IN-TRACK PERFORMANCE OF GEOTEXTILES
AT CALDWELL, TEXAS

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S. M. Chrismer
G. Richardson

ABSTRACT

A performance test of geotextiles in track was performed jointly by the Monsanto Corporation and Southern Pacific Railroad. The test site at Caldwell, Texas was chosen because of the poor subgrade conditions. The track was instrumented to determine the influence of the geotextiles upon track behavior. The instrumentation measured the extent of the anticipated geotextile functions of reinforcement, subgrade moisture transport, filtration, and separation. There was no evidence of reinforcement or moisture transport, but filtration and separation appeared to be the main advantages.

INTRODUCTION

In November, 1977, an extensive field investigation of geotextile performance and the associated influence on track behavior was begun, as a joint project of the Monsanto Corporation and Southern Pacific Railroad. The test site was located in Caldwell, Texas, in an area with significant track maintenance problems due to poor subgrade performance. The subgrade soil is comprised of a medium to soft consistency, highly expansive clay, which typifies some of the worst soil conditions under which geotextiles are placed.

The geotextiles were installed in a new siding constructed alongside the main line track. New track construction was selected for the test to eliminate problems related to ballast pockets and undercutting programs that would have been experienced if the fabric and instrumentation had been placed in existing track. The main line carries about 10 MGT per year, which is considered to be a moderate tonnage for a main line track.

The test was planned with the objective of determining the extent to which fabrics perform the anticipated functions of:

(1) Reinforcement,
(2) Subgrade moisture transport,
(3) Filtration, and
(4) Separation.

Extensive instrumentation was required in order to differentiate the role that each mechanism played in a given test section. Figure 1 illustrates the subgrade instrumentation that was installed in each section.

Test Section Conditions

The existing and design grades at each of the six individual test sections are shown in Figure 2. Test Sections 1 through 4 were constructed with nonwoven fabrics placed on the subgrade. The properties of the geotextiles are listed in Table 1. Section 5 was a control section with no fabric, and Section 6 was a cement-stabilized zone. Section 6 was used to compare the performance of a conventional, but expensive, method of subgrade stabilization with the performance of the various fabric sections. The length of each of the fabric sections and the cement-stabilized section was 300 feet, whereas the control zone was only 150 feet in length. The control site was made shorter because, it was thought, this track section might fail or experience a large amount of settlement.

