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Case Study of a Geotextile Reinforced Levee on a Soft Clay Foundation

ABSTRACT

This paper presents the results of a levee test section that was reinforced by a single layer of high strength polyester geotextile. Strain gages were attached to the geotextile to measure the strain in the geotextile during and after construction. Settlement plates, piezometers, and inclinometers measured the deformation and performance of the composite structure. Geotextile tensile requirements were computed using the Spencer and Bishop circular arc methods, and the wedge method of slope stability analysis. The tensile values from the limit equilibrium slope stability analysis are compared to the tensile values recorded by the strain gages attached to the geotextile, to evaluate how accurately the theoretical values compare with the field data.

INTRODUCTION

Geotechnical engineers are often faced with the challenge of constructing a structure on a very soft foundation, or enlarging an existing structure. When the desired factor of safety for rotational stability can not be achieved, alternatives for building the structure on the existing alignment are generally expensive, and a new alignment is usually selected. In southern Louisiana, the two most commonly used methods to construct over very soft soils is to build on piles, or remove the soft organic material and replace it with sand or shell. Both alternatives are very costly, require specialized equipment, and are also very time consuming. With the development of high strength geotextiles a new alternative has been introduced.

This paper presents the results of a 152.4 meter long levee test section in which a high strength polyester geotextile (297.7 kN/m at 5% strain) was used to reinforce a levee enlargement. The project is located in the southeastern portion of the State of Louisiana, in lower Plaquemines Parish (county), between the towns of Nairn and Empire.

An aerial view of the site is presented in Figure 1.

