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16. Abstract

This report concerns the attachment of strain gages to polymer soil reinforcement grids (geogrids) for high elongation measurements, i.e. 5% and higher. Existing methods of attaching strain gages to geogrids are not suited for measurement of these high strains. Therefore, a research study was initiated to develop practical and repeatable procedures for attaching strain gages to geogrids to monitor large strains.

The study involves examination of the factors which can affect the gage-geogrid bond during laboratory unconfined extension tests. Samples of different types of geogrids instrumented with strain gages are pulled at a constant rate and the deformations are measured. Detailed attachment procedures are developed and specific recommendations for strain gage and coating selection are given for two common types of geogrid.

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EVALUATION OF METHODS AND MATERIALS USED TO ATTACH STRAIN GAGES TO POLYMER GRIDS FOR HIGH STRAIN CONDITIONS

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ABSTRACT

This report concerns the attachment of strain gages to polymer soil reinforcement grids (geogrids) for high elongation measurements, i.e. 5 percent and higher. Existing methods of attaching strain gages to geogrids are not suited for measurement of these high strains. A research study was initiated to develop practical and repeatable procedures for attaching strain gages to geogrids to monitor large strains.

The study involves examination of the factors which can affect the gage-geogrid bond during laboratory unconfined extension tests. Samples of different types of geogrids instrumented with strain gages were pulled at a constant rate and the deformations measured. Detailed attachment procedures were developed and specific recommendations for strain gage and coating selection are given for two common types of geogrid.

IMPLEMENTATION STATEMENT

As a result of the findings of this study, recommendations are made as to the strain gage type, strain rate, adhesive type, surface preparation method, and the protective and water-proofing coatings required for two widely used geogrid products.

Step by step procedures are outlined which enable their applications to other types of geogrids.

The results of this study will be used by LTRC and the LDOTD Pavement and Geotechnical Design Section on two instrumented embankment projects already being planned. One is a mechanically stabilized, vertical embankment and the other is a controlled pullout test embankment with both vertical and sloped faces. Prior to full scale application, confined laboratory tests will be performed in granular and cohesive soils using the procedures developed in this study.

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INTRODUCTION

Synthetic soil reinforcement grids, commonly known as geogrids, have found increasing use in construction of road bases, highway embankments, retaining structures, and other highway and geotechnical structures. Geogrids may be subjected to large deformations during their service life. The load induced deformations of geogrids can be monitored for design verification by instrumenting selected, critical sections of the geogrid with a low cost, sacrificial system. Strain gages can be used for this monitoring, and measured stress-strain relationships can be developed so that the stresses on the geogrid can be accurately determined at any location within the soil structure.

Currently, most of the commercially available geogrids fall into two general categories, woven fabric grid (usually polyester with a polyvinyl chloride (PVC) or other coating) and extruded or formed grids, made from high density polyethylene (HDPE) or other plastics. For the purpose of this study a woven fabric (Conwed) geogrid and a formed (Tensar) geogrid were selected.

Historically, strain gages have been used to measure very small strains, usually less than 2 percent. Because the large deformations of geogrids can far exceed this limit, and due to the harsh nature of the field environment, the use of specialized gages, materials, and attachment procedures are required. Specific procedures are developed for attaching strain gages to each type of geogrid for measurements of strains in excess of 5 percent in laboratory unconfined extension tests, and for protecting the gages from the field environment.

This report is limited to unconfined laboratory testing of the instrumented geogrids, but the procedures developed will be used in further studies for confined laboratory testing (including direct shear and pullout testing), and eventually for full scale field applications.

OBJECTIVE

The main objectives of this study were to:

(a) develop a specific procedure for the attachment of strain gages to geogrids for high strain conditions. This procedure contains step by step instructions for attachment, from sample preparation to the application of coatings.

(b) develop a summary of the results for varying ranges of strains and the behavior of strain gages and the adhesives used. This summary includes recommendations for types of gages, adhesives and coatings to be used.

SCOPE OF THE RESEARCH

This report is limited to laboratory unconfined extension tests on instrumented geogrid samples. Specific geogrid-strain gage attachment procedures are developed for one woven fabric (Conwed) geogrid and one formed (Tensar) geogrid.

The results of this work will be used to develop methods for confined extension tests, first in a controlled laboratory environment, and then in field studies. Confined testing is beyond the scope of this report, but this current work is the foundation for research which will lead to the ability to monitor the stresses exerted on geogrid reinforcement in soil structures.

In order to develop attachment procedures for the two geogrids selected, the effects of a number of parameters are investigated:

a. strain rate

b. excessive heat

c. surface preparation methodology

d. adhesive type

e. curing procedures

f. protective coating

g. water submergence

h. strain gage type

METHOD OF PROCEDURE

The methodology used in this study was as follows:

(a) preliminary tests investigating the effects of strain rate, moisture, and elevated temperature were performed.

(b) trial methods of attachment were developed.

(c) tensile tests were performed on geogrids instrumented with strain gages using the trial methods.

(d) effect of coating on the strain gage-geogrid bond was investigated.

(e) specific attachment procedures were developed for the two types of geogrids used in this study.

TESTING PROGRAM

The test factorial for each geogrid is described in the following table. The table indicates the number of tests required to achieve and duplicate satisfactory results for each task.

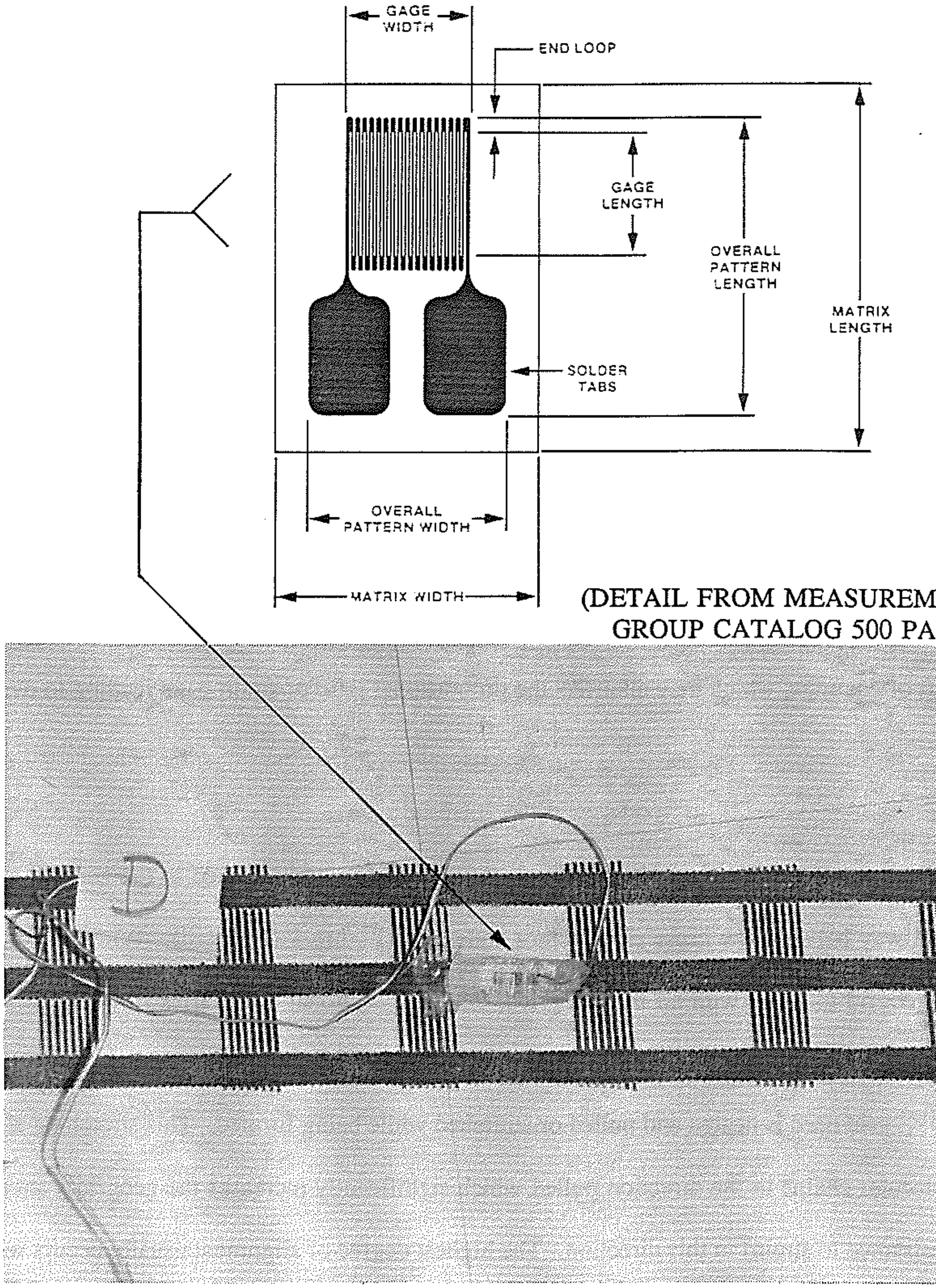
TASK	HDPE GEOGRID	WOVEN GEOGRID
STRAIN RATE EFFECT	IA:1 THRU 18	IIA:1 THRU 10
HEAT EFFECT	IB:1 THRU 12	IIB:1 THRU 12
SURFACE PREPARATION	IC:1 THRU 24	IIC:1 THRU 24
ADHESIVE TYPE	ID:1 THRU 24	IID:1 THRU 18
GAGE TYPE	IE:1 THRU 30	IIE:1 THRU 12
PROTECTIVE COATING	IF:1 THRU 18	IIF:1 THRU 30
WATER SUBMERGENCE	IG:1 THRU 12	IIG:1 THRU 30
FINAL CHECKS	IH:1 THRU 12	IIH:1 THRU 12
TOTAL SAMPLES TESTED	150	148

DISCUSSION OF RESULTS

It is necessary to make distinctions among the strains measured with a strain gage, the overall strain measured using the crosshead travel of the testing machine, and strains measured through the use of an extensometer (an instrument used for measuring minute deformations of a test specimen). Throughout the following discussions the term "strain" refers to the strain measured with a strain gage unless otherwise indicated.

