8. The prediction models have been obtained from data collected on pavement sections in cut and at grade with no protective measures to reduce swelling. On the other hand, research is now under way on some test sections where ponding was conducted prior to construction or vertical moisture barriers have been implemented. The models can help in the evaluation of these measures by comparing the actual roughness developed with that predicted. In the future, when more data are available, the models can be improved to account for the effects of protective measures, pretreatments, presence of fill, or rebound of deep excavations.

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# Deep-Vertical-Fabric Moisture Barriers in Swelling Soils

MALCOLM L. STEINBERG

**A deep-vertical-fabric moisture barrier has been placed on two Texas highways that have been severely damaged by swelling-soil subgrade. Previous testing of a ponding section has indicated the depth of the zone of activity. By developing additional mechanisms and making maximum use of prior developments, the Texas State Department of Highways and Public Transportation is using fabric on two San Antonio freeway rehabilitation projects: an 0.8-km (0.5-mile) test section on Interstate Highway Loop 410 and a 3.2-km (2-mile) section of I-37. DuPont EVA-coated Typar T063 fabric has been placed 2.4 m (8 ft) into the zone of activity. The goal is to minimize destructive pavement movements over expansive clays by minimizing moisture change. Testing includes moisture-sensor readings, profilometer measurements computer converted to serviceability indexes, photologging, elevation readings, and pavement surface inventories. There are no reportable results for the recently completed I-37 project. However, after a two-year testing span on Loop 410, profilometer serviceability indexes and other favorable measurements indicate a better riding surface on the fabric-protected lanes than on the adjacent control section. The results are viewed with guarded optimism.**

Expansive soils are estimated to cause between $7 and $9 billion/year in damages in the United States (1, p. 596). More than half of these damages are to transportation facilities, highways, railroads, airports, pipelines, canals, and sidewalks (2).

The problems of swelling soils are worldwide. Expansive soils occur in Australia, South Africa, South America, India, Israel, Poland, Canada, and in the United States, where they occur from border to border and coast to coast.

These soils have spawned many tests, reports, papers, international conferences, meetings, and cures. One of the more complete literature reviews was part of a study done by the U.S. Army Engineer Waterways Experiment Station (WES) for the Federal Highway Administration (FHWA) (3).

Texas has its share of swelling soils. Like many other agencies, universities, and consultants, the Texas State Department of Highways and Public Transportation (TSDHPT) has tried many cures and methods and has reported on them (4). The department has continued to work cooperatively with Texas A&M University, the Texas Transportation Institute (TTI), the University of Texas, the Center for Transportation Research, FHWA, and the WES project to seek solutions to this problem.

Another significant contribution of the WES study was the development of national and regional maps that show the relative occurrence of swelling soils (5). These are invaluable data. They must be viewed, however, with an awareness that they provide generalized information rather than a rigid rule. For example, if one examines the WES map of Texas, the El Paso area in the far western corner is noted as being lightly impacted by swelling soils (see Figure 1). Yet, in one residential development in this area, more than 100 homes were severely damaged as a result of expansive soils. These builders and buyers did not feel "lightly impacted"!

Tests with the deep-vertical-fabric moisture barrier (DVFMB) are being conducted by TSDHPT, in cooperation with Texas A&M University and TTI, in the San Antonio area of south-central Texas (see Figure 2). The city is in Bexar County, 200 km (125 miles) from the Gulf of Mexico. Since meteorologic and geologic conditions are so closely related to the

Figure 1. Swelling-soil areas in Texas (from WES study).

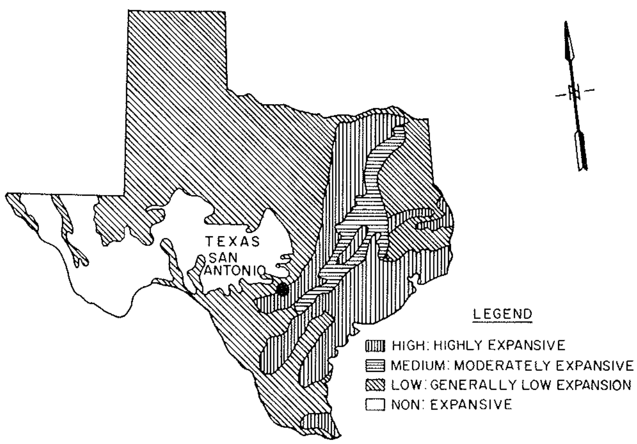



Figure 2. San Antonio/Bexar County DVFMB test sites.

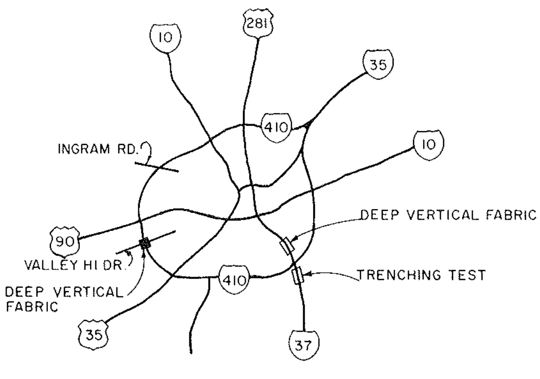



Figure 3. Bexar County geology.

