Controlling Expansive Soil Destructiveness by Deep Vertical Geomembranes on Four Highways

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ABSTRACT

Expansive soils are a worldwide problem. In the United States damages caused by expansive soils probably exceeded $10 billion in 1984. One-half of these damages involved highways, streets, and roads. Studies and research have been conducted by international, national, state, and educational institutions. The Texas State Department of Highways and Public Transportation has used relatively impervious fabrics (geomembranes) placed vertically along the pavement edges through the zone of moisture activity to minimize the destructiveness of expansive soils. These vertical geomembranes have been placed in sections of four highways in San Antonio, Texas, varying from 1/4 to 2 mi. Testing procedures involved measuring the smoothness of the riding surface and the cracking of the pavement surface, installing moisture sensors, and determining maintenance requirements. Two of the earlier projects had records of 4 and 5 years without significant surface cracking, which is an indication that the use of the geomembrane barrier contributed to a better riding surface and less maintenance. All four tests indicate that the fabric can be placed in a variety of ways. Conclusions to date offer guarded optimism that the deep vertical geomembrane barrier can reduce the destructiveness of expansive soils on pavement.

Expansive soils are a worldwide problem and the subject of international conferences and studies. In the United States these soils extend from coast to coast and from border to border. They were estimated to cause $2 billion in damages in 1973 (1) and $7 to $9 billion in 1980 (2), and these damages probably exceed $10 billion annually in the United States today. One-half of this destruction occurs to the nation's highways, roads, and streets (1). Additional damages are suffered by other transportation facilities such as airport runways, railroads, canals, pipelines, and sidewalks.

Controlling these soils has been the subject of studies by universities and state, national, and regional groups. The following methods have been used to control expansive soils: replacement, avoidance, chemical stabilization, electro-osmotic treatment, ponding, and membranes. A study by the U.S. Corps of Engineers Waterways Experiment Station (3) funded by the Federal Highway Administration reviews many of these methods. The encouraging results of shallow vertical barriers used in South Dakota (4) and the results of a ponding project (5) led the Texas State Department of Highways and Public Transportation (TSDHPT) to try a deep geomembrane. The ponding study showed that a zone of activity of the expansive clays in the San Antonio area is usually in the range of 6 to 8 ft below the surface. If the wide fluctuations of the moisture (from 3 to 35 percent) could be minimized, perhaps the destructive movements caused by these subgrades could be minimized.

Several questions arose: Could the geomembrane fabric be placed 8 ft deep? What kind of production of placement would be possible? How could effectiveness be measured? And would minimizing subgrade moisture change minimize pavement distortion over expansive soils?

INTERSTATE 410

The first test section of a deep vertical geomembrane on a Texas highway was part of a rehabilitation project on Interstate 410 in southwestern San Antonio (Figure 1). In this area, Interstate 410 crosses the Blacklands prairie physiographic zone, which contains Houston black clays from the Taylor and Navarro groups. These clays are firm when moist and sticky and plastic when wet. Atterberg limits included liquid limits from 50 to 79 and plasticity indices (PI) from 28 to 48. Built in 1960, the freeway section main lanes were a 4-lane divided highway with a 44-ft grass median. The main lanes contained 16 in. of foundation course, 9 in. of flexible base, and 3 in. of Type A and 2 in. of Type C asphaltic concrete. In the section where the deep vertical geomembrane was used, the main lanes transitioned from natural ground elevation to a depressed section between 20 to 22 ft below the original ground. Since their construction, the main lanes in this area distressingly revealed the destructiveness of the expansive clays. Repeated asphaltic concrete level-ups were followed by more pavement distortions, more level-ups, and heater-planer work where the "bumps" were burned off. Additional level-ups and exposed based patches indicated the need to try something different.

The Interstate 410 rehabilitation project was 15 mi long and included an asphalt seal coat, a 1 1/4-in. Type C asphaltic level-up, and a 3/4 in. Type D finish asphaltic concrete surface. In the Valley Hi area, a 1/2-mi long test section of the geomembrane barrier was placed along the inside and outside shoulders of the northbound main lane (Figure 2). The adjacent southbound main lane was to be the control section. The asphaltic concrete level-up placed varied from 1 to 12 in. thick.