It is also necessary to recognize that the strain measured by the strain gage should be proportional to, but may not be equal to, the overall or average strain measurement for several reasons. The reasons for this include the placement point of the strain gage on the geogrid, varying cross sectional area, possible alignment of polymer chains within the grid, and the added modulus of coatings, which may all affect the proportional ratio of strain gage reading to overall strain.

In all of the tests on both geogrids examined, the strain gage was attached to the geogrid at the point halfway between the cross rib juncture nodes (see Figure 1 for detail). With the formed HDPE geogrid used, as with all formed grids, the cross sectional area varies from a maximum at the cross rib juncture to a minimum exactly halfway between the juncture nodes. In addition, the HDPE grid used is heated and pulled or stretched while being formed. This stretching aligns the molecular chains in the direction pulled which significantly increases the geogrid's strength (and resistance to strain) in this direction. The highest degree of alignment usually occurs where the cross sectional area is smallest.



(DETAIL FROM MEASUREMENTS GROUP CATALOG 500 PART B)

Figure 1. Detail of a Typical Strain Gage and Gage Location.

For the combination of HDPE geogrid, strain gage and adhesive used in the following discussion, the ratio of strain gage reading to overall strain was about 0.8 before the protective coating was added, and about 0.7 after the coating. For the woven geogrid examined, there was no formed polymer chain alignment and the cross sectional area was essentially uniform, so the ratio was approximately 1.0 before the protective coating was applied.

Early in the strain gage testing, an attempt was made to predict what the ratio would be of a specific combination of materials. Due to the number of potential variables, it was decided that it would be more practical to determine the ratio experimentally. If the gage strain to overall strain is known, the ratio may be used to monitor overall strain and to calculate stress from published or experimentally generated stress-strain relationships. For any desired combination of gage, grid, adhesives, coatings, and procedures, laboratory tests should be performed on a series of prepared specimens, following the guidelines of this report, to determine the correct and case specific ratio.

PART 1

ATTACHMENT PROCEDURES FOR A FORMED HDPE GEOGRID

This part of the discussion summarizes the steps taken to develop an adequate geogrid-strain gage attachment procedure for a Tensar UX1500 HDPE geogrid (see Figure 2). These steps include detailed discussions of the materials used, and the surface preparation and gluing techniques developed.

For most tests, a standard specimen consisted of a piece of uni-directional geogrid five tensile members or ribs wide, and four cross ribs in length. The outer tensile rib on each side was cut between each cross rib so that only three ribs provided tensile resistance. The purpose of the extra width was twofold; it provided additional width for secure clamping, and eliminated boundary effects in the tensile ribs created by cutting the sample too close to the tensile ribs. The sample length was selected such that it allowed the sample to be gripped on cross ribs for testing, and still provided one free unit length to be tested.

Strain gage readings were taken using a portable strain indicator at fixed intervals of load frame crosshead travel. The intervals were at 0.5 percent crosshead strain based on an 18" space between the testing grips for a standard test specimen at the beginning of a test. The crosshead travel was paused momentarily at each 0.5 percent crosshead strain to allow recording the gage strain and the tensile load.

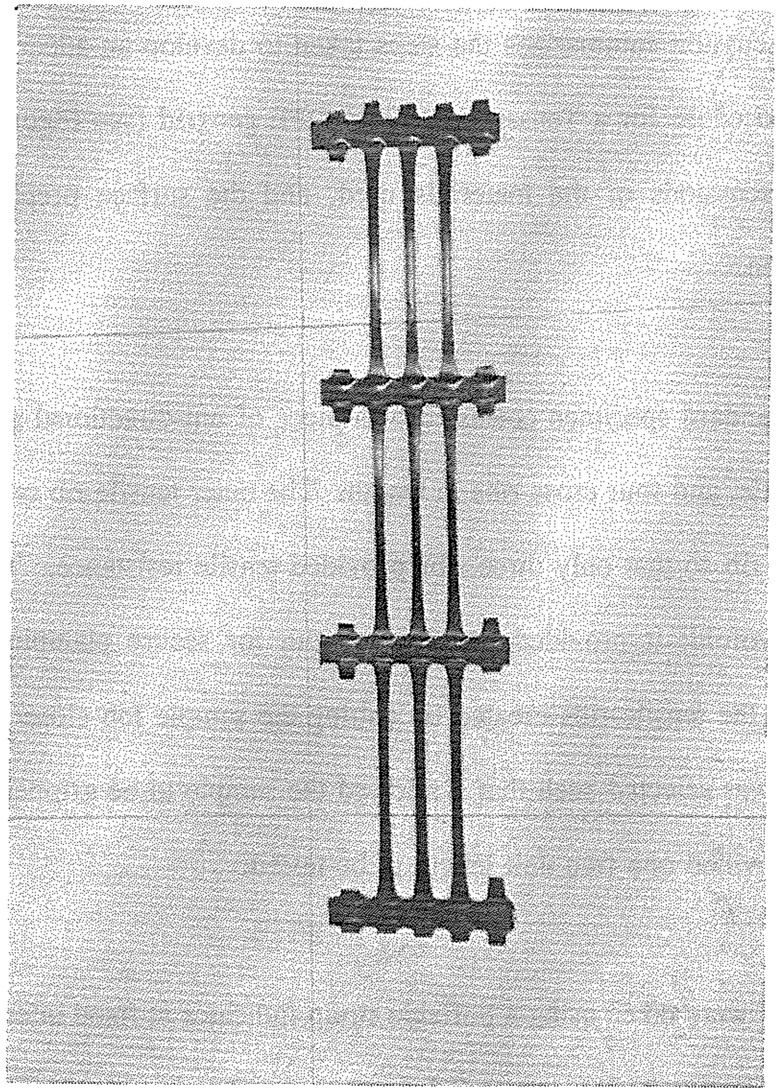


Figure 2. Tensar UX1500 HDPE Geogrid.

1.1 EFFECT OF CROSSHEAD STRAIN RATE ON ULTIMATE STRENGTH

Unconfined extension tests were performed on 18" long geogrid specimens at six different crosshead strain rates. Figure 3 illustrates the results of a typical extension test. At a crosshead strain rate of 1 percent per minute, there was no apparent effect on the ultimate geogrid strength as compared to the geogrid strength recorded at slightly higher or lower crosshead strain rates. At this rate, an extension test on an 18" sample failing at an average crosshead strain of about 30 percent took approximately 30 minutes to run, allowing for a reasonable number of experiments to be performed daily.

Based on the above observations the crosshead strain rate of 1 percent per minute was selected for all extension tests.

1.2 EFFECT OF ELEVATED TEMPERATURE

Twelve tests were performed on samples of HDPE geogrid exposed to high temperatures, since some strain gage adhesives require elevated temperatures to cure properly. The samples were exposed to different temperatures for periods of four and 24 hours by placing the samples in large drying ovens. Samples were allowed to cool overnight at room temperature prior to testing. At up to 165° Fahrenheit and 24 hours exposure, no apparent change in ultimate strength was found. The crosshead strain at failure increased only slightly (from 30 percent average at room temperature to 33 percent for elevated temperatures).

