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ACCELERATED TESTING FOR STUDYING PAVEMENT DESIGN AND PERFORMANCE – FY 2000

Effectiveness of Fiber Reinforced and Plain, Ultra-Thin Concrete Overlays on Portland Cement Concrete Pavement (PCCP)

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16 **Abstract**

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The full-scale accelerated test revealed that the thin non-dowelled overlays are effective when used on top of distressed, rubblized concrete pavements.

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Effectiveness of Fiber Reinforced and Plain, Ultra-Thin Concrete Overlays on Portland Cement Concrete Pavement (PCCP)

Final Report

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ABSTRACT

The objective of the research was to compare the performance of fiber reinforced and plain PCC concrete overlay when used as a thin non-dowelled overlay on top of a rubblized, distressed concrete pavement. The experiment was conducted at the Accelerated Testing Laboratory at Kansas State University, and consisted of constructing two pavements and subjecting them to full-scale accelerated pavement testing. The pavements were constructed in the environmental pit so that heat-cool temperature cycles were imposed. The two pavements were subjected to 500,000 full-truck axle passes. Stresses and strains at several locations in the two pavements, as well as the expansion/contraction of the slabs were periodically recorded during the test.

The stress-strains data, as well as the location, severity and extent of the cracking in the overlay clearly indicate that there is no benefit to including the plastic fibers in the concrete overlay. The full-scale accelerated test revealed that the thin non-dowelled overlays are effective when used on top of distressed, rubblized concrete pavements.

ACKNOWLEDGEMENTS

The research experiment described in this report was selected, designed and monitored by the members of the Midwest States Accelerated Testing Pooled Fund Technical Committee. The committee technical chair is Mr. Andrew J. Gisi, Kansas Department of Transportation (KDOT) and administrative chair is Mr. Richard L. McReynolds of KDOT.

Members of the committee include Mr. George Woolstrum, Nebraska Department of Roads, Mr. Tom Keith, Missouri Department of Transportation, and Mr. Mark Dunn, Iowa Department of Transportation.

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Chapter 1

Introduction

1.1 Report Organization

This manuscript is the final report that describes the research project conducted under Kansas Department of Transportation (KDOT) Contract C1155 (RE-0165-01), "Accelerated Testing for Studying Pavement Design and Performance (FY 2000)", (KSU Research Project No. 5-34035). This contract is funded by the Midwest States Accelerated Testing Pooled Fund Program. States participating in this program are Iowa, Kansas, Missouri and Nebraska.

The purpose of the project is to conduct the experiment selected by the Midwest States Accelerated Testing Pooled Funds Technical Committee for Fiscal Year 2000 (FY-00).

This experiment is the eighth experiment conducted at the Kansas State University Accelerated Testing Laboratory (ATL) and is identified as ATL-Exp #8. The first two experiments, ATL-Exp #1 and #2, were reported in Reference [1]. ATL-Exp #3 through #6 was reported in Reference [2]. ATL-Exp #7 is described in Reference [3]. A brief description of the testing facility which includes the lab space, test pits, test frame, wheel load assembly, and heating/cooling system is described in ATL-Exp. #7 Reference [3].

The remainder of this chapter is a general overview of the project. Chapter 2 provides a background on the history and theory of white-topping, and the types of instrumentation used in this project to evaluate the pavement performance. Chapter 3 gives a detailed description of the test experiment including the pavement construction process, loading conditions, heat application, and temperature settings, sensor installation and data acquisition, and the executed performance monitoring plan. Chapter 4 discusses the test results and data collection, and observed performance and conclusions.

1.2 Project Overview

The objectives of the project described in this report are to perform the experimental work and associated data acquisition/data processing for the research study entitled "Effectiveness of Fiber Reinforce and Plain, Thin, Non-Doweled, Non-Reinforced Portland Cement Concrete (PCC) Overlays on Rubblized PCC Pavement (PCCP)." The goal of the research is to compare the performance of fiber-reinforced and plain concrete thin overlays placed on rubblized PCCP. The research described in this report involved the applications of realistic wheel/axle load cycles to large-scale full-depth pavement slabs under controlled thermal conditions. The experiment was conducted at the Kansas State University ATL.

This experimental investigation, when compared with performance of similar applications used in control sections on in-service highways and supplemented with further analytical studies, can help the states in the pooled fund and other state agencies establish or modify existing special provisions for thin PCC overlays. It may also lead to standard guidelines for instrumentation of in-service highway pavement sections. Further work would include numerical modeling, evaluation of mechanistic responses, analysis of Falling Weight Deflectometer (FWD) data, and comparative studies with similar research in the United States and abroad.

Chapter 2

Background

2.1 Objective

The objective of experiment ATL-Exp # 8 was to compare the performance of fiber reinforced and plain PCC concrete overlay when used as a thin non-dowelled overlay on top of a rubblized, distressed concrete pavement.

In this experiment two thin, instrumented, PCC overlay on a rubblized base were constructed. A single 22 kip axle was used to apply 500,000 load repetitions. Pavement response and performance data was collected periodically.

2.2 Concrete Overlay (White-Topping)

The idea of concrete overlay (white-topping) came as an extension to asphalt overlays (black-topping). Asphalt overlays on concrete pavements have been in use for some time and have proved successful when reflective cracking is controlled.

It was found that movement/slab action, which shows up at joints, was the primary cause of reflective cracking in the overlay. Various means have been found to reduce, isolate or dampen this movement. One of the methods was to repair all joints prior to the overlay, reducing any joint movement. Another solution was to pad the overlay so the displacement of the joint is moderated and the movement/stress concentration is distributed.

Later it was found that one could break and seat the existing pavement which would make a tighter fit to the base and reduce vertical movement. This would also reduce the expansion and contraction of the slabs, which lead to smaller and distributed displacements, thus to reduce stresses on the overlay.

This resulted in the so-called "crack and seat" which completely breaks the bond between pavement slabs, thus making movement more independent and of less magnitude than "break and seat" slabs.

Breaking the slab into smaller pieces is called rubblizing. Pieces less than 12-in. in size are set to and into the base and are compacted and wedged against each other. No continuous joints or planes of weakness are left intact, and the rubblized pavement acts as a uniform base. Good success was obtained by applying asphalt to a rubblized pavement, without a padding/dampening layer.

Given the success of asphalt over rubblized pavements the next step was to try a PCC overlay. A concrete overlay may be thinner than the asphalt overlay, and transmits better wheel loading to the foundation layers. It also exhibits better strength, durability and wearability than asphalt overlays. When the overlay thickness is less than or equal to 4 inches, it is commonly called "ultra-thin white topping" (UTW). The UTW technology has been extensively used for the reinforcement of both highway and airfield pavements.

2.3 Design Concept

The test section consisted of two 4-in. thick, 20-ft. long, and approximately 6-ft. wide PCCP test sections. One slab was constructed with regular PCC and the other with fiber-reinforcement in the slab. The slabs are separated by a longitudinal joint that prevent any slab-to-slab interaction. The slabs were restrained on the ends using reinforcing bars welded to the pit walls. Two transverse joints were sawed into each slab approximately 5-ft. from each end.

The slabs were placed on top of a 6-in.thick rubblized PCCP, constructed over a 6-in. aggregate base. The aggregate base was placed on a silty clay subgrade that was proof-compacted from a previous test [3]. No moisture was added to the subgrade except the water spilled during the sawing of the transverse relief joints. The two overlay slabs were longitudinally separated by a 2-in. wide construction joint. The longitudinal joint was formed in place and required no sawing.

2.4 Instrumentation

Soil pressure cells were placed below the aggregate base. These were salvaged from a previous experiment [3] and are used to determine the vertical pressure in the subgrade, and to monitor its variation due to the deterioration of the overlay or the rubblized base. Thermocouples were placed below, in, and on top of the overlay slabs to monitor the slab temperature and see if there is a correlation between overlay slab temperature and stress/curling of the slabs. Strain gages were installed in the overlay to monitor the deterioration of the overlay slab and to determine a correlation between the slab movement due to loading and temperature. Linear Variable Displacement Transformers (LVDT's) were used to measure horizontal joint movements.

2.5 Description of the Test Facility

A detailed description of the testing facility can be found in “Development of an Accelerated Testing Laboratory for Highway Research in Kansas” [1].

Chapter 3

Description of the Test Experiment

This chapter gives a detailed description of the test experiment including materials and placement, loading conditions, heat cycling and temperature setting, sensor installation and data acquisition, and the performance monitoring plan.

3.1 Pavement Construction

3.1.1 Existing Sub-base

The subgrade is the same silty soil originally placed in the KSU ATL pits and used during past experiments. When originally placed, it was compacted to 90 percent of the Standard Proctor dry density (MDD), and the top 46-cm (18-in.) were compacted to 95 percent of the MDD. Density was monitored with a nuclear density gage. After the previous test the subgrade was not disturbed and therefore the soil density did not decrease.

3.1.2 Aggregate Base

The 6-in. Kansas aggregate base (Kansas AB-3) from the previous test was disturbed during the removal of the previous surface but was reworked and recompacted. The results of testing the aggregate base with a nuclear surface moisture density gauge indicated a minimum dry density of 122 lb/cu ft.

3.1.3 PCC Rubblized Base

A 6-in. PCC concrete slab with a strength of 3000 psi was placed on top of the aggregate layer. The slab was later rubblized. Slump and 28-day compressive strength cylinders were taken for the base slab. Table 3.1 shows the batch quantities for the PCC rubblized base mix delivered and the results of the quality control tests.

TABLE 3.1: Batch Sheet for the Rubblized Base

TRUCK	USER LOGIN			TICKET NUM		TICKET ID	TIME DATE
61				20526		16639	13:42 06/17/99
LOAD SIZE	USER MIX CODE					SEQ	LOAD ID
5.00 yd.	MIX # 08					N	17466

MATERIAL	DESIGN QTY	REQUIRED	BATCHED	VAR	% VAR	MOISTURE	ACTUAL WATER
A/E	1.00 oz	5.00 oz	5.00	0.00	0.00%		
CA-6	910 lb	4618 lb	4620	2	0.04%	1.50% M	8.18 gl
CEMENT 5	470 lb	2350 lb	2345	-5	-.21%		
DARA 65	18.80 oz	94.00 oz	94.00	0.00	0.00%		
SAND	2166 lb	11124 lb	11160	36	0.32%	2.72% A	35.39 gl
WATER	29.8 gl	90.5 gl	89.0	-1.5	-1.66%		89.00 gl

NON-SIMULATED NUM BATCHES: 1
LOAD TOTAL: 18874 lb WATER/CEMENT: 0.472T WATER IN TRUCK: 15.0 gl
SLUMP: 3.00" TRIM WATER: 0.0gl/yd
SLUMP ACTUAL: 2 1/4"

POURED TEST CYL.: June 17, 1999:	Test Cyl. 1	Broke 9/14/99	5128 psi
	Test Cyl. 2		4845 psi
	Test Cyl. 3		5305 psi

Randomly shaped cracks were formed by inserting a metal sheet into the fresh concrete to initiate a mortar crack. When the base concrete had set, several attempts were tried to rubblize the slab. Rollers and pavement breakers were not available for such a small project. A jack hammer on a Bobcat was used to break and set the rubblized base. Significant damage was inflicted to the slab surface and cracks were introduced through the thickness of the slab. The deeper recesses in the rubblized surface were leveled with concrete mortar. Figure 3.1 represents the rubblized PCC base, showing the cracked surface and the deeper displaced surfaces leveled with mortar. The dark lines are standard wooden pencils.

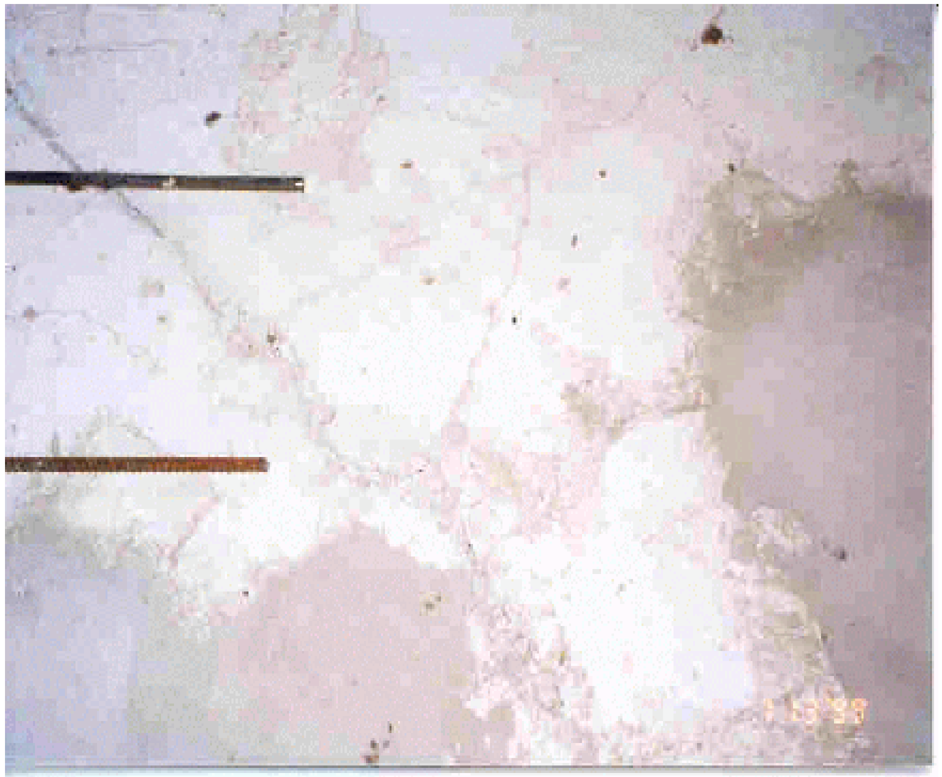


FIGURE 3.1: Rubblized PCCP Surface

3.1.4 Overlay

The top overlays were placed on July 13, 1999. The regular mix was placed on the North lane and a fiber reinforced mix was placed on the South lane. Both slabs were finished simultaneously with a concrete float. Plastic covers were used for 10 days for curing the concrete. Quality control consisted of slump test and 3 standard 28-day compressive strength test cylinders per lane. Tables 3.2 and 3.3, respectively, show the batch quantities of the standard and fiber reinforced concrete delivered and the results of the quality control tests.

3.2 Loading

Loading of 22 kips is applied through rolling wheel passes using a single axle, dual wheel test frame. The centerline of the tandem axle corresponds to the location of the center joint separating the two PCC mixes. A fixed wheel path (zero lateral wander) was maintained and two-pass cycles (one load application forward and one load application back per cycle) were applied throughout the test. Tire pressure was 621 kPa (90 psi).

TABLE 3.2: Batch Sheet for the Plain Overlay

TRUCK	USER LOGIN			TICKET NUM		TICKET ID	TIME DATE
41				21425		17539	13:45 7/13/99
LOAD SIZE	USER MIX CODE					SEQ	LOAD ID
2.00 yd.	MIX # 42					N	18400
MATERIAL	DESIGN QTY	REQUIRED	BATCHED	VAR	% VAR	MOISTURE	ACTUAL WATER
A/E	3.00 oz	6.00 oz	6.00	0.00	0.00%		
CA-6	844 lb	1692 lb	1700	8	0.47%	0.25% M	0.51 gl
CEMENT 3	658 lb	1316 lb	1310	-6	-0.46%		
SAND	2008 lb	4137 lb	4160	23	0.56%	3.01% A	14.56 gl
WATER	33.1 gl	53.2 gl	52.0	-1.2	-2.26%		52.00 gl

NON-SIMULATED NUM BATCHES: 1
LOAD TOTAL: 7604 lb WATER/CEMENT: 0.427A WATER IN TRUCK: 0.0 gl
SLUMP: 3.00" TRIM WATER: 1.0 gl/yd
SLUMP ACTUAL: 5 1/2"

POURED TEST CYL.:			
June 17, 1999:	Test Cyl. 1	Broke 9/14/99	5694 psi
	Test Cyl. 2		6260 psi
	Test Cyl. 3		5694 psi

TABLE 3.3: Batch Sheet for Fiber Reinforced Overlay

TRUCK	USER LOGIN	TICKET NUM	TICKET ID	TIME	DATE
58		21427	17541	13:45	07/13/99

LOAD SIZE	USER MIX CODE	SEQ	LOAD ID
2.00 yd.	MIX # 42	N	18402

MATERIAL	DESIGN QTY	REQUIRED	BATCHED	VAR	% VAR	MOISTURE	ACTUAL WATER
A/E	3.00 oz	6.00 oz	7.00	1.00	16.67%		
CA-6	844 lb	1692 lb	1700	8	0.47%	0.25% M	0.51 gl
CEMENT 3	658 lb	1316 lb	1325	9	0.68%		
SAND	2008 lb	4149 lb	4160	11	0.27%	3.31% A	15.97 gl
WATER	33.1 gl	51.8 gl	50.0	-1.8	-3.47%		50.00 gl

NON-SIMULATED NUM BATCHES: 1
LOAD TOTAL: 7603 lb WATER/CEMENT: 0.419A WATER IN TRUCK: 0.0 gl
SLUMP: 3.00" TRIM WATER: 1.0 gl/yd
SLUMP ACTUAL: 6" 3 lb/yd fiber mesh WR Grace

POURED TEST CYL.:			
July 13, 1999:	Test Cyl. 4	Broke 9/14/99	5022 psi
	Test Cyl. 5		4456 psi
	Test Cyl. 6		4633 psi

3.3 Heating/Cooling

Heat was applied to the surface of the pavement specimens using thermal coil panels containing a glycol water working fluid that heated or cooled depending on the phase of the test. All heating and cooling was applied to the surface. Temperature on the surface and inside the pavement were continuously monitored with thermocouples. Temperatures were raised and lowered during the weekends and maintained at the high or low values during the testing days. Load applications took place at extreme temperatures to impose a temperature-wheel load combination and to accelerate the damage of the concrete overlays. The heating and cooling was controlled to maintain a 20°F temperature gradient from the surface to the PCC base (4-in. from the surface).

