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Laboratory testing of long-term performance of clay-geogrid interaction

A. Pamuk
Department of Civil Engineering, Rensselaer Polytechnic Institute, USA

D. Leshchinsky & V.N. Kaliakin
Department of Civil and Environmental Engineering, University of Delaware, USA

H.I. Ling
Department of Civil Engineering and Engineering Mechanics, Columbia University, USA

ABSTRACT: Pullout tests are often conducted to evaluate soil-to-geogrid interaction properties in design. Most of these tests have used static loads with cohesionless soils to assess stress distribution along the soil-geogrid interface as well as pullout resistance. In this work, laboratory pullout tests were carried out to study the long-term performance of a polymeric geogrid embedded in a cohesive soil. Incremental long-term static or cyclic tensile pulling loads were applied to the embedded geogrid under various confining pressures. Some in-isolation creep tests were conducted to compare the long-term effects of confinement. Under dynamic loading conditions, different frequencies of tensile load were applied. Strain progress and creep development were measured. The testing method and results are presented and discussed in details.

1 INTRODUCTION

A limited number of reinforced earth structures constructed with cohesive soils has performed well, showing that they can be used in place of granular soils and thus, reduce the cost of construction. The results from both laboratory and full-scale field tests backfilled with cohesive soil demonstrated that both the short-term and long-term shear strength of cohesive soil might be increased by grid reinforcement (Jewell and Jones, 1981). Bergado et al. (1993) reported that cohesive soils compacted to 95% of standard Proctor's density on the dry side of optimum moisture content could generate pullout capacities comparable to those of the good quality granular soils. Accordingly, there has been great demand on using locally available cohesive soil in mechanically stabilized earth structures, especially in places where good quality granular soil is not readily available.

A variety of geogrids has been used for soil reinforcement to provide short-term and long-term stability under static and dynamic loads. Appropriate testing methods are needed to evaluate the long-term stress-strain properties of confined geogrids subjected to pulling loads. Laboratory and field pullout tests are often conducted to evaluate the properties of soil-to-geogrid interaction. Field tests are less common because of the high cost in constructing full-scale structures, but may be more representative. Laboratory pullout tests are often conducted because they offer more controlled testing environment with less cost. On the other hand, boundary effects (e.g., side wall friction, rigid front face etc.) increase due to various limitations in the size as well as various configurations of pullout apparatus geometries used (Juran et al. 1988; Juran and Christopher, 1989; Abremento and Whittle 1995; Farrag et al. 1993). These variations make it difficult to consistently compare the performance of geosynthetics in different soils (Farrag and Griffin, 1993; Abremento and Whittle 1995).

Most of the tests reported in the literature have used monotonically increasing loads with granular backfill materials to assess stress distribution along the soil-geogrid interface as well as pullout resistance. The related testing procedures (e.g., Christopher et. al., 1990) were developed for both short and long-term.

This paper presents the results from laboratory pullout tests that were conducted to study the long-term performance of a polymeric geogrid embedded in kaolin clay. The incremental static or cyclic tensile pulling loads were applied to the embedded geogrid under various confining pressures. Strain gages were used to monitor strain distribution and creep development in the geogrid reinforcement subjected to incremental tensile loads. Some in-isolation creep tests were conducted to compare the long-term effects of confinement on the geogrid reinforcement. Under cyclic loading conditions, and in-isolation, different frequencies of tensile load were applied. The testing method and results are presented and discussed in details.

2 TESTING FACILITY, MATERIALS AND PROGRAM

2.1 *In-soil tests*

Kaolin clay was chosen as backfill material because of its commercial availability as an ideal cohesive soil. Figure 1 displays the in-soil testing setup. The frictional resistance developing between the side walls of the box and the soil was reduced considerably by using high quality silicone grease to coat the walls as well as a 0.4 mm-thick latex membrane separating the wall and the soil. The soil was carefully prepared and then compacted in layers within the testing apparatus with inner dimensions of 60 cm long, 20 cm wide and 30 cm high. The compacted soil was slightly on the wet side of optimum (i.e., 1% above the optimum moisture content) corresponding to about 97 % of standard Proctor density. A normal pressure of 34.5 kPa was applied for 24 hours to settle the soil in the box and to equalize the water content especially around the confined geogrid.

