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EVALUATION OF LOAD TRANSFER RESTORATION TECHNIQUES AND UNDERSEALING PRACTICES

Shiraz D. Tayabji

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Final Report

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6300 Georgetown Pike
McLean, Virginia 22101

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16. Abstract

This report presents results of an investigation conducted to evaluate the performance of "retrofit" load transfer devices installed at a test site on I-75 in Georgia. Devices installed include dowel bars placed in slots and Double V devices placed in holes drilled along joints. Measured deflection data at the test site are compared with deflections calculated using a modified version of computer program JSLAB. The modified version of the program allows calculation of deflections of loaded slabs that are initially curled upward.

Calculated results indicate that there is no clear difference in calculated responses of joints using retrofitted dowel bars and Double V devices. However, field deflection data and visual observations of test sections indicate that sections retrofitted with dowel bars are generally performing better than sections retrofitted with Double V devices. Poor performance of some of the test sections using the Double V devices is attributed to field problems encountered with use of the patching materials. These problems may preclude achievement of desirable level of performance with Double V devices. Retrofitted dowel bars can be expected to provide a desirable level of long-term performance when used with commonly available patching materials.

The report also presents a synthesis of State DOT practices on undersealing of concrete pavements. Items discussed include void detection, grout materials and properties, grouting equipment, and grouting procedure. Data from Illinois and New York on performance of undersealed sections are also presented. Illinois data indicate that improvement in deflection response is obtained with undersealing only when initial deflections are high. The New York data showed that undersealing is not effective in eliminating faulting if the causative factors, especially lack of load transfer, are not eliminated. Therefore, undersealing by itself does not solve the problem of pumping and faulting. Steps must be taken to restore load transfer at joints and to eliminate saturated subbase/subgrade condition by providing effective drainage and positive joint sealing.

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Concrete pavements, dowel bars, grout mixes, joints, joint rehabilitation, undersealing, load transfer devices, pavement rehabilitation	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

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NOTICE

PREFACE

This report was prepared as a part of a contract between the Federal Highway Administration and the Construction Technology Laboratories, a Division of the Portland Cement Association. The contract objective is to develop improved joint systems and load transfer devices for jointed concrete pavements and to evaluate load transfer restoration techniques and undersealing practices.

The following reports have been prepared as part of the contract:

1. Analysis of Jointed Concrete Pavements, February 1984
2. Improved Rigid Pavement Joints, February 1984
3. Dowel Placement Tolerances, May 1986
4. Evaluation of Load Transfer Restoration Techniques and Undersealing Practices, May 1986

The first report presents details of a computer program for analysis of jointed concrete pavements. The program, denoted as JSLAB, can analyze concrete pavement sections consisting of a large number of jointed slabs. Joints may be modeled as doweled, aggregate interlock, or keyed. The computer program is available from the Federal Highway Administration.

The second report contains results of a study conducted to develop improvements to concrete pavement joints. Improvements in design identified to produce better joint performance include use of tied-concrete shoulders, widened lanes, and use of fewer non-uniformly spaced dowel bars. No new load transfer devices were developed as part of this study.

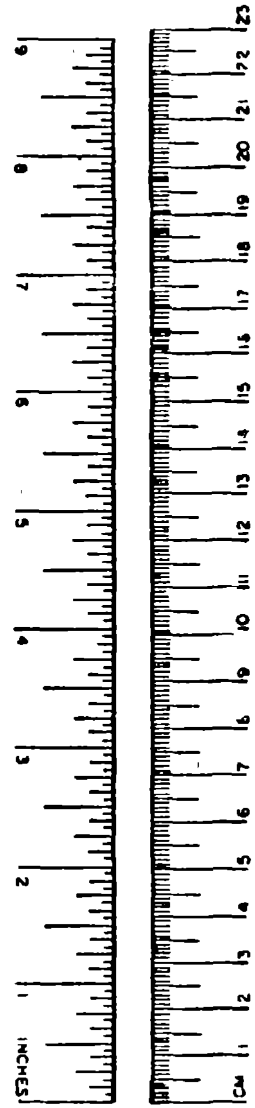
The third report presents results of an investigation conducted to obtain data to develop placement tolerances for dowels at concrete pavement joints. Pull-out tests were conducted in the laboratory on sections of concrete slabs incorporating a joint and dowels with different levels of misalignment. Test results indicate that pull-out loads were relatively low for dowel misalignment levels of less than 1 in. per 18 in. length of dowels bars and a maximum joint opening of 0.25 in. However, because of the limited amount of laboratory data, no recommendations were made to establish new acceptable levels of dowel misalignment.

The fourth report presents results of an investigation conducted to evaluate the performance of "retrofit" load transfer devices installed at a test site on I-75 in Georgia. This report also presents a summary and recommendations on practices of undersealing of concrete pavements.

METRIC CONVERSION FACTORS

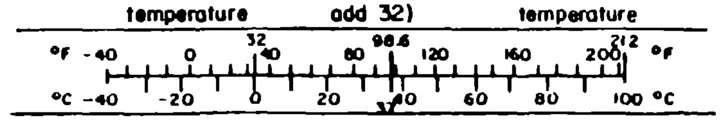
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

A large portion of the nation's highway system is being revitalized to ensure desirable serviceability to users. As part of the revitalization of the highway system, many miles of jointed concrete pavements are being rehabilitated. A large amount of the rehabilitation work is concerned with improving performance at joints. Common joint distress related to the structural adequacy of the joint include faulting, pumping, and corner cracking. Repair techniques commonly used to correct these distress items in jointed concrete pavements include undersealing, full-depth patching, grinding, restoration of load transfer, and use of longitudinal edge drains.

Plain concrete pavements built without mechanical load transfer depend on aggregate interlock to transfer load by shear action between the interlocking aggregate particles on each side of the joint face. The long term effectiveness of aggregate interlock is greatly dependent on joint opening, which is a function of daily and seasonal temperature variations, slab thickness and length, aggregate properties, subbase and subgrade type, drainage, and the amount of heavy truck traffic using the pavement. With time and under heavy truck traffic, a loss in joint load transfer efficiency occurs. This may lead to faulting and pumping if an erodible subbase is present. These distress items result primarily because of excessive deflections at a joint due to poor load transfer across the joint.

Currently, efforts are being made to reduce deflections at poorly performing joints by retrofitting these joints with load transfer devices and/or by undersealing to fill voids under pavement slabs with a grout that hardens to provide support to the slab.

A study was initiated during 1980 by Georgia Department of Transportation (GDOT) with funding from Federal Highway Administration (FHWA) to place and evaluate the in-service performance of load transfer devices (LTD).[(1)*] Load transfer devices installed by GDOT were dowels in slots, Double V, FHWA V, Figure 8, and split pipe devices. Load deflection data were collected by GDOT at different time intervals using a truck with a 20-kip single-axle load. The GDOT study did not include a theoretical analysis of the load transfer restoration techniques.

As part of the present contract with FHWA, a finite element computer program, Program JSLAB, was developed for analysis of jointed concrete

*Superscript refers to references at the end of the report pavements.[2] It was proposed that Program JSLAB be used to analyze joint behavior at the GDOT test sites and that an evaluation be made of the effectiveness of the load transfer devices.

This report presents the results of a study conducted by the Construction Technology Laboratories to analyze the effectiveness of techniques used to restore load transfer at joints at the GDOT test sites. The report also presents a summary of current practice in undersealing of jointed concrete pavements and makes recommendations for improving the practice of undersealing.

EVALUATION OF LOAD TRANSFER RESTORATION TECHNIQUES

In 1980 the GDOT received a research contract from FHWA to develop construction procedures for restoring load transfer in existing jointed concrete pavements and to evaluate the effectiveness of the restoration methods.

In the past Georgia had constructed many miles of plain jointed concrete pavements without use of dowel bars at joints. Many of these older pavements were exhibiting joint-related distress such as faulting, pumping, and cracked slabs. These pavements were generally rehabilitated by undersealing, full-depth patching, grinding at joints, and by resurfacing with asphaltic concrete. Load transfer restoration at existing joints was not attempted out because of a lack of practical and economical method for doing so. In the late 1970's, however, efforts were begun to develop cost-effective methods to restore load transfer at joints. It was believed that the service life of concrete pavements could be extended if adequate load transfer could be established at the joints.

Background

During 1981, a test site was selected on I-75 in the southbound lane approximately 40 miles south of Atlanta. The average daily traffic (ADT) along the test site was 15,000 to 17,000 vpd with about 19% heavy trucks.

The pavement along the test site is 9-in. thick plain jointed concrete constructed in 1967. Joints are spaced at 30 ft. The base course is a 3-in. bituminous stabilized soil aggregate on top of a 5-in. layer of granular subbase. The shoulder consists of a 6-in. thick cement stabilized graded aggregate with a 1-1/2 in. asphaltic concrete topping. In 1976 an extensive rehabilitation of the test site was conducted because of severe pumping and faulting. However, faulting and slab cracking continued at the site after the rehabilitation.

Test Sections

A total of thirty-seven test sections were established for the load transfer restoration study. Of these, nine sections were used as control sections. Test sections were designed to investigate variables such as type of load transfer device, patching (bonding) material, and the number of devices or dowel bars per joint. The load transfer devices used consisted of split pipe, Figure 8, FHWA V, Double V, and dowel bars. A total of 538 joints were incorporated in the test program. Of these, seventy-six joints were used as control joints. The experimental layout is detailed in Table 1. Twenty-four sections (sections 1 through 22) were constructed during 1981 and 13 sections (sections 23 to 35) were constructed during 1982. A detailed discussion of the test sections is given in Reference 1.

In this report, the discussion of the test sections is limited only to those sections incorporating dowel bars and the Double V devices.

Sections with Dowel Bars

Dowels used were 1-1/4 in. diameter and 18 in. long plastic-coated steel bars. Dowels were placed on chairs in slots cut into the pavement at specified locations. Slots were 5-1/2 in. deep and about 3-1/2 in. wide and were cut such that the bottom of the slots were 20 to 24 in. long. The slots were generally cut with a single saw blade. Four cuts were made per slot and the "fins" between the cuts were removed manually. Patching material used to fill the slots were high early-strength portland cement concrete, polymer concrete, and proprietary rapid setting materials such as Set-45, Roadpatch, and Horn 240. A total of 90 joints incorporated dowels. The number of dowels used per joint ranged from 3 to 8 as shown in Table 1.

Section with Double V Devices

The Double V device was developed at the University of Illinois at Urbana. An improved version of this device is currently being marketed under the trade name LTD Plus. The device used at the Georgia test site is illustrated in Fig. 1. The device was 7-1/2 in. deep and required a 6-in. diameter hole for placement. The device was epoxy-coated.

TABLE 1 - LOAD TRANSFER TEST SECTION VARIABLES

TYPE DEVICE	PATCHING MATERIAL	DEVICES PER JOINT	NUMBER OF JOINTS	TEST SECTION NUMBER	SPACING OF DEVICES
Split Pipe	Bonded with Epoxy	4	6	1	1' 3' 3' 3'
Figure Eight	Bonded with Epoxy	4	20	2 and 3	1' 3' 3' 3'
V	Polymer Concrete	4	10	4	1' 3' 3' 3'
Double V	Polymer Concrete	4	5	5	1' 3' 3' 3'
		4	35	5, 30, 31	1' 2' 4.5' 2'
		3	20	6	1' 2' 5'
		2	20	7	1' 2'
		4 every other joint	39	22	1' 2' 4.5' 2'
	Set-45, Roadpatch, Horn 240	4	30	17, 18, 19	1' 2' 4.5' 2'
	Portland Cement Concrete	4	98	20, 27, 29	1' 2' 4.5' 2'
		3	45	25	1' 3' 5'
		2	44	23	1' 2'
Dowel Bars	Set-45, Roadpatch, Horn 240	8	30	8, 9, 10	9" 15" 15" 15" 15" 15" 15" 15"
	Polymer Concrete	8	10	12	9" 15" 15" 15" 15" 15" 15" 15"
	Portland Cement Concrete	8	20	11, 14	9" 15" 15" 15" 15" 15" 15" 15"
		5	5	15	12" 18" 18" 18" 18"
		5	10	34	9" 15" 15" 5' 15"
		4	5	16	12" 18" 18" 18"
		3	10	33	9" 15" 15"

OUTSIDE PAVEMENT EDGE

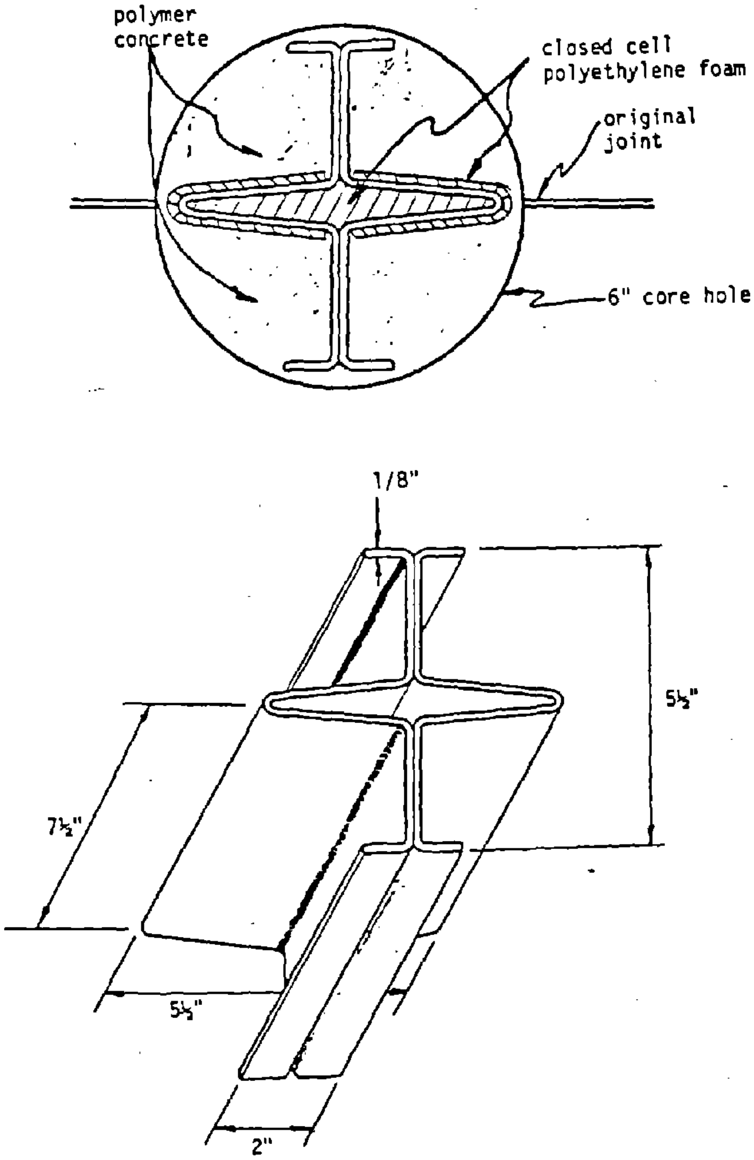

Fig. 1 Double V Device

A total of 336 joints incorporated the Double V devices. The number of devices used per joint ranged from 2 to 4 as shown in Table 1. Patching material used to bond the device to concrete were high early-strength portland cement concrete, polymer concrete, and proprietary rapid setting materials such as Set-45, Roadpatch, and Horn 240.

Performance of Test Sections

Performance of the test sections has been monitored by GDOT through deflection measurements and visual observations.[1] Deflection measurements were made using a loaded truck with a 20-kip load on a dual-tired rear single axle.

Deflections were measured at both slab corners at a joint along the shoulder side of the outside lane. Deflections were measured using dial gages mounted on a modified Benkelman beam. The loaded truck was positioned with the rear wheels within 3 in. of the transverse joint and close to the shoulder joint. The deflections of the loaded side of the joint and the unloaded side were then recorded. The truck then moved ahead slightly to position the rear wheels just past the joint and the deflections at both corners were once again recorded.

Visual examination was made during the time of deflection testing of each load transfer device installation. The condition of the concrete slabs along the entire test site was also noted.

Deflection measurements were made during January 1982, September 1982, March 1983, and April 1984. Three sets of tests were made each time. The first set of tests was made in the early morning generally starting at 7:00 a.m., the second set of tests was made at mid-morning at about 10:00 a.m., and the third set of tests was made in early afternoon at about 1:00 p.m. These three sets of tests were made to determine the effect of daily temperature variation on measured deflections.

Deflection data are classified into three categories as follows:

1. Average corner deflections
2. Average differential deflections at a joint
3. Average joint efficiency

Joint efficiency is defined as follows:

$$\text{Joint efficiency, JE (\%)} = \frac{Du}{Dl} \times 100$$

where: Du = deflection of unloaded slab
Dl = deflection of loaded slab

The deflection data were averaged over all joints in a given test section. Deflection data summaries are given in the following Tables:

Device	Deflection Data Category	Table No.
Dowel Bars	Average Deflections	2
	Average Differential Deflections	3
	Average Joint Efficiencies	4
Double V	Average Deflections	5
	Average Differential Deflections	6
	Average Joint Efficiencies	7
None (Control Sections)	Average Deflections	8
	Average Differential Deflections	9
	Average Joint Efficiencies	10

Data on the percent of joints in a test section with differential deflections of 0.010 in. or less for load on leave slabs is given in Table 11. The average test section deflections with load on leave slabs are shown in Fig. 2 for the September 1982 test period. Average differential deflections for each test section obtained during the March 1983 test period are shown in Fig. 3.

The following trends can be observed from the measured deflection data:

1. Higher deflections were measured during the early morning tests. Absolute deflections measured during the afternoon tests were considerably lower than those measured during the early morning tests.

TABLE 2 - DEFLECTION SUMMARY FOR SECTIONS WITH DOWEL BARS

Section No.	Number Devices	No. Joints	Patching Material	Time of Testing	Deflection (Mils)							
					Approach				Leave			
					Jan	Sept	Mar	Apr	Jan	Sept	Mar	Apr
8	8	10	Set-45	Dawn	11	23	17	14	10	25	20	22
				Morning	5	5	15	—	7	5	18	—
				Afternoon	1	1	7	--	1	2	10	--
9	8	10	Roadpatch	Dawn	9	41	18	18	8	50	22	17
				Morning	3	14	15	--	3	15	16	—
				Afternoon	2	3	7	—	2	1	10	--
10	8	10	A.C. Horn	Dawn	8	35	21	18	9	41	25	22
				Morning	3	13	13	—	4	15	19	—
				Afternoon	1	3	7	—	2	2	10	--
12	8	10	Polymer Concrete (Concresive)	Dawn	13	31	19	21	19	39	23	22
				Morning	9	9	15	--	12	11	20	—
				Afternoon	5	3	9	—	5	2	10	--
11	8	10	Portland Cement Concrete	Dawn	10	21	13	11	13	26	15	13
				Morning	10	5	6	—	11	6	15	—
				Afternoon	3	1	6	—	4	1	8	—
14	8	10	Portland Cement Concrete	Dawn	12	21	16	14	17	28	21	16
				Morning	10	8	11	--	12	12	15	—
				Afternoon	7	2	6	—	7	2	9	—
15	5	5	Portland Cement Concrete	Dawn	11	18	14	11	15	23	19	13
				Morning	7	7	9	--	9	8	14	—
				Afternoon	4	3	4	—	3	2	6	—
34	5	10	Portland Cement Concrete	Dawn	—	4	6	7	—	5	7	14
				Morning	--	1	3	—	—	3	3	--
				Afternoon	—	0	1	--	—	0	2	—
16	4	5	Portland Cement Concrete	Dawn	8	21	10	11	13	21	13	11
				Morning	6	6	5	—	8	7	9	—
				Afternoon	3	2	2	--	5	2	3	—
33	3	10	Portland Cement Concrete	Dawn	--	6	7	8	--	9	9	13
				Morning	—	2	2	--	--	3	3	—
				Afternoon	—	0	3	—	—	0	2	--

Notes:
(1) Data were obtained during January 1982, September 1982, March 1983, and April 1984.
(2) Data for January 1982, September 1982, and March 1983 were obtained from Reference 1.

TABLE 3 - SUMMARY OF DIFFERENTIAL DEFLECTIONS FOR SECTIONS WITH DOWEL BARS

Section No.	Number Devices	No. Joints	Patching Material	Time of Testing	$D_\ell - D_u$, Mils: Load on Approach				Load on Leave Slab			
					Jan	Sept	Mar	Apr	Jan	Sept	Mar	Apr
8	8	10	Set-45	Dawn	6	5	4	5	1	3	6	4
				Morning	3	3	3	—	2	3	5	—
				Afternoon	1	0	2	—	1	1	4	—
9	8	10	Roadpatch	Dawn	5	5	4	6	2	9	5	6
				Morning	2	4	6	—	1	3	3	—
				Afternoon	1	2	1	—	1	0	4	—
10	8	10	A.C. Horn	Dawn	4	5	4	5	3	8	7	8
				Morning	2	3	4	—	2	3	7	—
				Afternoon	0	2	1	—	1	1	1	—
12	8	10	Polymer Concrete (Concresive)	Dawn	2	8	5	8	8	9	6	8
				Morning	5	4	4	—	5	3	8	—
				Afternoon	3	3	3	—	2	0	4	—
11	8	10	Portland Cement Concrete	Dawn	2	2	3	3	4	4	4	3
				Morning	4	0	0	—	3	1	9	—
				Afternoon	1	1	1	—	2	0	3	—
14	8	10	Portland Cement Concrete	Dawn	3	3	2	2	5	4	5	3
				Morning	4	3	2	—	4	3	5	—
				Afternoon	4	1	0	—	2	1	3	—
15	5	5	Portland Cement Concrete	Dawn	4	2	2	2	6	3	6	5
				Morning	3	3	2	—	1	3	5	—
				Afternoon	3	1	0	—	1	1	2	—
34	5	10	Portland Cement Concrete	Dawn	—	1	2	5	0	1	2	9
				Morning	—	1	1	—	—	1	2	—
				Afternoon	—	0	0	—	—	0	1	—
16	4	5	Portland Cement Concrete	Dawn	2	4	3	2	6	1	4	3
				Morning	3	1	1	—	2	2	3	—
				Afternoon	2	0	0	—	1	1	1	—
33	3	10	Portland Cement Concrete	Dawn	—	2	2	4	—	2	3	5
				Morning	—	1	1	—	—	2	1	—
				Afternoon	—	0	1	—	—	0	0	—

Notes:
(1) Data were obtained during January 1982, September 1982, March 1983, and April 1984.
(2) Data for January 1982, September 1982, and March 1983 were obtained from Reference 1.