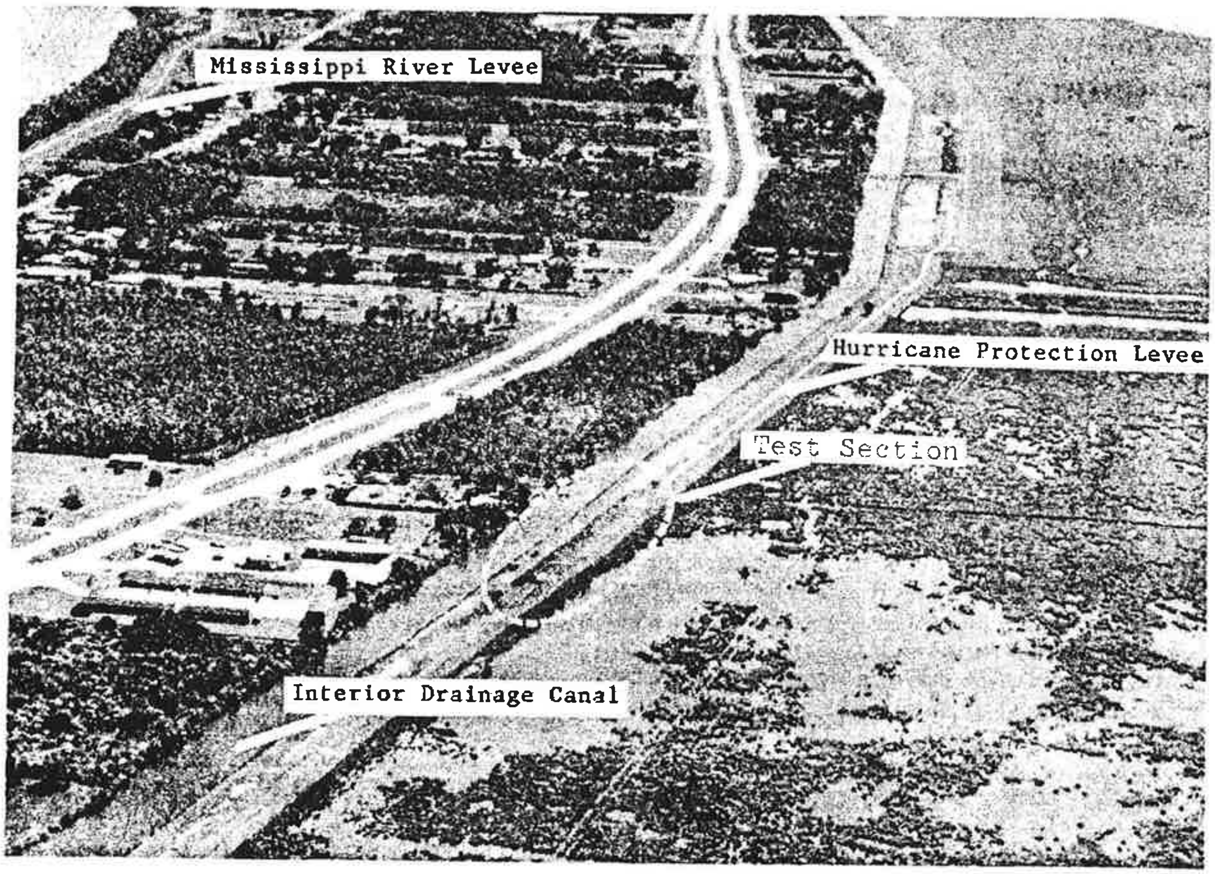


Figure 1. Aerial view of construction site.

The people who live on the very narrow strip of land between the Mississippi River and the bays that lead to the Gulf of Mexico are protected from river floods and hurricane surges by the levee systems. The test section was constructed on the hurricane protection levee.

Currently, the crown of the existing levee is at approximate elevation 2.29 meters National Geodetic Vertical Datum (N.G.V.D.). It has to be raised to an elevation of 4.42 meters to provide protection against a 100-year storm, and also to compensate for foundation settlement. Stability analysis of the existing levee indicates that the factor of safety is approximately 1.1. Raising the crown elevation to 4.42 meters, with the required side slopes, results in a factor of safety of 0.8 for a slide into the drainage canal, and a factor of safety of 0.85 for a slide towards the gulf. Stability berms cannot be constructed to improve the stability of the section because the canal is too close to the existing levee.

Construction without a reinforcing geotextile requires moving the centerline of the levee approximately 36.6 meters towards the gulf and excavating a 3 meter deep trench to remove the highly compressive organic material. A hydraulic dredge would be used to pump sand into the trench, and after allowing the sand to drain, several clay pumpings would be required to bring the section to design grade. This type of construction is estimated to cost $85,000,000, covers 4000 acres of marsh, and take 13 years to construct 13 miles of levee.

The primary objective of the study is to determine if a single layer of high strength geotextile can be used effectively to reinforce the section so that the present levee can be enlarged on the existing alignment. Other items of interest are the strains in the reinforcing geotextile and the deformations and performance of the composite section.

DESIGN SECTION

The levee was enlarged by holding the landward existing levee toe and raising the levee towards the gulfside, thus resulting in a 6.1 meters gulfward shift of the present baseline. The top 0.9 meters of the existing levee were degraded to establish a flat wide platform to work from, but more importantly to provide more anchorage by placing the geotextile deeper into the section. The high strength geotextile was placed on the degraded levee portion, down the existing levee slope, over the marsh grass, and submerged