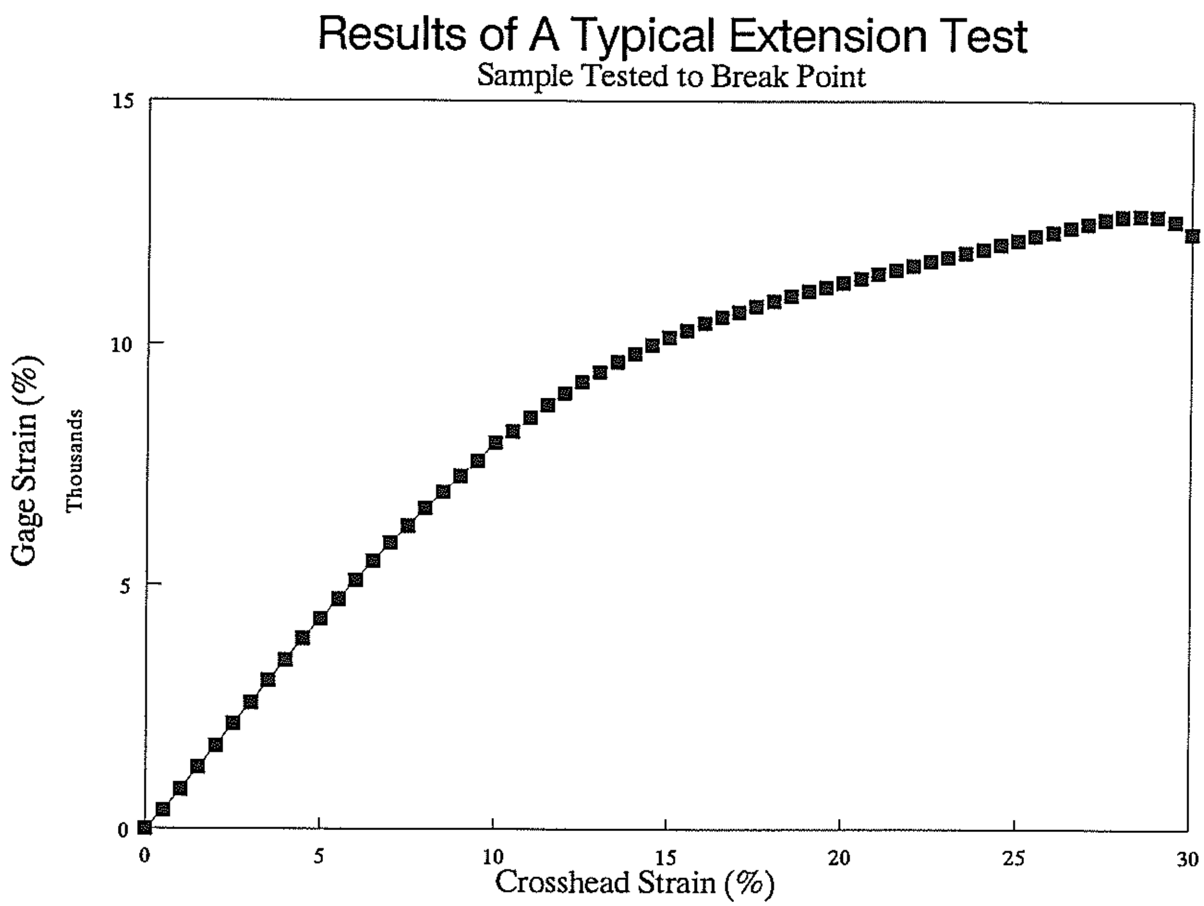


Figure 3. Result of a Typical Extension Test on Formed HDPE Geogrid.

1.3 SURFACE PREPARATION TECHNIQUE

Surface preparation required some abrasion of the HDPE geogrid to remove surface gloss and create a surface on which the adhesive would adequately stick. Prior to choosing a specific preparation technique, a sample of geogrid was heavily abraded with 220 grit sandpaper and tested for tensile strength. None of the preparation techniques which were later tried were as aggressive as this test. The sample's tensile strength was not significantly affected.

Regular rubbing alcohol was used for cleaning and degreasing on all specimens, and was applied to the preparation surface before and after each abrasion step.

Additional tensile tests were planned and run at various stages of the attachment procedure to ensure that no part of the developed procedure would adversely affect tensile strength.

1.4 GEOGRID-STRAIN GAGE ATTACHMENT

Previous efforts at attaching strain gages to geogrids at LTRC have used clothes pins or dead weights to hold the gage in place while the adhesive cured. For the purpose of this study, a new clamping and curing procedure was developed which applies more uniform pressure. A neoprene sponge was glued to aluminum blocks to evenly distribute the force of large spring clamps which held everything together while the adhesive cured. Because the adhesives cured more rapidly at elevated temperatures, the samples were placed in a large oven with clamps attached, at 125° Fahrenheit, for at least four hours. The neoprene sponge conforms to the strain gage, attached wires, etc. extremely well, so the pressure distribution from the clamp is very uniform.

In order to examine the effect of the type of adhesive, clamping technique, and curing procedure on the strength of the gage-geogrid bond, a number of controlled extension test series were performed. Test specimens were usually prepared in groups of six, holding some parameters constant while varying others to determine an effective preparation and attachment procedure.

In the first tests examining surface preparation, the new clamping procedure was tried using 350 ohm high elongation strain gages with attached leadwires, and Micro Measurements (MM's) AE-15, a general purpose adhesive. All samples were cured for five hours at 125° F.

Different surface preparation techniques were tried using various combinations of 000 steel wool, and 220 and 400 grit sandpaper. Gage versus crosshead strain results from these tests are shown in Figures 4 and 5. All tests exceeded 10 percent crosshead (average) strain, and test repeatability was exceptional. Plots of strain gage readings vs. crosshead strain appear almost linear through 10 percent crosshead strain. Repeatable and linear strain gage readings at 10 percent overall strain was considered acceptable for this study. Geogrid reinforced soil structures are seldom designed for more than 5 percent strain in the geogrid, and a structure with 10 percent strain in the geogrid would normally be considered to have failed.

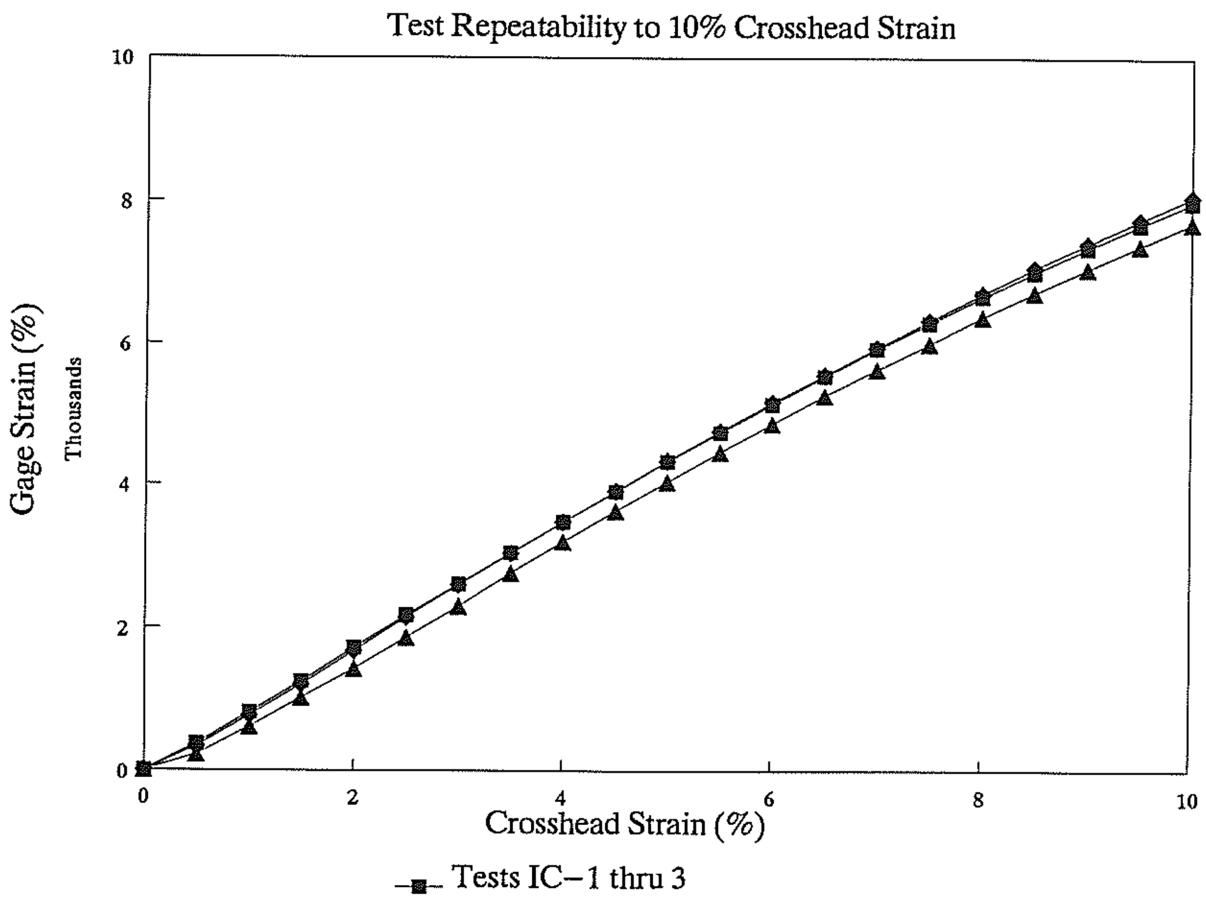


Figure 4. Typical Extension Test Results through 10 percent Crosshead Strain.