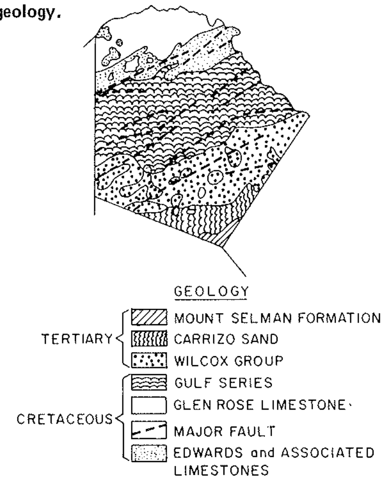
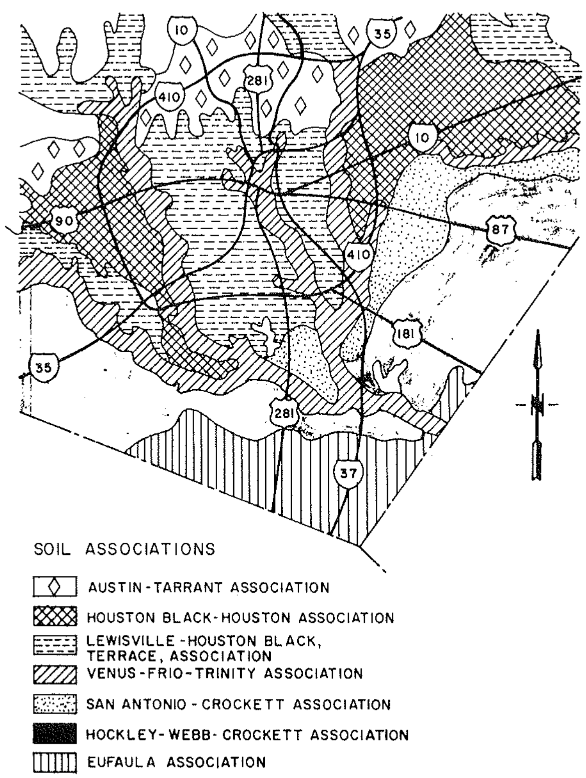



Figure 4. General soil map of San Antonio and Bexar County.




activity of swelling soils (predominantly clays in this area), San Antonio's subtropical climatic zone is of significance. It averages a daily maximum temperature between 30° and 35°C (87° - 90°F) from June through September. Between November and March, it sustains minimum readings of 10°C (40°F). The record high and low are 42°C (107°F) in August 1909 and -32°C (8°F) in January 1949, respectively.

On a yearly average, on 116 days the temperature is 32°C (90°F) or above, and on 21 days the minimum is 0°C (32°F) or below. July 1980 broke all previous records for average monthly temperatures in San Antonio. The average temperature during the month was 31°C (88°F), compared with the previous high of 30°C (87°F), and average afternoon highs were 38°C (99.9°F).

Yearly precipitation averages 70 cm (28 in). Between 1892 and 1979, 14 years had drought periods that varied from 42 to 74 months. Rains are most likely in August and November and least likely in February, April, June, or July. In July 1980, rainfall totaled 0.06 cm (0.26 in).

Geologically, Bexar County lies in two major provinces. The northwestern part is on the Edwards plateau--usually hard limestone formations of the Cretaceous age with surface elevations up to 450 m (1500 ft) above sea level. The Edwards plateau is separated from the Gulf Coastal Plains by the Balcones fault, an escarpment that passes through the county in a northeast-southwest direction, defining the area's regional dip and its large faults. To the south are the softer clays, sandy clays, and sand deposits in the Midway, Wilcox Hills, Carrizo, and Gulf series (see Figure 3). The clays are frequently montmorillionites, illites, and bentonites. Elevations in the southern part of the county range from 150 to 180 m (500-600 ft). Stream terrace deposits cover much of the Gulf Coastal Plains and are usually of the Tertiary and Cretaceous ages. The county has 12 significant geological faults (6).

The WES map of Texas indicates that Bexar County has active expansive soils. An examination of the county map prepared by the Soil Conservation Service, however, emphasizes their diversity in the San Antonio area (see Figure 4) (6). This nonuniformity, as opposed to the desired homogeneity, should be remembered throughout these operations.

Earlier TSDHPT testing on US-90 in southwestern San Antonio involved ponding an expansive-clay subgrade. Water was held in dikes about 1 m (3.3 ft) high for 30 days to cause the clay to swell prior to

Figure 5. Subsurface profile of Interstate Highway Loop 410, Valley Hi Drive.

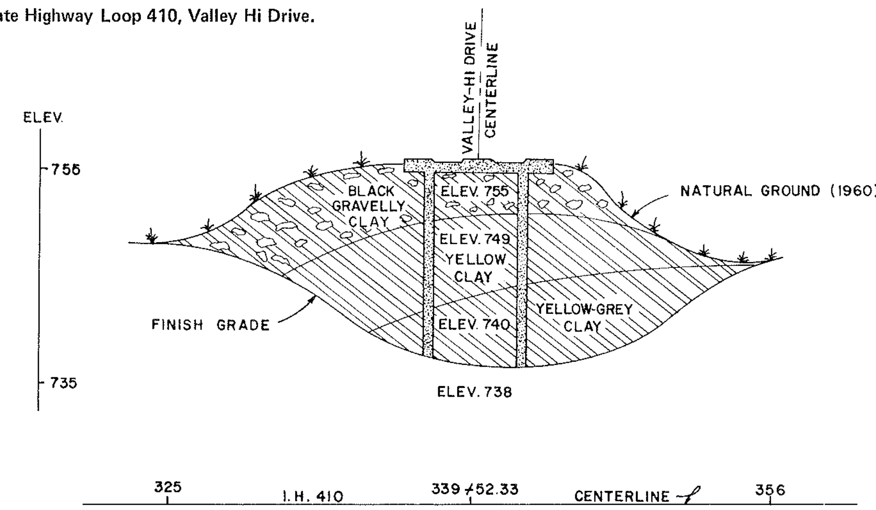



Table 1. Atterburg limits at selected sensor locations.

