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GEOTEXTILES IN LANDFILLS

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16. Abstract

This experimental study was initiated to evaluate the performances of 4 different geotextiles used as reinforcement underneath a 30 foot high embankment. The foundation material consisted of 40 foot deep fly ash which was deposited over an 8 year period.

A comprehensive instrumentation program was designed for this study, and the performance of the embankment, foundation material, and the geotextiles were monitored for 9 consecutive months. The results indicated that all selected geotextiles performed well, and each of them could have been selected with high safety factor. It was also concluded that each project should be individually analyzed and investigated before a geotextile is selected to meet the needs of a particular project.

Implementation

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I. INTRODUCTION

A. Background

The development of the geotextile industry, in the past two decades, has been astronomical, interesting, and to a degree, confusing. There are hundreds of qualified manufacturers in this business, and each one is producing and marketing its own line of geotextile products. The advantage is that these manufacturers are under constant pressure to update their products and literature in order to keep up with this ever-changing industry. The disadvantage is that there is a massive amount of misunderstanding among the users of geotextiles due to lack of a uniform set of guidelines on the application of various geotextiles. Therefore, the engineers in the field are generally on their own, and they make decisions based on their own judgments and experiences.

The staff of the Colorado Department of Highways has utilized geotextiles to solve various engineering problems related to highway construction. After many years of dealing with geotextiles, a unique opportunity was provided to examine the performances of four different geotextiles on a single project. Therefore, this research project was developed to evaluate the performances of these materials in a one-year period, and make recommendations based on the findings of this study.

B. Research Study

This project consisted of a 30 foot high embankment on top of a sanitary landfill filled with fly ash with 2 feet of expected settlement after construction of the embankment. Therefore, it was decided to use geotextiles to reduce the possible differential settlements and to increase the factor of safety against shear failure.

To make an appropriate geotextile selection, an experimental research study was initiated to evaluate the performances of the following geotextiles under the same field conditions:

1. Typar 3601, a non-woven geofabric
2. Supac 4WS, a woven geofabric
3. Tensar SS2, high strength geogrid
4. Mirafi 5T, high strength geogrid.

The research study consisted of building a test embankment 30 feet high, 120 feet wide, and 400 feet long on top of four test sections, as shown in Figure 1. A comprehensive instrumentation program was planned and used to determine the actual field performances of geotextiles and the foundation material after construction of the test embankment. The monitoring program continued for about one year. The embankment was then removed and geotextile samples were recovered to examine their integrity after completion of the foundation's primary settlements.

II. SITE INVESTIGATION

A. Site Location

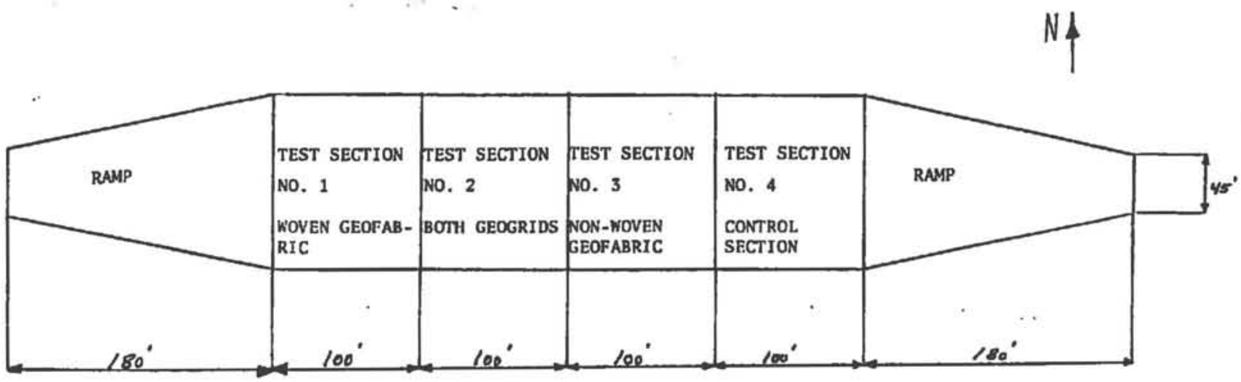

Figure 1a. Top View Of The Test Embankment

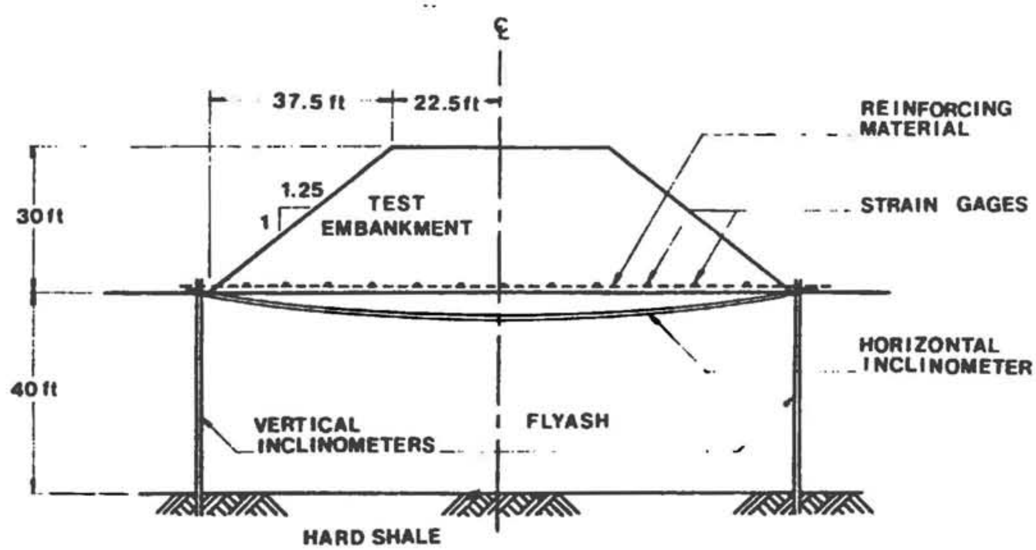

Figure 1b. Cross Section Of The Test Embankment

Figure 1. Top View And The Cross Sectional View Of The Test Embankment

The test embankment was designed to be built along the future path of the I-76 (105) embankment between stations 295+00 and 299+00, as shown in Figure 2. The embankment was constructed as planned, and it was removed in its entirety after completion of the primary settlements. This was done in an effort to recover samples of geotextiles to determine their durabilities at the completion of the primary settlements.

B. Geology and Subsurface Conditions

The location of the test embankment was carefully selected, such that it would be built on top of a landfill filled with uniform fly ash. The excavated pit originally contained approximately 40 feet of Clear Creek River alluvium. The alluvium was mined out and sold as aggregate for local Denver construction projects. The empty pit was then lined with clay and converted into a fly ash disposal site. Placement of the fly ash began in the early 1980's and has continued to date. The source of the fly ash is the Public Service Company's Cherokee coal-fired generating plant located in north Denver.

The fly ash was apparently end dumped either moist or as a slurry mix from large-haul trucks. The methods of placement consisted of dumping the fly ash directly down a pit slope or by dumping it on the ground and shoving it into the excavation with a bulldozer. The fly ash was backfilled to the design elevation, and covered with approximately 2 feet of top soil.

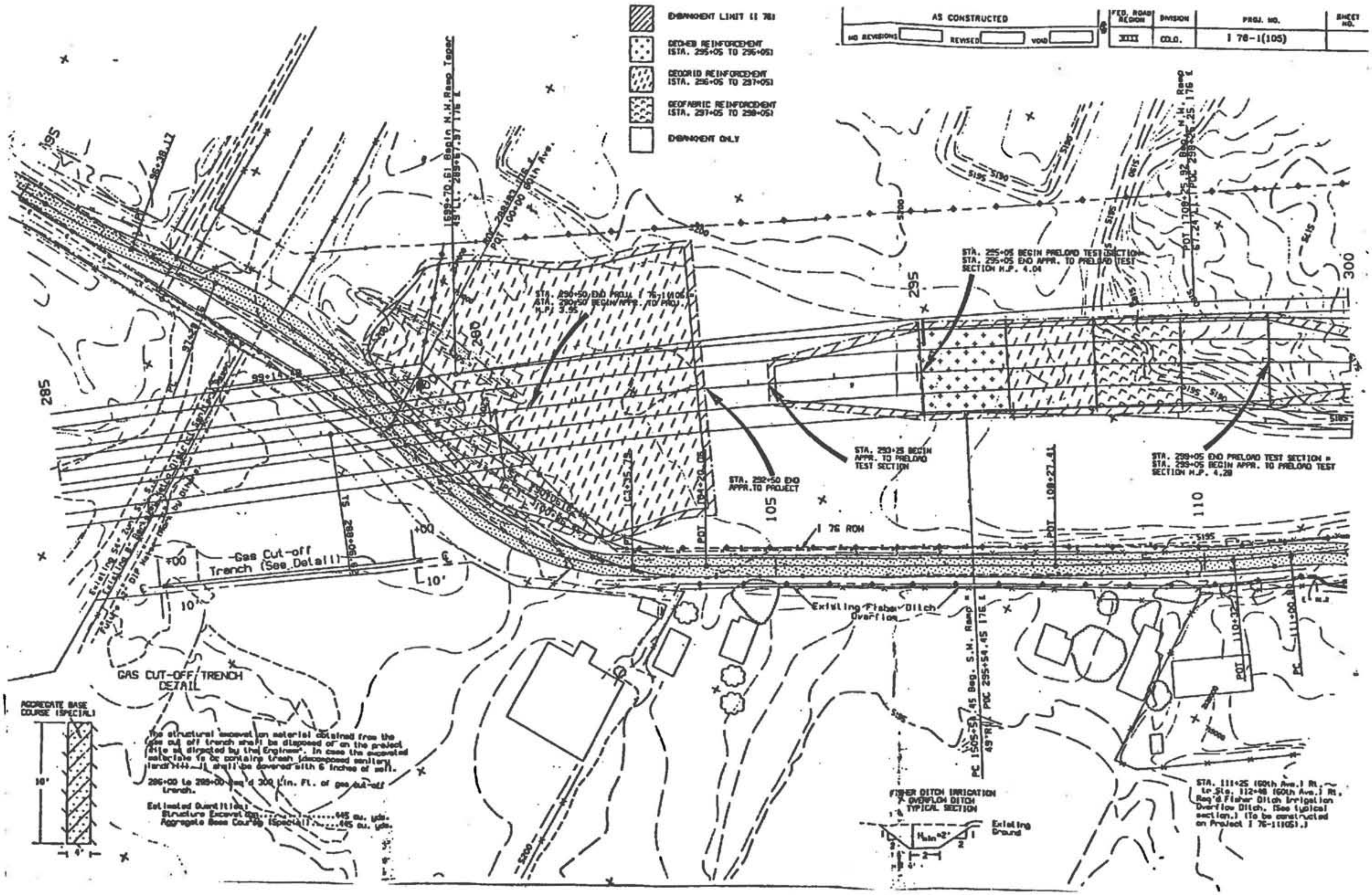

Figure 2. Location Of The Test Embankment Along The I76-1(105) Project

Classification of the fly ash ranged from AASHTO A-4 to A-5, with a zero elasticity index. Figure 3 shows the typical subsurface profile. The top 3-5 feet of fly ash was much denser compared with the lower deposits. The hardened condition was thought to be the result of densifiction as well as compaction from the haul trucks. The lower fly ash deposits were very loose with standard penetration test (SPT) blow counts ranging from 0 to 3 throughout the area. Laboratory consolidation tests indicated a settlement potential of 18 to 20 inches. Hard shale bedrock was encountered at approximate depth of 40 feet.