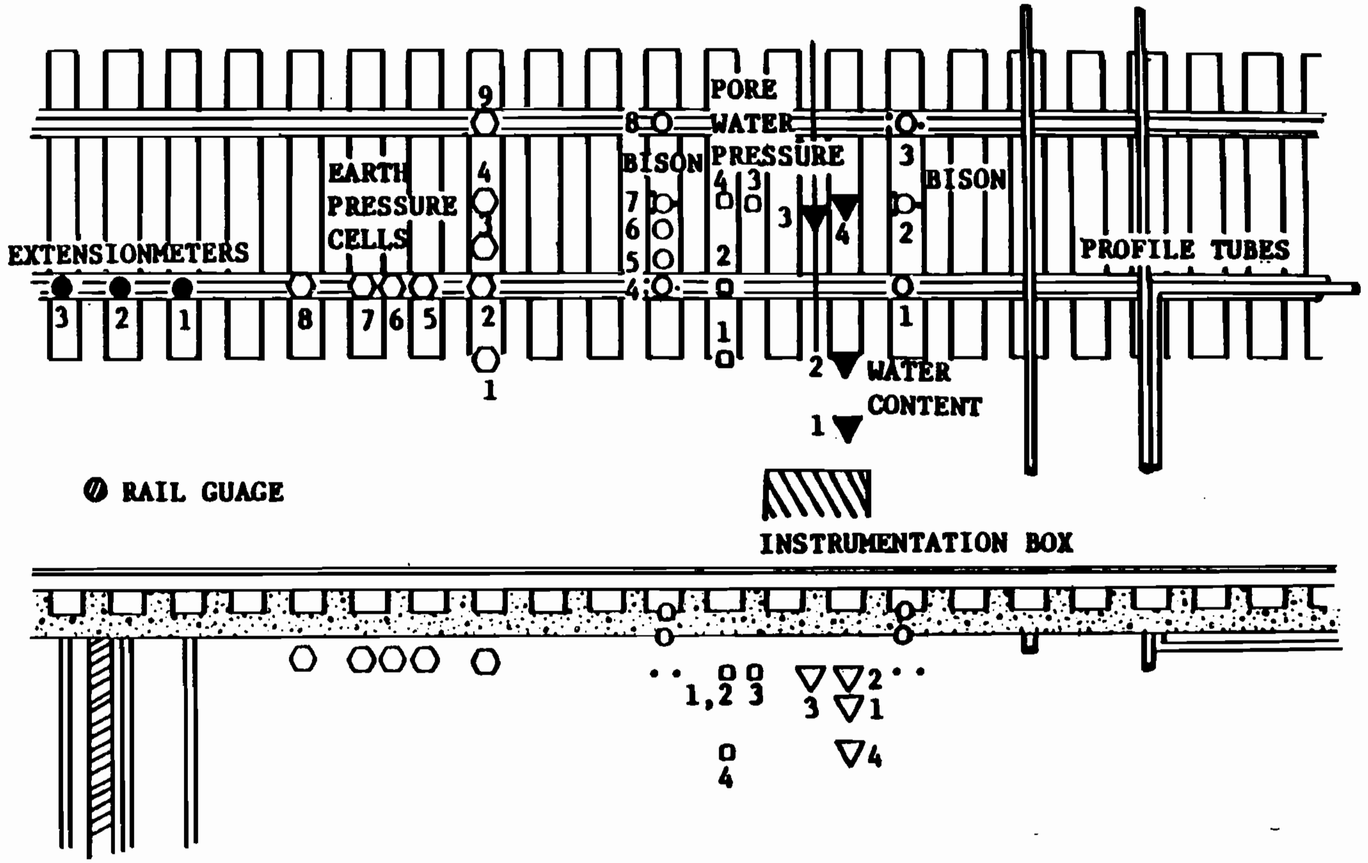

Figure 1. Typical Subgrade Instrumentation

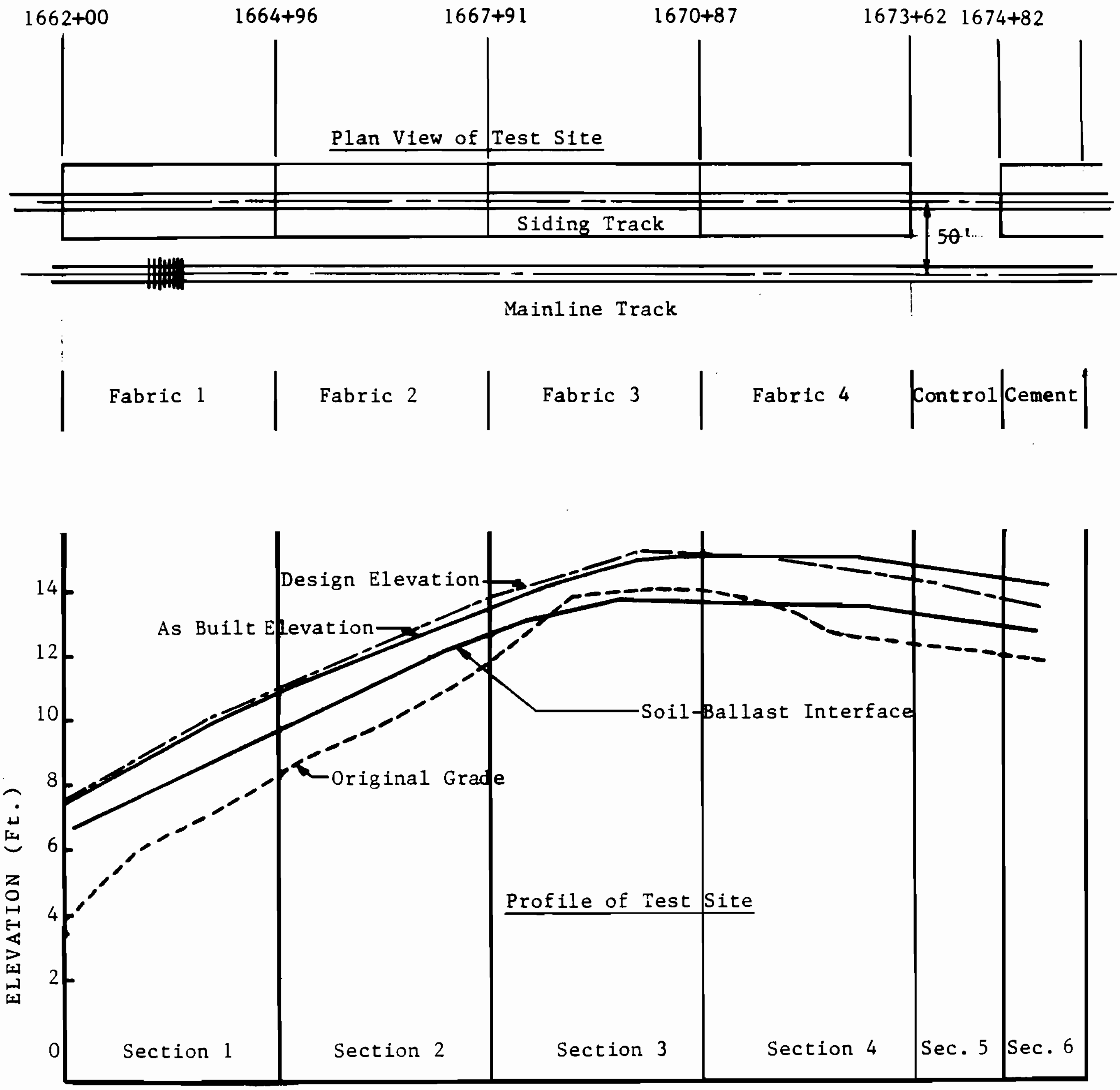

Figure 2 Caldwell Test Site Configuration

Table 1

Physical Properties of the Caldwell Test site Geotextiles

Property		Fabric 1	Fabric 2	Fabric 3	Fabric 4
Basic Weight, ounces per squar yard (osy)		10.7	10.7	6.1	6.7
Thickness at 0.03 bar, mils		173	99	22	78
Porosity, %		91	90	60	92
Density, kg/m^3		83	144	364	114
Puncture Strength, lb		113	143	74	88
Puncture Toughness, lb		40	34	24	25
Burst Strength, psi		344	458	270	311
Grab Strength, lb	MD[a]	165	279	233	238
	TD[b]	271	301	225	184
Apparent Elongation, %	MD	129	66	61	63
	TD	112	61	75	75
Toughness, lb	MD	106	92	71	75
	TD	152	92	84	69
Trap Tear Strength, lb	MD	62	114	76	95
	TD	88	109	102	86
Abrasion (Grab Strength), lb		104	177	184	71
Lateral Permeability,					
at 0.24 bar, cm/sec		0.27	0.32	0.06	0.38
at 2.00 bar, cm/sec		0.08	0.13	0.01	0.14
Normal Permeability, cm/sec		0.57	0.45	0.02	0.44
litre/sec/cm^2		.022	.022	.004	.034
Equivalent Opening Size (EOS)		50	-	200	-
Denier per Foot (DPF)		7	7	12	7
Polymer		Polypropylene	Polyester	Polyester	Polyester
Structure		Needled	Needled	Thermal Bonded	Needled
		Crown Z.	Bidim	Fibertex	Bidim

a: Machine Direction
b: Transverse Direction

An eight-inch layer of lightly cement-stabilized soil was compacted over the natural soil of the entire test area to provide a zone of intermediate strength between the ballast and subgrade. Field California Bearing Ratio (CBR) tests were performed on the compacted soil at three locations within each test section. The average CBR values at 0.1 inch penetration for the six sections were 24, 23, 21, 20, 32, and 15, respectively. The CBR values were much greater than would be expected for clayey loam, due to the surface cement stabilization and heavy compaction.

Ballast was placed in Test Sections 1 through 4 after each of the fabrics were placed. No subballast was used. Section 6 had the ballast resting on 12" of cement-stabilized rock screenings.

Track Loadings

Switcher locomotives, running at speeds between 2 and 50 mph, provided the load input to the track structure for those tests which required a load. The cumulative wear on the track was provided by revenue trains which were allowed to run over the test sections. Unfortunately, records of the amount of actual traffic tonnage passing over the test sections were not kept. However, because approximately 50% of the main line traffic was diverted onto the siding test section, it may be assumed that the siding recieved about 5 MGT per year, i.e., one-half of the single track total of 10 MGT per year.

QUASI-STATIC TRACK SYSTEM RESPONSE

As mentioned earlier, there are four postulated mechanisms by which a geotextile is thought to influence track behavior in general: (1) reinforcement, (2) moisture transport, (3) Filtration, and (4) Separation. The data readings from instrumentation used to measure such influences will be presented next. Near the end of the report is a discussion in which the measurements are reviewed to determine if any of the above mechanisms were indicated.

Soil Moisture Measurements

Soil moisture in the compacted clay loam and the natural clay subgrade were measured to monitor the relative percentage ratio of pore water to soil solids. A smaller seasonal change in soil moisture contents in the fabric test sections as compared to the control section would indicate that a fabric may keep the subgrade drier.

Drainage in the test sections was dependent upon the topography and local soil properties. Figure 2 indicates the grade conditions for the overall test site. The steeper grade in Section 1 provided better drainage; however, this section also received runoff from Sections 2 and 3. Thus, various combinations of grade and watershed did not appear to favor any particular section.

Three methods were used to monitor the soil water content: (1) manual corings, (2) electrical resistance transducers, and (3) electrical capacitance transducers. The last two methods, those using instrumentation, gave values of moisture content that were close to those of the field corings. However, the instrumentation responses were more "flat" and did not show the increase due to the rainy months of March through June as did the samples recovered from the field. Because the water content measurements from the manual corings are believed to be the most reliable, only the data from the field corings will be shown. Soil samples were obtained every 6 inches, to a depth of 24 inches, at the middle of each test section. Figure 3 illustrates the variation of subgrade water content in the test sections over approximately one and one-half years. Figure 4 shows the test section differences between the seasonal maximum and minimum soil moistures which occured during the 17 months.

Pore Water Pressures

Pore water pressures in the natural subgrade were monitored using piezometers. It was thought that subgrade moisture transport in the fabric test sections might be apparent from reduced pore water pressures compared to the control section. The piezometers were implanted within the subgrade in each section in a plane perpedicular to the rails. Shallow piezometers were placed 15 inches beneath the finished subgrade at locations below the south edge of the ties, the south rails, and the centerline of the siding. An additional piezometer was placed to a depth of 4 feet beneath the finished subgrade at the centerline of each test section.

