PB87-155487

INVESTIGATION OF LOCATION OF DOWEL BARS PLACED BY MECHANICAL IMPLANTATION

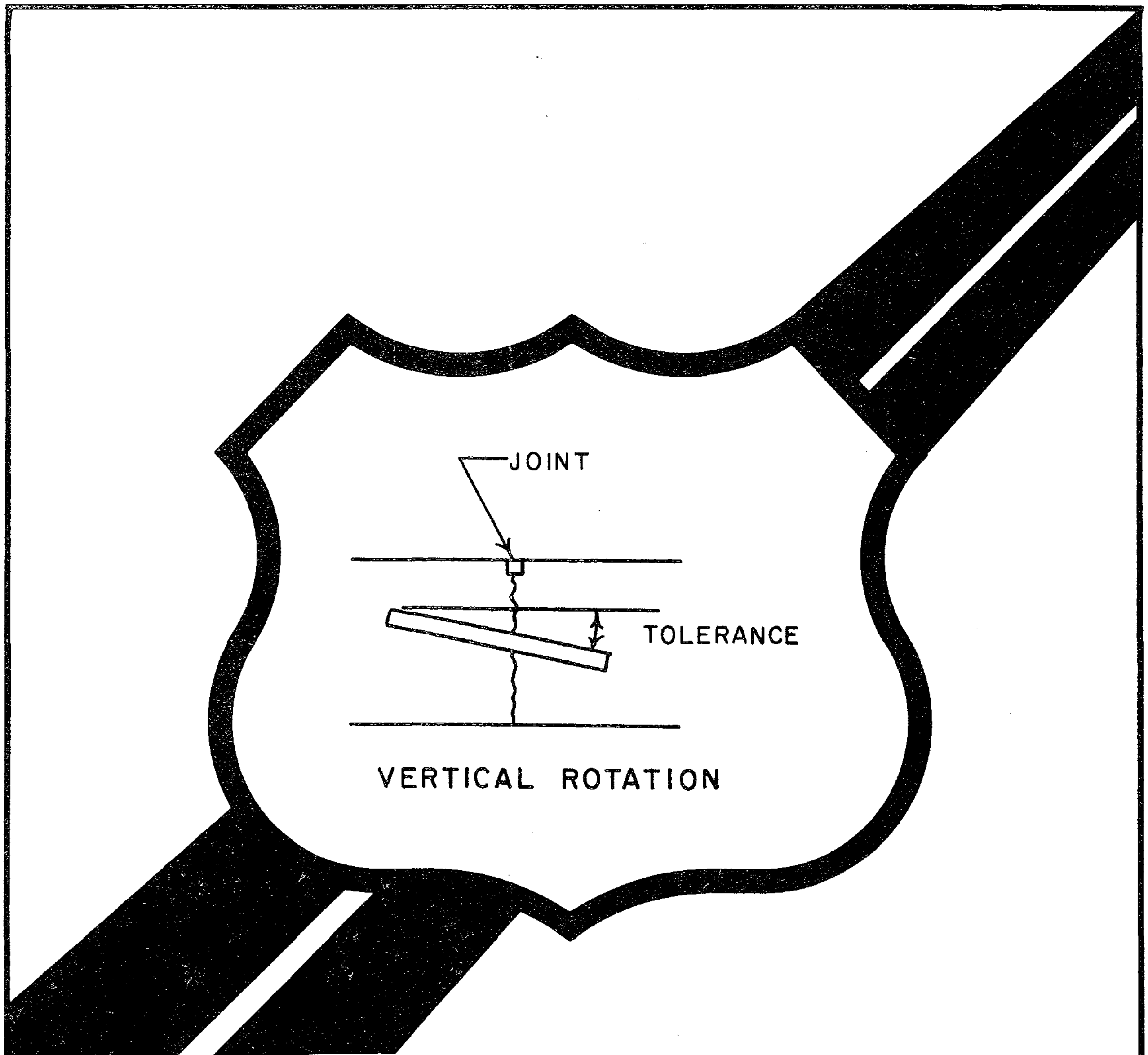
Offices of Research
and Development
Washington, D.C. 20590

Report No.
FHWA/RD-82/153

Interim Report
May 1983

U.S. Department
of Transportation

Federal Highway
Administration



FOREWORD

This report, FHWA/RD-82/153, presents the results of research conducted by the Georgia Department of Transportation for the Federal Highway Administration (FHWA), Office of Research, under Contract DTFH61-81-C-00026. This work was a part of FCP Project 6D, "Structural Rehabilitation of Pavement Systems." The report describes the results of work conducted as an interim phase of a study concerned with the restoration of load transfer to existing jointed concrete pavements. Overall performance of a pavement joint was evaluated in relation to the physical placement of the dowel bar.

In this study, a 1 percent sample of dowel bars was selected for coring to determine depth, horizontal and vertical rotation, and vertical alignment, in addition to taking measurements with a metal detector. Five different pavement sections were selected to determine the compliance to specifications of dowel bars placed by mechanical implantation and in basket assemblies. After 3 years of traffic, no pavement distress related to dowel bar misplacement had occurred even for locations with dowel bars with extremely large horizontal and vertical rotation.

