Effect of materials and loading parameters on monotonic and post-cyclic pullout resistance of geogrids

Fakharian, K., & Nayeri, A.
Department of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran 15875,

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ABSTRACT: This paper presents results of monotonic and cyclic pullout tests on extruded uniaxial geogrid embedded in silica sand. The effect of structural extensibility on the pullout resistance mobilization in monotonic tests is investigated. Attempts have been made to compare monotonic and post-cyclic pullout resistance of geogrids, under different vertical surcharges and cyclic force loading levels and amplitudes. The results suggest that, structural stiffness of geogrid has a direct effect on pullout resistance in different surcharges. In cyclic tests, under high surcharges, an average 10% degradation of post-cyclic strength is observed. The post-cyclic resistance decreases as the loading level and cyclic loading amplitude are increased; nonetheless, instable behavior is not probable.

1 INTRODUCTION

Geogrids implemented for earth reinforcement are subjected to both static loads, i.e. dead weight and line surcharge, and cyclic loads during their serviceability life. Cyclic loads are commonly induced by traffic loading on highway embankments and reinforced bridge abutments, railways and machinery foundations. Such repetitive vertical surcharges induce cyclic tensile forces in reinforcing elements that should be considered along with static forces, in design practice of internal stability issues of earth structures. Little is available in the literature regarding the effects of cyclic loading on pullout resistance and cyclic pullout displacement behavior (Moraci & Cardile 2008). The host of parameters, viz. soil gradation, geogrid type and loading path, all having significant affects in monotonic loading conditions, deserve further investigation under cyclic pullout test conditions. This paper studies the effects of vertical pressure and cyclic loading parameters on post-cyclic pullout resistance of uniaxial geogrids in silica sand using cyclic pullout tests.

EQUIPMENT AND MATERIALS

The pullout apparatus, Figure 1, comprises a pullout box, a hydraulic actuator, surcharge pressure setup, and instrumentations for load and displacement measurements. The main box has inside dimensions of 1.2 m length, 0.6 m width and 0.6 m height and is fixed at the bottom to a grid-type pad that distributes the weight of equipments to the floor. Two parallel plates are mounted horizontally above and below the inside front box groove as a casing. A closed-loop computer-controlled servo system operates the actuator, to apply user-defined load or displacement paths. Monotonic loading at various rates and cyclic loading with frequencies less than 0.1 Hz to 20 Hz, and different wave shapes, either displacement- or load controlled can also be generated.

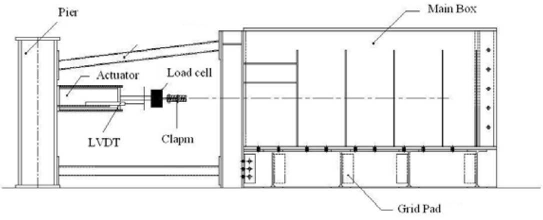

Figure 1. Large scale pullout testing apparatus

Vertical surcharge pressure is applied via an airbag designed to sustain pressures over 150 kPa.

Table 1 presents the general geometry and strength properties of the utilized uniaxial HDPE geogrids; namely, G1 (Tenax TT 060) and G2 (Tenax TT 120 SAMP). Two uniform silica sands, i.e. S1 and S2, with D_{50} of 1.2 and 3.5 mm were used. Table 2 presents the physical characteristics and strength parameters of the sands.

Table 1. Geometry and strength properties of geogrids

Characteristic	G1	G2
Aperture size, longitudinal (mm)	220	220
Strength at 2% strain (kN/m)	17	36
Peak tensile strength (kN/m)	60	120
Yield point elongation (%)	13	13

Table 2. General properties of silica sands

Characteristic	S1	S2
γ_d (kN/m^3)	16.7	16
e_{max}	0.86	0.96
e_{min}	0.58	0.66
D_{50} (mm)	1.2	3.5
φ (°)	37.1	40.7

2 TEST PROCEDURE

For specimen preparation, sand is pluviated in 8 layers of 125 mm and the geogrid is placed after leveling the forth layer, in front of box groove. Relative displacement of four embedded transverse ribs of geogrids is measured by an LVDT set-up system. The airbag is placed on top of the final soil surface, then pressurized and regulated at the target vertical pressure. The displacement-controlled pullout force is commonly applied at constant rate of 1 mm/min. The test is terminated when; pullout failure occurs, the geogrid is damaged, or frontal displacement reaches 100 mm.

In cyclic tests, the initial monotonic load is increased to T_1, that is the load level; thereafter, cyclic loading with the amplitude of T_a is applied. T_1 and T_a are specified as a percentage of ultimate monotonic pullout resistance in uniform test conditions, i.e. T_u. Generally, T_1/T_u=0.6 and T_a/T_u=0.4, but higher and lower values (0.2 to 0.8) are also applied to assess the effects of loading pattern on post-cyclic pullout behavior. Cyclic loading is continued for 100 cycles, with the frequency of 0.1 Hz (Raju & Fannin 1998). After the last cycle, displacement-controlled post-cyclic loading starts and continues to test termination. Post cyclic results are compared and contrasted with monotonic tests.

