Analysis of pullout behavior of T-sec geogrid system

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ABSTRACT: Geogrid is a high-performance polymeric material that is employed routinely in the construction of mechanically stabilized earth (MSE) walls. One of the mechanisms that should be controlled in such structures is the pullout mechanism. In general, pullout resistance of MSE walls reinforced by geogrid can be increased provided that soil-geogrid interaction increases. Thus, in this research, the pullout performance of a new reinforcement system, called the T-sec geogrid- which is fabricated by adding an upright geogrid to an ordinary one- is experimentally evaluated. The results of the large-scale pullout tests show that the soil-reinforcement interaction and thereby pullout resistance of the new reinforcement system increase significantly compared with those of traditional geogrid. As a result, it is possible to employ the reinforcement with a shorter length in the anchorage areas of MSE walls.

Keywords: Geogrid, T-sec system, Pullout, Large-scale.

1 Introduction

The better behavior of mechanically stabilized earth (MSE) walls, due to their high flexibility and ductility in comparison with other retaining walls, such as gravity and cantilever retaining walls has been extensively demonstrated (Lee et al., 2002; Moraci and Cardile, 2012; Yu et al., 2015). Reinforced soil derives its better performance due to the stress transfer from the soil to the reinforcement at the interface (Abdi et al., 2009). Thus, the precise assessment of soil–reinforcement interface properties is one of the important factors for reliable design of MSE walls, which can be evaluated via pullout tests (Hatami and Esmaili, 2015). The pullout mechanism of different rein-

forcements and the parameters affecting it have not only experimentally been studied, but also numerically studied by many researchers (Jewel, 1990; Sieira et la., 2006; Teixeira et al., 2007; Fakharian and Nayeri, 2010; Khedkar and Mandal, 2009; Tran et al., 2013; Moraci and Recalcati, 2006; Suksiripattanapong et al., 2013; Mosallanezhad et al., 2016). Since with the increase soil-reinforcement interaction, the internal stability of MSE walls increases, some researchers have tried to enhance the soil-reinforcement interaction by means of improving the soil-reinforcement interface or the reinforcement itself.

Suksiripattanapong et al. (2013) and Sukmak et al. (2015) studied the pullout resistance of a system, named bearing reinforcement earth (BRE), which consisted of a longitudinal member (deformable bar) and a number of transverse members (a set of equal angle steels). Abdi and Zandieh (2014) studied the pullout resistance of conventional geogrid in clayey soils; they found that the pullout resistance of a geogrid is markedly increased by encapsulating the geogrid in a sand layer of 8cm (optimum thickness).

In this research, along with the introduction of a new reinforcement system named T-sec geogrid, the performance of this reinforcement in increasing pullout resistance is compared with conventional geogrids, experimentally. It should be noted that this system is formed by adding a geogrid upright to a horizontal (base) geogrid using industrial strips (Fig. 1). Both the base and upright geogrids are made of HDPE materials.

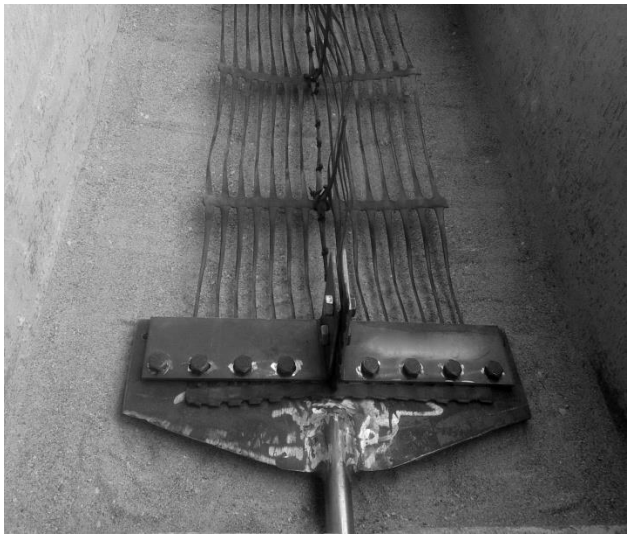

Figure 1. (a) Ordinary (conventional) geogrid; (b) T-sec geogrid.

2 EXPERIMENTAL STUDIES

2.1. Test apparatus

The large-scale pullout test apparatus used in this research was fabricated according to ASTM D6706. This apparatus consists of a pullout box, hydraulic jack, clamp, flexible airbag, reaction frame, and all the tools required for recording the pullout force, overburden pressure, displacement, etc. (Fig. 2). It is necessary to mention that, according to ASTM D6706, the pullout force in pullout tests of reinforcements can be applied to the reinforcement in a controlled stress rate(less than 2kN/m/min). The uniform loading continues until the reinforcement pullout or geogrid rupture is achieved.