Copies of this report are being given widespread distribution by FHWA Bulletin. Additional copies may be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

Richard E. Hay
Richard E. Hay, Director
Office of Engineering
and Highway Operations
Research and Development

NOTICE

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/RD-82/153		PB87 155487/AS

4. Title and Subtitle	5. Report Date
INVESTIGATION OF LOCATION OF DOWEL BARS PLACED BY MECHANICAL IMPLANTATION	May 1983
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Gary Fowler; Wouter Gulden, P. E.	RP 8009-1
9. Performing Organization Name and Address	10. Work Unit No.
Georgia Department of Transportation Office of Materials and Research 15 Kennedy Drive Forest Park, GA 30050	FCP 36D2-704
	11. Contract or Grant No.
	DTFH61-81-C-00026
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Federal Highway Administration	Interim Report March 1982 - July 1982
	14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Manager Paul Teng, HNR-20

16. Abstract

The report describes the results of work conducted as a phase of a study concerned with the restoration of load transfer to existing jointed concrete pavements. Five projects were selected for study to determine the location of dowel bars placed by mechanical implantation and in basket assemblies. A one percent stratified random sample of bars were selected for coring to determine depth, horizontal and vertical rotation and vertical alignment. Measurements were also made with a metal detector on additional bars.

The study found substantial problems with the mechanically placed dowels with respect to alignment and rotation with much better results being obtained with the basket assemblies. It was noted that saw-cut location affected longitudinal alignment to a large extent on both basket and implanted dowels. It was noted that no pavement distress related to dowel bar misplacement had occurred after three years of traffic even for locations with dowel bars with extremely large horizontal and vertical rotation.

17. Key Words	18. Distribution Statement
Dowel Bars, Concrete Pavement Performance, Mechanical Implantation, Misalignment	No restrictions. This document is available through the National Technical Information Service, Springfield, Virginia 22161.

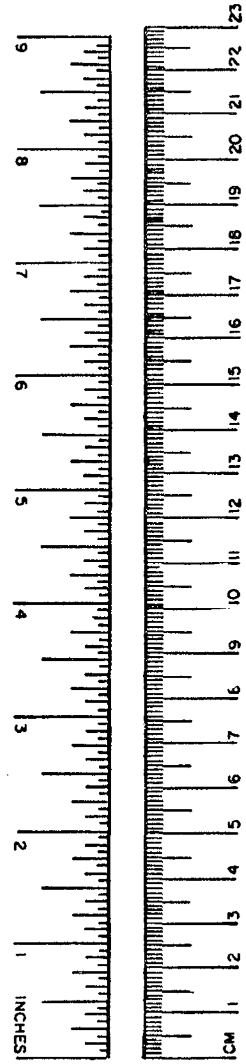
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	38	

Form DOT F 1700.7 (8-69)

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	8.03	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

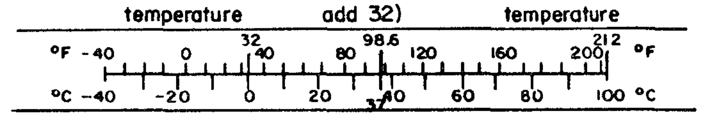


TABLE OF CONTENTS

OBJECTIVE OF STUDY

The objective of this investigation was to determine the final position of load transfer dowel bars placed by the mechanical implanter in fresh concrete and to establish the existence or nonexistence of joint distress due to misaligned dowels in Georgia pavements.

INTRODUCTION

The importance of proper joint design in portland cement concrete pavement has been emphasized for years by engineers. Materials and techniques for constructing and sealing contraction joints have improved markedly, although many disagree on the best methods and materials. Many states also use load transfer devices in contraction and construction joints.

Load transfer devices are generally in the form of round steel dowels and may be fixed in supportive "baskets" or placed into the plastic concrete by mechanical implanters. The use of the implanter and the degree of dowel alignment achieved by this construction method are the subjects of this report.

The Department began specifying load transfer dowels in 1975. The first project (M-5020 Richmond) to be doweled utilized baskets and the next project (I-16 Bulloch) paved in 1976, was done by an implanter. The contractor utilized a Maxon spreader with the spreading hopper removed, internal vibrators attached to the forward end of the dowel implanter and center tie bar implanter attached to the aft end. The concrete was vibrated and the dowels were implanted at locations indicated by a tack in the outer edge of the track line on both sides of the pavement. A CMI paver then shaped the pavement without additional internal vibration.

Dowels for ten-inch pavement were 1 1/4 inches in diameter and 18 inches long. Spacing was 15 inches center to center on the projects herein; however, this has been changed to 12 inches recently.

The specifications for the implanted bars required a vertical and horizontal tolerance of ± one inch. Tolerance for rotational misalignment was 1 1/8 inches in the horizontal plane and 9/16 inch in the vertical plane for an 18-inch bar.

A third project (APD-056 Forsyth) was done with a similar implanter except the contractor tried placing the dowels after the paver had passed. This resulted in extra finishing, dowel depressions filled with grout and poor riding surface. The implanter was positioned ahead of the paver after a short period.

During the initial days of construction of these first projects, tests were made in the wet concrete to determine position of the dowels. Tests consisted of probe measurements and in many cases complete excavation of the bars. Measurements were taken from a string line set between the tack points established for location of the contraction joint. The final position of the bars was good except for a few instances when poor orientation of one or two bars in each joint installation was discovered. On I-16, vertical and horizontal tolerances were substantially within the Specifications (extremes were from 1/8 inch high to 1 1/8 inch low measured from slab center). Maximum misorientation was 1/2 inch in the vertical plane. A considerable number of bars on the APD project measured out of specifications at first; but as the job progressed the measurements improved to tolerance levels.

The final and most convincing factor indicating that successful implanting had been achieved was the apparent lack of influence the dowels had on the normal functioning of the contraction joints. On APD within 3 to 7 days, alternate joints were functioning. On I-85, all joints were working in 3 days. Joint spacing on all doweled projects were 20 feet.

Approximately a one mile section of the APD project was placed using plastic coated dowel bars. Other dowels were red lead painted and grease coated. There was no observable difference in the functioning of joints. The plastic bars were saw-cut (painted bars were shear-cut) and this provided a better shape at the ends.

Implanting dowels appeared to be a satisfactory method and the practice was continued until 1980. During this time, spot inspection of dowel position indicated increasing problems with placing dowels within specification tolerances. Reports from other states received at this time indicated that serious problems were being encountered elsewhere. These factors led to the suspension of the use of the implanting method until investigation could determine dowel position on projects constructed between 1976 and 1980.