A biaxial Polypropylene geogrid (MD 30.5 kN/m and TD 45 kN/m) was used during in-soil tests. A load actuator that is capable of generating both static and cyclic loads was used to apply tensile load in the transverse direction. The tensile loads were transmitted through the clamp of the geogrid specimen as shown in Figure 2. The clamp was made by bonding the geogrid specimen between a pair of rigid metal plates using epoxy glue. The epoxy, together with the metal plates, made very stiff clamping so that negligible deformation of the grid occurred within clamp. During the test the clamping assembly was embedded 10 cm into the soil to reduce the boundary effect of the rigid front wall on the applied net normal pressure. The frictional resistance on both faces of the clamp was further reduced by a similar method that was used for reducing side wall friction. Strain distribution along the geogrid specimen was measured using strain gages bonded at five locations. Figure 2 displays the instrumented geogrid specimen along with configurations of bonded strain gages on the geogrid ribs. The location of the first strain gage was approximately 1.9 cm away from the applied tensile load. The testing plan is given in Table 1. The vertical pressures of 34.5, 69.0 and 103.4 kPa were applied uniformly through an air bag at the top boundary of the box (Fig. 1). The details of the testing facilities and procedures can be found in Pamuk (1997). The long-term tests with the cyclic loads were conducted only with a frequency of 0.1 Hz.

A series of laboratory tests was carried out to obtain the index properties and the shear strength of kaolin clay used. The direct shear tests were con-

Table 1. Loading sequence during in-soil tests.

Loading Type	Initial Load (kN/m)	Load Increment (kN/m)	Frequency (Hz)	Normal Pressure (kN/m^2)
Static	1.75	1.75	-	34.5, 69, 103.4
Cyclic	0.25-1.75	1.75	0.1	34.5, 69, 103.4

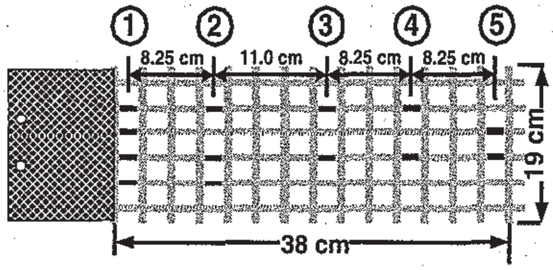

Figure 2. Geogrid specimen.

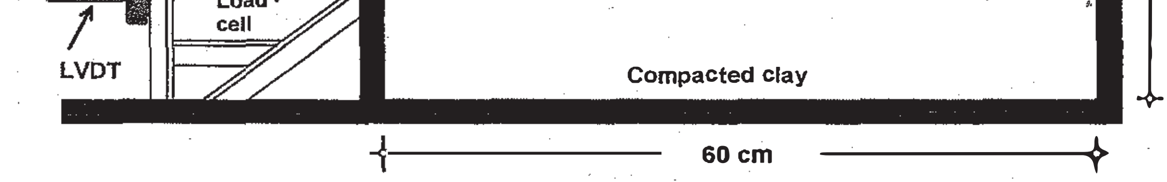

Figure 1. In-soil testing: (a) Testing setup, (b) Geogrid specimen.

ducted on the soil specimens (3.1 cm high, 6.4 cm in diameter) extracted from the testing box at the end of each pullout test as well as on the compacted soil specimens at the desired Proctor's densities. Consolidated-drained conditions were considered to simulate long-term effects. The tests were carried out under the same confining pressures that were used in pullout tests with a constant shearing rate of 0.23 mm/min. The triaxial tests were conducted on the soil specimens compacted to the desired density, as used in the direct shear tests and than tested under consolidated-drained conditions with an axial displacement rate of 0.13 mm/min. The index properties and the results from direct and triaxial tests are summarized in Table 2 and Table 3, respectively.

