FURTHER MONITORING OF TWELVE GEOMEMBRANE SITES IN TEXAS

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16. Abstract

EXECUTIVE SUMMARY

Geomembranes may help solve the expansive soils problems. Expansive soils are global. Reports of damages from these soils have come from China, Australia, Egypt, Canada, Israel, India, South Africa and the United States. Conservative estimates of the damages caused by the expansive soils, frequently a swelling clay, in the United States exceed $10,000,000,000 a year. Over fifty percent of these damages occur on our nation's highways and streets. Additional damages are caused by these soils to other transportation facilities including airport runways, canals, sidewalks, railroads and pipelines.

To seek ways to minimize these destructive soil movements, the Texas State Department of Highways and Public Transportation has engaged in a prolonged, continuing effort. Field testing and laboratory work by others had indicated the possibility that minimizing the subgrade moisture change would reduce pavement damage. Geomembranes, impervious engineering fabrics, have been used in tests on the highway system across the state. Geomembranes were first used in Texas in 1976 to control swelling clays. Other projects followed. An initial test involved the horizontal use of the fabric, while others used a deep vertical moisture barrier. Twelve geomembrane sites are being monitored. Monitoring by profilometers (computer reduced to serviceability indices), instrumenting for moisture sensors, and photologging to compare the amount of surface cracking have been used to assess geomembrane effectiveness. Many indications are positive that geomembranes can control the destructive impacts as indicated from serviceability indices. They probably are cost effective. Some results do raise concerns, though none seem insurmountable.

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By Malcolm L. Steinberg

District 24

Texas State Department of Highways
and Public Transportation

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EXECUTIVE SUMMARY

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To seek ways to minimize these destructive soil movements, the Texas State Department of Highways and Public Transportation has engaged in a prolonged, continuing effort. Field testing and laboratory work by others had indicated the possibility that minimizing the subgrade moisture change would reduce pavement damage. Geomembranes, impervious engineering fabrics, have been used in tests on the highway system across the state. Geomembranes were first used in Texas in 1976 to control swelling clays. Other projects followed. An initial test involved the horizontal use of the fabric, while the other eleven used a deep vertical moisture barrier. Twelve geomembrane sites are being monitored. Monitoring by profilometers (computer reduced to serviceability indices), instrumenting for moisture sensors, and photologging to compare the amount of surface cracking have been used to assess geomembrane effectiveness. Many indications are positive that geomembranes can control the destructive impacts as indicated from serviceability indices. They probably are cost effective. Some results do raise concerns, though none seem insurmountable.

PROCEDURES

The use of engineering fabrics is increasing. They provide the engineer with a new variety of tools to meet the increasing challenges of society today. Geomembranes are but one segment of the engineering fabric galaxy. They provide an impervious barrier that is potentially useful in a variety of engineering situations. One that is addressed in Texas is dealing with expansive soils, frequently observed as swelling clays.

Expansive soils are a worldwide problem. Reports on their destructiveness, as well as attempts to control them, have come from China, Australia, Egypt, Canada, Israel, India, Belgium, South Africa and the United States. These soils have been the subject of international conferences, Transportation Research Board, Federal Highway Administration, university and highway department meetings, studies, text books and reports.(1,2,3,4,5,6,7,8,9,10,11)

In the United States, these expansive soils are identified in all but six of the contiguous states.(12) They extend from coast to coast, from border to border. Expansive soils damages were estimated to cost $7 to $9 billion a year in 1980.(1) Today the cost must easily exceed $10,000,000,000. More than half of these damages occur to highways and streets. Significant amounts occur to other transportation facilities such as airport runways, railroads, canals, pipelines and sidewalks.

Several techniques have been, and are being, used to minimize these damages. Where possible, engineered facilities can be located to avoid these expansive soils. These soils, frequently swelling clays, extend across the state (fig. 1). Climatic conditions, rainfall, evaporation rates, temperature variations, all play a part in the damages. Only the generally mountainous areas in the southwest sections seem immune.(12) Yet even in far west Texas, in El Paso, in neighboring Hudspeth and Culberson Counties, these swelling clays appear and roadways take on the all too familiar washboard effect.

Minimizing the moisture changes in the swelling soils led to the twelve Texas tests and trial sections using geomembranes (fig. 2). The early test sections were in the San Antonio area in south central Texas. An initial test in 1976 used a geomembrane horizontally on the subgrade of an urban systems project.

Subsequent projects used the impervious fabrics as deep vertical fabric moisture barriers.

One of the test sections in northeast Texas compared the deep vertical fabric moisture barriers (DVFMB) at 6 and 8 foot depths with lime and lime fly ash barriers. Costs and more detailed construction information on many of the test sites can be found in earlier publications.[13, 14, 15, 16, 17]

Generally, placing the fabric vertically 8 feet deep was done at daily rates varying from 600 to 2000 feet in length. Bid prices ranged from $10 to $25 per lineal foot. This study will note the data available to date and offer observations and conclusions.

One of the basic questions was: would the geomembrane retard the destructive movements of the expansive solid? This was followed by a variety of questions that included: how is this to be measured? Particularly in the case of the deep vertical fabric moisture barrier, could the geomembrane in fact be placed? Initially, fabric effectiveness was measured in a variety of ways. Dynaflect tests have been conducted prior to pavement rehabilitation and then as part of the finished roadway. These tests were used on the first Texas geomembrane project. Photologging was also used in the early projects. The amount of surface cracking could be compared from section to section by this method. Sensors were used to determine whether the fabric helped minimize moisture change in the subgrade underneath the pavement as compared to the unprotected area on the outside. Profilometer testing was used. The profilometer readings were taken on a moving vehicle with a recording device. They were computer reduced to serviceability indices (SI). A maximum smooth surface was rated 5.0 with decreasing values indicative of roadways suffering more distortions.

Another question was why the depth of 8 foot embedment was chosen for the deep vertical fabric moisture barrier. This resulted from previous testing on a ponded area located on U.S. 90 in San Antonio.[13] Repeated testing over a decade-long period indicated that the maximum moisture changes occurred from the surface to a depth of 6 or 8 feet. These moisture changes range from 5% to 35%. This was considered a zone of activity. The range below 8 feet indicated that instead of the 30% change, a variation of 4% to 6% occurred.

GENERAL McMULLEN DRIVE

The first Texas test with the geomembrane occured on General McMullen Drive, an urban system project located in west central San Antonio.[14] The pavement had shown severe distortions due to the swelling clays. Dupont Typar 3353 and Typar 3153, donated by the manufacturer, were placed horizontally on generally 600 foot test sections. Adjacent 600 foot sections to the north and south were used for control. Dynaflect tests were conducted prior to the placement of the fabric. These tests were used to compute stiffness coefficients, maximum deflections and spreadability indices.

The initial subgrade tests taken in 1973 indicated the area where fabric was placed to have stiffness coefficients equal to the adjacent sections, greater maximum deflections and higher spreadability indices, all indicative of a weaker section. Following placement of the fabric, the geomembrane pavement segment indicated a stronger section in Dynaflect tests. Profilometer readings were taken initially in 1981 (fig. 3). The latest readings were in 1987. Averaging the outside, center and inside lanes of the six-lane arterials of both the control and fabric-protected sections generally shows the geomembranes provide the higher SI's. The averages reflected the pattern. There is a decrease in SI's for all sections with time. Some of the increases in the indices are not reflected by improvements in the pavement. This would indicate some lack of consistency in the profilometer readings. As the vehicle moves through an urban area with cross streets it is difficult to maintain the uniform speeds required to get ideal readings.

