Large Strain Measurements in Geogrid Reinforcement

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Strain gauges are usually used in measuring deformations of geosynthetics in reinforced soil walls, where maximum strains around 2 percent are usually monitored. For the higher strain levels encountered in confined extension and pullout tests, extensometers and linear variable differential transformers (LVDTs) are usually used. The use of strain gauges in monitoring larger strains (5 percent and higher) requires a special procedure for the attachment of the gauges and a correlation between strain gauges and LVDT readings in confined soils for the proper interpretation of the measurements. A standardized procedure for attaching strain gauges to geogrid reinforcement was developed to monitor large strains (in excess of 8 percent) in confined conditions. The procedure was examined for different types of geogrids, adhesives, and protective coatings. It was first evaluated in unconfined extension tests. The correlation between strain gauge measurements and strains measured across the specimen length (cross-head strains) was investigated. Strain gauges monitored up to 16 percent cross-head strain with a linear relationship up to 10 percent strain. Strain measurements under confined conditions were evaluated in confined extension tests and pullout tests. The strains between the geogrid transversal elements (element-strains) were obtained from LVDT measurements. Strain gauge readings were correlated to element strains at different locations along the specimen. Strain gauge measurements were less than those calculated from LVDT measurements. The relationship between both was linear up to 8 percent strain. A correlation factor to correct strain gauge measurements to element strains is used and a numerical procedure is used to estimate the tension forces at various locations along the geogrid reinforcement from strain measurements.

Geosynthetics strains monitored under working stress conditions in reinforced soil walls are usually small because of the high factors of safety inherent in the design of such structures. Maximum tensile strains are usually about 2 percent in typical reinforced walls and may reach 3 to 4 percent in the base reinforcement of embankments above soft soils (*1*,*2*). Strain gauges are typically used in the field to monitor such strain levels in geogrid reinforcements (*3*), woven geotextiles (*4*), and nonwoven fabrics (*5*).

Higher strain levels up to 10 percent are usually reached in model walls tested under ultimate loading conditions (*6*) and in confined extension and pullout tests (*7*). For the higher strain levels encountered in such conditions, extensometers and linear variable differential transformers (LVDTs) are usually used. The use of a sacrificial array of strain gauges to measure large strains offers an economical solution for monitoring large deformations in the laboratory as well as in the field. However, the use of strain gauges requires a special procedure for the attachment of the gauges and a correlation between strain gauges and LVDT readings in confined soils for the proper interpretations of the measurements.

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A procedure was developed to attach strain gauges for measuring strains in excess of 8 percent. The procedure was examined in unconfined extension tests for two different types of geogrids and various adhesives and protective coatings. The performance of the strain gauges under confined conditions was evaluated in confined extension tests and pullout tests. The strain gauges were tested in compacted cohesive soil under various confining pressures. Strain gauge readings were correlated with the LVDT measurements at different locations along the specimen. The measurements were used in defining the confined stress-strain properties of the geogrid and in estimating the induced tension forces along the geogrid reinforcement in pullout tests.

STRAIN MEASUREMENTS IN UNCONFINED TESTS

The geogrid–strain gauge attachment procedure was investigated in two types of geogrids of different geometry, material properties, manufacturing processes, and surface texture: (high-density polyethylene (HDPE) geogrid Tensar UX1500 and woven fabric geogrid Conwed Stratagrid 6033. Two types of strain gauges from Micro Measurements (MM), namely, EP-08-250BG 120 ohm and EP-40-250BF 350 ohm, were used for both geogrids. Preliminary unconfined extension tests were conducted to investigate the effects of strain rate, surface preparation, gauge and adhesive type protective coatings, and water submergence. The tests were performed on specimens 18 in. long with three longitudinal ribs. Strains were monitored using the MM P3500 strain indicator. The gauges monitored up to 12 percent strain in most tests. The procedure for strain gauge attachment is discussed in detail elsewhere (*8*) and is summarized in the following sections.