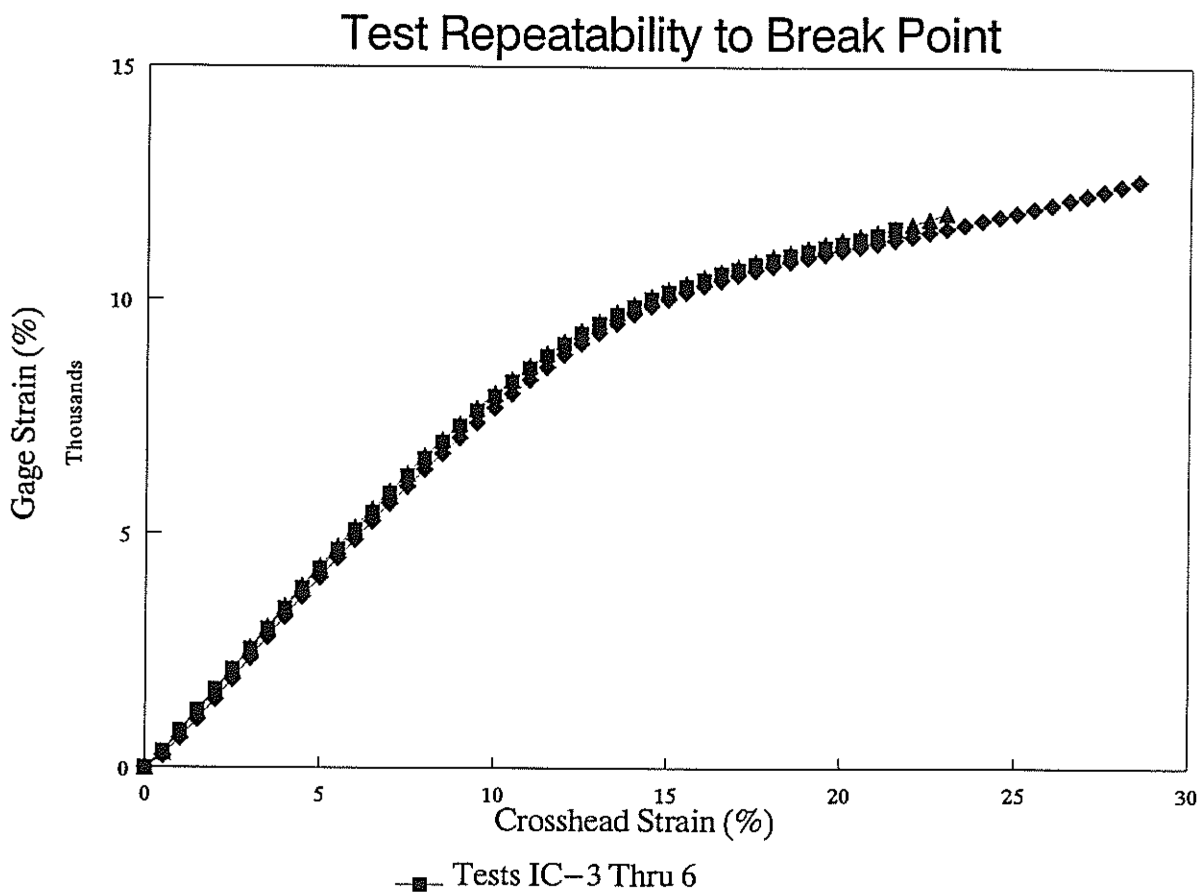


Figure 5. Typical Extension Test Results through Failure.

In the next group of tests, the constants and variables were changed. All surfaces were prepared using 000 steel wool, 220 grit sandpaper, and 400 grit sandpaper, in that order. MM's A-12 adhesive, a two part epoxy used for high strain conditions, was used for all tests, and MM's EP-08-250BG 120 ohm strain gages were used for the first time. The clamping procedure and oven curing used in the first tests was repeated. Two tests were run using the 350 ohm gages with attached leadwires. Two tests each were run using the 120 ohm strain gages with the leadwires attached prior to, and after gluing the gages to the geogrid.

The results of the gage versus crosshead strains are shown in Figure 6. All tests exceeded 10 percent crosshead strain. Again, test repeatability was very good, and readings were essentially linear through 10 percent crosshead strain. Both types of gages performed well. Literature available from MM states that "higher resistances...reduce elongation limit". For this reason, it was decided to use 120 ohm gages as the standard for all tests. Soldering the leads to the gage after gluing did not affect the strength of the geogrid (load versus crosshead strain readings were taken throughout all tests), and was considered to be a better technique. Laboratory personnel preferred working with the A-12 adhesive instead of the AE-15. The two part epoxy was less wasteful, and easier to control. The technique and materials used in these tests became the standard for all subsequent tests on HDPE geogrid.

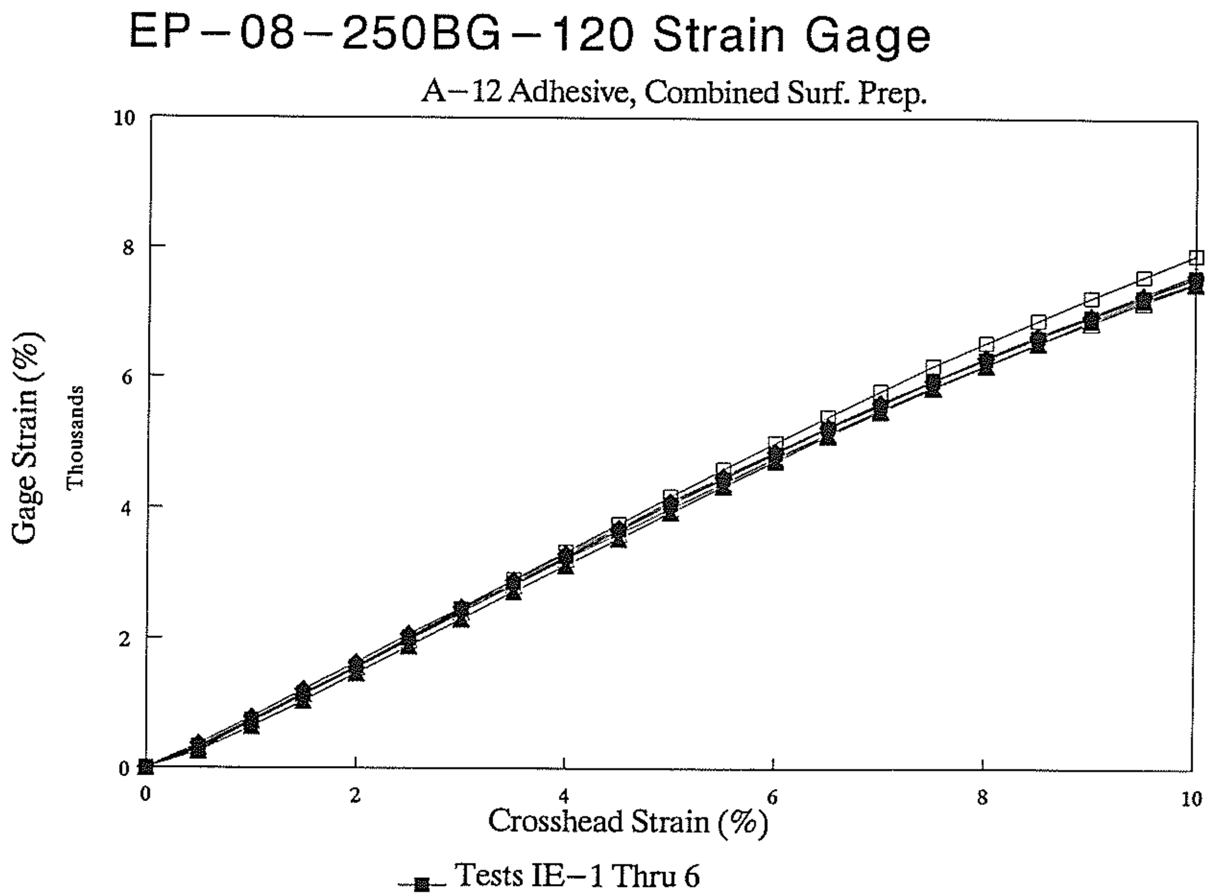


Figure 6. Test Results using A-12 Adhesive and 120 ohm Gages.

1.5 PROTECTIVE COATING

A number of specialized protective coatings were tried but found unsuited for the specific application at hand. Two types of silicone rubber caulks were then tried; one with an acetic acid base and the other with an ammonia base. The ammonia based caulk results in formation of extensive air voids around the area being protected. The acid based caulk, (GE 35 year Silicon Rubber General Household Sealant) is transparent and allows the glued gage to be observed after the caulk is placed around it and cured in the oven. In the first tests with coatings, three 120 ohm gages were coated with the GE 35 year silicone caulk, and another three with the ammonia based caulk. Two inch long pieces of TYGON clear plastic tubing were split and placed around the geogrid rib and strain gage to act as a mold and to contain the caulk. Premature gage failure resulted in two out of three specimens coated with the ammonia based caulk. In the following tests, 120 ohm gages and the 35 year caulk were used on all specimens. Out of 12 specimens tested, nine passed 10 percent crosshead strain, two had unstable gage reading prior to testing and therefore were not tested, and one gage failed prematurely at 4.2 percent crosshead strain.

The next step was to identify a protective coating for lead wires and gages prior to application of the silicone caulk. Two commercially available specialty coatings were tried but were found ineffective and difficult to work with. Looking for a simple, non-reactive coating, rubber cement was tried. Six coats of the material were placed on the gage and on the lead wires at time intervals of 30 to 60 minutes. The combined silicone caulk-rubber cement coated gages were placed in a 2 percent saline solution. The gage readings on all specimens were monitored periodically for two weeks after being placed in the solution. The combined coating system was found adequate.

1.6 CROSSHEAD-EXTENSOMETER CORRELATION

In order to check the validity of the strain measurements, it was necessary to verify the crosshead readings through an independent measurement of strains. An extensometer manufactured by the United Corporation was used in this correlation study. Figure 7 indicates the results of one of the correlation tests, indicating a good correlation between the crosshead strain and the strain measured by the extensometer. The specimens were prepared using identical attachment procedures.

1.7 FINAL CHECKS

A batch of 12 specimens was prepared using: 120 ohm gages, six coats of rubber cement, and 35 year silicone caulk on all specimens. Four specimens were tested to grid failure, four specimens were tested to 10 percent crosshead strain, unloaded at the same speed, and were tested to grid failure at a later date. The last four specimens were soaked in a 2 percent saline solution for four days before being tested to grid failure.

Figure 8 illustrates the results of six of the final unconfined extension tests. The repeatability of results among the 12 final tests was very satisfactory. The grid-strain gage attachment method developed for HDPE geogrid provided an adequate bond during the extension tests for strains well beyond the expected field range of less than 5 percent.