3.4 Sensor Installation, Placement and Data Acquisition

Several sensors were placed in the test sections to monitor pavement behavior. In addition to complement measurements obtained from these sensors, FWD tests were conducted and material quality control tests were run.

3.4.1 Pressure Cells

Pressure cells (Geokon) were placed below the aggregate base level (16-in. from the surface). Two cells were placed in the middle of the slabs and two additional cells were placed in the location of the future transverse west joint. The location of the pressure cells and corresponding channel designations are shown in Figure 3.2. These particular types of sensors were successfully used in pervious projects and have shown good performance and acceptable results. In particular, data from similar Geokon pressure cells and Dynatest strain gauges were measured and digitally recorded during previous tests (ATL-Exp #5, 6 and 7). The sensors were installed according to the manufacturer's guidelines and following procedures recommended by the MnRoad research program [3]. Response traces are similar to those reported by other experimental researchers and previously obtained during earlier experiments [3].

3.4.2 Thermocouples

Six thermocouples were placed on top of the subgrade, below the rubblized base (10-in. from the surface). Six additional gages were placed on top of the rubblized base (4-in. from the surface). Six thermocouples were placed on the surface of the PCC overlay. These thermocouples were fabricated by the lab personnel. Figures 3.3, 3.4 and 3.5 show, respectively, the location and corresponding channel designations of the thermocouples placed as described. Similar thermocouples were used in ATL-Exp #3, 4 and 7 and showed acceptable results when compared to other conventional temperature measurement devices.

3.4.3 Strain Gages

Strain gages were installed at the bottom of the overlay, 4-in. from the top surface. When near a joint line the strain gage was placed 5-in. from the joint line. The orientation of the strain gages is longitudinal to the long dimension of the slab, i.e., parallel to direction of the wheel travel. Figure 3.6 shows the location and corresponding channel designation for all strain gauges.

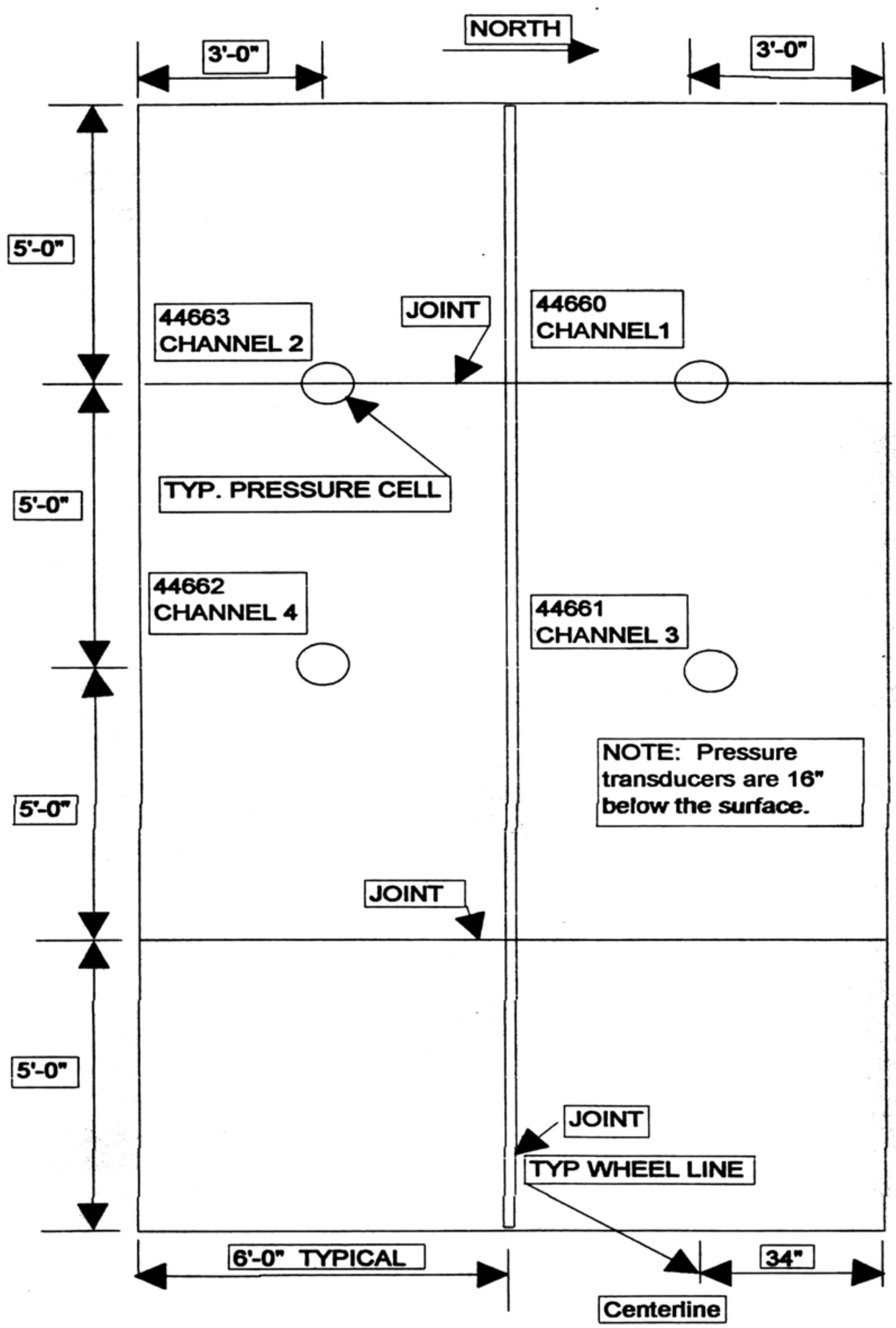


FIGURE 3.2: Soil Pressure Transducer Locations

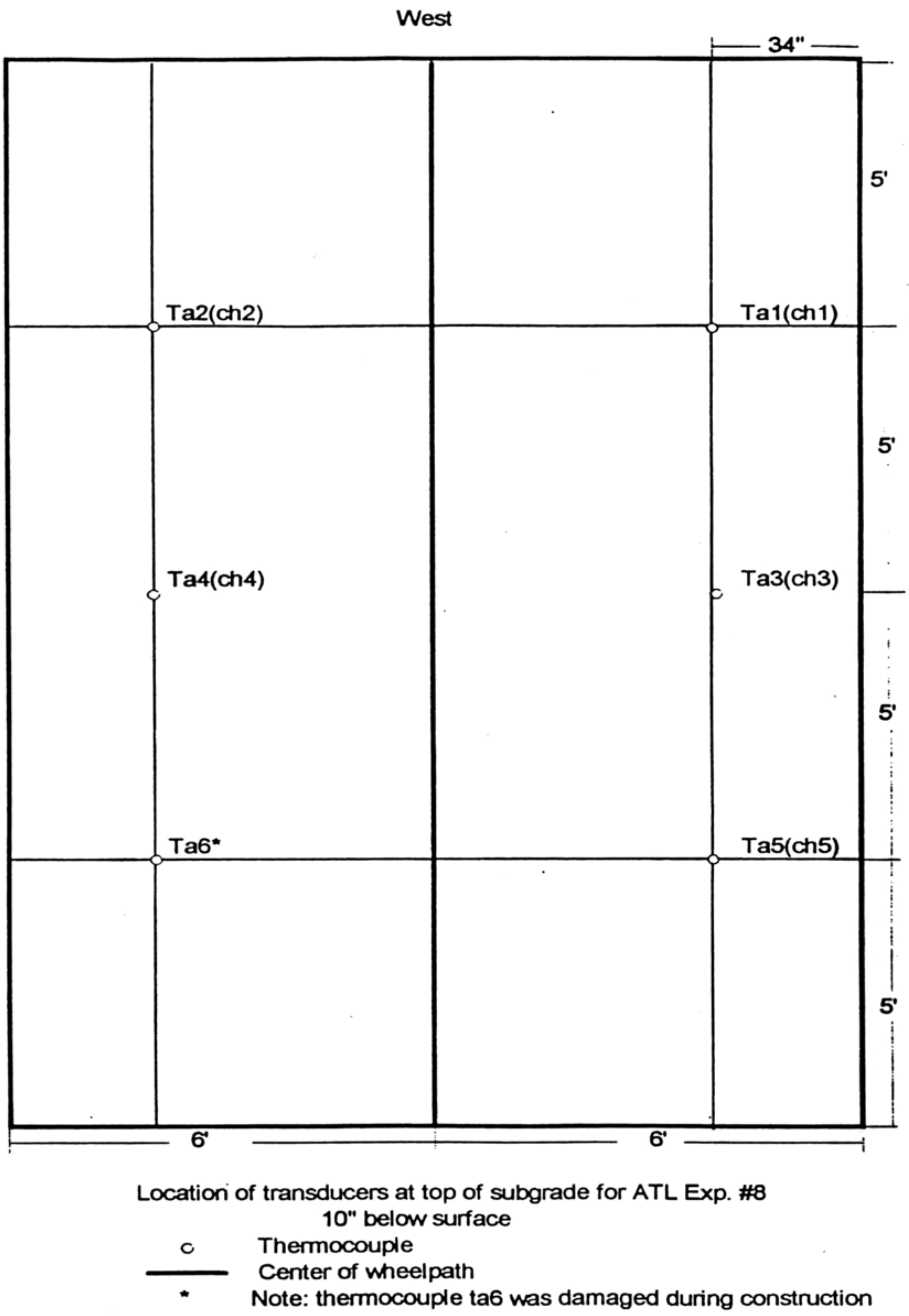


FIGURE 3.3: Thermocouple Locations (10-in. below surface)

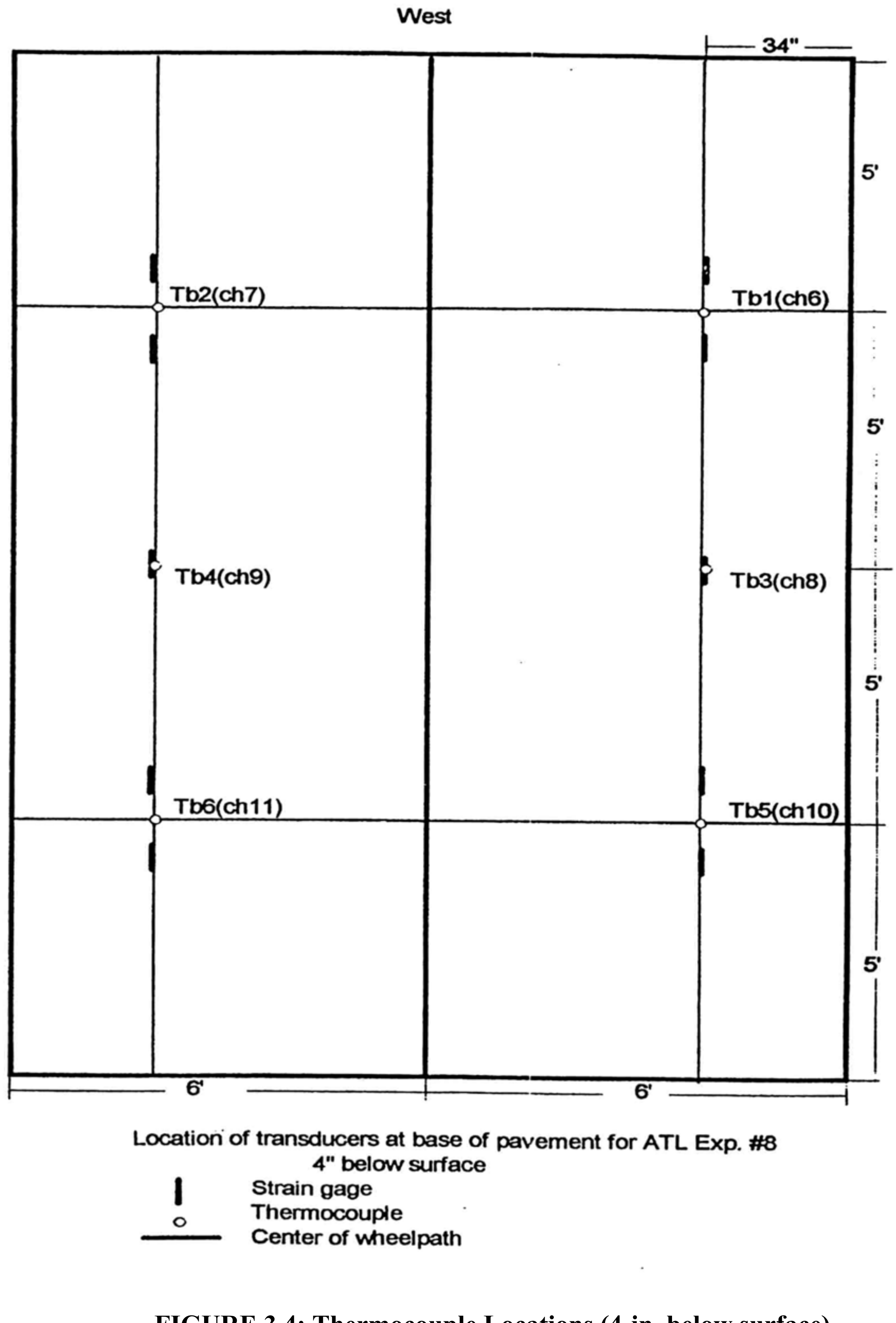


FIGURE 3.4: Thermocouple Locations (4-in. below surface)

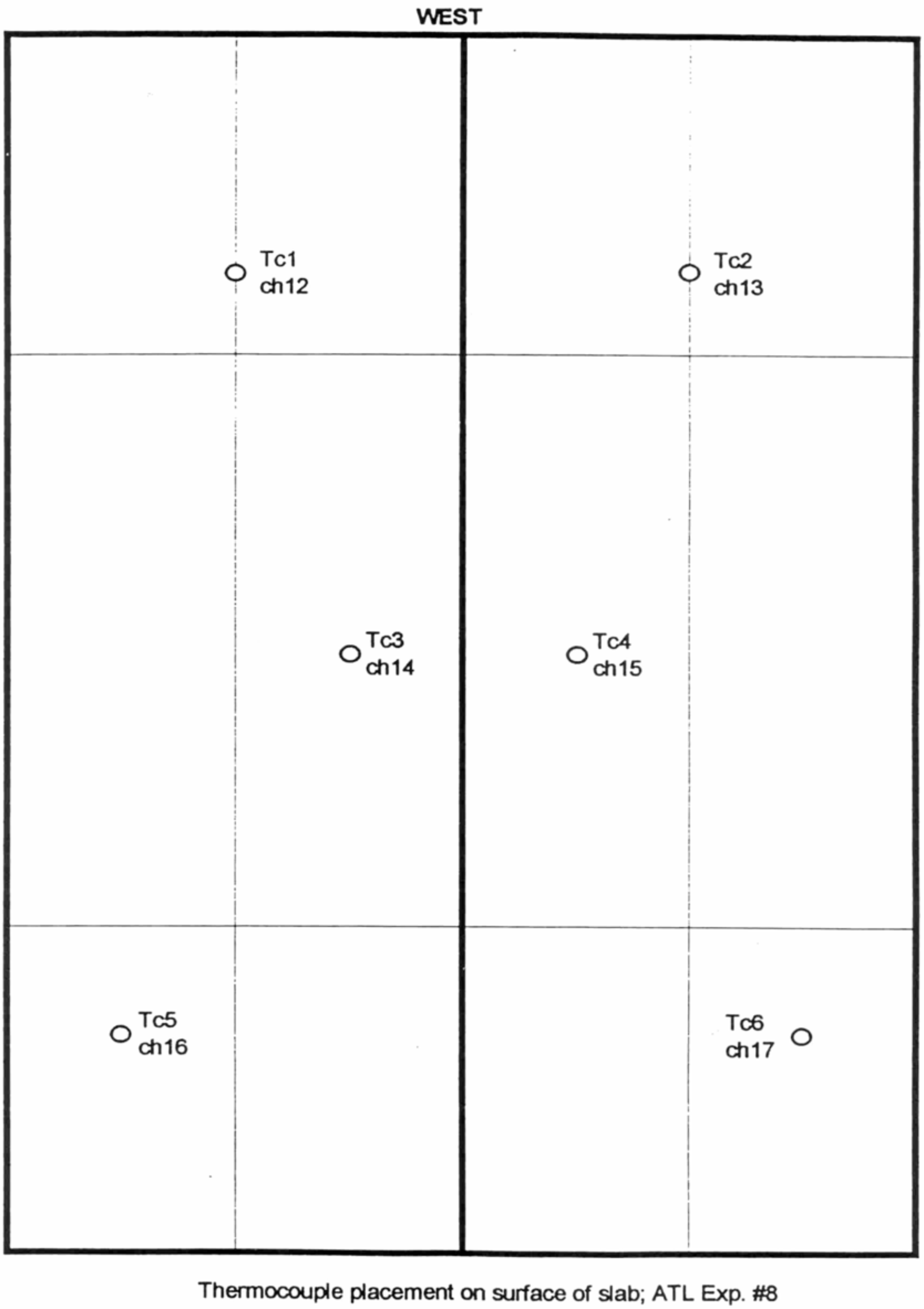


FIGURE 3.5: Thermocouple Locations (surface of overlays)