TABLE 4 - SUMMARY OF AVERAGE JOINT EFFICIENCY FOR SECTIONS WITH DOWELS
(EARLY MORNING READINGS DURING SEPTEMBER 1982)

Section Number	No. of Devices	No. of Joints	Patching Material	Joint Efficiency, % Load on Approach Slab	Load on Leave Slab
8	8	10	Set-45	78	88
9	8	10	Roadpatch	88	82
10	8	10	AC Horn	86	80
12	8	10	Polymer	74	77
11	8	10	PCC	90	85
14	8	10	PCC	86	86
15	5	5	PCC	89	87
34	5	10	PCC	75	80
16	4	5	PCC	81	95
33	3	10	PCC	67	56

(1) Joint Efficiency, % $= \frac{\text{Deflection of unloaded slab}}{\text{Deflection of loaded slab}} \times 100$

(2) Sections 34 and 33 had absolute deflections of 10 mils or less.

(3) Polymer refers to polymer concrete; PCC refers to portland cement concrete.

TABLE 5 - DEFLECTION SUMMARY FOR SECTIONS WITH DOUBLE V DEVICES

Section No.	Number Devices	No. Joints	Patching Material	Time of Testing	Deflection (Mils) Approach Jan	Approach Sept	Approach Mar	Approach Apr	Leave Jan	Leave Sept	Leave Mar	Leave Apr
5	4	20	Polymer	Dawn	12	32	12	14	19	40	13	15
			Concrete	Morning	8	9	4	—	13	13	6	—
			(Concresive)	Afternoon	6	1	4	—	3	3	6	—
30	4	10	Polymer	Dawn	—	5	7	20	—	9	12	26
			Concrete	Morning	—	2	4	—	—	2	5	—
			(Crylcon)	Afternoon	—	0	3	—	—	0	3	—
31	4	10	Polymer	Dawn	—	15	8	33	—	15	12	45
			Concrete	Morning	—	3	4	—	—	4	6	—
			(Silikal)	Afternoon	—	0	2	—	—	0	3	—
17	4	10	Set-45	Dawn	9	18	16	11	13	24	22	16
				Morning	6	6	7	—	7	8	12	—
				Afternoon	3	1	2	—	4	1	5	—
18	4	10	Roadpatch	Dawn	7	18	14	12	19	27	35	23
				Morning	5	4	8	—	8	5	14	—
				Afternoon	4	1	4	—	4	0	4	—
19	4	10	A.C. Horn	Dawn	10	30	13	7	14	37	16	8
				Morning	5	9	4	—	5	10	5	—
				Afternoon	3	1	2	—	2	1	3	—
20	4	10	Portland	Dawn	15	30	11	6	19	38	14	7
			Cement	Morning	7	6	6	—	8	8	6	—
			Concrete	Afternoon	2	1	1	—	3	0	2	—
27	4	55	Portland	Dawn	—	10	8	10	—	13	11	12
			Cement	Morning	—	3	4	—	—	4	5	—
			Concrete	Afternoon	—	1	2	—	—	1	3	—
29	4	34	Portland	Dawn	—	12	12	11	—	16	15	15
			Cement	Morning	—	2	4	—	—	2	7	—
			Concrete	Afternoon	—	1	2	—	—	1	3	—
22	4	39	Polymer	Dawn	7	21	8	11	13	32	15	34
			Concrete	Morning	5	5	3	—	7	7	8	—
			(Concresive)	Afternoon	1	1	2	—	2	1	4	—
6	3	20	Polymer	Dawn	16	30	17	16	22	38	21	22
			Concrete	Morning	9	12	12	—	10	14	15	—
			(Concresive)	Afternoon	5	2	8	—	4	3	12	—
25	3	45	Portland	Dawn	—	12	5	5	—	15	7	5
			Cement	Morning	—	4	3	—	—	5	5	—
			Concrete	Afternoon	—	0	1	—	—	0	2	—
7	2	20	Polymer	Dawn	16	30	17	13	25	59	30	18
			Concrete	Morning	10	10	13	—	15	16	25	—
			(Concresive)	Afternoon	4	2	8	—	5	2	13	—
23	2	44	Portland	Dawn	—	8	6	7	—	13	13	12
			Cement	Morning	—	1	3	—	—	2	5	—
			Concrete	Afternoon	—	0	1	—	—	0	2	—

Notes:
(1) Data were obtained during January 1982, September 1982, March 1983, and April 1984.
(2) Data for January 1982, September 1982, and March 1983 were obtained from Reference 1.

TABLE 6 - SUMMARY OF DIFFERENTIAL DEFLECTIONS FOR SECTIONS WITH DOUBLE V DEVICES

Section No.	Number Devices	No. Joints	Patching Material	Time of Testing	$D_\ell - D_u$, Mils: Load on Approach: Jan	Sept	Mar	Apr	Load on Leave Slab: Jan	Sept	Mar	Apr
5	4	20	Polymer	Dawn	4	6	5	8	8	12	3	5
			Concrete	Morning	4	3	2	—	6	5	2	—
			(Concresive)	Afternoon	4	1	2	—	4	2	3	—
30	4	10	Polymer	Dawn	—	1	1	3	—	4	5	6
			Concrete	Morning	—	1	2	—	—	0	1	—
			(Crylcon)	Afternoon	—	0	2	—	—	0	1	—
31	4	10	Polymer	Dawn	—	3	3	10	—	3	5	19
			Concrete	Morning	—	1	1	—	—	2	2	—
			(Silikal)	Afternoon	—	0	1	—	—	0	2	—
17	4	10	Set-45	Dawn	2	3	2	4	5	6	8	8
				Morning	2	2	1	—	4	3	6	—
				Afternoon	2	0	0	—	2	0	3	—
18	4	10	Roadpatch	Dawn	2	8	5	8	11	12	26	17
				Morning	3	2	5	—	5	1	8	—
				Afternoon	3	0	1	—	1	0	1	—
19	4	10	A.C. Horn	Dawn	1	1	1	1	3	4	4	2
				Morning	3	3	1	—	1	3	3	—
				Afternoon	2	1	0	—	0	0	2	—
20	4	10	Portland	Dawn	2	2	2	3	4	6	5	3
			Cement	Morning	3	1	1	—	1	3	1	—
			Concrete	Afternoon	2	0	0	—	1	0	1	—
27	4	55	Portland	Dawn	—	2	2	3	—	3	5	5
			Cement	Morning	—	1	2	—	—	1	2	—
			Concrete	Afternoon	—	0	1	—	—	0	1	—
29	4	34	Portland	Dawn	—	2	2	3	—	3	5	5
			Cement	Morning	—	1	2	—	—	1	3	—
			Concrete	Afternoon	—	0	1	—	—	0	1	—
22	4	39	Polymer	Dawn	2	3	1	9	5	11	11	27
			Concrete	Morning	2	3	1	—	4	3	3	—
			(Concresive)	Afternoon	1	0	1	—	1	0	2	—
6	3	20	Polymer	Dawn	9	13	9	11	12	15	11	10
			Concrete	Morning	8	9	5	—	5	5	6	—
			(Concresive)	Afternoon	4	1	4	—	2	1	7	—
25	3	45	Portland	Dawn	—	1	1	2	—	3	3	1
			Cement	Morning	—	1	1	—	—	1	2	—
			Concrete	Afternoon	—	0	0	—	—	0	1	—
7	2	20	Polymer	Dawn	13	24	11	13	21	45	22	10
			Concrete	Morning	8	9	6	—	12	11	17	—
			(Concresive)	Afternoon	4	1	4	—	3	1	8	—
23	2	44	Portland	Dawn	—	1	1	4	—	4	7	7
			Cement	Morning	—	0	1	—	—	0	2	—
			Concrete	Afternoon	—	0	0	—	—	0	1	—

Notes:

(1) Data were obtained during January 1982, September 1982, March 1983, and April 1984.

(2) Data for January 1982, September 1982, and March 1983 were obtained from Reference 1.

TABLE 7 - SUMMARY OF AVERAGE JOINT EFFICIENCY FOR SECTIONS WITH DOUBLE V DEVICES (EARLY MORNING READINGS DURING SEPTEMBER 1982)

Section Number	No. of Devices	No. of Joints	Patching Material	Joint Efficiency, %	
				Load on Approach Slab	Load on Leave Slab
5	4	20	Polymer	81	70
30	4	10	Polymer	80	56
31	4	10	Polymer	80	80
17	4	10	Set-45	83	75
18	4	10	Roadpatch	56	56
19	4	10	A.C. Horn	97	89
20	4	10	PCC	93	84
27	4	55	PCC	80	77
29	4	34	PCC	83	81
22	4	39	Polymer	86	66
6	3	20	Polymer	57	66
25	3	45	PCC	92	80
7	2	20	Polymer	20	25
23	2	44	PCC	88	69

(1) Joint Efficiency, % $= \frac{\text{Deflection of unloaded slab}}{\text{Deflection of loaded slab}} \times 100$

(2) Polymer refers to polymer concrete; PCC refers to portland cement concrete

(3) Test Sections No. 5, 31, 27, 29, 25, and 23 had absolute deflections of 15 mils or less

TABLE 8 - DEFLECTION SUMMARY FOR CONTROL SECTIONS

Section No.	No. Joints	Time of Testing	Deflection (Mils)							
			Approach				Leave			
			Jan	Sept	Mar	Apr	Jan	Sept	Mar	Apr
10A	3	Dawn	--	31	16	18	--	68	32	42
		Morning	--	12	17	--	--	23	25	--
		Afternoon	--	3	6	--	--	3	11	--
13	10	Dawn	13	23	15	15	42	45	27	30
		Morning	10	7	11	--	23	7	17	--
		Afternoon	8	2	5	--	8	1	8	--
18A	6	Dawn	8	12	13	11	24	29	38	25
		Morning	6	5	7	--	9	4	10	--
		Afternoon	4	0	2	--	4	0	2	--
21	9	Dawn	9	25	10	7	40	51	27	14
		Morning	8	7	5	--	19	10	7	--
		Afternoon	2	0	3	--	2	1	3	--
24	10	Dawn	--	27	12	8	--	47	37	20
		Morning	--	8	8	--	--	18	12	--
		Afternoon	--	0	2	--	--	0	3	--
26	10	Dawn	--	7	7	5	--	13	9	11
		Morning	--	4	2	--	--	3	4	--
		Afternoon	--	0	1	--	--	0	1	--
28	10	Dawn	--	11	10	11	--	37	42	34
		Morning	--	4	6	--	--	4	8	--
		Afternoon	--	0	2	--	--	1	3	--
32	8	Dawn	--	12	14	22	--	26	22	38
		Morning	--	6	7	--	--	8	6	--
		Afternoon	--	1	4	--	--	2	3	--
35	10	Dawn	--	5	5	9	--	12	11	26
		Morning	--	1	2	--	--	2	4	--
		Afternoon	--	0	2	--	--	0	2	--

Notes:

(1) Data were obtained during January 1982, September 1982, March 1983, and April 1984.

(2) Data for January 1982, September 1982, and March 1983 were obtained from Reference 1.

TABLE 9 - SUMMARY OF DIFFERENTIAL DEFLECTIONS FOR CONTROL SECTIONS

Section No.	No. Joints	Time of Testing	$D_\ell - D_u$, Mils							
			Load on Approach				Load on Leave Slab			
			Jan	Sept	Mar	Apr	Jan	Sept	Mar	Apr
10A	3	Dawn	--	28	14	18	--	51	29	39
		Morning	--	12	11	--	--	21	20	--
		Afternoon	--	1	2	--	--	1	5	--
13	10	Dawn	10	19	12	14	38	37	20	26
		Morning	9	7	8	--	20	5	12	--
		Afternoon	7	1	2	--	4	0	5	--
18A	6	Dawn	7	12	11	8	22	25	32	22
		Morning	5	3	6	--	6	1	5	--
		Afternoon	2	0	1	--	1	0	1	--
21	9	Dawn	7	18	8	7	37	42	21	11
		Morning	6	6	3	--	15	7	3	--
		Afternoon	2	0	2	--	1	1	1	--
24	10	Dawn	--	26	9	8	--	42	32	16
		Morning	--	7	5	--	--	16	7	--
		Afternoon	--	0	1	--	--	0	1	--
26	10	Dawn	--	2	5	3	--	9	5	8
		Morning	--	3	1	--	--	2	3	--
		Afternoon	--	0	0	--	--	0	1	--
28	10	Dawn	--	11	7	10	--	34	36	29
		Morning	--	4	4	--	--	2	3	--
		Afternoon	--	0	1	--	--	0	0	--
32	8	Dawn	--	12	11	22	--	23	22	27
		Morning	--	5	8	--	--	5	4	--
		Afternoon	--	0	4	--	--	1	1	--
35	10	Dawn	--	5	3	9	--	11	8	23
		Morning	--	1	1	--	--	1	2	--
		Afternoon	--	0	1	--	--	0	1	--

Notes:

(1) Data were obtained during January 1982, September 1982, March 1983, and April 1984.

(2) Data for January 1982, September 1982, and March 1983 were obtained from Reference 1.

TABLE 10 - SUMMARY OF AVERAGE JOINT EFFICIENCY FOR CONTROL SECTIONS (EARLY MORNING READINGS DURING SEPTEMBER 1982)

Section Number	No. of Joints	Joint Efficiency, %	
		Load on Approach Slab	Load on Leave Slab
10A	3	10	25
13	10	17	18
18A	6	0	14
21	9	28	18
24	10	4	11
26	10	71	31
28	10	0	8
32	8	0	12
35	10	0	8

(1) No load transfer devices were used along control sections.

(2) Joint Efficiency, % $= \frac{\text{Deflection of unloaded slab}}{\text{Deflection of loaded slab}} \times 100$

(3) Test Sections No. 18A, 26, 28, 32, and 35 had absolute deflections of 15 mils or less.

TABLE 11 - PERCENT OF JOINTS WITH DIFFERENTIAL DEFLECTIONS OF 10 MILS OR LESS (REF. 1) (LOAD ON LEAVE SLAB)

DOUBLE V			DOWEL BARS			CONTROL		
Test Section	Sept 82	Mar 83	Test Section	Sept 82	Mar 83	Test Section	Sept 28	Mar 83
5	85	95	8	90	100	10A	33	33
6	70	65	9	60	90	13	0	20
7	20	30	10	80	90	18A	17	17
17	70	70	11	100	90	21	0	33
18	50	40	12	80	100	24	0	10
19	90	100	14	100	100	26	90	80
20	90	90	15	100	100	28	0	10
22	71	76	16	80	100	32	0	38
23	95	75	33	90	100	35	50	80
25	98	98	34	100	90			
27	95	93						
29	100	91						
30	90	90						
31	90	90						

<u>Note</u>: Differential Deflection = Deflection of Loaded Slab - Deflection of Unloaded Slab

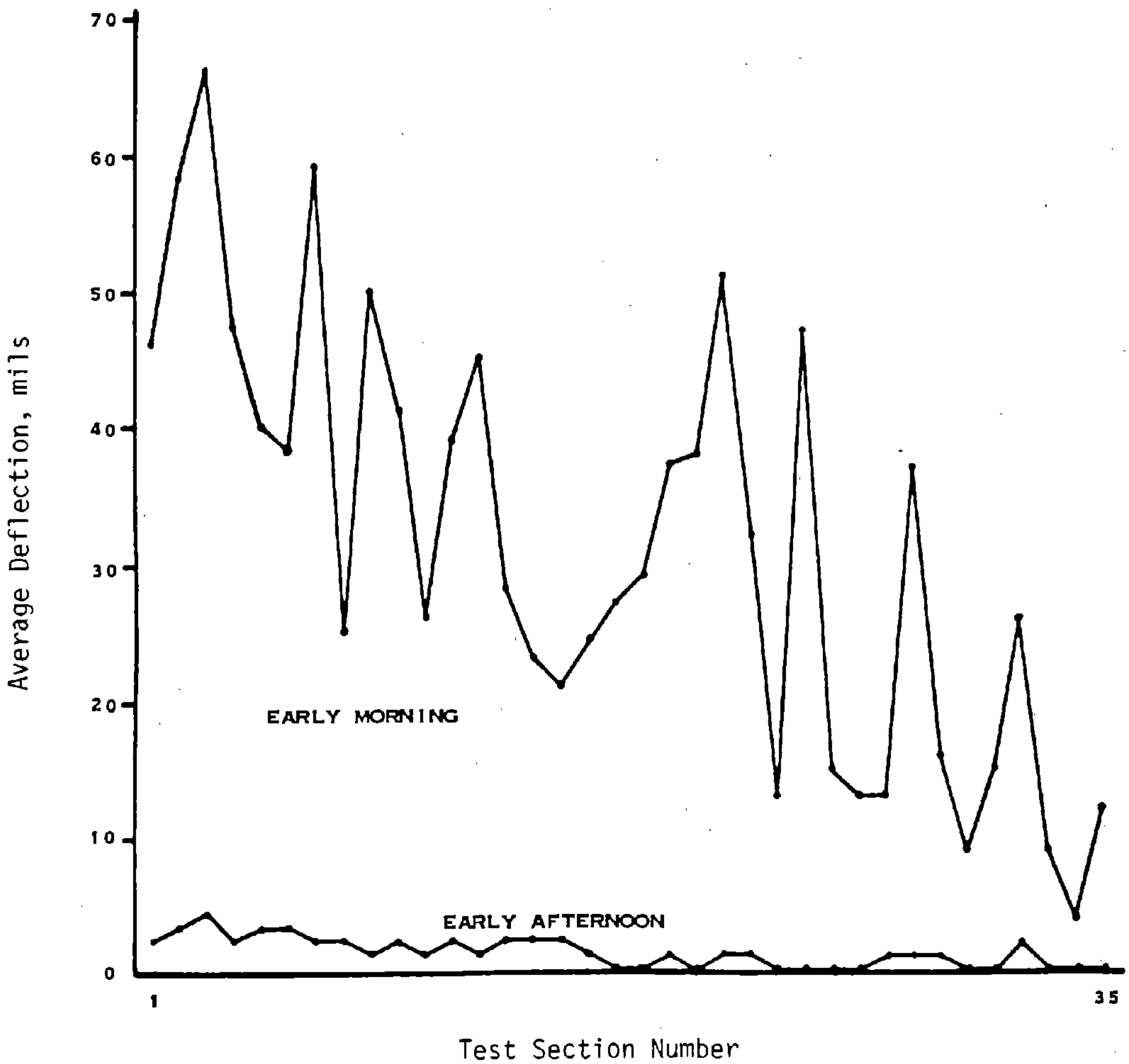

Fig. 2 Deflection Levels of Leave Slab Corners
September 1982

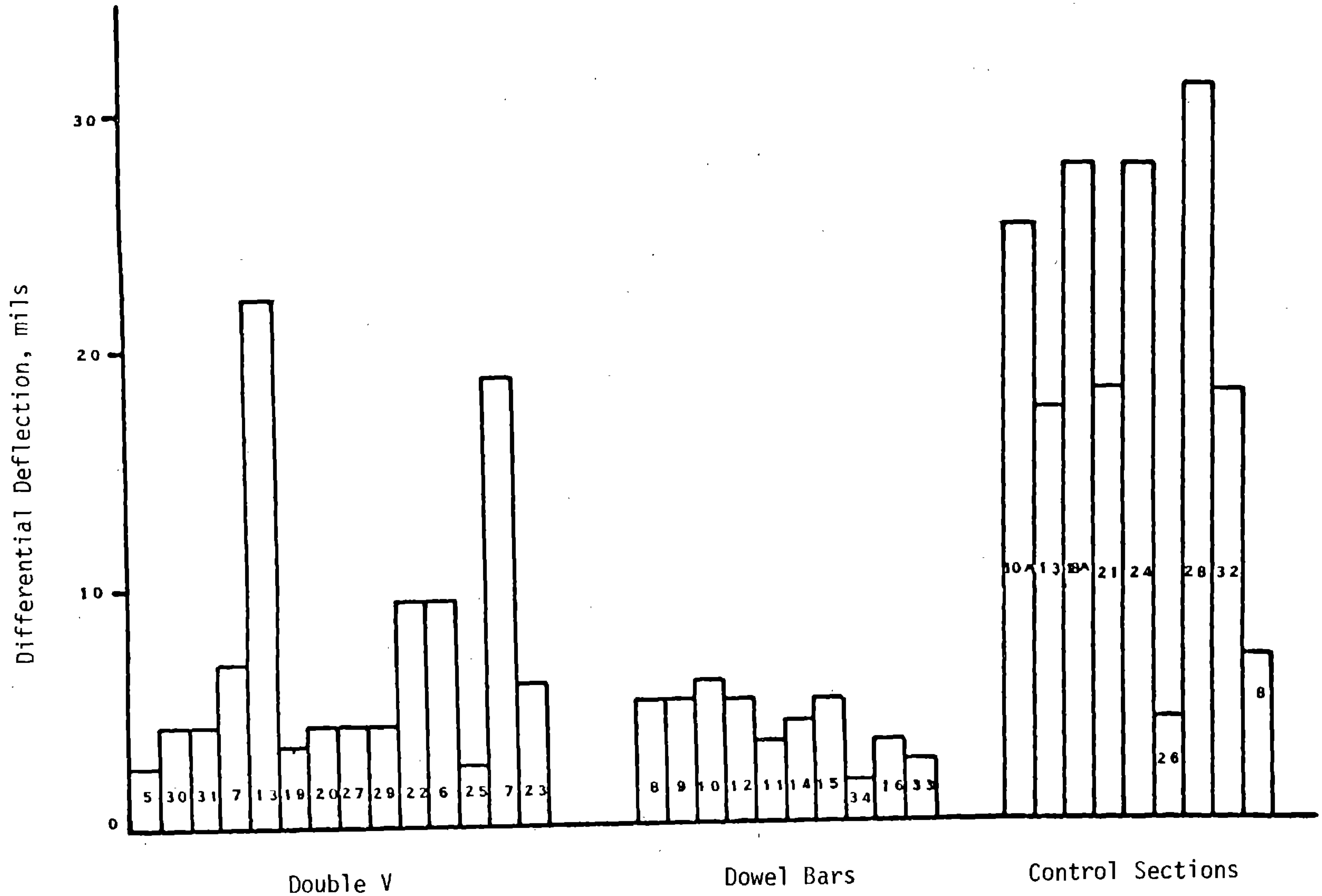

Fig. 3 Differential Deflection Values - March 1983
Early Morning Load on Leave Slab

2. Deflections obtained with the load on the leave side were generally higher than those obtained with the load on the approach side of the joints.
3. Because of seasonal effects, no clear trends can be observed in the deflections measured at the four different time periods between January 1982 and April 1984.

