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Pullout resistance of geogrid embedded in cohesive soil subjected to sustained and repeated tensile loads

Résistance à la retriate de geogrid encastré dans un terrain cohésif et soumis à des chargements soutenus et repetitifs de tensions

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ABSTRACT: This paper focuses on the long-term interaction and pullout behavior of a geogrid embedded in clay subjected to sustained and repeated loads. A fixture was modified to apply the tensile load incrementally. Under repeated loading conditions, different intensities of tensile load were applied. Strain distribution along the length of the confined geogrid was measured using strain gages. It was found that as the magnitude of the applied static or repeated load increased, an increased rate of creep developed in the embedded geogrid. The creep intensity was highest near the load application. Creep strain rate under static loads was larger than that under repeated loads. The confining pressure had significant influence on as well as on the strain distribution along the embedded geogrid.

RÉSUMÉ: Ce papier converge sur le comportement d'interaction et retraite à long terme d'un geogrid enfoncé dans l'argile soumis à chargements soutenus et repetitifs. Un accessoire a été modifié pour appliquer une charge de tension. Sous des conditions de chargement répétées, de intensités différentes de chargement de tension ont été appliqués. La distribution des deformations sur la longueur du geogrid a été mesurée avec un instrument de tension. Il a été trouvé que quand la magnitude de la charge appliquée statique ou répétée augmentes, le taux de glissement développé augmentes aussi dans le geogrid enfoncé. L'application de la glissement sous charge statique était plus large que sous charges répétées. La pression a eu une influence significative sur le taux de glissement et sur la distribution de tension dans le geogrid enfoncé.

1 INTRODUCTION

Use of polymeric geogrids in mechanically stabilized earth structures that are subjected to traffic and earthquake loading requires understanding of soil-geogrid interaction under repeated loads. However, guidance for designs considering the dynamic behavior of reinforced soil structures is substantially lacking.

Design properties for soil-reinforcement interaction are obtained from laboratory tests. Pullout experiments are commonly used. However, most of these tests have been conducted under short-term conditions subjected to monotonically increasing load. Furthermore, most of the work that was done on stress distribution along the soil-geogrid interface as well as pullout resistance used cohesionless backfill. Long-term pullout tests to assess soil-reinforcement creep behavior should be conducted when lower quality soil (i.e., silt or clay) is used as reinforced backfill (Mitchell & Christopher 1990). Many common problems have been identified when using lower quality soil in mechanically stabilized earth systems. Proper use of geosynthetics allows for use of cohesive soil and reduces the cost of construction (Chew & Loke 1996) up to 60 %.

This paper presents some results from laboratory pullout tests conducted to study the long-term performance of a polymeric geogrid embedded in clay. Strain gages were used to monitor strain development in the geogrid reinforcement during pullout. In studying the clay-geogrid interaction, several parameters were varied, that is, effect of confining pressure along with applied sustained or repeated pulling load on the clay-to-geogrid interaction was studied. The study was aimed to provide baseline information for future research and development on the interaction behavior between geogrids and cohesive soils. The testing method and results are presented and discussed.

2 PULLOUT TESTING

2.1 *Loading equipment and pullout box*

The pullout loading test setup used is shown in Figure 1. The test box had a plan view of 60 cm by 20 cm. A load actuator controlled by a servo console system generated the sustained and repeated pullout loads. The front end of the box had a slot at the mid-height. Through this slot the clamping plates were connected to the loading actuator. A load cell was used to measure the pullout load applied to the embedded geogrid specimen. The relative soil-to-geogrid movement was measured using an LVDT connected to the rigid clamps in the front. Latex sheets were pasted onto the sidewalls, and a layer of lubricant grease was applied between the latex sheets and the walls, attempting to create plane strain conditions. The confining pressure was applied uniformly through an air bag.

