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Comparison between uniaxial and pull-out tests setup for polyester and HDPE geogrids

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Abstract. Uniaxial tensile and/or pull-out tests are performed to obtain the stress-strain curve of geogrids. The clamp lining in contact with a specimen in the uniaxial tensile test or the grit of a sandpaper clamp liner in a pull-out test affects the results. In this study, one geogrid made of polyester and another one made of high-density polyethylene (HDPE) are tested in the uniaxial tensile test using various clamps and in pull-out test using sandpapers of different grits. Based on the results obtained, it is recommended to test HDPE in uniaxial tests with serrated steel-lined clamps and in pull-out tests with sandpaper (grit 180) lined clamps. A polyester geogrid shall be tested in uniaxial tests with plastic-lined clamps and in pull-out tests with sandpaper (grit 400) lined clamps.

1 Introduction

The uniaxial tensile test (ASTM D6637) is a simple and important test to get the in-isolation tensile properties of a geogrid. The geogrid's tensile behavior is affected by different factors, including polymer type, loading, geogrid geometry, and ambient temperature. Shinoda and Bathurst [2] performed uniaxial tests on HDPE and polyester geogrids. They found that as the loading rate increased, the tensile strength and stiffness increased, while Amjadi and Fatemi [3] found that increasing temperature led to a reduction in ultimate tensile strength. The axial tensile loading failure mechanism was described by Amjadi and Fatemi [3], where the molecules in the polymer structure, when subjected to external tension force, move relative to each other, and re-form till the molecular chain breaks and can no longer be re-formed and failure happens.

Geogrid's polymer type affects its behavior during tensile loading. Stress-strain curve is material dependent, where for example, HDPE stress-strain curve have initial linear segments which reflect the stiff material response at early periods of the test, then during the geogrid stretching, the curve becomes non-linear as plastic deformation begins and the polymer chain molecules take more time to re-align and orient until the ribs thin down and failure happens [4, 5]. Polyester geogrids have sigmoidal shape stress-strain curve that reflect the characteristics of woven and knitted multifilament polyester yarns forming the geogrid [4, 6]. Shinoda and Bathurst [2] performed uniaxial tensile tests on HDPE and polyester geogrids and found that the lateral strain at rupture resulted for HDPE geogrids with its axial loading varied from 40% to 80% of its axial rupture strain, while polyester geogrids reached lateral strain at rupture equals 2.5% of its axial rupture strain which is a very small value due to the straightening of longitudinal filaments during axial tension.

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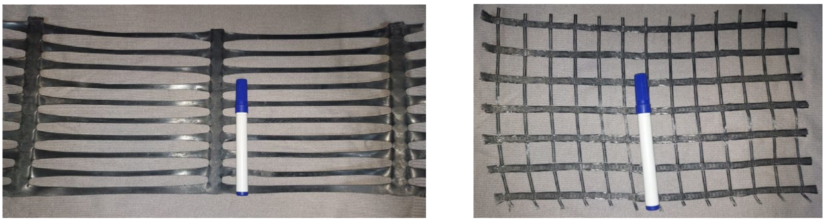
Unlike a uniaxial test, the pull-out test (ASTM D6706) is useful for modeling the soil-geogrid interaction and considering the confinement effect on geogrids [8, 9]. The geogrid pull-out resistance can be defined as the tensile force required for outward sliding of the geogrid from the reinforced soil, and it is composed of friction resistance along geogrid longitudinal members and bearing resistance along geogrid transverse members [10, 11]. Many researchers performed pull-out tests on uniaxial geogrids to investigate their in-soil behavior and the different factors affecting it, including geogrid geometry, applied normal stress, and soil type. Three failure mechanisms were described by Wilson et al. [8] after performing pull-out tests on polyethylene and polyester geogrids which were pull-out of entire geogrid sheet from the pull-out box, tension failure in geogrid longitudinal ribs and junction failure. Prabhakara et al. [12] found that geogrid pull-out strength increased with increasing the applied normal stress. Abdi et al. [13] found poor clay-geogrid interaction after performing pull-out tests on geogrids reinforcing clay soils where the shear stress along the geogrid specimen was constant and the transverse members were linearly displaced, which indicated the little pull-out resistance mobilized by fine clay particles. The geogrid was pulled out while encapsulating the clay soil with an 80 mm thick sand layer, increasing the pull-out resistance by 48% and 68% for polyester and HDPE geogrids, respectively, which showed the effect of the soil particle grain size and distribution to enhance the pull-out resistance. The geogrid geometry affects the pull-out resistance since the geogrid aperture size influences the interlocking with soil particles and the bearing resistance associated with the number of transverse ribs [14].

