Overlays on Faulted Rigid Pavements

DAN MCAULIFFE, LUIS JULIAN BENDAÑA, HONG-JER CHEN, AND RICK MORGAN

Steel dowels for load transfer at joints were replaced with two-component, malleable iron devices in New York State's rigid pavements from 1960 to 1973. Unfortunately, this joint system proved to be less effective, losing load transfer capability much sooner than the steel dowel joint system it had replaced. The performance of bituminous overlays on nine faulted rigid pavements containing load transfer devices over periods of 6 to 9 years is summarized. The study investigated (a) the trend toward fault return and its relation to other variables, (b) the relation between fault return and underlying slab movement, (c) the overall performance of overlays on faulted pavements, and (d) the effects of overlays on temperatures and stresses within the underlying rigid pavements. The results show that return of faulting through the overlay is minimal (60 percent of the joints had no or little fault return, and with thinner overlays the fault return was faster) and that the use of overlays should be considered only when surface distress is substantial. Although differential vertical joint movement generally increased with time, no exact relation was found between such movement and fault return. Thicker overlays were found to reduce daily and seasonal temperature changes in the underlying rigid pavements, which in turn reduced curling and compressive stresses as well as the potential for fatigue cracking and blowups.

Many pavements in New York State fail prematurely because of severe joint deterioration. The major problem is corrosion of load transfer devices (LTDs), which, combined with water infiltration and vertical deflections, creates ideal conditions for pumping, loss of support, and subsequent faulting and slab cracking. The study reported here was specifically designed to investigate long-term solutions to faulting problems by using various bituminous overlay thicknesses on rigid pavements constructed from 1960 to 1973 with two-component malleable iron LTDs (MILTDs) (*1–3*). Unfortunately, these MILTDs proved to be less effective than the steel dowels that they replaced, losing load transfer capability much sooner. During that period MILTDs were installed in about 1,800 lane km of jointed concrete pavement. As more of these pavements require rehabilitation, it has become necessary to determine the most effective rehabilitation procedure for fault removal. In New York State two long-term rehabilitation techniques have been used on faulted pavements: load transfer retrofit and bituminous overlay. The study reported here considers how initial faulting and overlay thickness affect fault return and will shortly be reported in greater detail (*4*).

INVESTIGATION

Bituminous overlays are a standard rehabilitation procedure in New York State, but no hard data on the performance of various overlay thicknesses on faulted pavements existed. To find a more rational method for selecting overlay thickness for faulted rigid pavements with LTDs, the following three questions had to be answered: (a) what effect does initial faulting have on overlay performance, (b) what factors (including other rehabilitation procedures) affect the continuation of faulting, and (c) what effects do overlays have on thermal gradients and critical stresses within overlaid slabs. The other rehabilitation procedures considered were sawing and sealing, installation of underdrains, installation of stress relief joints, and use of truing-and-leveling (T&L) and/or shim courses. Rigid pavements with MILTDs were chosen as a worst case; few rigid pavements in New York State have no LTDs. Subsealing was not included because no subsealed overlay site could be found. Grinding was not evaluated because it is not used as a preparation for overlays in New York State.

RESULTS AND DISCUSSION OF RESULTS

Faulting

Initial faulting (*4*) before overlay and fault return after overlay were measured at 18 sites on nine highways. Figure 1 indicates the absence or continuation of joint faulting reflected through the overlay. Faults were measured with a device called a fault meter, which was developed by the Transportation Research and Development Bureau in New York in the 1970s (Figure 2). It is placed 150 to 230 mm from the original shoulder-pavement joint and measures in millimeters.

When the study began in 1984 it was decided to select some test roads that were already overlaid but that had exhibited faulting recurrence in the overlay to obtain immediate results concerning the factors that affected fault return. These sites are called older overlay sites here. It was also necessary to include faulted concrete pavements scheduled to receive overlays as test sites, so that preoverlay pavement conditions could be measured, and they are termed newer overlay sites.

For seven older overlay sites the amounts of faulting before overlay were determined by coring at the joint. Before filling the core holes the overlay thickness on each side of the joint was measured. The amount of faulting before the overlay was calculated by subtracting the overlay thickness on the approach slab from that on the leave slab (Figure 3). For the 11 newer overlay sites, preoverlay faults were measured directly on the concrete slabs by using the fault meter.

Faulting was measured annually for 7 years. Measurement began 4 years after overlay for the older overlay sites, 1 year after overlay for 10 of the 11 newer overlay sites, and 2 years after overlay for the last site. The amount of faulting at each joint is shown in Figure 1. All pavements had 230-mm rigid slabs. Table 1 summarizes slab lengths, joint types, the year each pavement was built, the year it was overlaid, annual average daily traffic (AADT), percent trucks, and preoverlay treatments.

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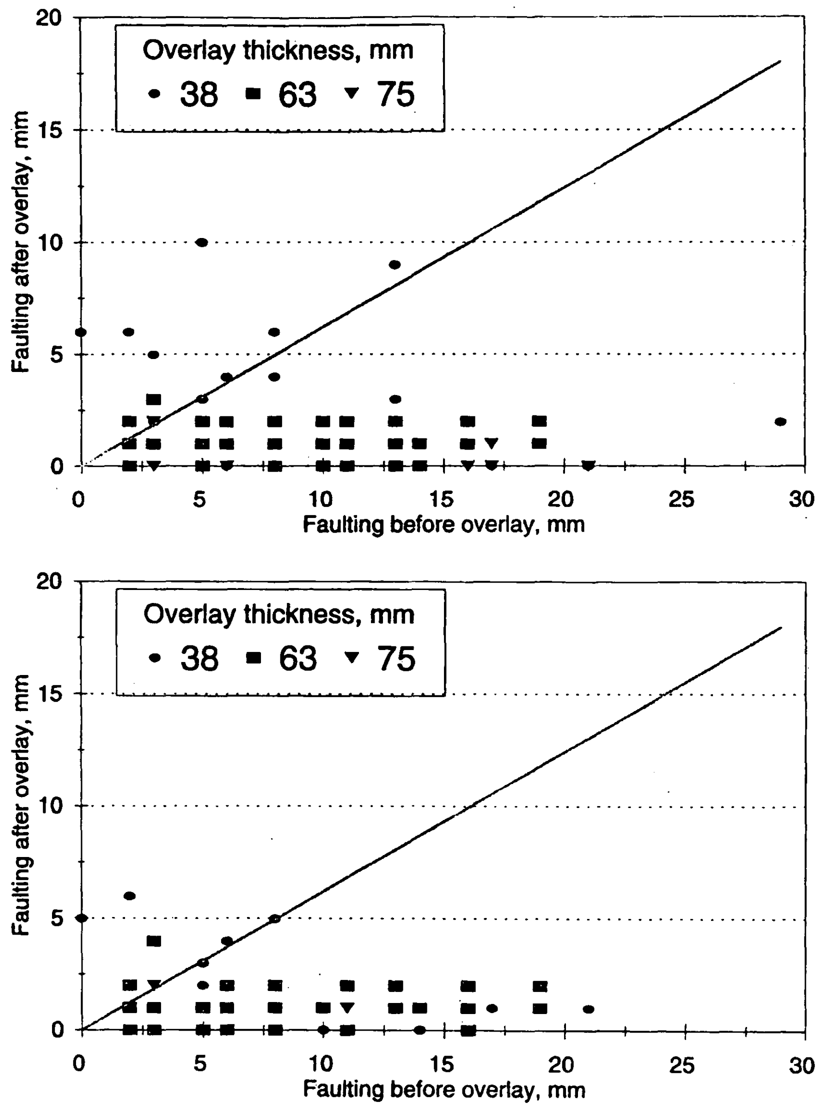