| Hole No. | Depth (m) | Liquid Limit | Plasticity Index |
|---|---|---|---|
| 2 | 0.6 | 70 | 42 |
| | 1.5 | 74 | 46 |
| | 2.4 | 72 | 42 |
| 3 | 0.6 | 79 | 46 |
| | 2.4 | 76 | 43 |
| 4 | 1.5 | 68 | 38 |
| | 2.4 | 73 | 43 |
| 10 | 0.6 | 71 | 43 |
| | 1.5 | 72 | 48 |
| | 2.4 | 70 | 44 |
| 12 | 1.5 | 74 | 38 |
| | 2.4 | 70 | 36 |
| 15 | 0.6 | 71 | 41 |
| | 2.4 | 56 | 29 |
| 16 | 1.5 | 50 | 28 |
| | 2.4 | 67 | 33 |

Note: 1 m = 3.3 ft.

Table 2. Moisture contents by depth of sensor placement.

| | Moisture Content (%) | | |
|---|---|---|---|
| Hole No. | 0.6-m Depth | 1.5-m Depth | 2.4-m Depth |
| 1 | 8.6 | 31.3 | 28.9 |
| 2 | 27.6 | 28.6 | 26.6 |
| 3 | 30.5 | -[a] | 27.8 |
| 4 | 24.1 | 27.7 | 27.2 |
| 5 | 7.7 | 28.7 | 29.6 |
| 6 | 32.5 | -[a] | 29.3 |
| 7 | 32.7 | 28.3 | 28.7 |
| 8 | 28.2 | 30.4 | 32.2 |
| 9 | 12.8 | 28.4 | 29.2 |
| 10 | 33.7 | 29.3 | 28.8 |
| 11 | 30.8 | 30.8 | 29.7 |
| 12 | 15.4 | 29.7 | 30.8 |
| 13 | 29.9 | 29.1 | 26.5 |
| 14 | 33.7 | 26.9 | 30.4 |
| 15 | 34.1 | -[a] | 23.6 |
| 16 | 23.9 | 25.1 | 31.2 |
| 17 | -[a] | -[a] | -[a] |
| 18 | -[a] | -[a] | 21.7 |

Note: 1 m = 3.3 ft.
[a]Not reported.

pavement placement. Observations over almost a decade indicated the "zone of activity" to be 2.4-3.1 m (8-10 ft) deep. Maximum moisture changes and elevation test-rod movements occur there. Beneath this zone, these changes appear minimal. Pavement surface maintenance was less over the ponded areas than in the adjacent control section (7).

LOOP 410

Description of Test

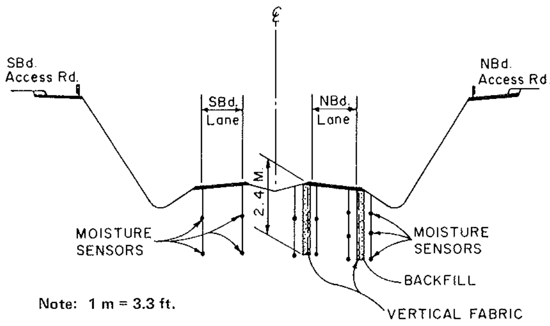
The first Texas highway test of deep vertical fabric as a moisture barrier was located on Interstate Highway Loop 410 in the Valley Hi Drive Interchange area in southwestern San Antonio. The questions to be answered included could the fabric be placed and would it do any good. If it helped, significant energy and dollar savings on maintaining transportation facilities could be achieved.

In this area, Loop 410 crosses an intermediate physiographic area, the Blacklands prairie. It is in the Taylor and Navarro group, lying between the Edwards to the north and the Gulf Coastal Plains to the south. The soils are the Houston Black and the Houston Association--deep calcareous, gravelly clays (see Figure 5). Their surface layers are usually black to grayish brown, about 35 cm (14 in) thick, with 8-15 percent gravel in the upper horizons; the depth in some profiles is 50-100 cm (20-40 in). There is a gradual change to a yellow-to-gray calcareous clay subsoil 75 cm (30 in) thick. It has medium-sized peds of natural aggregate that are angular and blocky and have shiny surfaces. Small, rounded quartzite gravel occurs in the surface layers. These clays are firm when moist and very sticky and plastic when wet. Atterberg limits, from samples taken when the sensor test holes were drilled, indicated liquid limits from 50 to 79, plasticity indexes from 28 to 48, and moisture contents from 7.7 to 34.1 percent (see Tables 1 and 2).