Surface Preparation

A combination of 000 steel wool and 220 and 400 grit sandpaper was used for surface abrasion at the location of the strain gauges. Unconfined extension tests (*8*) showed no reduction in the tensile strength due to the surface abrasion of the specimens.

For the woven geogrid, the surface texture is rough and irregular, with a uniform cross-sectional area. A thin layer of MM A-12 adhesive was placed on the woven geogrid to create an adequate surface for gauge attachment. The adhesive was cured for at least 4 hr at 125°F and clamped between metal plates with sufficient pressure to allow the epoxy adhesive to impregnate the woven fibers. The surface was then abraded and cleaned.

Strain Gauge Attachment

MM A-12 adhesive, a two-part epoxy used for high strain conditions, was used to attach the gauges. After the gauges were glued, pressure was applied on the gauges by spring clamps while the adhesive cured. A neoprene sponge was placed on the gauges to protect them and to evenly distribute the pressure. The geogrid specimens were cured for at least 4 hr at 125°F. The preliminary tests showed that no apparent change in the ultimate geogrid strength was found when the geogrid was exposed to temperatures up to 165°F and for 24 hr. After curing the leads were soldered to the gauges.

Unconfined Extension Tests

After the preliminary tests to investigate the attachment procedure of strain gauges, additional unconfined extension tests were performed on the HDPE geogrid specimens instrumented with the MM EP-08-250BG 120-ohm strain gauges. The specimens were 0.15 m (6 in.) wide and 0.48 m (19 in.) long. In these tests strain gauges were attached at different locations along the geogrid longitudinal ribs. Figure 1 shows the geogrid specimen with the locations of the strain gauges. Typical test results on the HDPE geogrid are shown in Figure 2. The strain gauge readings are plotted with the cross-head strain measured along the overall length of the specimen. The strain gauges monitored up to 12 percent (corresponding to 16 percent cross-head strain) in most tests.

The results in Figure 2 show that strains are uniform within the gauges *A* to *C* and the location of the gauge along the longitudinal ribs has no effect on the measurements. However, strain gauge readings are not equal to the cross-head strain along the specimen length. This is mainly due to the varying geometry and stiffness modulus at the transversal ribs, which causes a nonuniform strain distribution along the specimen length. Within the range of the linear strain gauge reading (10 percent), a correlation factor of 0.8 relates the strain gauge reading to the cross-head strain for this specific type of geogrid. It should be noted that the correlation factor was approximately 1.0 for the Stratagrid woven grids of uniform cross-sectional area before the protective coating was applied.

STRAIN MEASUREMENTS IN CONFINED TESTS

Specimen Preparation

The procedure for strain gauge attachment to the geogrid is essentially the same for confined applications. To protect the gauges

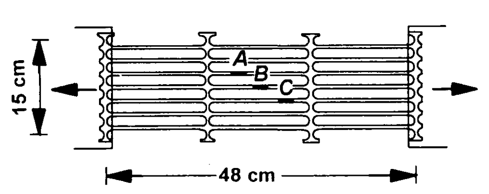

FIGURE 1 HDPE geogrid specimen and location of strain gauges.

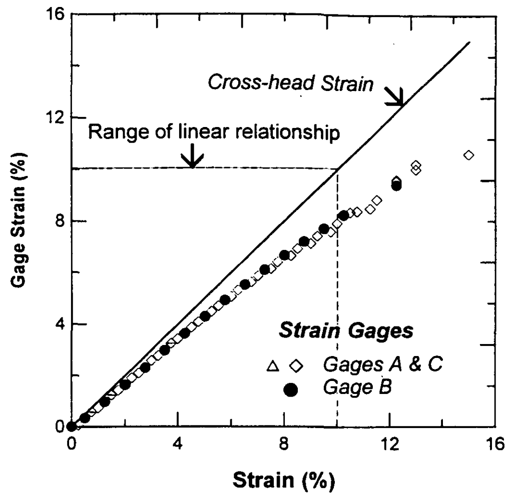

FIGURE 2 Strain measurements of HDPE geogrid in unconfined extension tests.