2.2. Test materials

In this study a granular soil was used. According to Unified Soil Classification System (USCS), the soil used in this test was classified as SP. The physical and mechanical properties of which are provided in Table 1. In addition, an extruded HDPE geogrid was used in this test program. The product is identified as TT 060 SAMP and is manufactured by Tenax International Corporation. The geometrical features and strength characteristics of this geogrid provided by the manufacturing company are given in Table 1.

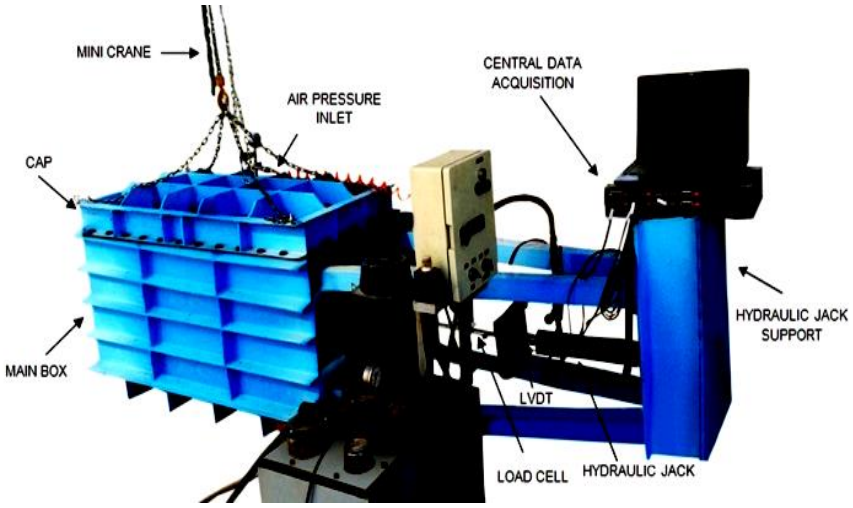

Figure 2. Large-scale pullout apparatus.

Table 1. Soil and geogrid materials properties used in this research

Soil				*Geogrids*	
Maximum dry unit weight (kN/m^3)	17.8	Angle of friction (φ)	33°	Aperture size MD*, longi-tudinal (mm)	220
Dry unit weight (kN/m^3)	16.7	Cohesion (c) (kN/m^2)	5.0	Aperture size TD**, transverse (mm)	13/20
Minimum dry unit weight (kN/m^3)	14.3	Relative density (D_r)	73%	Strength at 2% strain (kN/m)	17
Uniformity coefficient (C_u)	3.37			Peak tensile strength (kN/m)	60
Coefficient of curvature (C_c)	0.78			Yield point elongation (%)	13

*MD: machine direction (longitudinal to the roll)
**TD: transverse direction (across roll width)

2.3. Test Setup

First of all, the lower half of the test box was filled with soil, which was compacted in three layers of approximately 8cm manually. The abovementioned soil layers were compacted by two blows of an 8kg hand-held steel plate tamper with a metal surface 30×15cm and 5mm thick. This tamper was dropped from a 30cm distance; by doing this the energy transferred to the sand approximately equaled 13000 N m/m^3. Sand relative density obtained in the test box was 73%, and soil unit weight was 16.7 kN/m^3.
After the soil compaction in the lower half of the test box, the clamp and the reinforcement connected to it were placed on the compacted soil and perfect horizontality have been carefully checked. Then the upper half of the test box was also filled and compacted. The airbag was put on the top layer of the compacted soil. In the next step, the cap was closed using bolts and nuts, and the airbag was filled and set to the desired pressure. Finally, the pullout force was applied to the reinforcement through a controlled stress method and with a uniform loading rate equal to 2kN/m/min.

2.4. Experimental Plan

In total, 16 pullout tests were performed on the two types of clamps, ordinary geogrid, and T-sec system. The applied overburden pressures were 10, 20, 30, and 40 kN/m^2. For all the overburden pressures, the friction between the various clamps and the test soil were evaluated using the pullout test of each clamp without a geogrid. Then the pullout force, resulting from the clamp and the reinforcement was subtracted from the pullout force of the sole clamp, to obtain the pullout resistance of the reinforcement. The upright geogrid in a T-sec system, its length was the same as the base geogrid (65cm) and its height was selected to be about 10cm.