FIGURE 1 Faulting at all sites: (*a*) 4 years after overlay; (*b*) 6 years after overlay.

The first finding that should be noted is that there are fewer joint readings for the sixth year than for the fourth year. This was because some joints were no longer being monitored because either the site containing that joint had been rehabilitated or joint distress made accurate readings impossible. Nearly all of the joints omitted were in the 38-mm overlays. Next, it should be noted that with regard to overlay thickness, the 63- and 75-mm overlays performed well for up to 6 years, with all readings being in the mild faulting range, and that only a few sites had as much or more faulting as they did before overlay. Joints beneath the 38-mm overlays, however, generally showed more faulting after 4 years than they did before overlay.

The effects of the following factors were assessed: (a) joint type, (b) overlay thickness, (c) use of sawed-and-sealed joints, (d) use of underdrains, (e) use of pressure relief joints, (f) use of a shim course, (g) use of T&L course, (h) rigid pavement slab length, and (i) AADT. The program used to assess the effects of these factors was PROC GLM in SAS (*5*), which permits examination of the effect of each factor on the response variable. Those factors contributing a significant amount of variation were judged to be influential. After the first computer run, joint type was eliminated because it was shown to have the least effect on fault return. Of the factors examined, only two, overlay thickness and slab length, were found to influence fault return at the 95 percent significance level. Table 2 gives the results of these analyses. The last column indicates the probability that a given factor does not influence fault return. A relationship between fault return and slab length was found through this analysis, but closer examination of overlay thickness and slab length revealed that slab length and overlay thickness were not inde-

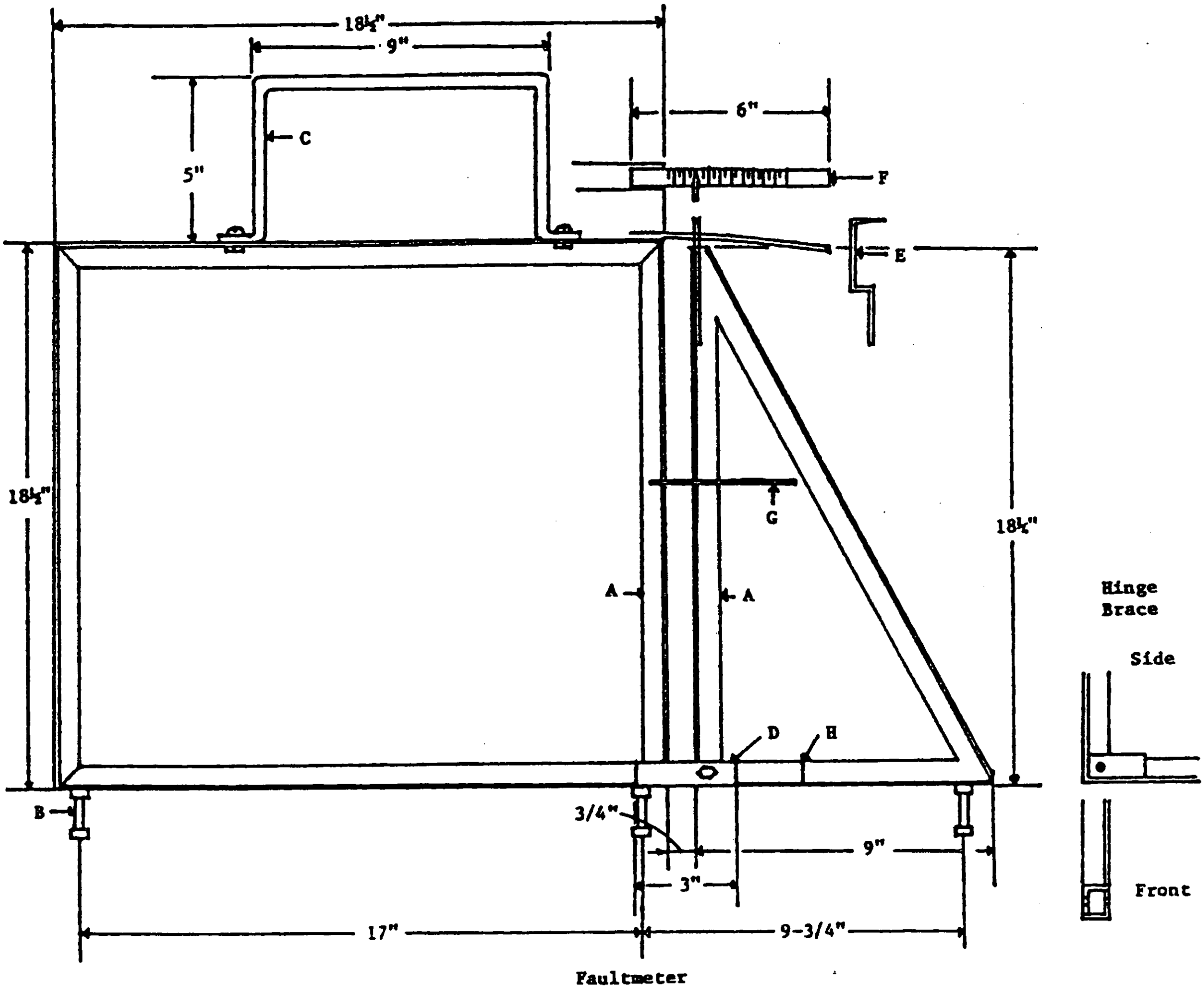
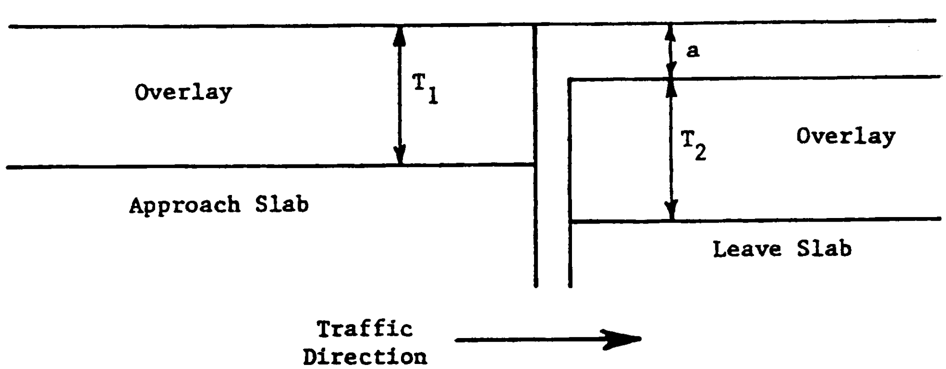