III. TESTING PROGRAM AND FIELD WORK

A. Selection of the Geosynthetic Reinforcement Materials

The geosynthetic[1] materials were selected such that they would be reasonable representatives of most of the applicable geotextiles in the market. The selected materials included Typar 3601, a nonwoven heat-bonded geofabric; Supac 4WS, a woven geofabric; Tensar SS2, a polymer heat-strengthened bi-axial geogrid; and Mirafi 5T, a fibrous spun-bond bi-axial geogrid. These materials are shown in Figure 4, and their pertinent physical properties are listed in Table 1.

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1. Geosynthetic is a general term which is used in the industry to represent all types of geotextiles and geofabrics. When the term geofabric is used, it applies only to those materials which have fabric appearance and they are either woven or non-woven. The term geotextile is a more general term, and it applies to all geofabrics and geogrids.

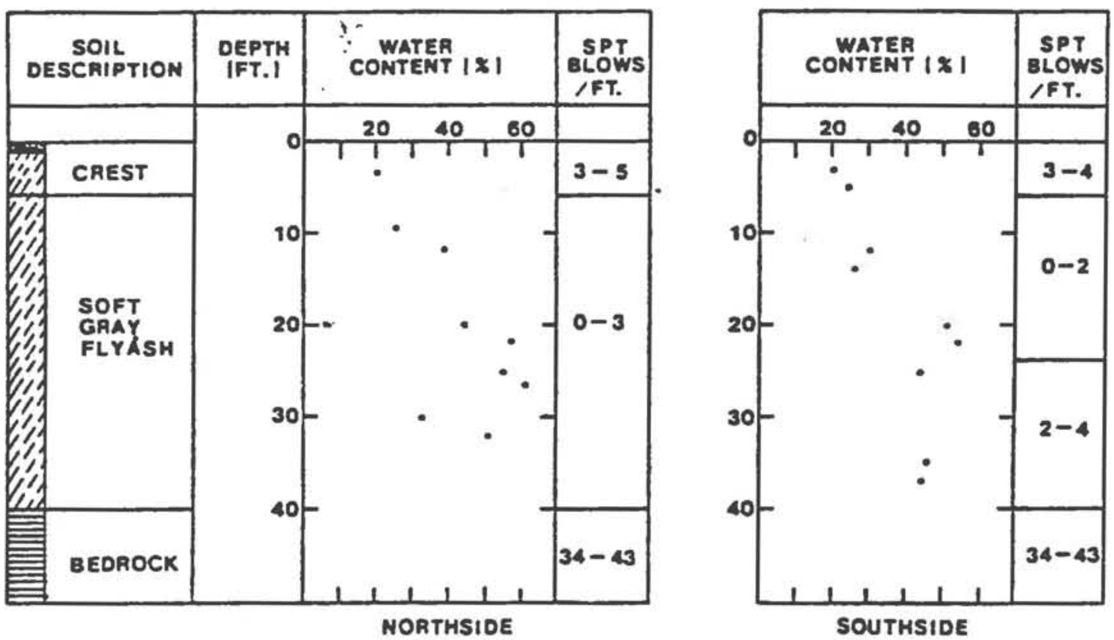


Figure 3. Typical Subsurface Profiles

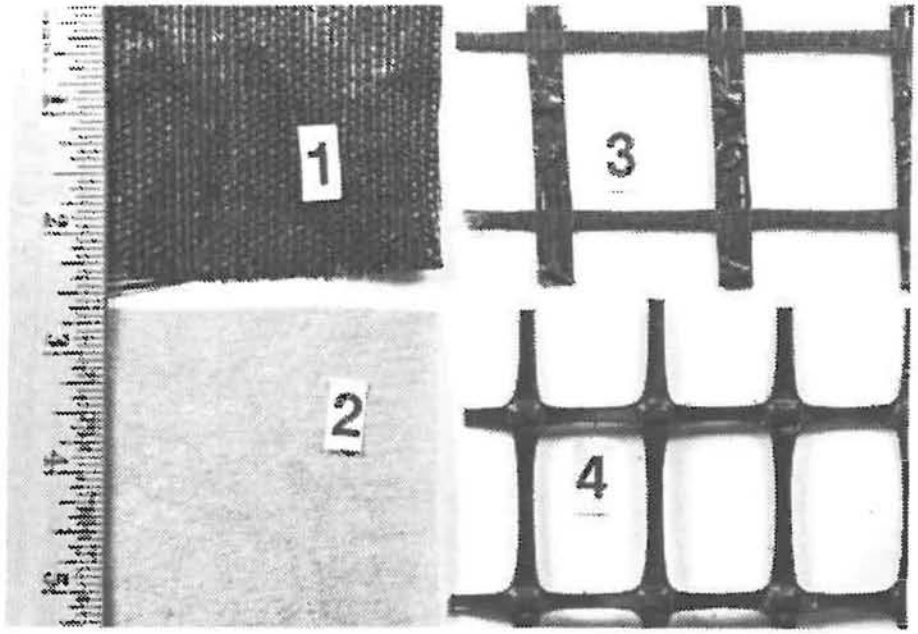


Figure 4. Selected Geosynthetics.

Material Type	MIRAFI-5T	TENSAR-SS2	TYPAR-3601	SUPAC-4WS
Structure	Geogrid	Geogrid	Non-Woven	Woven
Grab Strength (lb/in) (ASTM D-1682)	242 (43 kn/m)	98 (17 kn/m)	239 (42 kn/m)	85 (15 kn/m)
Grab Elongation (%, ASTM D-1682)	21	12	120	22

Table 1. Physical Properties Of The Selected Geosynthetics.

B. Test Embankment Description and Specifications:

The geometric configuration of the embankment with its four test sections is shown in Figure 1. Each test section was approximately 100 feet long and 120 feet wide. The test embankment side slopes were designed to be 1 to 1, but after the construction, the slopes eventually slouoghed to 1.25 to 1. The embankment height across all four test cells was constructed to a design height of 30 feet and was approximately 45 feet wide across its top. The test embankment width along its base was approximately 120 feet from toe to toe. Access ramps with 6 to 1 slopes were constructed on each end of the test embankment so that heavy construction equipment could access the top of the embankment. The embankment was constructed in 10 days and consisted of decomposed clay-shale material, uncompacted, with no moisture control. The test embankment was monitored for about nine months, and it was removed in July of 1988 so that the main I-76 production embankment could be constructed.

C. Instrumentation Program:

Prior to the embankment construction, the monitoring instruments were installed in each test section. The first instruments to be placed were the vertical inclinometers. Eight vertical inclinometers were used to monitor the lateral movement of the soil below the embankment slopes. Each test section contained two vertical inclinometers which were placed opposite to one another along the approximate center of each test section and close to the embankment toe. The vertical inclinometers were anchored in shale bedrock and grouted in place with a Bentonite/cement grout. Initial data readings were then obtained following hardening of the grout.

The next step was to install four horizontal inclinometers in the designated test sections. Each Test section contained one horizontal inclinometer to measure the settlement within that test section. Each horizontal inclinometer was located in its own trench excavated across the approximate center of each test section. Figure 5 shows the location of the vertical and horizontal inclinometers for all the designated test sections.

One of the primary objectives of this study was to determine the behavior of the geotextiles under the actual field conditions. To accomplish this task, strain gages were selected to be glued to the geotextile to measure the induced strains due to the application of the embankment load. A literature review was conducted, and it was found that only a handfull of researchers had considered or used strain gages to determine the stress-strain behavior of geotextiles. Therefore, extra care was devoted to the selection of the strain gages in order to minimize the potential problems associated with strain gages in conjunction with geotextiles. Finally two different kinds of gages were selected and purchased from Micro-Measurement Company. Strain gage specifications and details are presented in Appendix A. The selected gages for the geogrids had to be smaller than the ones selected for geofabric in order to appropriately glue them on the geogrid ribs. All

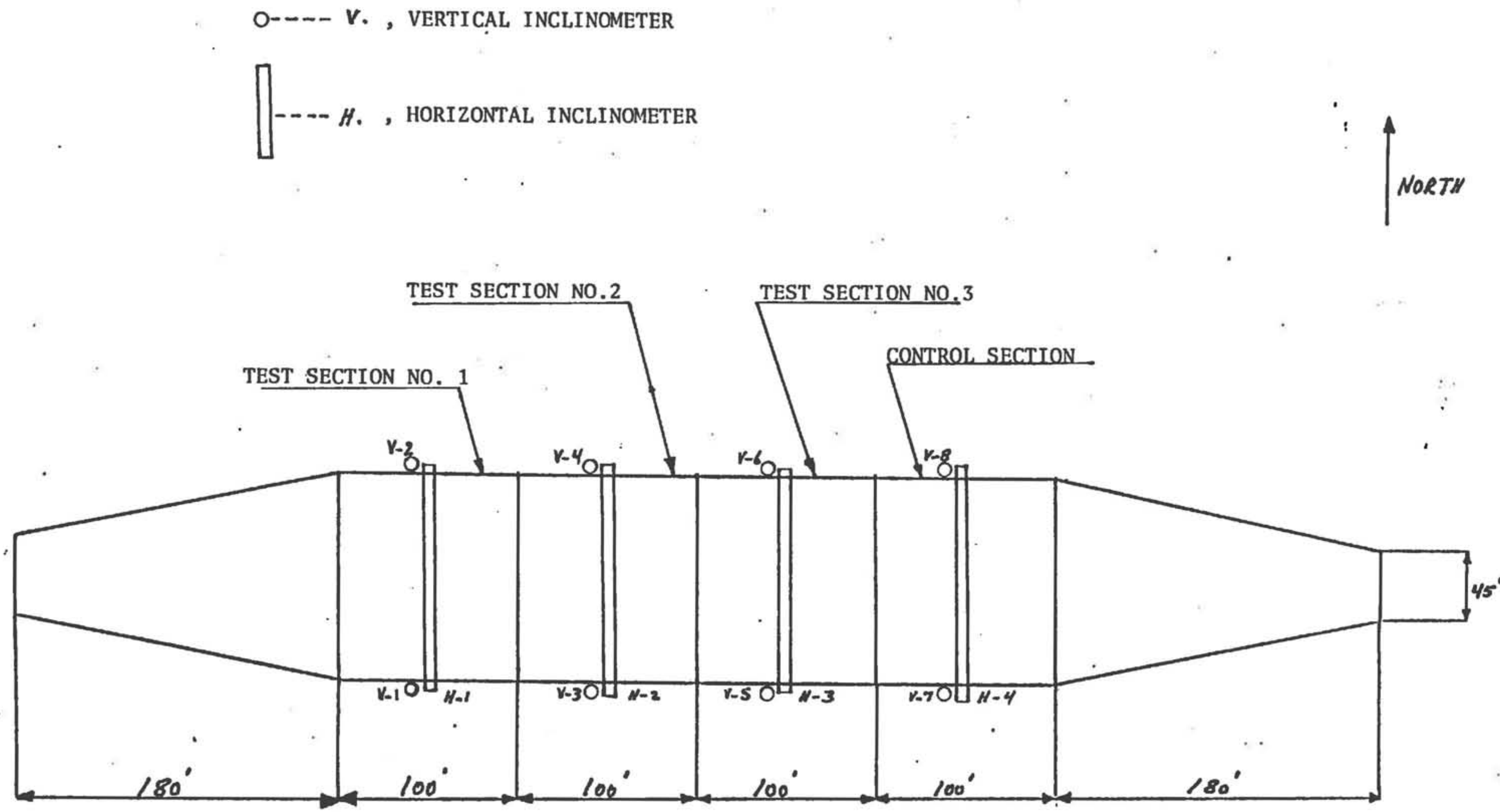


Figure 5. Distribution of The Vertical and Horizontal Inclinometers Within the Test Embankment

gages were glued on the geotextiles, and they were tested and calibrated in the CDOH Central Laboratory. Figures 6 and 7 show two different types of strain gages glued on a geogrid and a geofabric.