INTERSTATE 410

Interstate 410 in the vicinity of Valley High Drive undercrossing in San Antonio was the first Texas SDHPT section where the deep vertical fabric moisture barrier (DVFMB) was used.[15] Subgrade Atterburg limits included liquid limits (L.L.) of 50 to 79 and plasticity indices (PI) from 28 to 48. In 1978, a half-mile long section of the northbound lane of the four-lane divided highway had fabric placed 8 feet deep along both shoulders (fig. 4). Bid price for the fabric in place was $20 per lineal foot. The median ditch remained, and the adjacent southbound lane without the fabric was used as the control section. The contractor excavated the trench with a backhoe. A sliding shoring was developed that held the roll of a

Dupont Typar T063, a spun-bonded polypropylene with ethyl vinyl acetate coating, vertically while restraining subgrade movement. Moisture sensor testing, photologging and profilometer testing were conducted. The Soiltest MC 374 moisture sensors were placed inside and outside of the fabric at depths of 2 through 8 feet, along both lanes. Readings generally indicated greater moisture changes in the unprotected southbound lane subgrade than under the northbound lane. Irregularity and total nonresponse led to the abandonment of these moisture readings.[16]

Photologging began in August 1980. Photographs were taken covering 8-foot lengths along each of the lanes. In the first 3 years, photologging indicated that there was significantly less pavement cracking in the fabric protected lanes. This testing has since ceased.

The profilometer tests indicated that the northbound lane consistently had a higher SI than the southbound lane (fig. 5). Generally, there has been a steady decline in the indices in both lanes. In 1981, level up work was done on both lanes by department maintenance forces. One hundred tons of asphaltic concrete were used on the northbound lane, while two hundred tons were used on the southbound. As the profilometer tests continued, the northbound lane continued to show higher SI's. In 1986, the section was part of a complete rehabilitation with roadways being added both to the north and southbound lanes in a widening project. This time the southbound lanes also received protection with the fabric.

INTERSTATE 37

Interstate 37, from South Hackberry Street to Pecan Valley Drive in southeast San Antonio, is a two-mile section that had proved to be a significant maintenance problem. A minimum of $50,000 a year had been spent on leveling up the concrete pavement severely distorted by the expansive soils. The section had an excavated depth up to 25 feet below natural ground and had subgrade PI's between 34 and 59 with LL's ranging from 56 to 92. This rehabilitation project in 1980 had the median ditch removed, positive drainage established across the roadways, an asphalt seal followed by asphaltic concrete level up and 23,750 feet of a deep vertical fabric moisture barrier, Dupont Typar T063, placed along the outside shoulders of both mainlanes (fig. 6). The contractor's fabric bid price was $21 per square yard. Testing with moisture sensors, photologging and profilometer followed. Moisture Control Systems Series 6000 Sensors were installed at four locations, two inside the fabric protected sub-grade and two outside. Readings indicated high moisture levels from the time of initial measurement. The sensors outside the fabric showed significant moisture changes while those inside showed little variation.[17] Within a two-year period, most of the sensors became inoperable and their use was discontinued.

Photologging revealed little surface cracking. Two 1750 foot sections on the north and southbound lanes were used to compare the fabric-protected roadway with the adjacent controls. The fabric sections showed less surface cracking than the controls with no fabric protection.

Profilometer readings began in 1979 (fig. 7). They show that the sections to be rehabilitated had significantly lower SI's than the adjacent control lanes. Following the rehabilitation and installation of the fabric in mid-1980, the geomembrane-protected section showed uniformly higher values indicating a smoother riding surface. Rehabilitation work and asphaltic concrete level up was done on the north-bound control during late 1983. The work resulted in higher SI's than the fabric section. There is some discontinuity in these readings on the south control with improved SI's though no maintenance was done. This is difficult to explain. In general, all sections show a decrease in the SI's. No maintenance expenditures on the roadway surface of the fabric-protected lanes have been required through 1988.

US 281

US 281, in north central San Antonio, was the next section to receive a deep vertical fabric moisture barrier to control the destructive swelling clay movements. The subgrade had PI's from 25 to 58 and LL's from 47 to 80. The southbound lanes just south of Interstate 410, underpassing the Airport Boulevard connection, required rehabilitation.[16] The fabric moisture barrier, a Mirafi MCF 500 consisting of a woven polypropylene with polypropylene film coating, was placed 8 feet deep along both the inside and outside shoulders. The contractor chose to use a backhoe to excavate the fabric trench. Progress was slow. There was no problem with sliding of the trenched subgrade.

Following completion of the project, profilometer tests were conducted. Since placement in 1984, the fabric-protected southbound lane has maintained relatively uniform serviceability indices. The adjacent "unprotected" northbound lane had sharply decreasing indices. They were lower than the fabric section until a rehabilitation project in 1987, with an asphaltic concrete level up, improved its ride considerably (fig. 8).

SH 97

South of San Antonio, SH 97 in Atascosa County, near Charlotte, experienced considerable deterioration of its pavement surface. As there were expansive clays in the subgrade, a rehabilitation contract was awarded in 1986 to place 5600 feet of deep vertical fabric moisture barrier and asphaltic concrete level up for the flexible pavement. The contractor used a Vermeer trencher to cut the ditch for the Dupont geomembrane. A gravel backfill was used. The fabric operation's unit price was $10 per lineal foot and the average daily rate of placement was 700 feet. Reports indicated the pavement has since cracked severely in the entire half mile section where the fabric was placed (figs. 9 & 10). Adjacent structures have suffered similarly. Further studies have revealed considerable faulting in the area. This may have negated the value of the fabric barrier. No other test results are presently available. (A.G. Clement & Ace Farrer, unpublished data).

IH 10 PINE TO AMANDA IN SAN ANTONIO

This section of Interstate 10 on San Antonio's east side was having its pavement reflect the destructive movement of the swelling soils. The expansive clays had PI's between 35 and 55; LL's from 65 to 75. Considerable distortation and asphaltic concrete level ups were required on this important arterial. Rehabilitation work in 1985 included deep vertical fabric moisture barriers. The 21,500 lineal feet of Mirafi geomembrane were placed 8 feet deep along both shoulders of the east and westbound main lanes. A trenching machine excavated the material. Fabric was placed and backfilled at an average rate of 250 feet a day. Bid price for the work was $15 per lineal foot. Serviceability indices from profilometer testing begun in 1985 indicate the fabric-protected sections are maintaining higher values than the adjacent control sections. Both the east and west controls showed severe deterioration (fig. 11). No additional maintenance has been required, reflecting a considerable step forward. (R.E. Magers, unpublished data.)

IH 10 FROM ACKERMAN ROAD TO CIBOLO CREEK

This section of Interstate 10 in eastern Bexar County received 131,200 lineal feet of a deep vertical fabric moisture barrier in 1986. A Phillips Geoseal fabric was used on the 13-mile rehabilitation project. The bid price for the work was $13 per lineal foot. A trenching machine was used with an average placement rate of 900 lineal feet daily and a maximum one-day total of 2195 lineal feet. Severe problems have developed. Originally, the backfill was to be limestone screenings with a foot cap of cement-stabilized base. When screenings did not become available in quantity, permission was granted the contractor to use base scalpings. Shoulder cracking developed and depressions followed (figs. 12, 13 & 14). Investigation revealed a collapse was caused by voids developing beneath the stabilized base and scalpings. The inside shoulders were particularly severely affected. Depressions of 1 inch to 6 inches, 4 feet into the shoulder, 2 to 6 feet long occurred. Possibly, the base scalpings did not receive sufficient compaction. Plans are underway to check nondestructively the areas where this is occurring. The pavement ride remains very good. No profilometer testing has taken place. (Dale Stein, unpublished data).

IH 10 SANTA CLARA CREEK

In 1987, 12,000 feet of fabric were placed along Interstate 10 at Santa Clara Creek between San Antonio and Seguin to retard the expansive soil that caused pavement deterioration. In this short time period, no problems have developed. The trench backfill was a washed gravel. No testing was conducted. (Dale Stein, unpublished data).