FIGURE 2 Fault meter.



a = fault measurement 4 yr after overlay

T_1 = overlay thickness on approach slab

T_2 = overlay thickness on leave slab, and

$(T_1 - T_2)$ = fault before overlay

FIGURE 3 Asphalt density measurements.

TABLE 1 Characteristics of Test Sites

Highway	Test Site	Slab Length, ft	Joints Expansion	Joints Contraction	Year Built	Year Overlaid	AADT	Percent Trucks	Preoverlay Treatment*
A. OLDER OVERLAYS									
38 mm Thickness									
Rte 110	110-TS1	12	9	- -	1954	1981	38,500	10	T&L
Rte 146	146-TS1	29	10	- -	1947	1981	8,000	4	- -
63 mm Thickness									
I-495	495-TS1	18.5	10	- -	1962	1981	92,400	10	T&L
I-390	390-TS1	18.5	- -	10	1968	1981	9,400	31	Shim, S&S, UD
	390-TS2	18.5	- -	9	1968	1981	9,400	31	Shim, UD
	390-TS3	18.5	- -	10	1968	1981	9,400	31	Shim
B. NEWER OVERLAYS									
63 mm Thickness									
I-81	81-TS1	18.5	- -	5	1964	1986	17,700	26	Shim, T&L, S&S, UD
	81-TS2	18.5	- -	9	1964	1986	17,700	26	Shim, T&L, S&S
Rte 5S	5S-TS1	27.5	15	- -	1959	1983	4,300	9	T&L
Rte 236	236-TS1	29	15	- -	1947	1985	5,600	7	T&L, S&S
75 mm Thickness									
Rte 17	17-TS1	18.5	- -	15	1961	1985	9,400	8	T&L, S&S
	17-TS2	18.5	- -	17	1961	1986	9,400	8	T&L, S&S
I-87	87-TS1	18.5	- -	5	1959	1985	44,200	11	Shim, T&L, S&S
	87-TS2	18.5	- -	5	1959	1985	38,600	9	Shim, T&L, S&S
	87-TS3	18.5	- -	11	1959	1985	38,600	9	Shim, T&L, S&S, PR
	87-TS4	18.5	- -	11	1959	1985	43,400	9	Shim, T&L, S&S, PR
	87-TS5	18.5	- -	5	1960	1985	22,800	10	Shim, T&L, S&S
C. TEMPERATURE SITES									
38 mm Thickness									
Rte 29	29-TS1	27.5	5	- -	1940	1982	5,200	1	- -
75 mm Thickness									
I-87	87-TS5	18.5	- -	5	1960	1985	22,800	10	Shim, T&L, S&S
Control (no overlay)									
Rte 29	29-TS2	27.5	6	- -	1940	1982	5,200	1	- -
I-87	87-TS6	18.5	- -	5	1960	1985	22,800	10	Shim, T&L, S&S

* Shim = shim course, T&L = truing and leveling course, S&S = sawing and sealing over underlying rigid pavement joints, UD = underdrain, PR = pressure-relief joint.

pendent and that the determining factor was overlay thickness, not slab length. Slab length could affect faulting because there would be less load transfer between slabs at lower temperatures. Joints between longer slabs open more than those between shorter slabs, reducing aggregate interlock more between longer slabs. This relationship could lead to greater faulting between longer slabs. However, the present study found greater faulting between shorter slabs, and because this statistical result could not be logically supported, slab length was removed from the analysis, and thus no conclusions could be drawn concerning slab length.

It was also desired to determine if rigid pavements continue to fault under overlays without this being apparent on the surface. Initially, cores were taken from 12 joints (6 joints at each of two test sites), and if evidence of faulting had been found, cores from more joints would have been taken. Two cores were taken at each joint (one on the approach slab and one on the leave slab), and overlay thickness was measured at both locations. If the difference in the two overlay thicknesses at a given joint was greater than the original overlay faulting, this would indicate that faulting had continued under the overlay without being detectable on the surface. Table 3 summarizes the initial faulting and measured overlay thicknesses in 1991 after 6 years of service. Of the 12 joints examined, only 1 was found to have greater faulting than before overlay, showing that joint faulting did not continue under overlays without this being detectable on the surface.

Some variation in fault recurrence may be attributed to the decreasing number of joints being measured and to problems with the overlay surface that became increasingly obvious. Unlike rigid slabs with two level surfaces on which to measure faulting, the overlay surface was not necessarily flat. The problem was twofold: (a) bumps and depressions at or near the joint resulting from shoving and/or (b) the presence of cracks in the overlay due to aging and reflective cracking. Also, a bituminous surface is more susceptible to temperature change than a rigid pavement surface, resulting in seasonal variations in the surface profile. This problem first became apparent when selecting the older overlay sites and became more noticeable as the overlays aged. These profile irregularities were most severe in 38-mm overlays. The depressions and bumps affected faulting measurements and made many of the faulting measurements on 38-mm overlays questionable after the fourth year.