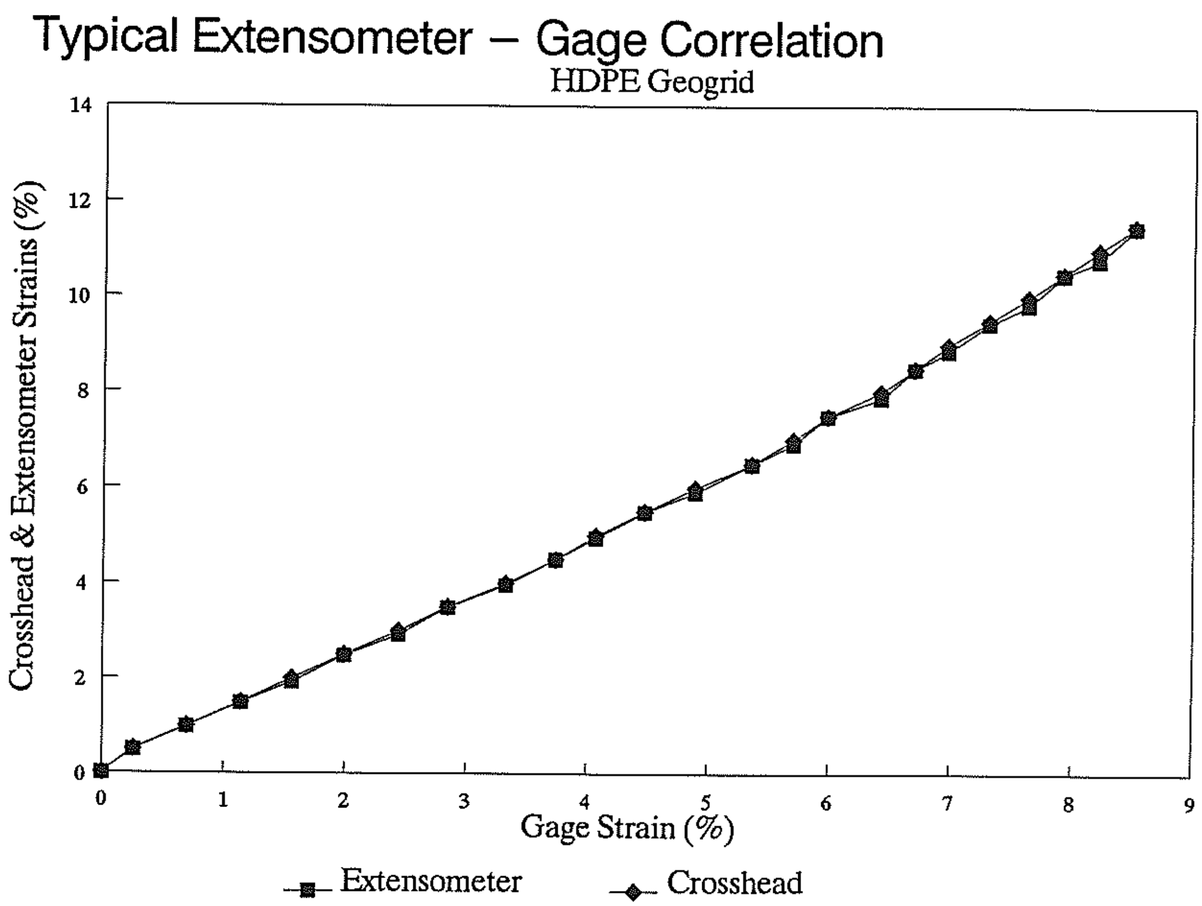


Figure 7. Results of Crosshead-Extensometer Correlation Test.

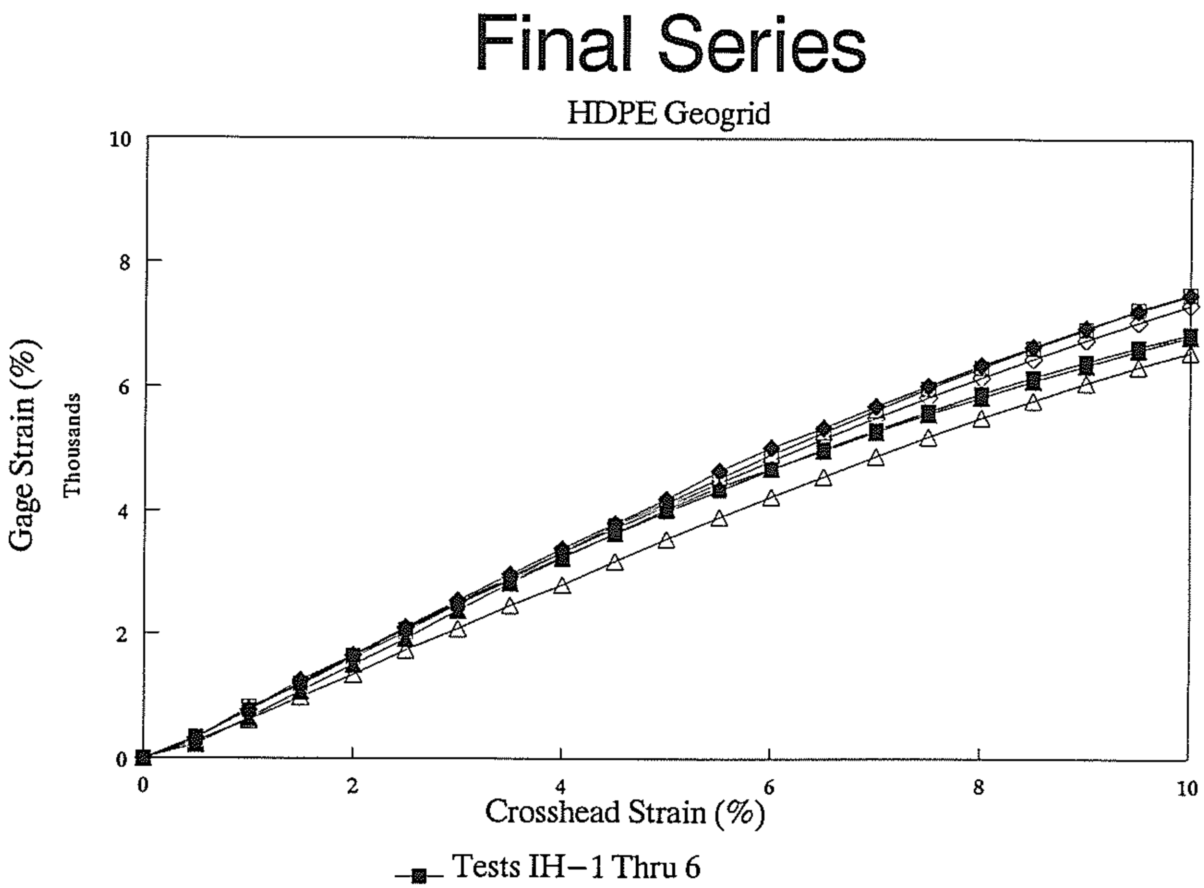


Figure 8. Final Check Testing on Formed HDPE Geogrid.

1.8 RECOMMENDED PREPARATION AND ATTACHMENT PROCEDURE

It should be obvious that the correlation between the strain gage reading and the overall strain on an HDPE geogrid will vary, depending on the geogrid selected and the products and materials used. These test results show that highly repeatable correlations can be established if the attachment and clamping procedure used is carefully established and repeated. Every combination of gages and materials used gave good results through 10 percent crosshead travel. The recommended attachment procedure in the appendix is only one possible solution, but appears to be the best combination of materials and procedures examined.

PART 2

ATTACHMENT PROCEDURES FOR A WOVEN GEOGRID

The second type of geogrid used in this project was STRATAGRID-600-MD (see Figure 9) manufactured by Conwed Plastics, Inc. STRATAGRID is made of polyester yarns knitted or woven into a uniform network of apertures. A PVC coating provides chemical and physical protection for the polyester yarns. The surface texture of the woven grid is much rougher than that of the HDPE grid. It is also considerably more flexible, and has a uniform cross sectional area. Although the two products have the same purpose, they are vèry different in appearance, manufacturing process, and materials used.

The steps followed to develop the attachment procedure for the woven geogrid were very similar to those followed with the HDPE geogrid. A summary of each stage is described in the following sections.

2.1 EFFECT OF CROSSHEAD STRAIN RATE ON ULTIMATE STRENGTH

Based on the results of the various crosshead strain rates examined with the HDPE geogrid, a crosshead strain rate of 1 percent per minute was also selected for the tests performed on the woven geogrid. Six three rib specimens were tested, with consistent ultimate strength results. A number of single rib specimens were also tested, with similar results. Specimens with lengths of 16" and 32" were tested yielding nearly identical strength per strand. These tests indicated that a 16" long, three rib specimen pulled at a rate of 1 percent per minute was satisfactory.