METHOD OF INVESTIGATION

Three interstate projects with dowels implanted were chosen for study of dowel placement. Two additional projects with basket assemblies were selected for comparison to the implanted projects. These projects included four major paving contractors for this area and four different saw-seal contractors. The quality of work done by the joint sawing contractor has a critical effect on the final position relationship of dowel bars to the contraction joint.

A one percent stratified sample was taken by random number selection of one contraction joint within each 100 joint section of each project. The 20 dowel bars in each joint were then subjected to random selection of one bar. This bar was cored at each end for determination of actual depth, longitudinal alignment, vertical and horizontal rotation as defined in Figure 1, and verification of metal detector accuracy. Three other bars in the joint were selected for horizontal rotation and joint alignment tests by use of the metal detector. Each sample joint and the two adjacent joints were examined for distress indicators, i.e., cracking and spalling. Also the exposed bar was checked for powdering of concrete, locked joint and condition of paint.

The five projects listed in Table I were evaluated by the methods described above.

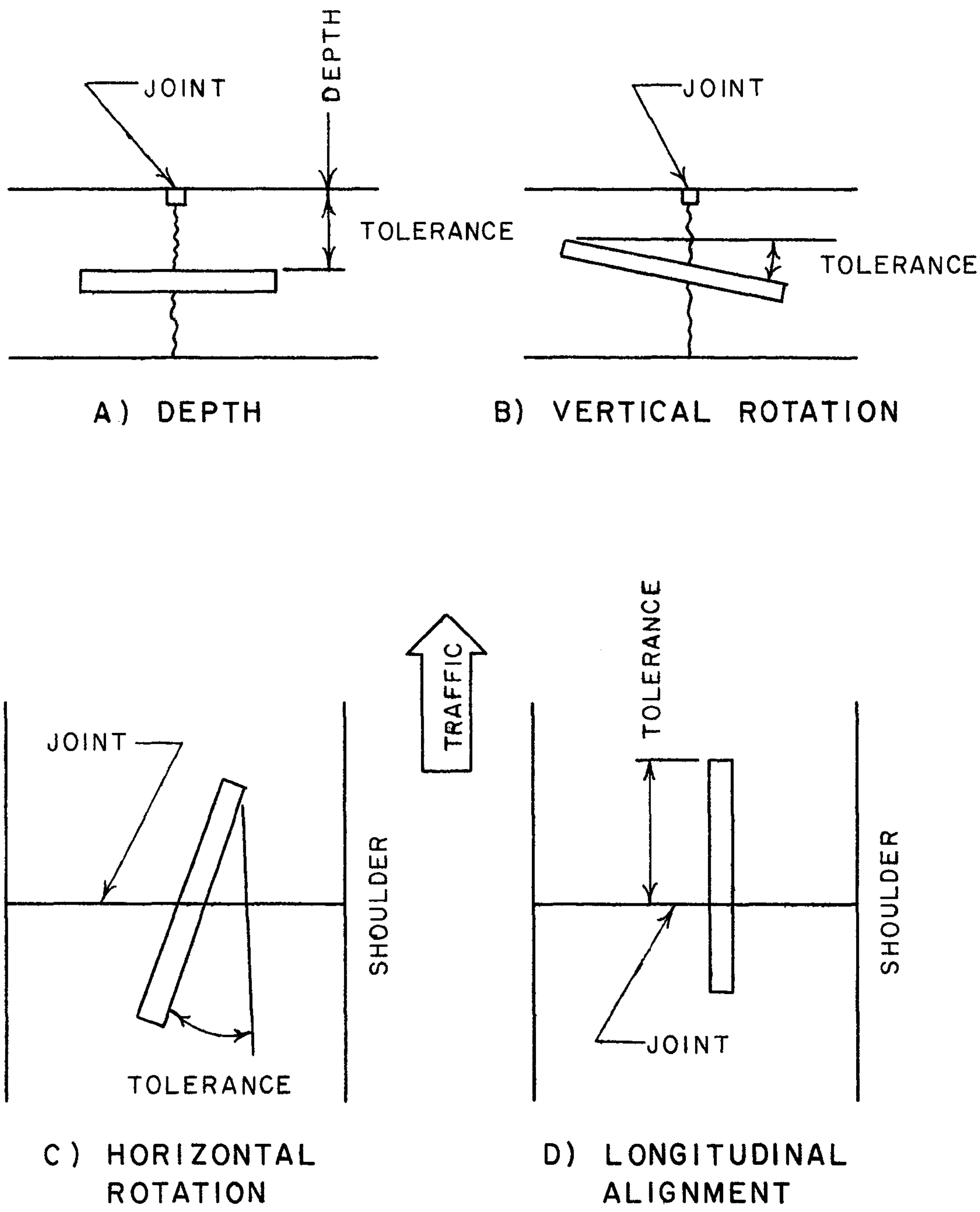


FIGURE 1. DOWEL ALIGNMENT DEFINITIONS

Table 1. Project identification

PROJECT DESIGNATION	PROJECT NUMBER	LOCATION	AGE	DOWEL PLACEMENT METHOD
A	I-16-1(38)115 Ct 3 Bulloch County	SR 73 to SR 67 10.285 miles	5 yrs.	Implanter
B	I-20-1(23)00 Ct 4 Carroll-Haralson	Alabama Line to US 27 11.585 miles	3 yrs.	Implanter
C	I-85-1(33)12 Ct 3 Troup County	SR 219 to Hines Rd. 8.538 miles	3 yrs.	Implanter
D	I-20-1(27)11 Ct 4 Carroll County	US 27 to SR 61 11.874 miles	3 yrs.	Baskets
E	GS 7-ACS-13-1(42) GS 9-ACF-13-1(44) Hall County (SR 365	SR 23 to SR 52 8.111 miles	3 mos.	Baskets

All five projects were placed using the same method and sequence of concrete placement and finishing techniques. Projects D and E were included in the study as a comparison of the basket placement method against the implanting method. Actual paving sequence and type of equipment used on each project is listed in Appendix A. Projects will be designated throughout the report with the letter designation shown in Table 1.