Differential Vertical Joint Movement

Differential vertical joint movement (DVJMs) are measurements of the differences in the vertical movements of adjoining slabs at the transverse joint during loading, which indicate the amount of load transfer that has been lost. They were measured with another device developed by New York reseachers in the 1970s (Figure 4); this

TABLE 2 Analysis of Variance

	Factor	DF	F Value	P Value
Test 1:	Joint Type	1	0.10	0.7581
	OL Thickness	2	7.80	0.0006
	Saw & Seal Jt.	1	0.10	0.7569
	Underdrain	1	0.53	0.4659
	Pressure Relief Jt.	1	1.09	0.2979
	Shim Course	1	0.90	0.3445
	T & L Course	1	2.14	0.1458
	Slab Length	2	5.87	0.0035
Test 2:	AADT	2	0.73	0.4820
	OL Thickness	2	3.21	0.0429
	Saw & Seal Jt.	1	0.10	0.7566
	Underdrain	1	0.54	0.4654
	Pressure Relief Jt.	1	0.12	0.7295
	Shim Course	1	0.03	0.8573
	T & L Course	1	0.02	0.8975
	Slab Length	2	5.94	0.0007

General Linear Models Procedure

Dependent Variable Source	Total DF	Sum of Squares	Mean Square	F Value
Model:	12	15.808	1.317	19.66
Error:	160	10.722	0.067	P Value
Corrected Total:	172	26.530		0.0001
R Square	C. V.	Root MSE	Total Mean	
0.596	159.205	0.259	0.163	

TABLE 3 Average Faulting by Site

Site	Total Joints	Year Overlaid	Overlay Thickness, mm	Initial Fault, mm	Year after overlay 2nd	3rd	4th	5th	6th	7th	8th	9th	Annual Rate of Faulting, mm/yr
110-TS1	9	1981	38	3.2	- -	- -	4.1	4.0	3.5	3.2	- -	- -	0.46
146-TS1	10	1981	38	6.7	0.1	0.7	0.1	0.4	0.5	0.5	- -	- -	0.08
5S-TS1	15	1984	38	3.3	0.5	0.8	0.7	0.7	0.6	- -	- -	- -	0.10
236-TS1	15	1985	63	7.8	0.3	0.3	0.3	- -	- -	- -	- -	- -	0.08
81I-TS2	9	1985	63	6.5	- -	- -	1.4	1.1	1.4	2.1	1.8	1.6	0.18
390I-TS1	10	1981	63	5.8	- -	- -	1.3	0.5	- -	- -	- -	- -	0.10
390I-TS2	9	1981	63	7.6	- -	- -	1.4	0.5	1.2	1.5	1.2	2.2	0.25
390I-TS3	10	1981	63	6.5	- -	- -	1.4	1.1	1.4	2.1	1.8	1.6	0.18
495I-TS1	10	1981	63	6.2	0.4	0.2	0.3	- -	- -	- -	- -	- -	0.08
17-TS1	15	1985	75	6.1	0.3	0.2	0.3	0.4	- -	- -	- -	- -	0.09
17-TS2	17	1986	75	6.2	0.4	0.2	0.3	- -	- -	- -	- -	- -	0.08
87I-TS1	5	1985	75	2.0	0.4	- -	0.2	0.4	0.6	- -	- -	- -	0.10
87I-TS2	5	1985	75	5.2	0.6	0.2	0.4	0.2	0.4	- -	- -	- -	0.07
87I-TS3	12	1985	75	2.6	0.3	0.3	0.4	0.4	0.5	- -	- -	- -	0.08
87I-TS4	12	1985	75	4.3	0.3	0.3	0.3	0.5	0.5	- -	- -	- -	0.08
87I-TS5	5	1985	75	2.6	0.4	0.4	0.8	1.0	0.8	- -	- -	- -	0.13
81I-TS1	5	1985	75	6.0	0.0	0.0	0.4	- -	- -	- -	- -	- -	0.10

Average Annual Rate of Faulting, mm/yr	38 mm Overlays	63 mm Overlays	75 mm Overlays
	0.21	0.14	0.09

device spans the joint while a truck with a 100-kN single rear axle is driven across it. DVJM is the maximum deflection reading of the approach slab (usually occurring near the joint) subtracted from the maximum deflection reading of the leave slab (also usually near the joint). DVJMs were measured annually at about the same time as faulting measurements.

DVJMs were measured to determine the amount of load transfer across transverse joints. No definite relationship appeared between load transfer efficiency and faulting. Table 4 gives average DVJM measurements for selected overlay sites. These readings show that the greatest vertical movement of concrete slabs occurred when temperatures were below 6°C. For the three highest annual average DVJMs for these sites, 13 of 18 readings occurred under such conditions. Between freezing and 6°C the effect of aggregate interlock is reduced or eliminated, and the not-yet-frozen subgrades do not provide any additional support, so that load transfer occurs almost exclusively through the LTDs.

Temperature Study

Pavement and ambient air temperature data were recorded for 20 months on I-87 and for 25 months on Route 29. The overlay thickness of each section is given in Table 1. Pavement temperatures at each depth were recorded as the average reading at that depth for five locations at each site (Figure 5). For reporting purposes average monthly temperatures were classified in three categories: hot,

