EFFECT OF BASE TYPE ON CONCRETE SLABS RESPONSETO LOADING

Shie-Shin Wu and Yu Qian
North Carolina Department of Transportation

ABSTRACT

Concrete pavement slabs curl and warp due to changes in the moisture and/or temperature gradient of the slab. In general, the moisture content changes slowly and does not fluctuate frequently. On the other hand, the temperature change from day to night causes slabs to change shape daily. Slab curling and warping changes the status of support provided by the base layer. This effect may be more significant when the relative stiffness of the slab and the base increases. If this is true, slabs on different types of bases will have different mechanical response under the same load. Concrete pavements with different design features and base types were constructed. Instrumentation was installed to measure deflection and strain of the slab under controlled loading. Test results are summarized in this report. Data collected indicates that slabs with different base types response differently to loading.

CURLING AND WARPING

As the air temperature changes, concrete pavement slabs curl and warp due to the temperature gradient within the slab. Wu and Hearne (1) found that the maximum movement of a slab corner was greater than 1.78 mm during a fall day. They also found that curling and warping actually lift the slab and separated it from the underlying lean concrete base with the measured maximum separation of 0.58 mm. It was suggested that they separated because the lean concrete base is too stiff to conform to the shape of the bottom of the slab. The separation violated the design assumption that the base layer provides uniform support to the concrete slab at all times. Huang (2) pointed out that slab curling induces stresses and "curling stresses may be added to or subtracted from loading stress to obtain combined stresses...due to this compensative effect...it may not be critical if curling stresses are ignored."
Cracking distress in a slab is caused by concrete fatigue. Fatigue life of concrete specimens under laboratory conditions is a function of the stress strength ratio (3). Although the correlation between fatigue life and a specific slab developing cracking is low, the percentage of cracked slabs and accumulated fatigue damage can be predicted with reasonable accuracy.

Separation of the slab from the base alters the support conditions, changing the mechanical response (specifically, stress) of the slab under load. If the relative stiffness of the slab and the base is an influencing factor for slab/base separation, than slabs on different types of base will have different mechanical responses, which affects fatigue life. Therefore, concrete pavement performance life is a function of base type.

THE PROJECT

North Carolina Department of Transportation (NCDOT) decided to participate in the Strategic Highway Research Program (SHRP), Special Pavement Study 2 (SPS2), which is a concrete pavement study project. A concrete test project was constructed according to SPS2 requirements. The project is US 52 which is a four lane divided highway approximately 36 km south of Winston-Salem, North Carolina. The test section is located on the southbound lane. Each test section is 152.4 m long with a minimum of a 60 m transition area between sections. The 12 test sections stretch over a five km long highway. The concrete paving operation was completed in late 1993 and the road was opened to traffic in July of 1994.

The SPS2 experimental design is a nationwide two tiers complete factorial design. The second tier design consists of two level of concrete strength (3800 kPa and 6200 kPa flexural strength), two levels of pavement thickness (20 cm and 28 cm), two levels of pavement width (3.6 m and 4.3 m) and three levels of base type (aggregate, lean concrete and permeable

asphalt drainage base). Twelve (12) different sections were constructed in this project. Instrumentation was installed in 8 of the 12 sections.

Test Sections

The North Carolina SPS2 project is a part of the complete factorial design. In fact, it is one half of the second tier experimental design. Because of this, some of the factors can not be analyzed using data collected from this site only. Besides the twelve SPS2 sections, an additional section is included. This section has a conventional dense graded asphalt base and is designated as section 260. Design features and section numbers are summarized in Table 1.

Typical cross sections of the test sections are shown in Figure 1. All sections were constructed with untied concrete shoulders. It is NCDOT's standard practice to stabilize the top 20cm of subgrade with either lime or cement. Although shoulder drains were installed throughout the project, none was installed in the test sections. The only exception was installation of shoulder drains in sections with PADL (permeable asphalt drainage layer) base.

Instrumentation

The objective of this study is to understand if and how concrete pavements on different types of base respond differently under load. In other word, it is to investigate the quantitative variation of deflection and strain of the slab under loading. In order to do this, the mechanical response of the slab under different weather and loading conditions is needed. Instruments installed include: 1) an on-site weather station to collect air temperature, solar radiation, wind speed and direction, and precipitation, 2) a weigh-in-motion station to record traffic information such as vehicle classification and individual axle weights, 3) thermistor probes installed at different depths to record the temperature gradient in concrete pavement and subgrade soil, 4) time-domain reflectometry (TDR) probes to measure moisture content, 5) strain gauges on the bottom and the surface of the slab, and 6) linear variable differential transformers (LVDT) to measure deflection and vertical movement of slabs.

Multidepth deflectometers (MDD), designed in South Africa, were installed in four of these sections. In the remaining four sections, a specially designed multi-LVDT holder (MLH) was used to minimize the size and the number of installation holes. The MLH design and LVDT setup are shown in Figure 2. A maximum of three LVDTs can be mounted in one MLH. MDDs are very expensive; however, they remain on the site after installation and are easy to hook up for data collection. On the other hand, the MLHs requires installation before every data collection session. The advantages of the MLHs are low initial cost and easy of replacement in case of LVDT failure. LVDTs used in this project are model GPD-121-125 by Lucas/Schaevite.

Embedded PAST strain gauges (manufactured by Dynatest) were installed prior to the paving operation. Surface mounted strain gauges are installed prior to data collection. These gauges are covered by car body putty to protect them from testing trucks. After a data collection session, surface mounted gauges are destroyed by regular traffic. Therefore, new gauges are installed just before each data collection session. The strain gauges used are supplied by Texas Measurements (model PL-30). Figure 3 shows the location of the strain gauges and the LVDTs.

Eight sections were selected for instrumentation. A summary of design components and instruments installed in these eight instrumentation sections is shown in Table 2. These sections were selected to facilitate a comparison of rigid and flexible types of base.