in the ponded areas. Both ends of the geotextile were folded back to form anchors to provide additional resistance to pull-out. Sand was placed over the fabric to a maximum height of 1.2 meters, and clay was placed above the sand to design grade. The final section has a 2.44 meter crown width, a protected side slope of 1V on 3H, and a marsh side slope of 1V on 4H. Refer to Figure 7 for more details.

INSTRUMENTATION

Several lines of instruments were placed perpendicular to the levee centerline to measure the performance of the test section during and after construction. Instruments consist of strain gages, settlement plates, piezometers, and inclinometers. This report focuses mainly on strain gage and inclinometer data. The strain gages provide feed back on the tensile demand on the geotextile, and the inclinometers provide information on the lateral deformations. Both are essential in determining the potential failure plane and the magnitude of the resistance required to balance the driving force and increase the factor of safety.

STRAIN GAGES

Strain gages were placed at three locations approximately 30.5 meters apart. Two of the locations contained displacement transducers that were manufactured at the Waterways Experiment Station (WES), and the third location contained foil gages. A schematic of the foil gage layout is presented in Figure 2. Most gages were placed perpendicular to the levee centerline to determine the maximum tensile demand on the fabric. The data obtained from the WES gages is inconclusive and erratic, and therefore is not presented. Data from the foil gages appears to yield good values, but unfortunately, the foil gages were only placed in a limited area over the marsh. The foil gage readings were normalized to an initial reading of 0.9 to facilitate comparisons among the gage plots. This value is convenient because one third of the gages which are perpendicular to the centerline had this value for their initial reading prior to fill placement. This offset value is approximately the same as that obtained from the laboratory tests that were performed at Drexel University, and shown on Figure 5. The strain measured by the foil gages increases towards the marsh, with the furthest marshward gages showing a strain of 3.5%, indicating that the greatest tensile demand on the geotextile is at or beyond this location. Strain gage plots showing the strain at selected locations on the instrumented geotextile panel are presented in Figure 3.