Table 2. Index properties of the soil.

Atterberg Limits:	
-Liquid Limit (LL)	59%
-Plastic Limit (PL)	32%
Compaction: Standard Proctor:	
-Maximum dry unit weight	14.7 kN/m^3
-Optimum moisture content (OMC)	26%
Specific gravity	2.6

Table 3. Direct and triaxial test results of the soil.

Test type	Water content (%)	Dry unit weight (kN/m^3)	C (kN/m^2) Peak	C (kN/m^2) Residual	Φ (degree) Peak	Φ (degree) Residual
Direct shear	27	14.5	52	19	14.7	14.1
Triaxial	27	14.5	73	-	15.8	-

2.2 *In-isolation tests*

The testing apparatus (Fig. 1) that was used in in-soil tests was modified to conduct in-isolation tests. The tensile load was applied with different frequencies of 0.1 and 0.5 Hz to measure the effects of frequency variations of the cyclic tensile load on the geogrid reinforcement. The loading program is given in Table 4.

3 TESTING RESULTS AND DISCUSSION

In-isolation tests were carried out to study the fundamental behavior of the geogrid without soil confinement so that the effects of the confining soil and the normal pressure on the soil-to-geogrid interaction could be assessed well. Under cyclic loading conditions, the tensile loads were applied at the different frequencies of 0.1 and 0.5 Hz, and with a minimum tensile load of 0.25 kN/m during unloading (see Table 4). Some results from these tests are and 0.5 Hz. It was observed that the frequency variations of an applied load did not affect the strain-time relationships. The figure indicates that strain increased with the tensile load, and creep strains appeared to be higher under static load than that under cyclic load.

Table 4. Loading sequence during in-isolation tests.

Loading Type	Initial Load (kN/m)	Load Increment (kN/m)	Frequency (Hz)
Static	1.75	1.75	-
Cyclic	0.25-1.75	1.75	0.1 & 0.5

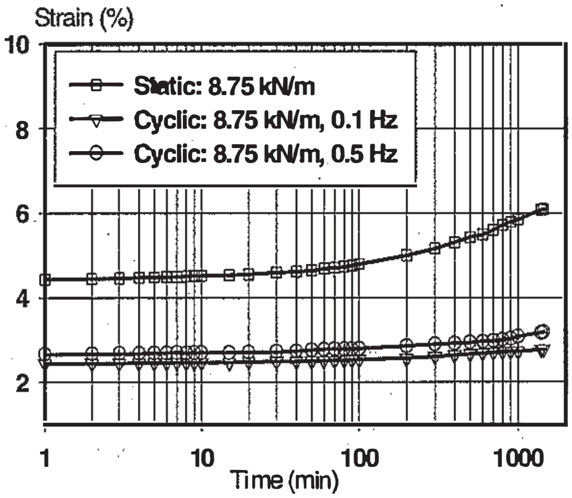

Figure 3. Strain-time relationships from in-isolation tests: Effects of frequency variations.

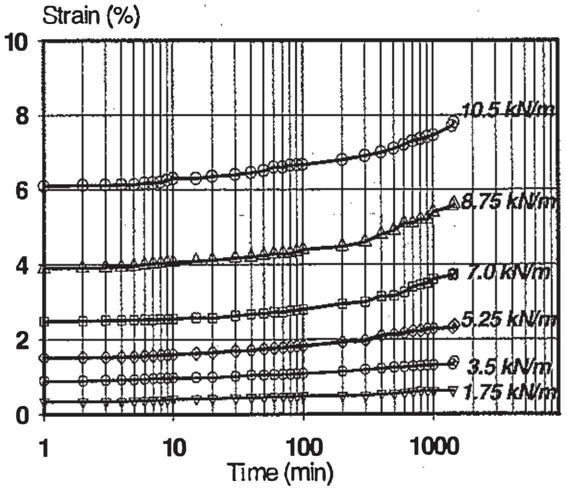

Figure 4. Strain-time relationship at the front of geogrid: Static load, σ_n=34.5 kN/m^2.