in the soil, a number of specialized protective coatings were tried. A layer of rubber cement covered by a layer of silicon rubber coating was found to be simple, inexpensive, and adequate. The coated gauges were tested on the HDPE geogrid specimens in a 2 percent saline solution. The gauge readings were monitored periodically for 2 weeks in the solution before testing. The coating was found to be adequate to waterproof the gauges.

The coating system was also applied to the polyester yarn woven geogrids. Specimens were coated on both sides of the grid and soaked in the solution for various periods of time. High strain readings (approximately 5 percent) were monitored during the period of submergence, which suggested that the woven grid was absorbing water and swelling. When the geogrid was soaked in the solution it absorbed 16 percent water by weight after 40 hr.

In order to ensure that the saline solution was not getting to the strain gauges through the soaked woven grid, a strip of elastic foil, slightly larger than the gauge, was glued to the prepared surface before gauge installation. The gauge was glued directly to the strip and coated using the standard procedure. The strain readings increased to approximately 5 percent within 3 days of soaking, showing that the grid was swelling; however, the readings were stable, showing that the saline did not reach the gauges.

To protect the gauges during compaction, two pieces of plastic pipe 1 in. long and 0.5 in. in diameter were split and placed around the geogrid rib and the gauge. Compaction in the box was performed with a minimum soil thickness of 4 in. above the tubes.

Confined Extension Tests

In the confined extension tests, instrumented HDPE geogrid specimens of 0.3 m (1 ft) wide and 0.92 m (3 ft) long were tested in a box 1.22 m (48 in.) in length, 0.6 m (24 in.) in width, and 0.45 m (18 in.) in height. Figure 3 shows a schematic diagram of the confined extension box. The details of the box are presented elsewhere (7). The geogrid specimen was placed at mid-height of the box with one end clamped to the box. The soil was silty clay with a plasticity index of 24. The tests were conducted at the optimum water content of 22 percent, at 90 percent of the maximum dry

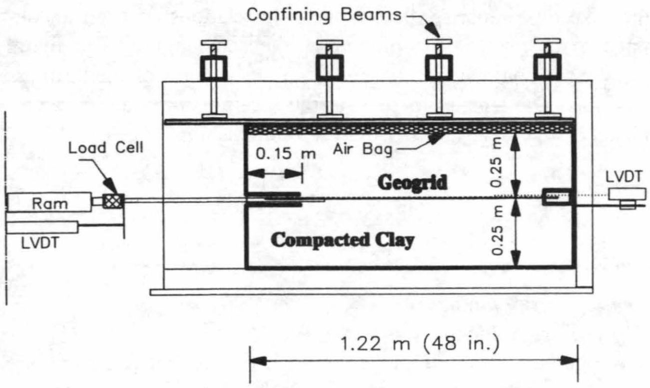

FIGURE 3 Schematic diagram of confined extension box.

FIGURE 5 Placement of instrumented HDPE geogrid in confined extension test.

density, and at different confining pressures. Four strain gauges were placed on the first two geogrid elements. Figure 4 shows a schematic diagram of the geogrid specimen and the location of the strain gauges and Figure 5 shows the placement of the geogrid in the large testing box.

The nodal displacements along the geogrid specimen were also monitored by the LVDTs. The strains ϵ_i between the grid nodes (element-strains) were calculated from the LVDT measurements from the relationship

$$\epsilon_i = [\delta_i - \delta_{i-1}] / \Delta x \qquad (1)$$

where δ_i and δ_{i-1} are the displacements at two consecutive nodes and Δx is the element length.