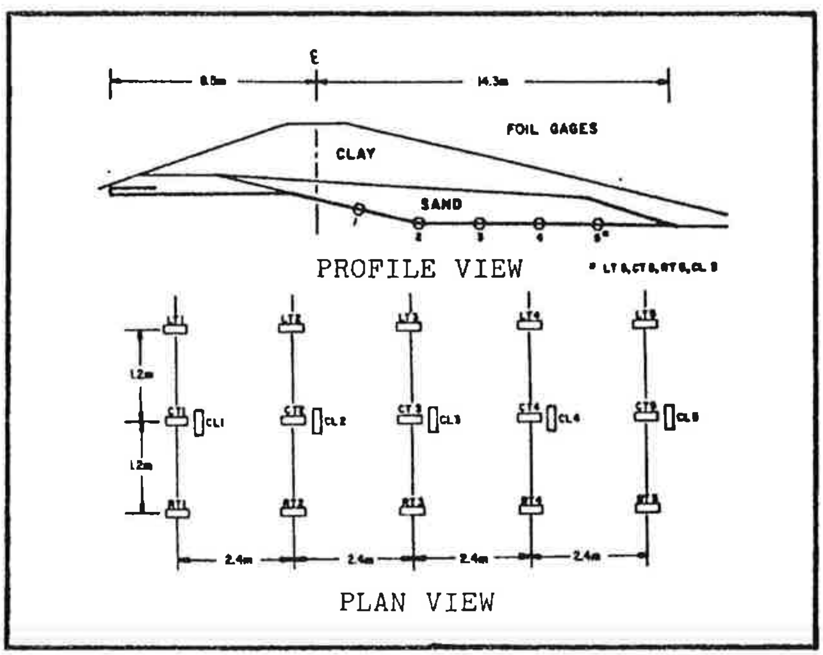


Figure 2. Strain gage locations

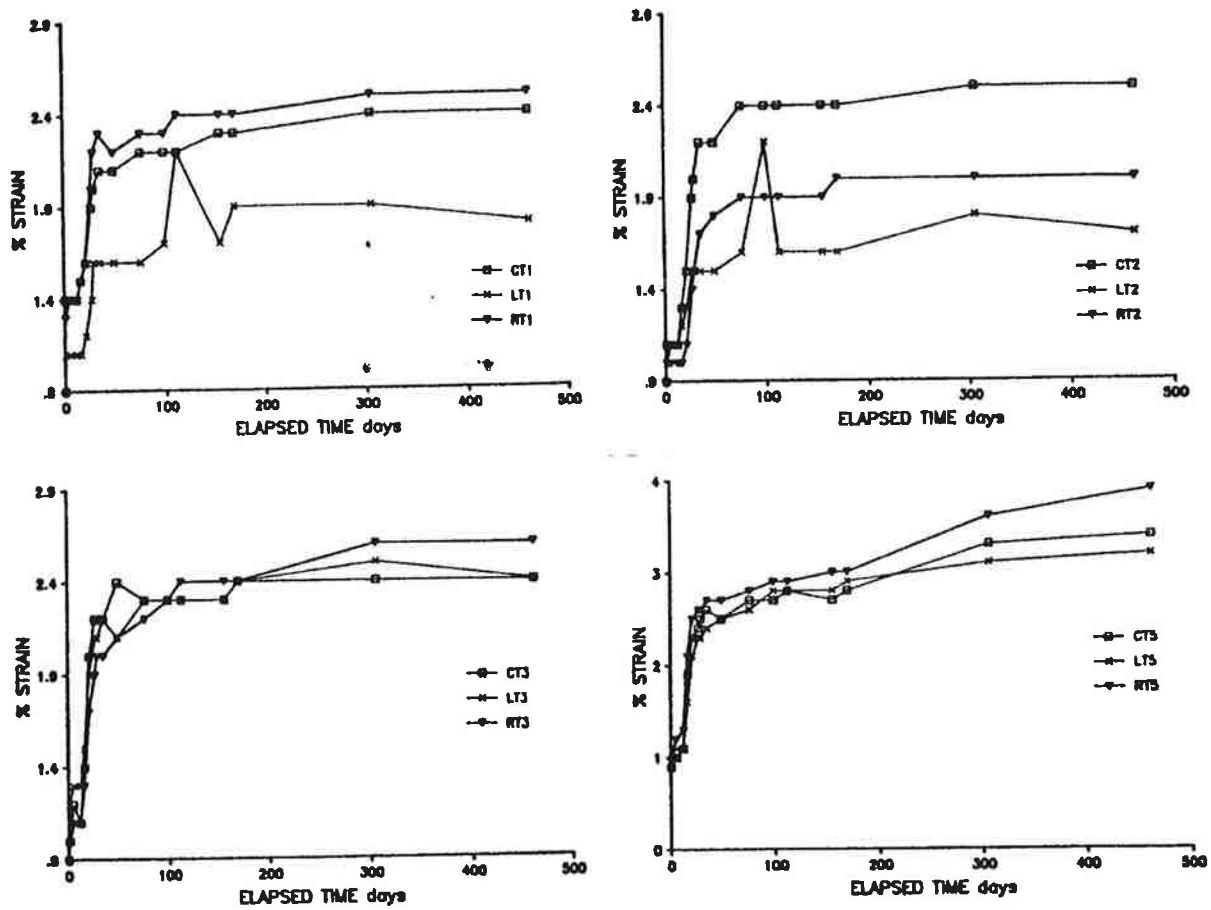


Figure 3. Strain gages plots.

INCLINOMETERS

Inclinometers were placed at two levee stations approximately 30.5 meters apart. Three inclinometers were placed at each station. Figure 4 presents the inclinometer layout and deflections for the station containing inclinometers 11, 13, and 15. Inclinometer 11 was placed next to the existing canal to monitor the ground movement toward the canal. Inclinometer 13 is at a distance of 1.7 meters gulfward of the new levee centerline, and inclinometer 15 is at a distance of 9 meters. The inclinometers close to the center of the slope experienced the largest gulfward movement, approximately 35.6 cm. at inclinometer number 15. Inclinometers adjacent to the crown, also experienced significant movement towards the gulf, approximately 30.5 cm. at inclinometer number 13. No apparent movement was recorded by the instruments next to the canal. Maximum movement occurred above approximate elevation -3.4m. This information was used to establish the critical elevation for the gulfside slope stability analysis.