FM 465 IN GUADALUPE COUNTY NORTH OF SEGUIN

This section of Farm to Market Highway 465 in Guadalupe County, north of Seguin, used 3100 feet of Dupont Geomembrane fabric that had been in the SDHPT'S district stores. The contractor dug the fabric's trench with a backhoe. Following fabric placement, a gravel backfill was used. The average daily progress was 200 feet. The price for the work was $10 per lineal foot. The repair has been in place since 1986 and is holding up very well. Prior to this time, repeated level ups with asphaltic concrete frequently showed distortion within a month of the rehabilitation being completed. Although in a high clay subgrade area, no rehabilitation nor pavement distortion have taken place since fabric placement. (Dale Stein, unpublished data.)

IH 30 NORTHEAST OF DALLAS AND GREENVILLE

Testing is also continuing in northeast Texas along Interstate 30 near Greenville. This section of highway was built in the early 1950s with 10-inch concrete pavement on 6 inches of roadbed treatment. It had been overlaid and leveled up with asphaltic concrete in depths varying from 4 inches to 22 inches. The 1984 rehabilitation contract was 10 miles long. Four types of vertical moisture barriers, two fabric and two lime slurries, were involved. Each test section was 1000 feet long. The barriers were placed on both of the eastbound lanes, with the unprotected adjacent westbound lane serving as the control section. The Dupont Typar polyethylene fabric was placed along the inside walls of the trenches, folded and tacked with bitumen to the shoulders. These test trenches were backfilled with native soil to within 2 feet of the finished grade, and capped with one sack concrete. The fabric sections were 6 and 8 feet deep. The low bidder's price for the fabric was $10 per square yard, and $62 per cubic yard for the stabilized material, for a cost of $27.17 for a roadway centerline foot. The placement rate was 1000 feet of fabric a day. Injected lime slurry barriers were placed in 3 staggered rows, one foot apart, parallel to the travel lanes. One section had a lime slurry, the other a lime and fly ash slurry. The lime, type A hydrated, was mixed at a rate of 2.5 pounds per gallon of water. The fly ash used was 3 pounds with 1.25 pounds of lime to a gallon. The bid of these lime injections was $12.75 per centerline foot. The fabric and slurry sites were in the same general soil type but were 3 miles apart. Atterburg limits varied. In the fabric barrier areas, LL 's ranged from 55 to 98, PI 's from 34 to 70, and in the injection barrier sites, from 60 to 90 and from 40 to 75 respectively. (H.P. Black, unpublished data). As part of this planned stage construction on Interstate 30, a 3/4 inch open-graded friction course was placed over all sites in August 1986. Profile measure-ments and serviceability indices measured after that date must be regarded as starting from a new datum. Matrix suction measurements were made with the Aqwatronics thermal moisture sensors. Problems developed in checking the manufacturer's calibration equation.

All sections developed a rougher ride in the two years since the installation of the barriers. Serviceability indices indicated barrier sections became rougher at a faster rate than the control sections. The authors assess this phenomenon as an indication of the ability of the barriers to retain moisture beneath the pavements. Both fabric barriers were not quite as effective as the lime fly ash slurry section in controlling moisture loss. The barrier sections are viewed as retaining moisture beneath the pavements, swelling more and approaching moisture equilibrium faster than the control sections. The 8-foot deep fabric barrier was considered better than the 6-foot fabric in preventing moisture exchange beneath the pavement.[18]

Coring and excavation in the lime sections have indicated that a "curtain" was not achieved. Visual indications were the slurries followed existing soil cracks, fissures and seams.

Later testing offers the conjectures that barriers placed along each side of the pavement will permit the moisture beneath to move more quickly toward a more stable condition. The barrier pavement may become rougher at a faster rate than others. However, in the long term, they will achieve a stable moisture condition making subsequent overlays and level up courses more effective. This test period reports 2 years' tests and further results are awaited.[18]

IH 10 HUDSPETH COUNTY

In 1984, a rehabilitation contract was awarded on IH 10 in Hudspeth County. When the project was initially constructed two decades earlier, the presence of active clay subgrades in the area were identified. Plasticity indices varied from 23 to 35 in a dark brown, fissured clay and from 30 to 59 in a light grey to green clay, thought to be bentonitic. The construction undercut the finished subgrade 5 feet, removing the expansive clay, and replacing it with an inactive material. For a decade, the pavement remained stable. Then the clay's activity began to distort the pavement. The remedial contract included placement of 50,000 lineal feet of a vertical fabric moisture barrier. The geomembrane was placed 8 feet deep along both shoulders of the east and westbound lanes. A Dupont Typar style 3358 EVA coated polypropylene was used. The contractor who bid $13.28 per lineal foot for the fabric work used a Vermeer 600 trencher with a side conveyor belt for loading the excavated material in dump trucks. Following fabric placement, a pea gravel trench backfill was used with 1 foot 6 inches of cement-stabilized base at the top. (R. Ellison and J. McDonald, unpublished data.) Fabric placement and backfilling averaged 500 feet a day. The pavement has shown no signs of distress. Twelve psychrometers were placed in 1987 and observed. Profilometer testing was conducted in 1987 and 1988 (table 1). Testing is continuing, but no definitive assessments are currently available.[19]

IH 10 CULBERSON COUNTY

East of El Paso and Hudspeth County is Culberson County. A 48-mile rehabilitation project on IH 10, extending from the Jeff Davis County line westward toward Van Horn, included 40,000 lineal feet of vertical fabric moisture barrier. The successful low bid contractor used a Phillips Fibers Geoseal (Petromat MB), nonwoven polypropylene with polyethylene backing. The barrier was placed 8 feet deep along both shoulders of the east and westbound lanes. A graded aggregate was used as trench backfill to within 18 inches of the surface, which received a cement-stabilized base. The bid price for this barrier work was $19.95 per lineal foot. Five backhoes were used to excavate the trench. Average daily production was 400 lineal feet with a one-day maximum of 1000 feet. Pockets of bentonite were identified as causing the pavement distortion in the two-mile segment of fabric placement. Clay was identified in the trenching operation as extending only 200 feet. Rock was encountered in most of the two-mile segment. The pavement section in 1988 shows no significant signs of distress, just two small patch areas in four miles of roadway. No other testing has taken place. (Tom Schlegel and Al Bazan, unpublished data.)

OBSERVATIONS

As deterioration of rideability with time continues, indicated by lower serviceability indices, the question of why arises. Particularly in the case of the deep vertical fabric moisture barrier, where preliminary indications revealed reduced moisture change, the deteriorating pavement ride remains conjecture. Tests by others have revealed that concrete or asphalt pavements are not the impermeable barriers desired.[8] Water intrudes. It possibly reaches the swelling soil subgrade. Movement takes place. Pavement cracking frequently takes place in the outer lanes. Heavy vehicles use these lanes more often. The repeated heavier loads may cause the earlier pavement cracking. Again water intrudes, the clay subgrade swells, and the ride deteriorates.

In the San Antonio area, work is under way to place 45,000 lineal feet of deep vertical fabric moisture barrier along US 87, from Loop 410 to China Grove. A Dupont Typar spun-bonded polypropylene is being installed along both the outside and inside shoulders of the four-lane divided highway. The contractor's average daily placement rate is 800 lineal feet. His bid price was $13.50 per lineal feet. Also planned is the construction of frontage roads along Interstate 37 in San Antonio's McCreless shopping area. The main lanes there received the fabric barrier, and the frontage road contract, to be let in 1989, will include placement of deep geomembranes.

The SDHPT Seguin residency plans to use deep vertical fabric moisture barriers on other projects along Interstate 10. This includes 14,000 lineal feet of fabric from Cibolo to Santa Clara Creeks and 30,000 lineal feet of fabric from the Santa Clara Creek area to the Guadalupe River.

Unreported sections of fabric moisture barriers apparently exist in Arizona on US 160, another in New Mexico and possibly a projected one on IH 55 in Jackson, Mississippi.