The strain gauge measurements are plotted with the element-strains from the LVDT measurements in Figure 6. The strain gauge readings were stable up to 12 percent element-strain. The correlation factor between the element-strain and the strain gauge readings was 0.7, which is lower than that deduced from the unconfined tests. The reduction of the correlation factor is possibly attributed to the increase in the stiffness modulus of the geogrid due to the addition of the protection coatings around the geogrid ribs.

ESTIMATION OF TENSION FORCES FROM STRAIN MEASUREMENTS

The tension forces along the geogrid reinforcement during pullout can be estimated from strain measurements. In the pullout tests, testing parameters were identical to those in the confined extension tests. Geogrid specimens were tested in the box shown in Figure 3 with the back of the specimen not attached to the box.

A schematic diagram of the HDPE geogrid specimen and the locations of the strain gauges for pullout testing is shown in Figure 7. The strain gauge measurements during pullout are shown in Figure 8 while the LVDT measurements during pullout are shown in Figure 9. The displacement distribution along the geogrid length is plotted for different pullout loads in Figure 10. It can be seen from this figure that the displacement of each geogrid element between node i and $i - 1$ results from the elongation of the element ($\delta_{i-1} - \delta_i$) and the shear displacement δ_i. The strain ϵ_i between the grid nodes (element-strains) can be calculated from Equation 1.

Figure 11 shows the pullout load versus the strain of the first geogrid element, and the confined stiffness modulus of the geogrid (E) can be obtained from the initial slope of the relationship. For

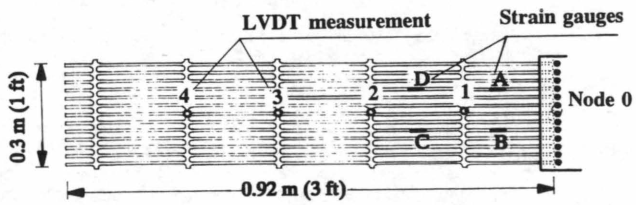

FIGURE 4 Locations of strain gauges and LVDT measurements.

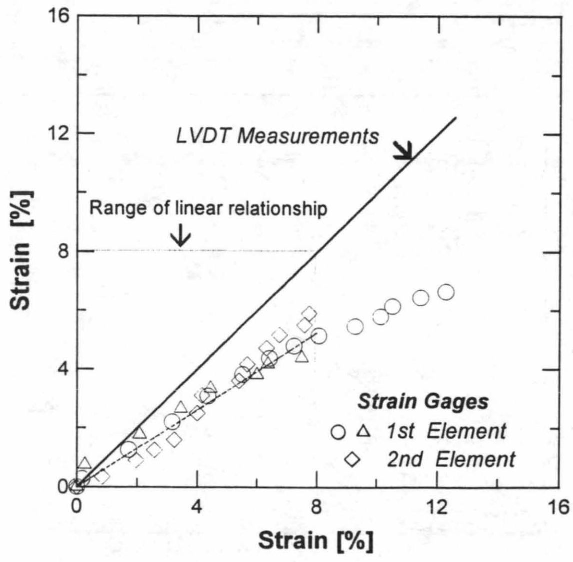

FIGURE 6 Strain measurements in confined extension tests on HDPE geogrid: confining pressure, 48 kN/m^2 (7 psi).

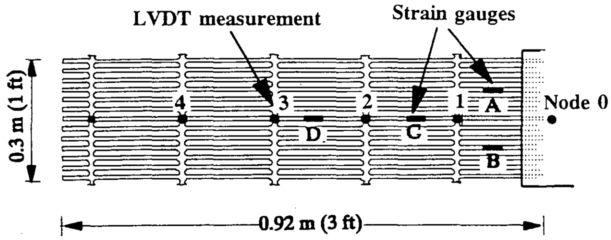

FIGURE 7 Locations of strain and LVDT measurements in pullout tests.