This Loop 410 section, built in 1960, is a four-lane divided highway constructed on 40 cm (16 in) of foundation course, 20 cm (8 in) of flexible base, and 7.5 cm (3 in) of type A and 5 cm (2 in) of type C hot-mix asphaltic concrete (HMAC) pavements. Both the northbound and southbound main lanes have two 3.6-m (12-ft) driving lanes, 3.9-m (10-ft) outside shoulders, and 1.2-m (4-ft) inside shoulders separated by a 13.2-m (44-ft) grassed median. Access roads parallel the main lanes (see Figure 6).

Since the construction of the Loop 410 section, swelling-soils activity has been reflected in this area in repeated asphaltic concrete level-ups, followed by more pavement distortions, more level-ups, "heater planner" work, irregularity in the curb profiles, and attemped pressure injection of lime.

Figure 6. Typical section of Loop 410.




When rehabilitation plans were being considered for Loop 410, TSDHPT decided to try something different. The WES project's Expansive Soils Technical Advisory Group, looking at potential cures for the clay problem, examined South Dakota's limited successes with the shallow-fabric moisture barrier (8). The decision was made to try placing the fabric through the zone of activity, as observed on the ponding project a few miles to the west. (It seems possible that this DVFMB may provide a basis for examination of the frost-heave problem.)

The Loop 410 rehabilitation contract awarded in June 1978 was 24.4 km (15.2 miles) long. It included an asphalt seal coat, 3.1 cm (1.25 in) of type C HMAC as a level-up, to be followed by 1.8 cm (0.75 in) of type D HMAC. The level-up actually placed varied from 2.5 to 30 cm (1-12 in). This low-bid \$3.8 million contract included a 0.8-km (0.5-mile) test section for the DVFMB.

The fabric was placed along the northbound lane. DuPont Typar (style T063) coated with ethylene-vinyl acetate (EVA) was specified and used. A spun bounded polypropylene with the EVA coating is 15.5 mils thick and weighs 34 $g/m^2$ (7.5 $oz/yd^2$). The DuPont fabric was placed 2.4 m (8 ft) deep at the edges of the outside and inside shoulders. Installation included tacking 0.6 m (2 ft) of the fabric to the paved shoulder with asphalt emulsion. The Typar is delivered in rolls 300 cm (117 in) wide. The diameter of each roll is 27 cm (10.75 in), and that of the core is 7.5 cm (3 in). A sand backfill was selected as being easily placed and compacted in a narrow trench.

Construction problems presented themselves. The contractor's initial attempt to place the material in December 1978 was not successful. A small, rubber-tired, tractor-type backhoe with outriggers and a D14 caterpillar maintainer with a special attachment for fabric placement were used. The maintainer carried the fabric roll horizontally and was able to rotate the material into the vertical position for trench placement. Unfortunately, it never placed any fabric on the project. After 6 m (20 ft) was excavated to a 3-m (10-ft) depth, a slide occurred that filled the trench (the clay contained considerable gravel). This serves as a reminder that site soils are frequently not uniform and the unexpected can always occur.

A second effort was made by a subcontractor on February 19, 1979. A larger crawler-type John Deere 690-B backhoe with a 0.6-m (2-ft) bucket was used. A Deere 920-930 front-end loader placed the sand backfill and loaded the excavated material on dump trucks to be hauled to a waste site. On the first day, 36 m (120 ft) of excavation had been completed when a slide occurred. A sliding steel shoring that used a 0.6-cm (0.25-in) plate that held the fabric roll vertically and was pulled by the backhoe was used to solve the problem. Placement, including the cutting and filling of a 0.9-m (3-ft) wide trench 2.7 m (9 ft) deep, averaged 105-120 m/day (350-400 ft/day). Fabric placement was completed on March 28, 1979. The \$66/m (\$20/ft) bid price reputedly did not cover costs.

After fabric placement, TSDHPT personnel placed moisture sensors inside and outside the protected area of the northbound lane and the adjacent southbound-lane control section on May 30 and 31 and June 28, 1979. Holes 30 cm (12 in) in diameter were drilled 2.4 m (8 ft) deep by using a Texoma Rotary rig at 18 locations--16 along the northbound main lane and two along the southbound control section (see Figure 7). In the fabric sections, the holes were located 0.9 m (3 ft) on either side of the material.

Two or three of the 46 Soil Test moisture cell (MC 374) sensors were placed at each location at depths ranging from 0.6 to 2.4 m (2-8 ft). The wires of the sensors were then extended, and the hole was backfilled. Slots for the wires were sawed in the pavement. The sensor wires were gathered in plastic bags at control sites drilled 0.9 m (3 ft) deep. A section of 20-cm (8-in) polyvinylchloride pipe provided a housing for the wire recovery and for reading with a Soil Test ohmmeter (model 305 B).

The sensors are 2.5 cm x 5 cm x 22 gauge (1 in x 2 in x 22 gauge). They have two stainless steel plates separated by a processed fiberglass pad that attracts moisture to the fiber surfaces. The moisture accumulates until an energy equilibrium is reached between the fibers and the soil, which reduces the electrical resistance of the fiberglass material between the plates. The resistance reading was made with a battery-operated, 90-cycle, AC-type meter. The sensors were calibrated at TTI in a potassium chloride solution so as to relate resistance (in ohms) to suction. These efforts were felt to be unsuccessful since they yielded nonuniform results.

Postconstruction problems have also appeared. The backhoe trench was 0.9 m (3 ft) wide. Two tractor-trailer trucks and a trailer house have sunk into the shoulder's soft sand. "Soft-shoulder" signs were used to no avail.