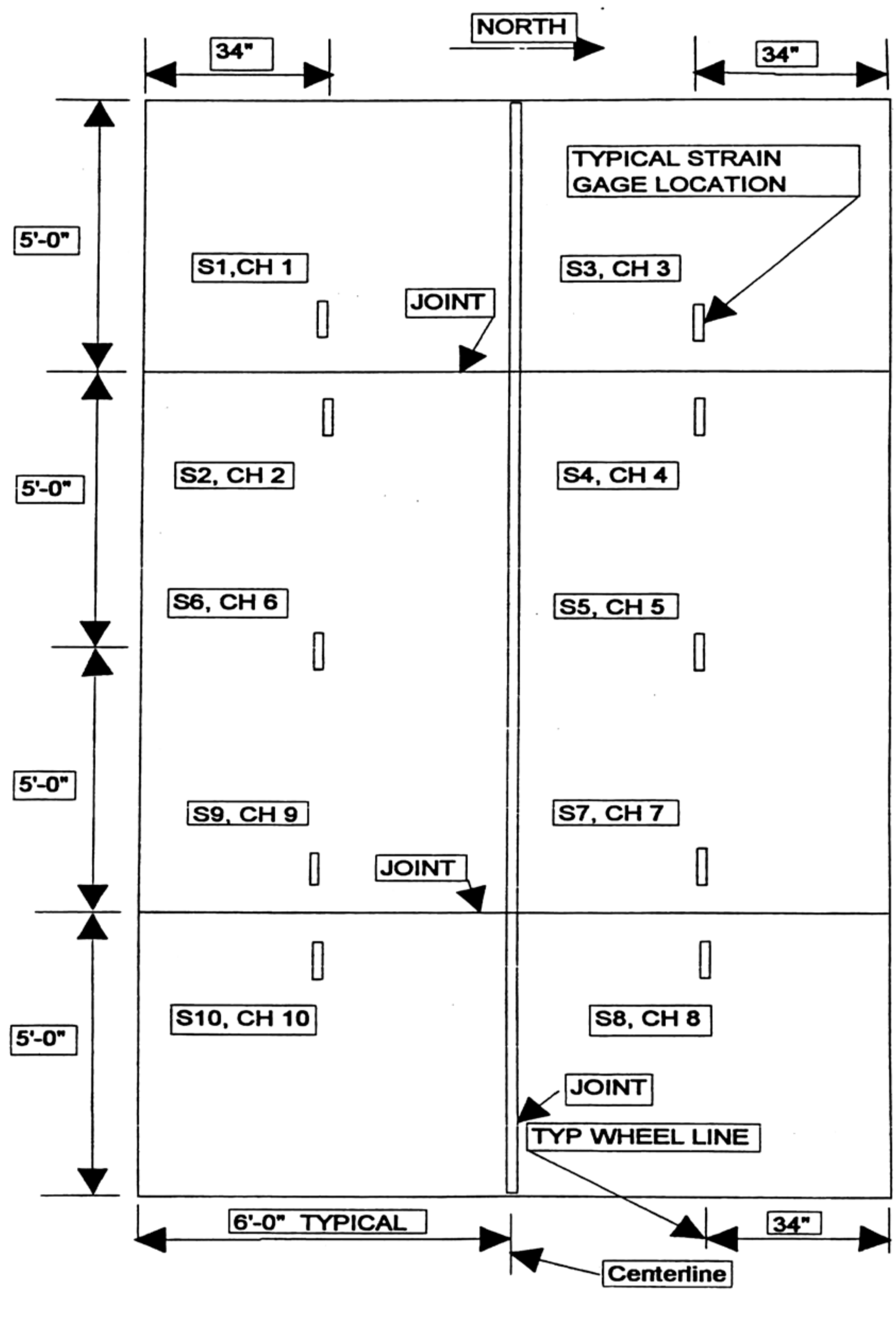


FIGURE 3.6: Strain Gage Locations

3.4.4 Falling Weight Deflectometer (FWD)

FWD readings were taken on the intermediate slab at ambient temperature before it was rubblized. The FWD testing locations are shown in Figure 3.7. FWD testing on the overlay was also done at the beginning of the test, at 240,000 repetitions and at the end of the experiment. Figures 3.8 through 3.10 show the location of the drops for 0K, 240K and 500K repetitions, respectively.

3.4.5 Dynamic Response to Weight Drop

Data was taken to evaluate the pavement's dynamic response to a weight drop. The weight drop position and the layout of the data collection locations are shown in Figures 3.11 and 3.12, respectively. Positions 11 and 12 were added after the transverse cracks have occurred. The large black circles in Figure 3.12 represent the location of the weight drops and the small circles are the positions of the displacement transducers (LVDT's). The drop weight apparatus, shown in Figure 3.13, was used in previous ATL experiments. The data analysis was not supported by this project but it is reported in an M.S. report [9].

3.4.6 Joint Movement

Joint movement (expansion and contraction) was measured during the temperature cycle from hot to cold and cold to hot. LVDT location and orientation to measure longitudinal movement is shown in Figure 3.14.

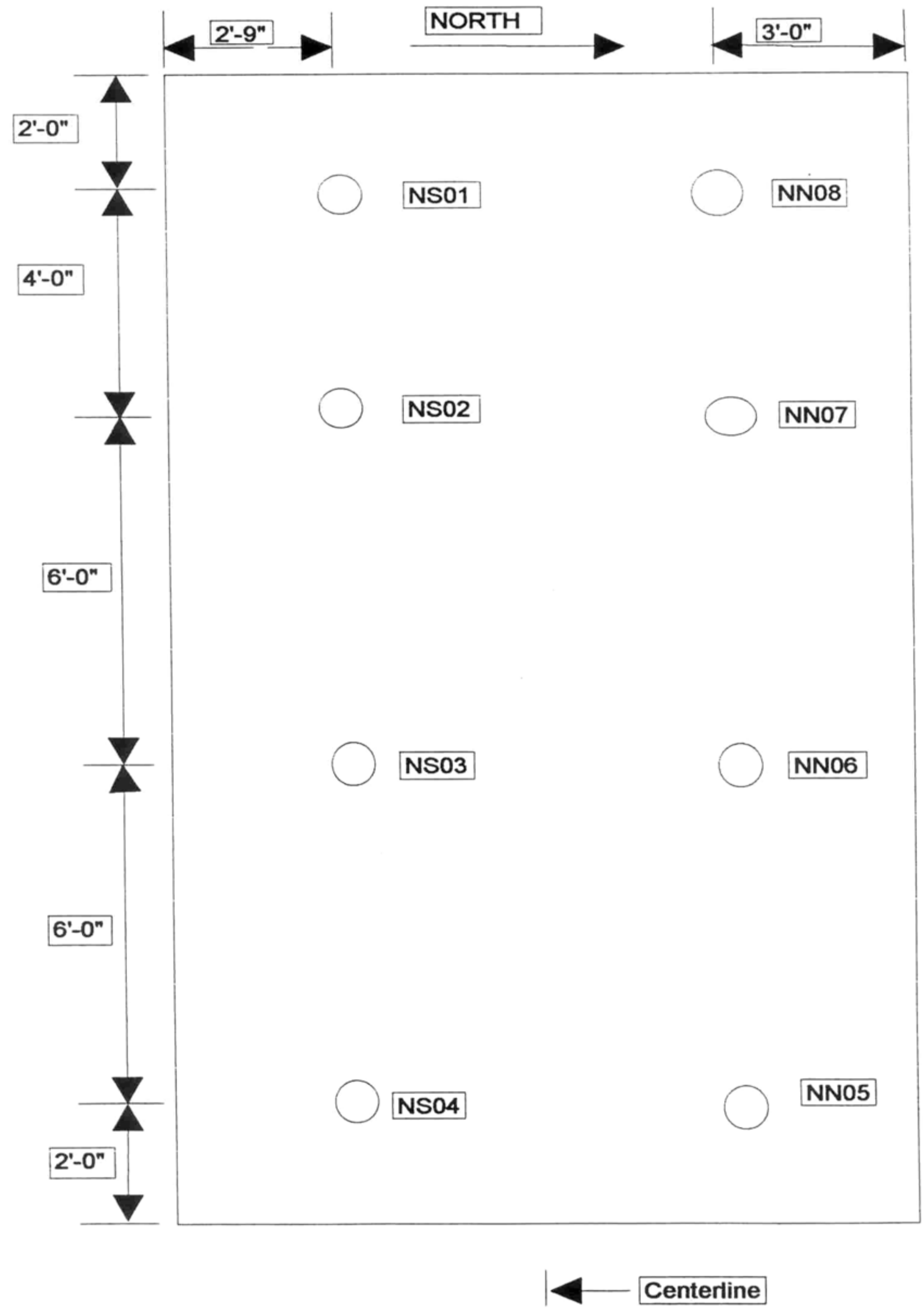


FIGURE 3.7: FWD Test Locations (rubblized slab)

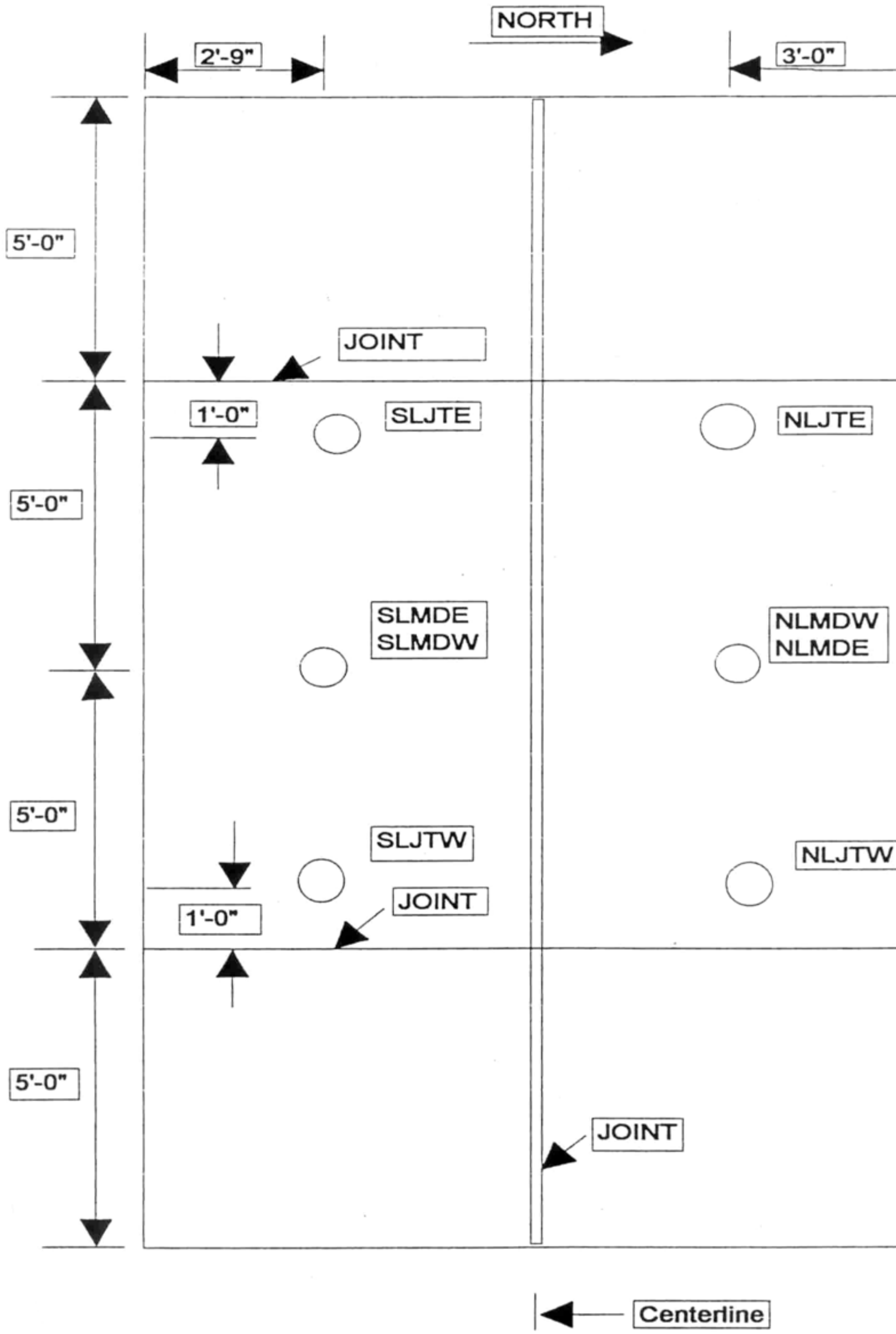


FIGURE 3.8: FWD Test Locations (0 K repetition)

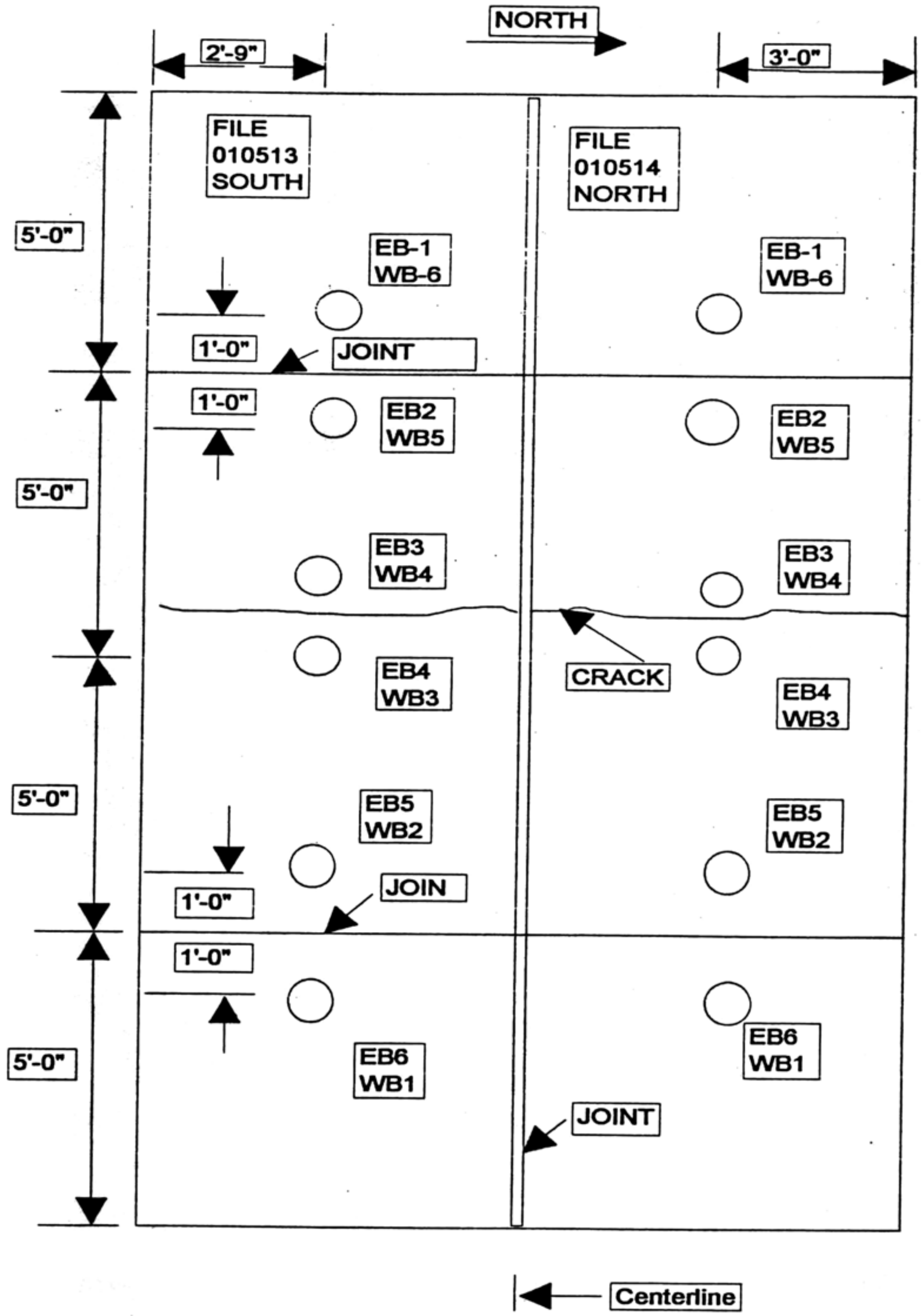


FIGURE 3.9: FWD Test Locations (240 K repetitions)