Three different tests were conducted under various confining pressures with static and cyclic pullout loads. The confining pressures varied from 34.5 through 103.4 kPa, and the pullout loads were increased with a load increment of 1.75 kN/m. The strain-time relationships that were measured approximately 1.9 cm away from the point of load application (i.e., at the front) are shown in Figure 4 for the static loading with a confining pressure of 34.5 kPa. The strain-time relationships that were obtained at the front of the geogrid specimen for each in-soil test are summarized in terms of creep strain rates in Figures 5 and 6 for the static and cyclic loads, respectively. The creep strain rate was higher under static load than that under cyclic load The effect of the confining pressure was negligible at the point of load application where the actual load in the geogrid is known (unlike nodes away from the applied load where only the strain is measured and the actual load depends on the interface performance).

Strain distributions along the length of the geogrid specimen embedded in the clay were recorded by the strain gages bonded at five different locations as shown in Figure 2. The development of strain at various locations of the geogrid is shown in Figure 7 and 8 for static and cyclic loads with a normal pressure of 34.5 kPa. Note that these measurements were recorded 24 hour after the load application. The strain in the geogrid reduced along the length due to interaction between the soil and reinforcement, and then eventually became zero at the end of the geogrid. The zero strain in the grid reinforcement indicated that the applied tensile load did not cause a pullout failure. The tensile load that may cause the failure could not be increased due to limited capacity of the load actuator. Accordingly, for

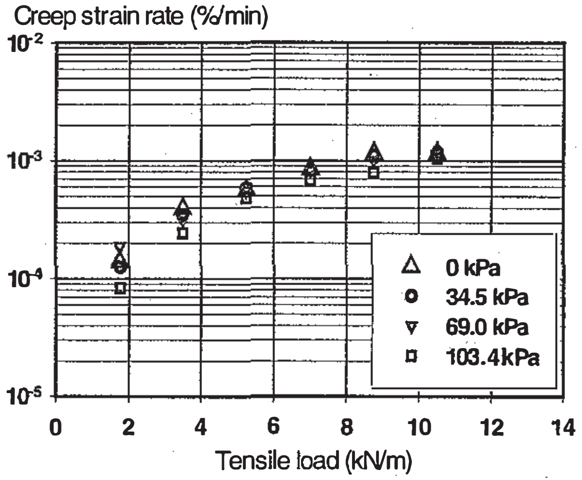

Figure 5. Creep strain rate at the front: Static load, σ_n=34.5, 69.0 and 103.4 kPa.

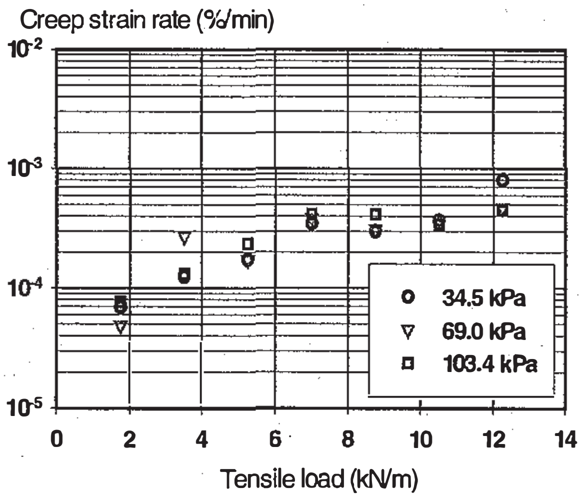

Figure 6. Creep strain rate at the front: Cyclic load, σ_n=34.5, 69.0 and 103.4 kPa.