2.5. Results

2.5.1. EXPERIMENTAL RESULTS AND DISCUSSIONS

In general, the pullout resistance (P_r) for a geogrid can be obtained through a pullout test via the following equation resulting from ASTM D6706:

$$P_r = \frac{F_p \times n_g}{N_g} \tag{1}$$

where P_r = the pullout resistance (kN/m); F_p= the pullout force (kN); N_g = the number of ribs of the sample geogrid in the direction of the pullout force; and n_g = the number of ribs of the sample geogrid per unit width in the direction of the pullout force.
As for the T-sec geogrid system — since, in this system, both the base and upright geogrids resist the pullout force with a different number of ribs in the direction of the pullout force — pullout resistance per unit width of reinforcement can be obtained through the following equation:

$$P_r = P_{(r1)} + P_{(r2)} = n_g \left[\frac{F_{p(1)}}{N_{g(1)}} + \frac{F_{p(2)}}{N_{g(2)}}\right] \tag{2}$$

where $P_{(r1)}$ and $P_{(r2)}$ are the pullout resistance per unit width of base and upright geogrid, respectively (kN/m); and $N_{g(1)}$ and $N_{g(2)}$ are the numbers of the ribs in a base geogrid and an upright geogrid in the direction of the pullout force, respectively. $F_{p(1)}$ and $F_{p(2)}$ are the pullout forces applied to the base and upright geogrids, respectively (kN).
In the following sections, the results obtained from the assessment of the pullout resistance of the two systems used in this research, based on the abovementioned equations, are provided.

2.5.1.1. The comparison of the two reinforcement systems' experimental results

In Fig. 3, the pullout resistances of the ordinary geogrid and T-sec system are given separately under each overburden pressure.
Generally, as seen in Fig. 3, with the increase of confining pressure, the pullout resistance increases considerably. This occurs due to the fact that higher overburden pressures can produce higher compression in the vicinity of reinforcement. Thus, higher bearing resistance can be built up in front of the transverse ribs of the geogrid. Moreover, the T-sec system under different overburden pressures, a strain-hardening behaviour is observed with the increase of pullout force and reinforcement displacement, when compared to a conventional geogrid. The reason for this phenomenon might be related to the less extensible behaviour of a T-sec reinforcement system in comparison with the conventional geogrid, especially under low overburden pressures. On the whole, a reinforcement system with greater extensibility under lower overburden pressures leads to less pullout resistance at the identical frontal displacement (Nayeri and Fakharian, 2009).
On the other hand, adding an upright geogrid to a conventional geogrid under higher overburden pressures leads to a more non-uniform distribution of pullout resistance along the reinforcement.

2.5.1.2. The comparison of the interactions of the two reinforcement systems with soil

To assess the soil-reinforcement interaction, the pullout interaction coefficient can be used by the following equation:

$$f = \frac{\tau_a}{\tau} = \frac{\sigma_v.\tan\delta a + c_a}{\sigma_v \tan\phi + c} \quad (3)$$

where τ_a = apparent contact shear strength; τ = soil shear strength; c_a and δ_a are adhesion and angle of shearing resistance between the soil and the reinforcement, respectively; c and ϕ are cohesion and friction angle of soil, respectively; and σ_v = normal stress at the reinforcement level. Pullout interaction coefficient (f) can be simply determined through the pullout test. To do so, τ_a can be determined through the pullout test and the following equation:

$$\tau_a = \frac{P_r}{2L_e} \quad (4)$$

L_e = the reinforcement length, which resists the pullout force. Thus, through the above equations, parameters of shear strength at the soil-reinforcement interface (c_a and δ_a) can be obtained (Fig. 4). As seen in this figure adding an upright geogrid to a conventional geogrid leads to the increase of soil-reinforcement interaction, which in turn can be useful in MSE walls, where there is a space limit in the backfill.