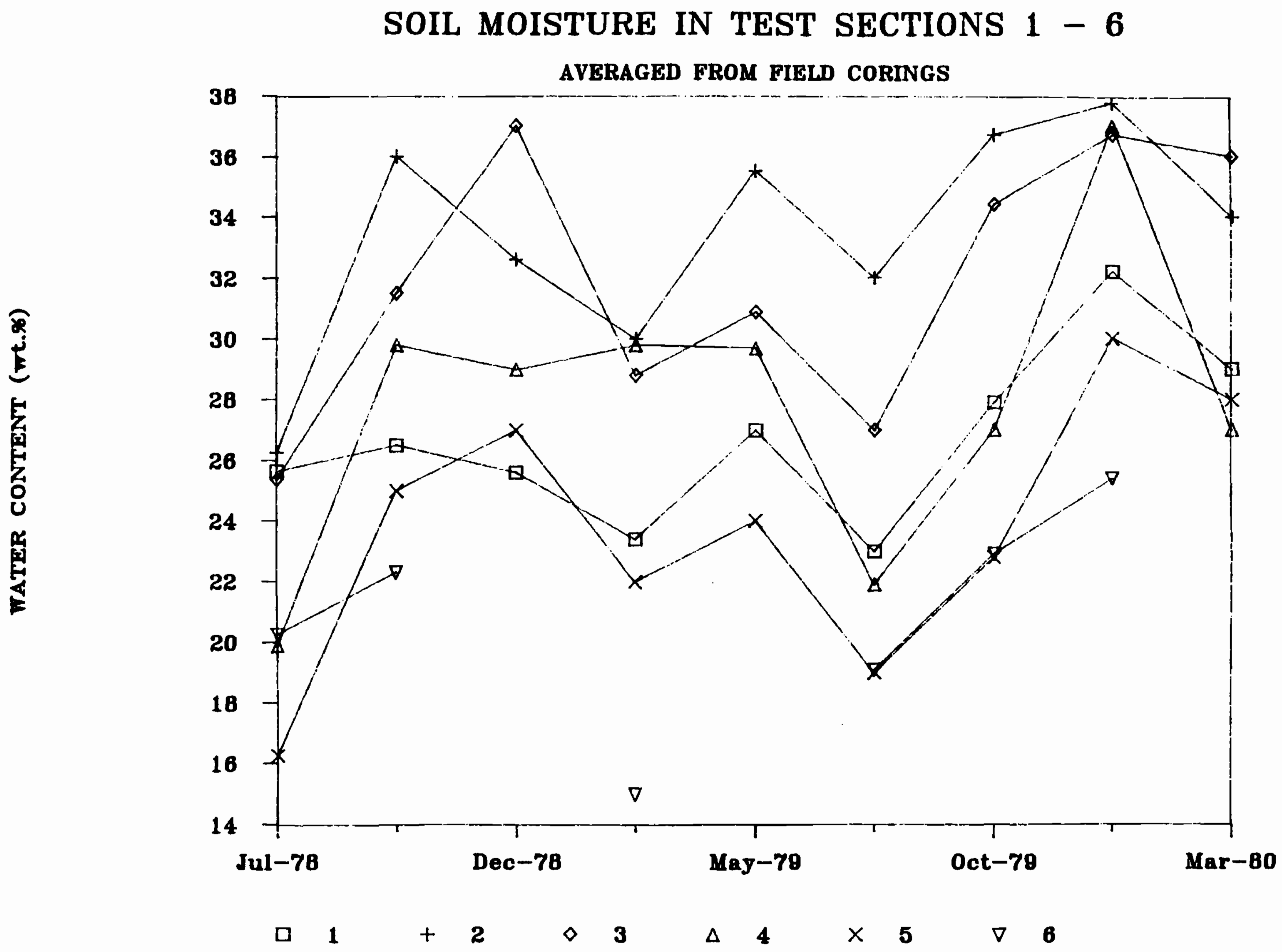

Figure 3. Variations in Average Soil Water Content With Time, in Test Sections 1 - 6

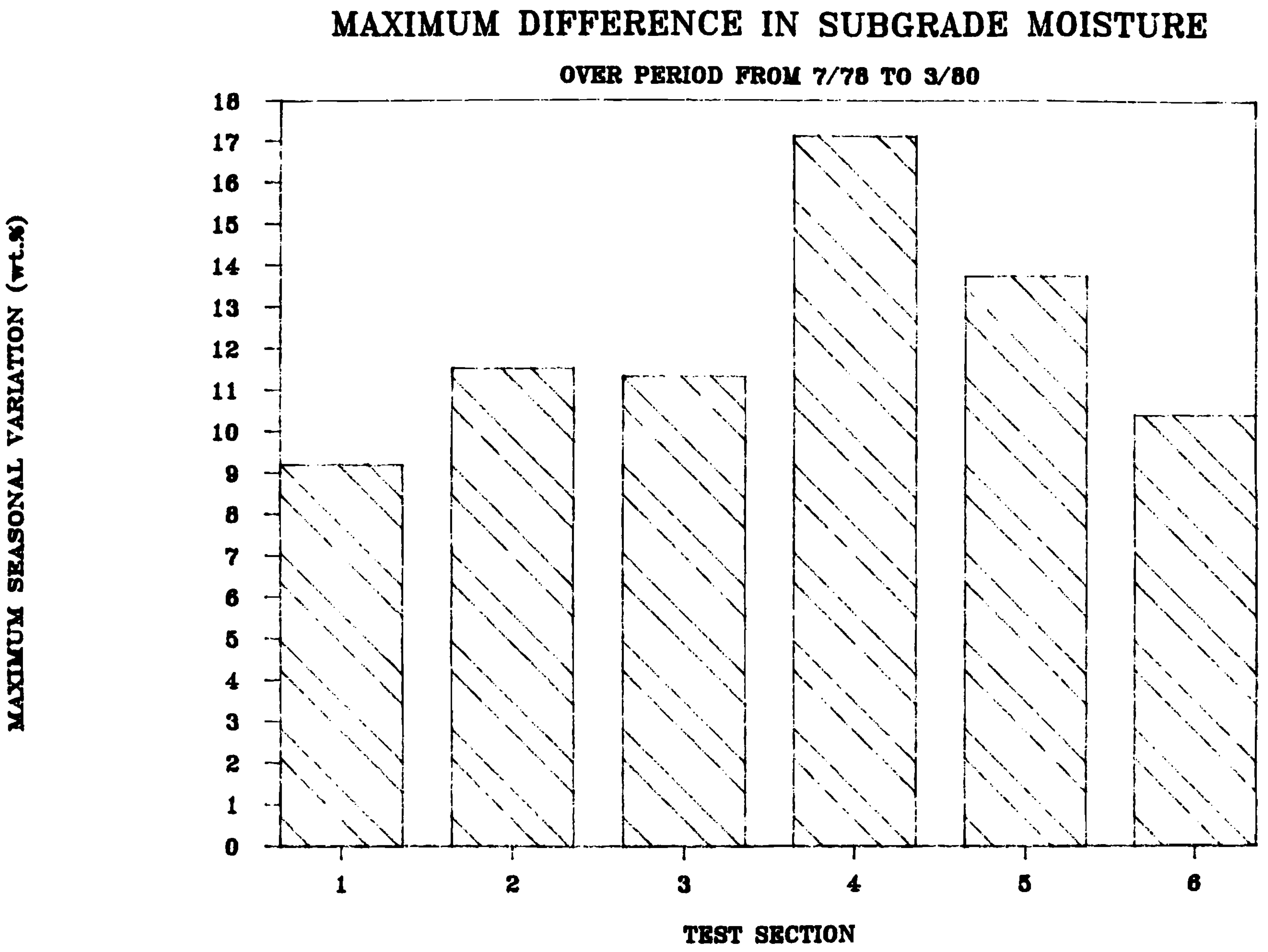

Figure 4. Maximum Seasonal Variations in Soil Moisture Content from July,1978 to March, 1980, for Test Sections 1 - 6.

Maximum positive pore water pressures would occur if the water table was at the surface of the subgrade. Thus, the maximum positive pore water pressures measured at Caldwell should be 0.54 psi for the shallow piezometers and 1.73 psi for the deep piezometers, based on the depth below the water table. However, pore water pressures in excess of 0.54 psi (some approaching 3.6 psi) were measured by the shallow piezometers at Sections 1, 2, 3, and 6 which conflicts with the maximum pore water pressure model just mentioned.

Excess positive pore water pressures could lead to reduced subgrade strengths and increased settlements, caused by water flowing out of the subgrade to reduce the pore water pressures. However, Sections 1, 2, and 6 did not experience significant settlements and certainly did not appear to be showing any signs of weak or failing subgrades.

Although there were erratic readings from a few of the peizometers, the others gave reasonable measurements. From this data, the reduced pore water pressures one would expect to see if soil moisture transport was occuring was not apparent. Therefore, no test section differences were observed with this instrumentation.

Subgrade Geometry

Static vertical extensometer readings were recorded to monitor the vertical movement of the soil-ballast interface with respect to a point 10 feet below. The static extensometer readings are shown in Figure 5. All of the curves show a