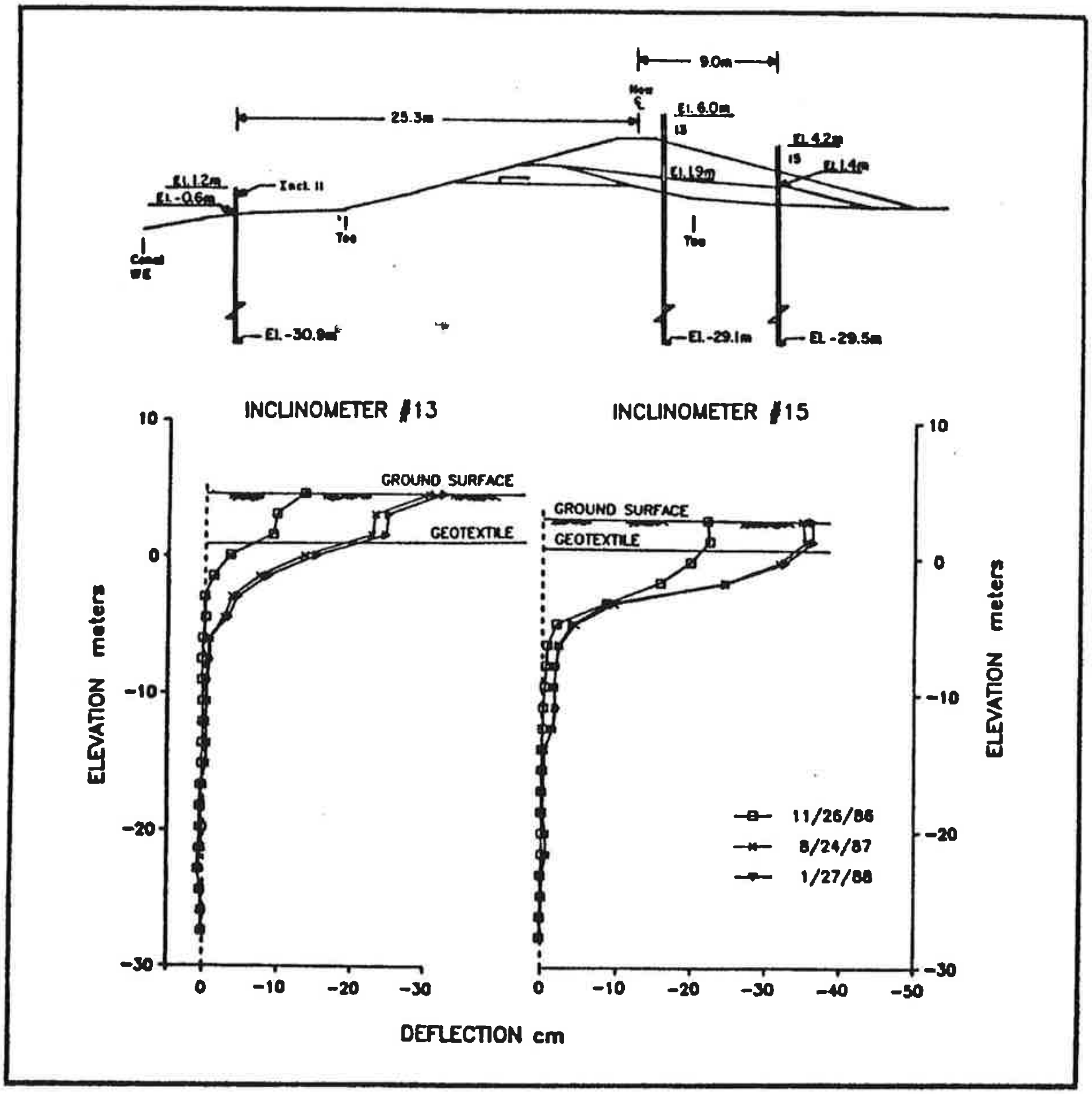


Figure 4. Inclinometer locations and gulfward movement

SETTLEMENT

Settlement plates were installed on top of the reinforcing geotextile at distances of 1.5 and 7.6 meters on the gulfside of the new crown centerline. Consolidation was relatively fast and constant during the first month after construction, but slowed down thereafter. Four hundred days after construction, the settlements were 0.62 and 0.78 meters, respectively. Consolidation is still progressing at a very slow rate.

PIEZOMETERS

Piezometers were installed under the gulfside edge ot the new levee crown at elevations -1.5, -3.3, -6.3, and -9.2 meters to monitor the pore pressure in the foundation. Pore pressures peaked at the end of construction and rapidly dissipated to a residual value above the initial readings. The maximum pore pressures were 1.6, 3.0, 0.8, and 2.3 meters, respectively.

GEOTEXTILE PROPERTIES

Laboratory results of the polyester geotextile test specimen indicate that the fabric has a tensile strength of 297.7 kN/m at 5% strain, an ultimate strength of 665.4 kN/m, a friction angle of 30 degrees when pulled over a silty soil and 14 degrees against a marshy organic clay with very high water content. The strains in this paragraph were measured by a linear voltage displacement transducer (LVDT).

SLOPE STABILITY ANALYSES

Before the test section was constructed, stability analyses were performed using the wedge method of analysis to determine the geotextile tensile strength that was required to resist the unbalanced forces and increase the factor of safety to 1.3. Based on the design parameters, x-section, and stratification that was available, the most critical failure mode was towards the canal, at an elevation of -12 meters. A geotextile with a tensile strength of 297.7 kN/m at 5% strain was chosen. The factors of safety presented in the introduction are also based on the same set of analyses. The analyses presented in this paper include the data that was obtained from the test section, which resulted in slightly different design parameters, x-section, and stratification than had been used in the previous analyses. Review of the test data reveals that the critical failure surface is towards the gulf at an elevation of -3.4 meters.

Stability analyses, using the latest information, were conducted to compare the tensile values that are obtained by the wedge method (1) and circular arc methods, and to determine how accurately these theoretical values compare to the values measured by the strain gages. Safety factors were computed for the unreinforced and geotextile reinforced sections using the Wedge method, and the Spencer (1967) and Simplified Bishop (1955) methods from the UTEXAS (2) slope stability program.