During the course of this investigation, 261 joints were evaluated, 522 cores were taken and 1,044 dowel bars measured. An additional 400 to 500 joints were examined for signs of distress on the projects listed. Approximately 8,000 joints were examined for distress on two more projects, I-16 Treutlen-Emanuel and I-16 Emanuel-Candler. Both of these projects have implanted dowels.

ANALYSIS OF DATA

Specification Compliance

The data was analyzed for the position of the dowels as compared to the specification requirements for depth, vertical rotation, horizontal rotation, and longitudinal movement. The summary of this data for the projects which were investigated is shown in Table 2 below.

Table 2. Percent of dowels out of specification tolerance

PROJECT	TYPE INSTALLATION	DEPTH(1)	VERTICAL ROTATION(1)	HORIZONTAL ROTATION (1)	HORIZONTAL ROTATION (2)	LONGITUDINAL ALIGNMENT (1)	LONGITUDINAL ALIGNMENT (2)
A	Implant	24	20	9	10	65	68
B	Implant	72	17	25	15	75	66
C	Implant	83	28	20	22	63	62
D	Basket	0	5	0	4	57	54
E	Basket	0	0	5	10	21	22

[1] Core measurements; [2] Metal detector measurements

It is clear from Table 2 that there is substantial non-compliance with the specification requirements for the projects with the implanted dowels. The projects where the dowels were placed in baskets showed good compliance with the specification requirements except for longitudinal alignment. The figures for horizontal rotation for Project E are misleading since a tighter specification of 9/16 inch maximum rotation was in effect as compared to 1 1/8 inch rotation for the other projects. None of the dowels checked on Project E were more than 1 1/8 inch out of tolerance. The misalignment of the dowel with respect to the joint could be due to the saw-cut not being made over the center of the dowels.

Dowel Depth

The depth of the dowel bar in the concrete was determined from cores taken at each end of the bar. Measurements were made from the top of the slab to the top of the bar and then averaged to obtain the depth at the midpoint of the bar. The average slab thickness for a project was also determined from the cores. The amount of excess slab thickness from the design thickness was subtracted from the measured bar depth. The designs call for the bars to be placed at mid-depth of the theoretical slab thickness. During construction the bar depth reference plane is established from the base, therefore, an excessive pavement depth may indicate an incorrect bar depth when the measurements are made from the top of the slab unless a correction is made to the measurements to account for the extra slab thickness. The distribution of the data for each project is shown in Figure 2. It is obvious that a large percentage of the implanted dowels that were checked were closer to the base than the specifications allowed while the dowels in baskets were found to be within specification tolerances of mid-depth plus or minus 1 inch. The frequency graph also shows that there is a wide range in dowel bar depth for projects B and C. Project A was the first project on which the implanting method was used in Georgia and perhaps was more closely controlled.