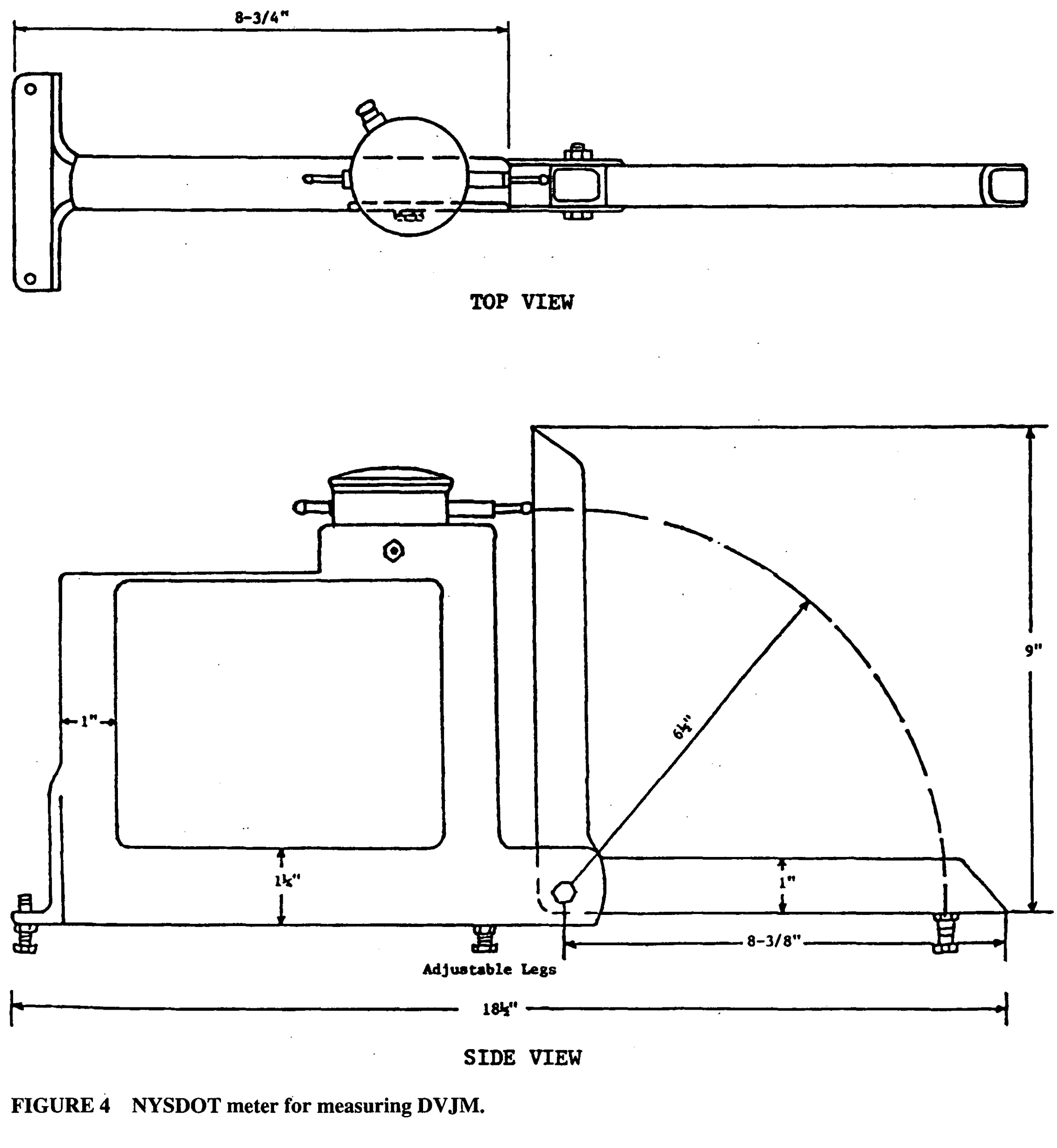


FIGURE 4 NYSDOT meter for measuring DVJM.

TABLE 4 Summary of DVJMs*

Site	Total Joints	Before Overlay	Year After Overlay 1st	2nd	3rd	4th	5th	6th	7th
5S-TS1	15	0.11	--	--	0.25	0.19	0.41	0.27	0.35
		None	--	--	20.0/18.9	13.3/17.2	3.3/5.6	6.7/11.1	5.0/7.8
236-TS1	15	0.93	0.33	0.33	0.44	--	0.48	--	--
		8.9/11.1	7.2/8.9	11.1/14.4	12.2/15.0	--	11.7/15.6	--	--
17-TS1	15	0.07	0.11	0.21	0.29	0.33	0.38	--	--
		13.3/18.9	-2.2/2.8	11.7/15.6	3.9/8.3	2.8/5.0	-2.8/2.8	--	--
17-TS2	17	0.30	0.03	0.07	0.12	0.23	--	--	--
		13.3/18.9	11.7/15.6	3.9/8.3	2.8/5.0	-2.8/2.8	--	--	--
I-87 ALL	37	0.05	0.09	0.14	0.11	--	0.23	--	--
		13.3/21.7	13.3/21.7	16.7/16.1	7.2/10.0	--	9.4/12.2	--	--
I-81 ALL	14	0.13	0.13	0.13	0.23	0.20	--	--	--
		16.1/25.6	13.3/18.3	2.2/6.7	10.0/4.4	8.9/5.6	--	--	--

*Upper value is average DVJM, mm;lower value is average air/pavement surface temperature, deg C

Range of DVJMs, mm	DVJM Severity
0 to 0.25	Low
0.25 to 0.50	Moderate
>0.50	High

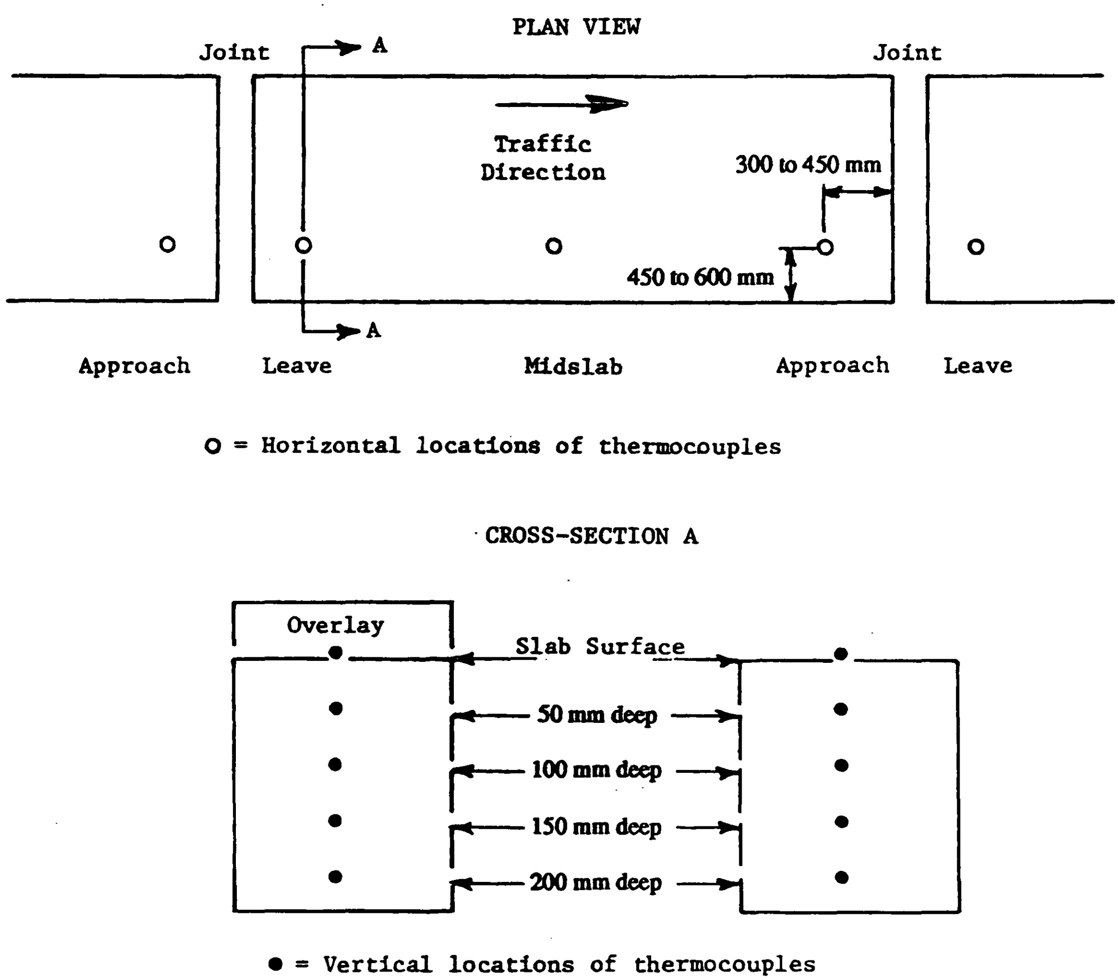


FIGURE 5 Thermocouple locations.

mild, and cold. Hot months were those when the average daily air temperature was over 15.5°C, mild months were those when the average daily air temperature was between 1.5 and 15.5°C, and cold months were those when the average daily air temperature was below 1.5°C. Note that monthly averages were based on from 2 to 4 days of data, not entire months. Control sections were pavements without overlays on the same route.