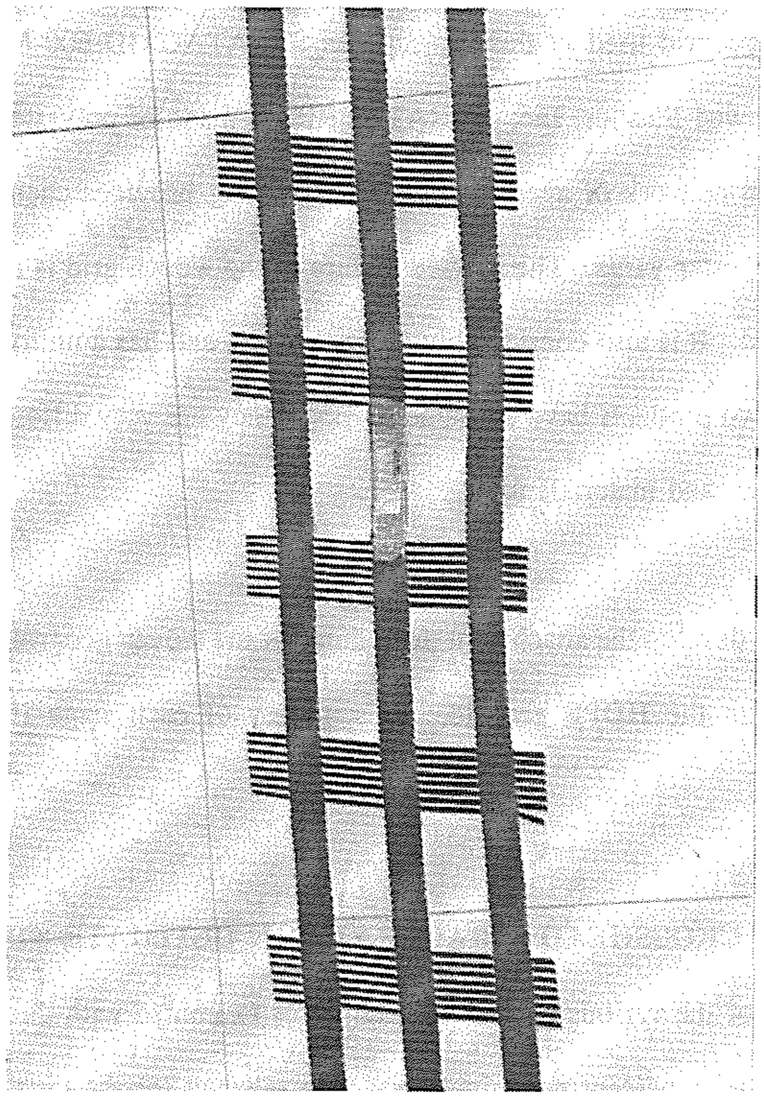


Figure 9. Conwed Stratagrid-600-MD Geogrid.

2.2 EFFECT OF ELEVATED TEMPERATURE

Heating up to 165° F for periods of four and 24 hours indicated no apparent effect on the ultimate strength of the woven geogrid specimens.

2.3 SURFACE PREPARATION TECHNIQUE

The surface texture of the woven geogrid is irregular and unlevel. In order to create an effective surface for attaching the strain gage, a thin layer of Micro Measurement's A-12 adhesive was placed on the grid carefully with a wooden spatula, covered with nonaggressive tape, and clamped using the same clamping procedure as on the HDPE geogrid. This allows the epoxy adhesive to impregnate the fibers of the woven geogrid, and create an adequate surface for preparation.

Test specimens were prepared using different combinations of 000 steel wool, #220 and #400 sand paper. During the extension tests performed at a later stage with gages attached, all specimens exceeded 10 percent crosshead strain. It was therefore determined that the same sequence used with the HDPE geogrid would be used for conformity.

2.4 ADHESIVE TYPE AND CURING METHOD

Micro Measurements' A-12 adhesive was found to provide an adequate bond between the grid and the strain gage. A curing period of four hours at 125° F was also found adequate. The same type of spring clamp and neoprene pads used for the HDPE geogrid specimens were utilized.

2.5 GAGE TYPE

Micro Measurement's EP-40-250BF-350 and EP-08-250BG-120 strain gage types were examined. The 350 ohm gages were tried first, but did well only up to about 7.5 percent crosshead strain. The 120 ohm gages used on all specimens in later testing consistently read beyond 10 percent cross-head strain, and in some cases read up to 18 percent.

2.6 PROTECTIVE COATING

An inexpensive rubber cement was tried as a coating on gages and exposed wires. Six applications of the coating material was placed on the gage and on the lead wires in time intervals of 30 minutes. The 35 year silicone caulk was then placed around the rubber cement coated gage and lead wires. During the extension tests which followed, all gages exceeded 5 percent crosshead strain, with most exceeding 10 percent.

2.7 EFFECT OF SUBMERGENCE

An initial group of four prepared and coated specimens were soaked in a 2 percent saline solution for two days. The gage readings on all specimens were monitored regularly during the period they were being soaked. The silicone covered only the side with the gage and leadwires. During the extension tests which followed, the gages on three out of the four specimens read only up to 8 percent crosshead strain. The last specimen was not tested due to unstable gage reading.

Since these results were unsatisfactory, an additional six specimens were prepared with silicone covering both sides of the grid. Two specimens were soaked for two days, another two for four days, and the last two for seven days, and all were monitored for change while soaked. Increasing strain readings were observed while specimens were soaking in the saline solution, prior to extension testing. The gages on all six specimens stopped reading between 7 to 10 percent crosshead strain when tested. This clearly indicated that the soaking process affects the ability of a gage to register higher strains. It should be pointed out that the gages on specimens which were not soaked were still reading at crosshead strains greater than 10 percent.

In order to address this issue, it was decided to try additional measures to waterproof the strain gage. The first measure was to coat the grid all around. A number of specimens were prepared with gages attached and silicone caulk covering all around them. The specimens were placed in a 2 percent saline solution for a period of two days. It was discovered that water still got to the gage and induced very high readings during the period of submergence.

The high strain readings (approximately 5 percent) after soaking suggested two possibilities. Either the saline solution was getting to the gages, or the woven grid was absorbing water and swelling. The latter possibility had not been considered until this time. To examine this possibility, two samples were soaked in water, one for five hours, and one for 40 hours. After five hours, the woven geogrid had absorbed 12.4 percent water by weight, and after 40 hours, it had absorbed 16.0 percent by weight. This confirmed that swelling of the geogrid was a potential problem that would have to be investigated further.

To ensure that the saline solution was not getting to the strain gage through the woven grid, an additional step in the strain gage attachment procedure was tried. A strip of aluminum foil, slightly larger than the gage, was glued to the prepared surface using MM's A-12 adhesive, and the same clamping and curing methods previously discussed. After extensive cleaning of the strip, the gage was glued directly to the strip, using standard procedure. After the protective coating was applied, these samples were soaked in a 2 percent saline solution. The strain readings increased to approximately 5 percent within three days, apparently showing that the grid was swelling. The readings were stable, however, which indicated that the saline was not getting to the gages.

The samples were oven dried to see if the grid would now "shrink". After drying, the gage readings did not change significantly. The samples were then re-soaked in 2 percent saline solution and checked periodically for two weeks. There was no apparent change, and the readings remained stable.

These results suggested that the gages were effectively coated, and that the woven geogrid acts like a compressed, dry sponge. When it is wetted, it expands, and then holds that expanded shape, whether wet or dry, unless it is recompressed. To verify this, a final set of woven geogrid specimens were soaked in water and then dried, prior to attaching the strain gages. When coated and soaked, the gage readings indicated values about 1/5 of those previously observed. In order to check the stability of the readings with time, the specimens were allowed to remain soaking in the lab for about one week. It was observed that during this time period the reading on the gages increased gradually to the same values as the previous series.

Based on these observations it was concluded that strain gage readings on the woven geogrid are affected by submergence, and that further study will be needed to investigate the feasibility of controlling the effect of submergence for this type of geogrid.

2.8 TEST RESULTS

The first tests performed on the woven geogrid specimens, not soaked in the saline solution, used 350 ohm gages. The tests resulted in gages failing at crosshead strains lower than 9 percent. 120 ohm gages were used in all subsequent tests. The unsoaked specimens tested with 120 ohm gages consistently read beyond 10 percent crosshead strain. In at least one test, the ultimate crosshead strain measured by the gage reached 22 percent. Figure 10 shows the results of a series of tests performed on the woven geogrid specimens using the 120 ohm gages. Test results were repeatable, and essentially linear through 10 percent crosshead strain.

The addition of a foil strip between the geogrid and the strain gage was sufficient, with the previously discussed coating procedure to effectively waterproof the gage. Unexpected difficulties were encountered with the woven geogrid due to swelling and transmission of fluid through the grid when soaked.