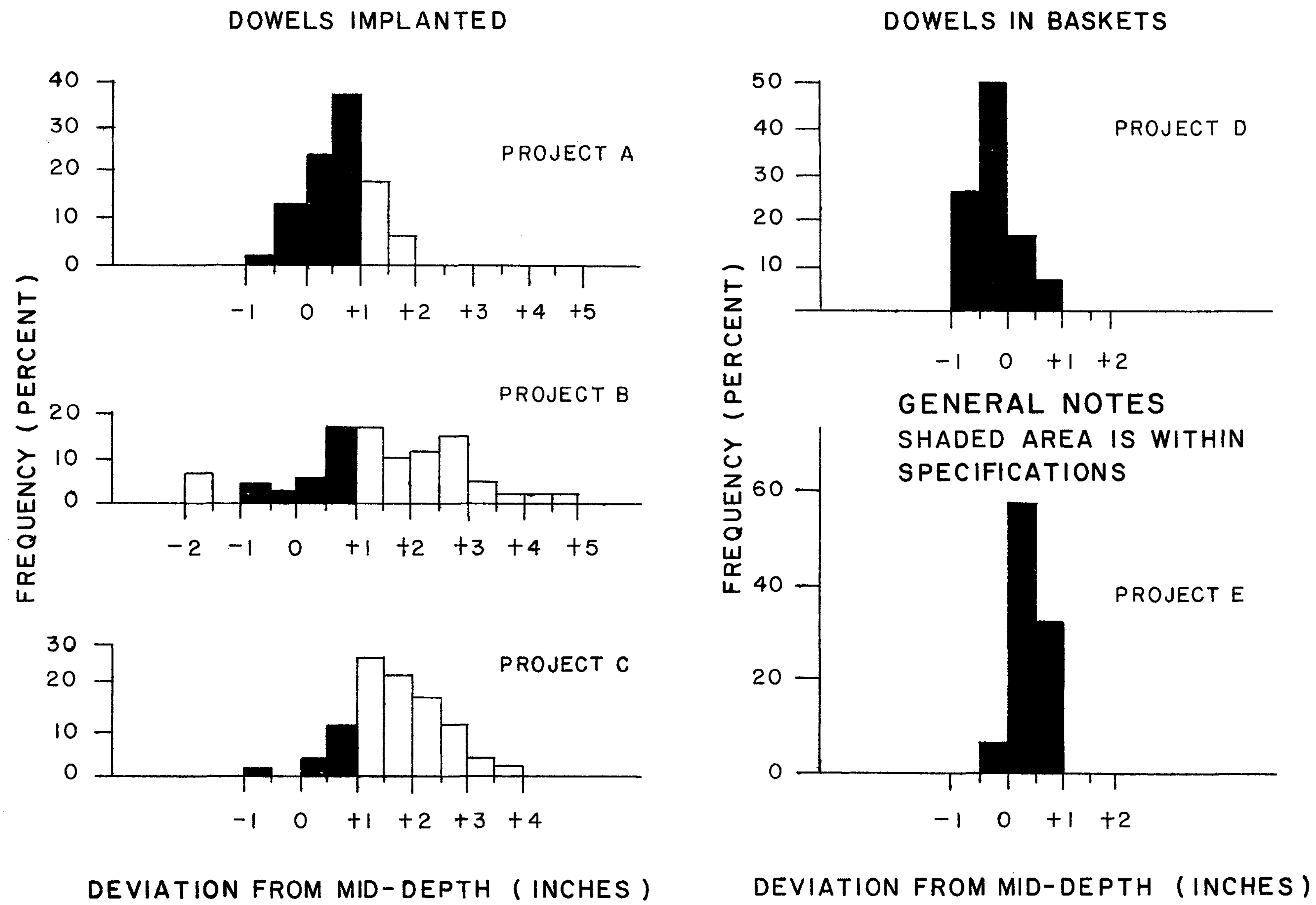


FIGURE 2. FREQUENCY GRAPHS OF DEVIATION OF DOWEL BARS FROM MID-DEPTH

Vertical Rotation

Vertical rotation is defined in this study as the difference in elevation between the two ends of the bar and was determined from cores. The specifications allow a 9/16 inch vertical rotation. The maximum rotation that was measured was 1.5 inches for one bar on one project. Table 3 shows a summary of the vertical rotation measurements.

Table 3. Summary of vertical rotation measurements

Vertical Rotation	Percent Occurrence				
	A	B	C	D	E
0	35	25	20	35	33
0 to 1/4 inch	63	57	49	82	92
0 to 1/2 inch	80	83	72	95	100
0 to 3/4 inch	96	92	87	97	
0 to 1 inch	96	95	93	100	

It has been reported that vertical misalignment greater than 1/4 inch greatly increases restraint stresses (1). Projects D & E which contain dowels in baskets have less bars with vertical alignment variations of over 1/4 inch than the projects with implanted dowels.

Horizontal Rotation

Horizontal rotation is defined as the amount of skew of the bar in the horizontal plane with respect to the centerline or edge line of the pavement. The data for this rotation was obtained from core measurements and readings obtained with a metal detector. Three dowel bars were located with the metal detector from each joint where cores were obtained to determine horizontal rotation. A summary of the data for both the cores and metal detector is shown in Table 4.

Table 4. Summary of horizontal rotation measurements

Horizontal Rotation (range inches)	Percent Occurrence									
	A		B		C		D		E	
	Core	Detector	Core	Detector	Core	Detector	Core	Detector	Core	Detector
0	26	18	12	14	22	9	45	18	36	23
0 - 0.25	54	50	29	34	37	25	85	56	76	63
0 - 0.5	72	68	46	60	69	46	95	76	95	90
0 - 1.0	91	90	75	85	80	78	100	96	100	100
0 - 1.5	100	96	88	93	93	93	100	99	100	100

The largest amount of rotation was measured with the metal detector at 3.75 inches on Project C. The specification requirements at time of construction was a 1 1/8 inch tolerance for Projects A through D and 9/16 inch tolerance for Project E. Present specifications allow a 9/16 inch tolerance. The data indicates that this requirement would be a problem for implanted dowels. There are some differences between rotation occurrence observed from cores and by the metal detector especially at the smaller rotation values of 0.5 inch or less. This difference can be attributable to the measurement accuracy of the detector which was found to be 1/3 inch on horizontal rotation and to the larger number of tests that were made with the metal detector.

Longitudinal Alignment

Longitudinal alignment is defined as the distance between the end of the bar and the transverse joint. All measurements were made from the transverse joint forward to the bar end in the direction of traffic flow. Measurements were made from cores and three additional measurements on each cored joint were made with the metal detector. A summary of the data is shown in Table 5. All dowel bars used in the projects are 18 inches in length and the specification required the saw-cut to be centered over the bars with a tolerance of ± 1 inch.

Table 5. Summary of longitudinal alignment

	Percent Occurrence									
	A		B		C		D		E	
Length (in.)	Core	Detector	Core	Detector	Core	Detector	Core	Detector	Core	Detector
0-1.9			3.4	1.1			1.7	1.7		
2-3.9			1.7	3.3			1.7	0.6		
4-5.9	1.9	6.6	10.2	11.1	4.3	2.9	-	1.1		
6-7.9	22.2	21.1	22.0	16.7	23.9	18.8	3.3	2.2	16.7	11.1
8-10	35.2	32.2	25.4	34.4	37.0	40.6	43.3	45.6	78.6	77.8
10.1-11.9	29.6	25.6	16.9	14.4	15.2	23.9	28.3	26.1	4.8	10.3
12-13.9	9.3	11.8	10.2	13.3	17.4	10.9	10.0	11.1		0.8
14-15.9	1.9	2.6	3.4	3.9	2.2	2.9	6.7	8.3		
16-17.9							3.3	1.7		
out of joint			6.8	1.7			1.7	1.7		

More than half of the bars checked were out of compliance with the specifications on embedment length for Projects A through D and one-fourth for Project E. The location and alignment of the saw-cut after placement plays a large role in the longitudinal alignment regardless of the method of dowel placement. On Projects B & D some dowels were found to be completely out of the joint. On Project B the reason appeared to be dowel movement and saw-cut location while on Project D paver contact with the baskets and saw-cut location were the factors involved. It also may have been possible that the basket assemblies were inadequately secured to the base thereby allowing some movement during paving operations since the dowels generally had a longer embedment length in the direction of paving operation.