CONCLUSIONS

The first question is, can geomembranes help minimize the damages to pavements caused by expansive soils? The indications from serviceability indices and some maintenance records are that they can. The twelve test site reports show a deterioration with time in the ride quality as reflected in the serviceability indices. Also, in the test sections, with reporting extending about a decade, they show that the geomembrane-protected sections had the smoother ride as reflected in these indices. This reflects itself in lower maintenance costs, though cost comparisons are noted on only two projects, and a reduction in destructiveness.

The next question to be answered is, could the fabric be placed vertically? The answer is yes, it can be placed. Is a geomembrane a cure-all? The answer is no, it is no cure-all. Apparently with the passage of time, the quality of the ride does deteriorate according to serviceability indices. Other problems can develop. It should not be used to control expansive clays in areas where there are none. Placing it in rock is counterproductive. There are faults or other area soil discontinuities that negate fabric value. The Greenville studies indicate that possibly the soils should be saturated before the fabric is placed. This is presently not a definitive conclusion.

These tests generally show that a deep vertical fabric moisture barrier can be effective in reducing the destructive impacts of expansive soils on pavements. Further recording of results of these tests sections should be maintained.

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TABLE 1

IH 10 EL PASO

EASTBOUND LANES				
	CONTROL		FABRIC	
	OUTSIDE	INSIDE	OUTSIDE	INSIDE
10/87	4.62	4.36	4.61	4.15
7/88	4.58	4.26	4.59	4.16

WESTBOUND LANES				
	CONTROL		FABRIC	
	OUTSIDE	INSIDE	OUTSIDE	INSIDE
10/87	4.37	4.55	4.16	4.31
7/88	4.53	4.54	4.41	4.28

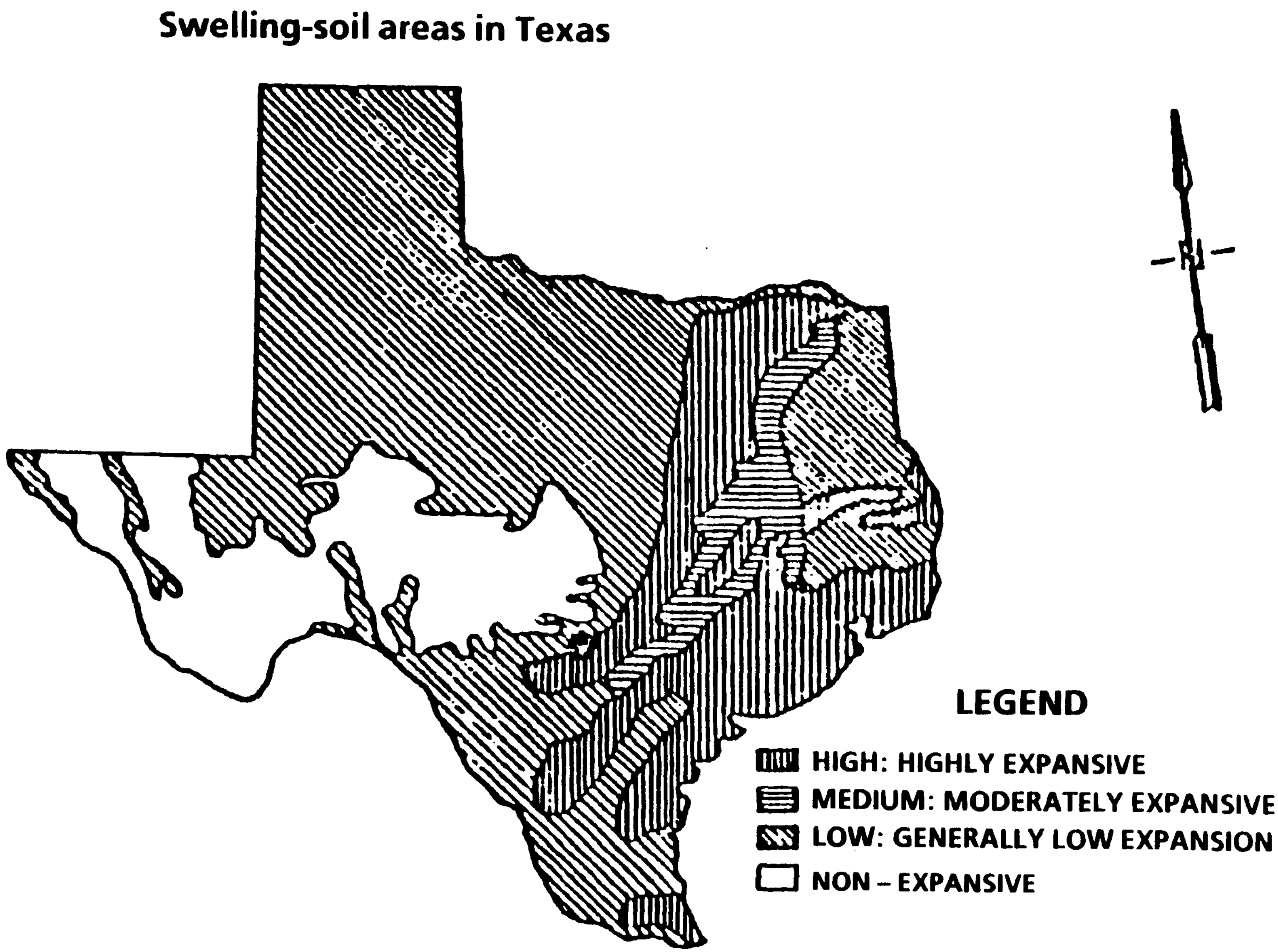


Figure 1: Swelling Soil Areas in Texas

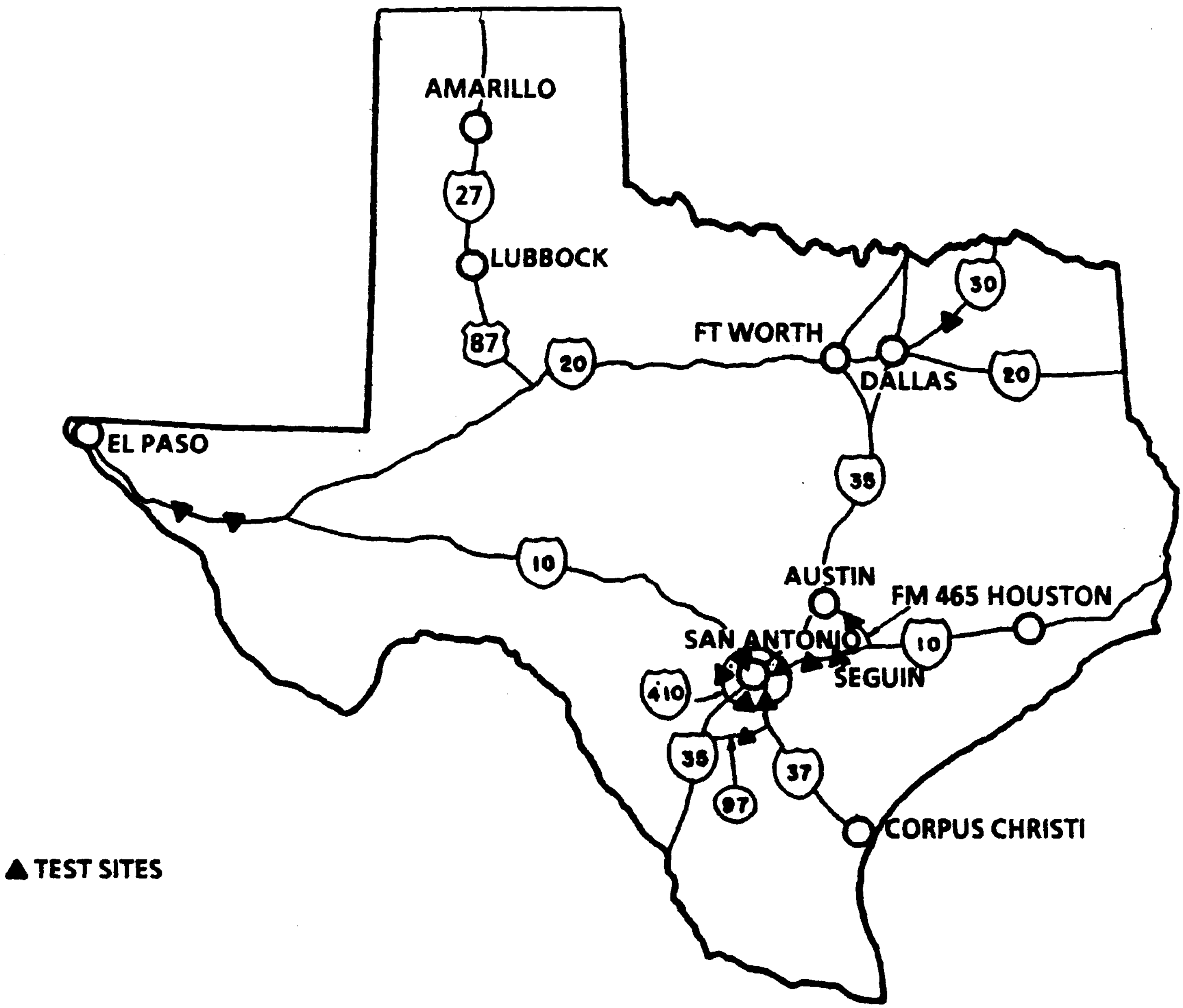


Figure 2: Test Sites

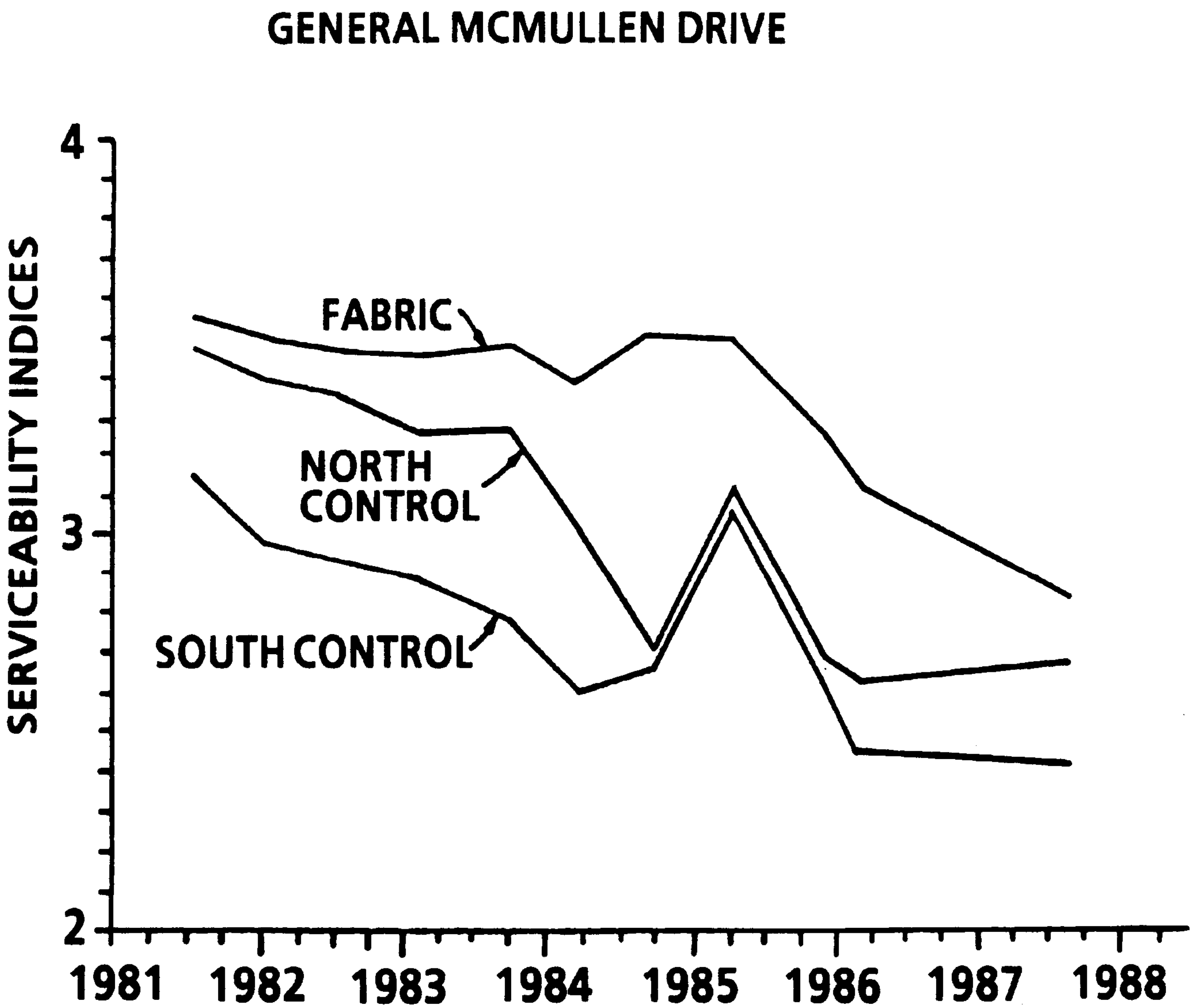
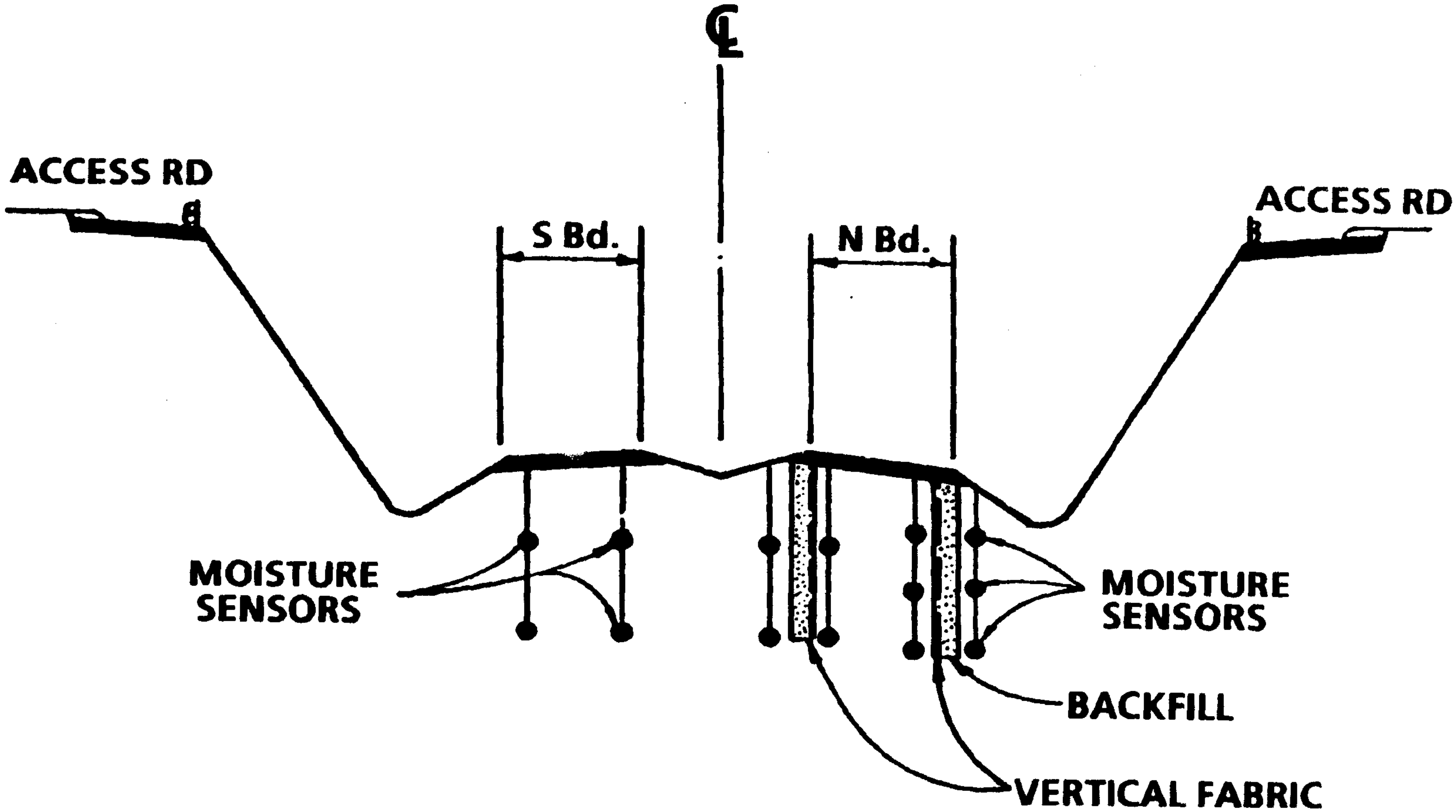


Figure 3: Profilometer Tests - General McMullen Dr.