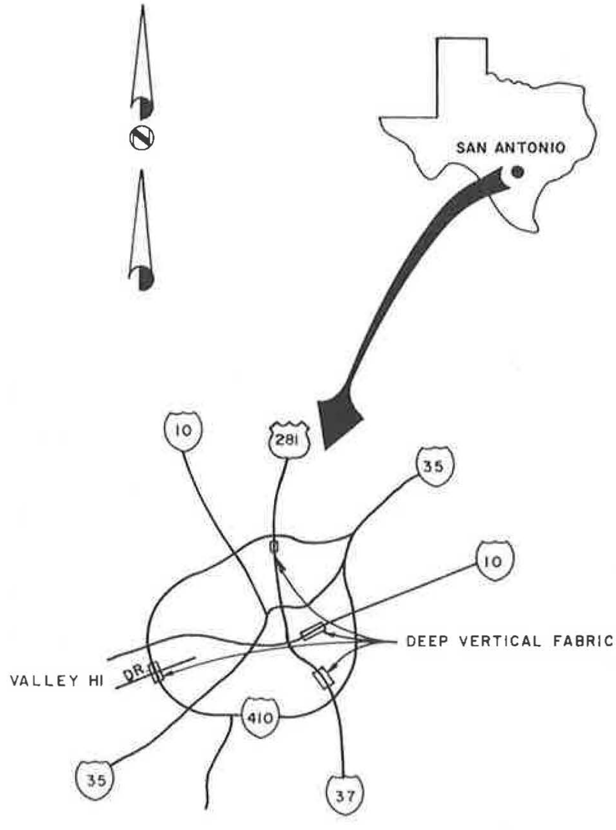

FIGURE 1 Test locations.

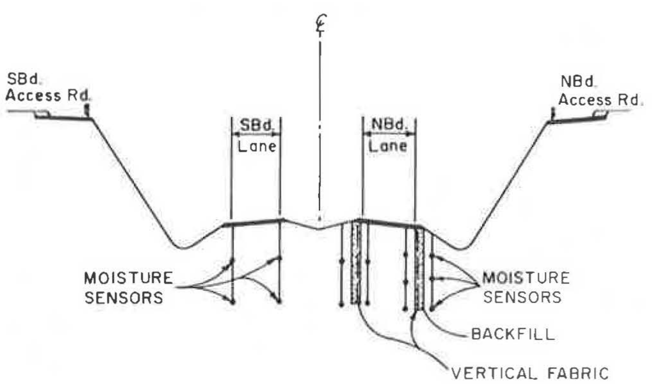

FIGURE 2 Interstate 410 section.

A spun-bonded polypropylene membrane coated with ethyl vinyl acetate (Dupont Typar T-063) 15.5 mils thick was used as the vertical geomembrane. It was placed 8 ft deep along the inside and outside shoulders of the northbound lanes with 2 ft lapped and tacked to the shoulders with an asphalt emulsion. The problem of installing the fabric after some initial sliding of the excavation was resolved by a subcontractor who used a backhoe that excavated the material and pulled a sliding shoring that held the roll of geomembrane vertically in the frame. The shoring consisted of two steel plates, each about 6 ft^2 separated by rods that held them rigid with the fabric roll held vertically between them. As the backhoe moved forward, the fabric unrolled in the trench and was tacked to the shoulder. A sand backfill was then placed in the trench. The vertical barrier work was done in February and March 1979 at rates averaging 350 to 400 ft a day.

Moisture sensors were placed inside and outside the geomembrane test section of the northbound lanes at depths of 2 to 8 ft. Sensors were also placed along the control sections of the southbound lanes adjacent to the fabric stations. Soiltest moisture cell sensors (MC374) were used following calibration under the direction of R.O. Lytton of the Texas Transportation Institute.

Sensor readings reported in detail in an earlier study (6) initially indicated greater changes in the subgrades in the unprotected southbound lanes than in the northbound lanes. These changes reflected a drying process, as indicated by the increase in resistivity in the cells, and also appeared outside the fabric along the northbound lanes. However, the irregularity and nonresponse in many cells led to abandonment of the readings.