Effect of Dowel Misalignment on Performance

The main concern with the use of dowels in joints is the effect of misalignment on the performance of joints. There is concern that vertical or horizontal rotation can cause the joint to lock-up which can lead to random cracking in the slab.

A study conducted by the Alabama Highway Department in 1967 investigated the effect of misalignment of dowels (1). The study found that misalignments of 1/4 inch or less was insignificant regardless of the plane of misalignment. Dowel misalignment errors on the horizontal plane could be as great as 3/4 inch without any appreciable increase in the load required to produce a joint opening of 1/2 inch. However, misalignment greater than 1/4 inch in the vertical plane required a considerable increase in load to produce a similar joint opening. It was further noted that spalling type failures may occur at contraction joints with a one-inch alignment error in the vertical plane while an error of 3 inches in the horizontal plane was required to produce spalling.

A study conducted by Teller in 1958 concluded that the length of dowel embedment required to develop maximum load transfer is six bar diameters for a bar with a 1-inch or 1 1/4-inch diameter (2).

Present Georgia specifications allow a misalignment of $\pm$ 1 inch in the vertical and horizontal placement location and a rotational error of 9/16 inch in the horizontal and vertical direction for an 18 inch bar. The specifications in effect at the time of construction for four of the projects allowed a 1 1/8 inch horizontal rotation.

It is obvious from this discussion that the maximum misalignment that can be tolerated has not yet been firmly established. The degree of misalignment that can be tolerated would be dependent upon the traffic load applications, amount of joint movement, and slab length. Shorter slab lengths could tolerate a larger degree of misalignment than longer slabs because the restraint forces are proportional to slab lengths.

During this study all dowels were examined in the core hole for evidence of movement, powdering, and distortion of the dowel cavity. The condition of the paint coating on the dowels were also observed. It was noted that all dowels were working even one dowel which had 1 1/2-inch vertical rotation and 3 1/2-inch horizontal rotation. No visible damage to the concrete was noted at this location and no powdering or destruction of the dowel cavity was evident at the ends of the bar where the cores were taken. Dowel movement had removed the red lead paint which was used for dowel coating on the working end in most cases. The paint appeared to provide little protection for this part of the dowel. Only one set of cracks were found in the doweled joints that were observed including all joints with implanted dowels. Cores were obtained at the location with the crack and revealed honeycombed concrete as the cause of the problem.

No dowel related distress was found in the 8700 joints that were examined as part of this study. There has also been no completely locked joints observed during construction although it would be reasonable to assume that at least a small number of dowels have restricted movement.

It has been noted during construction that all joints appear to start opening or "working" at the same time while the normal pattern would be for every third joint or so to open up initially with the remaining joints to start working at some later time. The fact that 20 foot slab lengths are used in Georgia reduces the magnitude of movement and alleviates a potential problem.

The data indicates that the 18 inch dowel length is the minimum that should be used to insure adequate embedment length because of the potential of some longitudinal dowel movement in the direction of paving and the difficulty in aligning the saw-cut over the mid-point of the dowels.

The data further shows that Georgia specifications for dowel alignment can be met with basket type installations, but not with the implanting method. It also appears that the tolerances could be somewhat relaxed based on the performance of the joints where the dowels are out of tolerance. It is premature for such a recommendation at this time until additional loadings and joint movement cycles are obtained on the projects.

Implanting vs Basket Assemblies

The first major project in Georgia with implanted dowels was constructed in 1976. The practice of placing dowels from the surface of the concrete by a machine was first reported in 1945 (3). The report also indicates that a dowel installing machine was used in 1949 in Georgia on the Atlanta Municipal Airport (Hartsfield International). The report concludes that the mechanical placement of dowels performs as well as conventional basket construction.

More recent reports describe the experience with the implanting method in Pennsylvania (4) and Florida (5).

The data obtained in this study indicates a wide variation in dowel alignment with the implanting method and substantial non-compliance with the Georgia specifications. It is believed that better installations can be made as evidenced by the results on I-16 (first project) through close inspection and by advances in equipment and construction techniques. The conventional method of placing dowels in baskets results in much better alignment of the dowels for an entire project.

CONCLUSIONS

1. The first project to utilize implanted dowel bars in Georgia substantially met the specification requirements and compared closely to the accuracy of one reference job which utilized supportive baskets (Project D).
2. The accuracy of implanted work deteriorated during the time Projects B and C were constructed. Possible reasons are reduced inspection and the resulting reduction in contractor effort. Project A provided no surface or internal vibration after the dowels had been placed. The other projects did vibrate the surface or vibrate to a shallow depth with internal vibration. This coupled with a large roll of concrete ahead of the paver is a cause of dowel movement in plastic concrete.
3. Utilization of baskets does not eliminate all problems of rotation and especially the problem of longitudinal alignment.
4. Longitudinal displacement is affected at least as much by location of the sawed joint as it is by actual dowel movement.
5. The most difficult factor to control with implanting seems to be the vertical height of the dowel.
6. No dowel related pavement distress has occurred to-date in the implanted projects or the basket projects.
7. All dowels which were examined on the five projects are working.
8. The dowel bar paint is ineffective as a coating on the working end

of the dowel. However, it does aid in breaking the concrete bond to the dowel.

9. The concrete cavities are presently providing a tight working sleeve for the dowel.

10. The longitudinal alignment compliance was substantially better on Project E as compared to the other projects which is the result of increased inspection of placing and marking of dowel positions and better control of joint saw-cut location.

RECOMMENDATIONS

1. The implanting of dowels should not be allowed at this time on jointed concrete pavement construction.

2. Increase the side clearance on baskets by allowing the basket to extend not more than one inch beyond the outside dowel and maintain a minimum clearance of 3 inches between the outside of the basket and the pavement edge.