Data Collection

Extensive material sampling and testing were performed during and after construction. Bulk samples of soil and aggregate were sent to the LTPP testing lab for storage and testing. Plate load testing on soil and aggregate base was performed. Weather data and vehicle axle weight data are collected continuously. The mechanical response of slabs under controlled loads is collected during different seasons of the year. Details of the data collection are described as follows.

Concrete Sampling

Concrete beams and cylinders were made during construction. These samples were tested at different curing times. Also, cores were taken from the concrete pavement at different times to test the strength of field cured concrete. Besides compressive strength, flexure strength, and indirect tensile strength, samples were also tested for Young's Modulus and coefficient of thermoexpansion. Test results are summarized in Table 3.

Weather Information

The on-site weather station collects climatic information which includes wind speed and direction, temperature, solar radiation, and precipitation. Around the clock weather condition information is stored in a Campbell Scientific CR10 data logger for periodic down loading.

An example of daily air temperature change is shown in Figure 4. These three days' records indicated that daily temperature change in a normal fall day can be as high as 15 °C.

Weigh-in Motion

IRD piezo weigh-in-motion (WIM) equipment was installed on site. Vehicle counts and axle weights are recorded on both southbound lanes. WIM data can be down loaded to the office through a modem. Operation of the WIM equipment can also be monitored through the same telephone line.

Environmental Data

Environmental sensors, described previously, were installed in four sites as shown in Table 2. Layer temperature, subgrade moisture content, and ground water level are monitoring continuously. Data are recorded and stored in Campbell Scientific CR10 data loggers and down loaded four times a year.

The most interesting environmental information of concern to this study is the temperature gradient of the concrete slabs. Surface temperature of the slab is affected by sun light, wind speed and air temperature, which are constantly changing. The temperature at the bottom of the slab remains fairly stable; therefore, the slab temperature gradient varies during the day. The most extreme temperature differences between the surface and the bottom of the slab in a day were identified. Slab daily extreme temperature gradients of all four monitored sections for 16 consecutive days in fall were plotted in Figure 5 as an example. This plot shows a wide range of temperature gradients which changed from 10 °C (day time) to -5 °C (night time) within a day.

Slab Responded to Loading

The magnitude of concrete slab curling/warping varies daily and seasonally. It is expected that this movement plays an important role in a slab's response to loading. For verification, data collection is scheduled to capture the representative values of these variations. The slab response to known loads is measured. Two single unit trucks, one with a single axle and the other with a tandem axle, are used for field testing. The loaded trucks provide 80 kN and 89 kN single axle load and 142 kN and 160 kN tandem axle load.

In their earlier study, Wu & Hearne (1) found that slab curling reaches its maximum value during early morning (6 a.m.) and maximum warping in mid afternoon (2 p.m.). It was decided that control load testing would be performed three times a day, i.e., early morning (6 a.m.), midmorning (10 a.m.) and mid-afternoon (3 p.m.). Under each loading situation, trucks run three repetitions at 50, 65 and 80 km/h. This results in a total of 108 test runs on every section.

To monitor seasonal slab response variations, data collection for the first year was performed three times, i.e., in October (hot day, cold night), February (cold day and night), and May (warm day, cold night). Data collection in subsequent years was cut back to two times a year (spring and fall).

Until now, six field data collection sessions have been conducted. Dates of data collection are presented in Table 4. Megadac, a data acquisition system developed by Optium Co., was selected to collect field data. PCS/Law, contractor for FHWA/LTPP, assisted in field data collection.

LVDT and strain measurements are recorded at a rate of 1 kHz. The high data acquisition rate allows us to record load history and capture peak values. All gauges were balanced (zero) before data collection. Minor data shifts were done by software to offset deflection and strain induced by temperature. Therefore, data reported represents the true deflection and strain induced only by the test trucks.

The original plan was to perform the first field data collection before the road was opened to traffic. The road was open to traffic on July 1, 1994; however, the first field data collection did not take place until the weeks of October 3 and 10, 1994.

Data Collection Problems

Due to delay in data acquisition system delivery, the first data collection session was performed after the road was opened to traffic. The first data collection session was much like the dress rehearsal. Field operation problems and instrument deficiencies were detected. The significant problems were:

1. unacceptable high noise/signal ratios were recorded from the embedded strain gauges.
2. technique of mounting surface strain gauge should be improved to prevent slippage.
3. method of mounting reference bracket for LVDT must be modified to prevent creeping.

Experience gained from the first session helped in developing the techniques and procedures used for the subsequent data collection sessions. Improved gauges installation in the later sessions produced high percentage of useful data.

DATA ANALYSIS

Data recorded in Megadac were processed using DLRCheck, developed by PCS/Law. This software processes raw data by first filtering noise and then performing data reduction. The output of DLRCheck includes maximum and minimum values and the time of occurrence of each channel's record. The output is then imported to a QuattroPro spreadsheet for further analysis.

Since the three repeat runs at the same speed were performed within 15 minutes, it is reasonable to assume that temperature change would be negligible and have the same effect on the slab, hence mechanical responses of the slab should remain the same. These three data points should be equal in magnitude. In reality, data were scattered across a fairly wide range. The scattering may be caused by the truck wandering in the wheelpath and/or equipment error (slippage of installed gauges). Data points with obvious errors (equipment malfunctions) were eliminated before calculating average values.

The three strain gauges were installed in a line no more than 30 cm long. Average strain was calculated using the three gauges on three repeat runs (nine data points). SPSS was used for statistics analysis.

Speed Variation

One dimensional analysis of variance tests (ANOVA) were performed to test the null hypothesis that operating speeds have no effect on deflection. Table 5 summarizes the results of the ANOVA testing. A "Rej" indicates that slab deflection at different speeds are significantly different, and a "Acc" indicates there is not enough difference to say that operation speed causes different deflection at 95% significant level.