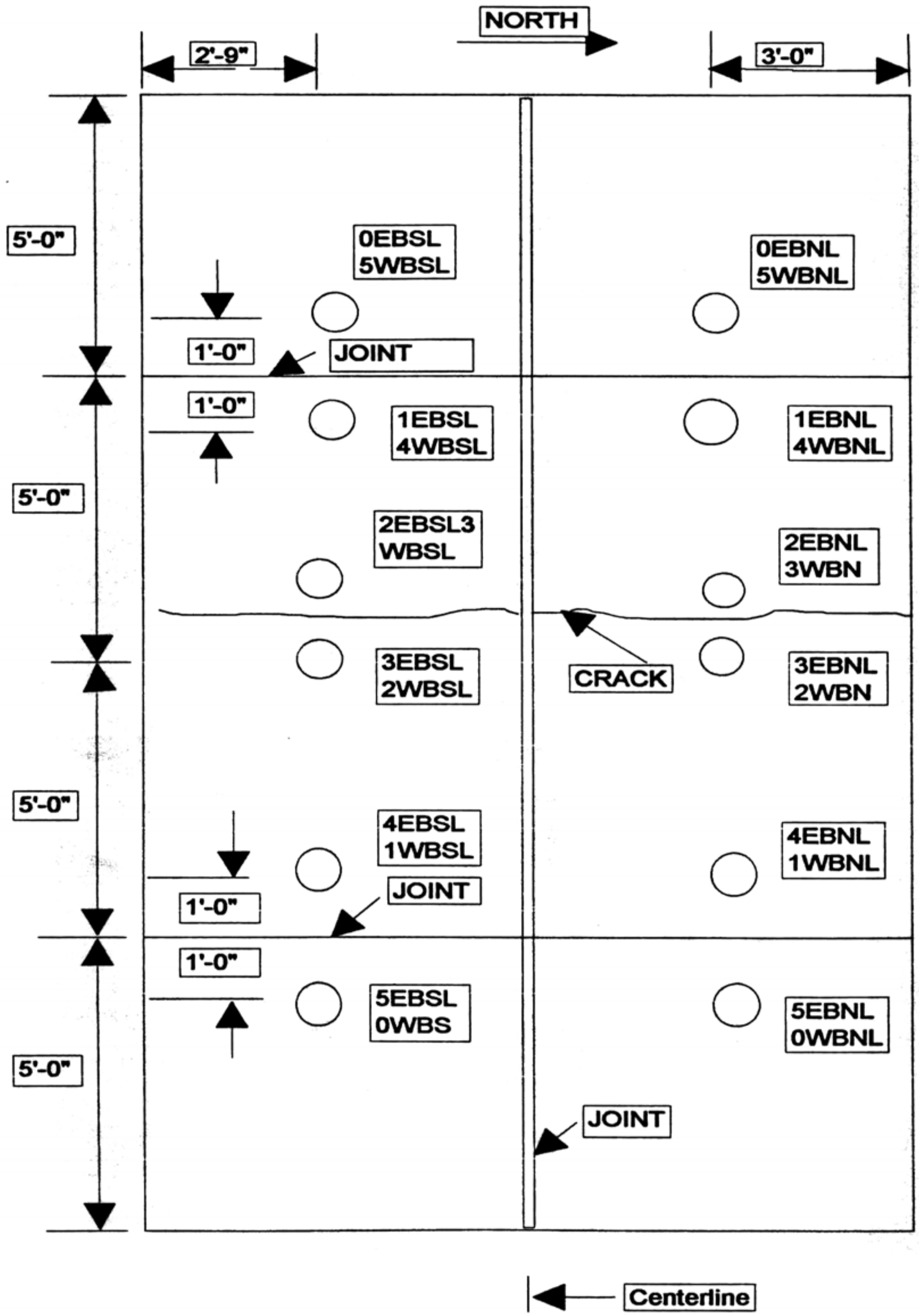


FIGURE 3.10: FWD Test Locations (500 K repetitions)

3.4.7 Testing and Monitoring

Up to 500,000 load applications were applied to the pavement. Load application was two-directions, i.e., 250,000 complete cycles. The load was applied at extreme temperature conditions alternating between 32°F and 110°F. Twenty-thousand cycles were applied per testing period, usually a week. Temperatures were raised and lowered on the weekend and the load applications took place at the extreme high and low temperatures which were maintained constant during the testing phase. The following monitoring plan and monitoring frequency was used for the test and is shown more clearly in the Table 3.4.

TABLE 3.4: Monitoring Plan and Frequency

FWD (Falling Weight Deflectometer) were recorded

- on the PCC base before being rubblized
- on the surface of the slab at the start of the test
- on the surface of the slab at the end of 240,000 load applications
- on the surface of the slab at the end of 500,000 load applications

Pressure and Strain measurements were recorded

- at the start of the test
- at the end of each 20,000 load applications
- at the end of the experiment

Dynamic Response to Weight Drop

- at the start of the test
- at the end of each 80,000 load applications
- at the end of the experiment

Temperature Reading

- throughout the test

Joint Movement

- during temperature cycling between load applications (hot-cold and cold-hot)

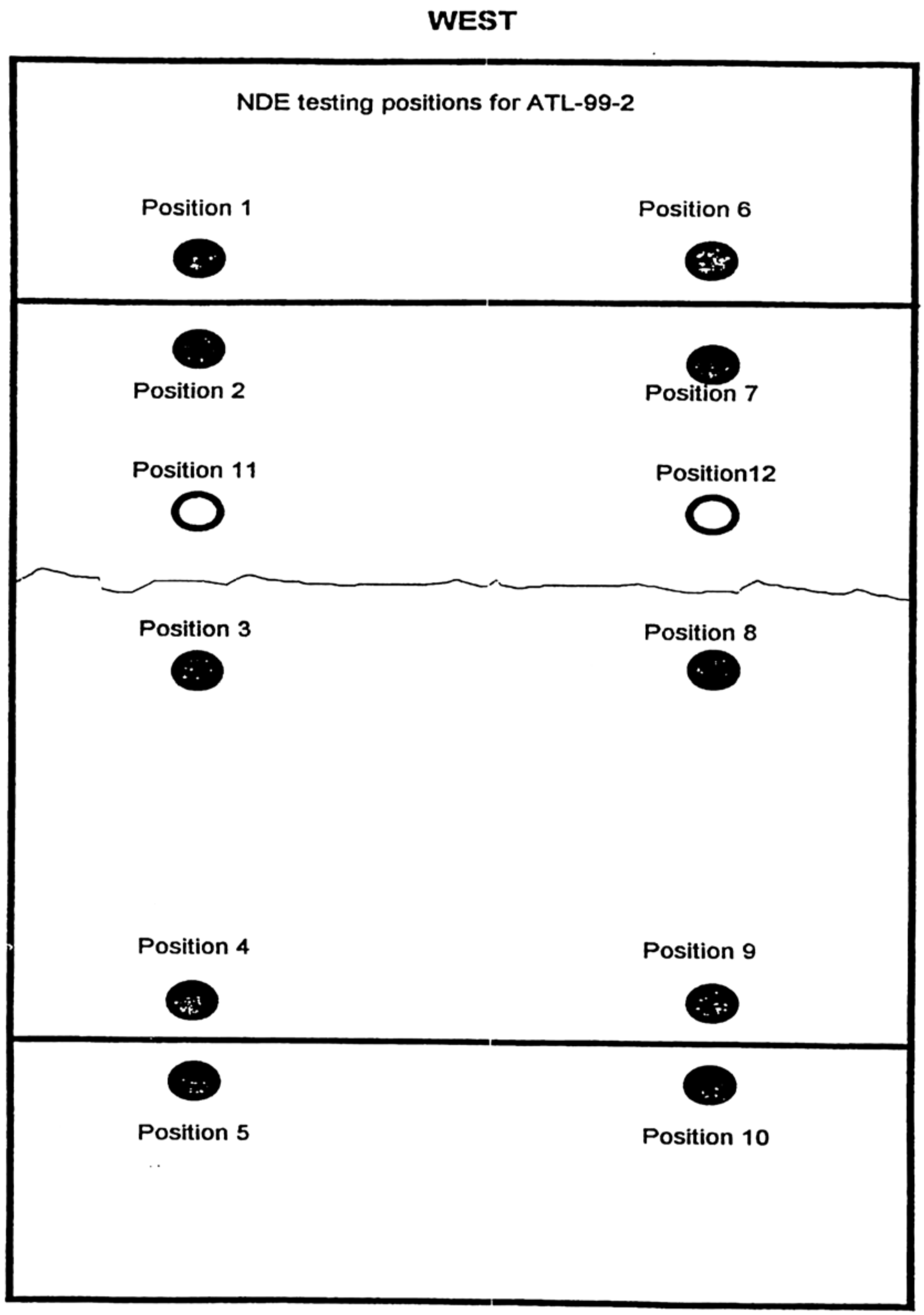
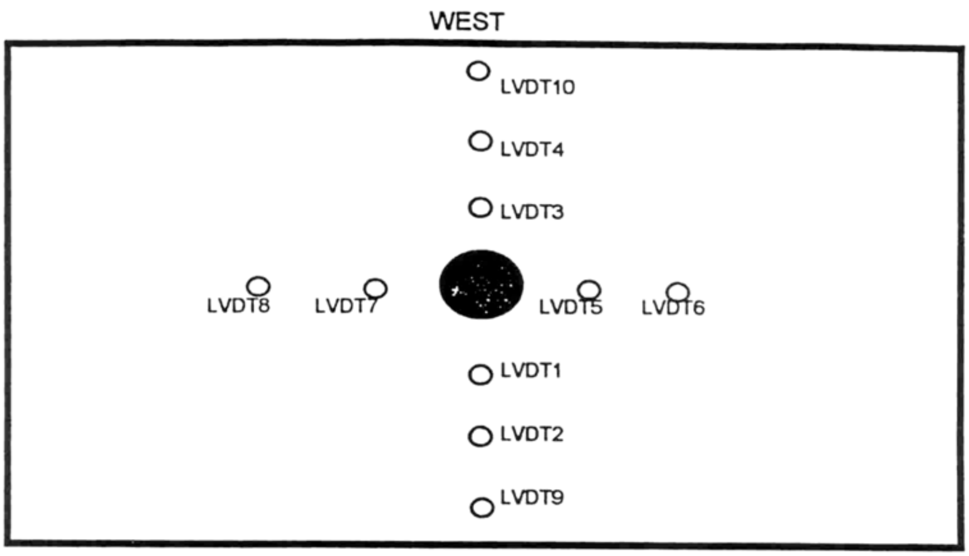
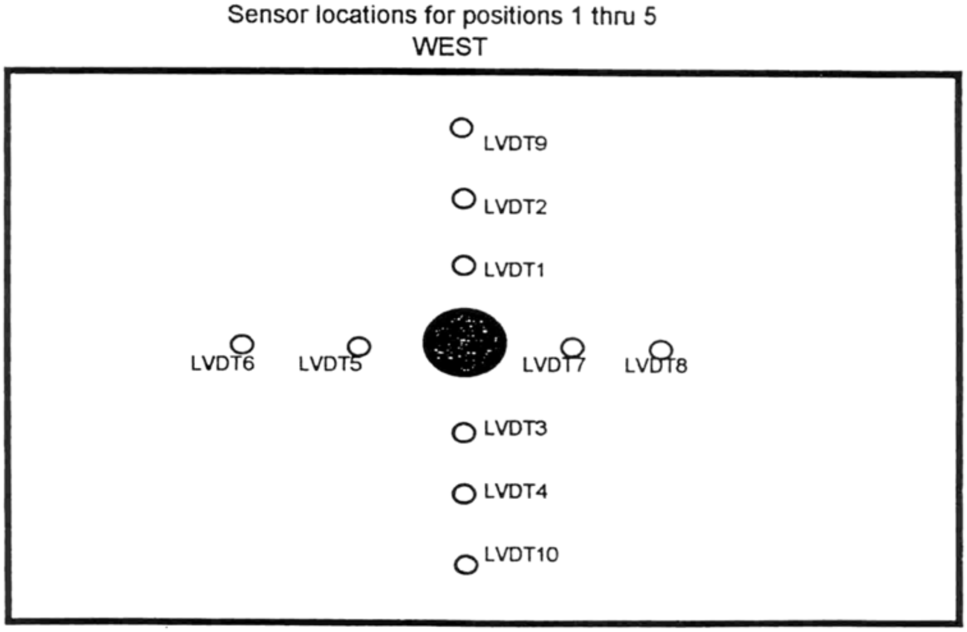


FIGURE 3.11: Weight Drop Locations

Sensor locations for positions 6 thru 10



Sensor locations for positions 1 thru 5



File name format: C:\LVDT\DDMMYY_POSX_DX
Drive\Folder\Day Month Year_Position(number)_Drop(number)