Four strain gage readout stations were installed with a pair of readout boxes opposite to one another situated in a similar manner as the vertical inclinometer. A total of 41 strain gages were installed on the non-woven geofabric (Typar, 3601) and both geogrids for measuring the strain of the reinforcing materials. Strain gages could not be glued on the woven geofabric (Supac, 4WS). Therefore, its stress-strain behavior was not detected after construction of the test embankment. Figures 8 through 10 show the installed vertical and horizontal inclinometers, as well as a strain gage read-out box. Table 2 shows the distribution of the instruments in each test section.

Following installation of all the monitoring instruments, two of the test sites were cleaned by removing most of the surface debris. Six inches of ABC (aggregate base coarse) material was then placed on these two test sections prior to placement of the geotextiles. The purpose of the cushion layer was to smooth out and level the ground surface so that the fabrics and geogrids could be easily installed. In addition, the interlocking force and friction between geogrid and surrounding soils can be increased because of the cohesionless cushion material. The test sections containing the woven fabric were not cleaned nor was a cushion layer installed so that the puncture resistance of the fabric could be assessed.

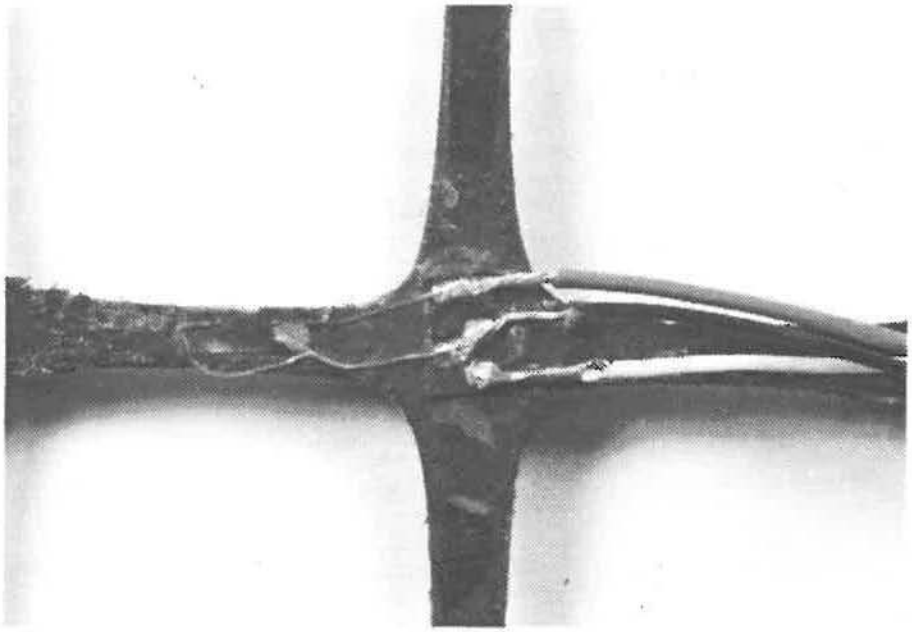


Figure 6. A Small Strain Gauge glued on Tensar SS-2 geogrid

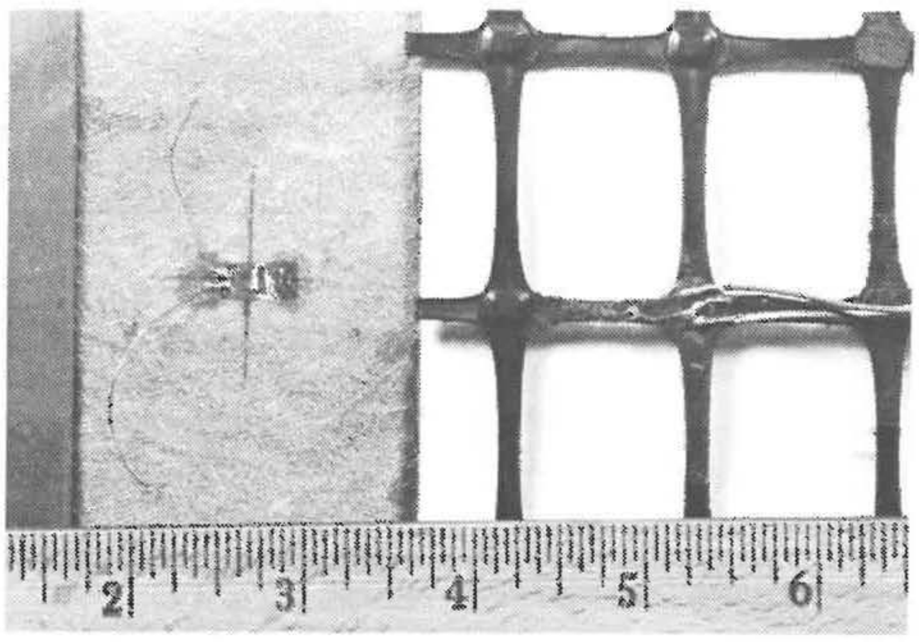


Figure 7. Comparison of Strain gauge sizes glued on Typar 3601(geofabric), and Tensar SS-2(geogrid)

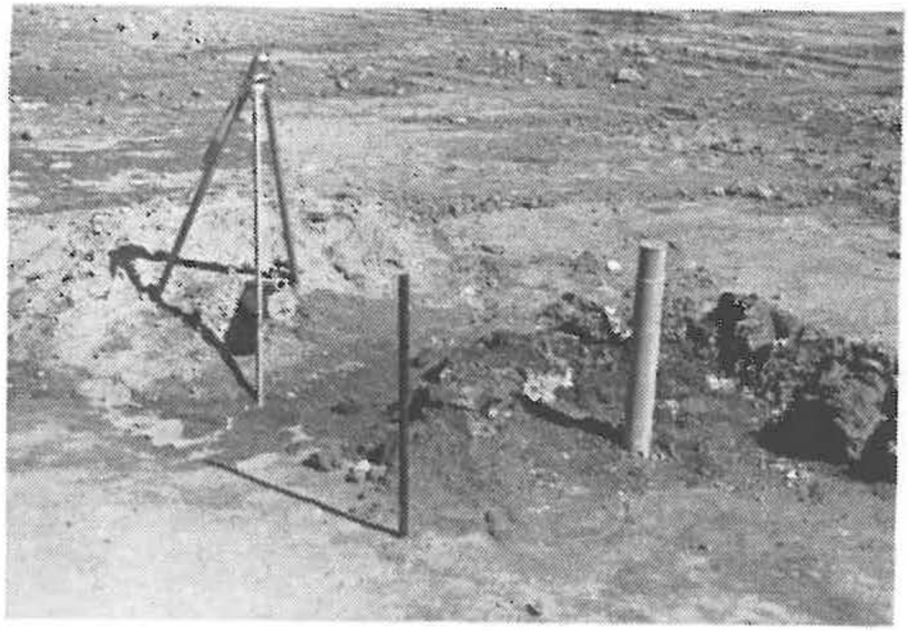


Figure 8. A Vertical and A Horizontal Inclinometers
In Place

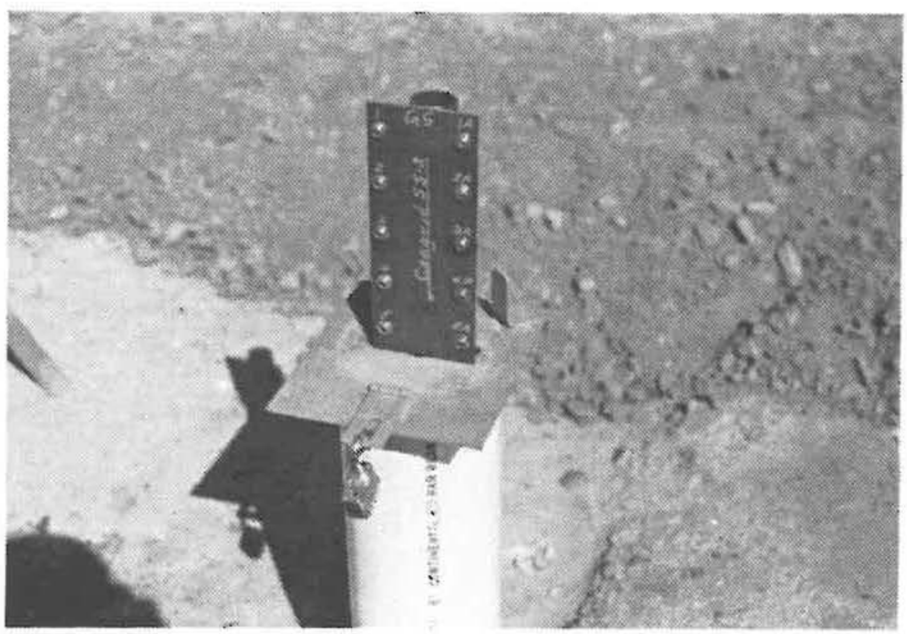


Figure 9. A Strain Gaüge Read-out Box

Figure 10. A Typical Read-Out Station For Both Vertical/Horizontal Inclinometers And The Strain Gages.

Reinforcement Materials	TYPAR-3601	GEOGRID-SS2	MIRAFI-5T	SUPAC-4WS	CONTROL SECTION
Horizontal Inclinometers	1	1	1	1	1
Vertical Inclinometers	2	1	1	2	2
Strain Gages	21	10	10	-	-

Table 2. Distribution Of Instruments Within The I-76 Test Embankment.