## Observations

Moisture-sensor readings, cross sections, roadway surface inventories, and photologging have been conducted, and regular testing schedules are planned.

For moisture-sensor readings, the wires from the sensors are attached to the ohmmeter and resistivity is recorded. The higher the reading, the greater are the resistance and the suction. This reflects a reduction in the moisture content of the soil sampled or a drying condition compared with the initial, possibly saturated, situations.

Readings were taken in May, June, August, and November of 1979 and in June and July of 1980. The subgrade was generally in a wet condition when the sensors were placed in 1979. In a wet condition, ohmmeter readings register little resistance to the passage of the current. As drying occurs, ohmmeter resistance readings increase (see Table 3).

The May 30, 1979, readings followed sensor placement in holes that could be drilled from the pavement because the shoulder subgrade was too wet from recent rains to support the equipment. The readings indicated fairly high values, a reflection of suction conditions, which indicated that the sensors had not yet been saturated by the surrounding soil.

All May 31 readings for the sensors placed the previous day decreased. The sensors were absorbing the moisture of the soil around them, and the readings reflected less suction and a higher moisture content. Sensors newly placed that day showed simi-

Figure 7. Sensor locations for Loop 410.

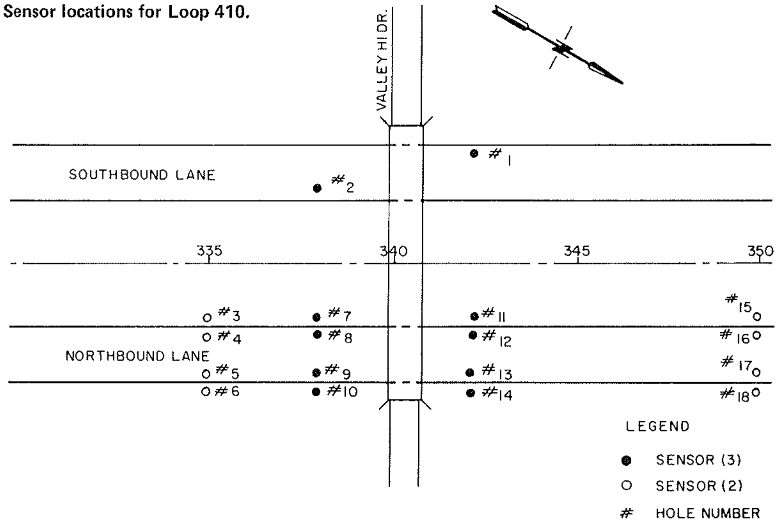



Table 3. Ohmmeter readings on I-410.

| Hole No. | Sensor No. | Depth (m) | Ohms (000s) 1979 5/30 | 5/31 | 6/28 | 8/15 | 11/14-15 | 1980 6/6 | 7/17 |
|---|---|---|---|---|---|---|---|---|---|
| Southbound Lane | | | | | | | | | |
| 1 | 01 | 2.1 | 260 | 20 | 0 | 0[a] | 0 | 6 | 4 |
| | 02 | 1.5 | 28 | 9 | 0 | 0[a] | 0 | 4 | 4 |
| | 03 | 0.6 | 280 | 10 | 0 | 0[a] | 63 | 40 | 600 |
| 2 | 04 | 2.2 | 120 | 0 | 0 | 0[a] | 0 | 0 | 1500 |
| | 05 | 0.9 | 300 | 0 | 0 | 0[a] | 5 | 0 | 1500 |
| | 06 | 0.6 | 165 | 0 | 0 | 0[a] | 11 | 5 | 1000 |
| Northbound Lane | | | | | | | | | |
| 3 | 07 | 2.4 | | | 500 | 0 | 0 | 0 | 0 |
| | 08 | 0.6 | | | 45 | 0 | 1500 | 0 | 0 |
| 4 | 09[b] | 2.1 | 800 | 17 | 0 | 0 | 0 | 0 | 21 |
| | 10[b] | 0.6 | 45 | 9 | 0 | 0 | 0 | 0 | 0 |
| 5 | 11[b] | 2.1 | 220 | 0 | 0 | 0 | 0 | 0 | 2 |
| | 12[b] | 0.6 | 350 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 13 | 2.1 | | | 47 | 0 | 0 | 0 | 0 |
| | 14 | 0.6 | | | 50 | 0 | 0 | 0 | 0 |
| 7 | 15 | 2.4 | | | 70 | 0[a] | 10 | 0 | 0 |
| | 16 | 1.5 | | | 150 | 0[a] | 0 | 0 | 0 |
| | 17 | 0.6 | | | 130 | 0[a] | 0 | 0 | 0 |
| 8 | 18[b] | 1.5 | | 0 | 0 | 0[a] | 0 | 0 | 240 |
| | 19[b] | 1.2 | | 0 | 0 | 0[a] | 0 | 0 | 10 |
| | 20[b] | 0.6 | | 0 | 0 | 0[a] | 0 | 0 | 0 |
| 9 | 21[b] | 2.1 | | 0 | 0 | 0[a] | 0 | 0 | 0 |
| | 22[b] | 1.5 | | 0 | 0 | 0[a] | 0 | 0 | 9 |
| | 23[b] | 0.6 | | 0 | 0 | 0[a] | 0 | 0 | 0 |
| 10 | 24 | 2.4 | | | 0 | 0[a] | 0 | 0 | 0 |
| | 25 | 1.5 | | | 38 | 0[a] | 0 | 0 | 0 |
| | 26 | 0.6 | | | 196 | 0[a] | 1500 | 0 | 0 |
| 11 | 27 | 2.4 | | | 300 | 0[a] | 7 | 5 | 1500 |
| | 28 | 1.5 | | | 450 | 0[a] | 0 | 0 | 1500 |
| | 29 | 0.6 | | | 5 | 0[a] | 40 | 12 | 1500 |
| 12 | 30[b] | 1.8 | 25 | 0 | 0 | 0[a] | 1 | 0 | 2 |
| | 31[b] | 0.9 | 175 | 0 | 0 | 0[a] | 0 | 0 | 0 |
| | 32[b] | 0.6 | 200 | 6 | 0 | 0[a] | 4 | 4 | 2 |
| 13 | 33[b] | 2.1 | 0 | 0 | 0 | 0[a] | 0 | 0 | 300 |
| | 34[b] | 1.2 | 280 | 0 | 0 | 0[a] | 0 | 0 | 0 |
| | 35[b] | 0.6 | 425 | 0 | 0 | 0[a] | 3 | 0 | 0 |
| 14 | 36 | 2.4 | | | 282 | 0[a] | 0 | 0 | 0 |
| | 37 | 1.5 | | | 72 | 0[a] | 0 | 0 | 350 |
| | 38 | 0.6 | | | 775 | 0[a] | 0 | 0 | 4 |
| 15 | 39 | 2.4 | | | 600 | 0 | 0 | 0 | 0 |
| | 40 | 0.6 | | | 450 | 0[a] | 40 | 1500 | 55 |
| 16 | 41[b] | 2.1 | 150 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 42[b] | 0.6 | 800 | 80 | 0 | 0[a] | 2 | 3 | 2 |
| 17 | 43[b] | 2.1 | 0 | 0 | 0 | 0[a] | 0 | 0 | 0 |
| | 44[b] | 0.6 | 0 | 0 | 0 | 0[a] | 0 | 0 | 0 |
| 18 | 45 | 2.4 | | | 0 | 0 | 0 | 0 | 0 |
| | 46 | 0.6 | | | 260 | 0[a] | 6 | 0 | 49 |