FIGURE 3.12: Layout of Data Locations for Weight Drops

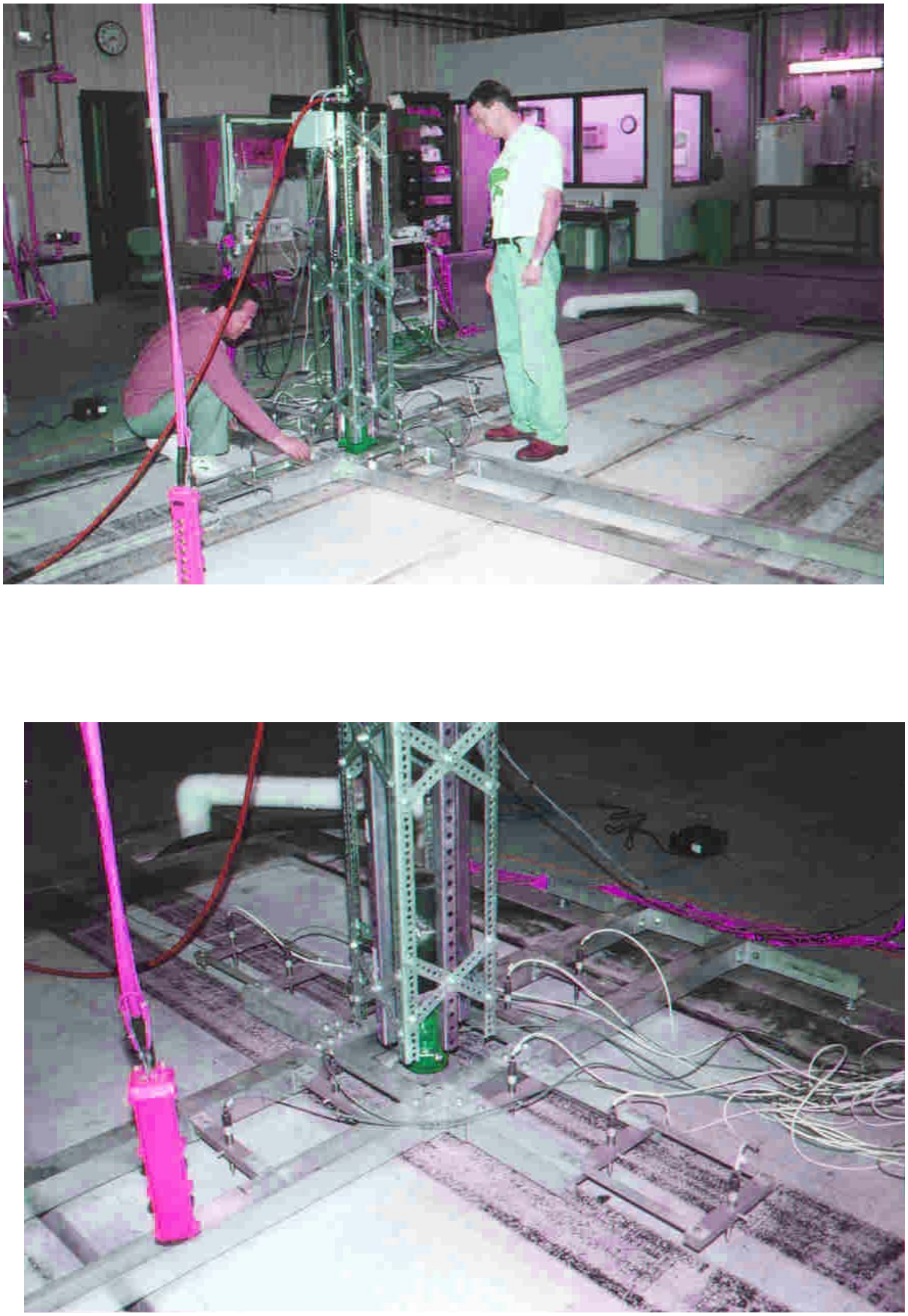


FIGURE 3.13: Drop Weight Apparatus

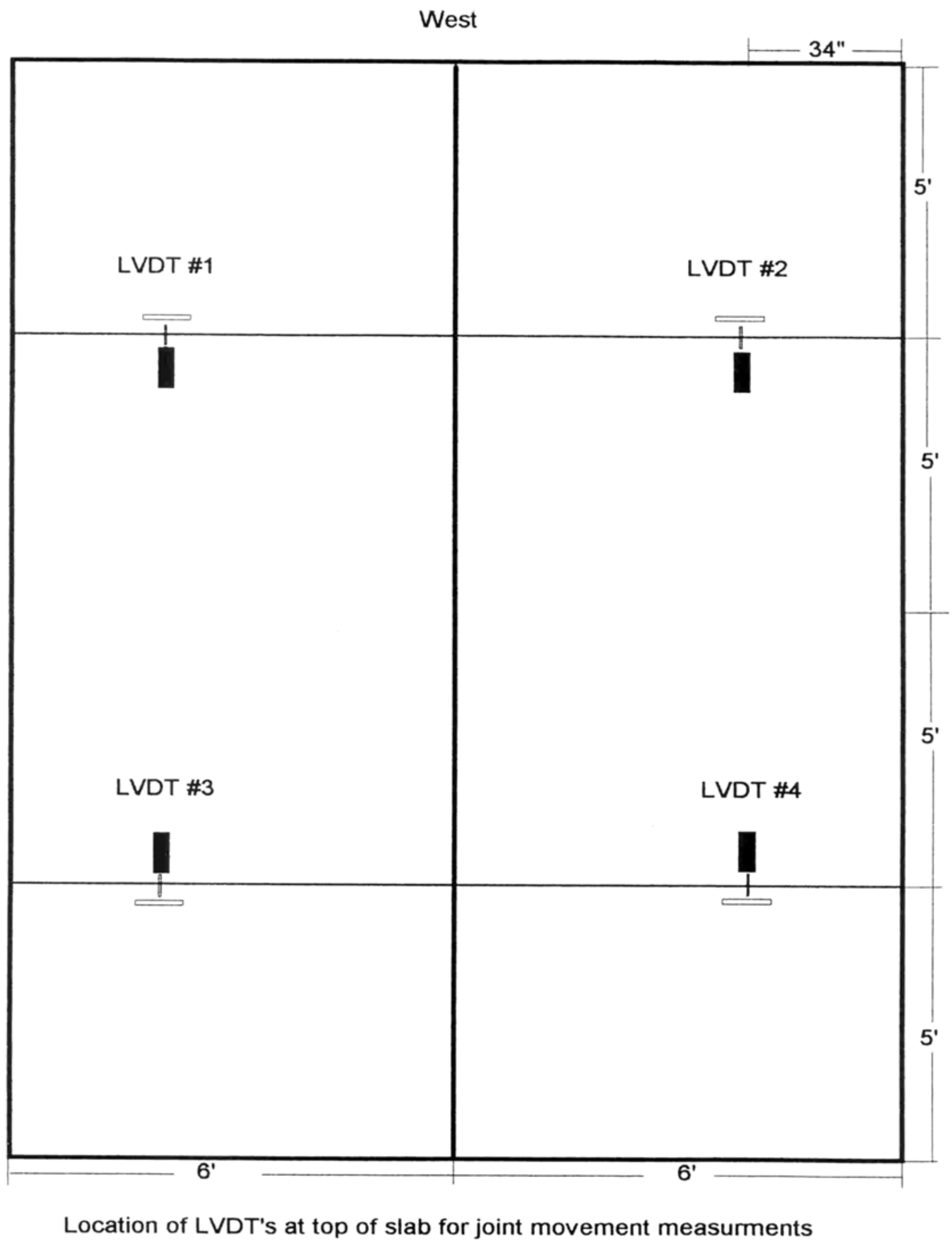


FIGURE 3.14: LVDT Location and Orientation

Except for the FWD tests, all measurements were performed by KSU personnel. Load and heat applications followed procedures described in Sections 3.2 and 3.3. The data was collected from the embedded instrumentation using the electronic data acquisition system, as outlined in Section 3.4. The testing and monitoring plan is presented in Table 3.4.

TABLE 3.5: Test Schedule for ATL – Experiment #8 (Actual)

Beginning of Cycle				End of Cycle				Impact Tests NDE
# of Rep at start	Temp. EF	Read Temp.	Read Jt. Opening	Record Strains	Record Pressures	Setup Jt. LVDT's	# of Rep at end	
0	110	*		T	T	T	20,000	
20,000	32	*	T	T	T	T	40,000	
40,000	110	*	T	T	T	T	60,000	
60,000	32	*	T	T	T		80,000	T
80,000	110	*		T	T	T	100,000	
100,000	32	*	T			T	120,000	
120,000	110	*	T			T	140,000	
140,000	32	*	T				160,000	T
160,000	110	*		T	T	T	180,000	
180,000	32	*	T			T	200,000	
200,000	110	*	T			T	220,000	
220,000	32	*	T				240,000	T
240,000	110	*		T	T	T	260,000	
260,000	32	*	T			T	280,000	
280,000	110	*	T			T	300,000	
300,000	32	*	T				320,000	T
320,000	110	*		T	T	T	340,000	
340,000	32	*	T			T	360,000	
360,000	110	*	T			T	380,000	
380,000	32	*	T				400,000	T
400,000	110	*		T	T	T	420,000	
420,000	32	*	T			T	440,000	
440,000	110	*	T			T	460,000	
460,000	32	*	T				480,000	T
480,000	110	*		T	T	T	500,000	

* Temperature is recorded every hour and upon inquiry

Chapter 4

Test Results and Analysis

4.1 Falling Weight Deflectometer (FWD) Testing and Results (On PCCP Prior to Rubblizing)

FWD deflection testing was first performed on top of the rubblized PCC slab. The locations where the FWD tests were performed are shown in Figure 3.7. The FWD deflection data are reported in the Appendix 1. Table 4.1 summarizes the values for the load (lbs) and the central deflection, D0 (mils). The values illustrate the variability of the pavement response to the FWD load. The maximum deflection D0 varies between 18 and 31 mils, for the same FWD load level of 9,000lbs. This can be largely attributed to the proximity of the cracks in the rubblized PCC slab that greatly increases the maximum FWD deflections.

FWD deflection tests were also performed on the overlayed pavement: right before ATL loading was started (Table 4.2), after 240,000 passes of the ATL machine (Table 4.3), and at the end of loading (Table 4.4). The tables contain only the values of the FWD load (lbs) and of the central deflection, D0 (mils). Figures 3.8, 3.9 and 3.10 show the location where these tests were performed.

For the same FWD load level, the central deflection, D0 (mils) data is useful in observing the relative stiffness of the pavement structure. The data in Table 4.3 indicates that, after 240,000 passes of the ATL machine, the central deflections are higher for the pavement with plain PCC overlay in most cases. At the end of loading, the deflections measured on the fiber-reinforced PCC pavement (Table 4.4) are, for most locations, higher than those measured on the plain concrete PCC pavement. This indicates that the pavement with plain PCC overlay will probably have a longer life. However, it is hard to infer only from the FWD data which pavement structure will give a better performance.

The Modulus 4.0 program was used to back-calculate the layer moduli from the FWD deflection bowls measured in the center of the slabs. The back-calculation was done only for the deflection bowls measured in the center because, for the other locations, the proximity of the concrete walls affects the response of the pavement under the FWD drop. No temperature adjustment of the FWD deflection was performed since the moduli of the layers in the tested pavement structures do not change with temperature. For each drop location, only the last deflection bowl at the 9,000 lbs load level was used in the back-calculation. This bowl was selected since the 9,000 load level simulates best the passing of a standard 18-kip axle.

The back-calculated layer moduli are reported in Table 4.5. The material moduli data clearly show that the modulus of the fiber reinforced PCC overlay is similar to that of the plain PCC overlay. The values remain similar even at the end of ATL loading. It is therefore clear that the structural contribution and the performance of the two overlay materials are very similar.

TABLE 4.1: FWD data on PCC Base before being rubblized (Location in Figure 3.7)

Fiber Reinforced PCC Overlay			Plain PCC Overlay		
Location	Load (lbs)	D0 (mils)	Location	Load (lbs)	D0 (mils)
NS01	8775	30.76	NN05	9053	22.69
NS02	9117	18.29	NN06	8831	29.58
NS03	8668	27.7	NN07	8918	21.27
NS04	8914	30	NN08	8656	29.35

TABLE 4.2: FWD data on the PCC overlay before ATL loading (Location in Figure 3.8)

Fiber Reinforced PCC Overlay			Plain PCC Overlay		
Location	Load (lbs)	D0 (mils)	Location	Load (lbs)	D0 (mils)
SLJTE	6448	6.44	NLJTE	6451	5.07
	9126	9.55		9277	7.47
	15541	16.69		15803	14.09
SLMDE	6869	4.38	NLMDW	6316	5.01
	9261	6.46		9113	7.44
	15827	12.35		15998	13.79
SLMDW	6655	4.56	NLMDE	6361	4.52
	9094	7.39		9173	6.8
	15585	13.18		15664	13.02
SLJTW	6213	6.91	NLJTW	6229	7.74
	9054	10.48		8927	11.12
	15482	19.75		15263	20.44

TABLE 4.3: FWD data on the PCC overlay at 240,000 ATL passes (Location in Figure 3.9)

File 010513 (South)			File 010514 (North)		
Fiber Reinforced PCC Overlay			Plain PCC Overlay		
Location	Load (lbs)	D0 (mils)	Location	Load (lbs)	D0 (mils)
EB-1	8978	19.15	EB-1	5816	14.95
	12053	23.6		9105	20.95
	15016	26.66		15720	29.88
EB-2	9208	13.47	EB-2	5979	8.55
	12021	17.46		9372	13.41
	15005	20.34		15760	21.64
EB-3	9145	14.23	EB-3	5736	13.13
	11981	18.44		8911	19.7
	15013	21.42		15633	29.23
EB-4	9253	10.58	EB-4	6253	7.26
	11806	14.24		9471	11.98
	14778	16.91		15620	20.1
EB-5	9038	17.79	EB-5	5562	13.2
	11779	22.65		9002	19.37
	14603	26.12		15458	29.53
EB-6	9216	15.67	EB-6	5670	11.5
	11965	20.42		9177	17.61
	14489	23.89		15172	27.62
WB-1	9126	17.17	WB-1	6265	14.16
	11859	22.16		9007	19.09
	14166	25.56		15803	29.61
WB-2	8994	18.34	WB-2	6321	11.57
	11989	23.46		9057	16.24
	14894	27.27		15834	26.82
WB-3	8914	10.23	WB-3	6547	7.54
	11798	14.17		9065	11.04
	15008	17.51		15998	19.42
WB-4	8983	17.6	WB-4	6094	13.7
	11918	22.54		8864	18.66
	15056	26.6		16062	28.52
WB-5	8967	14.82	WB-5	6186	9.86
	12037	19.36		9026	14.09
	14854	22.69		15807	23.17
WB-6	8784	18.55	WB-6	6110	12.68
	11764	23.85		8795	17.3
	14786	27.99		15707	27.38

TABLE 4.4: FWD data on the PCC overlay at the end of loading (Location in Figure 3.10)

File 010513 (South)			File 010514 (North)		
Fiber Reinforced PCC Overlay			Plain PCC Overlay		
Location	Load (lbs)	D0 (mils)	Location	Load (lbs)	D0 (mils)
0SLEB	5816	14.95	0EBNL	6536	10.7
	9105	20.95		9320	14.93
	15720	29.88		16407	24.24
1SLEB	5979	8.55	1EBNL	6496	8.58
	9372	13.41		9372	12.33
	15760	21.64		16038	21.3
2SLEB	5736	13.13	2EBNL	6242	12.35
	8911	19.7		9153	17.37
	15633	29.23		15935	27.62
3SLEB	6253	7.26	3BNL	6340	8.51
	9471	11.98		9205	12.13
	15620	20.1		16057	21.11
4SLEB	5562	13.2	4EBNL	6149	13.86
	9002	19.37		9010	18.51
	15458	29.53		15775	29.07
5SLEB	5670	11.5	5EBNL	6300	10.72
	9177	17.61		9030	15.03
	15172	27.62		15938	25.21
5SLWB	6265	14.16	5WBNL	6186	10.16
	9007	19.09		8967	14.48
	15803	29.61		15636	23.62
4SLWB	6321	11.57	4WBNL	6289	8.49
	9057	16.24		9097	12.21
	15803	29.61		15950	20.88
3SLWB	6547	7.54	3WBNL	6027	12.12
	9065	11.04		8879	17.24
	15998	19.42		15993	26.95
2SLWB	6094	13.7	2WBNL	6253	7.51
	8864	18.66		9081	10.74
	16062	28.52		15657	18.93
1SLWB	6186	9.86	1WBNL	6102	12.33
	9026	14.09		8935	17.28
	15807	23.17		15501	27.59
0SLWB	6110	12.68	0WBNL	6142	12.13
	8795	17.3		8883	16.73
	15707	27.38		15747	26.72

TABLE 4.5: Back-calculated Layer Moduli (ksi)

	Load	Measured Deflection (mils)							Calculated Moduli (ksi)			
	(lbs)	D0	D1	D2	D3	D4	D5	D6	SURF	BASE	SUBB	SUBG
TOP OF RUBBLIZED PCC												
NS02	9,116	18.29	17.26	13.75	10.98	8.58	5.13	3.02	791.	5.4	0.0	11.3
NS03	8,667	27.70	20.25	16.46	10.82	8.43	5.70	2.97	133.	20.5	0.0	8.9
NS06	8,830	29.58	20.18	16.76	12.17	9.07	5.59	3.26	113.	23.0	0.0	8.6
NS07	8,917	21.27	18.14	15.57	12.18	9.32	5.82	3.08	496.	13.0	0.0	8.6
Mean:		24.21	18.96	15.64	11.54	8.85	5.56	3.08	383.	15.5	0.0	9.4
Std. Dev:		5.31	1.50	1.35	0.74	0.42	0.30	0.13	324.	7.9	0.0	1.3
Var Coeff(%)		21.95	7.89	8.66	6.41	4.70	5.43	4.11	85.	51.3	0.0	14.1
BEFORE LOADING												
SLMDE	9,260	6.46	6.14	5.87	5.41	5.01	4.16	2.92	5700.	900.0	28.2	13.4
SLMDW	9,093	7.39	6.52	6.05	5.52	5.02	4.12	2.64	1828.	513.6	162.2	11.4
NLMDE	9,172	6.80	6.51	6.15	5.62	5.10	4.20	2.76	5700.	810.9	63.6	11.3
NLMDW	9,112	7.44	7.00	6.57	5.98	5.46	4.47	3.04	5576.	617.3	60.3	10.8
Mean:		7.02	6.54	6.16	5.63	5.15	4.24	2.84	4701.	710.5	78.6	11.7
Std. Dev:		0.47	0.35	0.30	0.25	0.21	0.16	0.18	1916.	176.5	58.0	1.1
Var Coeff(%)		6.76	5.39	4.82	4.39	4.12	3.74	6.19	41.	24.8	73.8	9.8
AFTER 240,000 PASSES												
EB4	9,470	11.98	10.00	9.11	7.70	6.62	4.39	2.52	822.	380.7	11.7	11.6
WB4	8,863	18.66	13.56	11.29	8.16	5.41	2.93	2.30	514.	50.0	8.7	16.1
Mean:		15.32	11.78	10.20	7.93	6.01	3.66	2.41	668.	215.3	10.2	13.8
Std. Dev:		4.72	2.52	1.54	0.33	0.86	1.03	0.16	218.	233.8	2.1	3.2
Var Coeff(%)		30.83	21.37	15.11	4.10	14.22	28.21	6.45	33.	100.0	20.9	23.0
END OF LOADING												
3EBSL	9,470	11.98	10.00	9.11	7.70	6.62	4.39	2.52	748.	380.2	19.3	9.5
3WBNL	8,878	17.24	13.09	11.39	9.06	6.76	3.06	2.19	878.	74.9	4.3	14.4
3EBNL	9,204	12.13	10.14	9.14	7.68	6.42	4.46	2.10	901.	253.5	27.2	9.1
Mean:		14.65	11.58	10.26	8.38	6.64	3.74	2.25	851.	195.9	13.8	11.0
Std. Dev:		2.99	1.74	1.31	0.79	0.16	0.79	0.18	70.	148.9	11.4	3.0
Var Coeff(%)		20.44	15.07	12.75	9.44	2.42	21.07	8.22	8.	76.0	82.7	24.9

4.2 Stresses and Strains in the Pavement Structures

Stress and strain measurements were taken at the start of the test and at 20,000 repetition intervals until the end of the test. The location of the pressure cells is given in Figure 3.2. Table 4.6 summarizes the stress data for the four pressure cells. Figure 4.1 illustrates the evolution of the vertical stresses with the number of ATL passes. It can be observed that the vertical stresses in the subgrade soil do not have a continuous variation, but the general trend is that the pressure increases with traffic. This indicates that the deterioration of the upper layer under traffic will cause increased stresses in the foundation layers. This phenomenon was observed in both pavements. Even though the values are quite similar, slightly higher stresses were recorded in the plain PCC overlay pavement.