D. Installation of the Geosynthetic Material

The Typar 3601, installed in test section No. 3, arrived at the site in rolls of 150 feet long by 13 feet wide. One roll of fabric was delivered to CDOH Materials Laboratory so that strain gages could be attached to the material in a clean controlled environment. This roll was to be located in the center of the test section directly above the horizontal inclinometer. Therefore, the instrumented roll was first installed, and it was located in such a way that strain gages on the fabric were offset from the surrounding disturbed material. The remaining fabric rolls were then laid out normal to the test embankment control line and sewed together using a double overlapped "J" seam. Figures 11 to 14 show the actual placement of the Typar 3601.

Two types of geogrids were supplied by different manufacturers, and they were installed in test section No. 2. The north half of this test section contained Tensar SS-2 geogrid and the south half was covered with Mirafi 5T geogrid. Ten strain gages were installed on each geogrid prior to their delivery to the field. Both geogrids were oriented with their roll length running normal to the center line of the test embankment. The geogrids were overlapped by 1 foot and were physically connected to one another by various means of attachments such as metal hog rings, steel tie rods, and plastic tie bands. Several geogrid rolls were not physically attached, but simply overlapped. geogrid installation is shown in Figures 15 through 21.

The last geotextile material installed was Supac 4WS. This woven

Figure 11. Attachments of strain gauge wires to the strain gauges on top of Typar 3601(geofabric)

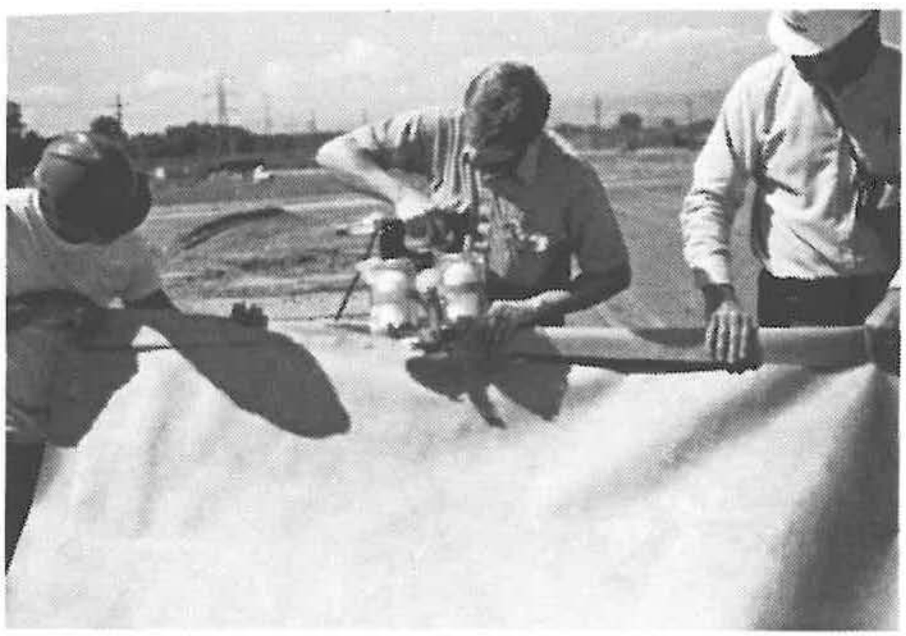


Figure 12. Geofabric rolls were sewed together using a double overlapped J seam

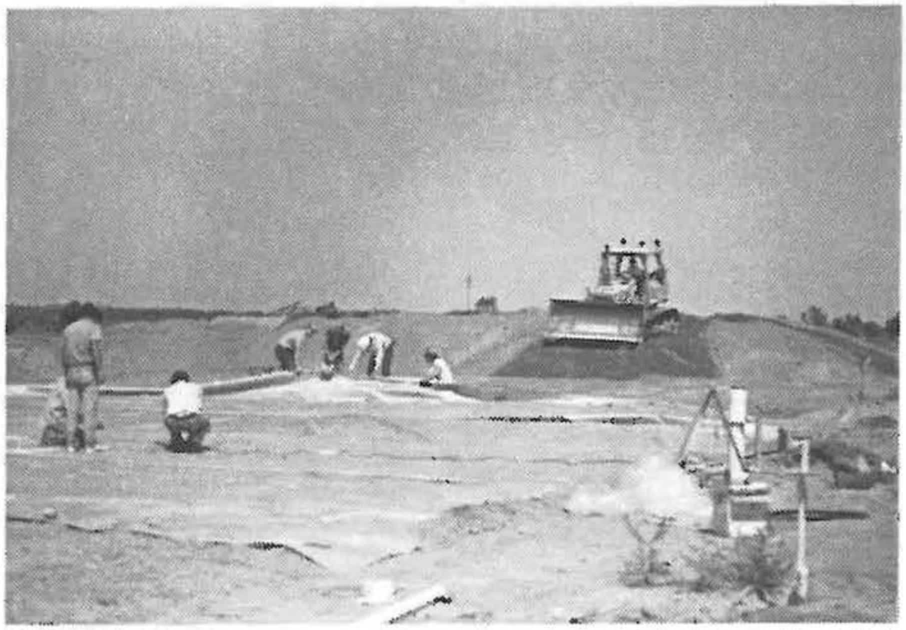


Figure 13. Manual Labor Was Used to Stretch the Fabric Rolls As Much As Possible

Figure 14. Extra Caution Was Excersized to Avoid The Direct Contact of Heavy Equipment and the Geofabrics

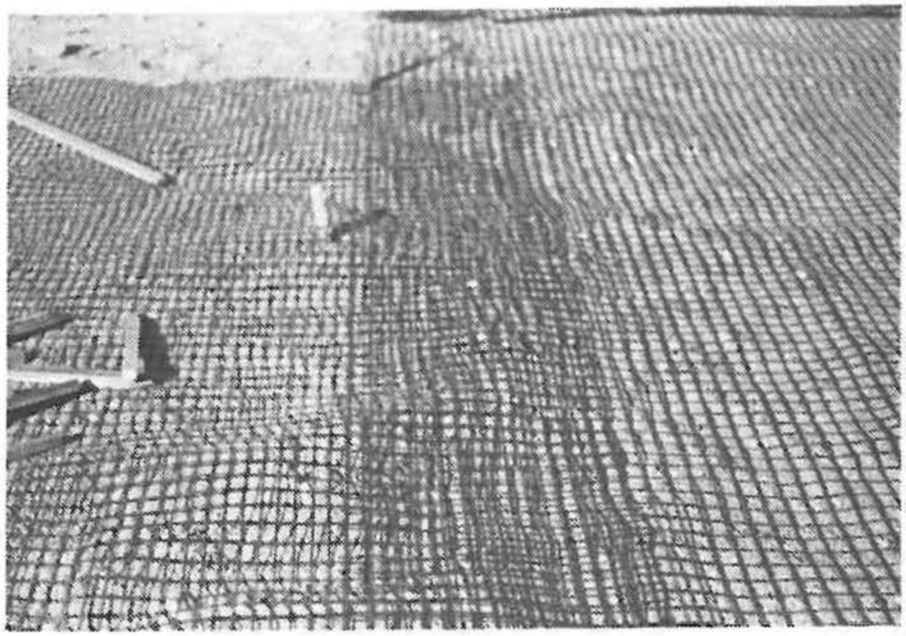


Figure 15. Most Geogrid Rolls Were Placed Directly on the Ground And Held In Place By Wooden Stakes. They were Then Overlapped By one Foot.