The effectiveness of the load restoration technique can be estimated by comparing the average deflections in a test section with the average deflections in an adjacent control section. A reduction in deflections of about 50 to 75% was obtained for test sections with dowels and for test sections with Double V devices which were still performing well.

Performance ratings of the test sections developed by Georgia DOT are given in Table 12. These data indicate that sections retrofitted with dowel bars are generally performing better than sections retrofitted with Double V devices.

It should be noted that within any given test section, there was a large variation in the measured deflections. For many sections, the coefficient of variation of the measured deflections exceeded 40%. The extent of variation is shown in Table 13 for a selected number of test sections. This large variation in data and the low absolute deflections at many joints may be due to very variable support condition and due to inclusion of data from sections that had apparently failed. Some of the variation in the test data may also be due to the failure of the grouting/bonding materials at some joints within a test section.

Effect of Cyclic Loading for the Double V Devices

Two types of cyclic loading are considered. These are "vertical deflections" due to traffic loading and the joint opening and closing due to daily and seasonal temperature changes.

Traffic Load Effects

The load transfered by the outermost device due to a 20-kip single-axle load has a magnitude of about 3,000 to 4,000 lb depending on the spacing of the devices. For design, it can be conservatively assumed that the maximum load transferred under repeated truck loading would be about 6,000 lb. Thus, assuming a factor of safety of 2.0, the device should be able to transfer about 12,000 lb load under static loading.

TABLE 12 - PERFORMANCE RATINGS OF TEST SECTIONS (REF. 3)

Patching Material	Type Load Transfer	Test Section No.	Number Joints	Devices Per Joint	March 83 Performance Rating	June 84 Visual Rating
Set 45	Double V	17	10	4	Marginal	Marginal
	Dowels	8	10	8	Good	Good
Road Patch	Double V	18	10	4	Poor	Poor
	Dowels	9	10	8	Good	Good
Horn 240	Double V	19	10	4	Good	Poor
	Dowels	10	10	8	Good	Marginal
Concresive	Double V	5	20	4	Good	Poor
		6	20	3	Marginal	Poor
		7	20	2	Poor	Poor
		22	39	4	Marginal	Poor
	Dowels	12	10	8	Good	Good
Crylcon	Double V	30	10	4	Good	Good
Silikal	Double V	31	10	4	Good	Marginal
Portland Cement Concrete	Double V	20	10	4	Good	Good
		23	44	2	Marginal	Marginal
		25	45	3	Good	Marginal
		27	55	4	Good	Marginal
		29	34	4	Good	Marginal
	Dowels	11	10	8	Good	Marginal
		14	10	8	Good	Good
		15	5	5	Good	Good
		16	5	4	Good	Good
		33	10	3	Good	Marginal
		34	10	5	Good	Good

TABLE 13 - VARIATIONS IN MEASURED DEFLECTION DATA
WITH LOAD ON APPROACH SLAB
(EARLY MORNING READINGS DURING SEPTEMBER 1982)

Load Transfer Device	Section Number	Patching Material	No. of Joints	Loaded Slab Deflection		
				Range, mils	Average, mils	CV, %
Dowels	9	Roadpatch	10	27 to 55	41	20
	12	Polymer	10	20 to 48	31	29
	14	PCC	10	14 to 25	21	20
	33	PCC	10	2 to 12	7	48
Double V	5	Polymer	20	20 to 50	34	20
	17	Set-45	10	10 to 25	18	23
	20	PCC	10	19 to 41	30	22
	25	PCC	45	2 to 27	12	48
	31	Polymer	10	6 to 35	15	64

Notes:
(1) Load on approach slab
(2) CV = coefficient of variation
(3) Polymer refers to polymer concrete; PCC refers to portland cement concrete

The bonding area between the concrete and the patch material on each side of the joint equals about 70 $in.^2$ Thus, the shear strength of the interface between the concrete and the patching material should be at least 170 psi. The bonding area between the device and the patching material on each side of the joint equals about 90 $in.^2$ Thus, the shear strength of the interface between the device and the patching material should be at least 130 psi.

Polymer concrete patching materials, properly mixed, handled, and placed, are capable of providing shear strengths in excess of 170 psi. However, polymer concrete requires great care when used and has a short pot life. Further it is required that the surfaces on which the patching material is to be applied are clean and dry. Thus, the patching material failure observed at the test site may possibly be due to inadequate bond between the patching material and concrete.

Cyclic Joint Opening and Closing

For a joint spacing of 30 ft and a daily temperature drop of about 20°F in the concrete pavement, the maximum calculated joint opening is about 0.04 in. If this joint opening is not achieved due to full restraint resulting from the high stiffness of the load transfer device, then the tensile stress developed in the concrete pavement would be about 440 psi, assuming very little subbase frictional restraint. Assuming that the load transfer devices are spaced transversely at 18 in., the tensile force developed per device would equal about 60,000 lb and the tensile stress developed at the interface between the patching material and the concrete would be about 850 psi (for a bonding area of 70 $in.^2$). The tensile stress developed would be less for partial restraint. However, results of tests conducted at the University of Illinois indicate that a tensile force of only about 2,000 lb per device is required to develop a joint opening of about 0.20 in.(6) Thus, the stiffness of the device by itself is not considered as a primary cause in the failure of the patching material for some of the devices. As stated previously, the patching material failure observed at the test site may possibly be due to inadequate bond between the patching material and concrete.

Analytical Modeling

Recent efforts to understand the behavior of jointed concrete pavements has involved the use of finite element methods for structural analysis. As part of the present contract with FHWA, a finite element computer program, Program JSLAB, was developed to analyze jointed concrete pavements.

Program JSLAB can analyze concrete pavement sections consisting of a large number of jointed slabs.[2] In addition, a two or three-layer pavement system can be considered. Layers may be bonded or unbonded. Slab sectors are represented by rectangular plate elements. Joints are modeled as doweled, aggregate interlock, or keyed. Dowels are represented as thick elements and can have different cross-sections. Aggregate interlock and keyways are represented by springs. Load input is in terms of wheel loads placed at any location on the slab. A rectangular tire footprint is used.

The subgrade is modeled as a Winkler (spring) foundation. Loss of support, variable support conditions, as well as variable material properties can be considered. Also, curling due to linear temperature gradient through the slab thickness can be analyzed.

For doweled joints, dowel properties such as diameter, modulus of elasticity, and modulus of dowel/concrete reaction are inputs. For aggregate interlock and keyway joints, a spring stiffness value is required. This value represents the load deflection characteristics of the joint. The computer program considers allocation of stiffness parameters of the LTD at actual locations. This feature is very useful for analysis of jointed slabs incorporating nonuniformly spaced LTDs at joints.

Modification of Program JSLAB

Program JSLAB was modified to allow analysis of joints at the Georgia test site. Deflection tests were conducted at different times of the day to consider the effect of slab curling. However, Georgia used results of early morning deflection tests to determine if a joint was performing adequately.

During early morning, slabs are generally curled upward due to a differential in temperature at the slab top and slab bottom. In the early morning hours, the slab top is generally cooler than the slab bottom and the average maximum temperature gradient within the slab may be about 1°F/in. of depth. The temperature distribution within the slab is not linear but is of a nonlinear form as shown in Fig. 4.

Calculated upward curling for a 9-in. thick slab is shown in Fig. 5. As shown in Fig. 5 there is a loss of support along the edges of the slab extending about 2 to 3 ft inward from the edge. As a load approaches a slab edge or a corner, it deflects the slab edge downward and depending on the

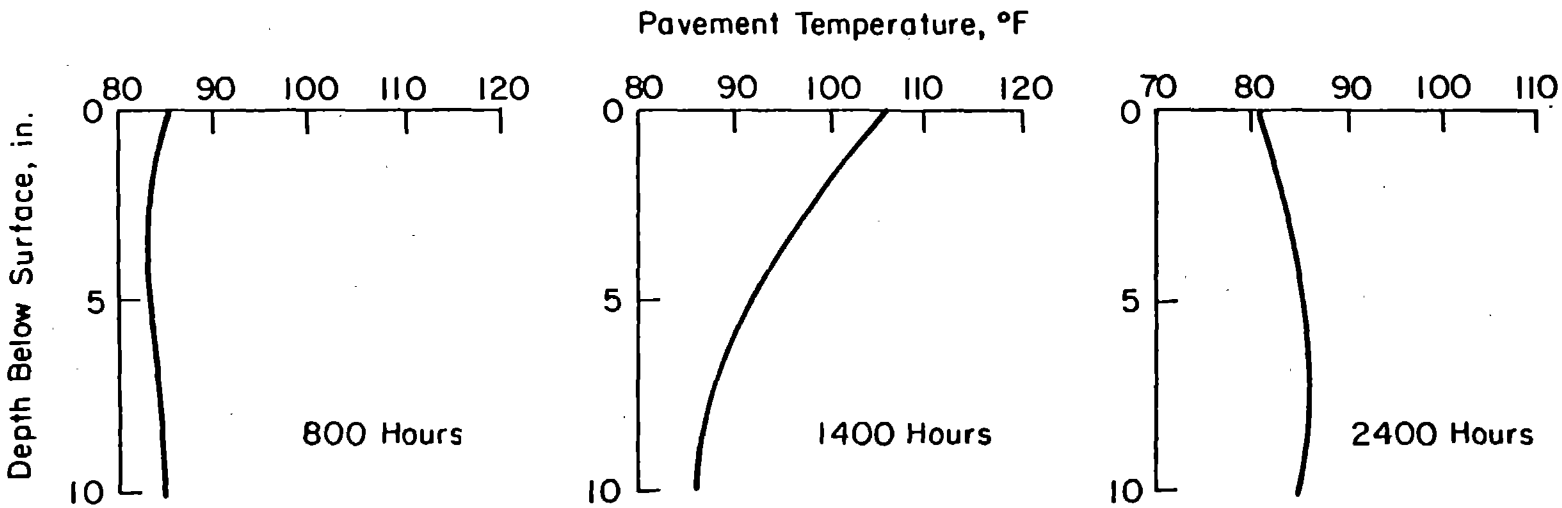

Fig. 4 Nonlinear Temperature Distribution Within a Slab Measured at the AASHO Road Test (Ref. 4)

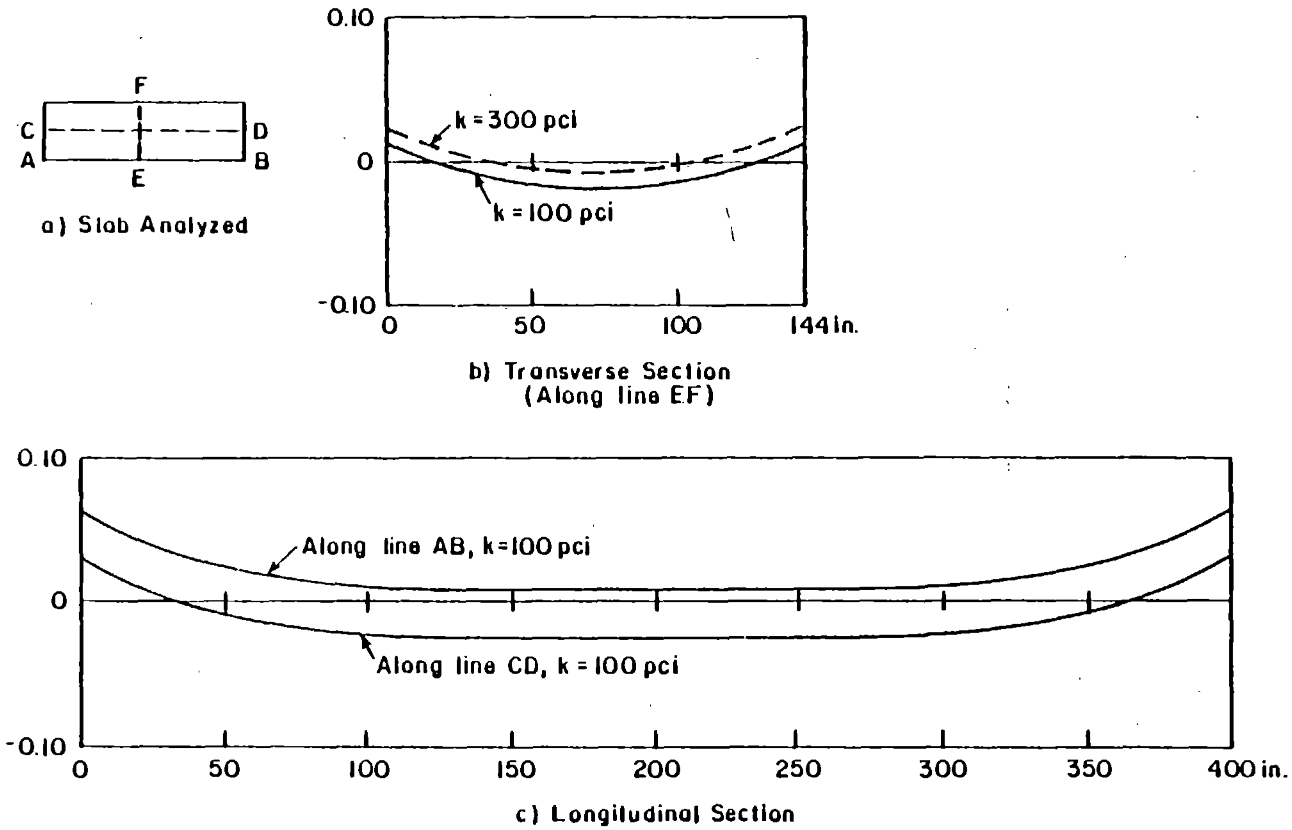

Fig. 5 Calculated Curling Upward of a Slab

magnitude of the load may cause the slab to contact the subbase. On the other hand, when a load crosses a joint with poor load transfer, the leave slab edge is instantaneously deflected. Thus, as a load crosses a point along the edge, the slab deflection consists of the portion that deflects the curled-up slab and the portion that deflects the subbase.

Program JSLAB was modified to allow the loading of a slab exhibiting upward curling due to a temperature differential between the slab top and the slab bottom. Upward curling of the slab is first determined for a known temperature differential between the slab top and the slab bottom assuming a linear temperature distribution. The curled profile is then used as a reference profile. Also, the support condition is defined based on the curled profile. At locations of uplift the slab is not supported on the subbase and the modulus of subgrade reaction at these areas is made equal to zero. Load is then applied in increments and the slab deflection profile is calculated after each load increment. The subbase support condition is adjusted after each load increment as more areas of the slab begin to bear on the subbase in the vicinity of the load location. The slab deflections due to each load increment are accumulated. The scheme of the analysis is illustrated in Fig. 6.

Analysis Results

Analysis was conducted for the pavement test sections incorporating dowel bars and Double V devices. The following parameters were considered in the analysis:

Pavement Details:

- Thickness = 9 in.
- Modulus of elasticity of concrete = 4,000,000
- Modulus of subgrade reaction
  over the subbase = 100, 200, 300, 400 pci
- Joint opening = 0.10 in.

Loading Details:

- Single-axle load = 20 kip
- Dual wheels
- Placement at jointed corner

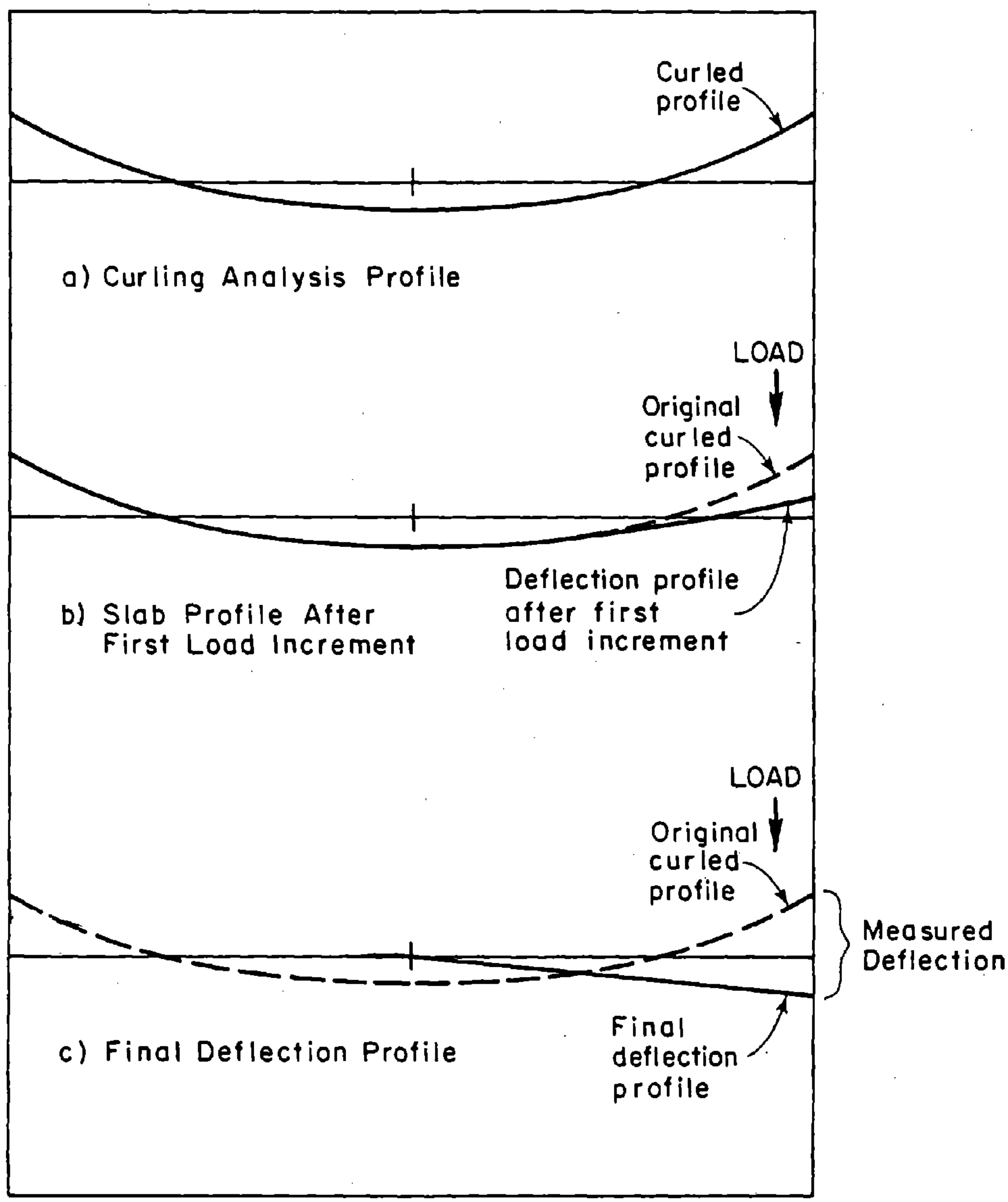

Fig. 6 Scheme for Analysis of Loading of a Curled Slab

Doweled Joint Details:

Dowel diameter = 1-1/4 in.

Modulus of dowel/concrete reaction = 2,000,000 psi

No. of dowels per joint = 3, 4, 5, 8

Variable dowel spacing

Double V Joint Details:

Cross-sectional area = 2 $in.^2$ per device

Cross-sectional moment of inertia = 10.7 $in.^4$ per device

Effective length across joint = 5.5 in.

No. of devices per joint = 2, 3, 4

Analyses were conducted for a range of modulus of subgrade reaction values. This was done because data on the variation of modulus values along the test site were not available. The effective length of the Double V device is the perimeter length of the device across the joint. The devices were assumed to be firmly bonded to the concrete faces.

Analyses were conducted for the case of full support condition and for the case of a curled slab.

Doweled Test Sections

Dowel spacings used for the analysis are shown in Fig. 7. Results of the analysis of doweled test sections are given in Table 14 for the case of full support condition. Analysis results indicate that when load transfer across the joint is very effective, the loaded slab deflection is reduced from 0.071 in. to about 0.040 in. for a modulus of subgrade reaction of 100 pci and is reduced from 0.029 in. to about 0.017 in. for a modulus of subgrade reaction of 400 pci.