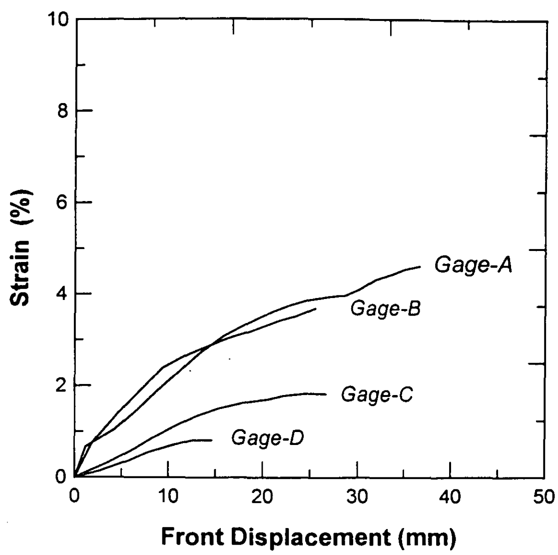

FIGURE 8 Strain gauge measurements in pullout tests on HDPE geogrid: confining pressure, 48 kN/m^2 (7 psi); geogrid specimen, 0.3 m wide × 1 m long.

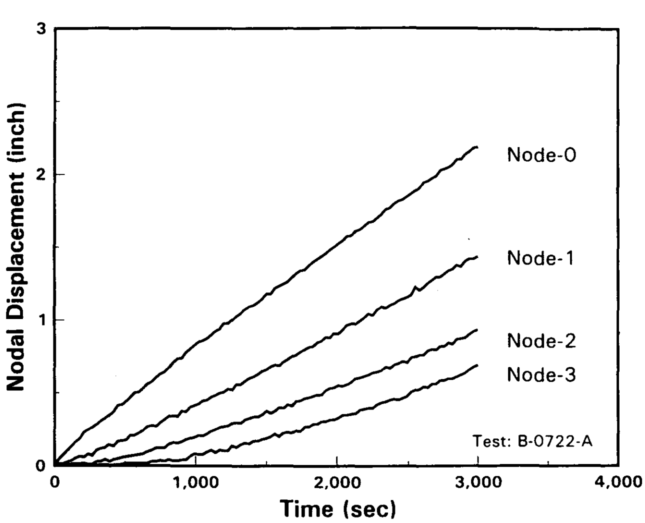

FIGURE 9 LVDT measurements during pullout test: HDPE geogrid, 3 ft long; cohesive soil, density 95 lb/ft^3, w/c 22 percent.

the sake of comparison the stess-strain relationship from unconfined extension tests is plotted in the same figure. The figure shows that confinement can result in an increase of the stiffness modulus. The tension force T_i at the locations of strain measurements can be determined from the relationship

$$T_i/b = E\ t\ (\epsilon_i) \tag{2}$$

where

b = geogrid width,
t = geogrid thickness, and
ϵ_i = geogrid strain at gauge i.

The calculated tension forces at the locations of the strain gauges are shown in Figure 12.

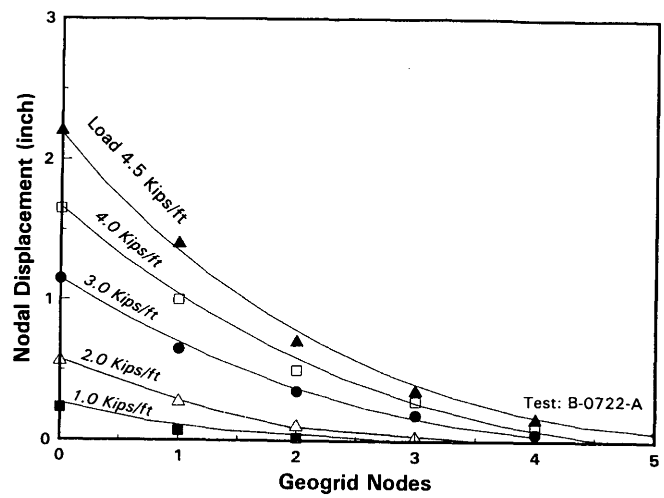

FIGURE 10 Displacement distribution along geogrid during pullout.