Figure 16. Metal Hog Ring Were Used to Connect Layers of Geogrid

Figure 17. Steel rods were used to connect layers of Tensar SS-2, geogrid

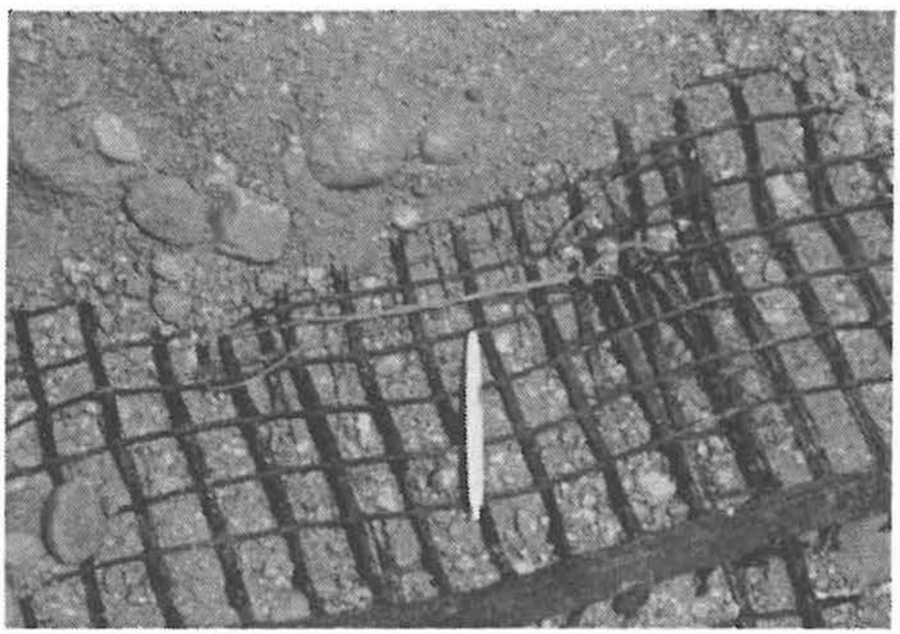


Figure 18. Metal wires connecting tow layers of Mirafi 5T, geogrid

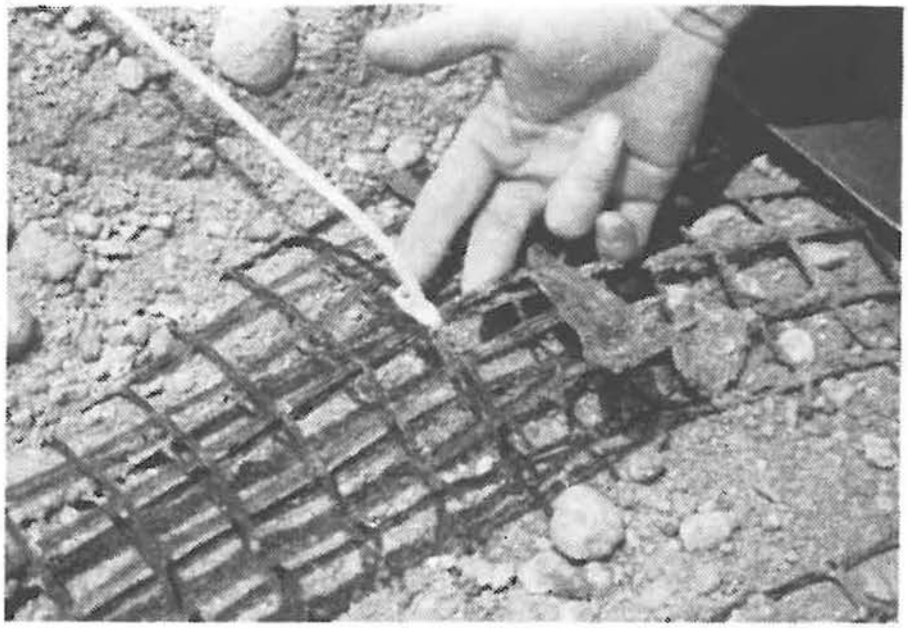


Figure 19. Plastic tie bands connecting two layers
of Mirafi 5T, geogrid

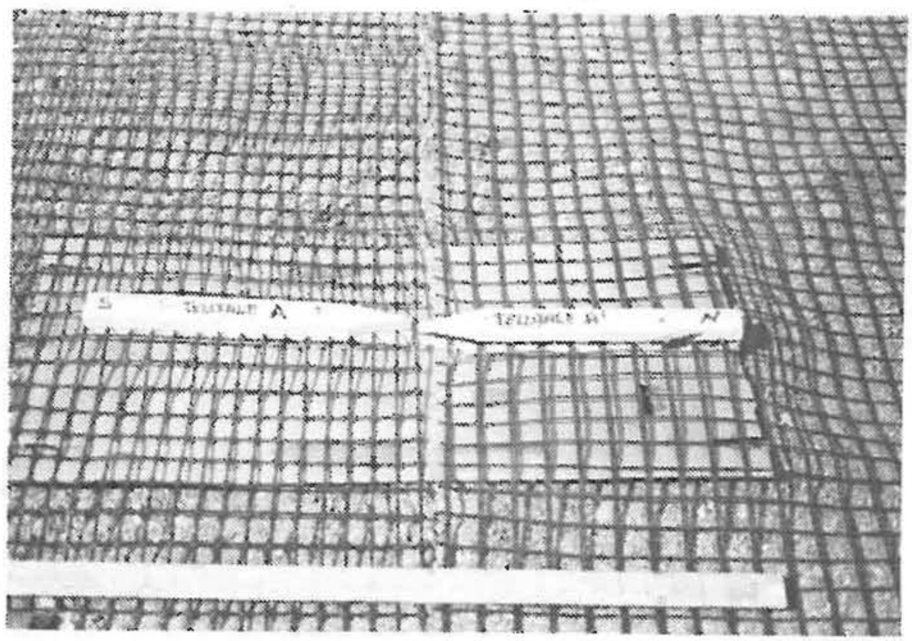


Figure 20. Wooden Stakes were used at the boundary of
Tensar SS-2 and Mirafi 5T at the center line
of the embankment for future evaluation purposes

Figure 21. Placing backfill soil on top of the geogrid reinforced test section

geofabric was placed in test section 1. It was laid out in a similar manner to the geogrids and the non-woven fabric, with the exception that the Supac WS was laid directly on the ground surface with no granular cushion material shielding the fabric from potential debris puncture. The same stitching pattern was used to sew the woven fabric panels. However, some of the woven panels were delivered to the job site with factory sewed seams. These seams were not sewed in the same manner as the double "J" seam, and consisted of a single overlap with double stitch. These factory seams were marked for future evaluation when the test embankment would be removed. None of the Supac 4WS rolls contained any strain gages since the texture and weave design of the fabric would not allow attachment of the gages by the methods employed on the non-woven fabric and the geogrids. Figure 22 shows the installation of the Supac 4WS rolls.

E. Monitoring Program

After completion of the test embankment, all strain gages, vertical and horizontal inclinometers were monitored on a monthly basis. This monitoring program continued for nine consecutive months, at which time, the embankment was removed and various samples of different geotextiles were recovered and examined.

IV. FIELD MEASUREMENTS

A. Vertical Displacement (Settlement)

Figure 22. Placing the first layer of Supac 4WS directly on top of the horizontal inlinometer in test section no. 1

Figure 23 shows the settlement profiles for each of the test sections plotted for two embankment heights. These profiles were obtained from the horizontal inclinometers H-1 through H-4 buried beneath the test sections. The test embankment was constructed within ten days to a maximum height of 30 feet. All instruments were monitored when the embankment reached the height of 11 feet. This only required 3 hours, and did not cause any major delays in constructrion of the test embankment. The inclinometers continued to be monitored for the following nine months after completion of the embankment, and the final results are presented in Figure 23. The inclinometer data suggests that the woven material (Supac) and the two types of geogrid (Mirafi and Tensar) appear to have more uniform settlement curves than the non-woven (Typar) and the control test section. It should also be noted that the maximum recorded settlement at the control section appears to be about 16 to 17 percent more than the sections reinforced by the geosynthetic material.

B. Lateral Displacement

The horizontal displacement profiles were measured by eight inclinometers anchored in the shale bedrock. Figure 24 shows the measured horizontal displacement versus the depth at various inclinometer locations for two embankment heights, both during construction and nine months after completion of the test embankment. The results suggest that the geogrid reinforced sections permitted less lateral movements than the fabric reinforced or the control test sections. This is most likely due to the higher material strength of

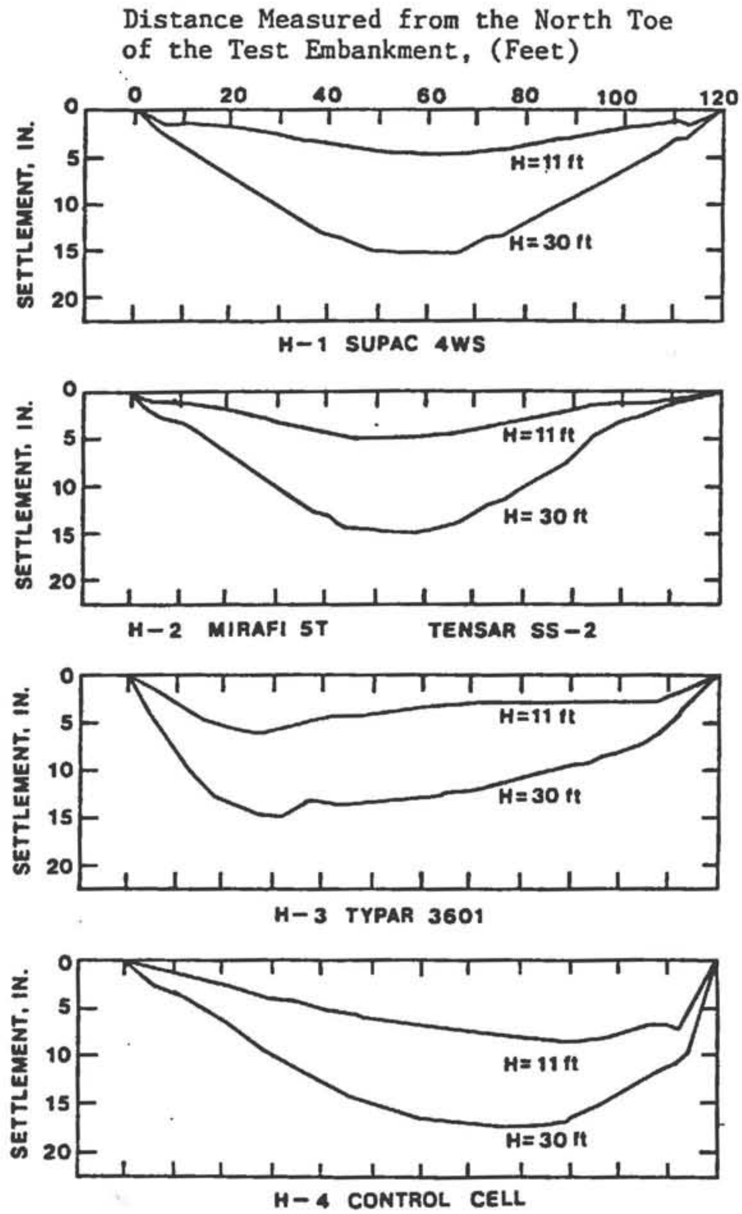


Figure 23. Settlement Profiles Along the Cross Sections of Test Cells for VARIOUS Fill Heights