The same ANOVA analysis was performed to test the effect of operating speed on mid-slab surface strain. Again, the null hypothesis that different operating speeds makes no difference in surface tensile strain was tested. Test results are summarized in Table 6.

Test results indicate that the truck operating speed has a greater effect on joint deflection during dawn data collection and much less in the afternoon. It also showed that operating speed had greater effect on mid-slab strain during the afternoon data collection.

Time of Day Variation

It was clearly indicated by the deflection data that the slab deflection at joints in early morning was significantly greater than that of midmorning and mid-afternoon. Midslab deflections, although slightly less in magnitude, follow the same trend. Table 7 summarizes deflections at different positions of section 201 during one data collection session.

Deflection data show that afternoon deflections are substantially lower in magnitude than in the morning. In the afternoon, edge deflections at mid-slab and joint were identical. This implies that the slab is in its natural position, i.e., with full base support.

Seasonal Variation

To understand the nature of pavement slabs' response to loading in different seasons is one of the objective of this study. Data collected from spring and fall were grouped together. ANOVA tests were performed to test the null hypothesis that the deflections at the joint are the same at different times of the day. Two extreme loading cases, i.e., heavy load tandem

axle and light load single axle were investigated. Testing results are presented in Table 8. Test results were mixed with majority of the situations suggesting that deflection in the spring and fall seasons were different.

Recorded deflections caused by the heavy tandem axle loading in the two seasons are presented in Table 9. Table 10 shows the strain induced by the same loading in spring and fall. Date collected from sections 201 and 205 were presented. Both sections are 20 cm thick concrete pavement. The only design different between these two sections are base material. Section 201 was constructed with 15 cm aggregate base course while 205 was constructed with 15 cm lean concrete base.

Year to Year Variation

It is important to know how data collected from the same season varies from year to year. ANOVA tests were performed to test the null hypothesis that data collected in the same season from different years are from the same population. Rejecting the null hypothesis means data collected from one year to the other are different. Test results indicate that the null hypotheses is accepted, which implies that from year to year, deflection data from the same site did not change significantly. It should be noted that the testing was done early in the pavement life and only two years were compared.

Effect of Base Type

Three types of bases were constructed; aggregate base, lean concrete base and drainable asphalt treated base. Of these, the aggregate base and the drainable base are flexible bases and the lean concrete base is a rigid base. When slabs curl/warp in response to temperature changes, they tend to separate from the base when the base is relatively rigid. This action results in lost of support on part of the slab and affects the slab response under loading. The only difference between Section 201 and 205 is the base type. Section 201 was constructed with aggregate base and section 205 was lean concrete base. ANOVA testing was performed to test the null hypothesis that the deflections at the joint of the slab with these two types of bases are the same. Test results indicated that the null hypothesis should be rejected, which means that at a 95% confidence level, the joint deflections for different types of base are different.

The amounts of joint deflection under the 106 kN tandem axle load of these two base types are shown in Table 11. The corresponding mid-slab strain is summarized in Table 12.

Deflections of the subgrade at joints for these two base types were compared. Results are shown in Table 13. The magnitude of compressive force induced by the axle loading to the subgrade is a function of the magnitude of the subgrade deflection. Results show that subgrade deflection at the joints is more sensitive to time of the day than other locations. They also show that, in general, subgrade deflection is greater in the fall than that in the spring. The most interesting point is that truck loading on sections with lean concrete base induce a higher subgrade deflection than sections with aggregate base.

Ratio of Subgrade Deflection And Slab Deflection

To study the relationship of the subgrade deflection and the slab deflection, the ratios of the measured deflections at the same location were calculated. A definite trend was observed as shown in Table 14. The subgrade slab deflection ratio at all positions is always lower at dawn than other times of the day. At mid-slab under the wheelpath, the ratio is always higher than at the joint or slab edge. Several points can be observed from these results. These are:

1. the ratios are higher in sections with lean concrete base than with aggregate base.
2. the ratios are higher at mid-slab under wheelpath.

FINDINGS AND CONCLUSIONS

This report summarizes the initial finding of a continuing research effort. Although it may not be conclusive, some of the results support the assumption that slabs with different base types respond differently under loading.

The most pronounce effect on load induced deflections is the time of the day. Deflection readings were much greater at dawn than at mid afternoon. The magnitude of difference at dawn was greater at joints and the edge than at the wheelpath. In the afternoon, edge deflections (at both joints and mid-slab) were less than that of wheelpath. This phenomenon can very easily be explained as the effect of slab warping. Mid-afternoon may very well be the time when the slab is in its natural position (when the slab has the full uniform support from the base layer). The results confirm the suggestion that slab curling/warping action plays an important role in its mechanical response to loading.

ANOVA test results indicate that deflection data collected in the spring were significantly different from that of the fall.

Deflection data of the same season collected from the same site in different years did not change significantly. Test results suggest that data from the same season were from the same population. Since this report includes only two years of data, it should be considered as the short term effect. Continuous data collection efforts should help determine the age effect on slab deflection.

Deflection data from section 201 and 205, which were constructed with different types of base material, show that the deflections of section 201 (aggregate base) are greater than section 205 (lean concrete base). Yet tensile strain results were not as clear cut. The reason for these mixed results may be caused by the faulty strain gauge installation due to improper adhesive material curing at low temperatures. Improvement in field gauge installation procedures should enhance the reliability of data collection, hence produce more realistic information regarding load induced strain.

Subgrade deflection, which is proportion to the compressive stress induced by the load to the subgrade, show that sections with lean concrete base had greater subgrade deflections than those with aggregate base.

The ratio of subgrade and surface deflection showed great differences between aggregate base and lean concrete base. This is a definite trend. How best to utilize this trend for design remains to be studied.