2.2 *Soil*

Kaolin clay was used in all tests. The maximum dry unit weight in standard proctor test was 14.7 kN/m^3 and optimum moisture content was 26%. During the test, the soil was compacted at the optimum water content in layers, 3.75 cm thick. Direct shear tests were conducted on samples extracted from the soil mass in the testing box. Peak and residual internal friction angles were measured as 14.7° and 14° and apparent cohesion measured as 52 and 19 kPa, respectively.

2.3 *Geogrid*

A biaxial geogrid, 38 cm by 19 cm, was used for all tests. The tensile loads were uniformly transferred to the geogrid using clamping plates in the longitudinal direction. Geogrid specimens were bonded at one end for confined tests, and at two ends for unconfmed tests, with a pair of rigid metal plates by epoxy glue. Table 1 shows the properties of the geogrid used.

2.4 *Geogrid Instrumentation*

Measurement of strains along the length of the confined geogrid specimen during the tests was of primary importance to study the interaction mechanism between the geogrid and the confining clay.

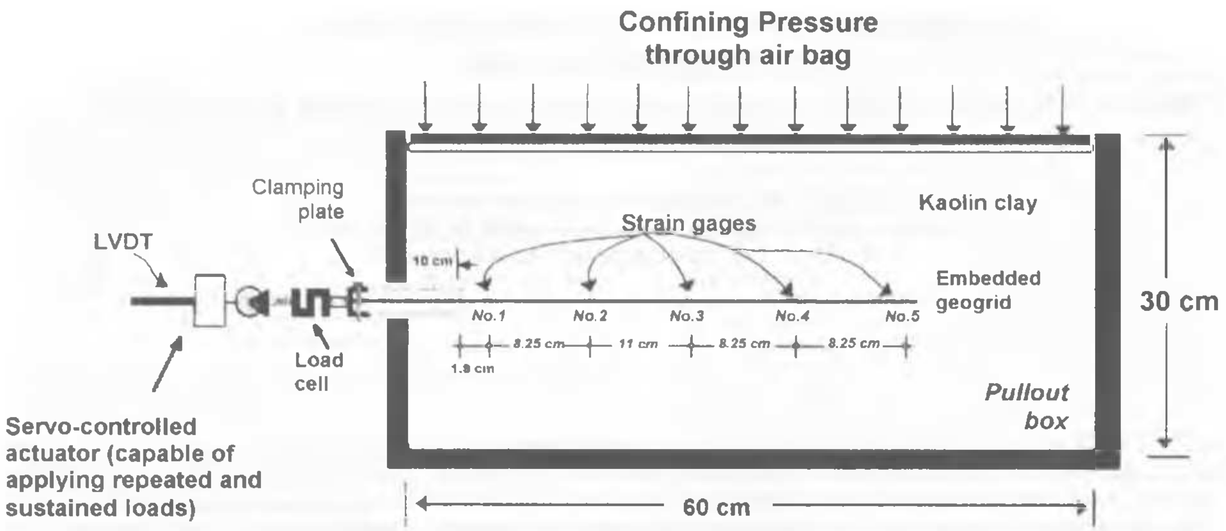

Figure 1. Pullout loading test setup

2.4.1 *Strain Gage Installation*

The strain gages used were KFE-5-120-C1 (Kyowa Co., Ltd, Japan) and YFLA-5 (Tokyo Sokki Kenkyujo Co., Ltd, Japan). YFLA-5 gages survived longer under repeated loading. Before the strain gages were attached, the geogrid rib surface was flattened and roughed using sand paper until the shiny surface texture disappeared. A surface treatment agent (S-9 provided by Kyowa) was applied to promote the bonding strength of the adhesive (CN cement). After curing was achieved, the strain gages were protected with a number of layers of an air-drying solvent (M-Coat provided by Measurements Group, Inc., USA). Finally, a piece of transparent plastic tube was placed around the gages to reduce the impact on the installed strain gage while placing and compacting the soil. The strains developed during pullout tests were monitored by a data acquisition system throughout the test. A total of nine strain gages were attached at five different locations (Fig. 1, strain gage No. 1 to 5) along the length of the geogrid.