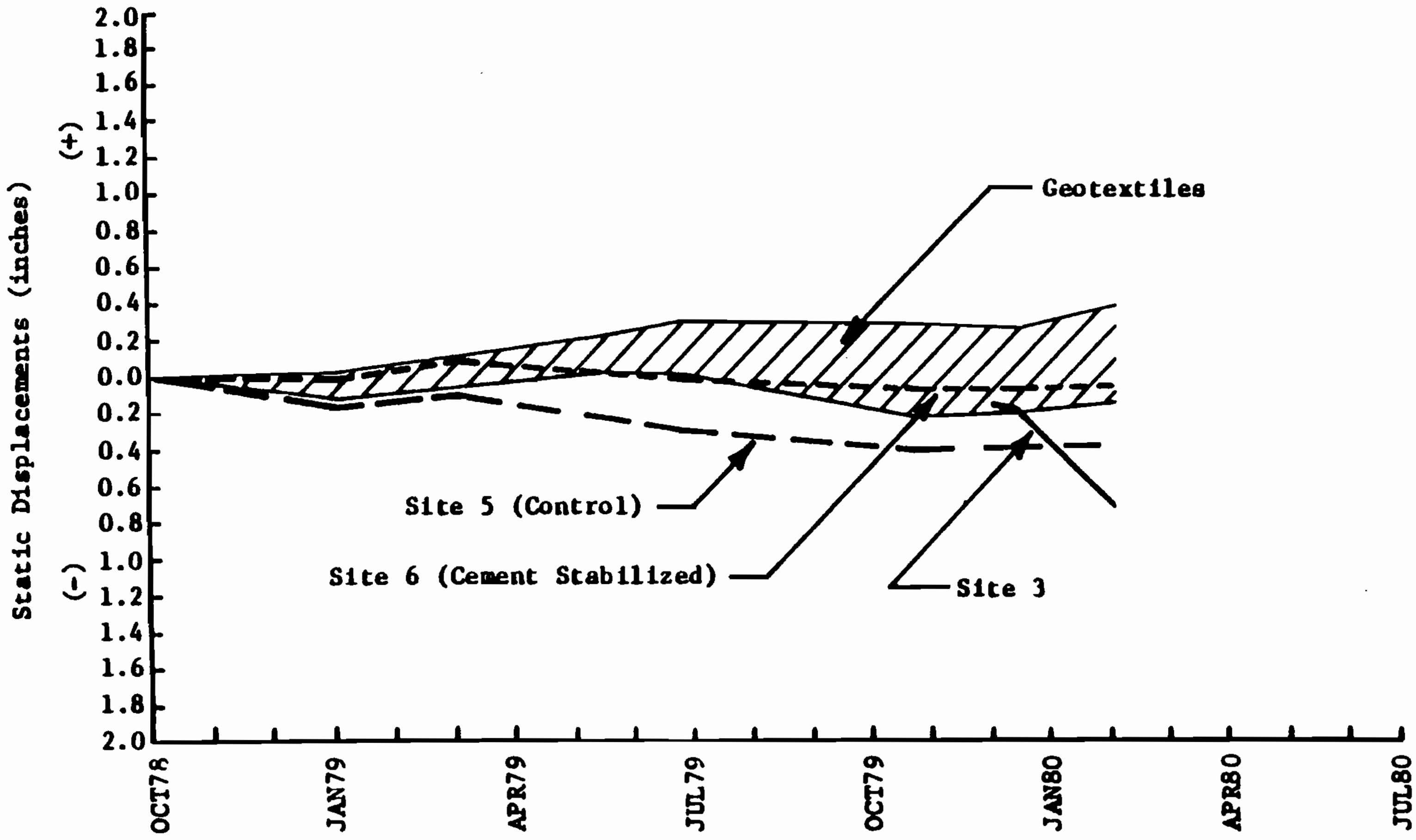

Figure 5. Extensometer Data Showing Static Soil Swelling and Settlement at Test Sections 1 - 6.

consistent trend in the rise and fall of the interface. Section 5, the control section, clearly experienced greater vertical settlements than the remaining sections. Note also that vertical movement of Section 3 began to accelerate rapidly during December, 1979. The failure of Section 3 occurred in January, 1980, as noted in Figure 5.

Track excavations were made in each of the fabric sections to observe the transverse subgrade profile under both a tie and a crib. Elevations were taken at the top of the fabric in each excavation before it was removed to reveal the subgrade. Large subgrade displacements were indicated for Section 3. The excavation in Section 3 was made in an area where the top-of-rail (TOR) profile had indicated large settlements. This provided further evidence of the soil-related failure of Section 3. The subgrade profiles from all of the geotextile sections showed a depression of the subgrade below the tie-rail Seats. The depth of this depression ranged from less than one inch in Section 4 to more than six inches in Section 3.

The most significant finding in the excavations was made at Site 3 where a layer of weak clay slurry was located just under the fabric. The shear strength of the clay slurry was less than 0.2 tons per square feet (TSF). This slurry layer appeared to be extruding from beneath the fabric. The existence of this layer pointed to a near surface soil failure as contributing to the excessive settlement in Section 3. The low permeability of the fabric appeared to be the cause of the slurry formation. More discussion of this problem Site will follow in a later section of this paper.

DYNAMIC TRACK SYSTEM RESPONSE

Subgrade Response

Earth Pressures

The transducers for measuring vertical earth pressures were installed 3-4 inches below the top of the subgrade. Figures 6 and 7 show the transverse and longitudinal layout of the transducers in the soil. The earth pressure measurements shown in these figures were obtained by selecting the maximum pressure registered by each transducer during each locomotive pass. These maximum pressures were generated under the wheel loads of switcher locomotives traveling at velocities ranging from 2 to 50 mph. Because the maximum pressures varied somewhat with locomotive speed (a small variation in most cases and with no definite trend), their average for each of the various speeds was calcluated and plotted in Figures 6 and 7.

The transverse and longitudinal earth pressure measurements showed approximately the same pressure profiles for each site. No significant differences could be observed between the pressure profiles observed in the fabric sections and those in the control section. It is interesting to note that the maximum subgrade pressures were measured beneath the cement-stabilized section.

Elastic Subgrade Deformations

Measurements of elastic subgrade deformations under load were obtained using three extensometers per section, which were installed under the rail-tie seats. The mean values obtained

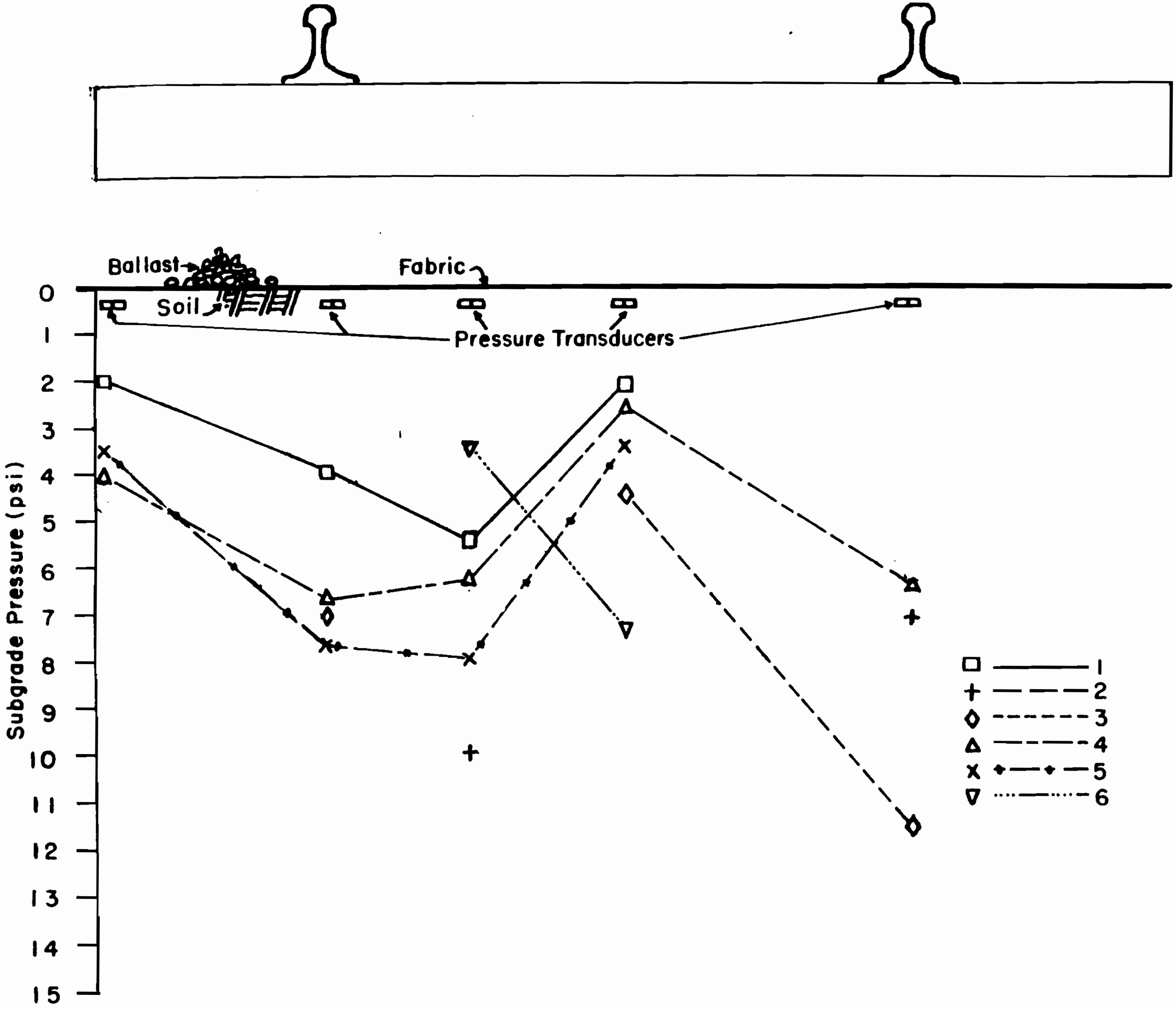

Figure 6. Subgrade Pressures Under One Tie in Each of Test Sections 1 - 6.