Profilometer testing began in June 1979. These measurements were computer reduced to serviceability indices (SIs) in which 5.0 was the perfect smooth riding road with descending values indicating increasing roughness. The first SIs on the southbound lanes were 4.13 on the outside and 4.02 on the inside lane compared with 4.16 and 4.11 on the northbound lanes (Table 1). Before rotomilling in March 1981, the SIs were 3.38 and 3.17 for the southbound lanes compared with 3.72 and 3.76 for the northbound lanes.

Rotomilling was followed by an asphalt level-up. The southbound lanes received 200 tons compared with 100 tons for the northbound lanes. Following these operations, in December 1981, the SI for the southbound outside lanes was 3.57 and the SI for the inside lane was 3.56 compared with the SIs of 3.76 and 3.66 for the fabric-protected northbound lanes. By March 1984, this variation had increased again; the unprotected southbound lanes' SIs were 3.12 and 2.87,

TABLE 1 Interstate 410 Serviceability Indices

Location	June 1979	November 1979	August 1980	December 1980	March 1981[a]	July 1981[b]	December 1981	June 1982	February 1983	September 1983	March 1984
Southbound Lane (Control Section)											
Outside	4.13	3.70	3.39	3.28	3.38	3.43	3.57	3.47	3.28	3.16	3.12
Inside	4.02	3.63	3.30	3.15	3.17	3.29	3.56	3.25	2.99	2.89	2.87
Northbound Lane (Deep Vertical Fabric)											
Outside	4.16	4.03	3.83	3.55	3.72	3.74	3.76	3.66	3.57	3.47	3.49
Inside	4.11	3.99	3.83	3.57	3.76	3.61	3.66	3.67	3.55	3.50	3.59

[a] Rotomilled southbound lane March 30-April 2, 1981. Rotomilled northbound lane (isolated spots) April 3-7, 1981.

[b] Project leveled up August 1981.

TABLE 2 Interstate 410 Vertical Photologging

Location	August 1980	December 1980	June 1981	January 1982	August 1982	January 1983
Northbound Lanes						
Outside	0.07	0.08	0	0.04	0	0.19
Inside	0.01	0.24	0.08	0.34	0.03	0.37
Southbound Lanes						
Outside	0.28	0.62	0.11	0.87	0.29	0.75
Inside	0.24	1.01	0.10	0.78	0.51	0.45

while the northbound lanes' SIs were 3.49 and 3.59. The fabric-protected lanes continue to provide the smoother ride as indicated by the profilometer testing.

Photologging results indicated a similar pattern. Photologging was conducted with a camera mounted on a trailer taking pictures of 8-ft long segments and a travel lane 12 ft wide. The number of frames showing surface cracking, which may be indicative of subgrade-caused movement providing for intrusion of surface water, is expressed as a percentage of the total 8 ft segments. The first photos were taken in August 1980; the northbound lanes showed 0.07 and 0.01 percent of their area cracked whereas the southbound lanes showed as much as 0.28 and 0.21 percent of their area cracked. By 1983 cracking had increased to 0.19 and 0.37 percent in the northbound fabric-protected lanes while cracking in the southbound lanes had increased to 0.75 and 0.45 percent (Table 2).

INTERSTATE 37

Encouraged by the results on Interstate 410, a decision was made to use geomembranes in the rehabilitation of Interstate 37 in southeast San Antonio. This highway segment was constructed in 1968. South of Interstate 10, between Fair Avenue and Pecan Valley Drive, the Interstate 37 main lanes were in a depressed section usually 20 to 25 ft below natural ground. The soils are Houston black clays with PIs from 34 to 59 and liquid limits from 56 to 92. The main lane section has four northbound and four southbound lanes with a sodded median 28 to 36 ft wide. The median has a concrete ditch on a flat grade with a steel beam guardrail (Figure 3). The main lanes are four 12-ft wide lanes; 10-ft outside and 6-ft inside shoulders were built on 6 in. of lime-stabilized subgrade, 8 in. of cement-stabilized base, and 8 in. of concrete pavement. Substantial swelling clay movement had caused considerable distortion of the riding surface, the median guardrail, curbs, and slopes. Pavement maintenance for the 2-mi section cost an estimated $50,000 each year. (Communication with W.B. Collier, District Maintenance Engineer, TSDHPT).