3. During construction, the location of the dowels should be checked on a daily basis by use of probes or metal detectors.

4. Rigidly inspect the location of contraction joint sawing in relation to the mid-point of the dowel assembly.

5. Inspections should be made on existing projects with doweled joints on a periodic basis for any sign of dowel related distress.

6. Maintain the existing joint-sealing maintenance program to provide protection for dowels and reduce chances of lock-up caused by rust and debris intrusion.

7. Research should be conducted in improved methods and equipment for implanting dowels because of the potential cost savings that can be realized with the implanting method.
8. Additional studies should be conducted to determine maximum variations that can be allowed without affecting performance. These tolerances should be established based on such conditions as slab length and joint movement (climatic factors).

REFERENCES

1. Segner, Dr. E. P., Jr. and John R. Cobb "A Study of Misaligned Dowels in Concrete Pavements," Bureau of Engineering Research, University of Alabama, Alabama Highway Research, HPR Report No. 32, August 1967.

2. Teller, Leslie W. and Harry D. Caskell "Performance of Doweled Joints Under Repetitive Loading," Public Roads, Volume 30 No. 1, April 1958.

3. Halm, Harold J. "New Equipment for Placing Distributed Steel and Dowels in Concrete Pavement," PCA paper presented at Ohio Highway Engineering Conference, April 1965.

4. Nichols, T. H. and G. L. Hoffman "Machine Insertion of Plastic Coated Dowel Bars in R.C.C.P.," Pennsylvania Department of Transportation, Project No. 78-8, May 1980.

5. "Misaligned Dowels in Concrete Pavements," Florida Department of Transportation, July 1980.

Appendix A

Detailed Project Information

PROJECT (A)

PROJECT NO.	- I-16-1(38)115 Ct. 3 Bulloch County
CONTRACTOR	- Southern Roadbuilders, Augusta, Georgia
PROJECTS LIMITS	- Extends east from SR-73 10.285 miles to SR-67
CONSTRUCTION DATE	- Began paving 3/2/76, completed paving 6/8/76
PAVEMENT TYPE	- 10" thick, 24-ft. wide and 20-ft. spaced transverse contraction joints
DOWEL BAR	- 1 1/4" Ø, 18" length - 15" center to center transverse spacing
TRAFFIC COUNT	- Annual average 24-hour two-way traffic count (all type vehicles) 1979 = 2900 1980 = 4600
TYPE BASE	- 5" Soil Cement Stab. Subbase with 1" Asphalt Concrete "H" cap.

PAVING SEQUENCE -
1. Maxon side dump spreader
2. Converted Maxon spreader with hydraulic dowel bar implanter
3. CMI quad track paver
4. Tube float
5. Transverse tine finishing machine (plastic grooving)

CONCRETE MIX - Class 1 (Natural Deposit Jobsite)

Cement	541 lbs.
Silicious F.A. #10	1165 lbs.
Crushed Stone #57	1930 lbs.
Water	30.5 gals.
Air	5.0%

Slump (Project Control, 166 tests)

$\overline{X}$ = 2.07"
s = .66"
V = 32%

PAVEMENT THICKNESS - Design 10" Actual (116 measurements)

	Eastbound Lane (60 tests)	Westbound Lane (56 tests)
$\overline{X}$	10.17"	10.07"
s	.19"	.26"
V	2%	3%

PROJECT (B)

PROJECT NO.	- I-20-1(23)00 Ct. 4 Carroll-Haralson
CONTRACTOR	- Claussen Paving Company, Augusta, Georgia
PROJECTS LIMITS	- Extends east from Ga.-Ala. state line 11.585 miles to US-27
CONSTRUCTION DATE	- Began paving 5/4/77, completed 12/1/77
PAVEMENT TYPE	- 11" thick, 24-ft. wide with 20' spaced transverse contraction joints
DOWEL BAR SIZE & SPACING	- 1 1/4" Ø, 18" length - 15" center to center transverse spacing
TRAFFIC COUNT	- Annual Avg. 24-hr. two-way traffic count (all type vehicles) 1979 - 8200 1980 - 13,200
TYPE BASE	- 5" cement stab. graded aggregate subbase with 1" Asp. Conc. "H" cap. (EBL from state line to GA-100 is non-stab.)

PAVING SEQUENCE -

1. Maxon side dump spreader
2. Converted CMI paver with hydraulic dowel bar implanter and internal concrete vibrators
3. CMI quad track paver suburban (surface vibration & jail bars)
4. Tube float
5. Transverse tine finishing machine (plastic grooving)

CONCRETE MIX - Class 2

Cement	- 525#
Fly Ash	- 60#
(silicious) No. 10 F.A.	- 1200#
No. 57 C.A.	- 1835#
Water	- 30.0 gal.
Air	- 5%

Slump (Project Control, 234 tests)

$\overline{X}$ = 1.94"
s = .76"
V = 39%

PAVEMENT THICKNESS - Design 11" Actual (122 measurements)

	Eastbound Lane (61 tests)	Westbound Lane (61 tests)
$\overline{X}$	11.33"	11.22"
s	.21"	.21"
V	1.9%	1.9%

PROJECT (C)

PROJECT NO.	- I-85-1(33)12 Ct. 3 Troup
CONTRACTOR	- Ballenger Corp., Greenville, S.C.
PROJECT LIMITS	- Extends north from SR-219 8.538 miles to Hines Road
CONSTRUCTION DATE	- Began paving 2/7/77, completed paving 10/12/77
PAVEMENT TYPE	- 10" thick, 24' wide with 20-ft. spaced transverse contraction joints
DOWEL BAR SIZE & SPACING	- 1 1/4" Ø, 18" length - 15" center to center transverse spacing
TRAFFIC COUNT	- Annual Avg. 24-hr. two-way traffic count (all type vehicles) 1979 - 10,800 1980 - 14,500
TYPE BASE	- 5" cement stab. graded aggregate subbase with 1" asphalt conc. "H" cap