Note: 1 m = 3.3 ft.
[a]Assumed. [b]Sensor not outside fabric.

lar ohm readings and indications of high moisture content.

After a drying period, the portable rig was able to drill the rest of the test-hole sites on June 28, 1979. These newly placed sensors were all located along the northbound lane outside of the fabric-protected subgrade. The significant ohmmeter readings obtained reflected the dry placement condition of the sensors and delay in absorbing soil moisture.

The August 15, 1979, observations followed a rainy spell. All sensors that were read indicated no resistivity values, a high-moisture condition. The November 1979 and June 1980 observations were regularly scheduled. The July 1980 observations followed a month of record-breaking high temperatures.

The unprotected southbound lane showed a higher percentage of increased resistivity readings than the fiber-protected northbound lane. This is attributable to possible subgrade drying from the in- itial saturated condition. Sensors outside the fab- ric along the northbound lane also reflected less drying than the sensors along the unprotected lanes.

The ohmmeter observations are summarized below:

| | Sensors Showing Increased Resistivity (%) | | |
|---|---|---|---|
| Location | November 1979 | June 1980 | July 1980 |
| Southbound lane (unprotected) | 50 | 66 | 100 |
| Northbound lane | | | |
| Inside fabric (protected) | 20 | 10 | 45 |
| Outside fabric (unprotected) | 35 | 15 | 35 |

This summary shows increasing resistivity in the southbound lane. By July 1980, 100 percent of the sensors in that lane indicated resistance readings whereas 35-45 percent of the sensors in the northbound lane showed resistance readings.

The movement of water through a pavement is a problem to be considered (9,10). Use of rubberized asphalt on the I-37 project may reduce the intrusion, or loss, of moisture from above the subgrade.

Were the moisture variations reflected in reduced pavement movements? These movements were measured in two ways: by readings with a profilometer, computerized to a serviceability index (SI), and by taking elevations over time with a level and a rod.

On the profilometer index, 5.0 is the perfect, smooth-riding pavement. As the ride becomes rougher, the readings become lower and the SIs decrease. The profilometer readings are taken for the inside and outside lanes of both the northbound and southbound lanes. The readings were taken in June 1979, November 1979, and August 1980. The best mean reading--an SI of 4.12--was taken in June 1979 on the protected northbound outside lane. The comparable reading for the southbound lane was 4.07.

The later readings, in November 1979 and August 1980, reflect continued "better" SIs on the protected northbound lane: The readings for this lane were 4.00 and 3.83 compared with readings for the unprotected lanes of 3.66 and 3.34. The increased roughness of the unprotected southbound lane is much more pronounced than that of the protected lane.