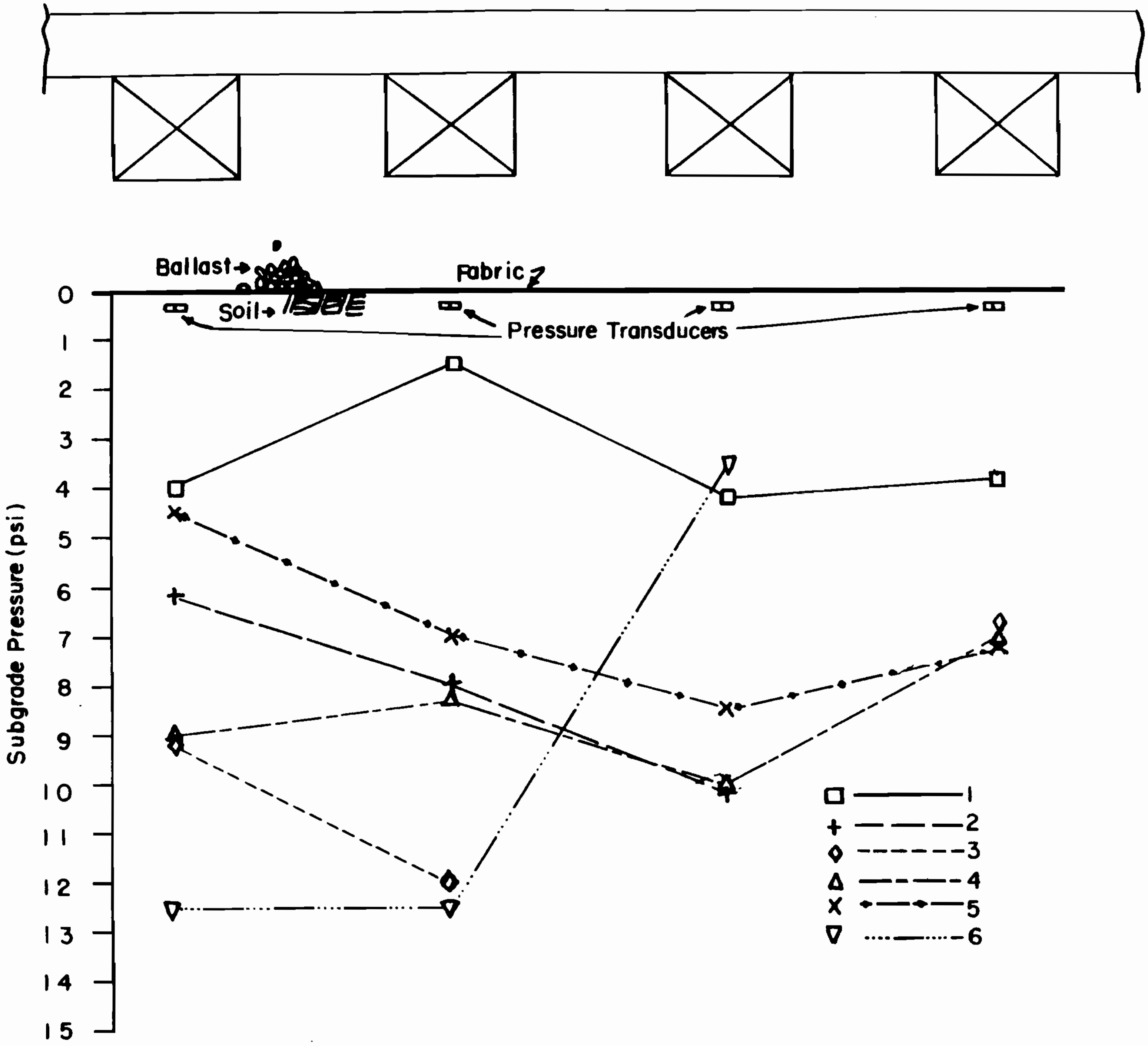

Figure 7. Subgrade Pressures Under Four Ties in Each of Test Sections 1 - 6.

under loading are plotted in Figure 8 for the respective test dates. The elastic deformations measured in Sections 2, 3, 4, and 6 showed the same climatic variations, with Section 6 having consistently smaller amplitudes. General weather data obtained from Caldwell, Texas showed that March through June were months which had significant amounts of rainfall.

The anomalous behavior of Section 5 during the wet season was shown by decreasing elastic deformation, while the other sections were experiencing increasing deformations. Section 1 also had anomalous behavior, as evidenced by the wide range in deformation with the seasons. The soil moisture content data did not indicate that the soil in Section 1 experienced greater variation in of moisture content; in fact, the moisture content in Section 1 was the most uniform during this period.

Because there was no consistent trend in subgrade elastic deformations between test sections, no sections differences are noted. It is interesting that the control section had lower than average elastic subgrade deflections.

Superstructural Response

Tie Plate Loads

The portion of the wheel load that was distributed to the single tie over which the wheel was located was measured at one tie in each section, using a load cell tie plate. The load cell tie plates were installed just prior to the time of measurement and then replaced with ordinary tie plates after the testing was completed.

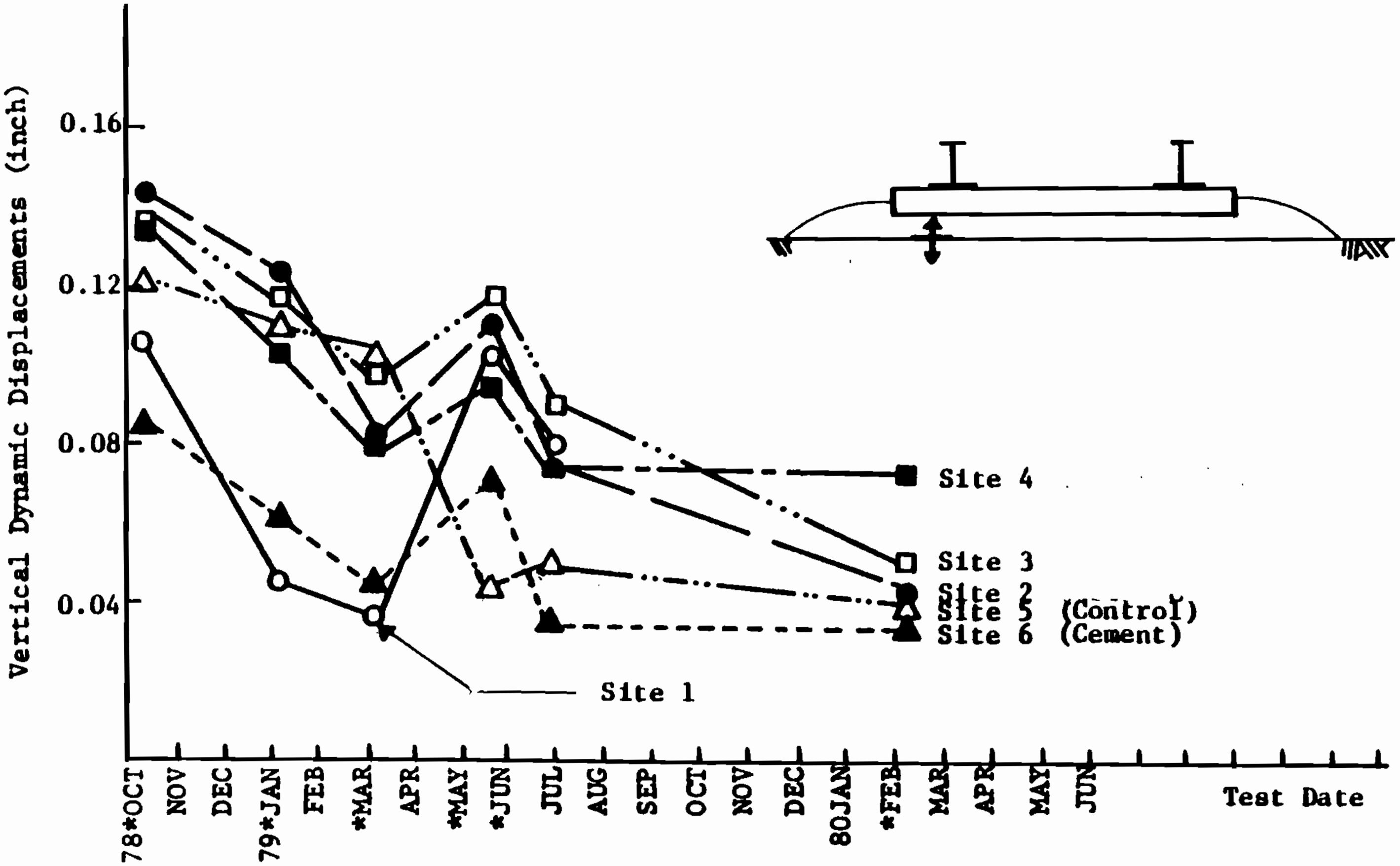

Figure 8. Variations in Mean Values of Elastic Deformation Under Load at the Ballast/Subgrade Interface With Time, for Test Sections 1 - 6.