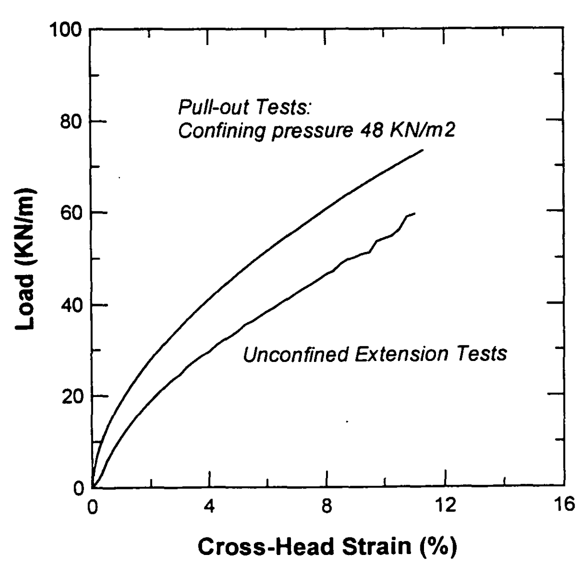

FIGURE 11 Confined and unconfined stiffness modulus of HDPE geogrid.

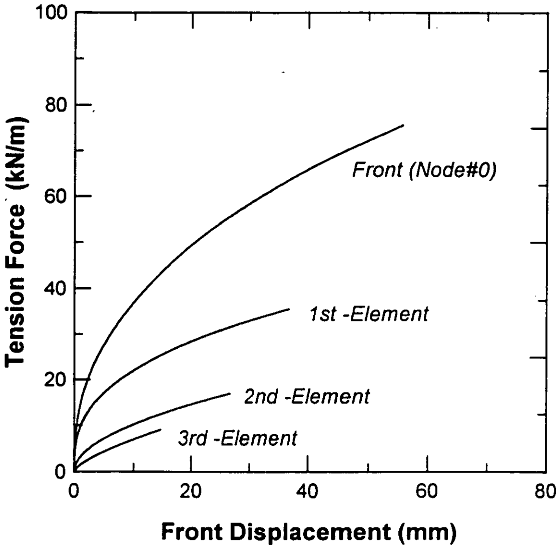

FIGURE 12 Estimated tension forces along geogrid elements during pullout test.

CONCLUSIONS

The geogrid reinforcement can be subjected to large strains during confined extension and pullout tests; moreover, large deformations may exist in reinforced-soil test walls under ultimate loading conditions. Deformations can be monitored by instrumenting selected sections of the geogrid reinforcement with a low-cost sacrificial strain gauge system. A standardized procedure for the attachment of strain gauges to monitor strains in excess of 8 percent has been developed.

The results of the unconfined extension tests showed that the strain gauges could monitor strains up to 16 percent cross-head strain. However strain gauge readings were linear up to 10 percent strain and they were not equal to the cross-head strains. The relationship between strain gauge reading and cross-head strain depends on the geogrid geometry and the change in the thickness and stiffness modulus along the geogrid length. The ratio between strain gauge reading and cross-head strain was close to 1.0 for the uniform Stratagrid woven grids and 0.8 for the HDPE geogrid.

The strain gauge installation procedure was also evaluated in confined applications. The results of the confined extension tests demonstrated the importance of protecting the gauge and the specimen from moisture and compaction damage. A lower correlation factor (0.7) between the strain gauge reading and element-strains was deduced from confined tests on the HDPE grids, possibly because of the addition of the protective coatings.

The deformation-induced tension forces in the reinforcement could be estimated from the strain gauge readings. The procedure demonstrated the importance of obtaining the strain measurements and the reinforcement stress-strain relationships from the appropriate tests in confined conditions.

ACKNOWLEDGMENTS

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