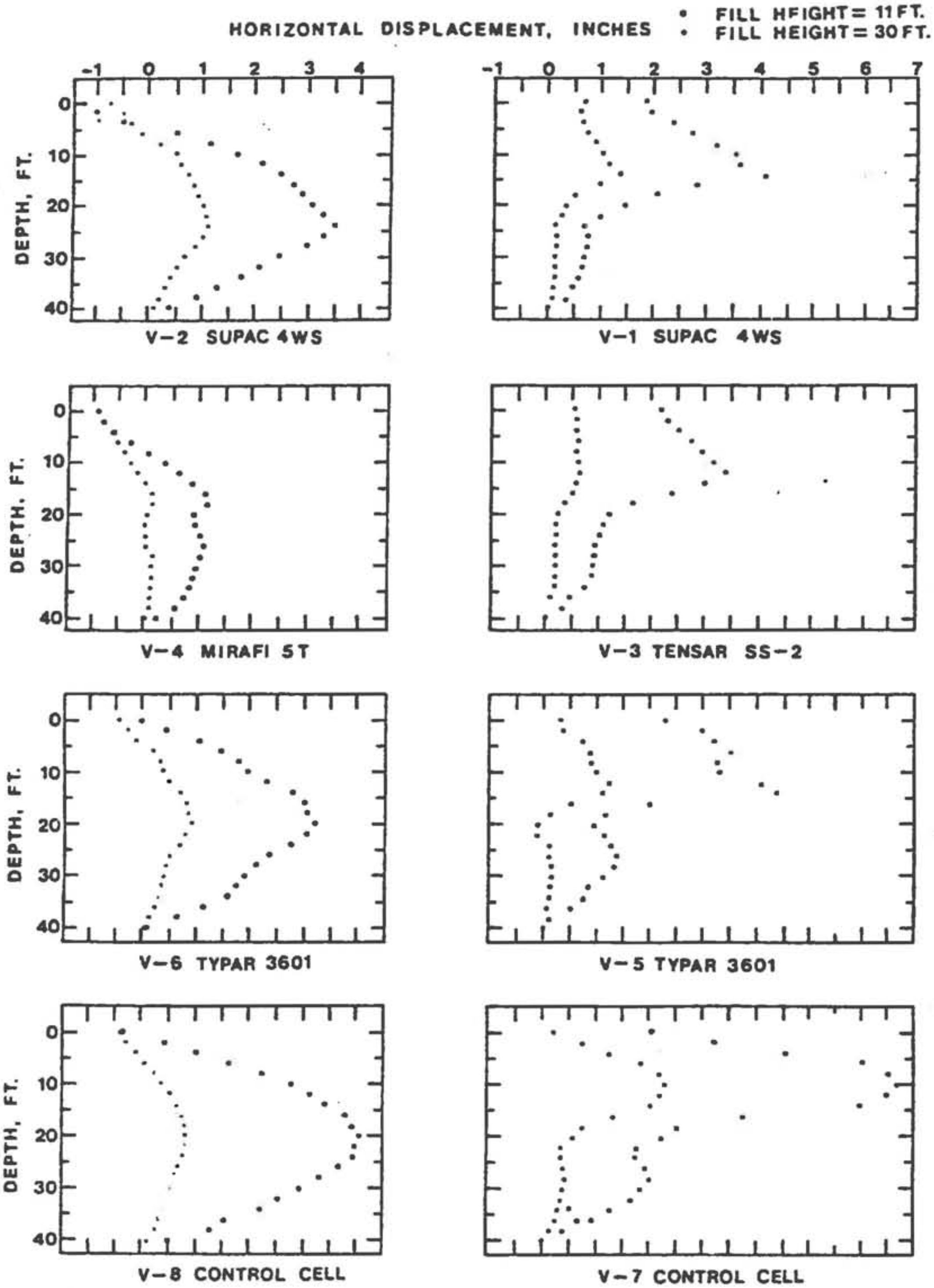


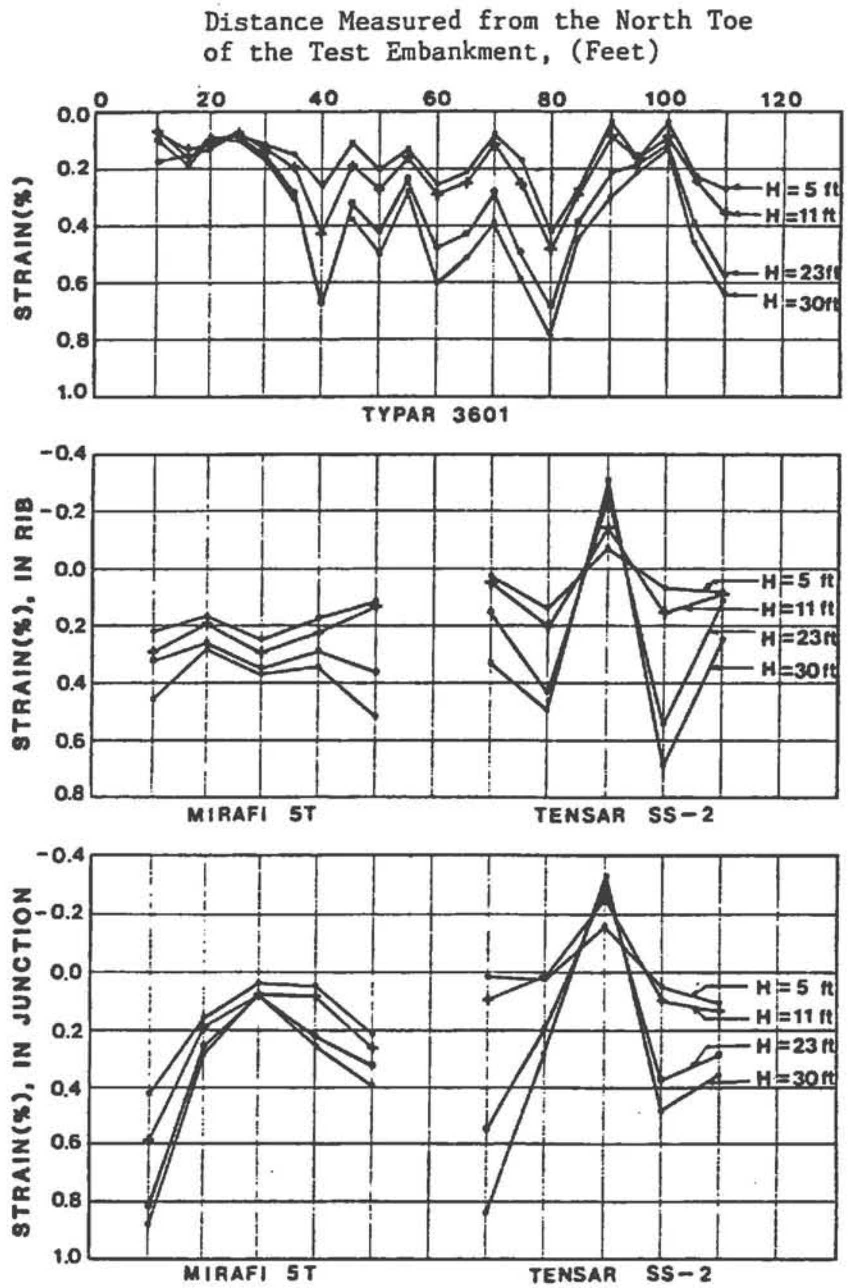
Figure 24. Horizontal Displacements Versus Depth at Various Embankment Heights

the grids compared to the fabrics.

It should be noted that none of the vertical inclinometer pairs, e.g., V-1 vs. V-2, showed similar lateral deformation profiles. Based on the observations made at the control test section, both the lateral deformation and settlement were higher on the south side of the test embankment than that on the north side. This suggested that the subsurface fly ash was not homogeneous, and furthermore, on the south side it was softer than that on the north side.

C. Strain Gages

Figure 25 shows data obtained from the strain gages installed along each cross section of the Typar, Mirafi, and Tensar reinforced test sections. The gages were installed to measure the tension expected to develop within the confined reinforcing material as the result of loading due to construction of the test embankment. The gages were mounted on the Typar fabric using the standard methods recommended by the gage manufacturer and were oriented parallel with the direction of expected maximum strain, which was perpendicular to the center line of the embankment. The orientation of the gages mounted on the Tensar and Mirafi were the same as the Typar; however, the Tensar and Mirafi gage locations were placed on both the connecting rib and the rib junction. This was done because during the laboratory testing, it was discovered that the Tensar geogrid tended to fail through the junction rather than the rib.



Ftgure 25. Strain Gauge Readings Along the Cross sections at Various Embankment Heights

During this study, a comprehensive laboratory testing program was conducted to calibrate the strain gages attached to the geosynthetics. After conducting a number of tests, it was found that it was feasible to obtain the calibration curve for the strain gages attached to Typar 3601 (geofabric), as shown in Figures 26 and 27. The same procedures were repeated for the strain gages attached to the other two geogrids. The results indicated that the stress-strain relationships could be obtained only based on the assumption that the stiffnesses of the geogrids and the strain gages were equivalent. This assumption was made due to the fact that both geogrids showed much better resistance to the applied tensile forces in the laboratory and behaved like rigid bodies. Therefore, it was decided to obtain the field strain gage data on the geogrids and use the charts shown in Figures 28 and 29 in order to find the magnitudes of the applied tensile forces.

The strains developed by the full enmbankment loads were found to be relatively small, ranging from -0.3 to 0.9 percent. The negative strain (compression) which developed in some of the gages was not fully understood, and they were assumed to be isolated occurrences. The rest of strain gage readings appeared to be reasonable indicating small amounts of strains imposed on the geosynthetics due to the embankment load.

For the Typar 3601 (geofabric), the chart shown in Figure 27 was used to convert the strain gage readings to the fabric strains. The results, as presented in Figure 25, suggested that the maximum strain of 0.8 percent occurred at 80 feet from the north toe of the test embankment. The calibration curve shown in Figure 26 indicates that this amount of strain was small, and it was well within the acceptable range.

For the Tensar SS-2 Geogrid, two types of calibration curves were established as shown in Figures 28 and 29. Strain gages were attached to the ribs and the rib junctions and the geosynthetic specimens were pulled in both the machine and cross machine directions. Assuming the cross machine direction controls, then the values of the maximum strains on the Tensar SS-2 and the Mirafi 5T geogrids were found to be less than 1 percent which was considered to be very small and insignificant.

D. After completion of the primary settlements, the test embankment was removed, and samples of geotextiles and strain gagtes were obtained and examined. The visual observation suggested that no wear and tear had taken place, and all strain gages, except one, were still in good working condition. It was also observed that overlaping the geotextiles would have been sufficient to keep the reinforcing rolls together without a need for other means of connecting these rolls. Figures 30 and 31 show samples of woven and non-woven geofabrics which were obtained after removal of the test embankment. Both samples suggested that the geofabrics were in good working conditions, and there were no apparent damages to either geofabrics.

