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Experimental and numerical studies of the performance of the new reinforcement system under pull-out conditions

M. Mosallanezhad [a, *], S.H. Sadat Taghavi [b, 2], N. Hataf [a, 1], M.C. Alfaro [c, 3]

[a] Department of Civil and Environmental Engineering, Shiraz University, Shiraz, Iran
[b] Young Researchers and Elite Club, Shiraz Branch, Islamic Azad University, Shiraz, Iran
[c] Department of Civil Engineering, University of Manitoba, Winnipeg, MB R3T 2N2, Canada

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ABSTRACT

Interaction parameters between soil and the reinforcement used in the design of reinforced soil systems, such as mechanically stabilized earth (MSE) walls, can be evaluated by measuring pull-out resistance. In the current study, the performance of a new system for increasing pull-out resistance is studied through numerical and experimental approaches. First, the performance of the new Grid–Anchor (G–A) system is tested through 15 experiments involving large-scale pull-out tests in the laboratory. The results show that the system is able to increase the interaction coefficient of the pull-out (CIR_p) by 100%, in comparison with the typical geogrid system. Finally, the results of a number of finite element analyses are compared with the experimental results, showing a positive relationship between the two studies.

1. Introduction

Geogrid is a member of the geosynthetics family, used in the reinforcement of soil structures. Generally, the evaluation of the interaction between the soil and reinforcement is limited to the two issues of direct sliding and pull-out. When the anchorage length is insufficient, there will be a failure in the upper and lower surfaces of the reinforcement, and it will be pulled out. This kind of failure is called "pull-out". This resistance in reinforced soil structures is caused both by the frictional effect between the soil and the geogrid, and by the passive resistance of the soil particles, which are mobilized against the transverse ribs. On the whole, the considerable increase in geogrid usage in MSE walls has resulted in increasing attention being paid towards pull-out features and shear strength at the interface between soil and reinforcement. Parameters of interaction between soil and reinforcement are determined through pull-out experiments. These parameters might be affected by several factors: for example, the physical and mechanical features of the soil, the geometry of the reinforcement, boundary conditions, the experiment equipment, and overburden pressure. Many researchers have studied the effects of various parameters on friction resistance between soil and reinforcement, through numerical and experimental approaches (Jewell et al., 1984; Milligan and Palmeira, 1987; Bergado et al., 1993; Alfaro et al., 1995; Perkins and Edens, 2003; Alfaro and Pathak, 2005; Sieira et al., 2009; Hsieh et al., 2011; Esfandiari and Selamat, 2012; Hussein and Meguid, 2013; Chen and McDowell, 2013; Shi and Wang, 2013; Balunaini et al., 2014; Chen et al., 2014; Esmaili et al., 2014; Hatami and Esmaili, 2015).

Grid–Anchor, the reinforcement system that was first introduced by Mosallanezhad et al. (2008), includes 10 × 10 × 10 mm cubic elements (anchors), attached to ordinary geogrids via elastic strips, in order to enhance the pull-out resistance. Both anchors and geogrids are made from high-density polyethylene (HDPE); the anchor surfaces are almost smooth (Fig. 1). This reinforcement, which includes geogrids with cubic anchors attached to them, is therefore named "Grid–Anchor" (G–A). There have been various studies in this field aiming to evaluate this system (Mosallanezhad et al., 2008; Alamshahi and Hataf, 2009; Mosallanezhad et al., 2010;

* Corresponding author. Tel.: +98 7136363538; fax: +98 713 6460530.
E-mail addresses: mmosalla@shirazu.ac.ir (M. Mosallanezhad), sh_st_civil@yahoo.com (S.H.S. Taghavi), nhataf@shirazu.ac.ir (N. Hataf), alfarom@cc.umanitoba.ca (M.C. Alfaro).
[1] Tel.: +98 713 6286433; fax: +98 713 6460530.
[2] Tel.: +98 7136363538.
[3] Tel.: +1 204 474 8155; fax: +1 204 474 7513.