Table 1. Geogrid properties

Aperture size	Longitudinal: 25.4 mm Transverse: 30.5 mm
Rib width	Longitudinal: 5.0 mm Transverse: 5.0 mm
Thickness	At rib: 1.8 mm At junction: 4.8 mm
Wide width strength	Longitudinal: 45.2 kN/m Transverse: 30.5 kN/m
Tensile Modulus	400 kN/m
Junction strength	30.6 kN/m
Polymer composition	Polypropylene
Open area	65 %

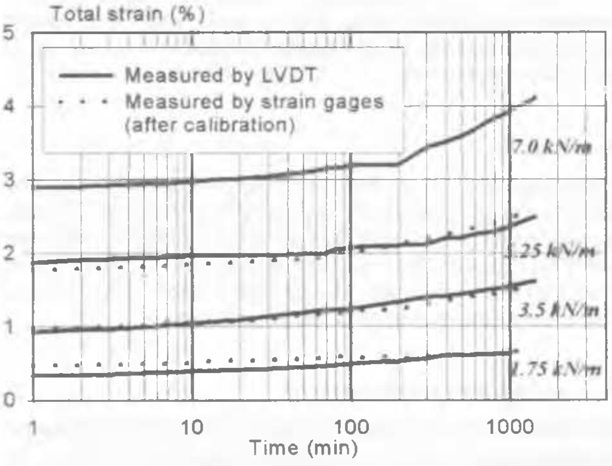

Figure 2. Calibration of strain gages according to average strain in the geogrid calculated from LVDT

2.4.2 *Strain Gage Calibration*

Strain distribution in the geogrid was not uniform because of the non-uniformity in its geometry. In order to obtain average strain reading in the geogrid by using strain gages, displacements over the entire geogrid length were used to calculate the average strain for a given displacement. The strain gage readings were then correlated (i.e., calibrated). The correlation was made for each sustained uniaxial tension load conducting unconfined tension loading tests. Figure 2 shows the consistency between calibrated strains measured from strain gage output and average strains calculated from displacements using LVDT.

2.5 *Experimental program*

Unconfined tests were first conducted to study the fundamental creep behavior under sustained and repeated tensile loads, and then confined soil tests were performed. These tests were carried out under normal pressures of 34.5 kPa to 103.4 kPa. In each test with sustained load, the pullout load was applied in the increments until the specimen was pulled out or until the load actuator reached its displacement or load capacity. Tests equivalent to the long-term sustained pullout tests were also conducted under repeated loads. The repeated loads were applied at a fixed frequency of 0.1 Hz., with a minimum tensile load of 0.25 kN/m. For all tests initial load was 1.75 kN/m and the same loading sequence was followed; i.e., each load was kept constant for 24 hours and then increased by a prescribed increments of 1.75 kN/m. The details about the pullout box, materials used and testing procedures can be found in Pamuk (1997).

3 TESTING RESULTS

Figure 2 and 3 show some of the strain-time relationships measured in the tests for sustained and repeated loads, respectively. Long-term behavior of the geogrid specimen during these tests was expressed as strain rate and summarized in Figure 4. In this figure, the tests were terminated when the load actuator reached

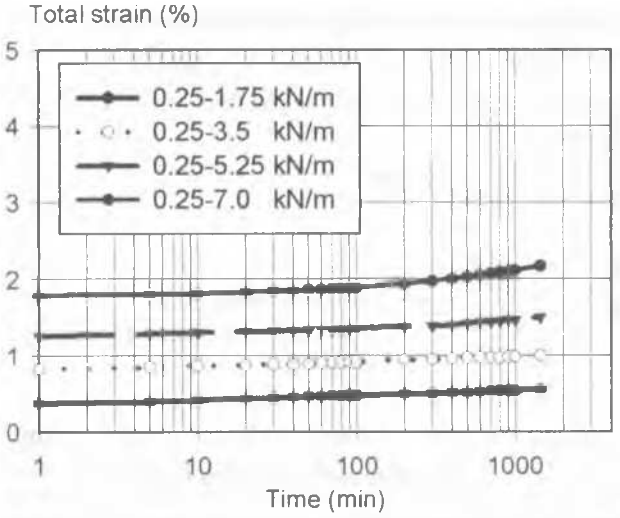

Figure 3. Strain-time relationships measured in unconfined tests (unconfined test with repeated load)