Another factor that affects both uniaxial and pull-out geogrid tensile testing results is the clamping technique. Any tensile testing equipment contains a clamping system to grip the geogrid specimen during the test. There are different types of clamping systems for tensile testing, including roller clamps [10, 15], bolted steel plates [11, 15-16], and hydraulic grips [9], which are more common in uniaxial tests. Both ASTM D6637 and ASTM D6706 recommend applying some modifications to the clamping technique of geogrids to prevent slippage of specimens or damage due to gripping. However, there are no clear guidelines for uniaxial and pull-out testing preparations regarding clamp lining material for various polymer resin types. Wilson et al. [8] used sandpaper as clamp lining material for pull-out tests on polyethylene and polyester geogrids, while Wang et al. [17] used a rubber bearing pad with polyethylene geogrids, and both recorded no problem with the lining material. Hatami et al. [15] used sandpaper as a clamp lining material in uniaxial polypropylene and polyester geogrids tests. They recorded that this clamping technique was unsuitable for polyester geogrids because the yarns were pulled out of the polymer coating, leaving a piece of coating within the clamp area. Following the foregoing, the current study involved various trials for testing polyethylene and polyester geogrids to examine the effect of the lining material on the uniaxial and pull-out test results. In subsequent, the suitable clamp lining in both tests is presented for HDPE and PET geogrids.

2 Materials and Method

2.1 Geogrid type

Two uniaxial geogrids, one made of high-density polyethylene (GG1) and the other of polyester (GG2), were tested (Figure 1). The tensile properties of the geogrids were obtained using the uniaxial tensile test (ASTM D6637) that will be discussed later in Section 2-3. The geogrid properties are provided in Table 1.



(a) (b)

Fig. 1. Uniaxial geogrids used: (a) GG1; (b) GG2.

Table 1. Geogrid properties.

Property	GG1	GG2
Material	High density polyethylene	High tenacity Polyester
Aperture size (mm)	17×220	35×35
Wide-width Tensile Strength-Method B per ASTM D6637 (kN/m)	82	80
Strain at failure, (%)	13	12

2.2 Soil

Poorly graded sand (SP- unified soil classification system) was used in the pull-out test. The soil properties (Table 2) were identified by the grain size distribution test (ASTM D6913), modified Proctor test (ASTM D1557), and direct shear test (ASTM D3080).

Table 2. Soil properties.

Soil property	ASTM Standard	Value
D_{30} (mm)	D6913	0.44
D_{60} (mm)	D6913	0.72
Coefficient of uniformity, C_u (unitless)	D6913	2.96
Coefficient of curvature, C_c (unitless)	D6913	1.11
Specific gravity, G.S (unitless)	D792	2.70
Maximum dry density (kN/m^3)	D1557	19.10
Optimum moisture content, OMC (%)	D1557	11.50
Angle of internal friction, Φ (degrees)	D3080	36.10

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2.3 Uniaxial test

Wide-width uniaxial tensile tests were performed on both types of geogrids using a universal testing machine (ASTM D6637; Figure 2). According to the test specifications, the specimen shall have three cross junctions. Therefore, the HDPE geogrid (GG1) had dimensions of 200×470 mm (width×length), while GG2 specimen dimensions were 200×300 mm (width×length). The test loading was applied at a displacement-controlled rate of 10% strain/min until specimen rupture. Therefore, the test rate was 50 mm/min for GG1 and 30 mm/min for GG2. Both geogrid types were tested with serrated steel-lined and plastic-lined clamps (Figure 3) to investigate the appropriate clamp type used with each material.