3 RESULTS

3.1 *Monotonic behavior*

These tests highlight the sensitivity of pullout resistance mobilization to load-strain characteristic of geogrids with similar geometrical structure. As seen in Figure 2, in monotonic tests, at each surcharge, the absolute difference of pullout resistance between G2 and G1 is about 12 kN/m. This corresponds to a relative difference of 58% for lower surcharges (less than 25 kPa), and 17% in high surcharges (more than 50kPa). In other words, the relative difference in pullout resistance for G1 and G2, decreases as surcharge increases. The physical interpretation is attributed to the extensibility of geogrids. Geogrid G2, with half stiffness of G1, shows inextensible behavior under low surcharges and this induces an immediate development of interaction mechanisms. But G1 is more extensible than G2 under low surcharges, resulting in lower pullout resistance at same frontal displacements. On the other hand, under high surcharges, friction and bearing resistance is mobilized progressively, where the role of effective bearing area of transverse ribs is preponderant to tensile strength of geogrids in providing the pullout resistance. This fact causes the difference in pullout resistance for G1 and G2.

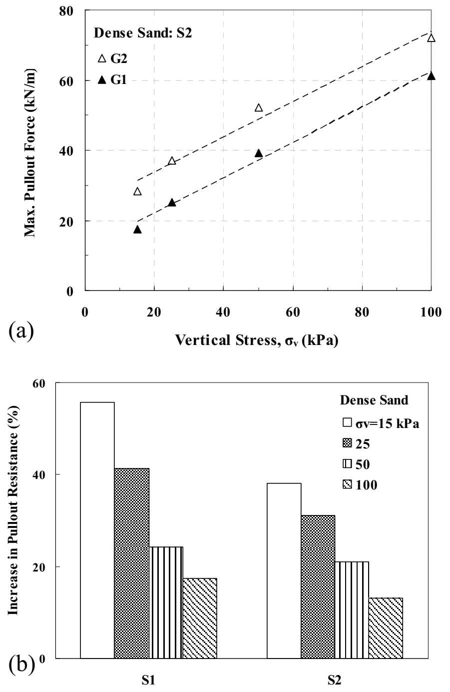

Figure 2. Variation and rate of increase in pullout resistance of G2 to G1

3.2 *Cyclic behavior*

Some test results are presented to elaborate the cyclic response of geogrids under different normal pressures and cyclic loading patterns. Figure 3 illustrates load-displacement variations of geogrid G2 under surcharges of 25 and 50 kPa. Accordingly, there is slight increase in post-cyclic strength under low surcharges, while post-cyclic strength decreases under high surcharges. Figure 4 shows the average variation trend of $(T_u)_{p\text{-}cyc}$ / $(T_u)_{st}$ versus normal surcharge, defined by 13 cyclic pullout tests with identical loading patterns.

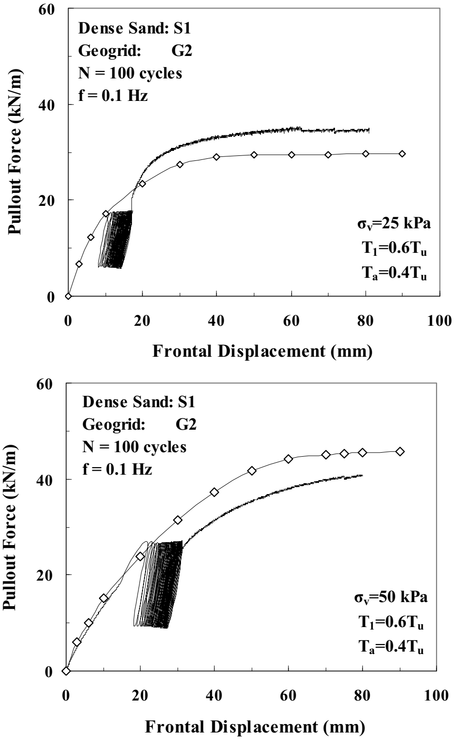

Figure 3. Monotonic and cyclic pullout behavior

Figures 5 and 6 illustrate examples of cyclic pullout curves at different values of T_l and T_a. Apparently, pullout cyclic loading applied in low levels of T_l and T_a, leads to enhanced mobilized post-cyclic resistance that significantly declines as T_l and T_a increase (see Figure 6a and 6b).

For higher T_l values at cyclic loading commencement, large frontal displacement occurs mobilizing a significant portion of friction and bearing resistance; therefore, during post-cyclic loading, the pullout resistance is lower than monotonic loading. At low amplitude cyclic pullout loads (i.e. $T_a < 0.4T_u$), sand particles are not rearranged; hence, a pullout resistance equal to, or about 15% greater than monotonic values are observed. By increasing the loading amplitude to $T_a > 0.6T_u$, degradation of the bearing soil structure, in front of transverse ribs, increases and this in turn reduces the ability of sand to mobilize the initial monotonic resistance in post-cyclic conditions.