This report includes only data from two full years of data collection. Missing data and the scattering of data points prevent drawing a sound conclusion. Data collection will be continued for the next few years. More data points will provide better information to formulate the nature of slab response to loading when different base types are used.

In some cases, equipment was installed under adverse weather condition. Improper installation compromises the reliability of data collected. Experience gained from the last two years has helped in the development of techniques that can minimize these problems. Future data collection should have a greater success rate and be more reliable.

LIST OF TABLES

Table 1. Test Sections
Table 2. Instrumentation Sections
Table 3. Summary of Concrete Testing Results
Table 4. Field Data Collection Sessions
Table 5. ANONA Test Results - Speed Effect on Deflection
Table 6. ANOVA Test Results - Speed Effect on Surface Tensile Strain
Table 7. Time of Day Effect on Deflection
Table 8. ANOVA Test Results - Seasonal Variation
Table 9. Seasonal Variation of Deflection
Table 10. Seasonal Variation of Tensile Strain
Table 11. Effect of Base Type on Joint Deflection
Table 12. Effect of Base Type on Mid-slab Tensile Strain
Table 13. Subgrade Deflection at Joints
Table 14. Ratio of Subgrade And Slab Deflection

Table 1. Test Sections

Section	Width (m)	Thick (cm)	Concrete (kPa)	Base Type
201	3.6	20	3,800	ABC
202	4.3	20	6,200	ABC
203	4.3	28	3,800	ABC
204	3.6	28	6,200	ABC
205	3.6	20	3,800	Eco
206	4.3	20	6,200	Eco
207	4.3	28	3,800	Eco
208	3.6	28	6,200	Eco
209	3.6	20	3,800	PADL
210	4.3	20	6,200	PADL
211	4.3	28	3,800	PADL
212	3.6	28	6,200	PADL
260	4.3	28	3,800	HB

ABC: Aggregate Base Course
Eco: Econocrete (Lean Concrete)
PADL: Permeable Asphalt Drainage Layer
HB: Dense Graded Asphalt Base Course

Table 2. Instrumentation Sections

Section	Width (m)	Thick (cm)	Concrete (kPa) *	Base Type	Defl. Gauge	Surface Strain	Embedded Strain	Enviro. Sensors
208	3.6	28	6,200	Eco	MLH	yes	yes	yes
212	3.6	28	6,200	PADL	MLH	yes	yes	yes
201	3.6	20	3,800	ABC	MLH	yes	yes	yes
205	3.6	20	3,800	Eco	MLH	yes	yes	yes
211	4.3	28	3,800	PADL	MDD	no	yes	no
260	4.3	28	3,800	HB	MDD	no	yes	no
210	4.3	20	6,200	PADL	MDD	no	yes	no
209	3.6	20	3,800	PADL	MDD	no	yes	no

Note: For base type description, see Table 1.
MLH : Multi-LVDT Holder
MDD: Multi-Depth Deflectometer
* Concrete Flexural Strength

Table 3. Summary of Concrete Testing Results

Concret Type*	Testing Day	Compr. (kPa)	Indir/Tensil (kPa)	Flexural (kPa)	Density (g/cm3)	Young's Modulu (kPa *E6)
A	14	24,698	2,727	4,710		
A	28	30,059	3,083	4,464		33.6
A	365	45,647	4,210	6,324	2.24	32.5
B	14	24,366	2,486	3,986		
B	28	25,444	3,345	4,741		26.7
B	365	51,701	4,052	5,441	2.36	31.7
C	14	34,428	3,689	5,821		
C	28	43,804	3,926	7,340		37.4
C	365	64,349	4,761	7,097	2.39	33.9
Eco	14	22,445				
Eco	28	25,655				
Eco	365	37,598				

*
A: Concrete with design flexural strength of 3800 kPa
B: Concrete with design flexural strength of 4000 kPa
C: Concrete with design flexural strength of 6200 kPa
Eco: Lean concrete base

Table 4. Field Data Collection Sessions

Session	Begin	End
A	10/03/94	10/13/94
B	02/13/95	02/24/95
C	05/08/95	05/19/95
D	11/06/95	11/30/95
E	05/06/96	05/16/96
F	10/28/96	11/08/96

Table 5. ANOVA Test Results - Speed Effect on Deflection

		Testing Time		
Axle	Load	Dawn	am	pm
Single	80kN	Rej	Acc	Acc
	89kN	Rej	Acc	Acc
Tandem	142kN	Rej	Acc	Acc
	160kN	Rej	Rej	Rej

Rej : Reject The Null Hypothesis (Effect is significant)

Acc : Accept The Null Hypothesis (Effect is not significant)

Table 6. ANOVA Test Results
Speed Effect on Tensile Strain

		Testing Time		
Axle	Load	Dawn	am	pm
Single	80kN	Rej *	Rej	Rej
	89kN	Acc *	Rej	Rej
Tandem	142kN	Acc	Acc	Rej
	160kN	Rej	Rej	Rej

* See Table 5

Table 7. Time of The Day Effect on Deflection

Average Deflection in mm

Location	Load	Testing Time Dawn	am	pm
Midslab/Edge	Single(80kN)	0.54	0.22	0.13
	Single(89kN)	0.68	0.23	0.17
	Tandem(142kN)	0.5	0.25	0.16
	Tandem(160kN)	0.77	0.3	0.19
Midslab/Wheelpat	Single(80kN)	0.33	0.17	0.17
	Single(89kN)	0.4	0.19	0.19
	Tandem(142kN)	0.36	0.24	0.23
	Tandem(160kN)	0.5	0.28	0.26
Joint	Single(80kN)	0.78	0.34	0.13
	Single(89kN)	0.93	0.34	0.16
	Tandem(142kN)	0.69	0.33	0.14
	Tandem(160kN)	1.04	0.41	0.18