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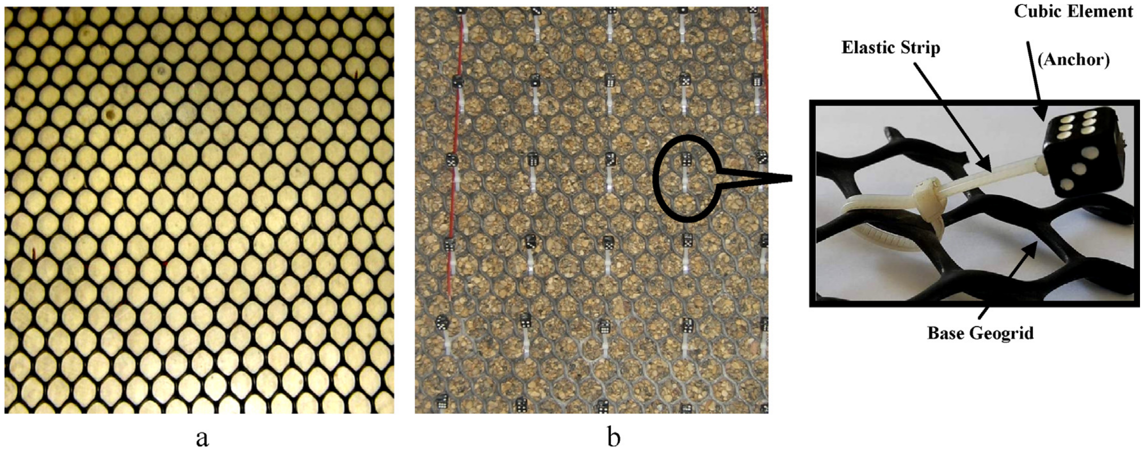

Fig. 1. Reinforcement systems used in this study; (a) Ordinary geogrid; and (b) Grid–Anchor (G–A).

Boushehrian et al., 2009, 2011; Hataf et al., 2010). Scholars like Jewell et al. (1984) and Milligan and Palmeira (1987) have categorized the interactions between the soil and the reinforcement into three groups:

1. Skin friction along the geogrid length;
2. Friction between soil and soil; and
3. Passive (bearing) resistance on the transverse members of the reinforcement.

For grid reinforcement systems, such as Grid–Anchor, the shear strength at the interface of the soil and the reinforcement depends on the movement mode. In terms of pull-out movement mode, the effect of the soil–soil friction mechanism on the pull-out resistance is almost zero. This is because the relative movement of soil on both grid surfaces is negligible (Milligan and Palmeira, 1987; Lopes, 2002).

In general, according to Fig. 2, shear strength of the interface can be defined as follows:

$$P = 2w_r L_r \sigma'_n f \tan\phi \tag{1}$$

where

P is the pull-out force;
σ'_n is the normal effective stress at the reinforcement level;
ϕ is the friction angle of the soil; and
f is the soil–reinforcement interface coefficient ($0 < f \leq 1$).
w_r and L_r are defined in Fig. 2.

f depends on the interaction mechanism mobilized along the interface of soil and reinforcement, as well as the relative movement that takes place between the above-mentioned interfaces. For planar sheets like geotextiles, the mobilized stress mechanism is purely skin friction; thus,

$$f = \frac{\tan\delta}{\tan\phi} \tag{2}$$

where δ is the skin-friction angle between the soil and the reinforcement.

In the current study, the G–A system's performance in increasing the pull-out resistance is evaluated experimentally and numerically.

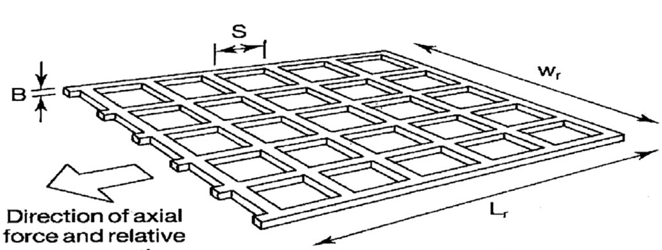

Fig. 2. Definition of reinforcement dimensions (after Jewell et al., 1984).

2. Experimental studies

2.1. Apparatus and instrumentation

To evaluate the performance of the G–A system against typical geogrid reinforcements, a number of large-scale pull-out experiments were conducted. The experiment box is 1200 mm long, 600 mm wide and 400 mm deep, and able to engage in pull-out experiments, based on ASTM D6706-01 (Fig. 3). To measure the movement of multiple points of the geogrid, as well as a clamp, a number of LVDTs (linear variable differential transformers) were used. A rubber airbag was used, in order to produce a uniform vertical pressure on top of the backfill soil. A hydraulic jack was used to apply the pull-out force. The pull-out force was measured via a load cell. All the LVDTs and load cells were connected to a central data acquisition system via linking wires, and at each moment, the force and the horizontal and vertical movements resulting from the dilation, along with the horizontal movements of the geogrid nodes, were recorded. Generally, it is possible to place the clamping system inside or outside the test box. The advantage of putting the clamp at a certain depth inside the soil is that the total reinforcement is confined during the test (Moraci and Recalcati, 2006). Since the clamping system was located inside the soil, the pull-out resistance of the clamping system was obtained through several sole clamp pull-out experiments, and was then subtracted from the resistance measured on the geogrid samples.

2.2. Materials

The geometrical and strength characteristics of the geogrid (Netlon CE 131), as a reinforcement provided by the suppliers, are presented in Table 1. In addition, well-graded sand—in accordance