WEDGE ANALYSIS

Stability analyses were performed for a failure surface at elevation -3.4 meters, the elevation above which maximum movement was indicated by the slope inclinometers, to determine the geotextile tensile strength required to increase the factor of safety to 1.0. A geotextile with a tensile strength of 117 kN/m is required. Geotextile tensile requirements were computed using the following equation:

$$T = F.S. (D) - R$$
$$D = Da - Dp \text{ (active \& passive driving forces)}$$
$$R = Ra + Rb + Rp \text{ (resisting forces)}$$
$$F.S. = \text{required factor of safety}$$
$$T = \text{Tensile requirement in the geotextile kN/m}$$

CIRCULAR ARC ANALYSES

Circular arc analyses were used to compute the safety factors of the same section that was analyzed by the Wedge Method. Results for the unreinforced section are presented in Figure 6. Analyses for the reinforced section are presented in Figure 7. A geotextile with a tensile strength of 96.3 kN/m is required to increase the factor of safety to one, for a failure surface at elevation -3.4 meters. This tensile value and the tensile value obtained by the wedge analysis will be compared to the tensile demand measured by the foil gages.

STRAIN GAGE ANALYSIS

Samples of the polyester geotextile were recovered from the field and instrumented with foil strain gages for tensile/strain tests (3). Each specimen contained a foil gage and an LVDT measuring device side by side to compare the strain measured by each instrument. It is necessary to establish a relationship between stress versus strain for the foil gages, because this relationship can be used to convert the strain that is measured by the foil gage in the field to a tensile force. The tensile force from the stability analysis is compared to the tensile force from the foil gages to determine how accurately the analysis predicts geotextile tensile demand. The largest strains were recorded by the gages furthest gulfward (CT 5, LT 5, RT 5). The average last reading for these gages is 3.5% strain which corresponds to an average tensile demand of 57.6 kN/m in Figure 5. The tensile demand measured by the foil gages that are attached to the geotextile is significantly less than the tensile values computed by the wedge or circular arc slope stability methods. The tensile value computed by the wedge analysis is 2.03 times that measured by the foil gages. For the circular arc analysis, the value is 1.67 times larger than the measured value.

Inspection of Figure 5 shows that the tensile values obtained by the circular arc and wedge analysis correspond to 4.5% and 5% strain.