Analysis of a slab that is curled upward due to a temperature gradient of 1F/in. indicate that the upward corner curl magnitude is about 0.008 in. for a 9-in. thick slab resting on a support with a modulus of subgrade reaction of 400 pci and that the amount of corner curl is directly additive to the corner deflection calculated for the case of a fully supported slab. Corner curl was also computed for other modulus of subgrade reaction values and was computed to be 0.006, 0.008, and 0.008 in. for modulus of subgrade reaction

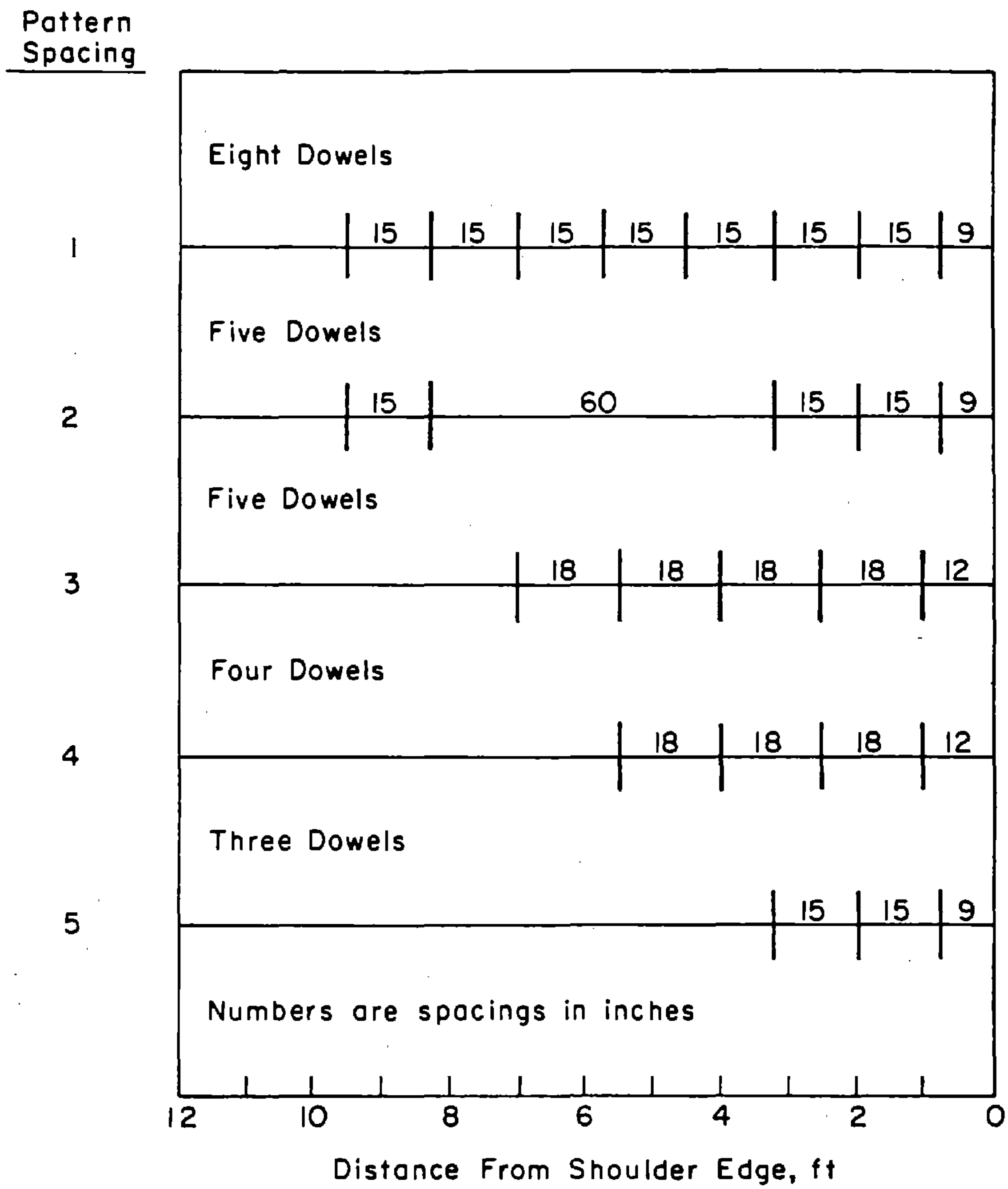

Fig. 7 Dowel Spacings Used for Analysis

TABLE 14 - RESULTS OF ANALYSIS OF DOWELED TEST SECTIONS (SLABS FULLY SUPPORTED)

Dowel Spacing Pattern (Fig. 7)	No. of Dowels	Modulus of Subgrade Reaction, pci	Maximum Dowel Shear Load, lb	Corner Deflections, in.		Joint Efficiency, %
				Loaded Slab	Unloaded Slab	
NA	0	100	--	0.071	--	--
		200	--	0.044	--	--
		300	--	0.034	--	--
		400	--	0.028	--	--
1	8	100	3100	0.039	0.035	90
		200	3000	0.025	0.021	94
		300	2900	0.020	0.016	80
		400	2900	0.016	0.013	81
2	5	100	2900	0.039	0.035	90
		200	2800	0.025	0.021	84
		300	2700	0.019	0.016	80
		400	2700	0.016	0.013	81
3	5	100	3600	0.040	0.034	85
		200	3400	0.026	0.021	81
		300	3300	0.020	0.015	75
		400	3200	0.017	0.012	71
4	4	100	3500	0.040	0.034	85
		200	3400	0.026	0.021	81
		300	3300	0.020	0.015	75
		400	3200	0.017	0.012	71
5	3	100	3000	0.039	0.035	90
		200	2500	0.025	0.022	88
		300	2500	0.019	0.016	84
		400	2500	0.016	0.013	81

values of 100, 200, and 300 pci, respectively. The calculated deflections of loaded slab sections that were initially curled upward are given in Table 15. Calculated deflections for loaded slabs that were initially curled upward range from about 0.046 in. to about 0.025 in. for modulus of subgrade reaction values ranging from 100 to 400 pci, respectively.

Deflections measured during September 1982 for the doweled test sections range from 0.004 in. average for Test Section No. 34 to 0.041 in. average for Test Section No. 9 for the case of load on approach slabs. For the case of load on leave slabs, deflections ranged from 0.005 in. average for Test Section No. 34 to 0.050 in. for Test Section No. 9. Thus, it is seen that for many test sections, the calculated deflection values encompass the measured deflection values.

Calculated dowel shear loads for each dowel along a joint are compared in Fig. 8 for the five dowel patterns used for the case of slabs fully supported. It is seen that the shear load transferred across a joint is influenced by dowel spacing and not necessarily by the number of dowels used per joint. Maximum shear load for joints of Pattern Nos. 1, 2, and 5 with the first two dowels spaced at 15 in. is about 20% lower than that for joints of Pattern Nos. 3 and 4 with the first two dowels spaced at 18 in. Calculated maximum dowel shear load is further decreased when the spacing between the first two dowels is further reduced to 12 in. Reduction in maximum dowel shear load is important for long-term effectiveness of doweled joints.

Double V Test Sections

Spacings used for the analysis are shown in Fig. 9. Results of analysis of test sections incorporating the Double V devices are given in Table 16 for the case of full support condition. As in the case of doweled joints, analysis results indicate that when load transfer across the joint is very effective, the loaded slab deflection is reduced from 0.071 in. to about 0.035 in. for a modulus of subgrade reaction of 100 pci and is reduced from 0.029 to about 0.015 for modulus of subgrade reaction of 400 pci. Once again, as in the case of doweled joints, the number of devices used and spacing of devices do not seem to affect the calculated results as long as two devices are located at the outside wheel path area. However, it should be noted that the maximum shear load transferred by a device for the case of joints with fewer devices does show a slight increase. This increase in

TABLE 15 - CALCULATED DEFLECTIONS OF SECTIONS WITH DOWELED JOINTS (SLABS INITIALLY CURLED UPWARD)

Dowel Spacing Pattern (Fig. 7)	No. of Dowels	Modulus of Subgrade Reaction, pci	Corner Deflections, in.	
			Loaded Slab	Unloaded Slab
NA	0	100	0.078	--
		200	0.053	--
		300	0.043	--
		400	0.039	--
1	8	100	0.045	0.041
		200	0.033	0.029
		300	0.028	0.024
		400	0.024	0.021
2	5	100	0.045	0.041
		200	0.033	0.029
		300	0.027	0.024
		400	0.024	0.021
3	5	100	0.046	0.040
		200	0.034	0.029
		300	0.028	0.023
		400	0.025	0.020
4	4	100	0.046	0.040
		200	0.034	0.029
		300	0.028	0.023
		400	0.025	0.020
5	3	100	0.045	0.041
		200	0.033	0.030
		300	0.027	0.024
		400	0.024	0.021

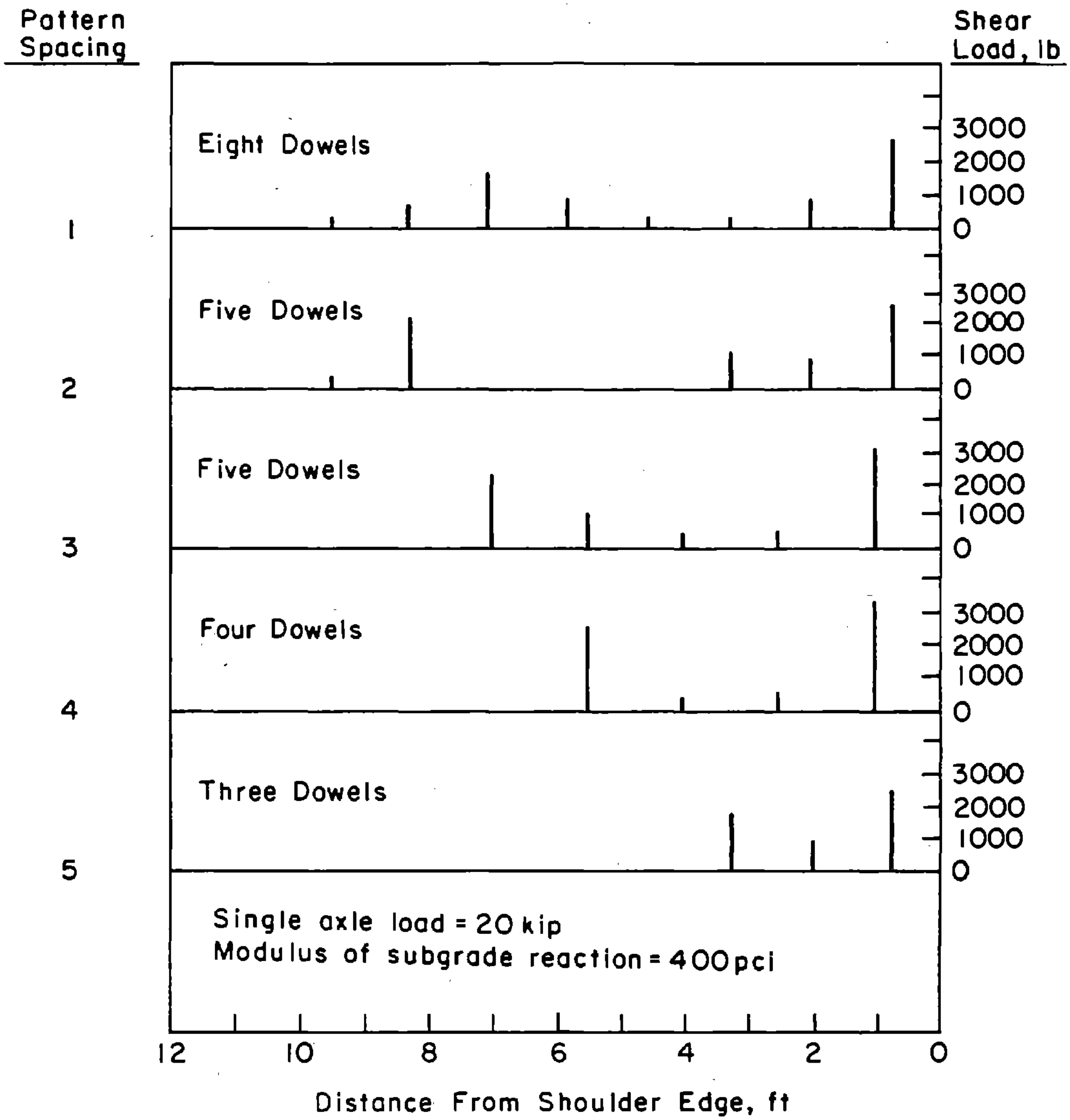

Fig. 8 Comparison of Dowel Shear Loads

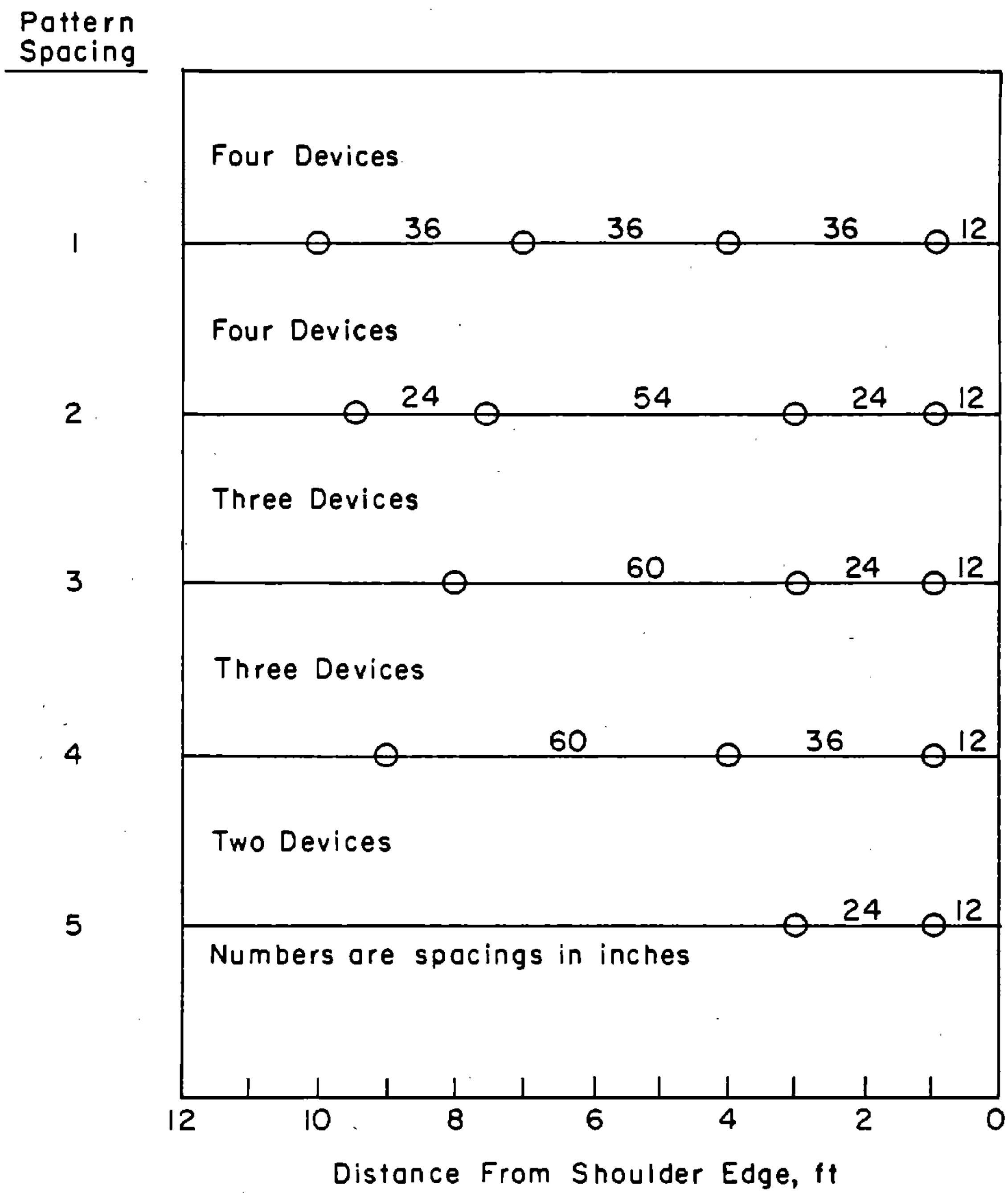

Fig. 9 Spacings of Double V Devices Considered for Analysis

TABLE 16 - RESULTS OF ANALYSIS OF SECTIONS WITH DOUBLE V DEVICES (SLABS FULLY SUPPORTED)

Dowel Spacing Pattern (Fig. 9)	No. of Devices	Modulus of Subgrade Reaction, pci	Maximum Shear Load, lb	Corner Deflections, in.		Joint Efficiency, %
				Loaded Slab	Unloaded Slab	
NA	0	100	--	0.071	--	--
		200	--	0.044	--	--
		300	--	0.034	--	--
		400	--	0.028	--	--
1	4	100	4100	0.035	0.030	86
		200	3900	0.023	0.019	83
		300	3800	0.018	0.014	78
		400	3700	0.015	0.012	76
2	4	100	3800	0.035	0.030	86
		200	3700	0.023	0.019	83
		300	3600	0.018	0.014	78
		400	3500	0.015	0.012	76
3	3	100	3700	0.035	0.030	86
		200	3600	0.023	0.019	83
		300	3500	0.018	0.014	78
		400	3400	0.015	0.012	76
4	3	100	3900	0.035	0.031	89
		200	3700	0.023	0.019	83
		300	3600	0.018	0.014	78
		400	3500	0.015	0.012	76
5	2	100	3500	0.035	0.031	89
		200	3100	0.022	0.019	86
		300	3100	0.018	0.014	78
		400	3100	0.015	0.012	76

shear load may affect the long-term ability of the device to perform adequately. A comparison of shear loads transferred by each device is shown in Fig. 10.

Results of analysis of slab sections that were initially curled upward are given in Table 17. Deflections range from 0.041 in. to 0.023 in. for modulus of subgrade reaction values ranging from 100 to 400 pci, respectively for the loaded slab. These data were developed in a manner similar to that described previously for doweled sections.

Deflections measured during September 1982 for sections using Double V devices range from 0.005 in. average for Test Section No. 30 to 0.032 in. average for Test Section No. 5 for the case of load on approach slabs. For the case of load on leave slabs, deflections ranged from 0.009 in. average for Test Section No. 5 to 0.059 in. average for Test Section No. 7. Thus, calculated deflection values are in the same range as measured deflection values.

Discussion

Analysis of measured data obtained by GDOT for the various test sections indicate that there is a large amount of variation in the measured data. This large variation may be due to a number of factors. These factors are listed below:

1. Variability in support condition
2. Effect of non-uniform slab curling influenced by the time and day of testing within a given test section and between test sections
3. Poor performance of a device or patching material at a joint

The variability in the test data makes it difficult to assess the influence on joint behavior of the various parameters such as type of device, number of devices used, spacing of devices, and bonding/grouting material used. Results of theoretical analysis indicate that properly installed dowels as well as Double V devices have potential for establishing good load transfer across a joint. This conclusion is based on structural analysis only and does not consider the problems related to development of inadequate bond between the patching material and concrete. Calculated results indicate that there are no significant differences in the deflection response of joints using dowels and the Double V devices. In addition, the number of

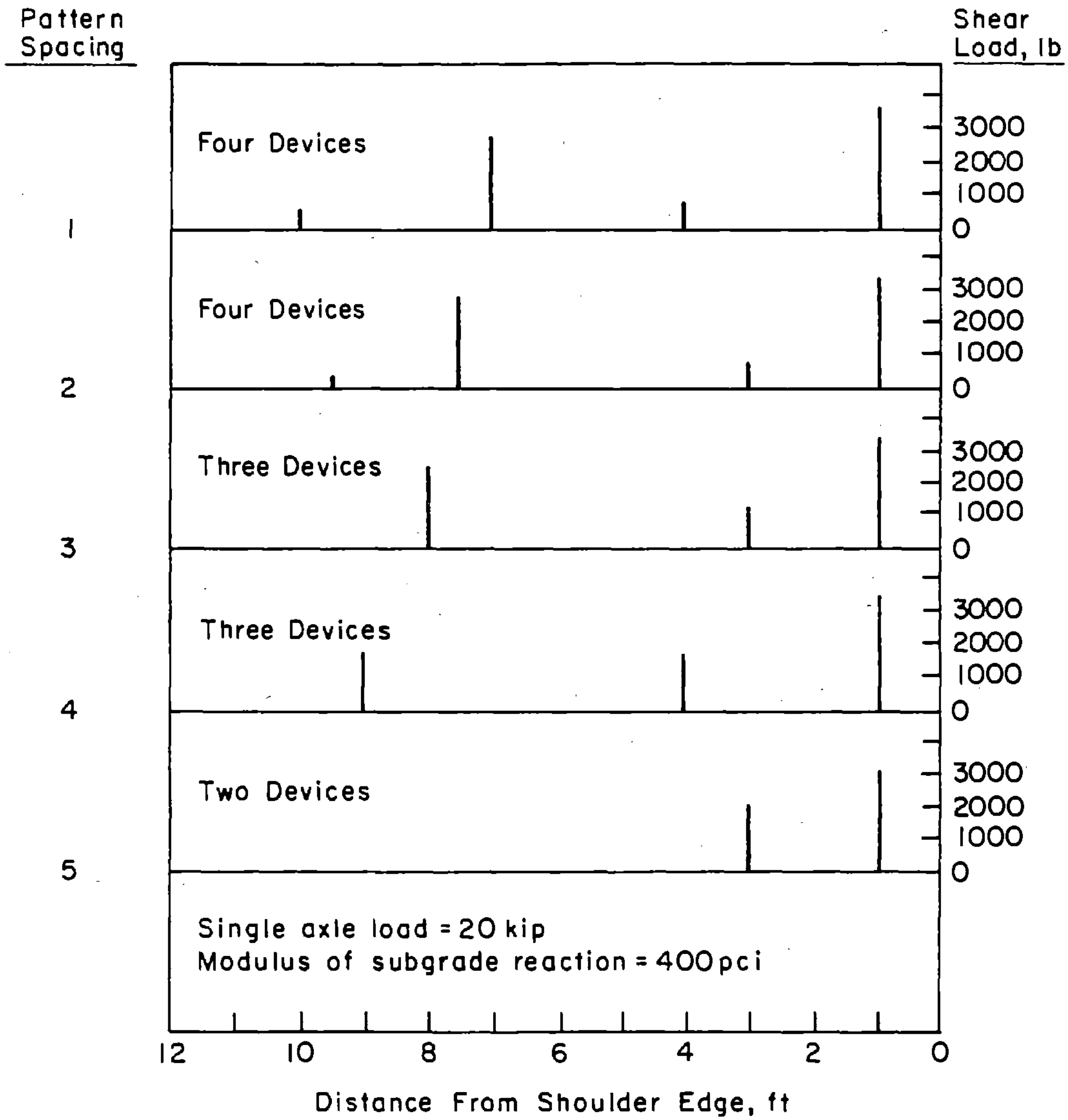

Fig. 10 Comparison of Shear Loads Transferred by Double V Devices

TABLE 17 - CALCULATED DEFLECTIONS OF SECTIONS WITH DOUBLE V DEVICES (SLABS INITIALLY CURLED UPWARD)

Dowel Spacing Pattern (Fig. 9)	No. of Devices	Modulus of Subgrade Reaction, pci	Corner Deflections, in.	
			Loaded Slab	Unloaded Slab
NA	0	100	0.078	--
		200	0.053	--
		300	0.043	--
		400	0.039	--
1	4	100	0.041	0.036
		200	0.031	0.027
		300	0.026	0.022
		400	0.023	0.020
2	4	100	0.041	0.036
		200	0.031	0.027
		300	0.026	0.022
		400	0.023	0.020
3	3	100	0.041	0.036
		200	0.031	0.027
		300	0.026	0.022
		400	0.023	0.020
4	3	100	0.041	0.037
		200	0.031	0.027
		300	0.026	0.022
		400	0.023	0.020
5	2	100	0.041	0.037
		200	0.030	0.027
		300	0.026	0.022
		400	0.023	0.020

devices used per joint did not have any influence on the calculated deflection response as long as two devices were used along the outside wheel path and were generally close together.