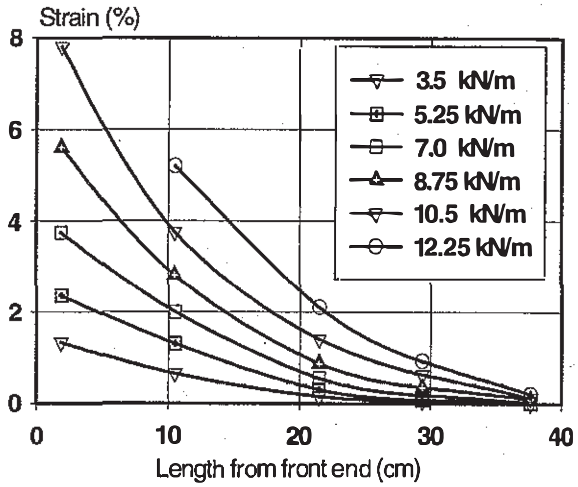

Figure 7. Development of strain at various locations of geogrid during in-soil tests: Static load, σ_n=34.5 kPa.

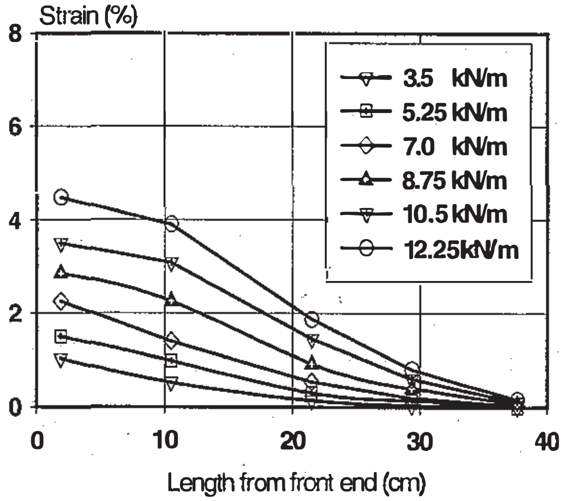

Figure 8. Development of strain at various locations of geogrid during in soil test: Cyclic load, σ_n=34.5 kPa.

most tests no pullout failure as well as breakage occurred in the confined geogrid. The results of the static and cyclic tests as shown in Figures 7 and 8 are compared in Figure 9 in such a way that the applied load required to produce 0.5, 1.0 and 2.0 % strain along the length of geogrid is displaced. It is seen that the difference in strains under the static and cyclic loads diminishes towards to the rear end, and increases in the front end.

Strain gage readings in the geogrid provided the measurement of the creep strain that was developed under the constant long-term loading. This helped interpreting the effects of the long-term loading on the pullout resistance of the geogrid reinforcement in the soil. The distribution of the creep strains developed under the long-term loads for a normal pressure of 69.0 kPa is shown in Figure 10. Figure 11 compares the creep strains developed along the length of the geogrid under various confining pressures with an applied load of 8.75 kN/m. The creep strain increased with an increase in the applied load, and decreased with the confining pressure along the length of the geogrid. However, the creep strain was not considerably influenced by the presence of the soil and normal pressure in the front.

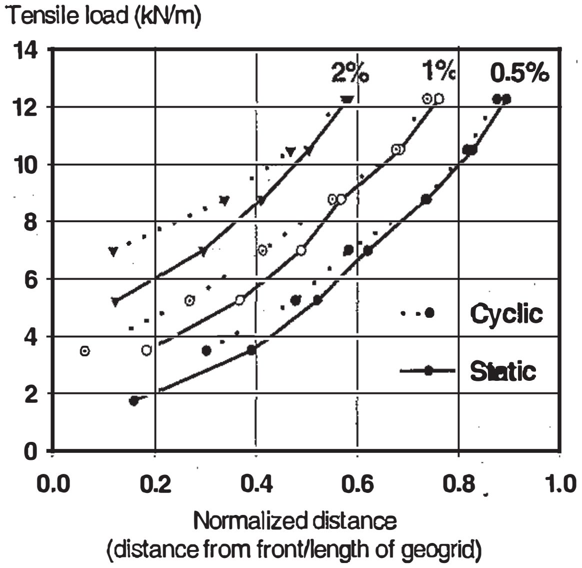

Figure 9. Strain propagation along the geogrid: Static and cyclic loads, σ_n=34.5 kPa.