Figure 6 shows typical temperature variations within a slab during a hot day on I-87, with air temperature plotted as a reference. It shows that at a given depth, daily temperature variation (i.e., variation between maximum and minimum temperatures) is less for test sections than for control sections.

Load Transfer Retrofit

From 1982 to 1985 on the New York State portion of I-84, 289 joints were retrofitted with I-beam LTDs or a double-V device (*1,2*). The objective was to establish the criteria for when load transfer restoration and various procedures for fault removal might be effective. Figure 7 shows faulting (in millimeters) versus the number of years in service for three or four double-V devices (LTDs) per joint and four or eight I-beams per joint. Comparing the three and four double-V devices, the former performed better, with an annual fault return of less than 0.8 mm. Paradoxically, the four double-V devices per joint performed worse, with an annual fault return of 2 mm.

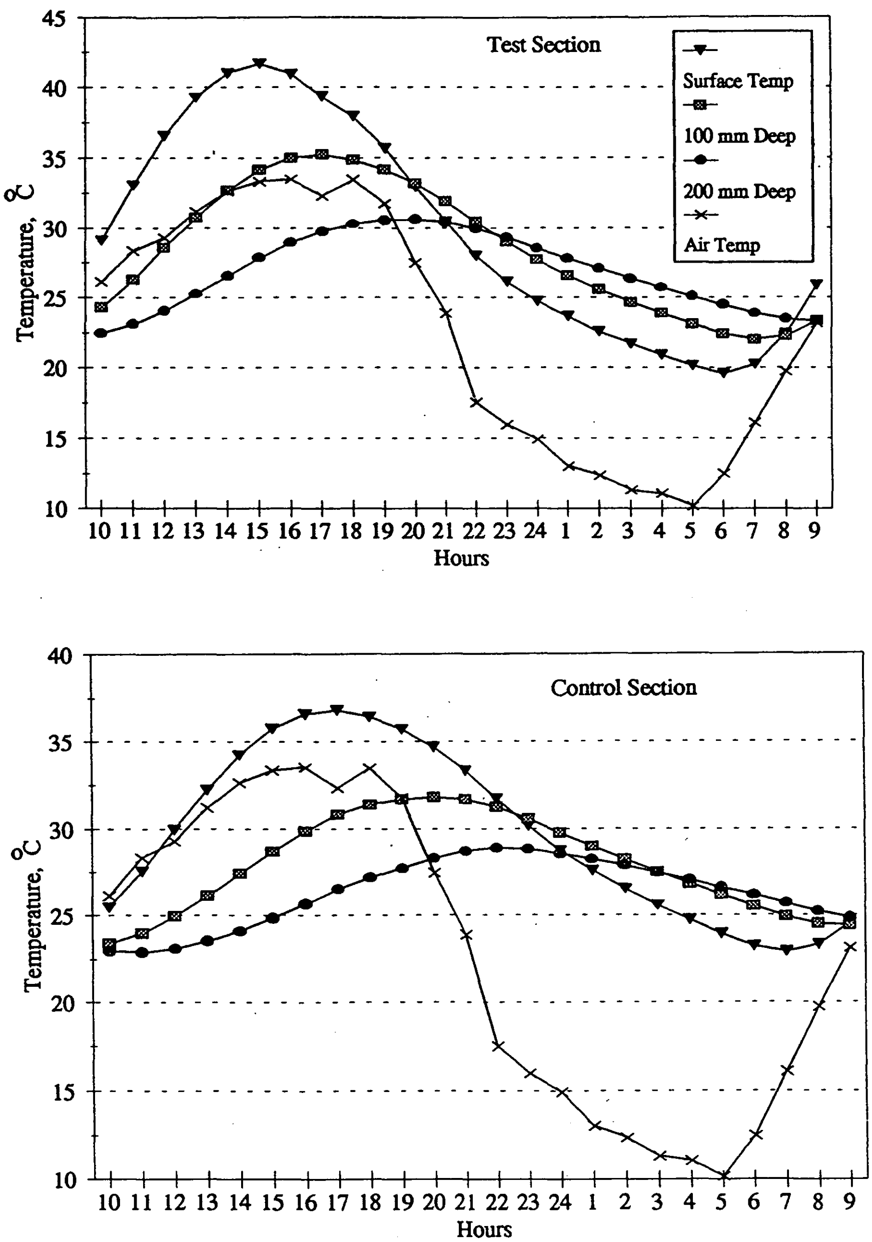


FIGURE 6 Hourly temperature at various depths.

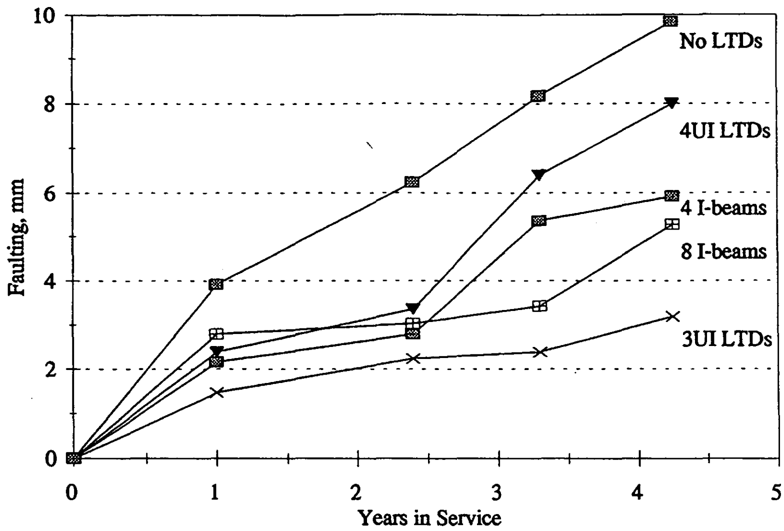


FIGURE 7 Faulting with and without LTDs.

Inadequate compaction of polymer concrete within the retrofitted joint and improper aggregate gradation of this concrete were two construction and material problems that resulted in the poor performance of joints containing four double-V devices.

Recently, with the availability of equipment capable of cutting multiple slots simultaneously, a patching material more thermally compatible with existing concrete, and better specifications and recommendations concerning the appropriate use of this technique, the New York State Department of Transportation (NYSDOT) is again considering the use of retrofitting. This rehabilitation technique is more cost-effective than other fault removal methods (slab jacking, etc.) when it is used for preventive maintenance to rehabilitate rigid pavements before serious surface deterioration problems are present.