Work on the 2.1-mi rehabilitation project began in October 1979 and included placement of 23,750 yd^2 of geomembranes 10 ft wide. The vertical geomembrane was placed 8 ft deep with backfill of gravel topped by 3 ft of cement-stabilized base. The decision to use this method was partly motivated by the experience on Interstate 410 of having two vehicles go axle deep in the sand backfill within a 6-month period. This process has not been repeated in the past 5 years. The fabric was placed along the outside shoulders of the southbound and northbound lanes. The project also included a rubberized asphalt seal, an asphaltic concrete level-up, and overlay. The median was reconstructed by removing the ditch and using positive drainage to the outside shoulders (Figure 4).

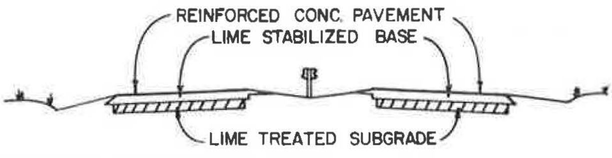

FIGURE 3 Existing Interstate 37 section before rehabilitation.

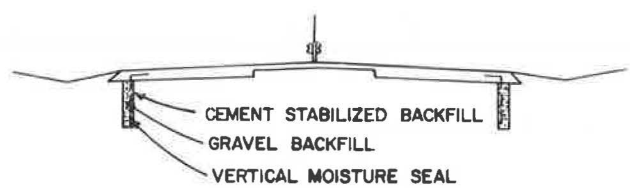

FIGURE 4 Proposed Interstate 37 section following rehabilitation.

The same subcontractor who used the backhoe on the Interstate 410 project was employed to place the geomembrane on the Interstate 37 rehabilitation project. However, the subcontractor used a trenching machine on the Interstate 37 project. The trenching machine pulled the sliding shoring with the fabric roll held vertically. A boom from the trenching machine deposited the excavated material into a dump truck. The cement-stabilized base was batched in a portable paving machine that followed the trenching and backfilling with the gravel. Polypropylene spun-bonded fabric coated with ethyl vinyl acetate (Dupont Typar T-063) was placed in February and March 1980. A maximum of 485 ft of fabric was placed in 1 day, and an average of 385 ft was placed daily. Generally when 400 ft was placed, the day's operation ended; frequently this occurred by 2 p.m.

The first profilometer tests were conducted in November 1979, before placement of the geomembrane. The control sections were usually embankments to the north and south of the depressed section being rehabilitated. The initial SIs in the control sections varied from 3.33 to 3.15. The lanes to be improved had SIs ranging from 2.92 to 2.79 (Table 3).

In December 1980 following the rehabilitation, the fabric-protected lanes had SIs of 3.81 and 3.68 while the SIs in the control section varied from 3.30 to 2.97. This pattern of higher SI readings for the lanes with geomembranes placed continued through August 1983, with the fabric-protected lanes showing SIs of 3.72 and 3.64 compared with SIs of 3.26 and 3.04 in the control sections.

By March 1984, an asphalt level-up was applied to

TABLE 3 Interstate 37 Serviceability Indices

Location	November 1979[a]	December 1980[b]	July 1981	December 1981	June 1982	February 1983	August 1983	March 1984
Southbound lane								
North control	3.22	2.97	2.79	2.99	3.04	3.09	3.04	2.96
Fabric section	2.79	3.68	3.72	3.67	3.69	3.61	3.64	3.75
South control	3.33	3.18	3.20	3.22	3.22	3.19	3.19	2.36
Northbound lane								
North control	3.15	3.09	3.02	2.93	3.12	3.01	3.05	4.24
Fabric section	2.92	3.81	3.84	3.75	3.80	3.68	3.72	3.83
South control	3.24	3.30	3.30	3.28	3.33	3.29	3.26	2.31

[a]November 1979 testing before rehabilitation work.
[b]December 1980 and later tests after work completed.

the northbound lanes' north control section, which raised its SI to 4.24. Otherwise the fabric-protected lanes continued to show higher SIs than the lanes in the control section, 3.83 and 3.75 compared with 2.31, 2.36, and 2.96.