INTERSTATE 410 SECTION

Figure 4: Interstate 410 Section

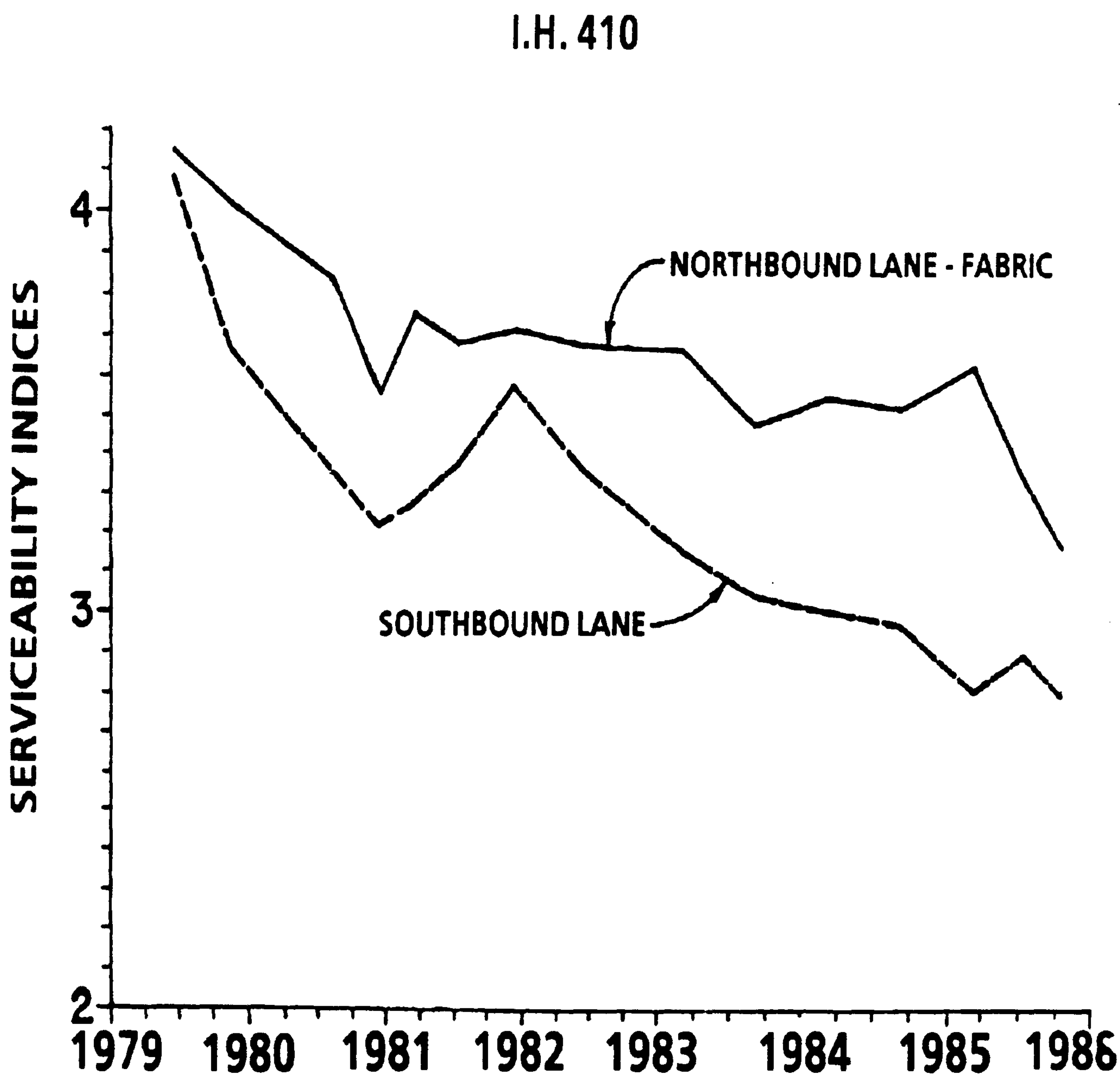


Figure 5: Profilometer Tests - Interstate 410

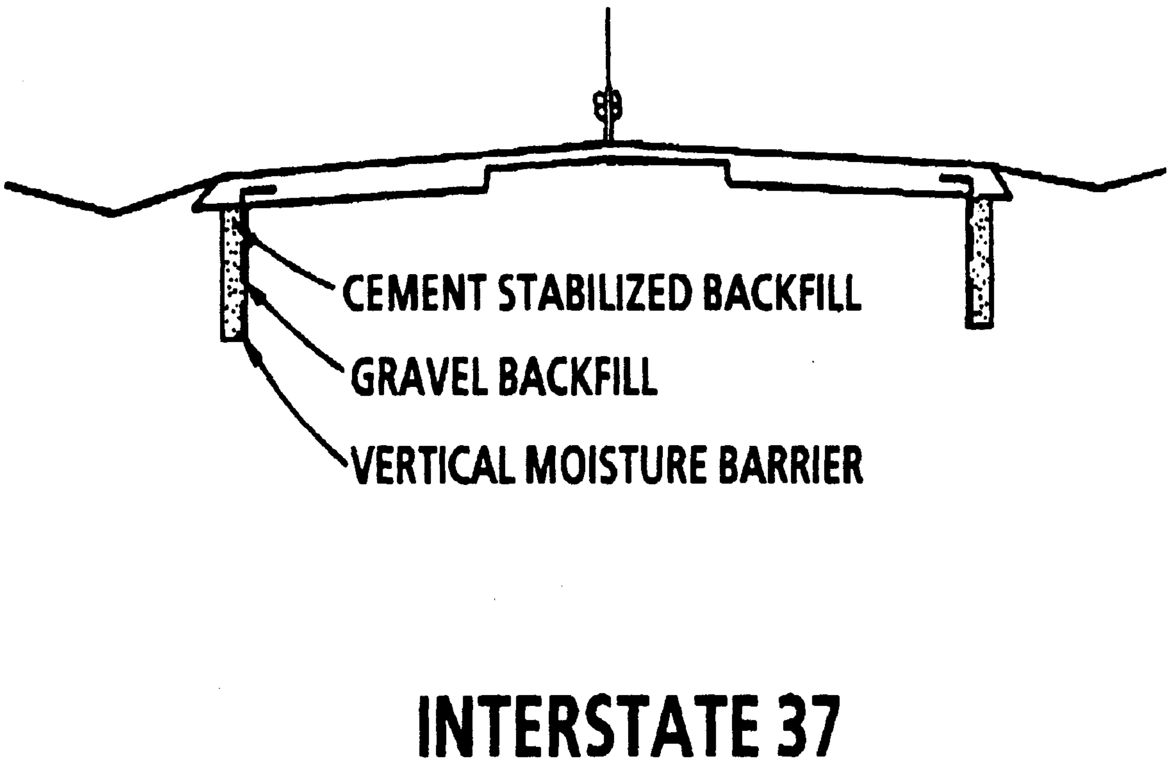


Figure 6: Interstate 37 Section