TABLE 4.6: Vertical Stresses in the Subgrade Soil (psi)

Repetitions (x 1,000)	Channel 1 Plain (at joint)	Channel 2 Fiber (at joint)	Channel 3 Plain (at center)	Channel 4 Fiber (at center)
Initial	4.8	3.1	1.7	2.8
20	4.0	3.8	1.8	2.7
40	5.4	3.0	2.1	3.2
60	4.3	4.0	2.3	3.0
80	5.5	2.3	2.9	3.0
100	5.0	3.8	2.4	3.4
120	5.6	4.5	3.7	3.1
140	4.3	3.8	2.4	3.3
160	5.3	4.4	3.6	3.3
180	5.1	3.6	3.4	3.2
200	5.3	4.4	3.4	3.2
220	3.9	3.6	3.4	4.6
240	5.4	4.2	3.0	3.9
260	4.3	3.7	2.6	3.6
280	4.6	4.4	3.9	3.7
300	4.3	3.5	2.8	3.6
320	5.2	4.4	3.9	3.9
340	5.2	4.8	2.8	1.8
360	5.0	4.3	4.0	4.2
380	4.5	4.5	3.0	4.3
400	6.0	5.2	4.2	4.8
420	5.1	4.0	3.8	4.5
440	6.1	5.1	4.2	5.0
460	4.4	4.5	2.9	4.3
480	5.8	4.9	4.5	7.1
500	5.1	3.3	5.2	4.6

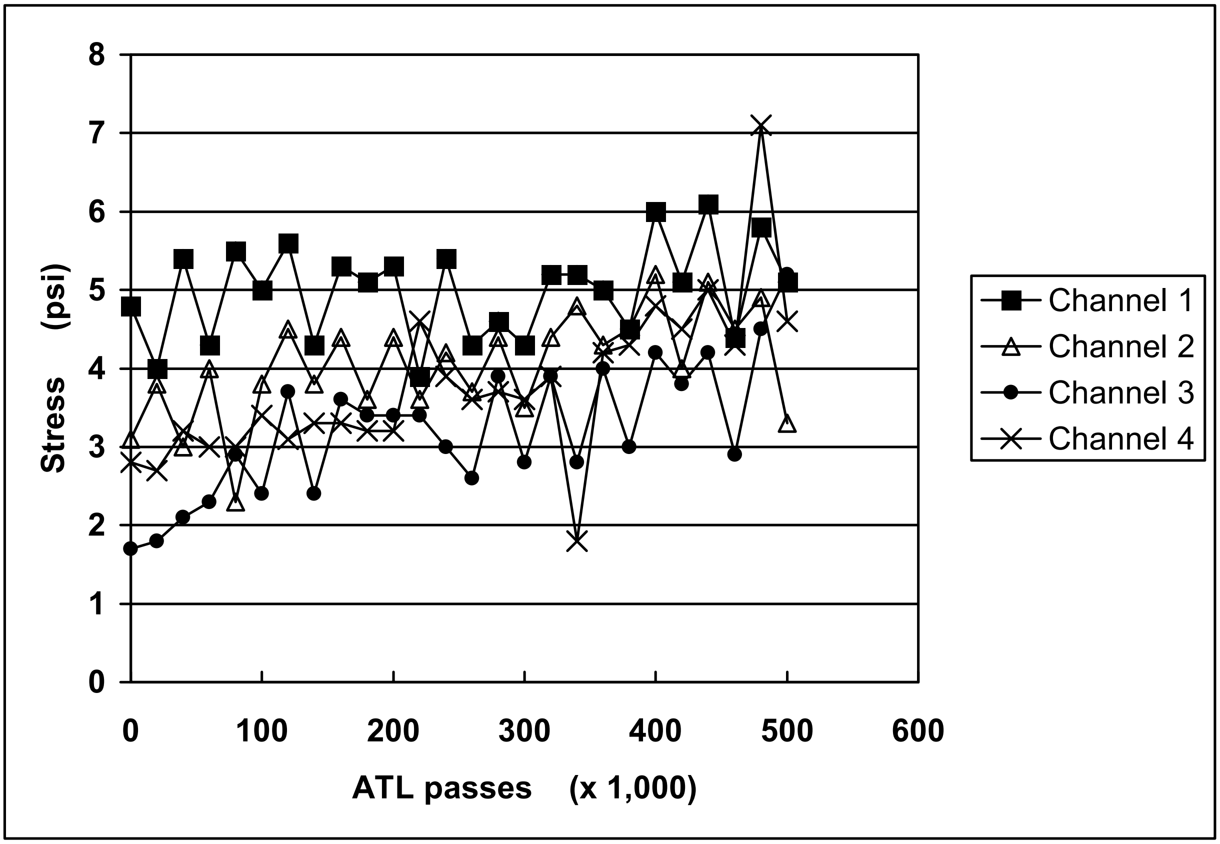


FIGURE 4.1: Evolution of Stress in the Pavement Subgrade with Number of ATL passes

The location of the strain gages are shown in Figure 3.6. All gages used in this experiment were positioned to measure longitudinal strains at the bottom of the PCC overlays. The tensile and compressive strains (in microstrain) measured by gages S2, S4, S7 and S9 are reported in Table 4.7, and measured by gages S3, S5 and S10 in Table 4.8. The remaining three gages (S1, S6 and S8) did not give any useful strain readings.

Similar to the trend observed for vertical compressive stresses in the subgrade, even though the measured strains at the bottom of the overlay do not show a continuous increase, the general trend is that the strains increase with the number of applied ATL passes. Figure 4.2 and 4.3 give the values of tensile and compressive strains measured by gages located in the central slabs, near the transverse joints (S4 and S7) and the fiber-reinforced PCC overlay (S2 and S9).

The data for these gages is plotted in Figures 4.2 and 4.3 since they correspond to the same location in the longitudinal direction.

The larger longitudinal strains, both compressive and tensile were recorded in the fiber reinforced PCC overlay by gage S9, and in the plain PCC overlay by gage S4. When the strains recorded by gages S2 and S4 are compared, the larger strains were measured by the gage in the plain PCC overlay (S4). When the strains recorded by gages S7 and S9 are compared, the larger strains were measured by the gage in the fiber reinforced PCC overlay (S9). Therefore, from the strain data alone, it is difficult to determine which overlay gives the best performance.

TABLE 4.7: Strain Data (microstrain)

Repetitions (x 1,000)	Strain Gage S2 Fiber PCC Overlay			Strain Gage S4 Plain PCC Overlay		
	Range	Tens.	Comp	Range	Tens.	Comp.
0	20	8	12	8	4	4
20	19	7	12	9	5	4
40	12	5	7	9	3	4
60	15	5	10	9	8	1
80	11	4	7	30	23	7
100	17	6	1	33	8	25
120	14	3	11	32	30	2
140	10	5	5	19	9	10
160	17	9	8	37	24	3
180	11	7	4	20	7	13
200	14	6	8	25	21	4
220	19	12	17	32	7	25
240	13	3	9	20	14	6
260	20	10	10	43	6	37
280	10	6	4	8	7	1
300	18	12	6	43	18	25
320	12	2	10	22	21	1
340	17	11	6	47	19	28
360	14	3	11	26	23	3
380	21	14	7	40	10	30
400	22	8	14	90	20	50
420	26	14	12	70	30	40
440	33	11	22			
460	27	21	6	310	240	70
480	27	7	20			
500	30	18	12			

TABLE 4.7: Strain Data (microstrain) (continued)

Repetitions (x 1,000)	Strain Gage S9 Fiber PCC Overlay			Strain Gage S7 Plain PCC Overlay		
	Range	Tension	Comp.	Range	Tension	Comp.
0	16	8	8	16	9	7
20	15	7	8	14	9	5
40	13	5	8	12	7	5
60	8	5	3	11	7	4
80	28	24	4	10	4	6
100	40	5	35	14	6	8
120	37	32	5	14	8	6
140	24	8	16	11	5	6
160	53	50	3	19	11	8
180	33	8	25	11	5	6
200	28	25	3	16	7	9
240	30	26	4	14	6	8
260	48	23	25	12	4	8
280	9	6	3	16	10	6
300	60	20	40	14	4	10
320	26	24	2	15	6	9
340	66	26	40	15	5	10
360	25	22	3	13	5	8
380	54	14	40	19	13	6
400	31	30	1	19	10	9
420	65	24	41	18	8	10
440	95	75	20	27	19	8
460	93	13	80	27	4	23
480	73	71	2	25	18	7
500	100	20	80	37	8	29

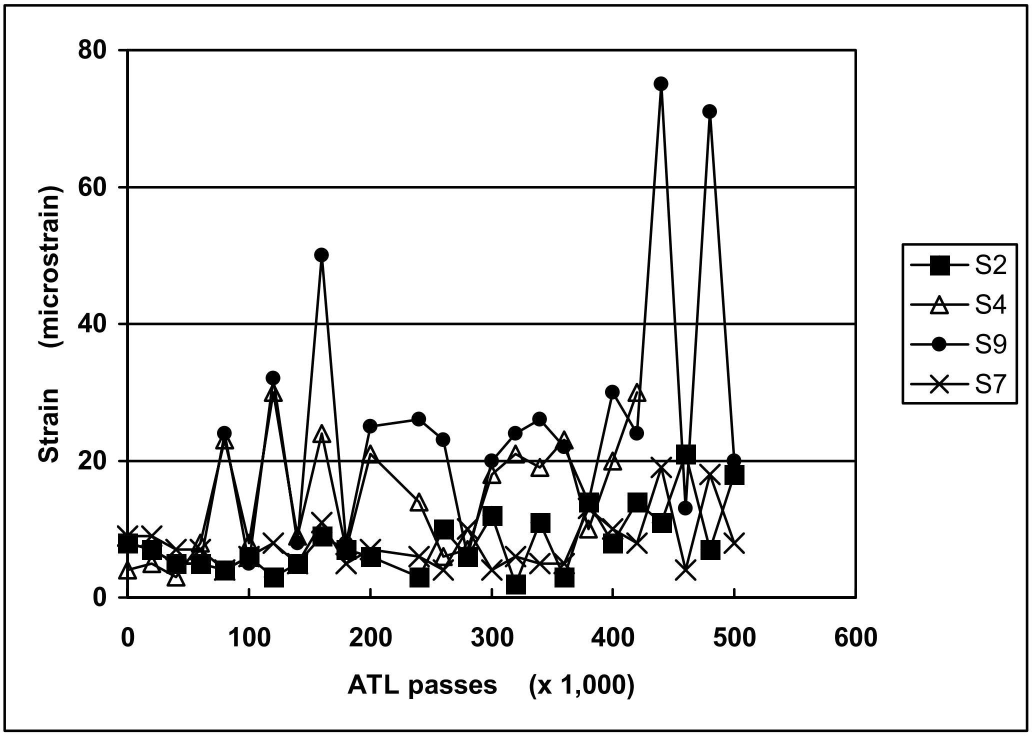


FIGURE 4.2: Evolution of Tensile Strain with Number of ATL passes

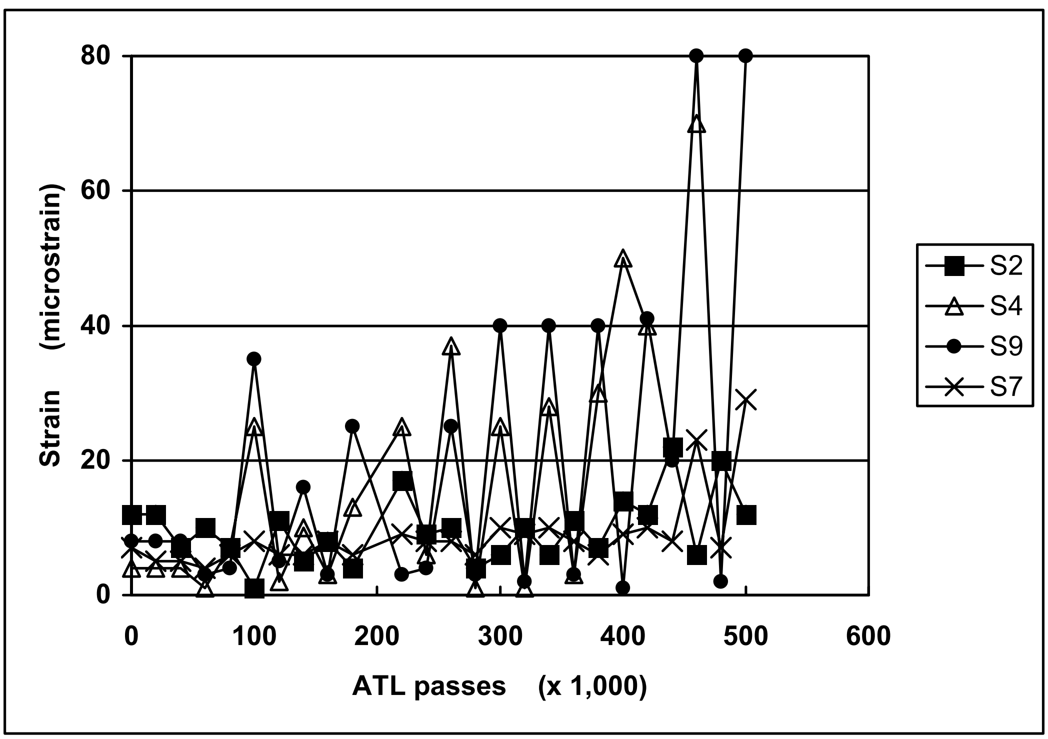


FIGURE 4.3: Evolution of Compressive Strain with Number of ATL passes

TABLE 4.8: Strain Data (microstrain)

Repetitions (x 1,000)	Strain Gage S10 Fiber Reinforced PCC Overlay			Strain Gage S3 Plain PCC Overlay		
	Range	**Tension**	**Compression**	**Range**	**Tension**	**Compression**
0	10	8	2	11	8	3
20	15	12	3	10	5	5
40	12	8	4	15	11	4
60	16	13	3	13	9	4
80	29	22	7	18	8	10
100	36	11	25	11	7	4
120	25	16	9	15	4	11
140	25	13	12	13	9	4
160	33	25	8	21	11	10
180	26	12	14	11	7	4
200	26	20	6	15	4	11
220	38	13	25	15	11	4
240	24	19	5	14	6	8
260	38	20	18	15	8	7
280	14	7	7	7	5	2
300	47	17	30	17	15	2
320	25	20	5	12	4	8
340	48	9	39	12	10	2
360	22	18	4	12	3	9
380	44	10	34	19	12	7
400	29	24	5	173	85	88
420	53	11	42	100	30	70
440	64	63	1	3700	0	3700
460	77	13	64			
480	56	52	4			
500	80	20	60			

TABLE 4.8: Strain Data (microstrain) (continued)

Repetitions (x 1,000)	Strain Gage S5 Plain PCC Overlay		
	Range	Tension	Compression
0	13	9	4
20	16	12	4
40	13	9	4
60	16	13	3
80	31	24	7
100	39	13	26
120	24	18	6
140	26	12	14
160	34	27	7
180	27	15	12
200	27	17	10
220	37	27	10
240	24	17	7
260	44	19	25
280	36	31	5
300	48	12	32
320	26	19	7
340	50	11	39
360	20	16	4
380	50	12	38
400	31	22	9
420	55	14	41
440	64	62	2

4.3 Temperature

The temperatures at several locations (Figures 3.3-3.5) in the two pavements were recorded every hour using 17 thermocouples. When the pavement showed more severe degradation, some of the thermocouples have failed and no useful data could be recorded. The temperature data is reported in Appendix 4. The format the data is recorded is shown in Table 4.9, which contains only the temperatures recorded when the time the joint displacement measurements were performed.