Photologging has revealed little surface cracking. In this testing, two 1,750-ft sections of both the northbound and southbound lanes were used to compare the fabric-protected lanes with the adjacent control sections. In general, there was very little cracking of any type. The initial photologging in June 1981 indicated cracking only in the northbound lane pavement with 0.15 percent in the fabric-protected section and 0.04 percent in the control section. A year and a half later, only the northbound control pavement showed any cracking, and it was a minimal 0.07 percent.

Moisture sensors installed on Interstate 37 have proven more reliable than those installed on Interstate 410. Reported fully in a paper by Picornell, Lytton, and Steinberg (7), these thermal block sensors were model MCS 6000. Ten sensors were installed at four locations in two areas within the lanes rehabilitated with geomembranes. Two of the locations were inside the fabric and two were outside. Periodic readings within a 90-week period indicated a uniformity of high moisture levels at the time of initial placement. However, the sensors placed outside the fabric, while showing this high matrix potential or high moisture readings initially, showed substantial change. All five sensors inside the fabric showed a uniform matrix potential over a 2-yr period, whereas those outside indicated considerable change. Several of the sensors have since become nonoperational. The sensors continuing to function indicated that inside the fabric the subgrade moisture remained relatively uniform whereas outside the fabric more significant changes occurred.

US-281

In 1983 two other highways built over expansive soils were contracted for pavement rehabilitation: US-281 in the north-central section of San Antonio and Interstate 10 between Pine and Amanda Streets on San Antonio's east side. The US-281 rehabilitation project is discussed next. On US-281, finished roadway elevations varied from original ground level to an excavation of about 20 ft below natural ground in 0.4 mi. The subgrade is an Austin Tarrant clay association. Atterberg limits indicated PIs from 25 to 58 and liquid limits from 47 to 80. Potential vertical rise values were calculated to range from 4 to 5 in. The freeway was built between 1970 and 1975, having sustained a 3-year period of construction. The main lanes included 6 in. of lime-stabilized subgrade, 6 in. of base, an asphalt seal coat, and 8 in. of continuously reinforced concrete pavement. In the rehabilitation area, the southbound lane was showing surface signs of significant distress. Rehabilitation of the southbound lane, beginning 0.3 mi south of Interstate 410, included applying an asphaltic seal coat, an asphaltic concrete level-up, and finish course with the geomembranes placed 8 ft along the inside and outside shoulders, similar to the Interstate 410 section (Figure 5). The fabric was to be lapped approximately 2 ft over the paved shoulder. A Class A gravel backfill was used in the trench with 12 in. of cement-stabilized base on top of the trench. Geomembranes were used again because of the favorable results on the Interstate 410 and Interstate 37 improvements.

The contractor used a gradall to excavate the trench. Progress was not rapid; an average of 50 to 120 ft of material was excavated per day. As time became shorter, suggestions to accelerate this operation resulted in excavation being done by two gradalls, and placement increased by 225 to 250 ft per day. The contractor experienced no sliding of the trench and no sloughing, and only saw cutting of the shoulders was necessary. The geomembrane, a composite system of woven polypropylene fabric with polypropylene film bonded 20 mils thick (a Mirafi MCF 500) was unrolled by hand and placed in the trench. The backfill operation followed. Profilometer testing followed the completion of the project in January 1984. The adjacent northbound lane, which had no rehabilitation work, was used as the control section (Table 4). Data are limited, but the initial