Table 8. ANOVA Test Results
Time of The Day effect on Deflection

Load	Location	Testing Time Dawn	am	pm
Single(80kN)	Joint	Rej *	Rej	Rej
	Wheelpath	Acc *	Rej	Rej
	Edge	Rej	Acc	Rej
Tandem(160kN)	Joint	Rej	Rej	Rej
	Wheelpath	Rej	Rej	Rej
	Edge	Rej	Acc	Rej

* See Table 5

Table 9. Seasonal Variation of Deflection (in mm)

Section	Location	Season	Time			Avg. Time		
			Dawn	am	pm	Dawn	am	pm
201	Joint	Fall	1.40	0.78	0.50	1.55	0.81	0.42
			1.69	0.84	0.33			
		Spring	1.04	0.41	0.18	1.07	0.40	0.18
			1.10	0.40	0.18			
	Midslab Wheelpath	Fall	0.39	0.24	0.23	0.35	0.21	0.20
			0.32	0.18	0.16			
		Spring	0.50	0.28	0.26	0.42	0.24	0.23
			0.34	0.20	0.20			
	Midslab Edge	Fall	0.66	0.28	0.23	0.60	0.28	0.21
			0.54	0.28	0.20			
		Spring	0.77	0.30	0.19	0.65	0.27	0.18
			0.54	0.25	0.17			
205	Joint	Fall	1.38	0.71	0.45	1.38	0.85	0.47
				0.98	0.50			
		Spring	1.04	0.46	0.17	1.07	0.40	0.17
			1.10	0.33	0.16			
	Midslab Wheelpath	Fall	0.20	0.14	0.11	0.20	0.14	0.11
				0.14	0.12			
		Spring	0.22	0.18	0.16	0.29	0.18	0.12
			0.36	0.17	0.08			
	Midslab Edge	Fall	0.39	0.25	0.16	0.39	0.26	0.20
				0.27	0.24			
		Spring	0.31	0.24	0.14	0.49	0.24	0.14
			0.66	0.23	0.13			

Table 10. Seasonal Variation of Tensile Strai (in Microstrain)

Section	Location	Season	Time			Avg. Time		
			Dawn	am	pm	Dawn	am	pm
201	Edge	Fall	28.80	16.52	11.17	33.44	17.08	9.95
			38.09	17.65	8.74			
		Spring	19.96	9.56	7.47	18.43	10.54	9.85
			16.90	11.51	12.22			
	Wheelpath	Fall	22.16	13.72	9.86	26.49	17.93	10.45
			30.83	22.14	11.03			
		Spring	17.05	7.95	7.52	17.07	8.62	10.35
			17.09	9.29	13.17			
205	Edge	Fall	28.95	19.12	12.71	28.95	16.83	10.87
				14.54	9.02			
		Spring	21.91	11.08	4.25	19.38	9.15	6.19
			16.85	7.21	8.14			
	Wheelpath	Fall	29.52	18.35	9.80	29.52	15.60	8.12
				12.85	6.43			
		Spring	22.38	10.78	5.02	20.40	9.09	7.10
			18.41	7.41	9.18			

Table 11. Effect of Base Type on Joint Deflect (in mm)

Location	Season	Section	Time		
			Dawn	am	pm
Joint	Fall	201	1.55	0.81	0.42
		205	1.38	0.85	0.47
	Spring	201	1.07	0.4	0.18
		205	1.07	0.4	0.17
Midslab	Fall	201	0.35	0.21	0.2
Wheelpath		205	0.2	0.14	0.11
	Spring	201	0.42	0.24	0.23
		205	0.29	0.18	0.12
Midslab	Fall	201	0.6	0.28	0.21
Edge		205	0.39	0.26	0.2
	Spring	201	0.65	0.27	0.18
		205	0.49	0.24	0.14

Table 12. Effect of Base Type on Mid-slab Tensile Str
(in Microstrain)

Location	Season	Section	Time		
			Dawn	am	pm
Edge	Fall	201	33.44	17.08	9.95
		205	28.95	16.83	10.87
	Spring	201	18.43	10.54	9.85
		205	19.38	9.15	6.19
Wheelpath	Fall	201	26.49	17.93	10.45
		205	29.52	15.6	8.12
	Spring	201	17.07	8.62	10.35
		205	20.4	9.09	7.1

Table 13. Average Subgrade Deflection at Joi (in mm)

Section	Axle	Time	Spring			Fall		
			Joint	WP*	Edge	Joint	WP	Edge
201	Single	Dawn	0.03	0.09	0.09	0.04	0.18	0.07
		am	0.05	0.09	0.08	0.08	0.16	0.12
		pm	0.06	0.07	0.07	0.06	0.12	0.09
	Tandem	Dawn	0.06	0.13	0.14	0.04	0.17	0.07
		am	0.08	0.13	0.13	0.05	0.10	0.07
		pm	0.10	0.11	0.12	0.07	0.10	0.10
205	Single	Dawn	0.07	0.09	0.09	0.13	0.16	0.11
		am	0.08	0.09	0.08	0.15	0.16	0.12
		pm	0.08	0.08	0.07	0.14	0.14	0.11
	Tandem	Dawn	0.11	0.13	0.13	0.13	0.14	0.10
		am	0.12	0.14	0.13	0.12	0.10	0.08
		pm	0.13	0.12	0.12	0.12	0.10	0.08