The mean SIs are given below:

| Lane | June 1979 | November 1979 | August 1980 |
|---|---|---|---|
| Northbound (protected) | 4.12 | 4.00 | 3.83 |
| Southbound (control) | 4.07 | 3.66 | 3.34 |

In the second method of measurement, field readings of pavement elevations were taken at the northbound and southbound-lane centerlines and crown points at the stations and their midpoints in June of 1979 and 1980. If one averages the changes, disregarding the signs of a plus or minus variation, little variation between the pavements is indicated. The southbound lane had average variations of 0.92, 1.22, and 1.53 cm (0.037, 0.046, and 0.055 ft) at left crown, centerline, and right crown, respectively; average variations for the northbound lane were 1.23, 1.22, and 1.25 cm (0.047, 0.046, and 0.049 ft), respectively. The protected lane was showing a little more averaged pavement movement, but the "unprotected" southbound lane had greater variations (see Table 4). The variations are minimal and not decisive at this time.

Movements were measured at 55 stations and, of the 165 total readings on the northbound and southbound lanes, only 116 were in the 0- to 1.5-cm (0.0- to 0.04-ft) range. The maximum change was 7.6 cm (0.25 ft) (there were only three readings in that range), and there were only 9 and 13 readings between 4.9 and 6.1 cm (0.1-0.20 ft).

Photologging was done in July 1980. Pictures were taken with a Nikkon camera mounted on a frame 2.4 m (8 ft) above the pavement. The frame was on a trailer pulled by a sedan. A photograph was taken every 2.4 m, and these were later projected on a screen and the areas of pavement cracking were computed.

The photologging reflected pronounced differences. The northbound, protected pavement had cracking in 0.01-0.07 percent of its surface area, and the southbound lane had cracking in 0.24-0.73 percent of its surface area.

The visual pavement inventory was also conducted in July 1980. The majority of the cracking seemed to be taking place over the outside shoulder of the northbound lane over the sand-backfilled trench. No significant crack patterns have become apparent in the riding lane (see Figure 8).

The fabric was placed on the Loop 410 project at a rate of 105-120 m/day (350-400 ft/day) and was completed on March 28, 1979. The entire project was finished on July 19, 1979. There was concern about the rate and the cost of placement, partly because expectations were higher and also because the contractor voiced the sentiment that the $66/m ($20/ft) received on the Loop 410 project did not cover the cost.

## Trenching-Machine Test

The use of a trenching machine in place of a backhoe had been suggested. An area equipment supplier offered its Vermeer 600 for use in a free demonstration, claiming that it would place 1515 m/day (5000 ft/day) in a pure clay to a depth of 2.4 m (8 ft). A test section was chosen on I-37 about 1.6 km (1 mile) south of Loop 13 in southeast San Antonio. The supplier built a special boom attachment to hold a roll of the Typar EVA fabric vertically, 2.4 m into the trench. A steel-plate sliding shoring was used with a boom-pivoted frame. The roll was held in a vertical position in the trench, and the material spread out behind it as the machine advanced. A narrower trench width than the backhoe provided--30 cm (1 ft)--was maintained. The first afternoon's trial averaged 0.6-0.9 m/min (2.3 ft/min). The second day's average increased to

0.9-1.05 m/min (3-3.5 ft/min) in a clay that had considerable gravel. A slide 6 m (20 ft) long, with a 20- to 25-cm (10- to 12-in) vertical roadway shoulder drop, occurred about 6 m behind the machine on the second day. Fabric placement was not impeded. Representatives providing the demonstration felt that in a clay without gravel they could excavate 2.4 m in depth at a rate of 1.8 m/min (6 ft/min), for a 10-h-workday rate of 1080 m (3600 ft), considerably better than the backhoe provided.

I-37

The largest placement of a deep vertical moisture barrier on a Texas highway has recently been completed on I-37 in San Antonio (see Figure 9). North of the trenching test, the project area has been experiencing a substantial swelling-clay movement since its construction 12 years ago. The movements have been reflected in severe distortions in the riding surface, median guardrail, and curbs and some slope slides.

These I-37 sections are generally in very active clays of the Houston Black series. Their plasticity indexes average 54 and their liquid limits 86.

In the contract area, I-37 is an eight-lane divided highway. The main lanes are separated by a sodded median 8.4-10.8 m (28-36 ft) wide that has a 0.9-m (3-ft) concrete median ditch and a steel median barrier guardrail. Each lane is 3.6 m (12 ft) wide and has a 3.0-m (10-ft) outside and a 1.8-m (6-ft) inside shoulder.

The main lanes were constructed on 15 cm (6 in) of lime-stablilized subgrade, 20 cm (8 in) of cement-stabilized base, and 20 cm of concrete

**Table 4. Changes in pavement elevation.**

| | Number of Readings | | | | | |
|---|---|---|---|---|---|---|
| | Southbound Lane | | | Northbound Lane | | |
| Change (cm) | Left Crown | Centerline | Right Crown | Left Crown | Centerline | Right Crown |
| 0.0-1.5 | 44 | 37 | 35 | 37 | 40 | 39 |
| 1.8-3.0 | 3 | 10 | 8 | 8 | 4 | 5 |
| 3.3-4.6 | 6 | 4 | 8 | 6 | 6 | 5 |
| 4.9-6.0 | 1 | 4 | 4 | 4 | 4 | 5 |
| 6.3-7.6 | 1 | 0 | 0 | 0 | 1 | 1 |
| ≥7.9 | 0 | 0 | 0 | 0 | 0 | 0 |

Note: 1 cm = 0.39 in.

pavement. The vertical alignment of the main lanes varies from a 6-m (20-ft) embankment to a 6.6-m (22-ft) excavation below natural ground. The clays have caused repeated asphaltic concrete level-ups, heater planner work, and construction of retaining walls to contain the slides. The present rehabilitation contract includes a rubberized asphalt seal coat, asphaltic concrete level-ups, and finish course and reconstruction of the median to provide positive drainage from a built-up section with a concrete jersey-type median barrier. It also includes placement of a DuPont Typar T063 EVA-coated waterproof DVFMB placed 2.4 m (8 ft) deep in trenches outside the shoulders of the northbound and southbound lanes. A 15-cm (6-in) perforated underdrain pipe is placed in some areas outside of the fabric. The fabric trench is backfilled with gravel, and the top 0.9 m (3 ft) is cement stabilized. The project contract called for the placement of 19 000 m² (23 753 yd²) of the fabric.