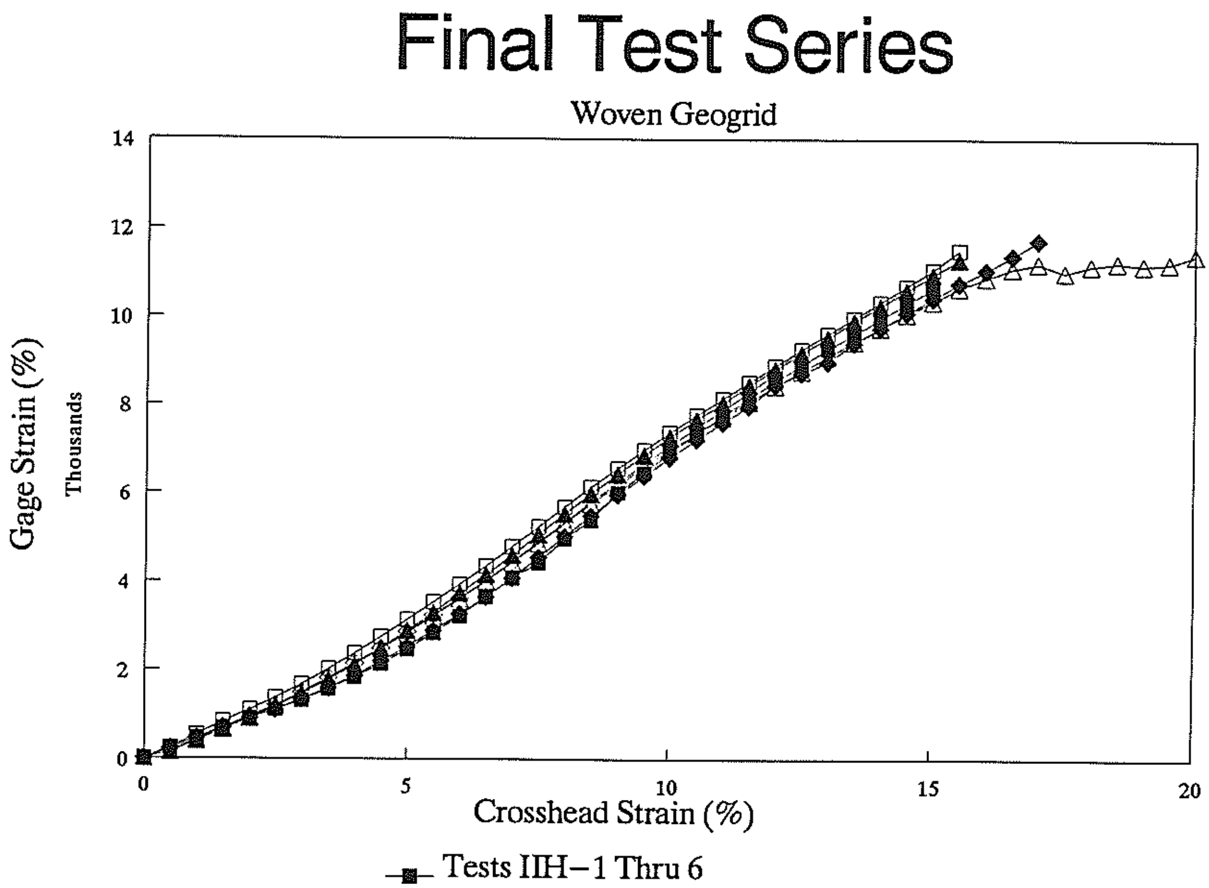


Figure 10. Repeatability of Test Results using Woven Geogrid.

PART 3

SUMMARY AND CONCLUSIONS

The present research program was aimed at determining a methodology to attach strain gages to geogrids to monitor large strains (up to 10 percent). Different surface preparation techniques, adhesives, clamping techniques, and strain gages were examined.

A. HDPE (TENSAR) GEOGRID

The HDPE geogrid used in all of the in-air extension tests was the Tensar UX1500 geogrid. The testing parameters for each of the series have previously been described in the text. The conclusions listed herein are chronological, and are not necessarily in the order of significance:

1. The surface preparation sequence of 000 steel wool, 220 and 400 grit sand paper, with alcohol cleansing at each step, provides an adequate bonding surface.
2. The combination of Micro-Measurements' EP-08-250BG-120 strain gage and A-12 adhesive yields the best results in terms of gage-grid bond.
3. The use of large spring clamps along with neoprene pads provides the uniform pressure necessary to develop adequate bondage.
4. Oven curing of the adhesive at 125° Fahrenheit for at least four hours seems adequate.
5. The strain measured by the gage will be a fixed and repeatable percentage of the overall strain, dependant on the geogrid configuration, strain gage location, and adhesive and coating materials selected.

6. Using the gage and adhesive type, surface preparation, clamping and curing techniques listed in items one through four, above, crosshead strains in the order of 25 to 30 percent were measured with excellent repeatability ($\pm$ 0.1 percent variation in crosshead strains at 10 percent), and near linearity through 10 percent overall strain.

B. WOVEN, PVC COATED POLYESTER (CONWED) GEOGRID

1. After creating a surface to work on, as described in section 2.3, the same surface preparation sequence used for the HDPE geogrid is also adequate for the woven geogrid.
2. The use of Micro-Measurements' EP-08-250BG-120 strain gage and A-12 adhesive provides adequate gage-grid bond.
3. The use of large spring clamps along with neoprene pads provides the uniform pressure necessary to develop adequate bondage.
4. Oven curing at 125° Fahrenheit for at least four hours is adequate.
5. The strain measured by the gage will be a fixed and repeatable percentage of the overall strain, dependant on the geogrid configuration, strain gage location, and adhesive and coating materials selected.
6. Using the gage and adhesive type, surface preparation, clamping and curing techniques listed in items one through four, above, crosshead strains in the order of 15 to 18 percent were measured with excellent repeatability ($\pm$ 0.1 percent variation in crosshead strains at 10 percent), and near linearity through 10 percent overall strain.
7. Problems because of the apparent swelling of the woven geogrid when saturated could not be overcome within the scope (unconfined testing) of this project. Further testing under confined conditions is suggested to attempt to eliminate this problem.

APPENDIX A

PREPARATION, ATTACHMENT AND COATING PROCEDURE FOR ATTACHING STRAIN GAGES TO POLYMER GEOGRIDS

APPENDIX A

PREPARATION, ATTACHMENT AND COATING PROCEDURE FOR ATTACHING STRAIN GAGES TO POLYMER GEOGRIDS

Materials:

1) Micro Measurement's (MM) EP-08-250BG-120 strain gages
2) MM's A-12 adhesive
3) non-aggressive cellophane tape, three strand wire, and standard tools for strain gage work
4) 000 steel wool, 220 and 400 grit wet/dry sandpaper
5) laboratory grade alcohol for cleaning
6) large spring clamps (clothes pin style)
7) 0.25 inch thick medium density closed cell neoprene sponge
8) 0.25 inch thick aluminum bar stock
9) oven with sufficient capacity for samples, capable of holding 125° Fahrenheit for four hours or longer
10) aluminum foil
11) rubber cement
12) TYGON tubing
13) GE 35 year silicon rubber General Household Sealant (or similar product)

Surface Preparation:

The surface preparation procedure developed uses commonly available materials. A clean, metal topped table was used as a firm surface for all preparation and gluing. Laboratory grade alcohol on gauze pads was used for cleaning the geogrid surface before and after each abrasive. For the woven geogrid, a thin layer of MM's A-12 adhesive was placed on the grid carefully with a wooden spatula, covered with non-aggressive tape, and clamped between aluminum backed neoprene sponges using a large spring clamp. The adhesive was then cured for at least four hours at 125° Fahrenheit. This allowed the epoxy adhesive to impregnate the fibers of the woven geogrid, creating an adequate surface for preparation. The surface was wiped until no residue or discoloration showed on the gauze pad each time. A cross-hatch pattern was used with each abrasive, 45 degrees clock-wise and counter clock-wise from the direction in which the grid was to be tested. 000 steel wool was the first abrasive used. The rib surface was scoured by pressing firmly, being careful not to damage or peel the edge of the tensile rib. The cross-hatch pattern was used to completely cover the surface seven times. This number of repetitions was sufficient to completely degloss the surface. After cleaning, 220 grit wet/dry sandpaper was used. The surface was abraded four times using the cross-hatch pattern. This produced a roughened surface without actually removing much geogrid material. After cleaning, the third and final abrasive, 400 grit wet/dry sandpaper was used. As with the 220 grit sandpaper, the surface was abraded four times using the cross-hatch pattern. The final cleaning with alcohol was very thorough. The prepared surface appears smooth, with a dull finish.

Attachment:

The techniques used to glue the strain gages to the geogrid are similar to those used for attaching strain gages to other surfaces. For the woven geogrid, a strip of aluminum foil, slightly larger than the strain gage, was glued to the geogrid surface first, using the same attachment steps as for the strain gage. Care was taken in handling the gages so that all surfaces stayed clean. Non-aggressive cellophane tape was used to hold the gage, and align it properly on the prepared surface. The tape was then pulled back from one end, lifting the aligned gage from the geogrid. A small amount of adhesive was then placed on the geogrid or foil strip, and the strain gage was placed back onto the prepared surface. Using a firm, smooth stroke, the tape is pressed down to spread the adhesive and remove any bubbles. Very detailed instructions for this type of gluing technique are available from strain gage manufacturers.

To apply uniform pressure while the adhesive sets, the clamping procedure described earlier was used immediately after the strain gages were glued to the geogrid. A 0.25 inch thick neoprene sponge glued to 0.25 inch thick aluminum was placed on the cellophane tape covering the strain gage. An unpadded piece of aluminum was placed on the back of the geogrid, sandwiching the gage and geogrid in between. Everything was then held together using a large spring clamp. It is important to center the clamp so that the pressure is evenly applied. After all the strain gages were glued and clamped in place, the samples were placed in a large oven, clamps attached, at 125° Fahrenheit, for at least four hours. After the samples were removed from the oven, they were allowed to cool overnight before the clamps were removed. The neoprene sponges and the cellophane tape should be removed carefully to avoid damaging the gages.

Protective Coating:

Six thin coats of rubber cement were applied to the entire strain gage surface, exposed leadwires, and soldered connections. Each coat was allowed to dry at least 10 minutes before another coat was applied. The silicon caulk, (GE 35 year Silicon Rubber General Household

Sealant), a transparent medium which allows the glued gage to be observed, was then applied. Two inch long pieces of TYGON tubing were split and placed around the geogrid rib and strain gage to act as a mold and to contain the caulk. The caulk will cure in about 24 hours at 125° Fahrenheit, or in three or four days at room temperature. After the caulk was cured, the TYGON tubing "mold" was removed. The sample is then ready for testing.