Summary

Based on the results of the study, the following items are noted:

1. A minimum of five dowels should be used per joint. Three of the bars should be located within the outside wheel path with spacing between bars of 12 to 15 in. The remaining dowels should be located within the inside wheel path with spacing between bars not to exceed 18 in.
2. There is no clear difference in calculated responses of joints using dowel bars and Double V devices.
3. A minimum of four Double V devices should be used per joint if it can be verified from long-term field performance that the larger maximum shear loads transferred by these devices are not detrimental to performance of the joints. Otherwise, Recommendation No. 1 above should be followed.
4. Poor performance of some of the test sections using the Double V devices is attributed to use of polymer concrete patching material. Polymer concrete requires great care when used and has a short pot life. Further it is required that the surfaces on which the patching material is to be applied are clean and dry. Thus, it is likely that some of the devices may not have achieved adequate bond with the concrete due to a combination of these factors.
5. It is believed that if the patching material performs satisfactorily, then a desirable level of long-term performance can be obtained for retrofitted dowel bars. However, field problems encountered with use of polymer concrete type patching materials may preclude achievement of desirable level of performance with Double V devices.

SURVEY OF CONCRETE PAVEMENT UNDERSEALING PRACTICE

A survey was conducted on the practice of undersealing. Several State highway agencies were contacted for information on undersealing of concrete pavements. This section of the report presents a summary of State experiences with undersealing. Several terms related to undersealing are defined below:

1. Undersealing or Subsealing - These terms refer to the practice of filling voids under a concrete pavement. It consists of introducing a cement grout under pressure through holes drilled in the slab to fill the voids and depressions under the slab. Slabs are not raised by this procedure.
2. Slabjacking - Slabjacking is a technique used to raise depressed sections of concrete pavement by forcing a flowable cement grout under it. The pavement slab is raised such that an acceptable profile is obtained.
3. Pressure Grouting - This term is used to describe the method by which both undersealing and slabjacking are accomplished.

Background

One of the major causes of distress at concrete pavement joints is loss of uniform support under the slab. Loss of support is due to pumping at joints and permanent deformation of the subbase and subgrade.

Pumping is the ejection of water and subgrade or subbase material through joints and cracks or along slab edges due to the action of traffic. When pumping occurs, it leads to faulting and broken slabs. For pumping to occur, three conditions must exist. These are:

1. Presence of free water
2. Heavy axle loading
3. Erodible support material

For free water to exist under a slab, void space under the slab has to be present. The void space initially develops due to upward slab warping. Warping results from moisture differentials between slab top and bottom. Warping is almost never recoverable. Curling due to temperature differentials between slab top and bottom modifies warping behavior. Along edges and joints, loss of support due to warping and curling may extend inward 18 to 36 in. depending on slab dimensions. Additionally, under heavy loading, permanent subbase/subgrade deformation may take place, thus aggravating an already serious condition.

Under very heavy loading resulting in large deflections and in the presence of free water, water escapes through joints and cracks and along edges at high velocity. Over a period of time, the high velocity water begins to erode the surface of the subbase/subgrade. Surface erosion begins as a particle by particle phenomenon, due to the relative instability of a given particle as compared to the remainder of the surface. This instability can arise from orientation, poor bonding, or particle structural matrix defects.

Another action that may occur is the development of high pore pressure in the subbase/subgrade material. If the pore pressure is high, it may create a condition similar to liquefaction in that the material possesses no strength. The pore pressure magnitude may be sufficient to break the bond that holds the soil or subbase matrix together. In addition, channeling or piping may be created due to movement of fine material in the subbase and subgrade.

As loss of support increases, deflections due to loading increase and a larger volume of water is ejected in a given loading cycle. Therefore, ejection velocity is higher and erosion is increased. Pumping can be eliminated or controlled by giving adequate considerations to the following design items:

1. Subsurface drainage
2. Load transfer at joints to reduce slab deflections
3. Nonerodible high quality subbase
4. Positive joint sealing
5. Tied concrete shoulder
6. Smaller slab lengths to minimize warping and curling deformations

Pavement drainage is an essential requirement for satisfactory pavement performance in wet regions. The main objective of pavement drainage is to ensure that free water does not remain in the subbase, subgrade, and at the pavement/subbase interface. Surface infiltration and ground water are the sources of water under pavements. Of these two sources, surface infiltration is the more significant for many pavements.

As stated before, for pumping to occur free water has to be present. Pumping does not occur in pavements that incorporate a properly designed and constructed subsurface drainage system. Field permeability tests at pavement sites show that drainage is almost nonexistent under many old concrete pavements. The use of open-graded drainage layers together with collector drains is being incorporated in new construction by many highway agencies to provide effective drainage.

Faulting is a distress related to pumping in which the approach slab edge becomes higher than the leave slab edge at the joint. One explanation for faulting is that as the load approaches a joint, there is a slow movement of water and some solids from under the approach slab to under the leave slab. However, as the load crosses the joint, there is a rapid movement of water and a considerable amount of solids in the reverse direction. This movement takes place at a high velocity. As the load moves away from the joint, the water slowly returns to under the leave slab, leaving most of the solids under the approach slab. After this action is repeated a large number of times, sufficient amounts of granular solids accumulate under the approach slab leading to faulting. This mechanism of faulting is illustrated in Fig. 11.

In existing pavement, when the conditions of pumping and faulting become severe enough to warrant repair, a technique commonly used for repair is undersealing followed by surface grinding if faulting exists. Undersealing is intended to fill voids under the slab and provide a more uniform support to the slab. Undersealing does not necessarily strengthen or stabilize the foundation. Thus, the stiffness (support modulus) of the subbase/subgrade material is not increased per se.

A summary of State highway agency practices related to undersealing is presented next.

Questionnaire

A questionnaire was sent to several State highway agencies during 1984. Responses were received from California, Georgia, Illinois, Iowa, Michigan, Minnesota, Nebraska, New York, and Pennsylvania.

The response from Michigan indicated that the State does not have a problem with pumping and consequently does not use the technique of undersealing. Michigan's concrete pavements are reinforced, contain doweled joints,

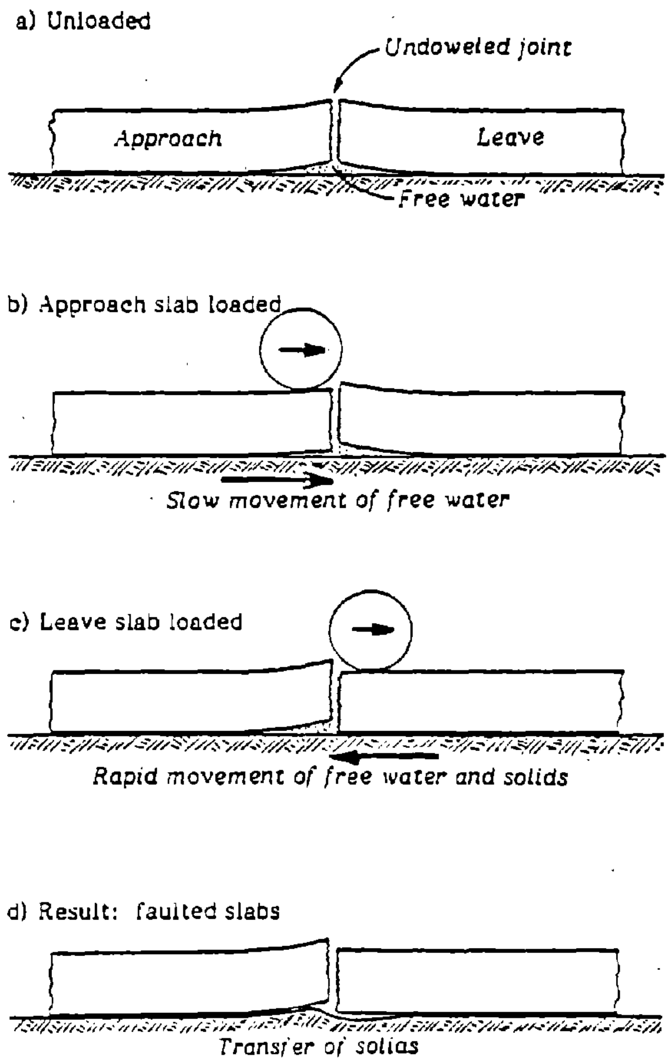

Fig. 11 Joint Faulting Mechanism (Ref. 5)

and are placed on a layer of sand topped with a 4 in. layer of aggregate base.

Minnesota's response also indicated little problem with pumping in the state due to use of fairly well draining granular bases. Minnesota, however, does perform a great deal of edge drain installation to alleviate saturated grade conditions where necessary.

The following information on undersealing was requested:

1. Equipment
2. Grout type
3. Grout consistency and other requirements
4. Void detection technique
5. Grouting procedure
6. Followup testing
7. Performance histories

Many of the respondents forwarded copies of specifications on concrete pavement undersealing. Specifications on provisions established by Georgia, Illinois, Iowa and Pennsylvania are given in Appendices A, B, C, and D, respectively.

Void Detection

Before a good undersealing program can be developed, voids under slabs must be located. Location of voids is the most challenging problem in undersealing. Currently, void detection is performed by visual identification of areas exhibiting pumping and faulting or by proof-rolling the pavement with a heavily loaded truck. Two new techniques being experimented with for location of voids under slabs are the impact type loading such as the falling weight deflectometer and use of radar evaluation.

Proof-rolling is generally done using a 18-kip or a 20-kip single-axle load and at slow speed. Areas exhibiting corner deflections in excess of a predetermined allowable deflection value are targeted for undersealing. Slab corner deflections at a joint are measured using a modified Benkelman beam with dial gage to read deflections of both the loaded and the unloaded slabs. Normally, an absolute slab deflection of 0.02 in. is considered as the allowable maximum deflection under an 18-kip single-axle load before requiring undersealing. Proof-rolling is generally done during the early morning hours to incorporate the effect of upward slab curl on deflections.

California's experience indicates that measurement of deflections under an 18-kip single-axle load does not yield any correlation with the need for, or amount of, the undersealing required because slab deflections are usually quite small. Coring data has also not provided usable data. Use of ground penetrating radar was also not successful. California intends to evaluate use of a falling weight deflectometer and the Dynaflect equipment for finding voids under concrete pavement.

Georgia uses a limiting criterion of 0.030 in deflection under an 18-kip single-axle load to define voids under slabs. Iowa determines undersealing needs based on amount of faulting. Undersealing is generally specified if faulting is in excess of 3/8 in. Iowa's experience with use of ground penetrating radar was not successful. Iowa's use of the Road Rater equipment indicate that there is improvement in the subgrade modulus value and slab structural rating after undersealing. Pennsylvania requires that all slabs having a deflection of 0.02 in. under an 18-kip single-axle load be undersealed.

Grout Material and Properties

Materials selected for grouting should remain incompressible, nonerodible, and insoluble after being pumped and having hardened. The grout slurry must flow with low internal friction to allow movement through small spaces under the slab. The grout must also be able to displace free water existing in voids under slabs and possess required strength and durability properties.

Grout materials may be sand-cement, cement and lime-dust, or cement and pozzolan. A typical mix specified by California is proportioned at the rate of 94 lb of cement to 225 to 255 lb of fly ash and water added to provide a grout efflux time of 10 to 16 seconds. The water requirement is approximately 17 gallons.

Georgia designates the type of grout mixture to be used. The mixture consists of one of the proportions by weight listed below:

	Grout Type				
Ingredients	1	2	3	4	5
Cement	25	25	25	25	100
Limestone Dust	-	25	75	50	-
Fly Ash	25	-	-	25	-
Fine Aggregate	50	50	-	-	-

Although the above five grout mixtures are allowed, generally mix 3 consisting of one part cement and three parts limestone dust is used.

Georgia's water requirement is based on obtaining a grout efflux time of 16 to 22 seconds. The consistency (fluidity) test performed to determine the efflux time is conducted according to the procedures of Corps of Engineers Test Method No. CRD-C611-80. The procedure uses a flow cone.

In Illinois, grouts are proportioned to meet the following requirements:

1. Minimum cement content of 20% of the absolute volume of the grout solids
2. Flow core efflux time of 10 to 17 seconds
3. Minimum design strength at minimum efflux time of 600 psi at seven days

Iowa specifies the following for grout mixtures for undersealing:

1. One part (by volume) of cement (Type I)
2. Three parts (by volume) of fly ash from an approved source
3. Water to obtain efflux time of 10 to 20 seconds

New York's and Pennsylvania's requirement for grout mixture are similar to Iowa's. New York also requires that the grout material have a minimum compressive strength of 300 psi at seven days while Pennsylvania requires a minimum compressive strength of 700 psi.

Grouting Equipment

Equipment for grouting consists of mixers, pumps, and injection pipes. Grout mixers for large jobs are highly mobile, self contained units that carry all the materials required for undersealing. Because of the small particle size and resulting increased surface area of the grout, high speed mixtures are used. High speed colloidal mixtures operate at a speed of 800 to 2000 rpm. The mixing unit should be capable of accurately measuring and batching the dry material and water. When calcium chloride is to be used, it should be premixed in the water before adding the dry ingredients.

Pumps used for grouting should be capable of working in the range of 70 to 200 psi for undersealing. Pumps may be positive displacement piston-type pumps or screw-type worm pumps. Piston-type pumps can cause pressure surges that may prematurely squeeze water out of the grout.

California specifies use of a colloidal mixing plant that operates between 800 and 2000 rpm and use of an injection pump capable of sustaining a gage pressure of 150 psi when pumping grout having an efflux time of 12 sec.

Georgia specifies that the mixing equipment shall consist of a water-tight batch type mixer that is capable of blending the various materials into a homogeneous mixture. Georgia allows use of a positive displacement piston-type pump or a screw-type worm pump.

Illinois has no special requirements for the mixing unit but requires that the mixer be capable of producing a consistent and homogeneous mixture free of lumps. As for pumps, Illinois requires that the pump be a positive displacement pump capable of producing 10 to 100 psi pressure at the grout packer.

Grouting Procedure

Layout of holes for grouting is generally based on local experience. Although layout of holes should be based on project needs, it is more often the practice to use a predetermined hole pattern. Use of a predetermined hole pattern may result in forcing of grout into area under slabs where no voids exist and where undersealing may not be required. Hole patterns should ideally be based on the results of the void detection study. Holes used for injection may be 1 to 2 in. in diameter.

California has used the hole pattern shown in Fig. 12. This pattern is used to fill voids existing under leave slabs due to faulting. Typical hole patterns used in Georgia are shown in Fig. 13. A hole pattern used in Illinois on an experimental project is shown in Fig. 14. This pattern was based on the results of a load-deflection study using a Model 2008-X Road Rater equipment. Hole patterns typically specified in Pennsylvania are shown in Fig. 15.

During grouting, the upward movement of the slabs being grouted is monitored. For undersealing, voids are filled without any slab uplift. Therefore, excessive slab uplift should be avoided to minimize problems such as slab cracking and creation of additional voids. Specifications generally limit slab uplift during undersealing to 0.05 in.

For undersealing, the maximum grout pressure should not exceed 200 psi. Normal grouting pressures range from 30 to 100 psi. Pumping should be stopped when no evidence of grout appears at joints and no lift is being recorded after a reasonable amount of time or when excessive loss of materials through joints and cracks takes place.