Fig. 2. Uniaxial tensile test.

(a) (b)

Fig. 3. Uniaxial tests' clamps: (a) Plastic-lined clamps; (b) Serrated steel-lined clamps.

2.4 Pull-out test

A box with inner dimensions 900×2000×1000 mm (width×length×height) was used to perform the pull-out tests (ASTM D6706) on geogrids (Figure 4). The box consists of a steel loading frame with a concrete base foundation, a steel box with a front slot to accommodate the reinforced soil, steel angles clamp with 100 mm legs and 650 mm length connected with 14 bolts, driving system to perform the pulling force on geogrids and an air bag with a maximum inflating capacity of 50 kPa to apply normal stress on the reinforced soil.

The box was filled with four lifts of sand (100 mm-thick each) compacted to the maximum dry density ± 5% resulting from the modified proctor test mentioned in section 2-2. Then a 600×1800 mm (width×length) geogrid was installed over this sand layer and was fixed into the clamp. Afterward, four lifts of sand, each of 100 mm thickness, are placed on the top of the geogrid. Finally, the normal stress was applied at the top of the reinforced soil using an airbag. The normal stress at the geogrid level was measured using pressure cells installed at the top face of the geogrid. The tension load cell and linear variable differential transformer (LVDT) were attached to the apparatus to measure the tension force and frontal displacement, respectively. A data logger was used to record the test data, including pull-out force, displacement, and normal pressure. All tests were performed at a constant displacement rate of 2 mm/min under normal stress of 50 kPa. The test progressed until the geogrid was ruptured. The pull-out tests were carried out using sandpaper and rubber liners for the clamp to investigate the effect of the lining material on the test results.


(a)


(b)

Fig. 4. Pull-out test setup: (a) Apparatus; (b) Clamp.

3 Results & Discussion

3.1 Uniaxial tests

The results showed that testing HDPE (GG1) with plastic-lined clamps resulted in minor deformations in the lining material because the HDPE geogrid was stiffer than the plastic lining and the specimen slipped outside the clamps without failure, and hence the test was terminated. In conjunction, the test resumed until HDPE geogrid failure when the clamps were lined with serrated steel. Testing polyester geogrid (GG2) with serrated steel-lined clamps resulted in sample rupturing within the clamp area, which is not acceptable according to the test standards, while using plastic-lined clamps showed good results without slippage or damage of polyester yarns inside the clamp. The specimens' failure mode of GG1 and GG2 tested with serrated steel-lined clamps and plastic-lined clamps, respectively, (Figure 5) was in good agreement with the guidelines of ASTM D6637 stating that specimen slippage outside the clamp or fracturing inside the clamp is not acceptable. Figure 6a shows the stress-strain curve obtained from testing GG1 with serrated steel-lined clamps where the uniaxial tensile strength equals 82 kN/m and the in-isolation secant stiffness at 2% strain equals 1100 kN/m, which agreed with the literature where the secant stiffness at 2% strain for HDPE geogrids with tensile strength 80 ± 20 kN/m ranged between 865 kN/m and 1750 kN/m [13, 16, 19-20]. Figure 6b shows the results of testing GG2 with serrated steel-lined clamps and plastic-lined clamps where the uniaxial tensile strength reached 55 kN/m and 80 kN/m, respectively, indicating a reduction of 31% when it was tested with serrated steel-lined clamps. The in-isolation stiffness of GG2 at 2% strain and 12% strain (failure strain), when plastic-lined clamps were used, was 625 kN/m and 666 kN/m, respectively, which agreed with the secant stiffness at failure reported in the literature for polyester geogrids with tensile strength 80 ± 20 kN/m as it ranged between 550 kN/m and 950 kN/m [10-11, 13, 15]. When serrated steel-lined clamps were used with GG2, the in-isolation stiffness at 2% strain and 12% strain was 500 kN/m and 440 kN/m, respectively. The effect of testing polyester geogrids with serrated steel-lined clamps on its in-isolation tensile stiffness was more evident at strains higher than 2%, which can be attributed to the uniform distribution of tension force over the entire specimen at low strain levels. However, throughout the test, the roughness of the serrated steel surface in contact with polyester material resulted in dissociation of the specimen yarns inside the clamped area, and it was ruptured at less tensile force than its tensile strength.

