Geotextiles and Geomembranes 32 (2012) 55–68

Contents lists available at SciVerse ScienceDirect

Geotextiles and Geomembranes

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

A comparison of static and cyclic loading responses of foundations on geocell-reinforced sand

S.N. Moghaddas Tafreshi [a,*], A.R. Dawson [b,1]

[a] Department of Civil Engineering, K.N. Toosi University of Technology, Valiasr St., Mirdamad Cr., Tehran, Iran
[b] Nottingham Transportation Engineering Centre, University of Nottingham, Nottingham, UK

ARTICLE INFO

Article history:
Received 18 July 2011
Received in revised form
1 December 2011
Accepted 6 December 2011
Available online 3 February 2012

Keywords:
Repeated loads
Geocell reinforcement
Strip footing
Foundation settlement
Plastic shakedown
Resilient behaviour

ABSTRACT

The results of laboratory-model tests on strip footings supported on unreinforced and geocell-reinforced sand beds under a combination of static and repeated loads are presented. The influences of various parameters are studied including reinforcement width, height of the geocell below the footing base and various amplitudes of repeated load. Mostly, a stable, resilient response is observed once incrementally accumulated plastic strain has ceased (usually during the first 10 cycles of loading). The reinforcement reduces the magnitude of the final settlement, acts as a settlement retardant, permits higher loads or increased cycling. The reinforcement's efficiency in reducing the maximum footing settlement decreased as the height and width of geocell were increased. Plastic deformation was limited by geocells more under repeated loading than under a similar static loading, with the reduction being greatest when more reinforcement was present and when the loading rate was fastest. It is deduced that the greater resilient stiffness of a rapidly loaded polymeric geocell attracts load to itself thereby protecting the soil from some of the more challenging stress states and, hence, reduces deformation. Simple dimensional analysis showed the need for an increased stiffness of the geosynthetic components in order to deliver full-scale performance similitude.

1. Introduction

Soils are periodically subjected to cyclic shear stresses in situ in many circumstances such as earthquakes, storm waves for offshore structures, wind forces in high buildings, pile construction, traffic loads and machine vibrations. Foundations under repeated loads are, therefore, of interest where in addition to permanent loads due to the external static load and the weight of foundation, loads are dynamic in nature due to the action of (for example) earthquakes or moving parts of a machine installed on a foundation. While these dynamic loads are generally small, as compared to the static load, they are applied repetitively over a very large number of loading cycles. The investigation and design of footings under dynamic loadings still remains a challenging task for the geotechnical engineer.

Many researchers have studied the behaviour of unreinforced sandy or clayey soil beneath the foundations under repeated or transient loads (e.g. Cunny and Sloan, 1961; Raymond and Komos, 1978). They reported that significant initial rapid settlement due to repeated load application takes place during the first ten cycles of loading and that an equilibrium response is reached after up to 20,000 load cycles. An equilibrium response to repeated loading has been given the general term "Shakedown" (Sharp and Booker, 1984) with the term "plastic shakedown" being used to label the development of such an equilibrium state after a number of cycles of response in which plastic strain is incrementally accumulated (Werkmeister et al., 2001, 2005).

In recent decades, due to its economy, ease of construction and performance, reinforced soil has been widely exploited in geotechnical engineering applications such as in the construction of roads, railway embankments, retaining wall, stabilization of slopes and improvement of soft ground (Shin and Das, 2000; Bathurst et al., 2003, 2009; Blatz and Bathurst, 2003; Deb et al., 2005; Sitharam et al., 2005, 2007; Dash et al., 2007; Guler et al., 2007; Laman and Yildiz, 2007; Madhavi Latha and Rajagopal, 2007; Chen and Chiu, 2008; Yoon et al., 2008; Zhou and Wen, 2008; Sireesh et al., 2009; Wesseloo et al., 2009; Ling et al., 2009; Madhavi Latha et al., 2009; Zhang et al., 2010; Pokharel et al., 2010; Leshchinsky et al., 2010; Lambert et al., 2011; Moghaddas Tafreshi et al., 2011; Yang et al., 2011).

* Corresponding author. Tel.: +98 21 88779473; fax: +98 21 88779476.
E-mail addresses: nas_moghaddas@kntu.ac.ir (S.N. Moghaddas Tafreshi), andrew.dawson@nottingham.ac.uk (A.R. Dawson).
[1] Tel.: +44 115 951 3902; fax: +44 115 951 3909.

0266-1144/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.geotexmem.2011.12.003