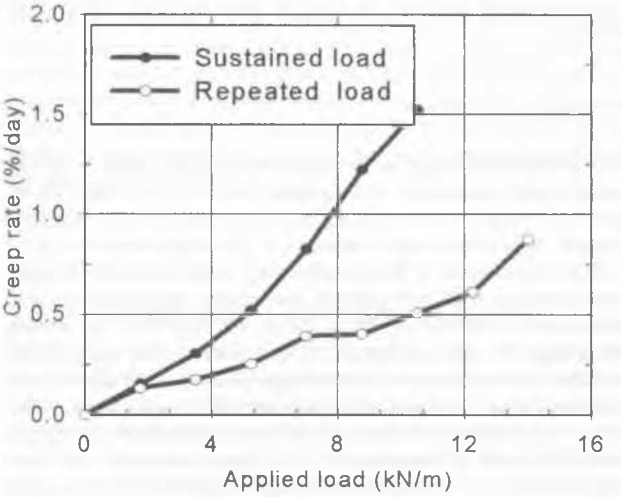

Figure 4. Creep rate from unconfined tests

its displacement or load capacity because the specimen did not rupture.

Tests were conducted on the embedded geogrid with confining pressures 34.5 kPa to 103.4 kPa, under sustained and repeated loads. Typical results obtained from tests under confining pressure of 34.5 kPa are shown in Figure 5 and 6. The figures represent the strain distribution along the length of the geogrid measured 24 hours after load application. The front-end displacements obtained from these tests are displayed in Figure 7. No pullout was experienced during the confined tests.

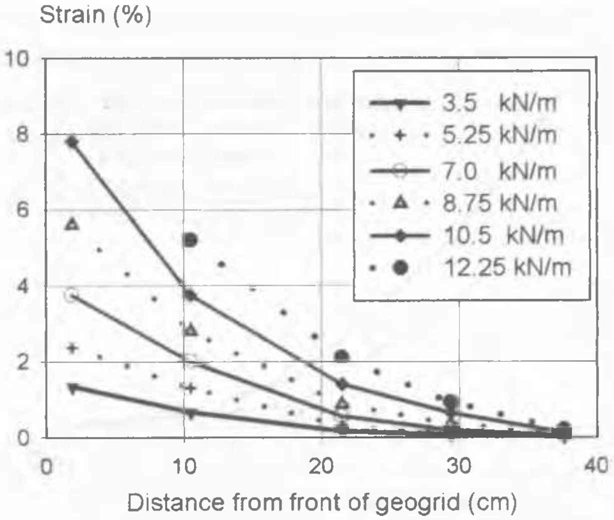

Figure 5. Distribution of total strain along the geogrid, σ_n=34.5 kPa, sustained loading

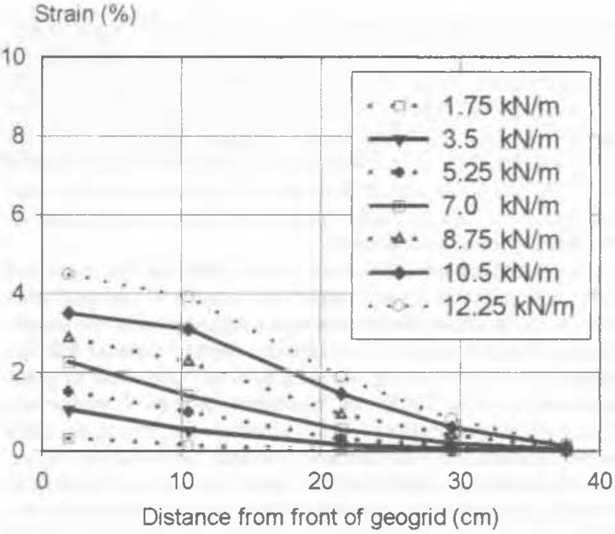

Figure 6. Distribution of total strain along the geogrid, σ_n=34.5 kPa, repeated loading