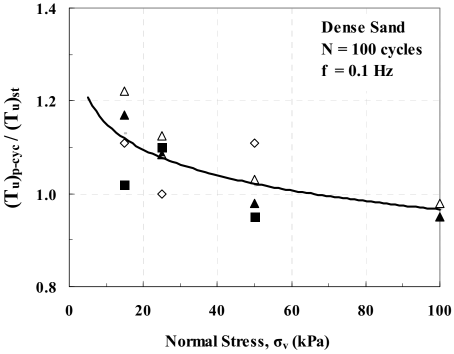

Figure 4. Variation of post-cyclic resistance with surcharge

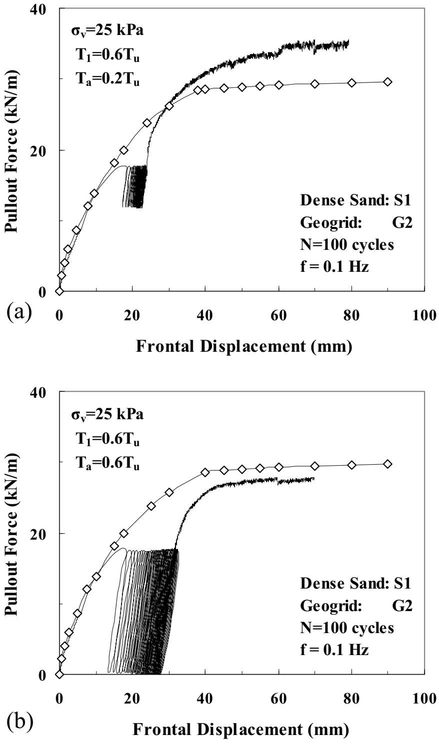

Figure 5. Cyclic pullout behavior under different loading path

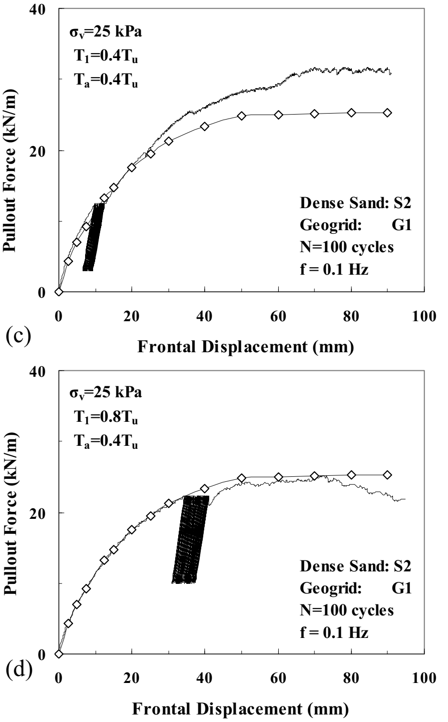

Figure 5. Continued

Overall observations have revealed that the post-cyclic strength under surcharge action ranges from minus 10% to plus 20% of monotonic strength values. The observed post-cyclic pull-out resistance variation is not indicative of instability. Nevertheless, in practice real prototype conditions should be considered; since repetition of cyclic loads, in large numbers under unexpected conditions of amplitude or load level, could reduce the overall stability of structures.

4 CONCLUSIONS

The monotonic, cyclic, and post-cyclic pullout tests manifest the following prominent findings:

- Tensile strength of geogrid has a direct effect on pullout resistance, in particular with high increase rate value under lower vertical surcharges.
- It can be cautiously stated that post-cyclic resistance degradation of about 10% is probable under different cyclic loading patterns, with high values of amplitude and load level at start of cycles.
- After low amplitude cyclic pullout, soil densification leads to an average 20% increase of post-cyclic resistance.
- Generally, the cyclic pullout behavior of geogrids does not show to be subject to internal instability; however repetition of cyclic loads in practical scales under unexpected patterns, could reduce stability.

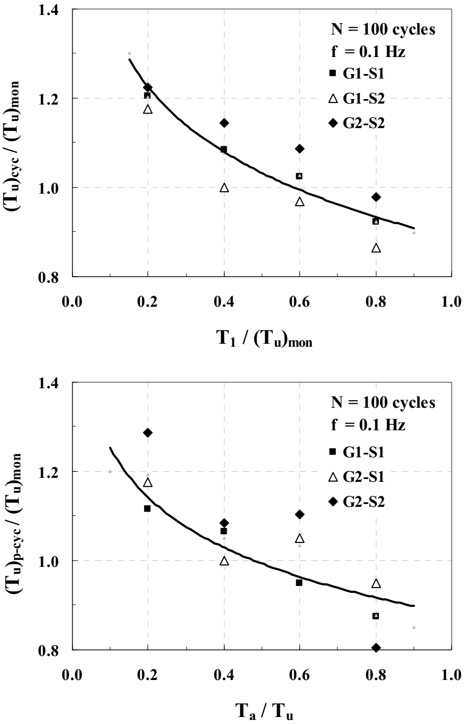

Figure 6. (a)-Effect of load level on post-cyclic pullout resistance, (b)-Effect of cyclic load amplitude on post-cyclic pullout resistance

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