TABLE 4.9 Temperature data collected at the time the joint displacement measurements

Date	Time	Ta1	Ta2	Ta3	Ta4	Ta5	Tb1	Tb2	Tb3	Tb4	Tb5	Tb6	Tc1	Tc2	Tc3	Tc4	Tc5	Tc6
		Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10	Ch11	Ch12	Ch13	Ch14	Ch15	Ch16	Ch17
9/24/99	12:02:59 PM	84.77	90.27	83.51	83.72	84.71	83.79	82.96	82.71	82.64	83.28	82.47	82.36	82.83	101.5	103.58	107.47	116.63
9/26/99	9:02:29 AM	83.68	89.67	82.92	83.22	83.55	82.41	82.1	81.7	81.93	81.82	81.46	79.92	79.72	83.43	83.3	82.6	81.39
9/27/99	1:02:14 PM	81	81.5	80.46	80.87	80.98	78.66	78.37	78.11	78.38	77.95	77.73	74.5	73.73	63.11	59.37	63.04	58.57
10/1/99	1:54:42 PM	52.84	55.29	52.39	52.79	53.88	56.19	58.24	55.19	56.49	57.03	57.59	62.85	61.68	35.69	34.11	38.3	40.64
10/3/99	10:15:41 PM	49.45	50.12	49.59	49.28	49.6	52.91	53.73	52.66	53.06	52.96	52.97	57.35	57.24	52.34	52.82	55.72	61.96
10/4/99	8:12:25 AM	51.01	51.51	50.77	50.51	51.02	55.72	56.47	54.8	55.06	55.65	55.14	60.16	60.32	84.29	87.43	100.36	116.34
10/8/99	10:04:22 AM	76.83	83.25	73.32	73.71	74.73	78.63	77.82	75.45	75.79	76.78	75.74	76.55	77.17	103.66	106.76	112	121.89
10/10/99	1:37:13 PM	73.12	72.9	70.8	71.35	71.42	73.34	73.13	71.44	71.98	71.84	71.53	73.78	73.81	72.75	72.59	73.49	73.17
10/11/99	1:12:35 PM	72.37	72.41	70.34	70.93	70.97	72.34	72.4	70.42	71.11	71.19	70.78	72.13	71.75	49.54	44.59	50.53	47.8
10/29/99	11:32:07 AM	85.81	84.27	83.08	82.83	84.81	84.91	82.71	82.32	81.65	83.39	82.22	80	81	106.03	108.67	112	111.3
10/31/99	11:45:25 AM	79.67	79.15	78.04	78.1	79.12	77.4	76.03	75.69	75.48	75.96	75.38	73.2	73.12	79.03	78.75	77.49	76.66
11/1/99	8:28:55 AM	72.96	73.88	71.31	72.38	73.15	69.56	69.82	67.34	68.64	68.81	68.74	67.25	65.87	39.31	34.57	39.96	39.43
11/4/99	5:00:48 PM	56.94	60.62	58.02	59.25	58.82	59.25	62.47	59.54	61.31	60.5	61.23	65.11	63.02	34.11	32.59	37.79	37.36
11/7/99	8:43:54 AM	61.26	62.98	62.09	62.86	62.15	62.04	63.31	62.48	63.23	62.5	62.7	64.55	63.72	61.03	60.65	63.04	62.01
11/8/99	8:16:17 AM	64.64	65.51	64.88	65.28	65.18	66.76	67.16	66.47	66.67	67.04	66.54	68.46	68.8	91.96	95.65	105.81	121.52
11/12/99	1:27:27 PM	84.28	82.7	81.76	81.17	83.82	83.74	81.74	81.4	80.56	82.85	81.6	80.01	81.02	105.01	108.37	111.19	112.31
11/14/99	12:59:24 PM	79.43	175.06	78.01	77.83	79.03	77.7	76.68	76.28	76.07	76.54	76.01	74.74	74.64	79.26	78.91	77.8	77.2
11/15/99	8:15:11 AM	73.35	74.17	71.6	72.47	73.54	70.07	70.16	67.67	68.91	69.32	69.15	67.65	66.32	40.43	33.83	40.82	39.63
12/3/99	10:47:48 AM	84.03	83.52	81.27	82.01	83.4	82.62		79.9	80.24		80.85	76.4	76.96	106.02	105.73	114.88	113.64
12/5/99	1:09:27 PM	77.63	77.68	76.06	76.66	77.21	75.39		73.59	73.96		73.78	71	70.77	76.18	76.08	75.65	74.46
12/6/99	8:15:41 AM	72	72.46	70.42	70.9	71.95	70.39		66.54	66.56		66.85	65.08	64.56	39.51	35.4	39.43	39.64
12/10/99	2:31:25 PM	55.69	56.72	55.94	55.29	55.97	56.54		56.28	56.03		55.9	60.48	59.95	42.87	42.25	44.22	19.05
12/12/99	1:30:58 PM	59.18	59.66	59.66	59.35	59.27	60.47		60.57	60.57		60.02	63.55	63.46	58.36	58.19	59.97	59.71
12/13/99	8:11:16 AM	64.64	64.8	64.01	64.07	64.49	66.74		65.52	65.77		66	66.92	67.39	95.18	96.68	110.44	120.77
12/17/99	10:04:29 AM	80.2	80.33	77.48	79.01	80.28	78.97		76.56	77.48		78.79	74.67	74.79	95.26	91.7	114.53	117.75
12/19/99	11:46:28 AM	75.25	75.59	73.81	74.7	75.34	73.75		72.22	72.82		72.89	71.16	70.92	74.03	73.65	73.8	71.59
12/20/99	8:25:08 AM	73.93	74.39	72.87	73.66	73.99	72.54		71.35	71.91		71.83	69.91	69.66	78.1	76.43	80.84	82.66
1/13/00	5:03:25 PM	83.7	83.68	81.08	81.65	83.1	82.42		80.17	80.57		80.66	77.85	77.74	106.25	107.57	113.25	113.74
1/14/00	2:40:29 PM	81.67	81.78	79.3	79.9	80.93	79.17		77.26	77.59		77.42	75.17	74.94	79.81	76.84	79.02	67.04
1/18/00	8:05:56 AM	58.02	60.08	57.57	58.57	58.8	56.75		55.99	57.04		57.59	59.08	57.87	32.78	23.19	34.56	32.65
1/21/00	9:47:25 AM	53.26	55.23	53.26	54.2	54.02	53.74		53.22	54.27		55.04	57.95	56.78	34.95	33.45	37.7	-5.3
1/21/00	3:44:24 PM	53.01	54.98	53.17	53.99	53.72	54		53.87	54.91		55.38	59.11	58.09	45.61	45.57	48.84	21.06
1/24/00	8:07:44 AM	73.45	73.46	71.04	71.59	72.87	74.19		71.53	71.86		72.27	70.97	71.27	103.73	106.25	115.86	127.49
1/27/00	5:12:39 PM	81.7	81.67	78.93	79.73	81.18	80.32		77.9	78.35		78.42	75.12	75.12	106.92	108.36	116.32	123.11
1/28/00	2:57:49 PM	80.18	80.14	77.71	78.45	79.53	77.86		75.69	76.18		76.03	73.32	72.89	75.73	70.01	75.77	63.72
1/31/00	7:56:33 AM	60.69	62.54	59.54	60.74	61.28	58.57		57.2	58.37		59	59.78	58.59	34.36	27.91	36.41	33.71
2/10/00	11:23:43 AM	83.75	83.68	81.24	81.62	83.07	82.14		80	80.21		80.2	76.45	76.88	110.02	174.11	109.43	124.12
2/11/00	2:58:32 PM	80.97	80.96	78.99	79.32	80.43	78.3		76.48	76.71		76.2	73.56	73.21	79.51	78.61	79.16	77.44
2/14/00	8:06:50 AM	60.8	63.11	60.2	61.43	61.63	58.77		57.71	58.68		59.29	60.62	58.56	35.45	27.94	37.26	33.16
2/17/00	9:41:22 AM	54.97	56.88	55.14	55.9	55.51	55.46		54.84	55.54		55.8	59.32	58.32	33.88	29.12	37.06	32.38
2/18/00	4:24:17 PM	56.44	57.91	57.14	57.56	57.01	57.91		58.16	58.75		58.44	62.2	61.73	69.59	78.13	76.83	120.5
2/21/00	8:17:09 AM	76.28	76.27	74.07	74.02	75.82	77.15		74.92	74.71		74.9	74.5	74.96	99.99	107.71	106.94	124.51
2/24/00	4:32:35 PM	84.53	84.79	82.17	82.41	84.19	84.3		82.25	82.59		82.52	81.55	81.68	102.01	107.96	107.03	119.56
2/25/00	3:01:09 PM	83.1	83.45	81.04	81.41	82.64	81.38		79.57	79.93		79.59	78.13	77.98	82.62	80.84	82.56	79.14
2/28/00	8:06:11 AM	62.67	64.54	61.72	62.66	63.41	61.03		59.59	60.33		60.98	62.78	61.53	35.21	26.25	37.02	34.17
3/9/00	4:46:39 PM	85.38	83.87	83.21	82.27	85.09	84.82		82.42	81.45		81.73	79.19	80.16	104.58	110.22	110.49	119.09
3/10/00	3:32:42 PM	83.11	82.12	81.11	80.64	82.64	173.03		78.85	78.42		78.42	75.71	76.18	83.01	83	82.39	81.88
3/13/00	8:12:48 AM	63.2	65.67	62.33	64.12	64.05	63.73		59.71	61.69		61.61	62.91	61.08	35.17	27.92	37.29	34.82
3/16/00	4:05:29 PM	55.94	58.71	56.47	57.92	57.11	61.41		58.35	60.15		60.09	63.37	62.21	29.99	23.26	36.28	36
3/17/00	2:14:23 PM	56.03	58.39	56.73	57.93	57.04	61.59		57.62	58.96		58.44	62.07	60.89	53.32	53.55	55.51	55.43
3/20/00	8:09:36 AM	75.75	74.49	73.63	72.82	75.32	88.84		73.98	72.92		73.61	72.27	73.38	102.07	108.38	110.01	122.53
3/23/00	4:25:23 PM	84.26	82.68	81.78	80.82	83.74	174.95		81.08	80.06		80.45	77.63	78.73	105.51	111.76	112.82	123.58
3/24/00	3:09:51 PM	82.9	81.74	80.8	80.17	82.32	176.65		79.39	78.8		78.87	77.45	77.63	83.39	83.76	82.83	82.79
3/27/00	8:10:34 AM	62.85	65.5	61.99	63.74	63.73	171.63		59.51	61.51		61.73	63.02	61.12	32.58	22.52	35.78	33.44

Note: Ta6 failed during construction; Tb2 & Tb5 failed during operation.

4.4 Joint Displacement

Joint displacements (opening or closing of the joints) were measured before each heating cycle and before each cooling cycle. Figure 3.14 shows the location where the LVDT's were positioned to measure joint displacement. Table 4.10 summarizes the joint displacement data. Positive values indicate a joint closing while negative values indicate joint opening.

The data clearly shows that not all joint are opening and closing in the same time. This phenomenon can be observed when the displacements in the two joints of the same overlay are compared (LVDT1 vs. LVDT3; LVDT2 vs. LVDT4), or when displacement data for joints in the same longitudinal location are compared (LVDT1 vs. LVDT2; LVDT3 vs. LVDT4).

Also, the joint displacement measurements indicate that the dilation and contraction of the joints are very small. This can mainly be attributed to the fact that the thin overlays are very well bonded to the rubblized PCC base, that restrict the movement of the slabs. This may cause supplemental stresses in the overlays and premature cracking.

Tables 4.11 and 4.12 summarize the temperature difference in joint displacement and temperatures in the PCC overlay between two consecutive displacement measurements, in the same heating or cooling cycles. The purpose of listing the temperature and joint displacement differentials is to investigate possible correlations between them. The data in Tables 4.11 and 4.12 clearly show that there is not a good correlation between the temperature in the overlay and the joint movement. Again, this can mainly be attributed to the good bond between the thin PCC overlays and the rubblized PCC base. Due to the good bond, the expansion and contraction of the overlays are greatly restricted by the rubblized PCC base. To preserve the integrity of the overlay, no pull off tests were performed to determine the bond between the overlay and the rubblized slab.

TABLE 4.10: Joint Displacement (inches)

Repetitions (x 1,000)	Date	Time	LVDT1 (Fiber)	LVDT2 (Plain)	LVDT3 (Fiber)	LVDT4 (Plain)
20	9/24/99	11:51:34 AM	-0.0061	-0.0032	0.0076	-0.0002
	9/24/99	1:17:44 PM	-0.0067	-0.0035	0.0073	-0.0008
	9/24/99	2:03:17 PM	-0.0070	-0.0037	0.0072	-0.0011
	9/24/99	4:06:57 PM	-0.0073	-0.0039	0.0071	-0.0015
	9/25/99	1:02:46 AM	-0.0073	-0.0039	0.0071	-0.0015
	9/26/99	9:08:28 PM	-0.0091	-0.0055	0.0065	-0.0036
	9/27/99	9:36:04 AM	-0.0106	-0.0067	0.0054	-0.0052
	9/27/99	1:10:29 PM	-0.0125	-0.0081	0.0041	-0.0073
40	10/01/99	1:51:15 PM	0.0011	0.0086	-0.0045	-0.0073
	10/03/99	10:12:07 PM	0.0021	0.0095	-0.0036	-0.0061
	10/04/99	8:08:53 AM	0.0028	0.0100	-0.0030	-0.0042
60	10/08/99	9:56:30 AM	0.0059	0.0063	0.0062	0.0066
	10/10/99	1:33:26 PM	-0.0011	0.0019	0.0044	0.0041
	10/11/99	1:07:46 PM	-0.0074	-0.0024	0.0001	-0.0006
100	10/29/99	11:30:27 AM	-0.0053	-0.0022	-0.0071	0.0018
	10/31/99	11:58:35 AM	-0.0148	-0.0049	-0.0108	-0.0026
	11/01/99	8:27:48 AM	-0.0210	-0.0090	-0.0160	-0.0082
120	11/04/99	4:58:47 PM	-0.0085	-0.0046	0.0003	-0.0028
	11/07/99	9:14:23 PM	-0.0022	-0.0009	0.0041	0.0012
	11/08/99	8:15:11 AM	-0.0003	-0.0010	0.0043	0.0023
140	11/12/99	1:26:19 PM	-0.0063	0.0070	0.0091	0.0081
	11/14/99	12:58:14 PM	-0.0123	0.0054	0.0068	0.0051
	11/15/99	8:14:16 AM	-0.0209	-0.0003	0.0005	-0.0020
180	12/03/99	10:25:27 AM	0.0051	0.0011	-0.0048	0.0086
	12/05/99	1:08:12 PM	-0.0201	-0.0005	-0.0070	0.0058
	12/06/99	8:14:38 AM	-0.0272	-0.0050	-0.0123	0.0002
200	12/10/99	2:28:24 PM	0.0004	-0.0019	-0.0017	-0.0031
	12/12/99	1:29:57 PM	-0.0035	0.0008	0.0021	-0.0008
	12/13/99	8:10:22 AM	-0.0015	0.0014	0.0032	0.0005
220	12/17/99	10:03:29 AM	-0.0025	-0.0065	-0.0010	0.0024
	12/19/99	11:45:35 AM	-0.0198	-0.0085	-0.0036	-0.0007
	12/20/99	10:00:22 AM	-0.0227	-0.0101	-0.0063	-0.0037

TABLE 4.10: Joint Displacement (inches) (continued)