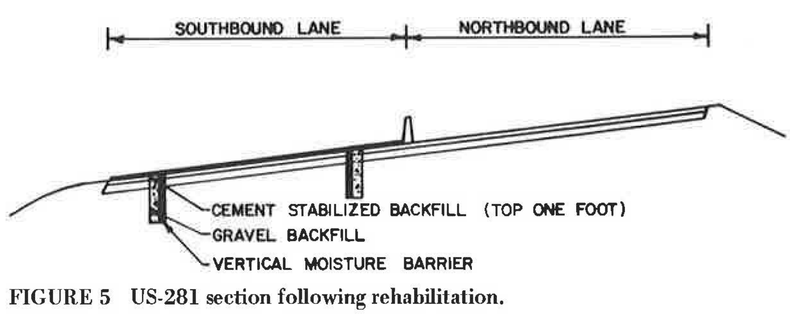

FIGURE 5 US-281 section following rehabilitation.

TABLE 4 US-281 Serviceability Indices

Date	Outside	Center	Inside
Southbound Lane (Geomembrane)			
July 1983	2.42	2.35	1.31
March 1984	3.08	3.07	3.00
Northbound Lane (Control)			
July 1983	2.90	2.86	2.72
March 1984	2.84	2.91	2.55

tests in July 1983 substantiated the decision to repair the southbound lane first. The asphalt level-up and finish course made the lane a smoother ride. However, it is too early to determine the impact of the geomembrane.

INTERSTATE 10

The final rehabilitation project in which geomembranes were used was Interstate 10 between Pine and Amanda Streets on the east side of San Antonio. Here the clays are Houston blacks with PIs of 35 to 55 and liquid limits from 65 to 75. During construction of Interstate 10 in 1968, problems arose with springs and water in the subgrade. This section of Interstate 10 has three eastbound and three westbound travelway main lanes separated by a sodded median. The pavement sections consist of 6 in. of lime-stabilized subgrade, 6 in. of lime-stabilized flexible base, an asphalt seal coat, and 8 in. of continuously reinforced concrete pavement. Usually the main lanes between Pine and Amanda Streets are in a depressed section, frequently 20 ft below natural ground.

Rehabilitation plans called for a rubber asphalt seal, asphaltic concrete level-up, and finish course. Plans also included placement of a vertical geomembrane 8 ft deep along the outside shoulders of the main lanes. The geomembrane will lap 2 ft over the paved shoulder. Its placement trench is approximately 2 ft wide with Class B gravel backfill, and the top 18 in. is a cement-stabilized base.

As in the US-281 rehabilitation project, the TSDHPT's generic specification and the supplier's low bid resulted in the Interstate 10 contractor using a Mirafi MCF 500 fabric. The estimated 24,745 yd^2 of geomembrane was placed by a trenching machine that excavated the material and also pulled a sliding steel shoring frame 7 ft at the top and tapered to 5 ft at the bottom and 8 ft deep. The sliding steel shoring frame held the fabric roll vertically in the trench, feeding the material out as the trenching machine moved forward. As on Interstate 37, the trenching machine had a conveyor belt on a boom that deposited the excavated material into a dump truck. The gravel was backfilled in the trench following placement of the fabric. The cement-stabilized base material was delivered to the site in transit mix trucks. The contractor experienced considerable sliding behind the trench excavation on this project. This resulted in the fabric placement being moved 6 to 8 ft out beyond the shoulder and extra geomembrane emulsion had to be tacked to the fabric placed in the trench to permit the "tie" to the paved shoulder. Despite this problem, on several days the contractor succeeded in placing more than 700 ft of the geomembrane.

Profilometer testing was conducted before construction and will continue at regular intervals when the project is completed. This project will also be monitored with moisture sensors and photo-logging. No test data are currently available.

OBSERVATIONS

The four different contractors on these pavement rehabilitation projects used three different methods to place the 8-ft deep geomembrane. Despite difficult sliding conditions on the Interstate 10 project, placement has exceeded 700 ft a day. A variety of testing procedures has been used. Perhaps the first test section on Interstate 410, which has a 5-year record of results, offers the best comparison. Adjacent lanes were compared: one lane with the fabric and one lane without the fabric. The lane with the fabric had consistently higher serviceability indices, indicating a smoother riding surface with less pavement cracking. When asphalt level-up was applied, twice as much was required on the southbound nonfabric-protected lane as on the northbound geomembrane lane. On the Interstate 37 project, a section that had maintenance costs of $50,000 a year has had no expenditure in 4 1/2 years. No doubt removing the median ditch and adding the rubberized asphalt surface seal have also contributed to this improvement. Research by others (8) and a small horizontal fabric project (9) in San Antonio has emphasized the effectiveness of minimizing the intrusion of surface water into the subgrade. Other research indicates that geomembranes can provide added strength to sections when used horizontally. Moisture sensors show that the geomembrane deep vertical protection may minimize subgrade moisture change. However, the need for greater sensor longevity remains.