Figure 26 - Geofabric Pull Test

Style 3601

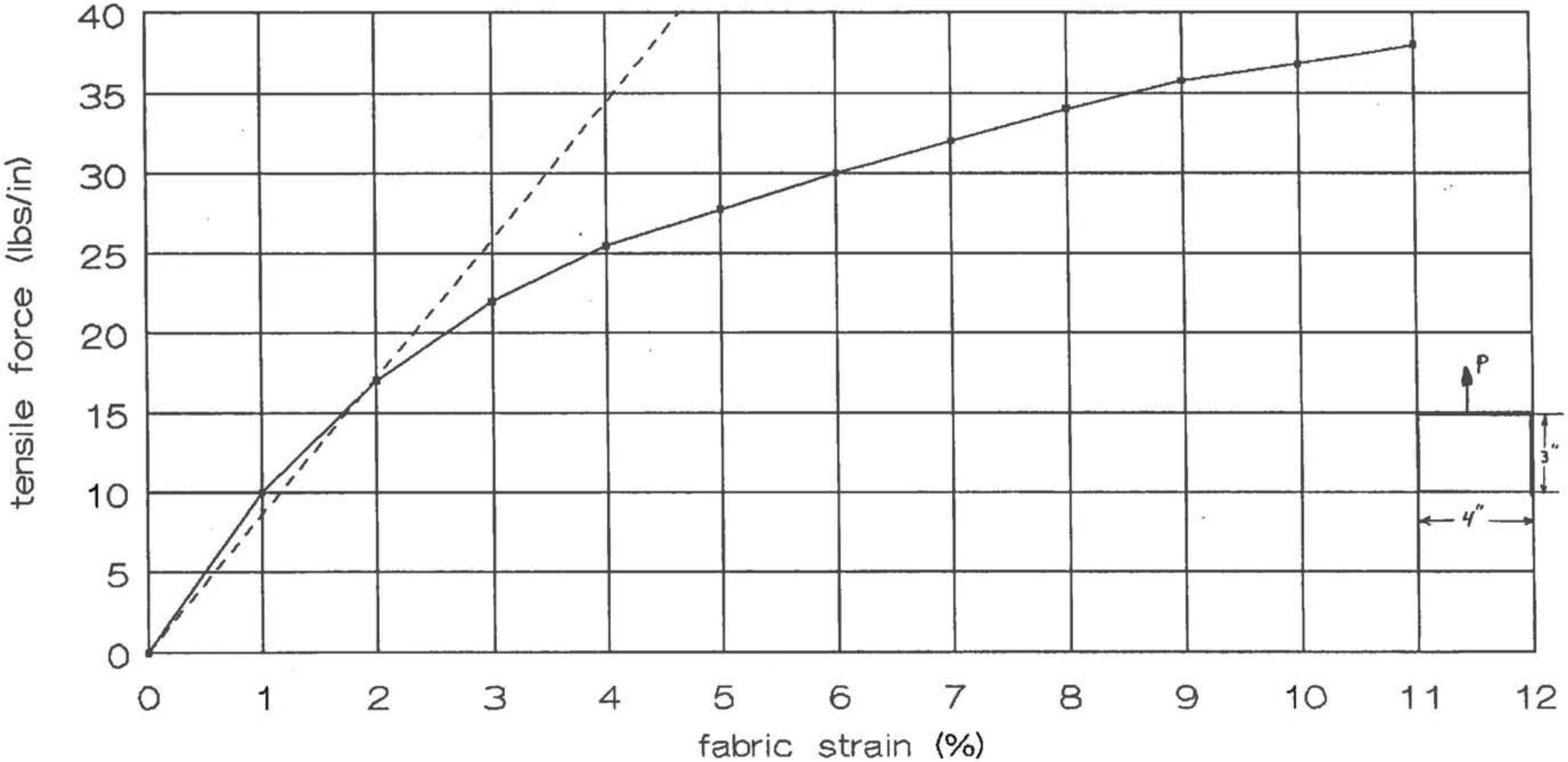


Figure 27 – Geofabric Pull Test
Style 3601

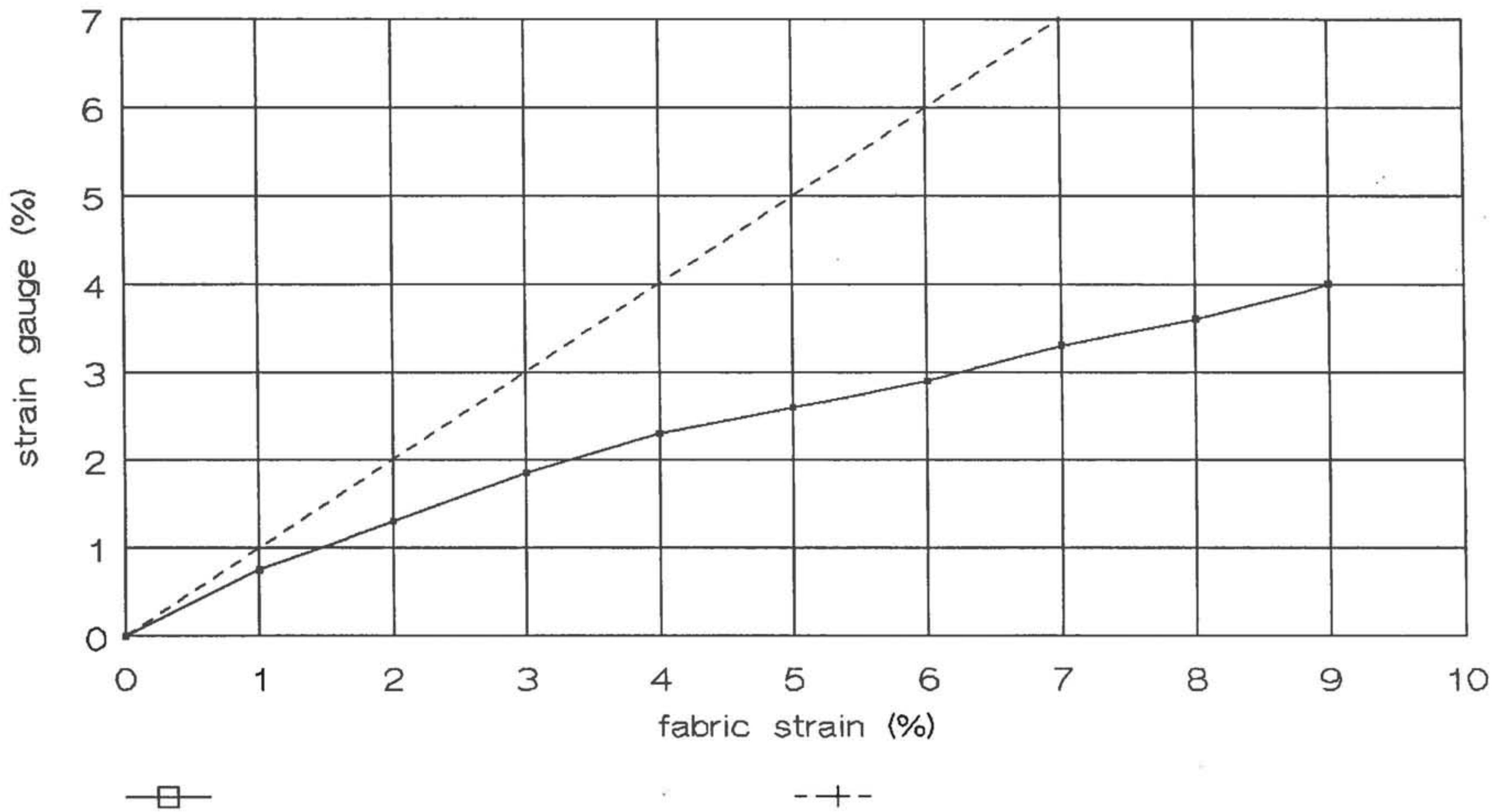


Figure 28 – Deviator Stress Plot

(TENSAR SS-2)

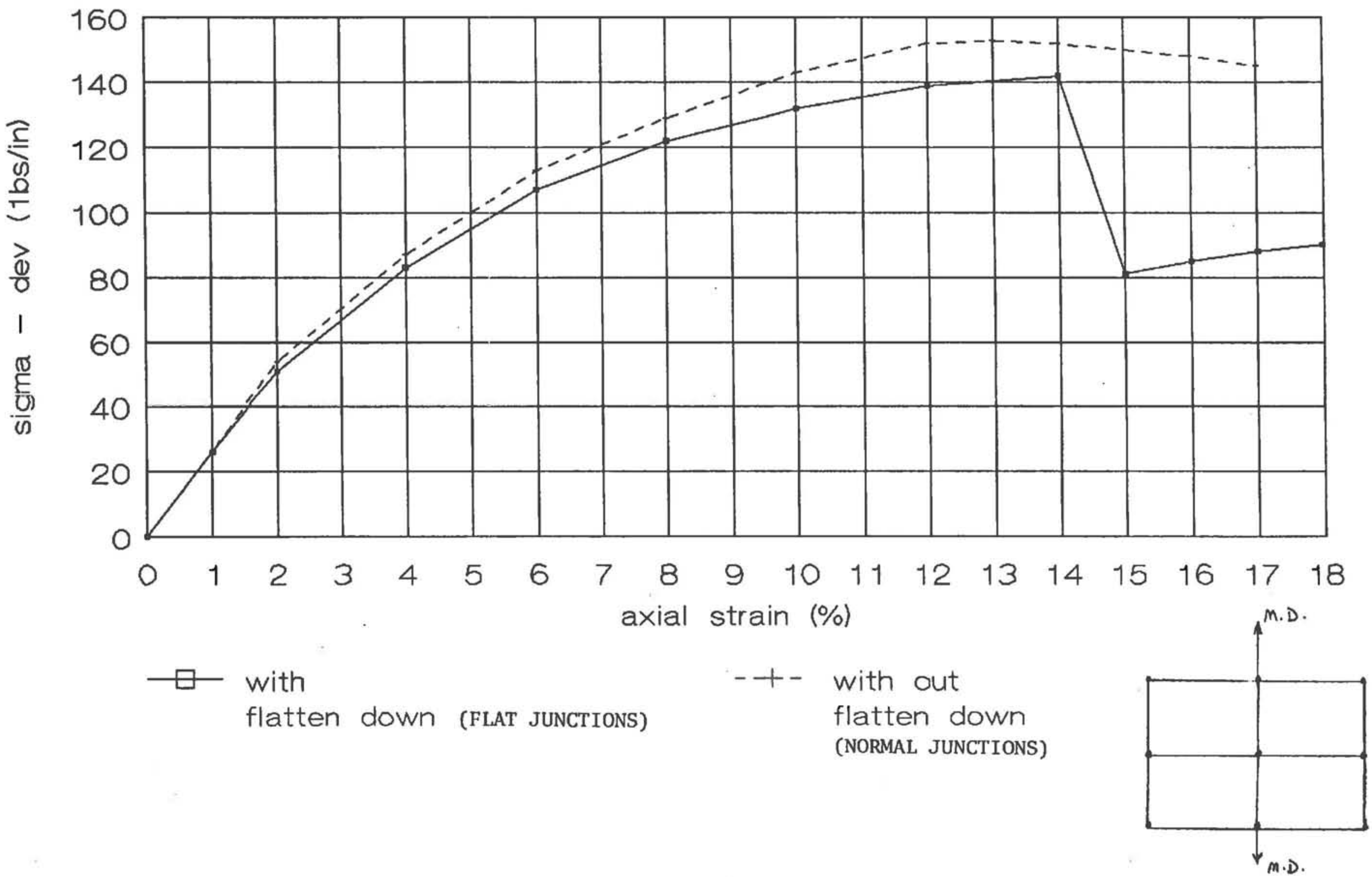
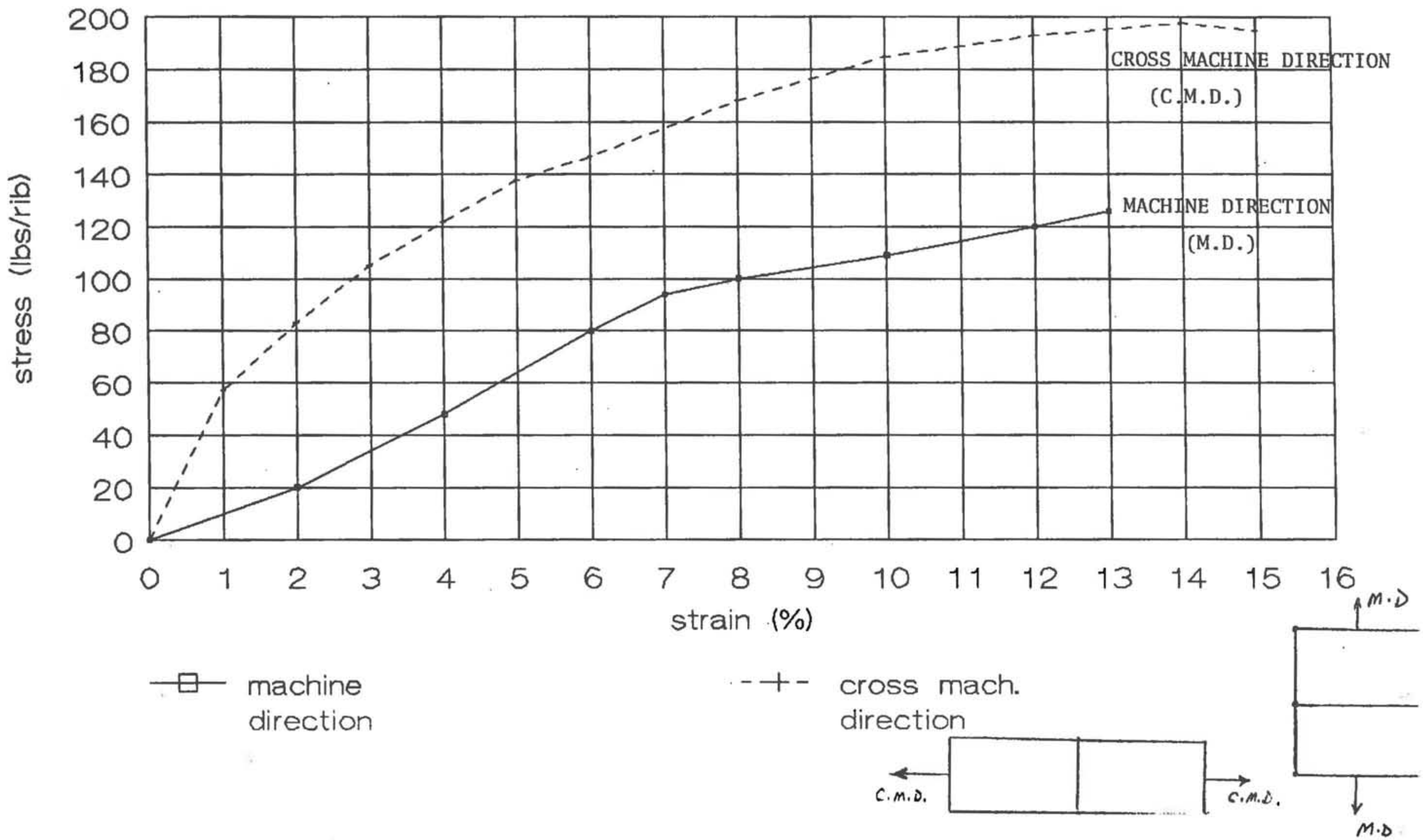