Repetitions (x 1,000)	Date	Time	LVDT1 (Fiber)	LVDT2 (Plain)	LVDT3 (Fiber)	LVDT4 (Plain)
260	1/13/2000	5:02:35 PM	-0.0616	0.0412	0.0367	-0.0106
	1/14/2000	2:39:35 PM	-0.0987	0.0389	0.0340	-0.0131
	1/18/2000	8:04:34 AM	-0.1223	0.0331	0.0268	-0.0201
280	1/21/2000	9:45:35 AM	0.0045	-0.0046	-0.0005	-0.0067
	1/21/2000	3:43:13 PM	-0.0139	-0.0028	0.0021	-0.0042
	1/24/2000	8:06:35 AM	-0.0173	-0.0004	0.0054	-0.0005
300	1/27/2000	5:11:25 PM	-0.0027	0.0057	0.0025	-0.0090
	1/28/2000	2:56:01 PM	-0.0080	0.0036	0.0002	-0.0121
	1/31/2000	7:55:34 AM	-0.0164	-0.0011	-0.0056	-0.0187
340	2/10/2000	11:22:06 AM	-0.0023	0.0057	-0.0027	-0.0057
	2/11/2000	2:54:51 PM	-0.0048	-0.0017	-0.0054	-0.0080
	2/14/2000	8:05:42 AM	-0.0127	-0.0064	-0.0113	-0.0154
360	2/17/2000	9:39:25 AM	-0.0070	0.0059	-0.0089	-0.0083
	LVDT 4	moved after	first	reading		
	2/18/2000	4:21:52 PM	0.0007	0.0119	-0.0019	-0.0030
	2/21/2000	8:16:15 AM	0.0022	0.0123	-0.0015	-0.0019
380	2/24/2000	4:48:32 PM	0.0064	0.0084	0.0080	-0.0083
	2/25/2000	2:59:33 PM	0.0051	0.0061	0.0060	-0.0109
	2/28/2000	8:05:14 AM	-0.0024	-0.0001	-0.0021	-0.0197
420	3/09/2000	4:45:39 PM	-0.0038	0.0070	-0.0052	-0.0003
	3/10/2000	3:32:22 PM	-0.0067	0.0045	-0.0076	-0.0035
	3/13/2000	8:11:57 AM	-0.0134	-0.0013	-0.0145	-0.0111
440	3/16/2000	4:04:34 PM	-0.0061	-0.0032	0.0071	-0.0034
	3/17/2000	2:13:03 PM	-0.0034	-0.0016	0.0108	-0.0006
	3/20/2000	8:08:47 AM	0.0001	0.0005	0.0127	0.0031
460	3/23/2000	4:22:56 PM	-0.0037	-0.0034	-0.0080	0.0041
	3/24/2000	3:09:05 PM	-0.0054	-0.0050	-0.0095	0.0020
	3/27/2000	8:09:45 AM	-0.0121	-0.0120	-0.0168	-0.0059

TABLE 4.11: Temperature Decrease vs. Joint Displacement

Repetitions (x 1,000)	LVDT 1 (Fiber)		LVDT 2 (Plain)		LVDT 3 (Fiber)		LVDT 4 (Plain)	
	Temp. (˚F)	Displ. (inch)	Temp. (˚F)	Displ. (inch)	Temp. (˚F)	Displ. (inch)	Temp. (˚F)	Displ. (inch)
20	-0.7 -3.9	-.0030 -.0034	-2.3 -3.8	-.0023 -.0026	-1.0 -3.9	.0009 .0024	-1.3 -4.0	.0034 .0037
40	-4.5	.0010	-3.3	.0009	-3.4	-.0009	-2.5	-.0012
60	-4.7 -0.7	-.0070 -.0063	-5.3 -1.0	-.0043 -.0043	-4.2 -0.2	-.0018 -.0043	-5.0 -0.6	-.0025 -.0047
100	-6.7 -6.2	-.0095 -.0062	-7.5 -7.8	-.0027 -.0041	-6.8 -7.7	-.0037 -.0052	-7.4 -7.2	-.0044 -.0056
180			-7.2 -5.0	-.0016 -.0045	-7.1 -6.9	-.0022 -.0053		
220			-5.2	-.0020	-5.9	-.0026		
260			-3.2 -22.4	-.0023 -.0058	-3.3 -19.8	-.0027 -.0072		
300			-2.4 -19.3	-.0021 -.0047	-2.4 -17.0	-.0023 -.0058		
340			-3.8 -19.5	-.0074 -.0047	-4.0 -16.9	-.0027 -.0059		
380			-2.9 -20.4	-.0023 -.0062	-2.9 -18.6	-.0020 -.0081		
420					-3.3 -16.8	-.0024 -.0069		
460					-1.6 -17.2	-.0015 -.0073		

TABLE 4.12: Temperature Increase vs. Joint Displacement

Repetitions (x 1,000)	LVDT 1 (Fiber) Temp. (˚F)	LVDT 1 (Fiber) Displ. (inch)	LVDT 2 (Plain) Temp. (˚F)	LVDT 2 (Plain) Displ. (inch)	LVDT 3 (Fiber) Temp. (˚F)	LVDT 3 (Fiber) Displ. (inch)	LVDT 4 (Plain) Temp. (˚F)	LVDT 4 (Plain) Displ. (inch)
40	2.8	.0007	2.8	.0005	2.0	-.0006	3.0	-.0019
120	2.7 2.0	.0063 .0019	4.6 2.9	.0037 .0001	3.2 2.1	.0038 .0002	3.8 2.7	.0040 .0011
140	6.5 5.0	-.0060 -.0086	7.6 6.0	-.0016 -.0051	5.2 5.6	-.0023 -.0063	7.2 6.4	-.0030 -.0071
200			4.0 6.2	.0027 .0006	6.0 4.1	.0038 .0011		
280			0.3 20.2	.0016 .0024	0.4 16.9	.0026 .0033		
360			2.4 19.7	.0060 .0004	2.6 16.5	.0070 .0004		
440			0.2 27.2	.0016 .0011	1.6 15.2	.0037 .0019		

4.5 Surface Cracking

The surface cracks are the best indicator of the performance of the thin PCC overlay. The first cracks in the PCC overlay were observed after 40,000 passes of the ATL machine. Two single transverse cracks were, one in each slab, located almost in the same longitudinal position. Each crack extended over the entire width of the slab (Figure 4.4). This clearly indicates that the performance of the plain PCC overlay and that of fiber reinforced PCC overlay is very similar. The first cracks appeared in identical location in both slabs and had the same extent. Their width was measured with the magnifying glass and proved to be very similar.

Dye was poured in the cracks to determine during the post-mortem analysis if their extended to the full-depth of the overlays, or they developed only at the surface of the overlays. Figures 4.5 and 4.6 clearly show, that the cracks extended on the entire depth for both the plain and fiber reinforced PCC overlays. These photographs were taken at the end of loading, when the pavements were destroyed and removed.

Two shorter cracks were later detected in the fiber-reinforced PCC overlay (Figure 4.4). The exact time of their occurrence is not known but they were detected during the removal for FWD equipment at 240,000 cycles. The extent of these cracks did not later increase, even though additional 250,000 ATL passes were applied. These cracks remained unchanged until loading on the two pavements ended. Therefore, even though more cracking appeared in the fiber reinforced PCC overlay, they are not a clear indicator that this overlay has lower performance that the plain PCC overlay. Overall, it can be concluded that the extent and severity of the surface cracks indicates a similar performance for the two overlay materials.

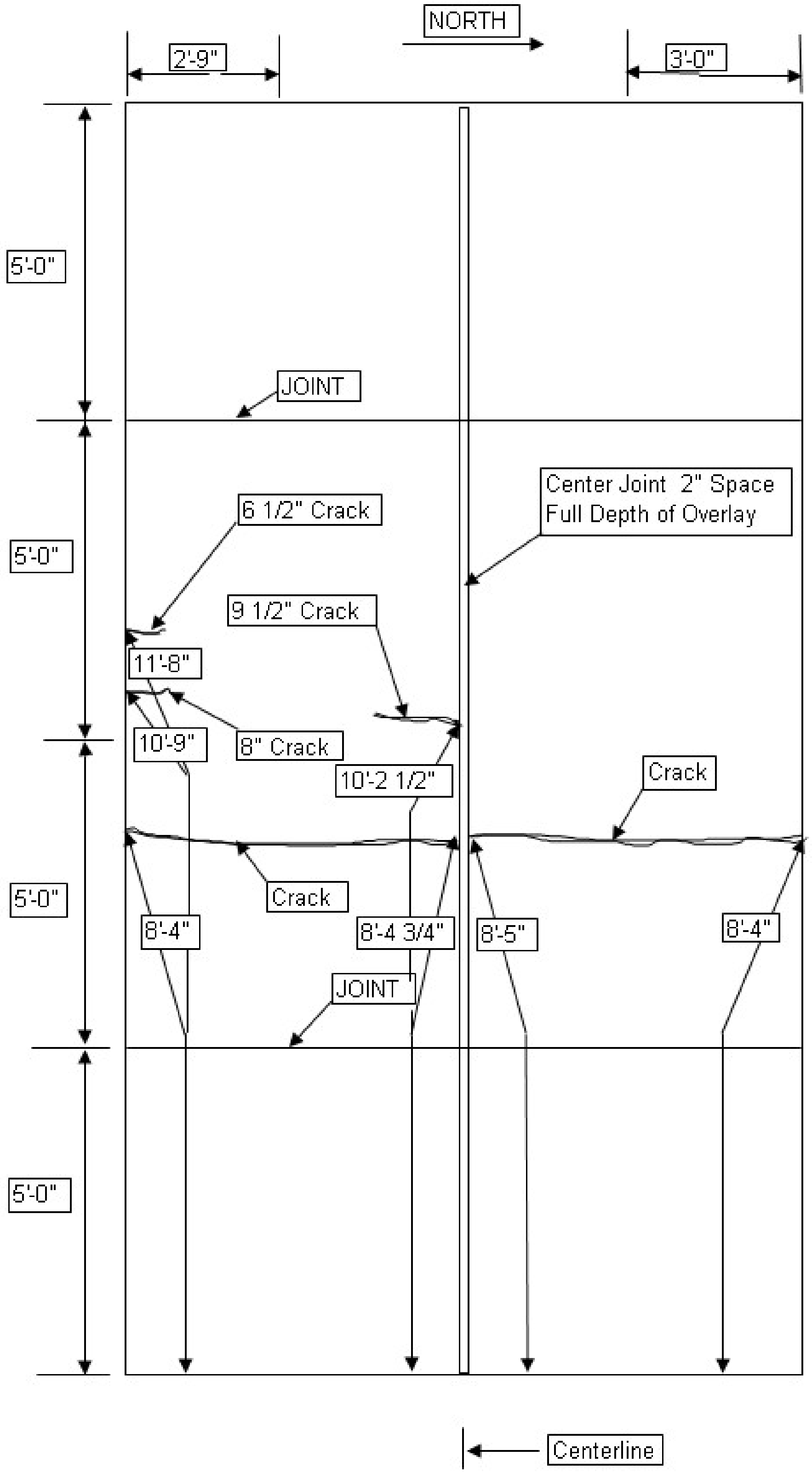


FIGURE 4.4: Surface Cracking in the PCC Overlay

FIGURE 4.5: Post-mortem investigation – crack depth in the plain PCC Overlay

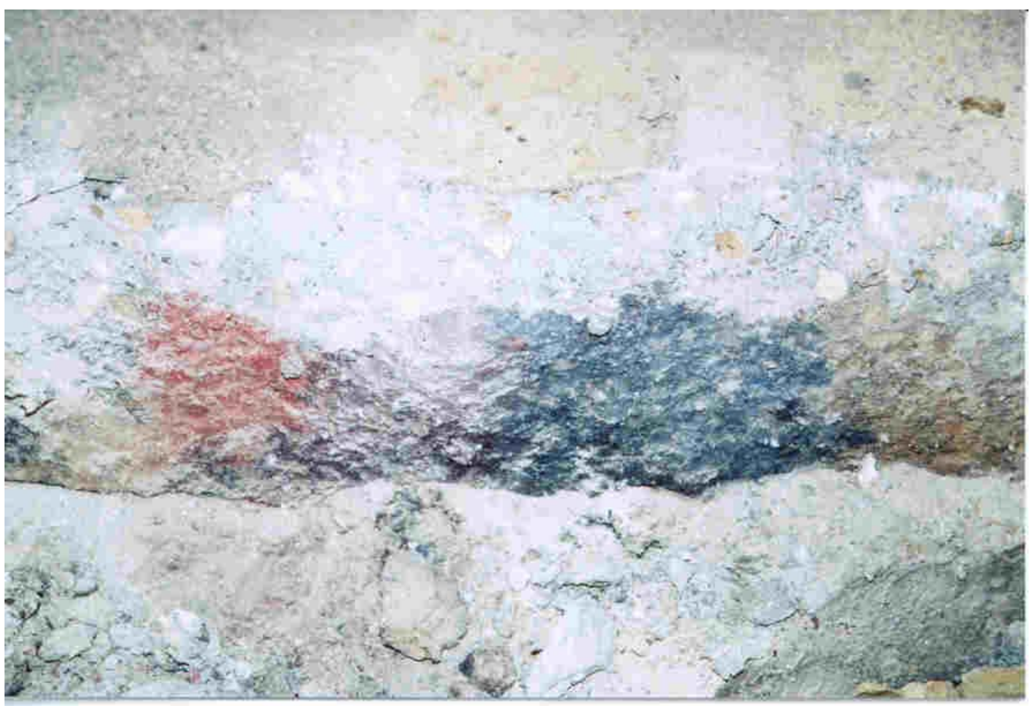


FIGURE 4.6: Post-mortem investigation – crack depth in the fiber reinforced PCC Overlay

CHAPTER 5

CONCLUSIONS

The major conclusions resulting from this research are:

1. ***There is no significant benefit in adding plastic fibers to the concrete PCC overlay.***

This conclusion is supported by the following:

- The surface cracking observed on both overlays is very similar in terms of location and extent, indicating that the two overlays have very similar performances. One large transverse crack, over the entire width of the overlay appeared about in the same time in each of the two overlays. The fiber reinforced PCC overlay exhibited two more cracks, that appear at about 250,000 passes of the ATL machine, and did not continue to grow in length or width after that.
- The vertical compressive stresses in the subgrade soil have very similar values for the two pavements, only slightly higher stresses were recorded in the plain PCC overlay pavement.
- The horizontal longitudinal tensile strains at the bottom of the slabs have very similar values for the plain and fiber reinforced PCC overlays.
- The back-calculated modulus of the fiber reinforced PCC overlay is similar to that of the plain PCC overlay. The values remain similar even at the end of ATL loading.

Therefore, considering the additional cost required by the production and mixing of the use plastic Fibers, their use in the Portland Cement concrete mixes for overlays on rubblized PCC pavements is not recommended.

2. ***Thin overlays on rubblized distressed PCC pavements may be an effective method of rehabilitating distressed PCC pavements with moderate traffic.***

This conclusion is supported by the following:

- Even after 500,000 passes of the ATL machine, the tested pavements did not exhibit severe joint faulting or roughness of the longitudinal profile.
- The overlays bond very well to the rubblized PCC layer. This is critical for assuring a good durability of the overlay and for reducing the risk of delamination.

REFERENCES

1. Melhem, H.G., *Development of an Accelerated Testing Laboratory for Highway Research in Kansas*, Report No. FHWA-KS-97/5, Kansas Department of Transportation, Topeka, KS, November 1997.

2. Melhem, H.G., *Accelerated Testing for Studying Pavement Design and Performance*; FY 97-98, Report No. FHWA-KS-99-2, Kansas Department of Transportation, Topeka, KS, May 1999.

3. Melhem, H.G. and Sheffield, F., *Accelerated Testing for Studying Pavement Design and Performance* FY99, Report No. FHWA-KS-99-7, Kansas Department of Transportation, Topeka, KS, July 2000.

4. Bhuvanagiri, Vijayanath K., *Fatigue Damage Evaluation in Plain Concrete Beams*. Ph.D. Dissertation, Kansas State University, 1998.

5. Iyer, S.K., *Methodology and Instrumentation for Vibrational Analysis of Structures for Non-Destructive Evaluation*. M.S. Thesis, Kansas State University, 1996.

6. Melhem, H.G. and Iyer, S.K., *Using the Falling Weight Deflectometer for Highway Bridge Rating*, Proceeding of the first Structural Engineers World Congress, July 18-23, 1998, San Francisco, CA, N.K. Srivastava, Ed., Elsevier Science, Abstract p. 77 and full paper (8 pp) on CD-ROM.

7. Melhem, H.G., Bhuvanagiri, V.K. and Yu, X., *Design and Development of a PC-Based Real-Time Strain data Acquisition System*, in Computing Development in Civil and Structural Engineering, B. Kumar and B.H.V. Topping, Eds., Civil-Comp Press, Edinburgh, Scotland, Sept. 1999, pp 229-235.

8. Melhem, H., Kim H. and Sheffield, F., *Damage Detection in Concrete by Experimental Vibration Analysis*, Accepted for presentation at the ASCE 2001 Mechanics and Materials Conference, June 27-29, 2001, San Diego, CA.

9. Sheffield, F., *Usage of Fourier Analysis and Fundamental Concepts of Vibration Analysis (of Linear Systems)*, M.S. Report, Kansas State University, 2000.