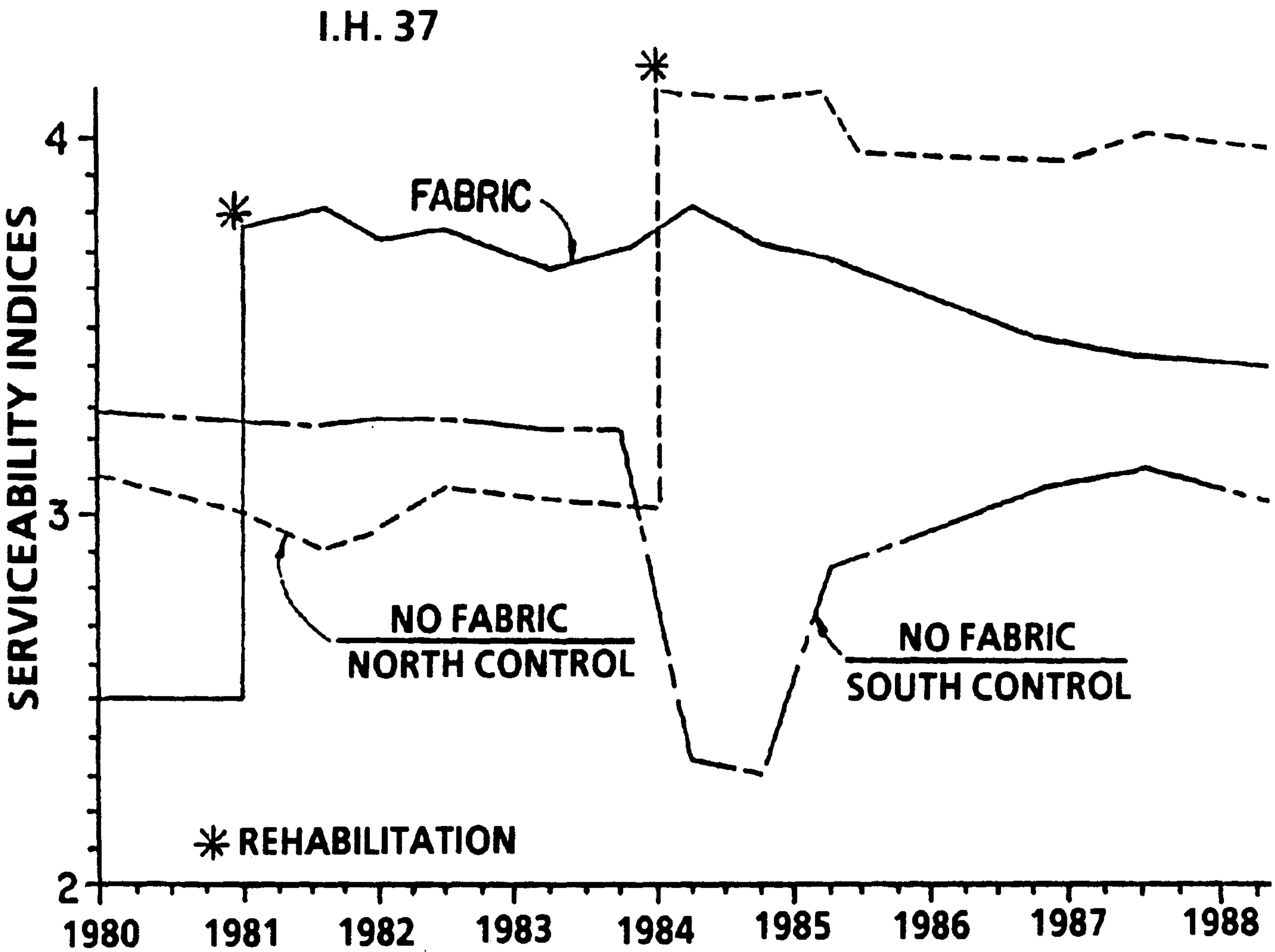


Figure 7: Profilometer Tests - Interstate 37

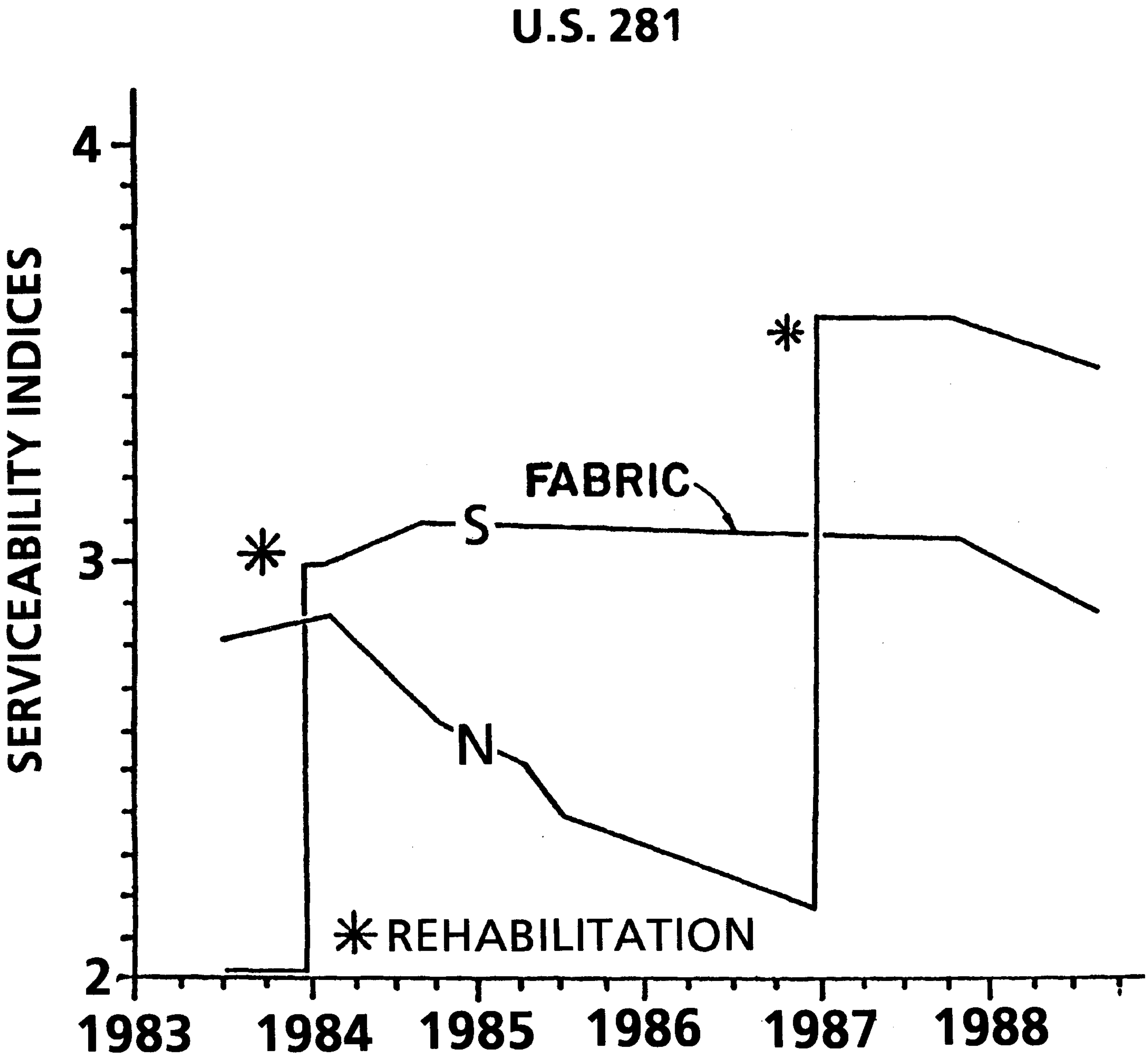


Figure 8: Profilometer Tests - U.S. 281

FIGURE 9: SH 97

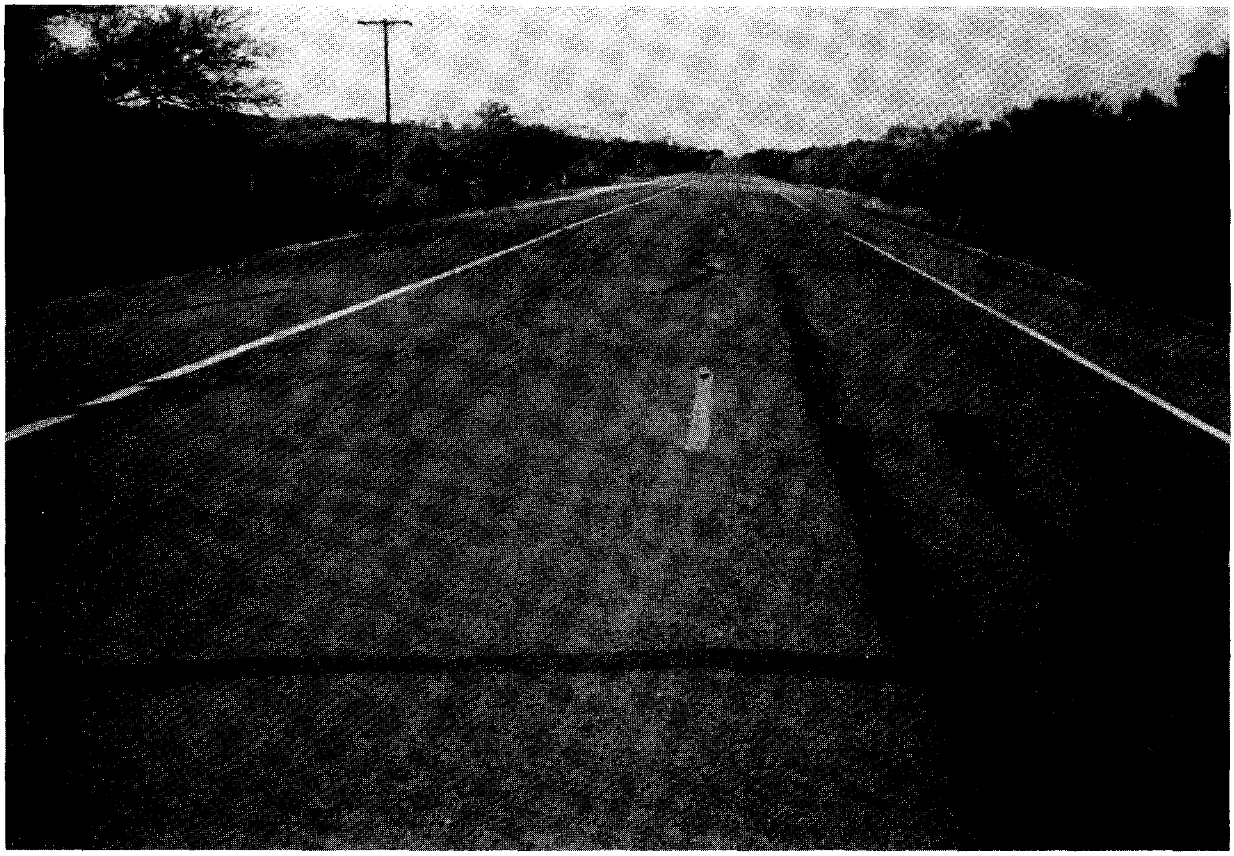


FIGURE 10: SH 97