Figure 29 – Stress Strain Curve

Tensar (TENSAR SS-2)



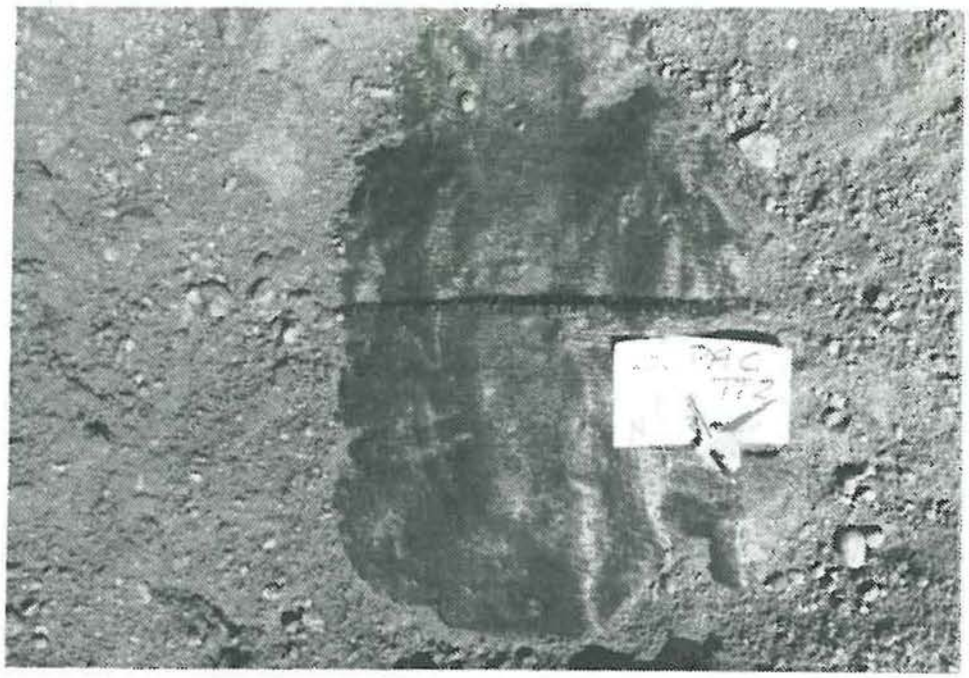


Figure 30. The recovered woven geofabric

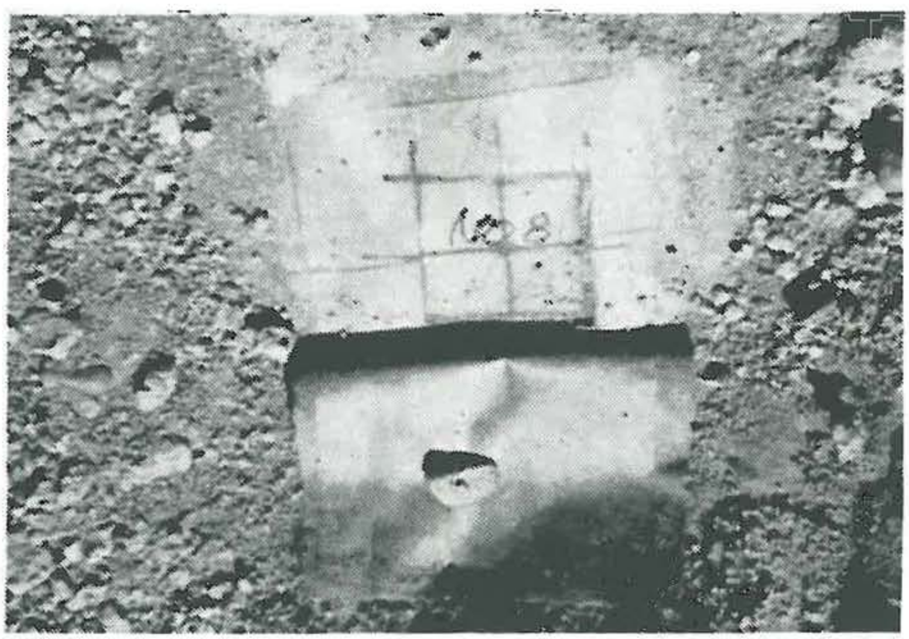


Figure 31. The recovered non-woven geofabric

V. SUMMARY, CONCLUSIONS AND IMPLEMENTATION

A. Summary

The experience gained from this research study was valuable, and it has enabled the CDOH engineers to make better decisions when working with various geosynthetics.

During this study, a woven geofabric, a non-woven geofabric, and two different geogrids were used to reinforce a 30 foot high embankment on top of a ground which was previously filled with fly ash. To evaluate the field performances of the geotextiles, various instruments such as strain gages, vertical and horizontal inclinometers were used to monitor the actual tensile strength of the geotextiles, settlements, and lateral movements of the ground at the toe of the test embankment.

The horizontal inclinometers provided the settlement profiles underneath the reinforced test sections as well as the control section. The average total settlement in all three test sections was measured to be approximately 15 inches. The largest settlement in the control section was about 17.5 inches which was about 14 percent more than the reinforced test sections.

The vertical inclinometers measured the lateral movements of the ground at the embankment toe due to displacement of the ground below the embankment. The largest lateral movements were observed on the south side of the embankment as shown in Figure 24. The maximum lateral movement among the three test sections was measured to be 4.25 inches. This test section was reinforced with the non-woven geofabric (Typar 3601). The control test section produced approximately 6.6 inches of maximum lateral movements which was about 2.35 inches more than the geofabric reinforced test section. This, based on the previous experiences with inclinometers, is considered a negligible difference. Figure 24 also suggests that there is a soft layer of fly ash at about 12.5 feet below the ground surface on the north side of the embankment which extends, with a gentle slope, toward the south side. This soft layer is detected at 20 feet below the ground on the south end of the embankment.

The strains developed by the full embankment loads were found to be relatively small, ranging from -0.3 to 0.9 percent. This range of strains was considered acceptable, and it suggested that the geotextiles were functioning well as reinforcements underneath the embankment.

Summaries of the instrumentation, results, and evaluation of the geosynthetic material are prepared, and they are presented in Tables 3 and 4. These two tables reflect the opinion of the authors based on the field observation and this particular situation. Therefore, it is suggested that each future project be analyzed individually prior to selection of any related geotextile reinforcement.

B. Conclusions

The experience gained from the test embankment will be valuable for similar projects in the future. All of the instrumentation performed well. The instrumentation data indicated that the use of reinforcing materials moderately or slightly reduced the vertical and horizontal displacements of the test embankment and its foundation. In addition, the strain distribution data, as presented in Figure 25, will assist in better understanding of how tensile stresses were developed during and after construction.

In general, the field performance of the four geosynthetic materials was satisfactory. The geogrids were found to be more effective in reducing lateral and vertical deformations than the geofabrics. However, it does not imply that the geogrids may be more cost effective in all applications. In addition, three layers of Typar 3601 could have been used for the cost of one layer of geogrid. But, on the other hand, because of the low strains realized in all geotextiles, the superior strength of the geogrids may not have been utilized.

The fly ash subsurface did not behave as a homogenous soil mass as was originally expected. The fly ash in the south side of the test embankment appeared to be weaker than that on the north side. But, the general trend of the settlements and lateral deformations remained valid.

Evaluation Of Geosynthetic Materials From I-76 Test Section Results

No.	1	2	3	4	5
Materials	TYPAR-3601	GEOGRID-SS2	MIRAFI-5T	SUPAC-4WS	CONTROL
Separation	Excellent (5)	Poor (2)	Poor (2)	Excellent (5)	-
Workability	Good (4)	Excellent (5)	Excellent (5)	Good (4)	-
Technical Assistance	Excellent (5)	Good (4)	Good (4)	Poor (2)	-
Availability					-
Cost ($/Sq. Yd)	0.75 2*(5)	2.40 2*(1)	2.40 2*(1)	2*(3)	-
Subtotal	24	13	13	17	

Table 3

Reinforcement Capability

Horizontal Movement (H)	S. 4.42" N. 3.30" (2)	3.47" (3)	1.20" (5)	S. 4.15" N. 3.51" (2)	S. 6.70" N. 4.11"
Vertical Settlement (S)	12.6" (3)	12.2" (4)	13.0" (3)	15.2" (1)	16.8"
Ratio of = H/S	S. 0.35 N. 0.26 (2)	0.28 (3)	0.09 (5)	S. 0.27 N. 0.23 (3)	S. 0.40 N. 0.24
Developed Strain (%)	S. 0.79 N. 0.84 (3)	0.82 (4)	0.89 (2)	- (2)	-
Subtotal	10	14	15	8	
Total Points	34	27	28	25	

Table 4

Note: The results presented are based on raw data of 11/14/87

5 - Excellent
4 - Good
3 - Fair
2 - Poor
1 - Very Poor
Weight Value = 2

C. IMPLEMENTATION

The results of this study were immediately implemented on the I 76-1(105) project. Tensar SS-2 geogrid was selected and used to reinforce an actual embankment along the future path of I 76 in northwest Denver.

Since the completion of this study, it has become clear to the end users of geosynthetics within the CDOH that each project must be analyzed separately in order to determine its possible needs for application of geosynthetics. Based on this preliminary study, a cost analysis may then be performed and presented to the field personnel for proper selection of a geosynthetic material to overcome a particular geotechnical problem.

APPENDIX A

Selection of Strain Gages

The selection of strain gages, during this study, required a substantial amount of time and research in order to be meaningful and appropriate. The Micro Measurement Company in Denver was contacted and through their assistance and advice we were able to specify the following strain gages for this study:

GEOSYNTHETIC	STRAIN GAGE TYPE
Mirafi 5T	EA-06-031DE-120
Tensar SS-2	EA-06-031DE-120
Typar 3601	EA-06-500BH-120, and EP-08-250BG-120

The strain limit for the EP-series strain gages was about $\pm$ 20% for 120 ohm gages. The strain limit for the EA-series strain gages was approximately $\pm$ 5% for gage lengths 1/8" and larger; and approximately $\pm$ 3% for gage lengths under 1/8".