(a) (b)

Fig. 5. Uniaxial specimen failure in tensile tests: (a) GG1 with serrated steel-lined clamps; (b) GG2 with plastic-lined clamps.

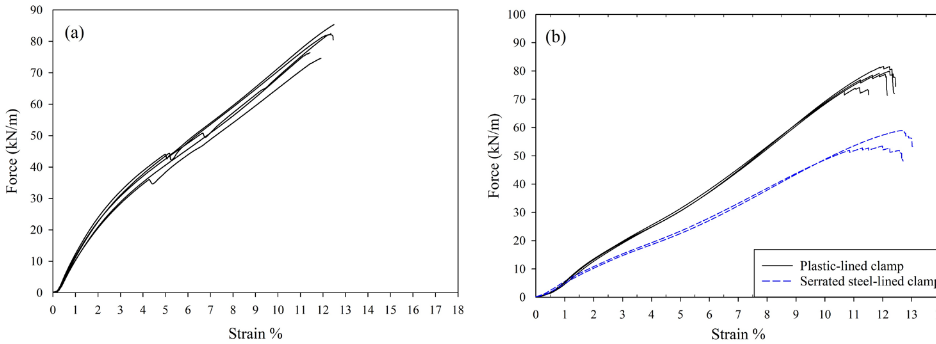

Fig. 6. Uniaxial tensile tests results: (a) GG1; (b) GG2.

3.2 Pull-out tests

The pull-out strength was calculated at geogrid rupture strength or at 75 mm displacement (used to end the test for most design works according to ASTM D6706), whichever reached first. Using rubber as lining material resulted in slippage of the polyester geogrid out of the clamp during the test (Figure 7a). Hence the stress-strain data were not recorded by the data logger. On the other hand, GG1 (HDPE) was stiffer than rubber which implied deformations in the rubber pads till it was totally ruptured and GG1 slipped out of the clamp with the rubber pads (Figure 7b), and the test was terminated.

When sandpaper was used as a clamp liner for GG1 and GG2, the failure mode of specimens (Figure 8) was close to the uniaxial test failure mode, and the test results agreed well with the literature [8, 11-13, 16, 18-21] performed at similar conditions including geogrid polymer resin and tensile strength, normal stress applied, and displacement loading rate (Figure 9). The secant in-soil stiffness at 2% strain for GG1 and GG2 was 1630 kN/m and 1250 kN/m, respectively, which agreed with literature results ranging between 1250 and 2500 kN/m for HDPE geogrids [8, 18], 500 to 1600 kN/m for polyester geogrids it ranged [8, 11-12, 21]. Another factor to be considered is the sandpaper grit. With increasing the grit number, the surface roughness decreases. Similar to uniaxial clamps, liners with suitable surface roughness shall be used with the tested geogrid material to prevent any slippage or deterioration of specimen in the clamped area. Sandpaper grit with surface roughness close to that used in uniaxial tests was chosen for each resin. Sandpaper with grit 180 was found suitable to test GG1, as it offers roughness close to the serrated steel clamp in uniaxial test. For GG2, sandpaper with grit 400 was found suitable as lower grits offer higher roughness levels that can deteriorate the yarns inside the clamp, while higher grits do not offer the required roughness to clamp the specimen well without slippage.