In the case of reinforced foundation beds, only a few studies into the behaviour of geosynthetic-reinforced foundations subjected to repeated loading appear to have been undertaken and these concentrate on planar-reinforced foundations (Das and Shin, 1996; Das, 1998; Shin et al., 2002; Moghaddas Tafreshi and Khalaj, 2008; Raymond, 2002; Boushehrian et al., 2011). Shin et al. (2002) investigated the possibility of using geogrid layers as reinforcement to reduce the settlement of a railroad bed and sub-ballast layer subjected to cyclic load. Based on the model test results, they reported that practically all permanent settlement due to cyclic load was completed after application of 10^5 cycles of load. The most beneficial effect of reinforcement was derived when one layer of geogrid was placed at the interface of the subgrade soil and the sub-ballast course. Raymond (2002) investigated the performance of a thin layer of granular material, whether reinforced or not, when acting as a foundation material for a repeatedly loaded surface footing using a plane strain model test. He reported that the effect of aggregate reinforcement was observed to be even more beneficial when the foundation soil was in a loose condition and noted the beneficial effect of ballast reinforcement in reducing plastic settlements. Moghaddas Tafreshi and Khalaj (2008) performed an experimental study to investigate the behaviour of pipes buried in geogrid reinforced sand when subjected to repeated loads. They reported that the use of geogrid reinforcement can significantly reduce the vertical diameter change of pipe and the settlement of the soil surface. The authors of the present paper have also contributed to this literature reporting the static and dynamic response of geocell and planar forms of geotextile reinforced sand beds at model scale in the two companion papers (Moghaddas Tafreshi and Dawson, 2010a,b). Their results indicated that, for the same mass of geotextile material used, the geocell-reinforcement system is both stiffer and more effective than the system with planar reinforcement, improving the bearing pressure and footing settlement under static and dynamic loads.

2. Concept and types of geocell reinforcements

Typical soil structures reinforced with geocell reinforcing elements for in situ applications are shown in Fig. 1. As are shown in this figure, the typical configurations of geocell reinforcing elements can be divided into three cases:

(1) Vertical geogrid elements prepared by cutting geogrids to the required length and height from full rolls and placing them in transverse and diagonal directions, on the soil bed, with bodkin joints (plastic or metallic rods) inserted at the connections (Fig. 1a). This type of geocell is hand made from geogrid and could be termed "hand made geocells with perforations" (Dash et al., 2003).

(2) Vertical perforated elements prepared as a cellular, honeycomb-like structure with an open top and bottom (Fig. 1b) that may be termed a "perforated geocell" (e.g. Bathurst and Jarrett, 1998).

(3) Geocell reinforcements, shown in Fig. 1c, made of sheet elements thermo-welded (or, perhaps, glued) into a frame structure, termed a "non-perforated geocell". This type of geocell reinforcement provides confinement chambers, which prevent the lateral displacement of infill from spreading, thus hindering settlement. When filled with soil or other mineral material, it provides a suitable surface for foundations, slopes and driveways. High tensile strength of both the weld and geosynthetic is required to deliver a structure with high load-bearing capacity, otherwise rupture of the geocell–soil matrix could result (Moghaddas Tafreshi and Dawson, 2010a,b). It is this last type that is investigated in this paper with the cells being made of geotextile sheets that are glued to adjacent sheets (Fig. 1c).

3. Aims

The preceding sections show that, although some relevant information may be deduced from other studies, there is no direct knowledge concerning the behaviour of footings under dynamic loading when supported on a geocell-reinforcement foundation bed. Thus a study was performed comprising 46 laboratory pilot-scale tests of strip footings supported on unreinforced sand and reinforced sand under monotonic load or under a combination of static and repeated loads.

The overall goal was to investigate the response of footings constructed on geocell-reinforced and unreinforced sand to repeated loading and, particularly, to demonstrate the benefits of introducing geocells beneath the footing and to determine the parameters controlling best usage. The specific aims were to investigate, under repeated loading, the following (in parentheses is indicated the relevant results section):

- the load–settlement properties of geocell-reinforced foundation beds under repeated loading (Section 5.2.1),
- the optimal depth of burial of the geocell assembly under repeated loads (Section 5.2.2),
- the effects of the geocell width and thickness and repeated load amplitude on footing settlement behaviour (Section 5.2.3),

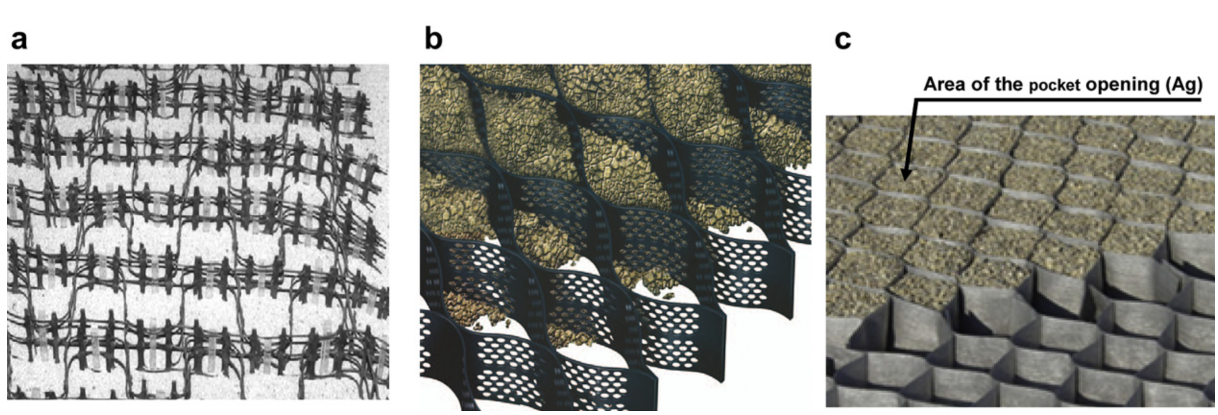

Fig. 1. Typical geocell reinforcing elements (a) hand made geocells with perforations (Dash et al., 2003), (b) perforated geocell (Bathurst and Jarrett, 1998), and (c) non-perforated flexible geocell (TDP Limited) used in this research and area of the pocket opening, A_g (see Section 4.1).