A look at costs is worthwhile. On the first deep fabric placement on Interstate 410, the low bid price was $20 per lineal foot along the pavement, which included all materials, excavation, placement, backfilling, and disposition of excavated materials. The bid price on Interstate 37 was $21 per lineal foot. The US-281 contract plans contained separate pay items for the fabric, the gravel backfill, and the cement-stabilized base. The low bidder's price totaled $15.66 per lineal foot for the fabric placement and related items. On Interstate 10, which had the same range of separate bid items, the low bidding contractor's price was $27.15 per lineal foot. With fabric prices from suppliers probably ranging from $1.25 to $1.75 per lineal foot, some further economies can be expected.

CONCLUSION

Deep vertical geomembranes can be placed in expansive soils 8 ft deep. A substantial number of feet of geomembrane can be placed in 1 day. Lanes with geomembranes can be considered to result in a generally smoother riding surface than unprotected lanes. Geomembranes appear to minimize the destructive impact of swelling subgrades on highway pavements and to reduce moisture change in the soils beneath the pavements; this may contribute to the reduced destructive movement. Further use of both vertical and horizontal geomembranes is worthy of serious consideration.

ACKNOWLEDGMENT

The author expresses thanks to R.E. Stotzer, G.H. Wilson, G.K. Hewitt, R.L. Lytton, Consuelo Flores, Ken Hankins, John Nixon, W.C. Garbade, A.O. Hilgers, T.J. Walthall, R.H. Magers, M.H. Hardy, M. Picornell, D.R. Snethen, R.D. Lockhart, Pablo De Arkos, and Rick Norwood.

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Publication of the paper sponsored by Committee on Environmental Factors Except Frost.

Long-Term Behavior of a Drilled Shaft in Expansive Soil

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ABSTRACT

A vertical load test was performed in November 1982 on an instrumented 30-in. diameter drilled shaft 36 ft long with a 4-ft underream. Shaft LAFB-2 was constructed at Lackland Air Force Base, Texas, during July 1966, in stiff, expansive clay soil that contained a perched water table in a clayey gravel stratum. Soil adjacent to LAFB-2 had heaved 7.7 in. at the ground surface by September 1981, while the shaft had heaved 3.4 in. Because soil within 3 ft of the shaft base had heaved only 1.8 in., LAFB-2 had stretched or fractured along the shaft length. Results of the vertical load test indicated a discontinuity in the load-displacement curve that separated the observed skin friction resistance of 250 tons from the end bearing resistance of 130 tons. Uplift thrust of the adjacent swelling soil mobilized skin friction and tensile forces in the shaft equivalent to the shear strength of the adjacent soil times the total shaft surface area. Long-term end bearing capacity was reduced to about 75 percent of short-term capacity because of long-term wetting of soil beneath the shaft base.

In July 1966 seven test shafts were constructed at Lackland Air Force Base to study the performance of drilled shafts in expansive soil. The test site was instrumented with porous stone piezometers, free-standing benchmarks, and two deep reference benchmarks to provide accurate pore water pressure and elevation profiles. Pressure heads recorded in the piezometers indicated a perched water table 8 ft below ground surface extending down to about 50 ft. A deep water table was observed 80 ft below ground surface.

A vertical load test was performed on shaft LAFB-2 in November 1982 to investigate the long-term performance of a drilled shaft in expansive soil. This 2.5-ft diameter by 36-ft long shaft, including a 4-ft diameter bell, is located in the southeast corner of a 100 x 100-ft covered area constructed in 1974 to observe trends in long-term heave in expan-