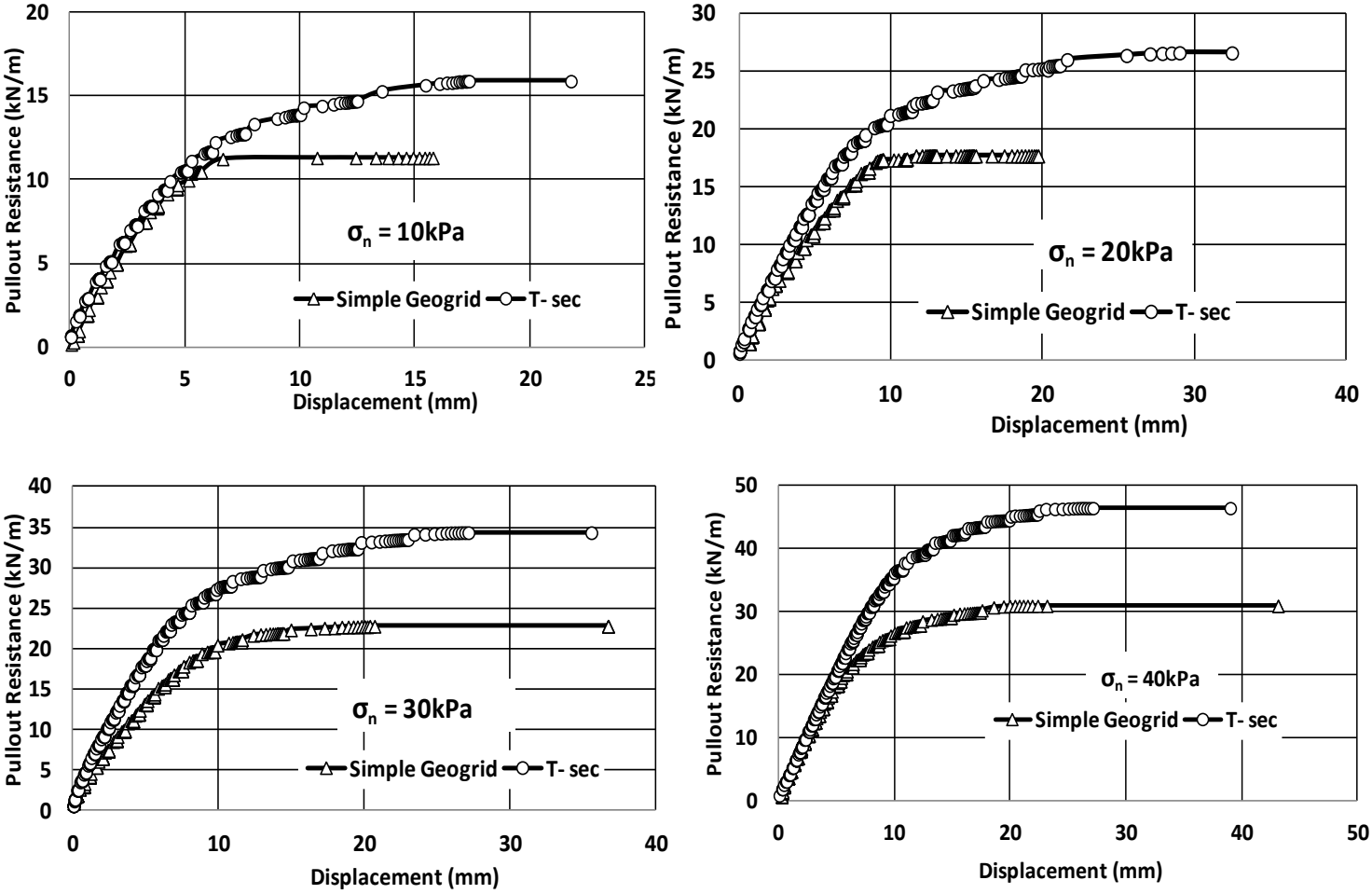

Figure 3. The comparison of pullout resistance between the two reinforcement systems used in this study, under various overburden pressures.

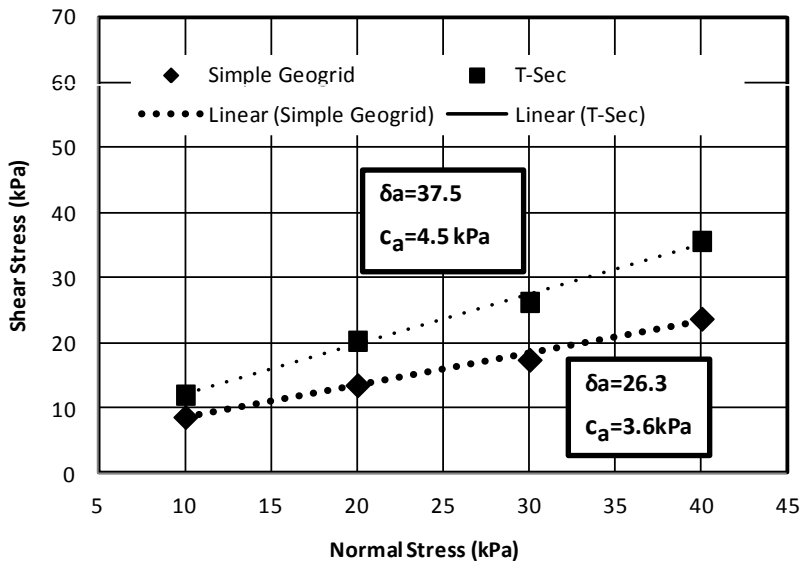

Figure 4. Adhesion and interface apparent coefficient of friction values in the two reinforcement systems used in this study.

3. CONCLUSIONS

The main conclusions of this research are as follows:
1) In the T-sec system the pullout performance is enhanced in comparison with an ordinary geogrid system. This improvement is a result of the decrease of extensibility as well as additional skin frictional and passive resistances of this system due to the existence of the upright geogrid.
2) Adding an upright geogrid to a base geogrid caused an increase in its interaction with soil. Thus, this system can be a useful alternative in designing MSE walls which suffer from space limitations.
3) T-sec system can cause faster mobilization of soil-reinforcement interaction in comparison with the conventional geogrid in early stages of displacement in the pullout test procedure. This can cause a better internal stability in MSE walls from the early stages of displacement compared to conventional reinforcements.

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