The maximum tie plate loadings for all six sections were 19, 18, 14, 10, 11, and 20 kips, respectively. Sections 1, 2, and 6 appeared to have the largest loads. However, tie loads can be variable from one tie to the next, even in new construction. Tests elsewhere have shown that the percentage of a wheel load taken by the tie directly under that wheel may vary between 20% and 50% [1], depending upon the tie support conditions and rail stiffness. In these tests, the range of the tie loads divided by the wheel loads (about 33 kips) for all six sections were between 30% and 60%. Because the test results were within the natural variations of the tie load spectrum, and because only one tie per section was instrumented, data from the instrumented tie plates could not be used to explain the observed differences in test section behavior.

Tie Strains

The tie strains were measured by gages attached to the top of one tie in each test Section. This enabled the dynamic bending strains in the longitudinal plane of a tie in each section to be monitored. The ties in Sections 5 and 6 were straining somewhat more in the tie middle than near the rail seats, whereas the fabric section ties were strained more uniformly. However, as mentioned previously, the tie support conditions, and therefore the bending could vary considerably from tie to tie. Therefore, because only one tie per section was instrumented, differences in section response could not be confirmed from these data.

BALLAST CONTAMINATION

Filtration and separation are two of the attributes most commonly associated with the use of geotextiles. To assess the performance of the fabric sections with respect to these two parameters, samples of ballast, soil, and fabric were taken from the field for laboratory analysis.

Differentiating the subgrade fines from fines of other sources, e.g., from ballast abrasion, windblown, etc. was essential to evaluating the performance of the various geotextiles. Section 6, the cement-stabilized section, played a key role in this investigation, because it contained fines from all sources other than those associated with the subgrade. Assuming reasonably uniform ballast and surface conditions, the contaminating fines measured in Section 6 should represent a control for the other test Sections.

Ballast samples were taken at uniform increments of depth below the top of the ties in Sections 1 through 6. Additional samples were obtained from the top of, and beneath, the fabric in Sections 1 through 4. Samples were also taken at the soil-ballast interface, and at the top of the cement at Sections 5 and 6, respectively. Samples were obtained from holes dug by hand in the ballast. A water spray mist was used to prevent the fines from being displaced due to the sampling disturbance. Approximately 700 to 800 grams of ballast were taken at each depth.

The amount of contamination, as quantified by measuring the amount of fines that passed through a #200 sieve (0.074 mm), consisted of both silt and clay-sized particles, and were assumed to be representative of the ballast contamination.

Mean values were established for the percentage of contamination versus depth data from each test section, and are presented in Figure 9. In the upper 12 inches of ballast, only Sections 3 and 5 had contamination in excess of that measured in Section 6 (the "control" section). Note the contamination of the ballast just above the fabric: Section 5, with no fabric, had significantly more contamination than the remaining sections, and only Sections 3 and 4 of the fabric sections had significantly greater contamination than Section 6.

In addition to the amount of contamination, laboratory hydrometer analyses were performed to measure the percentage of clay particles in the contaminant fines. Clay particles in the contaminant can originate only as wind-blown particles or in the subgrade. Crushing and abrasion of the ballast would produce more coarse silt-sized particles. The subgrade beneath the track consisted of both clay and silt-sized particles; therefore, the presence of excessive amounts of fines of a clay size would indicate a filtering of the silts by the fabrics, as the fines tried to pass through the fabric.

The average percentages of clay particles in the contaminant fines for Sections 1 through 6 were, respectively, 50.3%, 45.7%, 43.6%, 40.6%, 32.6%, and 25.3%. Therefore, using Section 6 as the control, it appears that the fabric sections received much of their subgrade contamination in the form of clay particles. Because Control Section 5 (the most fouled Section) exhibited a significantly lower percentage of clay within its ballast fines,

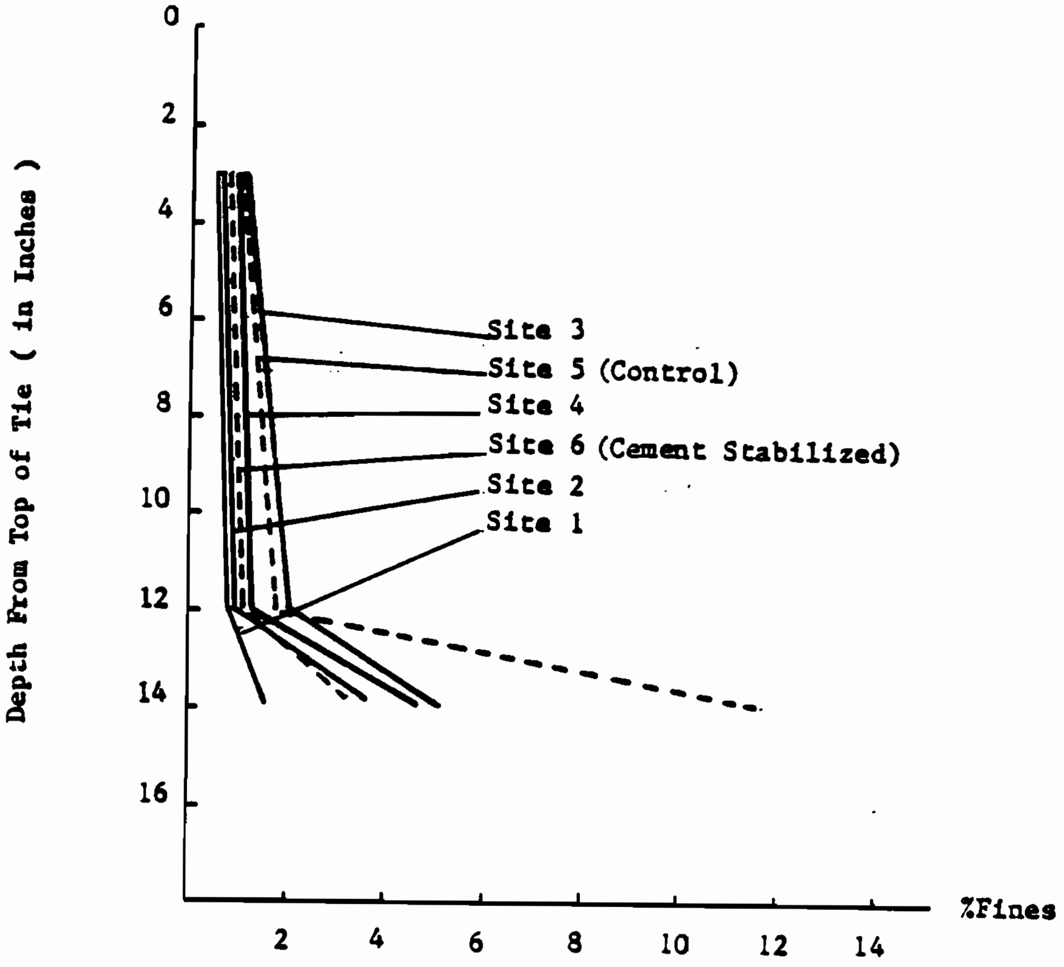

Figure 9. Percentage of Fines Passing a #200 Sieve Versus Sampling Depth in Test Sections 1 - 6.

this indicates that large quantities of subgrade silts in addition to the clay, were moving into the section 5 ballast because no fabric was present. This substantiates the filtering capabilities of the fabrics with respect to silt-sized particles.