APPENDIX B

EQUIPMENT LIST

APPENDIX B

EQUIPMENT LIST

The following equipment was used in performing the laboratory extension tests for this report. Equivalent equipment from other sources could also have been used.

1. Loading Frame: United Testing Systems, Inc., Model FM-30 with an extended frame, 30 K axial load capacity (Figure B1)
2. Digital Strain Indicator: Measurements Group, Model P-3500, portable, one channel (Figure B2)
3. Clamps: Curtis "Sure-Grip" Inc., "Geo-Grips", specially designed for testing geosynthetic materials (Figure B3)
4. Breakaway Type Extensometer: United Testing Systems, Inc., Model EHE 1-2
5. Interface Board: Analog Devices, Model 5B01, 16 Channel
6. Strain Gauge Conditioning Module: Analog Devices, Model 5B38
7. Personal Computer: IBM Model PS/2 30-286
8. Data Acquisition Board: Data Translation Model 2801-A, A/D

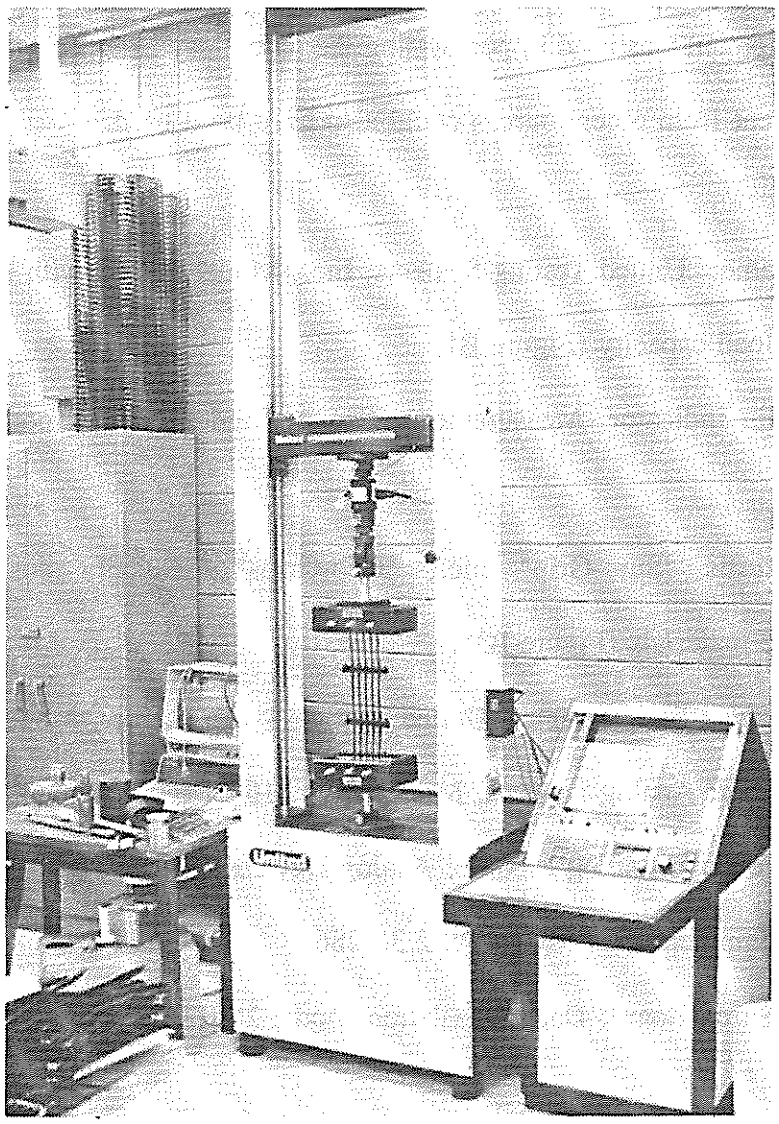


Figure B1. United Testing Systems Inc., Model FM-30 Load Frame.

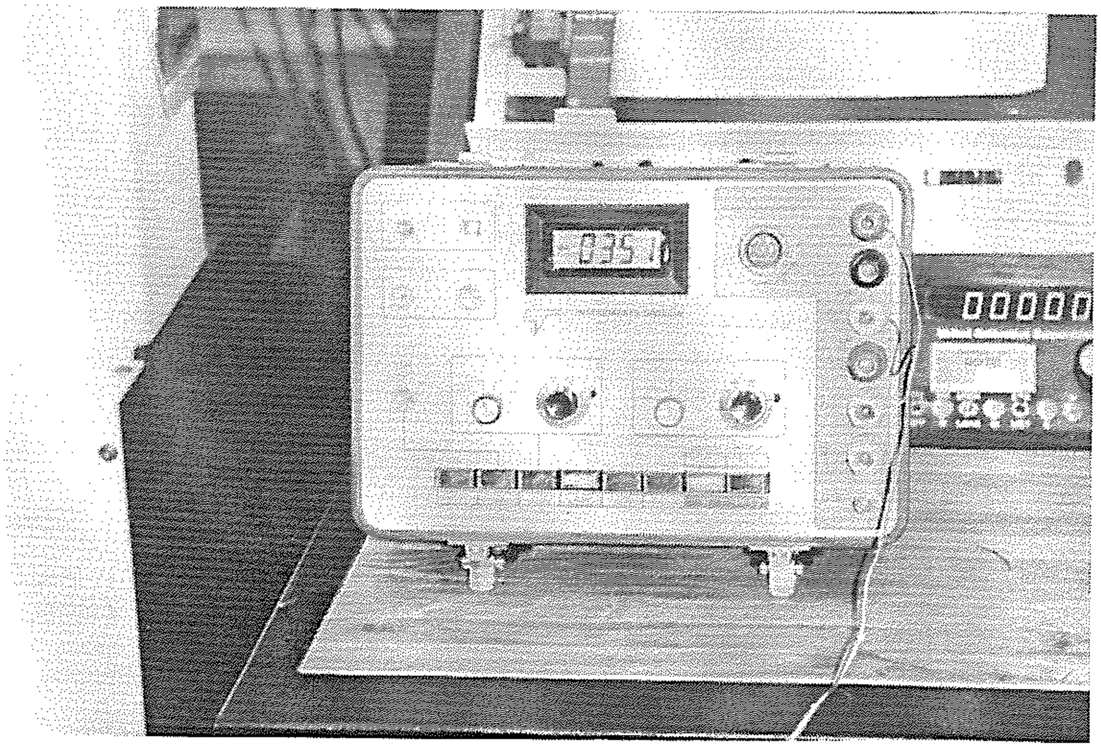


Figure B2. Measurements Group, Model P-3500 Digital Strain Indicator.

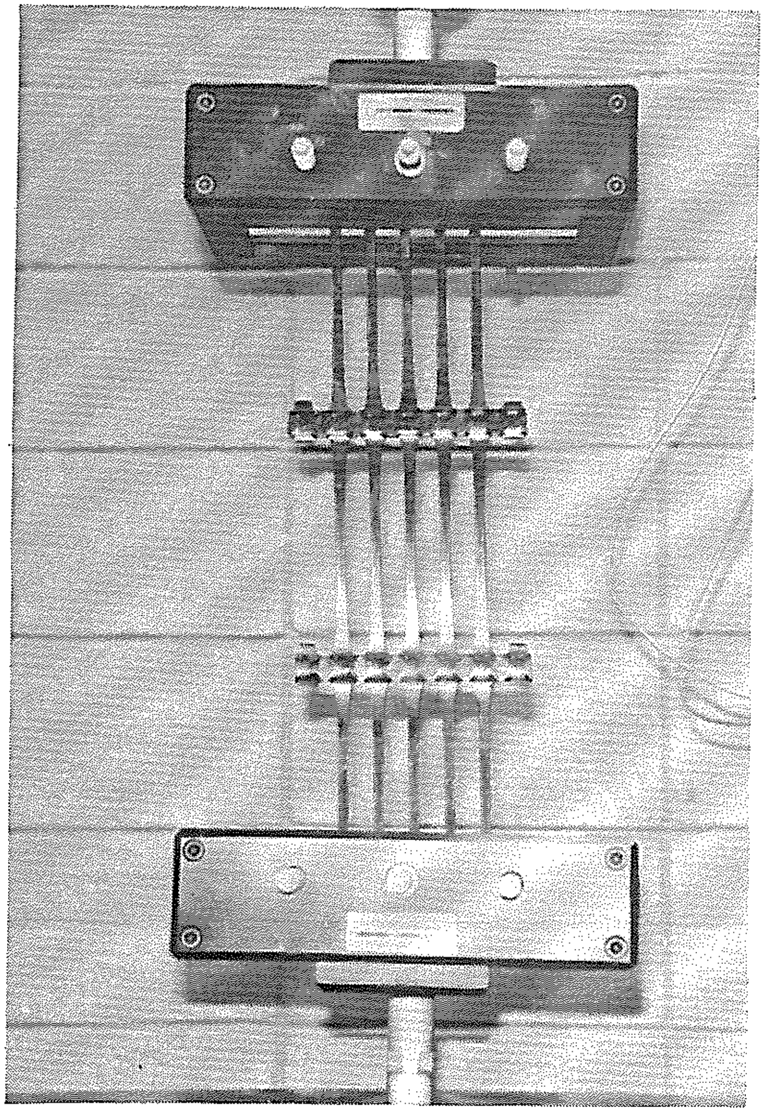


Figure B3. Curtis "Sure Grip" Inc., "Geo-Grips".

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