CONCLUSIONS

Faulting

Figure 1 shows faulting in relation to overlay thickness, and Figure 8 shows annual faulting progression. These figures indicate that the return of faulting through overlays is slight: 60 percent of the joints had little or no faulting. Figure 9 shows average fault return for three overlay thicknesses. Other distresses (shoving, raveling, and cracking) make it impossible to accurately measure faulting on many 38-mm overlays. These problems were less severe on the 75- and 63-mm overlays. The 63-mm overlay showed only slightly more faulting than the 75-mm overlay, suggesting that minimum overlay thickness on a faulted rigid pavement should be 63 mm.

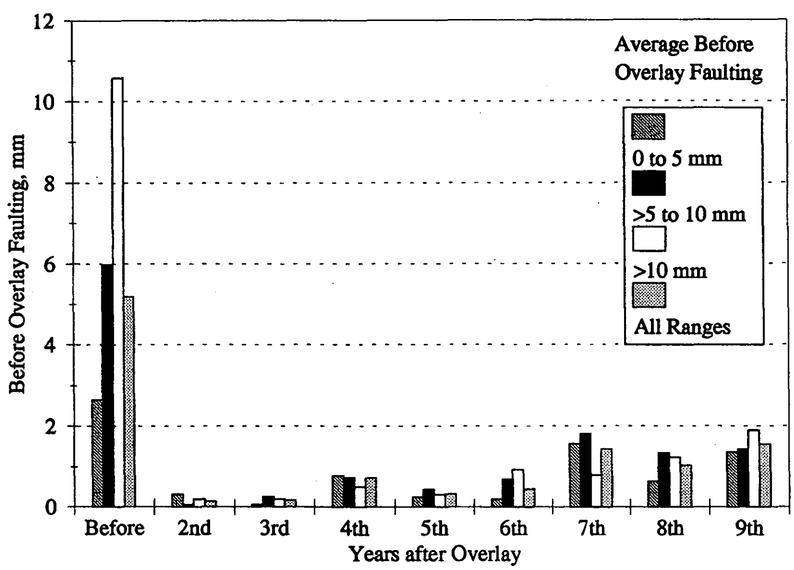


FIGURE 8 Annual faulting progression versus faulting before overlay.

Initial faulting and truck traffic were also examined. Figure 10 also shows the relation between initial faulting and fault return in the sixth year for 75-mm overlays. Although increased fault return might be expected, no noticeable relation was found. Figure 11 shows the percentage of fault return after 6 years versus AADT for the 75-mm overlay. Daily truck traffic was then grouped into two categories: one with about 300 and the other with about 3,000 trucks per day. Average fault return was found to be higher for the heavily traveled group than for the lightly traveled group: 25 percent and no average initial fault return, respectively. However, with only two truck volume groups it was not possible to determine an exact relationship between AADT and fault return.

DVJMs

The initial effect of overlays on DVJMs was inconsistent. In some cases differential movements were reduced after overlay placement, but in others they increased or stayed the same The only consistent trend was that regardless of the initial affect, DVJMs continued to increase with time.

Temperature Study

Thermal gradient is the temperature differential per unit length along the slab's depth. Figure 12 shows typical variations of temperature gradients over a 24-hr period, indicating positive gradients during daylight and negative gradients at night. The greatest thermal gradients occurred at about the same time of day, regardless of the month, with maximums for test sections occurring slightly later than those for control sections. However, the time for pavement to reach the minimum gradient varied with the season. Reduction of stresses due to thermal gradients is important, because stresses due to positive thermal gradients act to increase fatigue damage, and thus a reduction in thermal gradient results in less fatigue damage caused by each axle loading. In addition, it was found that thicker overlays reduced maximum and minimum rigid pavement temperatures and delayed the temperature cycle (the times to reach maximum and minimum temperatures were later for test sections than for control sections). The average time lag for all depths and temperature categories was 2 hr.

Retrofitted LTDs

Although the NYSDOT experience with retrofitting was not completely successful, several lessons learned from the results can help others to improve this technique: (a) retrofitting is effective when slabs are in good to excellent condition and distress is mostly due to LTD deficiencies, (b) retrofitting is essential for retarding fault recurrence when load transfer efficiency is low and the pavement is subjected to heavy truck traffic, and (c) good workmanship, sound concrete slabs, adequate LTDs, and good-quality patching material are critical for achieving satisfactory long-term performance.

RECOMMENDATIONS

The use of overlays 63 mm or thicker can be an effective rehabilitation procedure for faulted rigid pavements, but their use is recommended only when there is severe pavement surface distress. In cases in which faulting is the primary problem, retrofit LTDs are the preferred rehabilitation procedure. Finally, in any area where subsurface drainage is problematic, the use of retrofit underdrains should be considered.

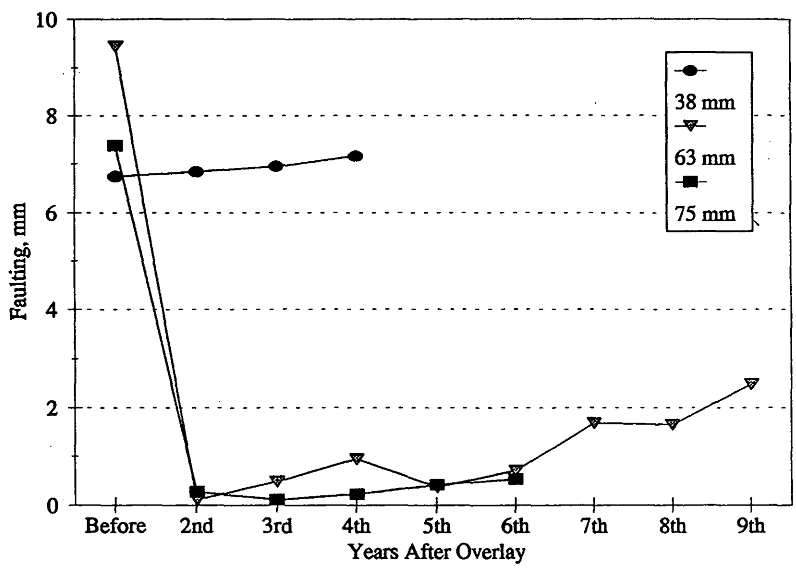


FIGURE 9 Faulting versus overlay thickness.