A testing schedule has begun with the first profilometer run prior to contract work. The profilometer tests will be supplemented by the use of psychrometers (Moisture Control Systems series 6000) for moisture readings both inside and outside the fabric-protected sections and by cross sections, roadway surface inventories, and photologging. The area monitored will be within the contract limits as well as adjacent sections to serve as control elements.

The contract bids were opened on October 26, 1979. The low-bid price for the fabric work was \$25/m² (\$21/yd²). This compared not unfavorably with the \$66/m (\$20/ft) bid for this work on Loop 410 two years previously. The successful low bidder and contractor, Houston Bridge Company, engaged as a subcontractor for the placement work of the fabric Utilities Consolidated, Inc. (UCI), the same organization that did the Loop 410 work.

This time, UCI used a Parson's 500 trenching machine with a special attachment to move the excavated material directly from the trencher to a dump truck. The boom of the trenching machine was fitted with a sliding shoring to hold the Typar roll vertically in the excavation and unroll it as the machine progressed. A portable paving machine batched the one-sack cement-stabilized base that topped the trench's gravel backfill.

UCI began placing the DVFMB on February 4, 1980, and completed it on May 21, 1980. On their best day, they placed 147 m (485 ft) of fabric. Soil conditions, several locations in sandstone rock and

**Figure 8. Pavement surface inventory for Loop 410.**

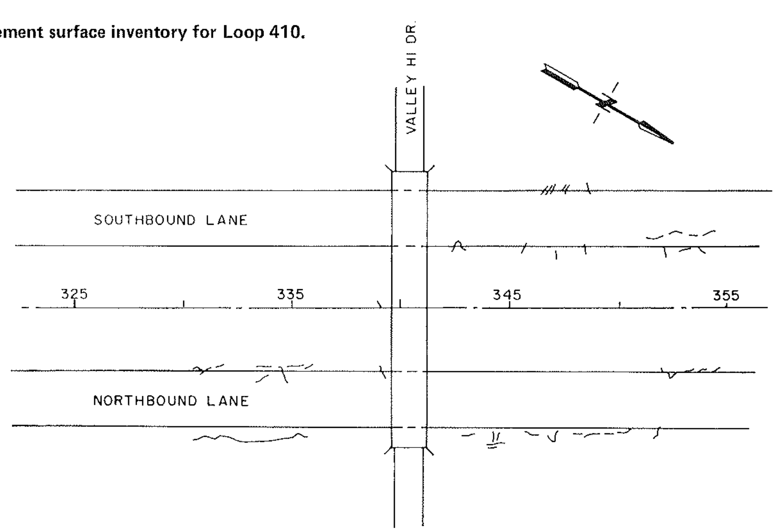
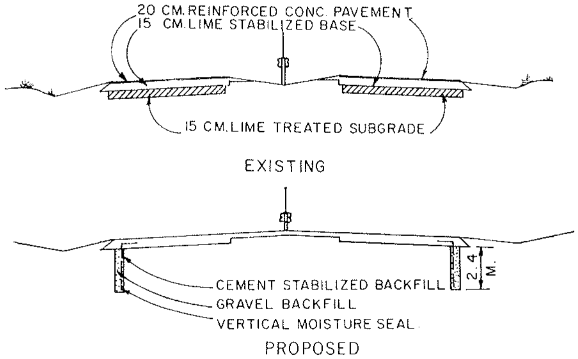


Figure 9. Existing and proposed sections of I-37.




boulders, utilities, drainage structures, and possibly the psychological effect of trying to meet the goal of 107-120 m/day (350-400 ft/day) all retarded productivity. There was little downtime due to weather conditions or machinery breakdown. UCI averaged 106.75 m/day (350 ft/day), no better than the production on Loop 410.

The subcontractor has said that if the specifications for the backfill were less rigid the work could be done for perhaps $50/m ($15 or $16/ft). This would represent a considerable cost reduction. A planned placement on US-90 in southwest San Antonio will provide an additional opportunity to make the performance of this work more economical.

## CONCLUSIONS

The DVFMB holds promise as a possible solution to the problem of swelling soil or expansive clay. Moisture barriers may provide energy and dollar savings for transportation facilities including roadways, railways, runways, canals, and other structures built in swelling soils. The Loop 410 highway section on which the DuPont Typar T063 EVA-coated fabric was used as the deep barrier has shown better riding qualities (as measured by serviceability indexes) and less pavement cracking (as revealed in photologging tests). The moisture sensors also indicated greater changes on the control section than in the Typar-protected subgrade. Results to date show that the fabric can be placed, and its impacts continue to be assessed with guarded optimism.

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