The quantities of clay-sized particles present within the ballast in Fabric Sections 1, 2, and 4 were between 2 and 3 percent by weight. Fabric Section 3 and Control Section 5 had about 8 percent clay fines near the bottom of the ballast layer. [In Fabric Section 3 this may be explained by the extrusion of the soil-slurry that had by then built up just under the fabric.] Percentages less than 4% or 5% are normally considered to be negligible, in that they will not influence the ballast performance. However, the amount of clay in Sections 3 and 5 may contribute to a degradation of the engineering properties of the ballast. An example of such degradation is the possible increased lateral spreading of the bottom layer of ballast under the lateral shear forces caused by traffic. Excessive track settlement can result.

It appears that the use of fabrics can control the pumping of silt-sized particles into the ballast. Fabrics will allow a small amount of clay to pump into the ballast. However, this amount of clay will be significantly smaller than would have occured if no fabric had been used.

6.0 PROPERTIES OF RECOVERED GEOTEXTILES

After 17 months of service, several ties were removed and the ballast was excavated, so that samples of fabric could be taken from each test section. The fabric samples were taken to a laboratory and tested for their permeability, both in-plane and normal to the fabric. Also, the strength in tension, as measured by the Grab Tensile Strength test, was determined.

Figure 10 illustrates the measured decrease in fabric permeabilities when tested in the soiled condition after removal from the field. As shown, the in-plane permeability of the fabric samples after 17 months in track have decreased by as much as a factor of 100. The fabric in Section 1 retained the greatest percentage of its initial in-plane permeability. The test performed on the fabric from Section 3 appeared to show a gain in permeability in the field, however, this test was reported by the techician to be in error. The fabric in Section 3 is known to have clogged more severely in the field than any of the other fabrics.

A combination of visual and microscopic inspections revealed that all of the fabrics had soil particles in the voids of the fibers and on the fabric surfaces. Fabric 1 had the least amount of soil in the fibers, while the other three fabrics had a greater (approximately equal to each other) degree of soil particles in them. These obervations confirmed the laboratory permeability results.

The tests that were conducted to determine the permeability normal to the plane of the fabric again showed the fabric from Section 1 to have the smallest percentage decrease and the greatest permeability. However, even with permeability decreases on the order of 100, the soiled fabric permeability

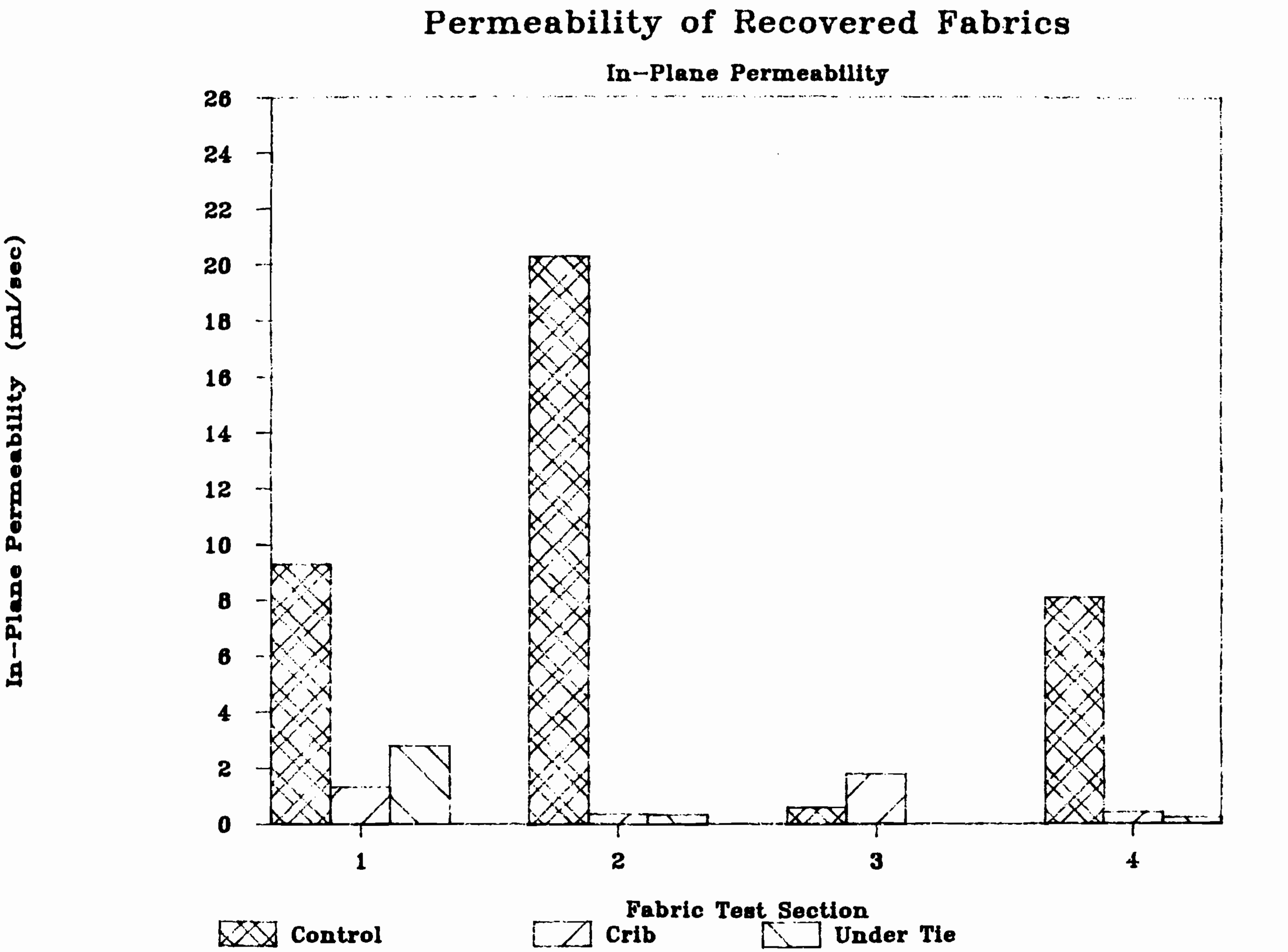

Figure 10. In-Plane Permeability of Geotextiles Recovered From the Field and Tested at a Pressure of 3.4 psi Applied Normal to the Surface.

was still much greater than that of the soil itself.

It appears desirable to permit a certain amount of clay to pass into and through the fabric, while the silt is retained in the surrounding soil. In this way, a soil-induced filter can be built-up at the soil-fabric interface. For such a filter mechanism to develop in the soil, the fabric must remain sufficiently permeable to allow pore water, carrying the clay fines under pressure from transient loads, to escape into the fabric. In other words, the filtration properties of the geotextile should not be 100% efficient. If some clay fines are not allowed to pass into the fabric, they are retained just under the fabric and, after time, may form a very weak soil layer. This buildup of slurry under a fabric was observed in a repeated load laboratory test by Hoare [2].

As evidence of this phenomenon, consider the fabric-related soil failure in Section 3. A derailment occurred that was directly related to the weak layer of clay particles that built up just under the clogged fabric. While it is not clear as to what extent the derailment was due to the differential rail settlement in Section 3, or the track sliding horizontally under load, or both, the failure was clearly exacerbated due to an impermeable geotextile. Ballast sliding laterally on top of the fabric due to a low coefficient of friction of the sheet-like fabric, also contributed to the track settlement, although to a lesser degree than than soil failure which caused six inch rutting.

The grab strength test was used to determine the tensile resistance to tearing, when subjected to a slowly increasing load applied to either end of a standard size strip. Fabric in a soiled and wet condition was tested in this manner; the results are shown in Figure 11 for samples recovered from under the tie and in the crib area. The fabric with the largest loss of strength, as compared to the control, was Fabric 1, which exhibited as 56% decrease. Fabric 2 had the least amount of strength loss, with only a 35% decrease. A visual inspection at the time of fabric sampling from the field revealed that Fabrics 3 and 4 had the most holes from tamper and traffic-induced ballast puncturing. Also, despite the relatively low amount of retained grab strength, Fabric 1 was observed in track to have the least number of puncture holes.

7.0 ANALYSIS OF RESULTS- INFLUENCE OF GEOTEXTILES UPON TRACK

Any final analysis of the effect of geotextiles upon track behavior should compare how the track was postulated to be improved and determine to what extent, if any, the testing indicated such an improvement. Data gathered over the year and a half of testing will be analyzed in more detail in this section. The four postulated beneficial effects mentioned in the Introduction will now be reviewed, in light of what the various track measurements indicated.