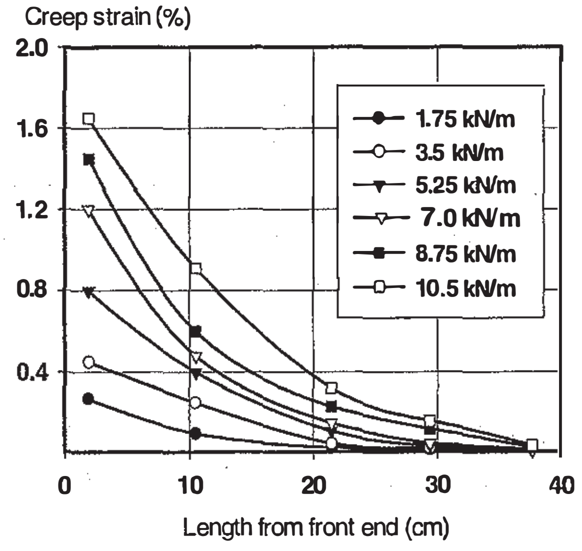

Figure 10. Creep strain distribution along the geogrid: Static load, σ_n=69.0 kPa.

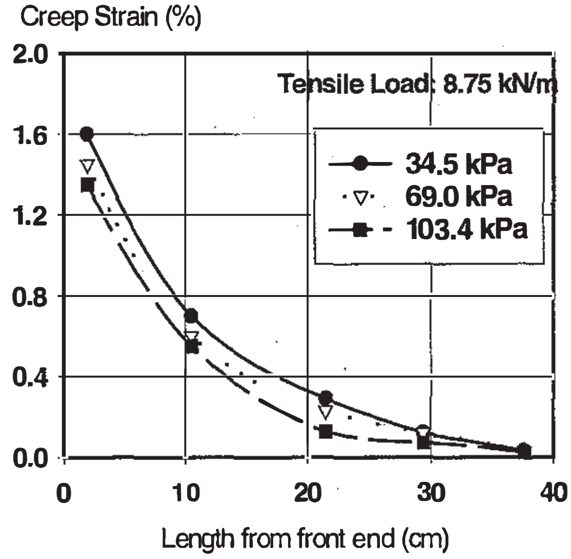

Figure 11. Creep strain along the geogrid specimen: Static load, 8.75 kN/m.

4 CONCLUSION

Some results are given from a long-term laboratory testing on geogrid embedded in clay. The purpose of the testing is to increase the understanding of cohesive soil-to-reinforcement interaction for the future research on utilizing low quality in-situ soils in mechanically stabilized earth structures. The long-term tensile loads were applied statically and repeatedly to the reinforcing geogrid confined in clay. The interaction behavior of the reinforcement was interpreted in different ways; that is, creep strain, creep strain rate, and strain propagation along the geogrid were evaluated under the static and cyclic loads with various confining pressures. The use of strain gages was found an efficient way to investigate the long-term loading effects on a confined reinforcement. The effects of both loadings were compared. It was found that creep strain was higher for static load than for cyclic load, and proportionally increased with the static and cyclic tensile load. Furthermore, for a known tensile load in the reinforcement, the creep strain is practically independent of soil confinement. That is, creep is an intrinsic property of the polymeric material though it could be also dependent on the reinforcement structure (e.g., some nonwoven geotextiles creep and tensile properties may depend on confinement).

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