4 DISCUSSION

Sustained and repeated long-term tests without confining soil were first conducted to prepare a baseline for confined tests. The effects of both sustained and repeated loads on the fundamental creep behavior of the geogrid specimen were determined. It was found that creep under sustained loads was higher than under equivalent repeated loads. That is, under the prescribed loads, creep rate was doubled under sustained loads.

The effect of confining soil on the interaction behavior of the reinforcement embedded in clay was studied under various pressures with the same loading pattern that was used during the unconfined tests. The displacements measured at the front end of the geogrid subjected to repeated loads were smaller than those for sustained loads. Figures 8 and 9 show the strain distribution under various confining pressures together with applied sustained and repeated loads measured 24 hours after load application. Strain development was significant at the front end of the

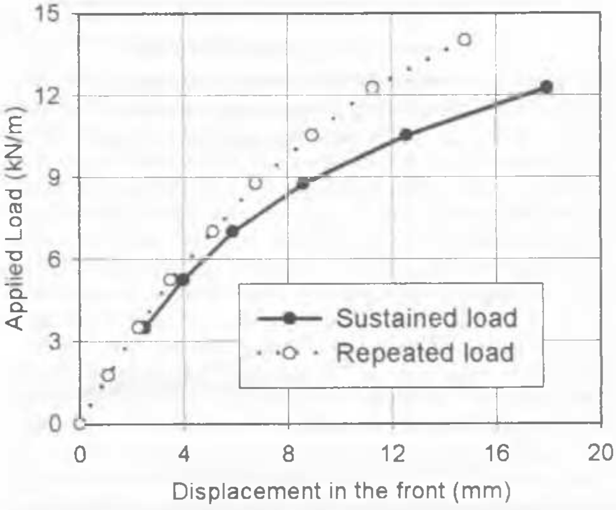

Figure 7. Applied load vs. displacement in the front, σ_n=34.5 kPa

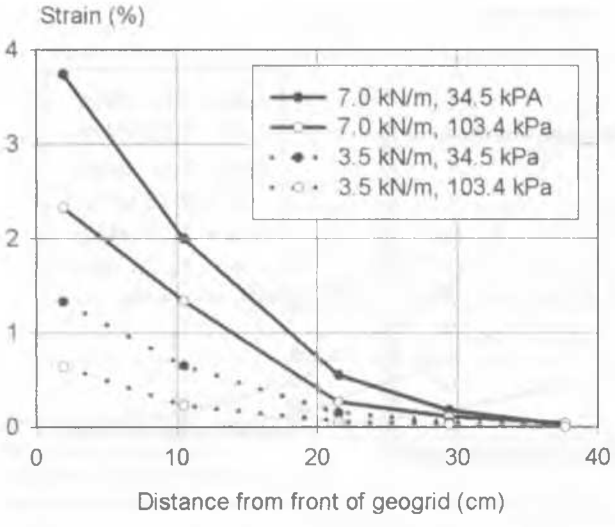

Figure 8. Distribution of total strain along the geogrid, σ_n=34.5 & 103.4 kPa, subjected to various sustained loading

geogrid and then reduced towards the rear end. The strain distribution seemed to diminish quickly along the length, especially at low tensile load levels. As the applied load level increased, the strain propagated towards the rear end. The results indicated that creep strain under sustained loads was higher than that under repeated loads and increased with time as well as with the number of cycles. The soil-to-geogrid interaction increased with the confining pressure. Strain along the geogrid length was reduced as the confining pressure increased.