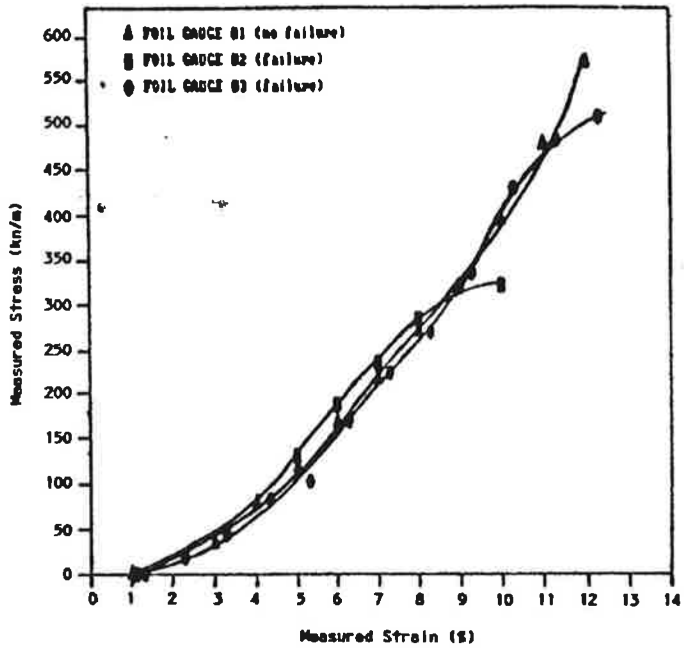
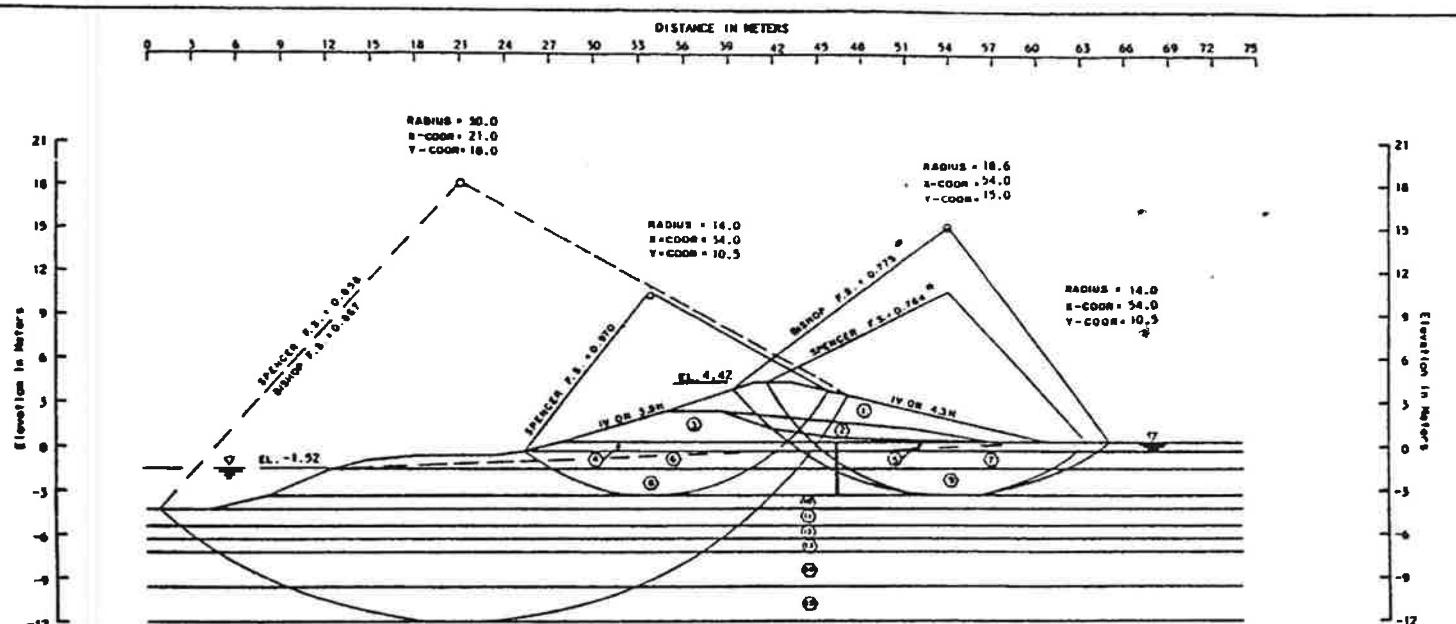


Figure 5. Stress versus strain of the three foil gages

CONCLUSIONS

Results of the test section clearly show that a geotextile reinforced levee is a viable alternative to increase the flood protection. The test section was completed over two years ago, and since then all of the instruments have been monitored extensively to determine the performance of the composite section. All of the data to date indicates that the section is working better than had been anticipated, especially since the field geotextile strains are lower than the computed values from limit equilibrium analysis. There is no evidence of cracks or any signs of unacceptable stress in the test section. Lateral deformations, measured by the inclinometers, have stopped for all practical purposes. Strain gage readings peaked during August 1987 and there has been no increase since then.