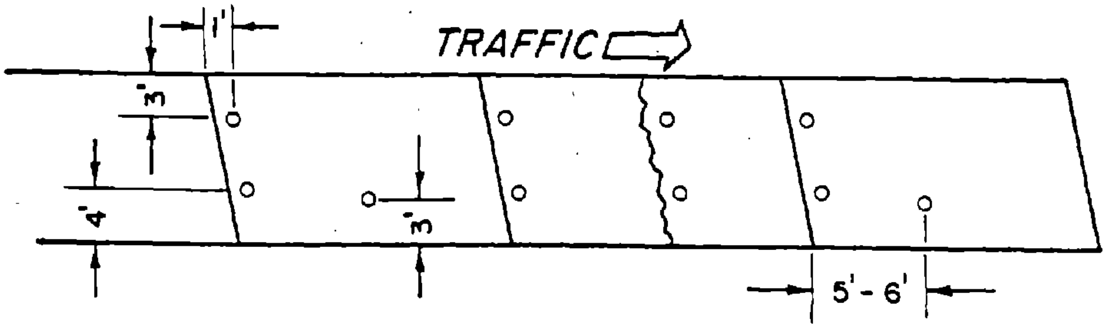

Fig. 12 Hole Pattern Used in California

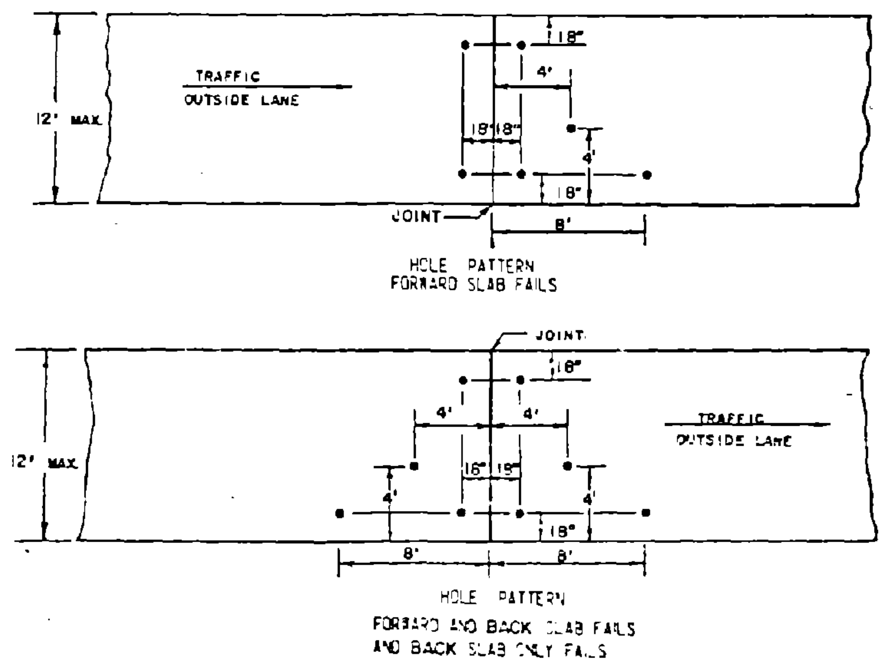

Fig. 13 Hole Pattern Used in Georgia

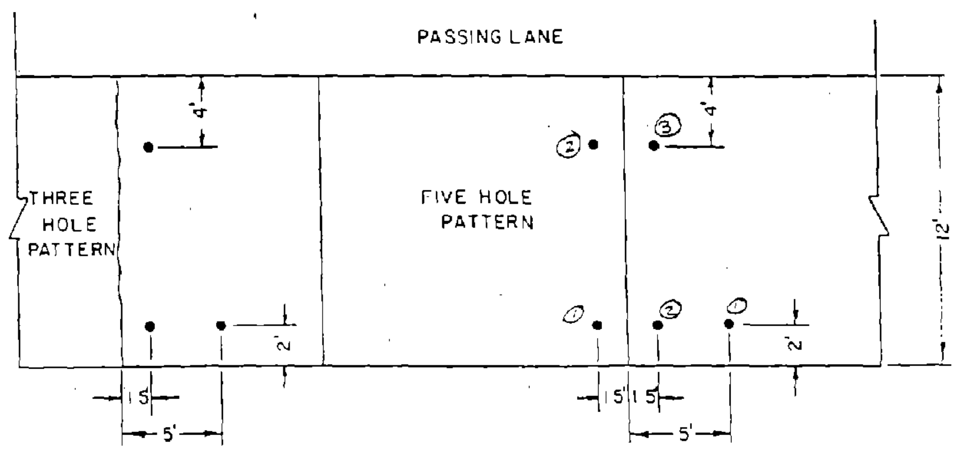

Fig. 14 Hole Pattern Used in Illinois on an Experimental Project

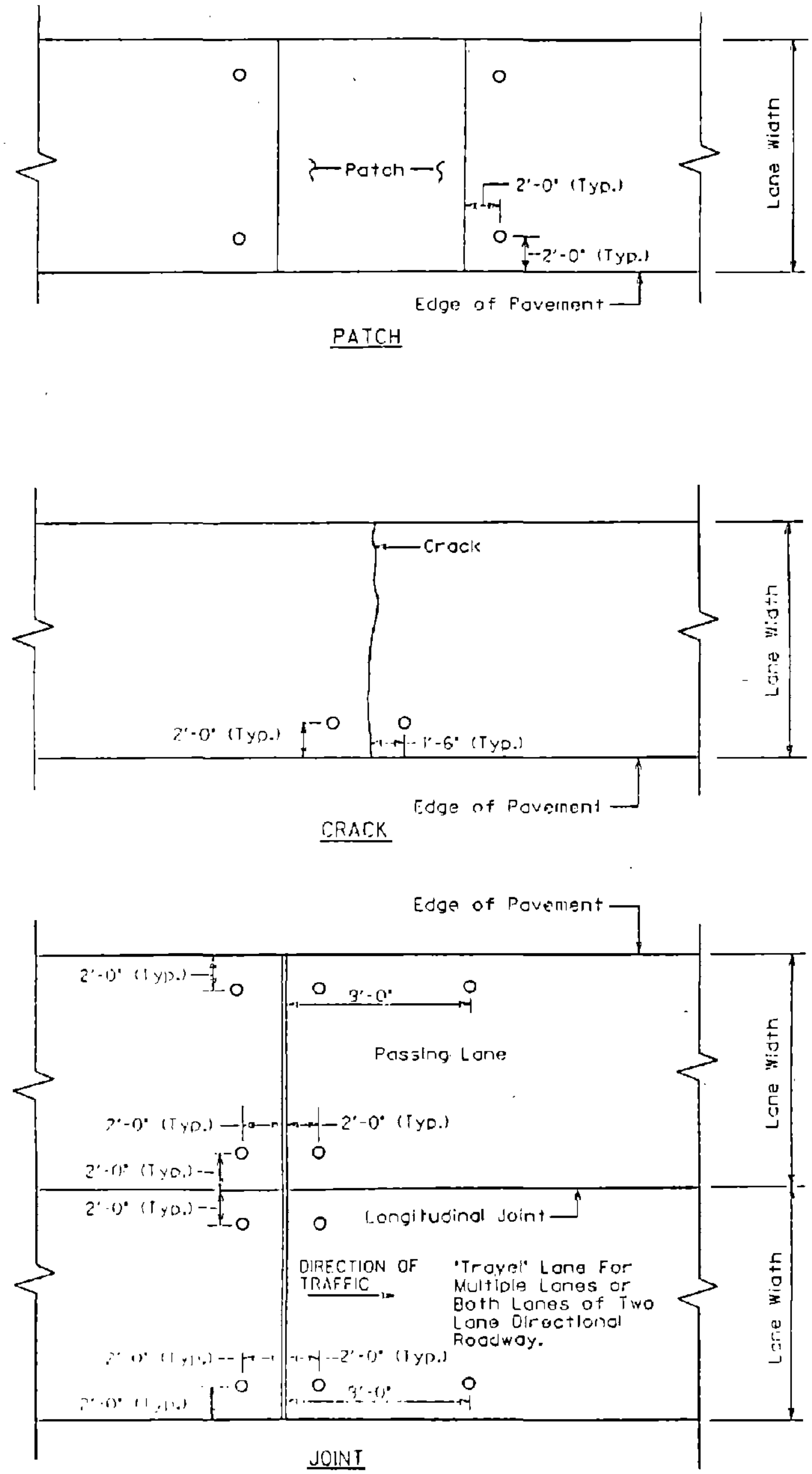

Fig. 15 Hole Pattern Used in Pennsylvania

Proof rolling of grouted sections is many times carried out after about 24 hours. This procedure is similar to that used for initial void detection. California does not perform follow-up testing of undersealed pavements due to a lack of "a satisfactory method for evaluation." Georgia and Pennsylvania require proof rolling after undersealing. Regrouting is required if slab deflection during proof rolling exceeds 0.02 in. in Pennsylvania and 0.03 in. in Georgia.

Supplementary Rehabilitation Work

Undersealing is usually only one item of a concrete pavement restoration (CPR) program. Undersealing may be done in conjunction with surface grinding, edge drain installation, load transfer restoration at joints, joint resealing, and slab replacement. Thus, effectiveness of undersealing is greatly influenced by the type of supplementary rehabilitation performed at a site. Concrete pavement rehabilitation work is generating considerable interest in the United States and many States now routinely specify CPR type activities to extend the service life of existing pavements.

Performance of Undersealed Sections

Although many State agencies frequently make use of undersealing as part of their concrete pavement restoration programs, very few of these agencies have documented the performance of the repaired sections. In addition, because undersealing in most projects is done in conjunction with other restoration measures such as surface grinding, edge drain installation, and load transfer restoration, it is difficult to isolate the degree of improvement in pavement performance due to undersealing only.

Recently, studies were conducted by Illinois and New York to evaluate the effectiveness of undersealing. Details of these studies follow.

Illinois Undersealing Study[7]

The Illinois study was conducted during September 1983 on a four-lane divided concrete pavement segment of I-55 in Sangamon County. The pavement was 10 in. thick reinforced concrete with contraction joints at 100 ft spacing. A 6-in. thick Type A granular subbase was used. The pavement restoration work included full and partial depth patching, undersealing, underdrain installation, and surface grinding.

The undersealing portion of the study was designed to evaluate the following:

1. Performance of limestone dust-cement and fly ash-cement grouts
2. Effect of admixtures (water reducer and superplasticizer) on the grout
3. Effect of pumping pressure (10, 20, and 30 psi)

The experimental design is given in Table 18. Limestone dust-cement grout contained 1499 lb of limestone dust, 589 lb of cement, and 939 lb of water. Water reducer (Hycol, W. R. Grace Co.) was added at rate of 8.5 oz per hundred weight of cement and superplasticizer (WRDA 19, W. R. Grace Co.) was added at a rate of 17 oz per hundred weight of cement. Limestone dust was required to meet the following gradation:

Passing No. 30 sieve	100%
Passing No. 100 sieve	92 ± 8%
Passing No. 200 sieve	82 ± 8%

The fly ash-cement grout contained 1387 lb of fly ash, 605 lb of cement, and 915 lb of water. The water reducer and superplasticizer were used at the same rates as for the limestone dust-cement grout.

Deflection reduction ranged from none for sections with low initial deflections to about 20 to 30% for sections with higher initial deflections. Deflection data were obtained at three days after grouting and seven months after grouting.

The following conclusions were drawn from study results:

1. The flyash-cement grouts were stronger (higher compressive strengths) than limestone dust-cement grouts treated with identical admixtures.
2. The flyash-cement grouts were more flowable than limestone dust-cement grouts.
3. Flyash-cement grouts with either no admixture or with superplasticizer produced the greatest decrease in deflections at cracks and joints.
4. Limestone dust-cement grouts with admixtures produced the least decrease in deflections.
5. Undersealing was most effective in reducing deflections when initial deflections were high.
6. A better method of estimating grout material requirement is needed.

TABLE 18 EXPERIMENTAL DESIGN (REF. 7)

Section	Aggregate	Admixture	Pressure psi	Length, ft
F-1	Flyash	SP*	30	300
F-2	Flyash	SP	20	300
F-3	Flyash	SP	10	300
F-4	Flyash	None	30	300
F-5	Flyash	None	20	300
F-6	Flyash	None	10	300
F-7	Flyash	WR**	30	300
F-8	Flyash	WR	20	300
F-9	Flyash	WR	10	300
L-1	Limestone	None	30	300
L-2	Limestone	None	20	300
L-3	Limestone	None	10	300
L-4	Limestone	WR	30	300
L-5	Limestone	WR	20	300
L-6	Limestone	WR	10	300
L-7	Limestone	SP	30	300
L-8	Limestone	SP	20	300
L-9	Limestone	SP	10	300

*SP = Superplasticizer
**WR = Water Reducer

New York Undersealing Study[8]

The New York study included rehabilitation work on two projects along I-84. each of the two projects is a four-lane highway, with 9 in. thick reinforced concrete pavement having a contraction joint spacing of 60 ft 10 in. Two-component wrought-iron load transfer devices were used for load transfer at joints. Project details are as follows:

1. Port Jervis Section - Constructed in 1964 and rehabilitated during 1980. Rehabilitation work included mechanical lifting of depressed slabs or grinding and undersealing. This section had an AADT of 8,000 vehicles with 25% truck traffic.
2. Fishkill Section - Constructed in 1962 and rehabilitated during 1981. Rehabilitation work included grinding and undersealing. This section had an AADT of 13,000 vehicles with 20% truck traffic.

Both projects exhibited substantial amount of joint faulting although the pavement slabs were in good condition. Originally, subsealing was to be done at joints where vertical movement exceeded 1/8 in. under an 18,000 lb single-axle load placed at the joint. However, because work was conducted in warm weather, most of transverse joints were closed resulting in very low measured deflection. The deflection testing procedure was therefore abandoned and joints were selected for rehabilitation on the basis of fault magnitude and visual observations.

Study Results

Faulting data for before and after treatment are given in Table 19 for Port Jervis section and in Table 20 for Fishkill section. Data in these tables indicate that faulting was recurring at both projects indicating that conditions that led to original faulting were still present in the pavement. Thus, even though faults are removed by grinding and less effectively by mechanical slab lifting, the improvements are short-lived if the causative factors, especially lack of load transfer, are not eliminated.

TABLE 19 MAGNITUDE OF FAULTING BEFORE AND AFTER TREATMENT AT PORT JERVIS (REF. 8)

Treatment	No. of Joints	Faulting*				
		Before Treatment	After Treatment	1981	1982	1983
Lifting	90	0-4	1.06	1.32	2.64	3.56
	150	5-8	2.33	2.70	4.23	5.63
	84	9-12	2.68	3.63	5.58	7.67
	45	>12	2.76	3.94	5.71	8.09
Grinding	195	0-4	0	0.63	1.25	2.33
	142	5-8	0	0.95	2.08	3.19
	28	9-12	0	0.89	2.64	4.21
	20	>12	0	0.95	2.45	3.90

*Measured in 1/16-in. units.

TABLE 20 MAGNITUDE OF FAULTING BEFORE AND AFTER TREATMENT AT FISHKILL (REF. 8)

Faulting Before Grinding*	No. of Joints	Faulting After Grinding*	
		1 Year	2 Years
0-4	265	0.25	0.99
5-8	369	0.53	1.81
9-12	108	1.21	2.25
>12	18	1.28	2.83

*Measured in 1/16 in. units.

Summary

Although undersealing of concrete pavement has been practiced for many years, performance data on undersealed pavements are not readily available. Also, the effectiveness of undersealing by itself cannot be determined easily because other pavement restoration measures are also performed in conjunction with undersealing. However, the use of undersealing as part of CPR is gaining popularity.

It should be noted that undersealing by itself does not solve the problem of pumping and faulting. Steps must be taken to restore load transfer at joints and to eliminate saturated subbase/ subgrade condition by providing effective edge drainage and by positive joint sealing. It should also be noted that the thin layer of hardened grout does not necessarily improve the stiffness properties of the subbase/subgrade.

A summary of several important items related to undersealing has been presented in this section of the report. The information presented is based on a review of practices of selected highway agencies.

ACKNOWLEDGMENTS

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The opinions and findings expressed or implied in the paper are those of the author. They are not necessarily those of the Federal Highway Administration.

REFERENCES

1. Gulden, W. and Brown, D., "Improving Load Transfer in Existing Jointed Concrete Pavements," report prepared by Georgia Department of Transportation for the Federal Highway Administration, November 1983.

2. Tayabji, S. D., and Colley, B. E., "Analyses of Jointed Concrete Pavements," report prepared by Construction Technology Laboratories for the Federal Highway Administration, February 1984.

3. Gulden, W. and Brown, D., "Establishing Load Transfer in Existing Jointed Concrete Pavements," paper presented at the 1985 Annual Meeting of the Transportation Research Board, Washington, D.C., January 1985.

4. "The AASHO Road Test," Special Report 61E, Transportation Research Board, 1962.

5. "Joint-Related Distress in PCC Pavement," NCHRP Synthesis of Highway Practice 56, Transportation Research Board, January 1979.

6. Korbus, L. and Barenberg, E. J., "Longitudinal Joint Systems in Slip-Formed Rigid Pavements: Volume IV-Recommendations for Alternate Joint Systems and for Strengthening Existing Joints," Report No. DOT/FAA/RD-79/4, IV, Federal Aviation Administration, November 1981.

7. Slifer, J. C., Peter, M., and Burns, W. E., "Experimental Project on Grout Subsealing in Illinois," Proceedings of the Third International Conference on Concrete Pavement Design and Rehabilitation, Purdue University, April 1985.

8. Vyce, John M., "Fault-Removal Procedures for Rigid Pavement Joints," Report No. FHWA/NY/RR-85/121, Engineering Research and Development Bureau, New York State Department of Transportation, April 1985.

Additional References on Undersealing

Information presented in the report is based on responses (including specifications) received from the following agencies:

1. California Department of Transportation
2. Georgia Department of Transportation
3. Illinois Department of Transportation
4. Iowa Department of Transportation
5. Michigan Department of Transportation
6. Minnesota Department of Transportation
7. Nebraska Department of Roads
8. State of New York Department of Transportation
9. Pennsylvania Department of Transportation

APPENDIX A

SPECIAL PROVISION FOR UNDERSEALING USED BY GEORGIA DOT

January 11, 1980
Rev. March 9, 1982
Rev. April 18,1983

DEPARTMENT OF TRANSPORTATION

STATE OF GEORGIA

SPECIAL PROVISION

Modification of the Standard Specifications dated September 15, 1977
and the Supplemental Specifications dated July 1, 1982

SECTION 450 - PRESSURE GROUTING PORTLAND CEMENT CONCRETE PAVEMENT

450.01 DESCRIPTION: This Work shall consist of pumping a slurry type grout mixture through holes drilled in the pavement into voids underneath the slabs to stabilize and underseal Portland Cement Concrete Pavement. The grout mixture shall be capable of forming a hard and insoluable mass that will effectively fill voids under the pavement. Slabs that are unstable after an initial undersealing and stabilizing attempt shall be regrouted as directed by the Engineer.

450.02 MATERIALS: Materials used in The Work and their Specification references are as follows:

Portland Cement Types I or III	830
Mineral Filler (Limestone Dust)	883
Calcium Chloride, Type I	884**
Fly Ash, Type A	831
Water	880
Fine Aggregate Size No. 20	801.02
Agricultural Lime	882.02*

* Agricultural lime when used for undersealing shall have 95% minimum passing the No. 30 Sieve and 30% minimum passing the No. 200 Sieve.

** The laboratory may approve other commercially available accelerators which may be substituted for calcium chloride.

Fine Aggregate: Fine aggregate shall meet the requirements of Section 801.02 except that mortar-making properties are not required.

Grout Mixtures: The bid item will designate the type or types of undersealing grout mixtures required. The mixture shall consist of proportions listed in the Table below. The quantity of mixing water used with the dry ingredients shall be that quantity which will produce a grout of such consistency that the time of efflux from the flow cone will be a minimum of sixteen (16) seconds and a maximum of twenty two (22) seconds. The consistency of the grout will be determined by Test Method GHD-84. Cement, cement and limestone dust, or cement and fine aggregate may be added in the proper proportions to a mixed batch to produce the required consistency.

TABLE OF GROUT MIXTURES

MIX PROPORTIONS, PERCENT BY WEIGHT OF DRY MATERIALS

DRY MATERIALS	GROUT TYPES				
	1	2	3	4	5
Cement	25	25	25	25	100
Limestone Dust		25	75	50	
Fly Ash	25			25	
Fine Aggregate	50	50			

Grout Type 5 may be substituted for any of the other Types specified. When Type 5 is so substituted, payment shall be made at 25% of the Contract Unit price bid for the other alternates.

450.03 WEATHER LIMITATIONS: Pressure grouting operations may not be started unless the air temperature, in the shade and away from artificial heat, is at least 35°F and rising. Pressure grouting will stop if the temperature is 40°F and falling or when the subgrade contains an abnormal amount of moisture.

450.04 EQUIPMENT: Equipment shall consist of at least the following:

A. Batching Equipment: The batching equipment shall include weight hoppers and scales for each dry material or calibrated volumetric batch hoppers. Volumetric batch hoppers shall be calibrated in increments that are equivalent to one 94 pound bag of cement. Aggregate scales shall be accurate to plus or minus 1% and cement scales shall be accurate to plus or minus 0.5%.

If conveyor belts are used to convey the dry materials into the mixer, they shall have windproof covers.

B. Mixing Equipment: The mixing equipment shall consist of a watertight batch type mixer that is capable of blending the various materials into a homogenous mixture.

C. Grout Pumping Equipment: The grout pumping equipment shall consist of a positive displacement, piston-type pump or a screw type worm pump.

The discharge line shall be equipped with a positive cut-off valve at the nozzle end, and a bypass return line for recirculating the grout back into a holding tank or mixer.

The end of the discharge line shall be equipped with a nozzle or device that will remain secure in the drilled holes and be free of appreciable leaks.

The Contractor shall furnish a blow pipe with sufficient air pressure to dislodge loose debris.

An auger of sufficient size and length is required to open clogged holes.

D. Drilling Equipment: Air compressors of sufficient capacity for operating penumatic hammers or drills.

Pneumatic hammers or drills equipped with bits that will cut 1-1/2" or other approved diameter holes through the concrete pavement. The equipment shall be operated so as to prevent damage to the pavement being drilled. *Excessive down pressure to force the bit through the concrete at a rapid rate will not be allowed. The drilling procedure must be approved by the Engineer.*

E. Slab Stabilization Testing Equipment: The Contractor shall furnish a two axle truck with dual rear wheels. The rear axle shall be loaded to 18 kips evenly distributed between the two sides. A truck driver and sufficient manpower to assist in the operation of static load measuring gauges shall also be furnished by the Contractor.

F. Equipment to measure slab lift shall be capable of detecting movement simultaneously of the two outside slab corners adjacent to a joint and the adjoining shoulder. The equipment shall have the capability to make such measurements to 0.001 inch.

450.05 CONSTRUCTION

A. Testing: All testing shall be performed between the hours of daylight and 9:00 AM. Unless otherwise directed by the Engineer. It is the intention of this work to detect all slabs having a deflection exceeding 0.030 inch, and the Contractor is to stop the testing if the slabs are beginning to "lock-up". In hot weather, the Contractor may be required to test between 4 AM and 7 AM to avoid "lock-up" of slabs, if so directed by the Engineer.

1. Preliminary Testing:

a. Testing by the Department:

When the slabs requiring grouting have been tested and marked by the Department, no preliminary testing will be required.

b. Testing by the Contractor:

(1) In the event preliminary testing has not been performed by the Department, each joint and slab on the Project or within designated areas of the Project shall be tested by the Contractor using static methods. This work shall be performed as follows:

The *Contractor* will furnish four gauges on two gauge mounts, two gauges per mount, that are capable of detecting slab movement under load. The Contractor shall maintain the gauges and mounts in operating order. The Contractor shall also furnish the required loaded truck, a truck operator, and necessary personnel to place and assist in operating the gauges.

One set of gauges will be positioned with one gauge referenced to the corner of each slab on both sides of the joint near the pavement edge. The gauges will then be zeroed with no load on the slab on either side of the joint. The test truck will then be moved into position and stopped with the center of the test axle about one foot behind the joint and the outside test wheel about one foot from the pavement edge. The back gauge will then be read. The test truck will then be moved across the joint to a similiar position about one foot forward of the joint and stopped. The forward gauge will then be read. This operation will be repeated for each joint to be tested. The inspector will be responsible for reading and recording the gauges. All slabs with a deflection more than 0.030 inch, or as shown on the Plans, will require additional testing.

The additional testing of slabs that move 0.030 inch or more, shall consist of one hole drilled in the corner of the slab where the movement was measured. The hole shall be the same diameter as the holes drilled for undersealing and shall be placed 18 inches from the transverse and shoulder joint. The test holes shall be drilled to the same Specifications as the undersealing holes. The test hole will be filled with water and observed.

If, in the estimation of the Engineer, the pavement system readily drains the water poured into the test hole, the slab will require pressure grouting. Based on the results of this initial testing, both deflection measurements and/or water drainage observations, a determination will be made by the Engineer as to which slabs require undersealing.

(2) Stability Testing: After the designated slabs have been pressure grouted in accordance with these Specifications, they shall be retested in accordance with A.1.b.(1) above.

Slabs which deflect 0.030 inch, or deflect the amount shown on the Plans, or more shall be regrouted and retested as directed.

Any slab which continues to show movement in excess of that specified after two properly performed groutings may be accepted or, if required, the slab may be removed, and replaced as directed by the Engineer.

Removal and replacement shall be in accordance with the Special Provisions for Sections 610 and 430.