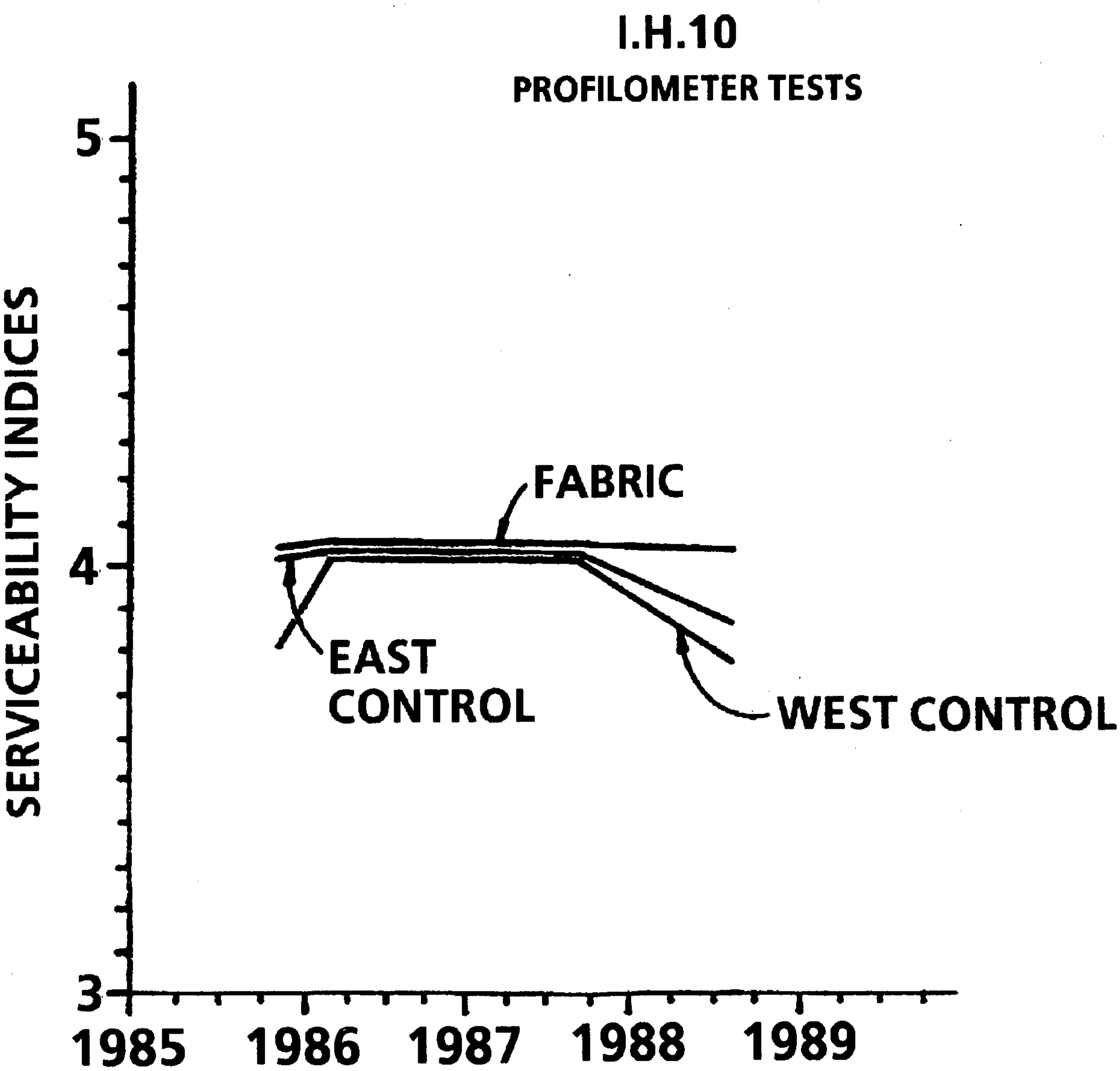


Figure 11: Profilometer Tests - Interstate 10 San Antonio

FIGURE 12: IH10 from Ackerman Road to Cibolo Creek

FIGURE 13: IH10 from Ackerman Road to Cibolo Creek

FIGURE 14: IH10 from Ackerman Road to Cibolo Creek