* WP: Wheelpath

Table 14. Average Ratio of Subgrade and Slab Deflect

Section	Location	Time	All	Spring	Fall
201	Joint	Dawn	0.04	0.04	0.04
		am	0.12	0.15	0.09
		pm	0.27	0.38	0.17
	Wheelpath	Dawn	0.53	0.51	0.55
		am	0.61	0.63	0.60
		pm	0.51	0.49	0.54
	Edge	Dawn	0.12	0.09	0.16
		am	0.30	0.28	0.33
		pm	0.43	0.47	0.40
205	Joint	Dawn	0.11	0.10	0.12
		am	0.23	0.29	0.18
		pm	0.53	0.75	0.31
	Wheelpath	Dawn	0.66	0.58	0.75
		am	0.82	0.83	0.82
		pm	0.90	0.93	0.87
	Edge	Dawn	0.25	0.21	0.30
		am	0.41	0.44	0.37
		pm	0.68	0.88	0.48

LIST OF FIGURES

Figure 1. Typical Section of Test Sections

Figure 2a. Multi-LVDT Holder

Figure 2b. Multi-LVDT Holder

Figure 3. Location of Instrument

Figure 4. Daily Temperature Change

Figure 5. Daily Extreme Slab Temperature Gradient

Figure 6. Seasonal Variation of Deflection - Section 201

Figure 1. Typical Section of Test Sections

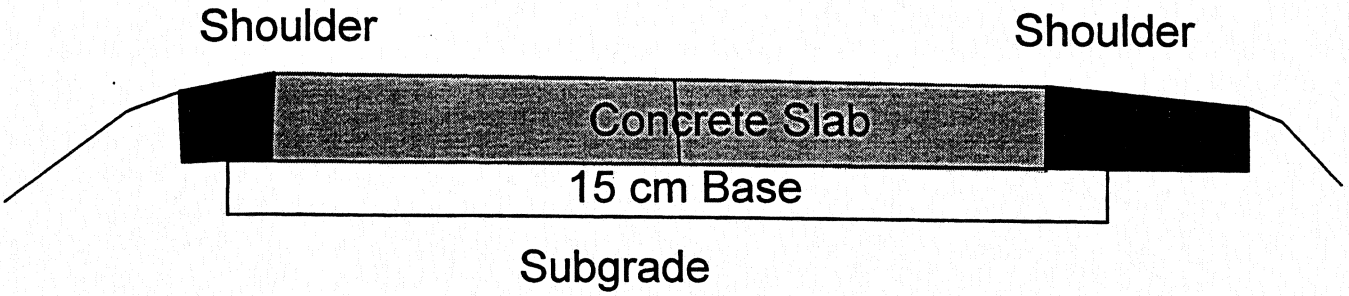


Figure 2a. Multi-LVDT Holder

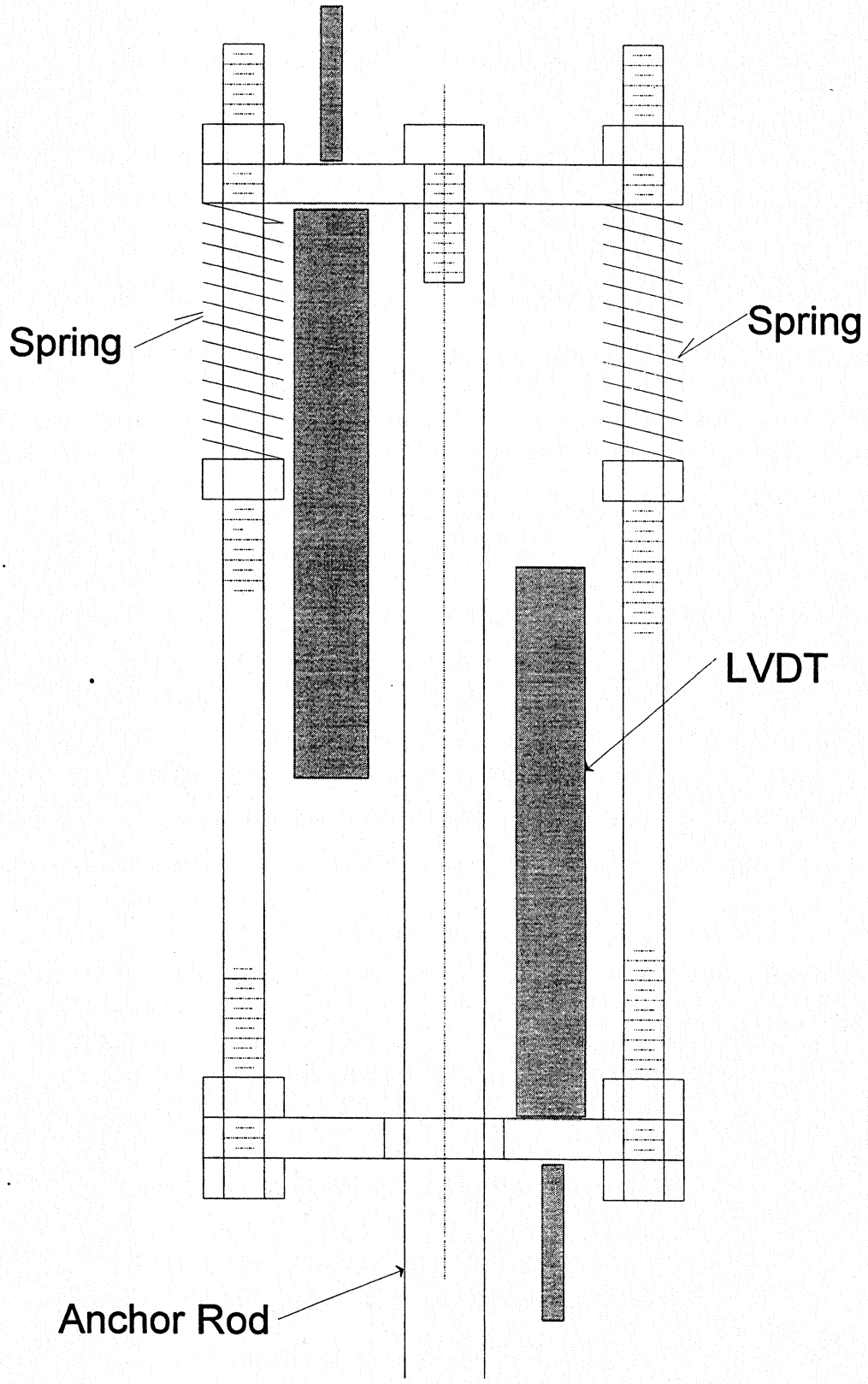


Figure 2b. Multi-LVDT Holder

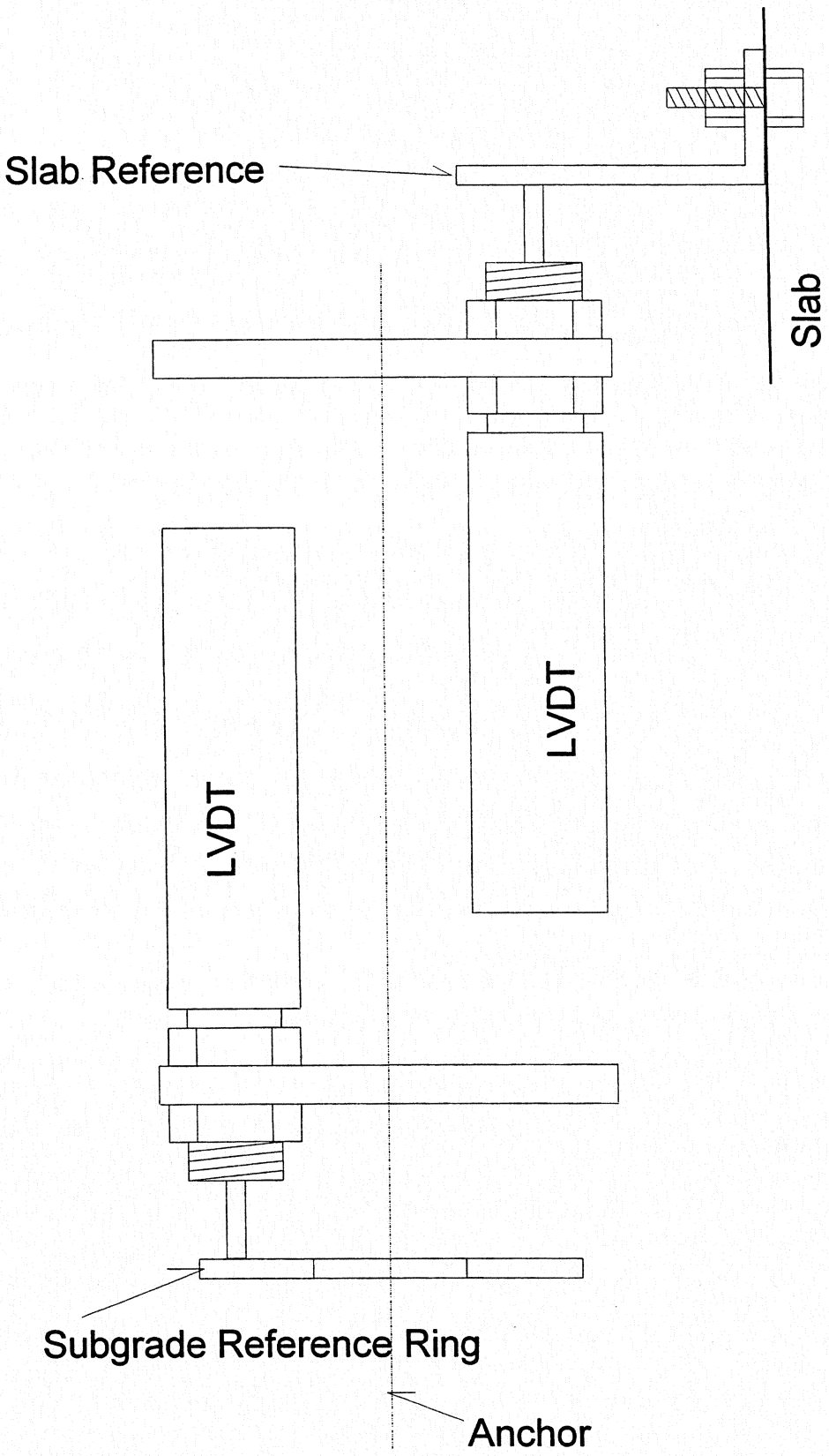


Figure 3. Instrument Layout

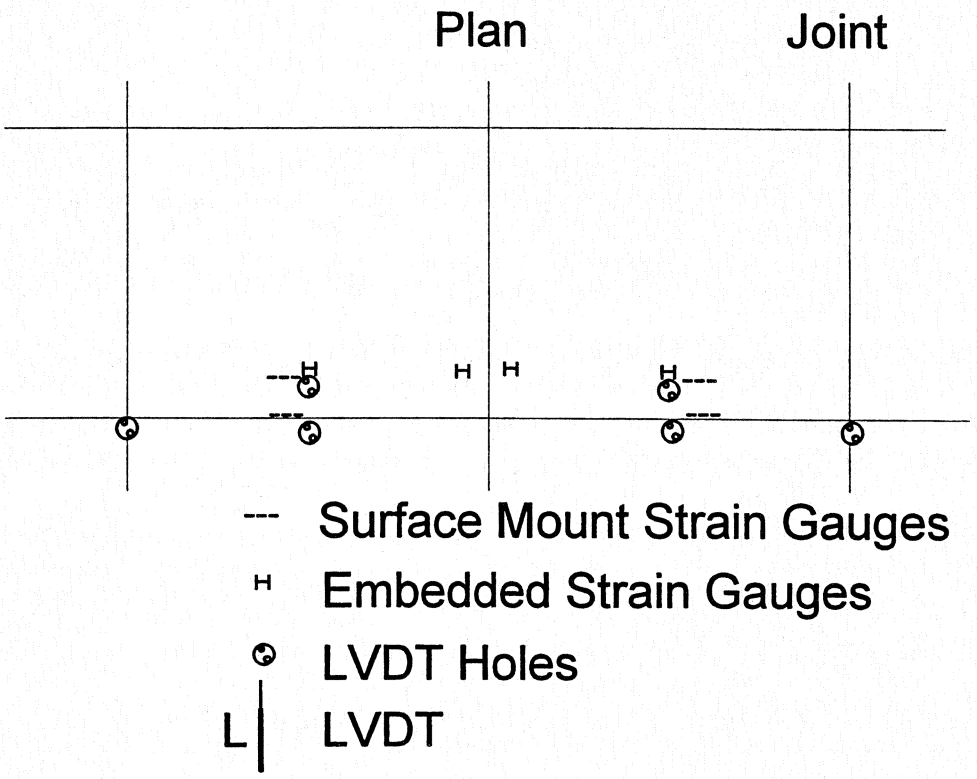


Figure 4. Daily Temperature Change

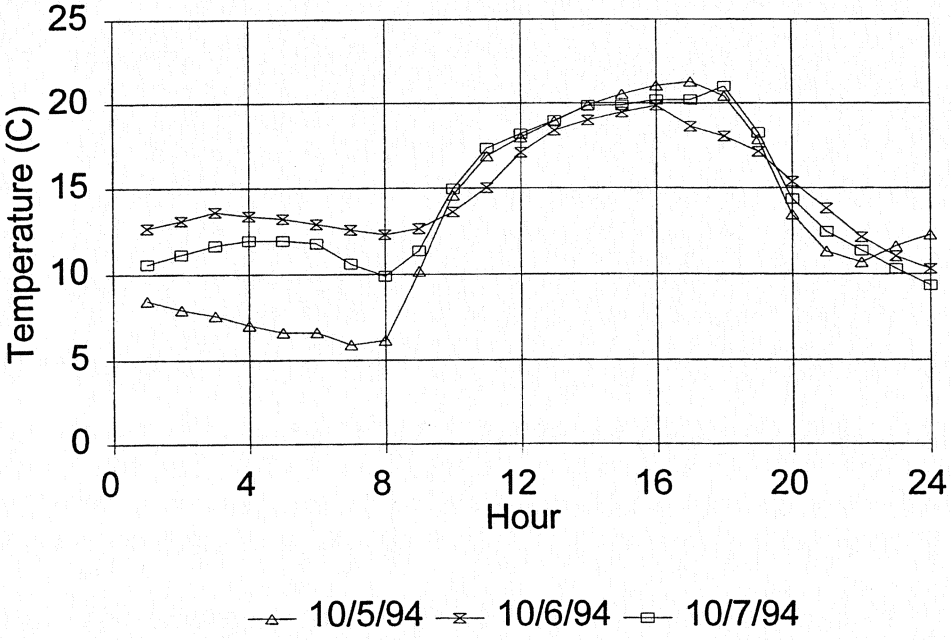
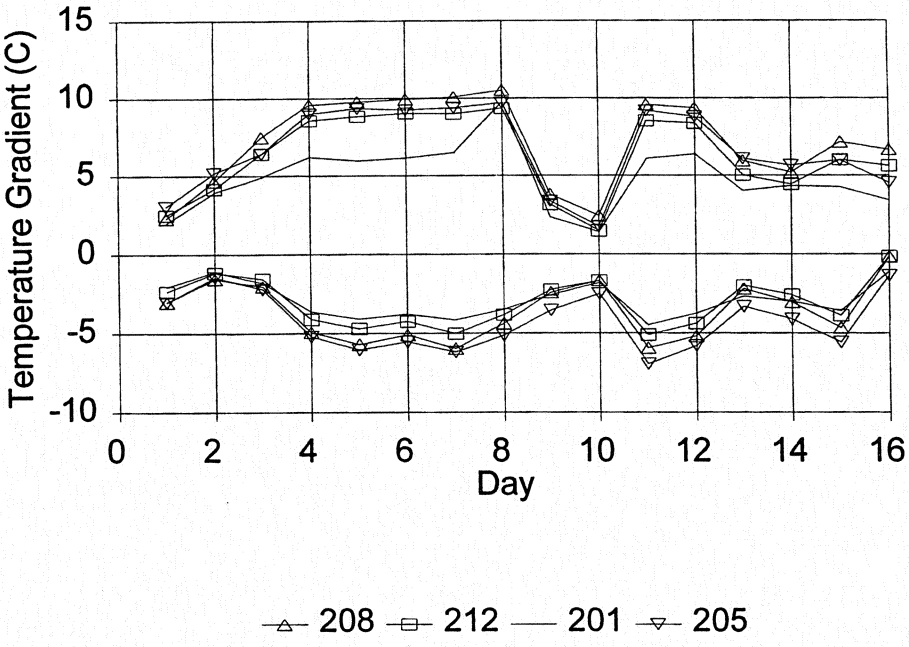


Figure 5. Daily Extreme Slab Temperature Gradient



REFERENCES

1. Wu, S. S. and Hearne, T. M., "Performance of Concrete Pavement with Economic Base," *Proceedings, 4th International Conference on Concrete Pavement Design and Rehabilitation*, Purdue University, 1989

2. Huang, Y. H., *Pavement Analysis and Design,* Prentice Hall, 1993

3. Transportation Research Board, 1990, *NCHRP 1-26 Calibrated Mechanistic Structural Analysis Procedures for Pavement*, University of Illinois and The Asphalt Institute

ACKNOWLEDGMENT

The authors would like to express sincere appreciation to Messrs. Richard Guerl, Andy Lewis of PCS/Law and many NC DOT fellow employees for their long and hard working hours to collect field data.