B. Drilling Holes: The Plans designate the location of holes to be drilled in each type of slab for the purpose of undersealing. However, to the maximum extent possible, the Contractor is to use (by "re-drilling") the holes present from previous undersealing work. The drilling work shall begin using the hole pattern and pumping sequence shown on the Plans with necessary modifications to use as many of the holes from previous undersealing work as feasible. The Contractor may alter this hole pattern with the Engineer's approval. However, only the actual number of holes drilled, not to exceed the number of holes per slab that is shown on the Plans, will be considered for payment. Holes in excess of this amount per slab shall be at the Contractor's expense.

Holes shall be drilled of a size and shape that best provide a positive seal for the pumping nozzle. For the first undersealing attempt, holes shall be drilled to a depth of approximately eight inches beneath the bottom of the concrete unless the Engineer approves an alternate depth. The number, depth and location of holes for all undersealing attempts after the initial attempt shall be approved by the Engineer.

The Contractor shall exercise sufficient precautions during all operations to insure that slabs are not broken or cracked. Any slab that contains a crack that extends through the drill hole will be considered to have been damaged during the process of the work and it shall be repaired at the Contractor's expense. Repairs will be in accordance with techniques specified in Section 528-Epoxy Pressure Injection of Concrete Cracks (minor cracks) or Section 610, Slab Removal, and Section 430 Slab Replacement, (moderate to major cracks).

C. Cleaning Holes: After the holes are drilled, and just prior to pumping the underseal grout, a pipe with sufficient air pressure to remove debris and to provide a passage for the grout will be inserted in each hole.

D. Pumping Underseal Grout: To fill all voids, pumping of grout will be required in holes designated by the Engineer. Normally, indication that grout is flowing out of an adjacent hole or joint or the edge of the slab is sufficient evidence that all cavities or voids are filled within the range of the hole being grouted and pumping in such hole shall cease. Additional evidence that grouting should cease is a rapid rise of the slab, or indications of a rise of the adjacent shoulder. A minimal lifting of the slab will generally be required to move grout into the existing cavities and voids but this lift should not exceed 0.125 inch total accumulative movement for a slab measured at the outside joint corner unless otherwise approved by the Engineer. Care should be taken not to crack slabs by differential lifting. During pumping, very close attention should be given to the lift measuring device to prevent excessive pumping pressures, rapid lift of the slabs, or substantial rising of the adjacent shoulders.

The Contractor shall provide personnel and equipment to satisfactorily control lift on every slab that is undersealed. This is to be rigidly controlled.

The nozzle of the discharge hose shall be secured in the hole in a manner that provides a seal adequate to maintain the grout pressure underneath the slab. The nozzle end will not extend below the bottom of the concrete. Pumping will continue in a hole until a clear flow of grout comes out other holes, joints, or cracks; or until the slab begins excessive lift. This procedure will be repeated in other holes until it is indicated that all voids are filled. *Plugging of holes during grouting operations will not be permitted.*

Precautions shall be taken by the Contractor to insure that the minimum amount possible of grout is pumped into the edge drain system which is located near the shoulder/pavement interface. These precautions, shall include but are not limited to, drilling one or more "observation holes" in the asphaltic concrete shoulder as close as possible to the shoulder/pavement interface and "timing" of the grouting operation to prevent and stop "excess grouting" in any hole to insure grout does not flow into the edgedrain system. Upon completion of the grouting operation, any "observation holes" are to be filled with asphaltic concrete. No separate payment will be made for this work and cost thereof is to be included in bid submitted for Portland Cement Pressure Grout Slurry. The precautions used will require prior approval of the Engineer

Precautions shall also be taken to prevent slab from cracking or breaking during the undersealing operation. Slabs determined to be cracked or broken during this operation due to the Contractor's negligence will be repaired at the Contractor's expense in accordance with procedures referenced in 450.04.B (minor cracks) or removed and replaced at no additional cost to the Department (moderate to major cracks).

E. Clean Up: Deposits of grout on the pavement or shoulders shall be removed and the surface cleaned before traffic is permitted on the section. Other debris, bags, spillage, etc., shall be removed from the right-of-way each day.

F. Permanently Sealing Holes: All grout shall be removed from the holes and the holes filled with a stiff sand-cement mixture or an approved quick setting patching material. Filled holes that ravel out or become damaged shall be repaired. All unsatisfactorily filled holes from previous undersealing work shall also be similarly repaired at no cost to the Department, as directed by the Engineer.

G. Testing for Slab Stability: After grout has been pumped under the designated slab and the slabs have been under traffic for at least twelve hours, they shall be tested for stability. These tests are conducted by static loading as referenced in 450.05.A.1.b(2). Based upon these test results and criteria established on the Plans, the slabs will be accepted as satisfactory or will be designated for further undersealing attempts or replaced as directed by the Engineer.

450.06 OPENING TO TRAFFIC: No traffic will be permitted on the grouted slabs until the grout has taken an initial set.

Initial set is defined as 200 psi with a 0.25 square inch probe in accordance with AASHTO: T 197 (Proctor Needle Test).

The Contractor shall schedule his operations so that the grout has taken the initial set and the work area cleared before traffic is allowed on the grouted slabs. See Special Provision "Sequence of Operations and Traffic Control Plan" for allowable lane closure periods.

450.07 MEASUREMENT:

A. Holes: Holes drilled through the existing concrete slabs at the locations and to the depths shown on the Plans or directed by the Engineer will be measured per each including holes required for subsequent stabilizing attempts when directed.

B. Portland Cement incorporated into the Pressure Grout Slurry will be measured by the 94 pound bag.

C. Preliminary Testing as described in sub-article 450.05.A.1.b(1) will be measured, when required, by the linear mile, horizontal measure for each lane of each roadway tested.

D. Stability Testing as described in sub-article 450.05.A.1.b.(2) will be measured by the joint each time the joint is tested up to and including a maximum of three (3) tests per joint.

450.08 PAYMENT:

A. Holes will be paid for at the Contract Unit Price per each. Such payments shall be full compensation for drilling and sealing the hole.

B. Portland Cement Pressure Grout Slurry will be paid for at the Contract Unit price bid per 94 pound bag of cement or fraction thereof. Such payment shall be full compensation for furnishing all materials to be incorporated into the specified type of grout slurry, for all hauling, mixing, pumping and clean-up required to stabilize the slabs.

C. Preliminary Testing, when shown on the Plans and in the Proposal as a payment item, will be paid for at the Contract Price bid per linear mile, horizontal measure.

D. Stability Testing: Static testing of slabs performed in accordance with the provisions of sub-article 450.05.A.1.b(2) will be paid for each time the joint is tested up to a maximum of three times per joint. Such payment shall be full compensation for furnishing the load test truck and driver and necessary personnel to assist in the testing.

Payment will be made under:

Item No. 450.	Holes-------------------------------------	per Each
Item No. 450.	Portland Cement Pressure Grout Slurry (Grout Type__, ___or___)------	per Bag (94 lbs.)
Item No. 450.	Preliminary Testing ------------	Per Linear Mile
Item No. 450.	Stability Testing-------------------	per Joint

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APPENDIX B

SPECIAL PROVISION FOR UNDERSEALING USED BY ILLINOIS DOT

State of Illinois
Department of Transportation

SPECIAL PROVISION
FOR
SUBSEALING OF CONCRETE PAVEMENTS

Effective November 1, 1984

Description: This work shall consist of filling voids beneath rigid and composite pavements with Portland cement grout.

Materials: Materials shall meet the following requirements of Section 700 of the Standard Specifications:

A.	Portland Cement (Note 1)	Section 701
B.	Water	Section 702
C.	Fly ash (Note 2)	
D.	Admixtures	Article 718.01

Note 1: Portland Cement shall be Type I.

Note 2: Fly ash will be accepted from approved sources by certification of compliance to the Bureau of Materials and Physical Research's Policy Memorandum - Subject: "Quality Control Requirements for Fly Ash for Use in Portland Cement Concrete", except that the sulfur trioxide requirements may be waived.

Equipment:

Grout Plant. The grout plant shall be capable of accurately measuring and proportioning ingredients by volume, weight, or a combination thereof. The mixer shall be capable of producing a consistent and homogeneous mixture free of lumps. Provisions for calibrating the batching or metering equipment and a positive means of monitoring total production including continuity of material delivery shall be provided.

Grout Pump. The grout pump shall be a positive displacement pump capable of producing 10 to 100 PSI at the grout packer. If the volume of the grout storage area is four cubic feet or more it shall be equipped with mixing paddles. The discharge line shall be equipped with a positive cut-off valve at the nozzle end, and a bypass return line for re-circulating the grout into the holding tank or mixer; otherwise, the packer shall be inserted into the grout holding tank and the pump operated to prevent setting or degradation of the grout.

Drill. The drilling devices shall be capable of drilling the grout injection holes through the pavement, and through the subbase. The equipment shall be in good condition and operated in such a manner that the holes are vertical and sufficiently round to permit sealing by the packer head. Means to monitor the down feed force shall be provided.

Movement Detectors. The Contractor shall supply equipment to measure slab lift. When used on jointed pavements, the equipment shall be capable of detecting simultaneously the lift of the corners of two adjacent slabs. The equipment shall have graduations of 0.001 inch. Two such measuring devices, conforming to the attached drawing or other approved devices, shall be provided.

Flow Cone. The flow cone shall conform to Corps of Engineers Specification CRD-C611.

Pressure Gauge. The pressure gauge, protected from direct contact with grout slurry, shall be mounted in the grout line at the packer head.

Construction Requirements:

General Requirements. Grout pumping shall not be performed when ambient temperature is below 40° F., or when the subgrade and/or base material is frozen.

Grout pumping will not be allowed after October 31 nor prior to April 15 unless written approval is given by the Engineer.

Drilling Holes. Grout injection holes shall be drilled in the pattern shown in the plans or as determined by the Engineer. They shall not be larger than 2 inches in diameter, drilled vertically and round, to penetrate 2" to 6" below the subbase material. The downfeed force shall not exceed 200 lb. Depth of spalling of the pavement underside due to drilling of the concrete pavement shall not exceed 20% of the pavement thickness. The Contractor will be penalized three (3) times the bid price for holes drilled for each hole determined to be excessively spalled. Inspection holes shall be drilled, as required by the Engineer, to determine if the voids under the pavement have been filled. If the voids have not been filled, grout shall be pumped into the inspection hole as described herein.

Washing Holes. Holes shall be washed with water prior to subsealing in order to assure an opening into the void system as directed by the Engineer.

Proportioning Grout. Grout for filling voids beneath pavement shall be composed of Portland Cement, fly ash, water and , if necessary, admixtures. Grout shall meet the following minimum requirements:

1. Minimum cement content of 20% of the Absolute Volume of the grout solids.

2. Flow cone efflux time shall be 10 to 17 seconds as determined in accordance with Corps of Engineers Specification CRD-C611.

3. Minimum design strength at minimum efflux time shall be 600 psi at seven days as determined in accordance with the applicable portions of AASHTO T106.

At least three weeks prior to the beginning of this work, the Contractor shall submit to the Engineer his proposed mixture proportions based on absolute volumes. The submittal shall include independent laboratory testing of the grout showing one day, three day, and seven day strengths, efflux time, time of initial set, and specific gravity of fly ash. Accompanying this submittal shall be sufficient quantities of all mixture components to permit laboratory verification of the grout properties listed herein.

Mixing Grout. Mixed material shall not be held for more than sixty minutes. With permission of the Engineer, grout that has lost fluidity may be re-tempered with mix water one time.

Pumping Grout. An expanding rubber packer or hose connected to the discharge from the plant shall be lowered into the hole. The discharge end of the packer or hose shall not extend below the lower surface of the concrete pavement. Each hole shall be pumped until lift is observed, or material is observed flowing from hole to hole. Movement detectors shall be transported and positioned by the Contractor at each joint and crack to monitor lift. The upward movement of the pavement shall not exceed 0.05 inch.

Transient pressures (2-3 seconds duration) of no greater than 100 PSI will be permitted to facilitate grout flow. Pumping pressures for void filling shall be no greater than 40 PSI.

Water displaced from the void structure by the grout shall be allowed to flow out freely.

Excessive loss of the grout through cracks, joints, holes or in the shoulder area will not be allowed. Pay quantities will be reduced by the Engineer accordingly.

Immediately after the grout packer has been removed from the hole, the hole shall be filled with a wooden plug or other approved methods when necessary to prevent grout loss from the hole. These plugs shall remain in place until the grout has set sufficiently to prevent grout escaping from the hole. Plugs driven flush may remain in place until the hole is patched.

Patching Holes. Upon completion of pumping, all drill holes shall be filled flush with the surface of the pavement using a fast setting sand cement material approved by the Engineer. Mortar for filling the holes in the concrete pavement may be composed of one part Portland cement and 2 parts fine aggregate, by volume, and only enough water to permit placing and packing of the mortar in the holes. An approved commercial quality pre-mixed rapid set mortar or concrete may be used.

Cleaning Pavement. All drill tailings, spilled grout and other debris shall be cleaned up at the end of each working day or before the lane is opened to traffic. When adjacent lanes are open to traffic, provisions shall be made to prevent grout from encroaching onto the open lane or squirting onto passing vehicles.

Opening to traffic. The lane in which pumping operations are completed may be opened to traffic 1/2 hour after the initial set of the grout measured at the placement temperature. Initial set will be as determined by AASHTO T154 except the test will be run at ambient air temperature at time of placement.

Method of Measurement:

Traffic Control. Traffic control will be measured in accordance with the Standard Specifications except when the Contractor chooses to operate at night. In such cases the additional required traffic control will be provided and will be included in the bid prices of other items and no additional compensation will be allowed.

Holes. Holes drilled through the pavement structure, including inspection holes, at the location and to the depths shown on the plans or as directed by the Engineer, will be measured per each. Incomplete or unsatisfactory holes not used for pumping grout will not be measured for payment.

Grout Material. Grout incorporated into the pavement structure will be measured in cubic feet (absolute volume)of dry solid material only. Weights will be converted to dry solid volume using the following formula:

$$V = \frac{Wc}{Gcx62.4} + \frac{Wf}{Gfx62.4}$$ Where:

V = Total absolute volume of the dry solids in cubic feet.

Wc = Weight of Portland cement in pounds.

Gc = Specific gravity of Portland cement.

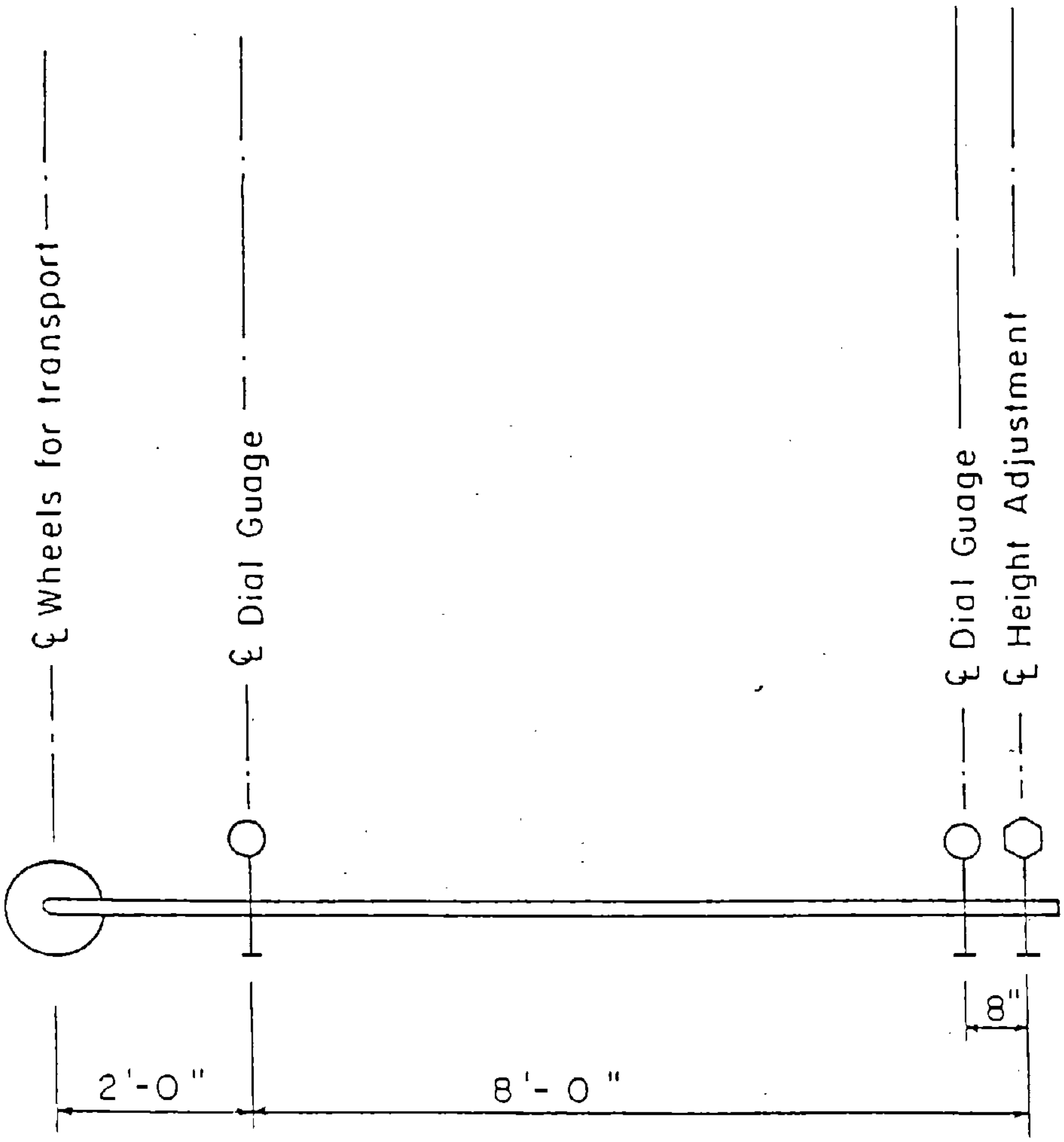
Wf = Weight of fly ash in pounds.

Gf = Specific gravity of fly ash.

Water and admixtures will not be measured for payment.

Basis of Payment:

This work will be paid for at the contract unit price per cubic foot for DRY GROUT SOLIDS and at the contract unit price per each for HOLES DRILLED which shall be payment in full for completing the work as specified herein.



ELEVATION

SLAB MOVEMENT DETECTION DEVICE

Dial gauges shall be spring loaded in order to measure both extension and compression.

APPENDIX C

SUPPLEMENTAL SPECIFICATION FOR UNDERSEALING USED BY IOWA DOT

Specification 975

Replaces SP-444

Iowa Department of Transportation

SUPPLEMENTAL SPECIFICATIONS
for
CONCRETE PAVEMENT UNDERSEALING AND JACKING BY PRESSURE GROUTING

August 31, 1984

THE STANDARD SPECIFICATIONS, SERIES OF 1984, ARE AMENDED BY THE FOLLOWING PROVISIONS. THESE ARE SUPPLEMENTAL SPECIFICATIONS AND THEY PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

975.01 DESCRIPTION. This work will consist of undersealing and supporting the concrete pavement to the specified grade tolerances by drilling and injecting cement/fly ash grout as shown on the plans.

This work is to be done in accordance with the Standard Specifications, the plans, and this specification.

975.02 CONTRACTOR QUALIFICATION. The Contractor (or his subcontractor if he is to do this work) must be competent in concrete pavement undersealing and jacking. Before the work is started, he must submit to the Construction Engineer evidence of his competence and previous experience with this type of work. This evidence may be submitted to the Contracts Engineer prior to the letting. Specific approval will be required before this work is started.

975.03 MATERIALS.

A. Mix Design. The mix design for the pressure grout for undersealing and jacking is as follows:

One part (by volume) portland cement, Type I, Section 4101.

Three parts (by volume) fly ash, Class C, Section 4108. The fly ash shall be from a source approved for this use in accord with IM 491.17.

Water to achieve required fluidity.

Additives as approved by the Engineer.

The mix design approval will include a suggested set time, intended for ideal temperature conditions.

B. Fluidity of the grout slurry shall be measured by the Corps of Engineers flow cone method according to their specification CRD-C611-80. Time of efflux shall range from 10 to 20 seconds for undersealing and from 16 to 26 seconds for jacking. A more fluid mix having a flow cone time of efflux of 9 to 15 seconds may be used during the initial injection at each hole. These measurements will be made by the Engineer, normally at least once every 4 working hours.

C. Material Proposal. The Contractor shall submit to the Engineer his proposal for materials and additives to be used as shown in the mix design above.

975.04 EQUIPMENT. The Contractor shall furnish all equipment necessary or incidental to the adequate performance of the work of this contract. As a minimum, these are as follows:

A. Grout Plant. Mixing may be with a colloidal mixer, or other type of mixer, as approved by the Engineer. The mixer shall have the capability of thoroughly mixing the various components of the grout in an approved manner.

The plant shall include a positive-action or rotor injection pump capable of forcing grout through a hole drilled in the pavement so that grout will fill voids and cavities beneath the pavement slab. The pump shall be capable of supplying a varying pressure up to at least 200 p.s.i. at the end of the discharge pipe so as to be able to lift the slab without damaging the pavement. The pressure shall be monitored by an accurate pressure gauge in the groutline. The supply tank shall be equipped with paddles or other means of agitation to maintain a homogeneous mixture.

The dry materials shall be measured by weight, if in bulk, or shall be packaged in uniform-volume sacks, and the water shall be batched through a meter or scale.

B. Water Tanker. Water shall be supplied from a water truck with adequate capacity and pressure for delivery to the grout plant.

C. Drilling Equipment. An air compressor and rock drills or other devices, which have the capability of drilling grout-injection holes through the pavement and subbase material, if any, shall be furnished by the Contractor. The equipment shall be in good condition and shall be operated in such a manner that the holes are vertical and not "out-of-round".