Reinforcement

If track reinforcement was occurring, these effects would probably manifest themselves in a decreased amount of vertical

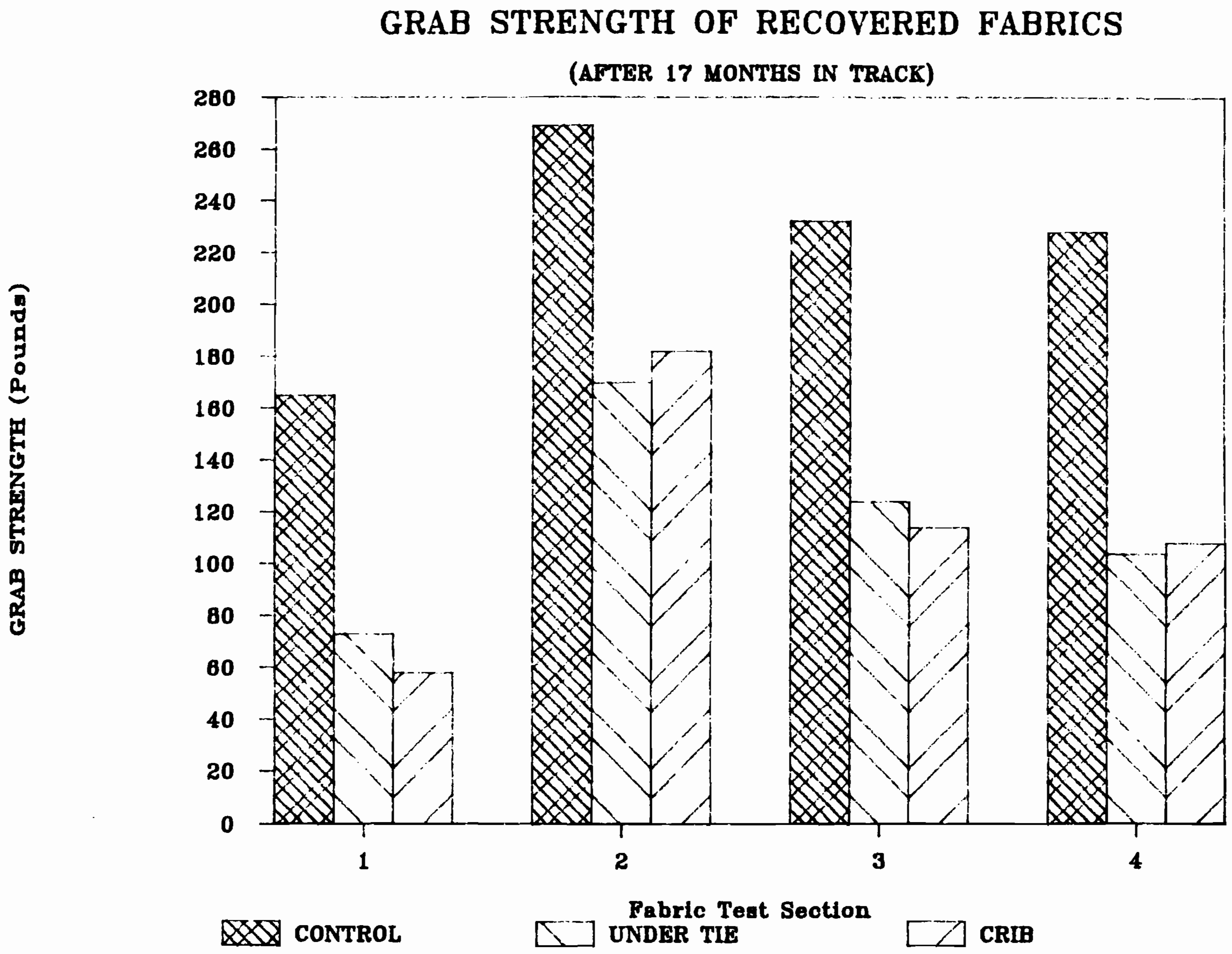

Figure 11. Grab Strength of Geotextiles Recovered From the Field and Tested Under Wet and Soiled Conditions

deformation under load and decreased pressure transmitted to the subgrade. A review of the data from the subgrade pressure and extensometer transducers indicated that no such reinforcement effect was observed, when the instrument readings of Fabric Sections 1 through 4 were compared to those of the control (Section 5) and the cement-stabilized (Section 6) locations.

The control section did experience somewhat more ballast/soil interface settlement than the other sections (Figure 5). However, this is most likely due to ballast penetration into the subgrade in Section 5. Therefore, rather than a reinforcement function, the decreased settlement is probably attributable to the separation function of geotextiles.

Subgrade Moisture Transport

Another anticipated benefit of geotextiles, that of moisture transport in the subgrade, could be assessed by the soil moisture measurements and the pore water pressure readings. Although the soil moisture measurements were not consistent between the different measurement methods, there was still enough evidence to conclude that there was no apparent subgrade moisture transport in the fabric sections as compared to the control section. The maximum seasonal variation of subgrade moisture content in Section 5 was not significantly greater than that of the average of all of the fabric sections (see Figure 4).

The pore water pressure readings, although somewhat difficult to interpret, also did not support the moisture transport mechanism. The reduced pore pressures that one would expect to observe in the fabric sections, relative to the control section, if the fabrics did transport moisture, was not apparent.

Filtration/Separation

The real success of these geotextiles in separating the layers, and limiting intermixing of the ballast and subgrade, could be seen by comparing the amount of fines above the fabric with the amount at the ballast/soil interface in the control section (Figure 9). The silty and clayey fines in the ballast of each fabric test section could be used to assess the filtration/separation functions of these geotextiles. There was a clear difference within the fabric sections with respect to the amount of subgrade fine contamination in the ballast. Of the fabric sections, Section 1 had the lowest amount of fines in the ballast, whereas Section 3 had the most.

However, as mentioned previously, filtration should not be 100% efficient. Passing some of the clayey fines which have access to the fabric should continue in order to prevent a buildup of these particles and a resulting weak soil layer.

CONCLUSIONS

Geotextiles apparently provide varying degrees of filtration and separation to the track structure. These two functions could be enough to justify the inclusion of fabric in the track. If reinforcement and/or subgrade moisture transport also resulted, then this would be an added bonus. However, the data collected from this extensively instrumented test did not show any evidence of moisture transport or reinforcement attributable to the fabric.

The graphs of subgrade moisture from the soils, obtained by hand sampling for over one and one-half years, show seasonal changes in the soil in each section, but the observed moisture variation were virtually the same among the fabric sections and the control section. It is in the variation of subgrade moisture that one would expect to observe evidence of fabric-induced subgrade drainage.

Reinforcement due to fabric membrane support was also not indicated from either the earth pressure measurements or the soil extensometers.

Perhaps one of the most interesting findings was the geotextile-related track failure which resulted in a derailment in Section 3. The soil failure was in the form of a clay slurry which built up under a fabric with a very low permeability. Because the clay particles in the compacted clay loam were displaced upwards under the loading conditions, these fines accumulated at the fabric-soil interface. Furthermore, the water in the clay fines did not escape through the fabric because of fabric clogging. This clogging is thought to have been caused by the "film-like" nature of the fabric. The low ballast-fabric friction resistance may also have contributed to the excessive settlement in Section 3, because of low lateral ballast restraint.

It appears that the installation of a geotextile that clogs can be more harmful than not installing one at all, as shown by the fact that Fabric Section 3 failed, while the control Section 5 was remarkably stable. Even though this particular type of sheet-like fabric is no longer used in track, it does illustrate what could happen if a fabric because clogged. With the more permeable fabrics that railroads are using currently, clogging may not occur for many years. However, these fabric properties which resist clogging should be further investigated.

In summary, the Caldwell geotextile tests indicated that these fabrics did not play a direct structural role or modify the soil conditions in an active manner. The benefit of these materials appeared to be in their application as barriers to intermixing of the ballast and subgrade.

8.0 REFERENCES

1. Scott, J. F., "Granular Depth Requirement for Railroad Track," Presented at the Transportation Research Board Conference, Washington, D.C., January, 1985.

2. Hoare, D. J., "A Laboratory Study into Pumping Clay Through Geotextiles Under Dynamic Loading," Second International Conference on Geotextiles, Las Vegas, Nevada, 1982.