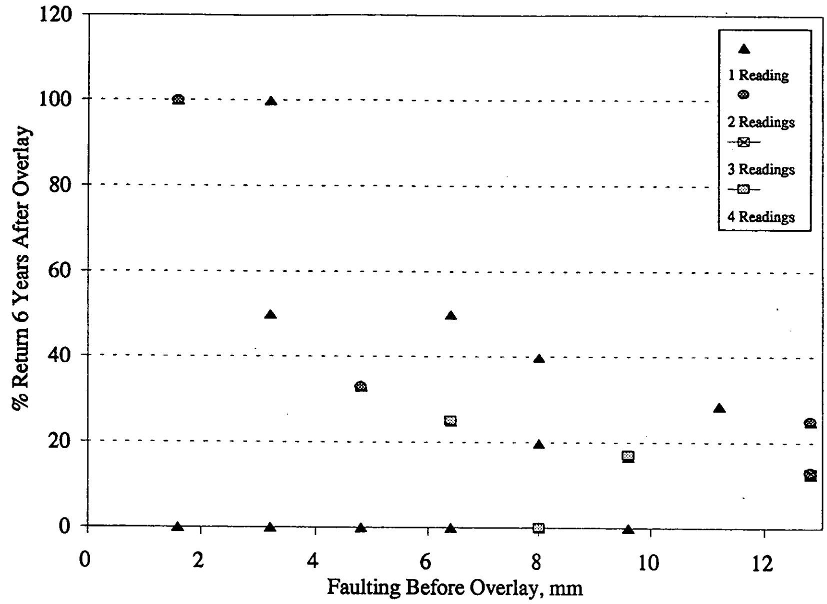


FIGURE 10 Fault return versus initial faulting (78-mm overlays).

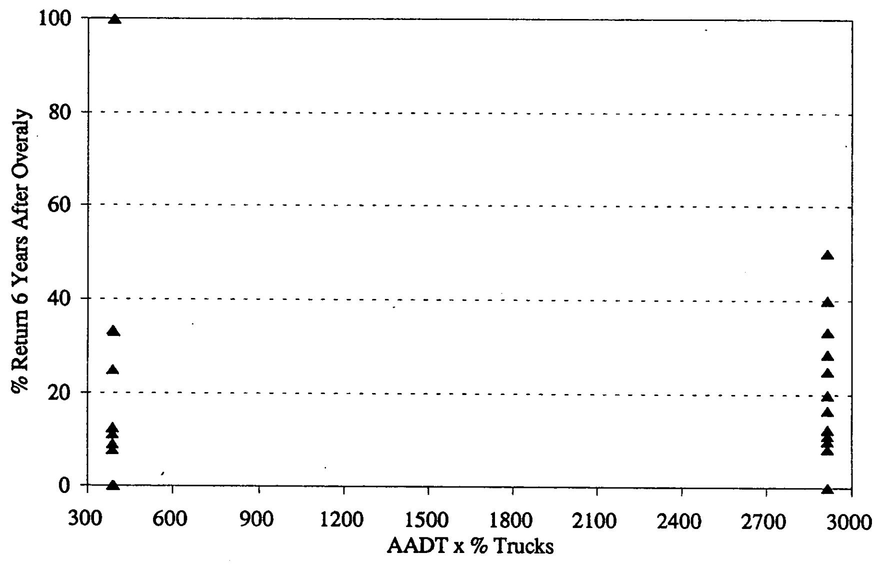


FIGURE 11 Fault return versus truck traffic (78-mm overlays).

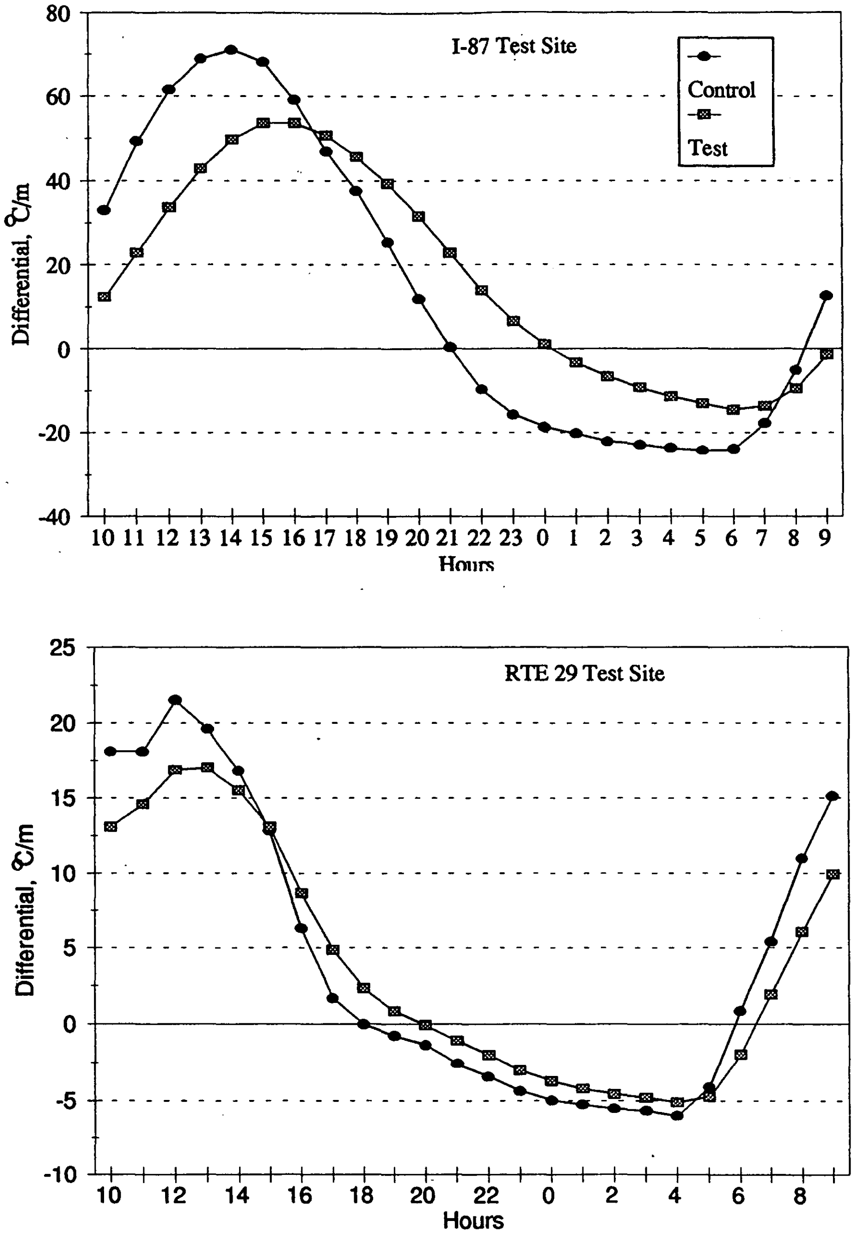


FIGURE 12 Typical daily variations in temperature differentials.

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