D. Transport. Necessary material transport and handling equipment shall be furnished.

E. Miscellaneous Equipment. The Contractor shall furnish all necessary hoses, valving, and valve manifolds to control pressure and volume, pressure gauge protectors, expanding packers for the grout injection, wood plugs, hole-washing tools, drill steel, and bits. The Contractor shall furnish any and all miscellaneous tools, equipment, and supplies that may be required to complete the work.

975.05 CONSTRUCTION. The pavement shall be undersealed by pressure grouting as shown on the plans. The Engineer will designate specific locations for pavement undersealing or jacking by pressure grouting. At his discretion, he may delete any location or he may add new locations.

A. Drilling Holes. Holes of 1 1/4 to 1 1/2-inch diameter shall be drilled through the concrete pavement at the locations designated by the Engineer and in a pattern approved by the Engineer. For holes nearest the edges of the slab, the joints, or a major crack, a maximum tolerance of 3 inches from the precisely marked location is considered to be reasonable. For other holes, a maximum tolerance of 6 inches is considered to be reasonable. Holes shall not be drilled directly over joints or cracks.

The drills shall be rotated to avoid cracking the pavement and to provide satisfactory holes of the proper diameter for effective operations in pressure grouting. When drilling holes, the drills shall be held as nearly perpendicular as possible to the pavement surface. Irregular or unsatisfactory holes which cannot be satisfactorily used in pressure grouting shall be plugged by filling with the hole-patching mixture, and new holes shall be drilled. The downfeed pressure shall not exceed 200 pounds during drilling. Spalling of the concrete resulting from drilling shall not exceed 20 percent of the pavement thickness. When such spalling occurs, the Engineer may require a lower downfeed pressure to be used.
In no case shall the holes extend more than 4 inches below the base of the pavement or stabilized subbase, if any.
When jacking is required, the Contractor may propose to the Engineer a hole pattern to be used. At all panels requiring jacking, at least one hole shall be drilled in each 12- by 20-foot panel, near the midpoint of the panel and the outside wheeltrack, for the purpose of monitoring the flow of grout into all void areas under the slab.
B. **Washing Holes.** Holes may be washed to create a small cavity, allowing initial spread of grout.
C. **Undersealing.** When undersealing, grout shall be pumped under the pavement panel until movement in the slab is detectable by a beam having a base length of at least 4 feet and at least two accurate gauges placed so that relative movement can be checked between both adjacent panels and the shoulder. In no case shall panel movement exceed 0.10 inch. The gauges shall be capable of detecting movement of 0.010 inch. Pumping pressure shall not exceed 100 p.s.i., but a higher pressure will be allowed when starting to pump the hole.
D. **Jacking.** Faulted panels exhibiting more than 0.02 foot displacement in relation to the adjoining panel, and which are capable of being adjusted by jacking, shall be jacked by grout injection. An expanding rubber packer, or other approved device, connected to the discharge hose on the grout plant shall be lowered into the holes. The discharge openings of the device may extend 1.5 inches below the lower surface of the concrete pavement, or the subbase, if any. Longitudinal stringlines shall be established by the Contractor to monitor movement of the panels. Pumping pressure shall not exceed 200 p.s.i., but a higher pressure will be permitted when starting to pump a hole. When jacking jointed panels of concrete pavement and bridge end panels, the Contractor shall pump, and repump, if necessary, in a pattern and in the amount required to raise the pavement to within 0.015 foot of the established stringline grade at that location. If both the low panel and the adjoining panel move, pumping shall be continued until the low panel is to grade. If only the low panel moves, grouting shall cease when the low panel is flush with the adjoining panel. The stringline shall be located and relocated as required.
When necessary to achieve the desired joint or crack match, the Engineer may require saw cutting certain transverse joints or cracks.
If the Engineer determines that continued grout injection at a specific location is no longer feasible due to major voids, he may direct the Contractor to cease grout injection at that particular location.
E. Overjacking. Pavement raised above the tolerances listed above shall be brought within tolerance by grinding. Should the overjacking be greater than 0.10 foot, the Engineer, at his option, may require removal and replacement of the pavement with portland cement concrete in accordance with the provisions of Section 2212 that he deems appropriate, and he will designate the area of pavement to be replaced. Where shoulder damage occurs, the Contractor shall repair such areas at no additional cost.
F. Water Displacement. Water displaced from the void structure by the grout shall be allowed to flow out freely. Excessive loss of the grout through cracks, joints, or in the shoulder area will not be tolerated.
G. Radial Cracks. Cracks emanating radially from the grout injection holes will be presumed to have been caused by improper injection techniques by the Contractor.
H. Hole Patching. Upon completion of the jacking, all drill holes shall be plugged by tamping the hole full of very dry concrete (1 part cement, 2 parts sand). The plug shall be finished flush with the pavement surface.

975.06 LIMITATIONS OF OPERATIONS. Pavement jacking and pressure grouting shall not be done when the temperature at the bottom of the pavement slab is below 40 F.

Grout may not be held in the mixer or injection pump sump for more than 45 minutes after mixing. Any grout held for a longer time shall be wasted and will be deducted from the pay quantity.

Traffic will be permitted on the undersealed or jacked pavement slab when the grout has obtained a set satisfactory to the Engineer. The minimum set time will be included in the mix design approval, intended for ideal temperature conditions. It is anticipated that the set time will be extended to approximately 6 hours at 40 F and 4 hours at 50 F. The minimum set time will vary with individual material combinations.

The work shall be conducted on only one-half the pavement width at a time.

Traffic shall be permitted to use the pavement during construction operations, and all operations shall be so conducted as to provide a minimum of inconvenience to traffic.

The work schedule shall be adjusted so that all traffic lanes can be opened to public traffic during nonworking hours. No more holes shall be drilled during a day's operation than can be grouted during the same day, unless specific approval is given by the Engineer. If unforeseen conditions should result in uncompleted sections being left overnight, and requiring protection, a sufficient number of traffic-control devices and flaggers shall be used to warn and direct traffic, from the time construction operations have stopped until they have resumed again, with no extra payment.

Except when an accelerated work schedule is required, the work schedule shall be adjusted so that all barricades and equipment will be removed from the roadbed from 30 minutes before sunset to 30 minutes after sunrise, and no work will be permitted on Sundays or holidays described in 1108.03.

Articles 1107.08 and 1107.09 shall apply. When there is a contract item for Traffic Control, the Contractor shall furnish, erect, and maintain all signs, barricades, and other traffic-control devices required by the plans and specifications.

Debris from the Contractor's operations shall be removed from the traffic lanes and shoulders as the work progresses and before the traffic lane is opened to public traffic.

Shoulder adjustments will be made by the Contracting Authority, as the Engineer deems appropriate. Except when additional shoulder work is required by the contract, the Engineer will provide and maintain signing, as he deems appropriate for vertical dropoffs at the pavement edges that remain after the Contractor has completed his pressure grouting operation. The Contractor will be responsible for signing, barricades, and other traffic control required by the plans and specifications for the shoulder while his work at the specific location remains uncompleted.

975.07 ACCEPTANCE. Before final acceptance, all waste material shall be cleaned up and the surrounding areas shall be left in a neat and orderly condition as provided in 1104.08.

975.08 METHOD OF MEASUREMENT. The work of pavement undersealing and jacking by pressure grouting will be measured for payment by the Engineer as follows:

A. **Holes (for Pressure Grouting)** drilled through the pavement at locations designated by the Engineer will be counted. Irregular or unsatisfactory holes which cannot be satisfactorily used in pressure grouting will not be included in the count.

B. **Portland Cement (for Pressure Grouting).** The weight will be calculated from the bulk weight or number of sacks of cement furnished and used in the work. This will include the quantity used in pressure grouting and in filling drilled holes. Cement that is wasted will be deducted.

When grouting is discontinued at any specific location, as directed by the Engineer, the holes drilled and the portland cement used will be included in the measured quantities.

Water and fly ash and sawing of existing transverse joints will not be measured for payment.

Grinding or replacement of pavement sections made necessary by overjacking will not be measured for payment; however, the holes and portland cement used in the jacking operation will be included in measured quantities.

975.09 BASIS OF PAYMENT. The work of pavement undersealing and jacking by pressure grouting, satisfactorily completed, will be paid for as follows:

A. **Holes (for Pressure Grouting).** For the number of holes drilled, the Contractor will be paid the contract price.

B. **Portland Cement (for Pressure Grouting).** For the number of tons of cement used in the work, the Contractor will be paid the contract price per ton.

When the contract includes an item for traffic control, the Contractor will be paid the lump-sum contract price.

When the jacking operation results in radial cracking, payment to the Contractor will be reduced by fifty cents ($0.50) for each linear foot of crack, measured by the Engineer to the nearest foot.

The payment described herein shall be considered full compensation to the Contractor for furnishing all materials, including fly ash and water and hole-sealing mixture, for proportioning and mixing, for drilling holes, for pumping and repumping, for filling the holes, for sawing existing transverse joints, and for furnishing all equipment, tools, labor, and incidentals necessary to complete the work in accord with the plans and specifications.

The quantities indicated in the contract are based on certain assumptions, as indicated on the plans, and the quantities needed may vary from that. The provisions of 1109.03 will not apply to this work.

APPENDIX D

SPECIFICATION ON UNDERSEALING USED BY PENNSYLVANIA DOT

SECTION 679 PAVEMENT SUBSEALING

679.1 DESCRIPTION - This work is sealing voids beneath existing rigid base courses or pavements at locations as directed.

679.2 MATERIALS -

(a) Cement - Section 701

(b) Water - Section 720.1

(c) Admixtures - Section 711.3. A multiphase wetting agent and an expansive agent may be used. Use an accelerator if required.

(d) Pozzolan - Section 724.2

(e) Rapid Set Concrete Patching Materials - Supplied by a manufacturer listed in Bulletin 15. Use within the shelf life and temperature limitations set by the manufacturer.

(f) Mix Design - Submit a mix design for review and acceptance, to the Materials and Testing Division (MTD), before starting work. Include, with the submittal, independent laboratory testing showing 1, 3 and 7 day compressive strengths, flowability, shrinkage and expansion results, and the time of initial set. Proportion the mix as follows:

1 part cement (by volume)
3 parts pozzolan (by volume)
Admixtures - if required and accepted
Water - an amount such that the time of efflux is within 10 to 15 seconds (ASTM - C939).

Furnish mix with an expansion of 0% to 10% (PTM No. 515), an initial setting time of one to three hours (AASHTO T-131), and bleeding which is no more than 2.5% of the volume (PTM No. 515).

A seven day compressive strength of at least 700 psi is required, based on the average of five test cylinders (PTM No. 521).

Submit a new mix design if source of any material is changed.

679.3 CONSTRUCTION -

(a) General. Do not proceed with this work until it can be satisfactorily shown that qualified personnel are available at the job site, who have had successful experience with this type of work.

Do not perform work when day time temperatures are below 35F or if the subgrade and/or base course material is frozen.

(b) Deflection Testing. In the event preliminary testing has not been performed, test each joint, and cracks as directed, as follows:

Perform all testing between the hours of midnight and 10 a.m.; however, do not perform testing if air temperature exceeds 75F.

Furnish and maintain in operating order four gauges on two gauge mounts, two gauges per mount, that are capable of detecting slab movement to 0.001 inches. Furnish a vehicle having a dual tire single axle with an 18,000 pound load.

Position one set of gauges with one gauge referenced to the corner of each slab on both sides of the joint near the pavement edge perpendicular to the pavement joint. Zero the gauges with no load on the slab on either side of the joint. Move the test vehicle into position and stop when the center of the test axle is about one foot behind the joint and the outside test wheel about one foot from the pavement edge. Read both gauges. Move the test truck across the joint to a similar position about one foot forward of the joint and stop. Read both gauges. Repeat operation for each joint and crack to be tested. Subseal all slabs having a deflection of 0.020 inches or more or as directed.

(c) Equipment.

1. Grout Plant. Consisting of the following: A satisfactory positive displacement cement injection pump and a satisfactory high speed colloidal mixing machine; the colloidal mixing machine capable of operating at a minimum speed of 800 RPM, and maximum speed of 2000 RPM, and having a rotor operating in proximity to a stator, creating a high shearing action and subsequent pressure release, to make a homogeneous mixture.

2. Water Tanker. Supply water from a water truck with adequate capacity and pressure for delivery to the grout machine.

3. Drill. Consisting of the following: Air compressor and rock drills, or other satisfactory equipment capable of drilling the grout injection holes through the pavement and base material; equipment in satisfactory condition and operated in a manner so the holes are vertical and not "out-of-round"; and a rock drill not heavier than 60 pounds, with a downfeed pressure, whether by hand or mechanical means, not exceeding 200 pounds.

4. Vertical Movement Testing. Supply satisfactory equipment to measure slab lift, capable of detecting simultaneously the lift of the pavement edge or of any 2 outside slab corners adjacent to a joint and the adjoining shoulder. Use equipment with a capability of making these measurements to 0.001 inch.

5. Miscellaneous. Provide necessary hoses, valving and valve manifolds with positive cutoff and bypass provisions to control pressure and volume, pressure gauges with gauge protectors, expanding packers or hose for positive seal during grout injection, wood plugs, hole washing tools, drill steel, bits, and any other miscellaneous tools required.

(d) Procedure.

1. Drilling Holes. Drill grout injection holes in the pattern indicated or directed. Drill holes not larger than 2 inches in diameter, vertical and round, and to a depth sufficient to penetrate any stabilized base.

2. Mixing. Accurately measure the dry materials by weight, if in bulk, or provide packaged in uniform volume sacks. Batch with

water through a meter or scale, with a totalizer for the day's consumption.

Do not hold mixed material in the mixer or injection pump sump for more than one hour after mixing. Waste material held for longer times.

Make flowability measurements at least 2 times during each work shift.

3. Void Filling. During the filling operation, use a positive means of monitoring lift as specified in Section 679.3(c)4. Upward movement of the pavement greater than 0.05 inch will not be permitted. Lower an expanding rubber packer or hose, connected to the discharge from the pump, into the hole. Do not extend the discharge end of the packer or hose below the lower surface of the concrete pavement. Pump each hole until maximum pressure is built up or material is observed flowing from hole to hole. Maximum pressure exceeding 200 psi will not be permitted, unless otherwise directed. Monitor the pressure in the grout line. Protect the gauge from the grout slurry. Allow the water, displaced from the void structure by the grout, to flow out freely. Excessive loss of the grout through cracks, joints, or from backpressure in the hose or in the shoulder area will not be permitted.

4. Correcting Panel Displacement. Grind pavement, which has been raised in excess of the 0.05 inch allowable tolerance, to the correct grade, if directed.

5. Radial Cracks. Radial cracks spreading outward from the grout injection holes indicate poor workmanship or improper methods. Stop work until the cause is determined and corrected.

6. Transverse Cracks. If transverse cracks develop between adjacent grout injection holes, repair these cracks by a satisfactory epoxy injection method or, if directed, satisfactorily replace the entire panel or a portion thereof.

7. Hole Patching. Upon completion of the work, seal drill holes flush with the surface of the pavement with a rapid set concrete patching material.

(e) Retesting. Prior to acceptance, retest each subsealed joint or crack as specified in Section 679.3(b). Regrout slabs which deflect 0.020 inches or more and retest. Any slab which continues to show movement in excess of that specified, after two properly performed groutings will be acceptable.

679.4 MEASUREMENT AND PAYMENT -

(a) Deflection Test. Each. Payment will be made only once for each location no matter how many times retesting is required.

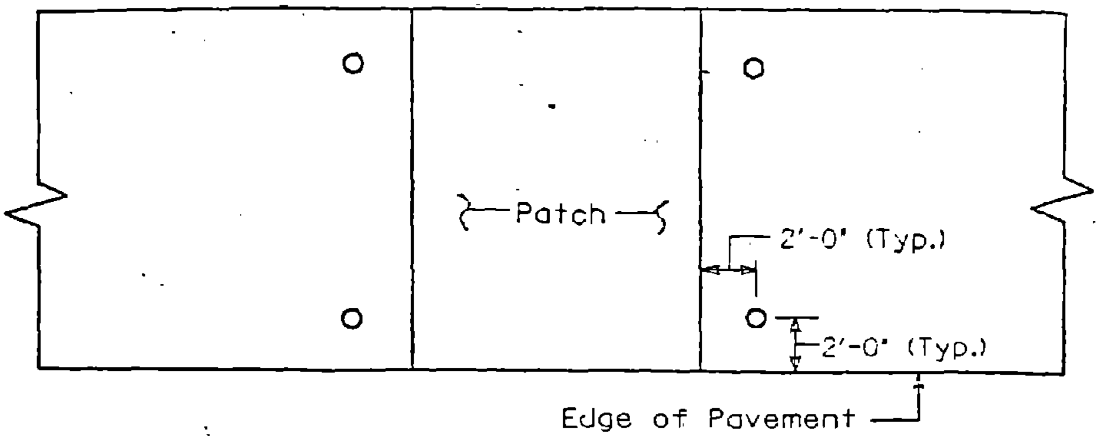
(b) Holes Drilled. Each.

Includes drilling, plugging and patching the hole.

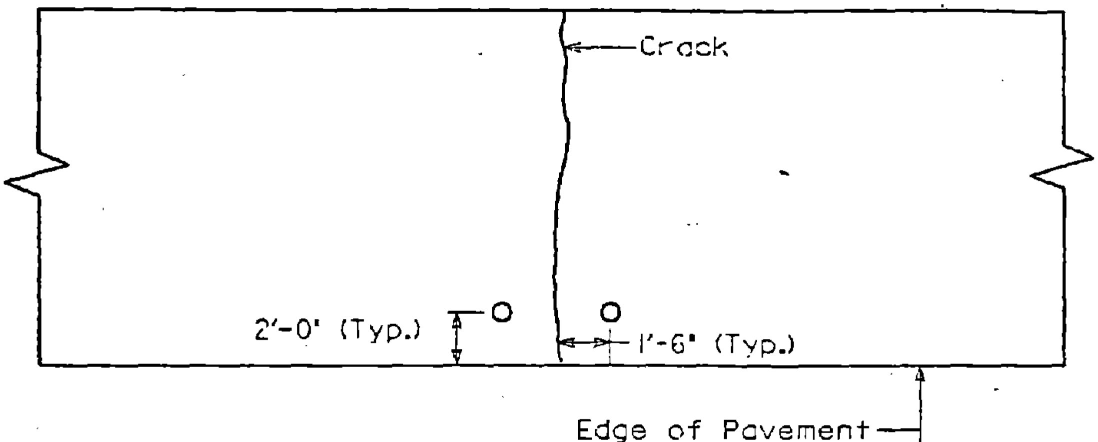
(c) Grout Material. Bags of cement.

Includes an accelerator, if required.

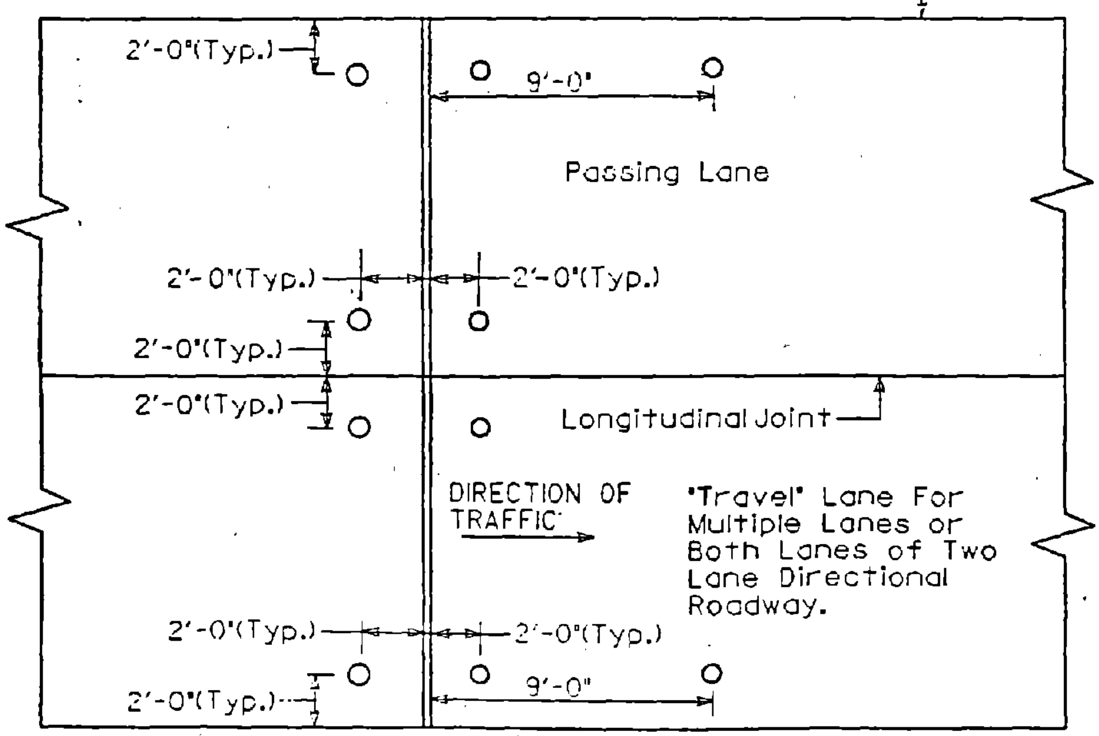
For each 5 linear feet of radial cracking, as specified in Section 679.3(d)5, the pay item will be reduced by 1 bag of cement. No payment will be allowed for any wasted grout material.



PATCH



CRACK



JOINT

NOTES: 1. Drill new holes for regrouting 6" closer to joint or crack.

HOLE PATTERNS FOR PAVEMENT SUBSEALING