After completion of the tests, the validity of the measured strains using strain gages along the length of geogrid was checked. The strain distribution was integrated over the length to obtain displacement at the front end. Figure 10 shows that the integration of strain along the length of geogrid was in good agreement with the LVDT measurements obtained from the test with a confining pressure of 103.4 kPa thus confirming the calibration method used to read average strains. Note that the measured strains were restricted to the strains developing in the deforming geogrid itself. Therefore, they also included creep or relaxation. It was a result of the applied load and the interaction of the embedded geogrid with the kaolin along its common interfaces, possible creep and relaxation developing in the kaolin were unknown, however, their effects were reflected in the measured behavior. The embedment in a different soil would have produced different interaction behavior (e.g., Min et al. 1995).

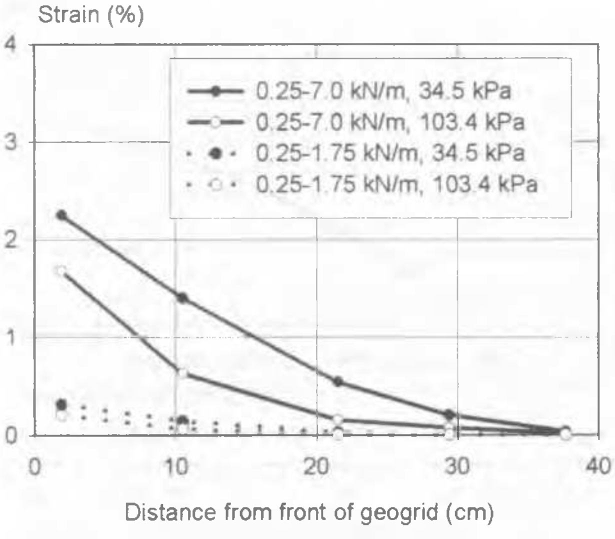

Figure 9. Distribution of total strain along the geogrid, σ_n=34.5 & 103.4 kPa, subjected to various repeated loading

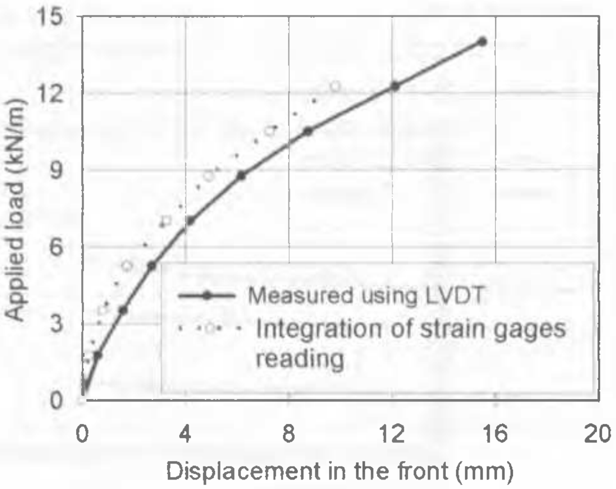

Figure 10. Load-displacement relationships: measured and integrated. σ_n=103.4 kPa, sustained loading

5 CONCLUSION

An experimental study on the long-term pullout behavior of the geogrid under sustained and repeated pullout loads was investigated. A series of experiments on unconfined and confined geogrids specimens were conducted. The experimental method and instrumentation of the geogrid were presented. Strain gages were useful to study soil-geogrid interaction and provided information about strain distribution along the length of the embedded geogrid in clay. Unconfined tests were useful in providing baseline information for interpreting the results obtained from confined tests. The confining pressure had a significant influence on front displacement as well as on creep strain developed along the length of the geogrid. Creep strain decreased with confining pressure. The confined geogrid exhibited different behavior under sustained and repeated loads. Creep strain under repeated loads was lower than that under sustained load.

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