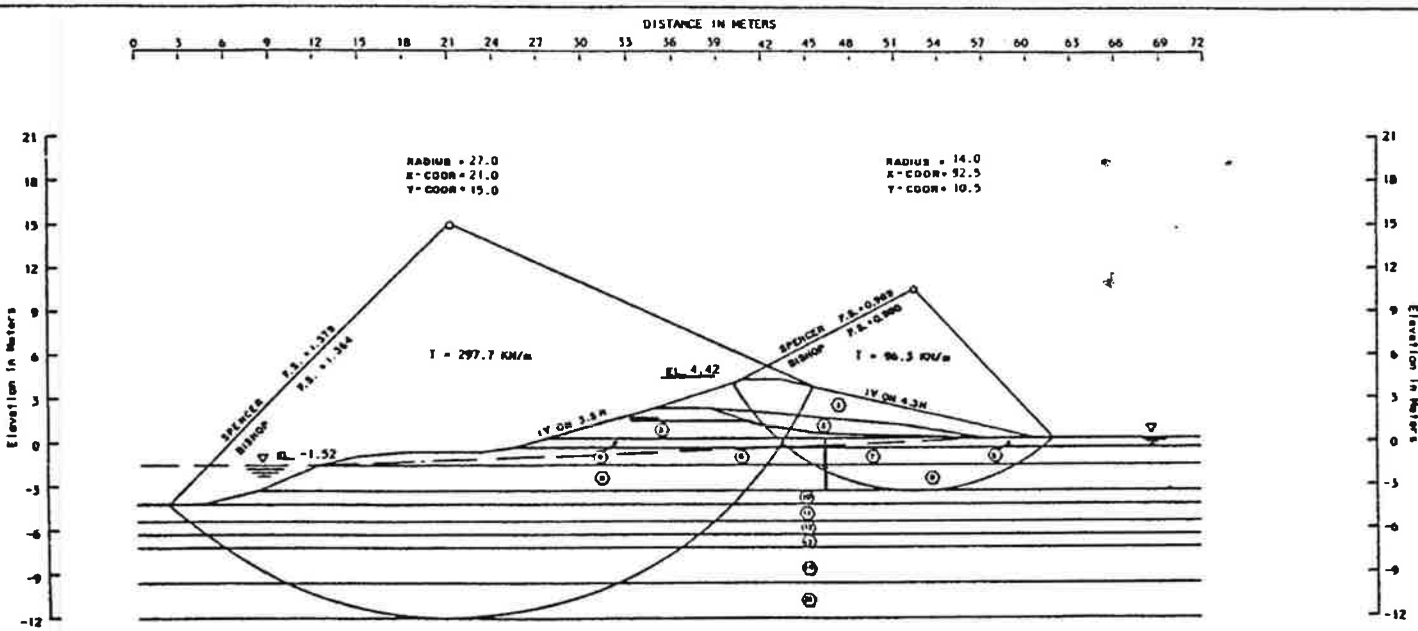
Circular arc slope stability analysis, for a factor of safety of one, require a geotextile with a tensile strength of 96.3 kN/m. The wedge method of slope stability requires a tensile strength of 117.0 kN/m, for the same factor of safety. Maximum tensile demand was



* COHESION = 4.8 IN STRATUM ⑤

STRATUM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SOIL TYPE	CH	SM	CH	CH	CH	CH	CH	CH	CH	ML	CH	SM	ML	CH	CH
UNIT WT.(kN/m3)	15.7	19.2	17.0	13.5	13.5	13.5	13.5	14.9	14.9	18.4	16.5	19.2	18.4	16.5	15.7
COHESION(kPa)	9.6	0	19.2	19.2	4.8	9.6	4.8	9.6	4.8	9.6	11.5	0	9.6	13.9	16.3
FRICTION ANGLE	●	30	●	●	●	●	●	●	●	15	●	30	15	●	●

Figure 6. Circular arc analysis for the unreinforced section.



STRATUM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SOIL TYPE	CH	SM	CH	CH	CH	CH	CH	CH	CH	ML	CH	SM	ML	CH	CH
UNIT WT. KN/m3	15.7	19.2	17.0	13.5	13.5	13.5	13.5	14.9	14.9	18.4	16.5	19.2	18.4	16.5	15.7
COHESION kPa	9.6	0	19.2	19.2	4.8	9.6	4.8	9.6	4.8	9.6	11.5	0	9.6	13.9	16.3
FRICTION ANGLE	0	30	0	0	0	0	0	0	0	15	0	30	15	0	0

Figure 7. Circular arc analysis for the reinforced section.

recorded by the gages furthest gulfside. A tensile demand of 57.6 kN/m was measured. Both stability methods gave conservative results, with the wedge analysis yielding a F.S. = 2.03 when compared to the demand measured by the foil gages. It should be noted that the zone of maximum tension was not at the circle/soil interface, but far from it, close to the toe of the new levee. This may suggest that a failure mechanism other than the circular arc is at work. Even if this is so, the current methods of stability analyses are requiring tensile strengths that are on the safe side. This is acceptable until the mechanics of the composite section can be better understood and the analysis can be refined to yield more accurate and economical designs.

The geotextile reinforced levee alternative will reduce the estimated construction cost for the 13 miles of levee from $85 million to $54.2 million; construction time from 13 years to 6 years; and marsh destruction from 4000 acres to 100 acres. Residents will also benefit from lower flood insurance premiums during the reduced construction time. After the levee is complete, the first floor of residential and commericial buildings will not have to be constructed 4.3 meters above the ground surface, as is presently required to prevent damages from flooding.

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