to assess transparent soil–geogrid interactions under small displacements and strains. They reported that deflections of ribs were developed at early stages of test, when only 25% of maximum pullout force was applied. Bathurst and Ezzien (2016) extended previous database of results to include tests with specimens of shorter length and loaded at other displacement rates using hyperbolic and three-component models to estimate tensile loads in the specimens. Results showed reasonably good agreement between predicted and measured loads at the front clamp.

In current research effects of grain size and distribution as well as normal pressures on soil–geogrid interactions, particle displacements and shear zone thickness under pullout conditions have been investigated. Particle image velocimetry (PIV) has been employed as a non-destructive method to take digital images during pullout tests to monitor particle displacements, strain distributions and the shear zone formation at the soil-geogrid interface together with three dimensional (3D) finite element modelling.

2. Experimental study

2.1. Test setup

The test setup consisted of pullout apparatus together with an image and data acquisition system as shown on Fig. 1. Pullout apparatus comprised of a $100 \times 60 \times 60$ cm box, a 60 kN pneumatic jack with maximum 10 cm stroke, and a closed-loop computer controlled servo system to operate the pneumatic jack through getting feedback from either load-cell or displacement transducer to apply the user-defined load or displacement paths. One of the box side walls was replaced with transparent Plexiglas in order to observe and be able to take images of soil deformations at different stages of testing. Normal pressures were applied via an airbag designed to sustain a maximum uniform pressure of 100 kPa with a regulator to maintain constant pressure during tests.

2.2. Particle image velocimetry (PIV) method

Particle image velocimetry (PIV), also known as Digital Image Correlation (DIC), is widely used as a non-invasive technique to measure displacements in the field of experimental mechanics. By comparing two digital images of an object before and after deformation, incremental displacement fields are calculated to subpixel accuracy without installing sensors that may disturb the material. Precision of PIV is a function of patch size and grid spacing. According to Lesniewska and Wood (2009) large patch size offers improved precision but does not provide sufficient details in the images to be examined. Grid spacing is the quantity that must be chosen for successive displacement estimates within each image. Strain calculations require the differentiation of displacement information. A finer grid implies greater details but also a greater probability of erratic values.