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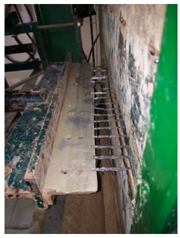
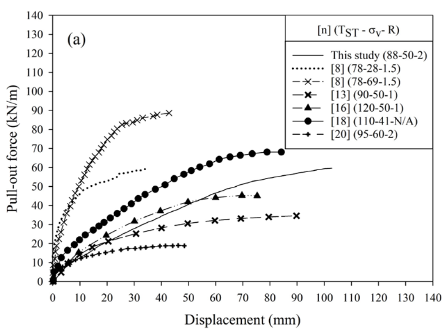


(a)

(b)

Fig. 7. Pull-out test failure when clamp is lined with rubber pad: (a) Rupture in the rubber pads with GG1; (b) Slippage of GG2 from rubber pads lining.

Fig. 8. GG1 failure when clamp is lined with sandpaper.



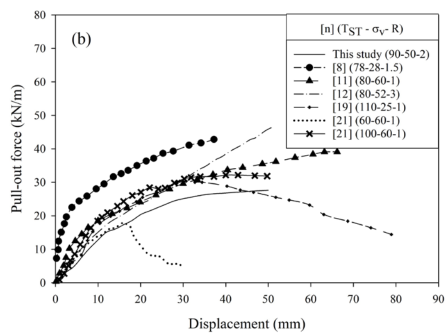


Fig. 9. Pull-out test results compared to literature for both geogrid materials: (a) HDPE geogrids; (b) Polyester geogrids, where [n] reference number, [T_{st}] geogrid short-term tensile strength, [σ_v] applied normal stress, and [R] pull-out test rate.

Figure 10a shows the results of using sandpaper and rubber pad as clamp lining for GG1, where the pull-out strength at a displacement of 75mm (4% strain) was 52 kN/m and 25 kN/m, respectively, indicating a reduction in the pull-out strength of 52% when rubber pad was used as a lining material. The secant in-soil stiffness of GG1 at 2% strain was 1630 kN/m and 900 kN/m, and at 4% strain was 1250 kN/m and 625 kN/m when sandpaper (grit 180) and rubber pad were used as clamp lining, respectively (Figure 10b). The reduction in in-soil stiffness at 2% strain was less than the reduction at 4% strain. This can be attributed to the mobilized tensile force in the geogrid that resulted in gradual deformations in the rubber lining during the test until its full rupture. The slippage of GG1 specimen when the rubber pad was ruptured can be seen in the Pull-out force-displacement curve (Figure 10a) as the portion of the curve (from 40 mm displacement till the end) tends to be horizontal.

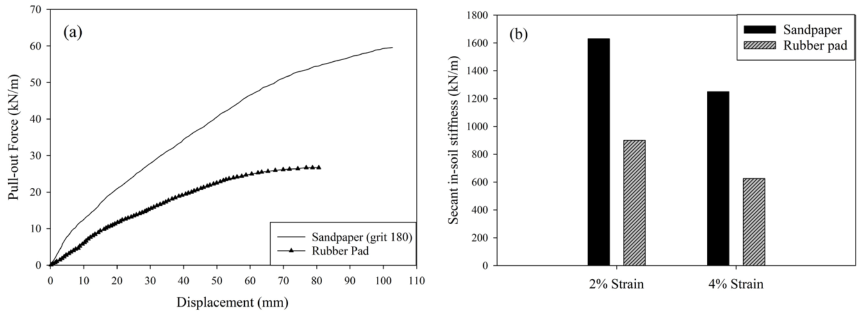


Fig. 10. Pull-out test results for GG1: (a) Pullout-displacement curve; (b) Secant in-soil stiffness at 2% strain and 4% strain.

4 Conclusions

This paper presented uniaxial and pull-out test results for two geogrids, one was made of HDPE, and the other was made of polyester. The following conclusions were reached for the geogrid materials examined and the testing conditions presented in this paper.

1) In uniaxial tests, serrated steel-lined clamps were found suitable for testing the HDPE geogrids, while plastic-lined clamps were suitable for testing polyester geogrids.
2) Sandpaper is a suitable lining material for pull-out test clamps. Sandpaper grit 180 was found suitable for testing HDPE geogrid, and sandpaper grit 400 was suitable for testing polyester geogrid.

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