PAVING SEQUENCE -
1. Maxon side dump spreader
2. Converted Maxon spreader with vibratory hydraulic dowel bar implanter
3. Rex double track paver (with raised internal vibrators and tamping bar)
4. Tube float
5. Transverse tine finishing machine (plastic grooving)

CONCRETE MIX - Class 1

Cement	- 503#
Fly Ash	- 57#
Blend 50/50 Silicious No. 10 F.A.	- 496# (Shorter)
" " " " "	- 496# (Molena)
No. 57 C.A.	- 2010#
Water	- 32 gal.
Air	- 5%

Slump (Project Control, 167 tests)

$\overline{X}$ = 1.69"
s = .59"
V = 34%

PAVEMENT THICKNESS - Design 10" Actual (92 measurements)

	Northbound Lane (46 tests)	Southbound Lane (46 tests)
$\overline{X}$ =	10.24"	10.26"
s =	0.22"	0.27"
V =	2.2%	2.6%

PROJECT (D)

PROJECT NO.	- I-20-1(27)11 Ct. 4 Carroll County
CONTRACTOR	- Ames & Webb
PROJECTS LIMITS	- Extends east from US-27, 11.874 miles to SR-61
CONSTRUCTION DATE	- Began paving 5/20/77, completed paving 12/13/77
PAVEMENT TYPE	- 11" thick, 24' wide with 20' spaced transverse contraction joints
DOWEL BAR SIZE & SPACING	- 1 1/4" Ø, 18" length - 15" center to center transverse spacing in basket assemblies
TRAFFIC COUNT	- Annual Avg. 24 hr. two-way traffic count (all type vehicles) 1979 - 11,300 1980 - 15,100
TYPE BASE	- 5" graded aggregate subbase with 1" asphalt concrete "H" cap.

PAVING SEQUENCE -
1. CMI belt spreader
2. CMI paver with internal concrete vibration
3. Tube float
4. Transverse tine finishing machine (plastic grooving)

CONCRETE MIX - Class 2

Cement	525#
Fly Ash	60#
Manufactured No. 10 F.A.	1120#
No. 57 C.A.	1182#
Water	31.0 gal.

Slump (Project Control, 213 tests)

$\overline{X}$ = 1.40"
s = .47"
V = 34%

PAVEMENT THICKNESS - Design 11" Actual (124 measurements)

	Eastbound Lane (62 tests)	Westbound Lane (62 tests)
$\overline{X}$	11.67"	11.35"
s	.46"	.42"
V	4%	4%

PROJECT (E)

PROJECT NO.	- GS7-ACS-13-1(42) & GS9-ACF-13-1(44) Hall County
CONTRACTOR	- Denton Construction Co., Grosse Pt., Michigan
PROJECT LIMITS	- Extends north from SR-23 to SR-52 (8.111 miles)
CONSTRUCTION DATE	- Began paving 9/14/81, completed paving 10/21/81
PAVEMENT TYPE	- 9" thick, 24 feet wide with 20' spaced transverse contraction joints
DOWEL BAR SIZE & SPACING	- 1 1/8" Ø, 18" length (basket assemblies) 15" center to center transverse spacing
TRAFFIC COUNT	- Annual average 24-hour two-way traffic count (all type vehicles) 1978 - 4860 1998 - 8991 (design traffic volumes)
TYPE BASE	- 6" graded aggregate base
PAVING SEQUENCE	- 1. CMI belt spreader 2. REX (STR) paver with internal vibration 3. Tube float 4. Transverse tine finishing machine (plastic grooving)

CONCRETE MIX - Class 1

	Cement	- 503 lbs.
	Fly Ash	- 57 lbs.
F.A. (Manufactured)	No. 10	- 1070 lbs.
Crushed Stone	No. 57	- 1935 lbs.
	Water	- 32.0 gals.
	Air	- 5.0%

Slump (Project Control, 132 tests)

$\overline{X}$ = 2.05"
s = 0.65"
V = 32%

PAVEMENT THICKNESS - Design 9" Actual (85 measurements)

	Northbound Lane (42 tests)	Southbound Lane (43 tests)
$\overline{X}$ =	9.27"	9.05"
s =	0.27"	0.33"
V =	2.9%	3.6%

Appendix B

Distribution of Values of Dowel Measurements

AVERAGE DEPTH (DOWEL BAR)
DISTRIBUTION OF VALUES

PROJECT -	A	B	C	D	E
Design Slab Thickness (in.)	10.00	11.00	10.00	11.00	9.00
Actual Slab Thickness (Cores) (in.)	10.12	11.28	10.25	11.51	9.16
Theoretical Bar Depth from Top of Slab to Top of Bar (in.)	4.375	4.875	4.375	4.875	3.94
Type Installation	Implanted	Implanted	Implanted	Basket Assemblies	Basket Assemblies
Range of Values (in.)	**Frequency of Occurrence**				
2.875 - 3.375		4			
3.376 - 3.875	1	0	1		3 (Spec.
3.876 - 4.375	7 (Spec.	3	0 (Spec.	16	24 Tolerance)
4.376 - 4.875	13 Tolerance)	1 (Spec.	2 Tolerance)	30 (Spec.	14
4.876 - 5.375	20	3 Tolerance)	5	10 Tolerance)	
5.376 - 5.875	10	10	12	4	
5.876 - 6.375	3	11	10		
6.376 - 6.875		6	8		
6.876 - 7.375		7	5		
7.376 - 7.875		9	2		
7.876 - 8.375		3	1		
8.376 - 8.875		1			
8.876 - 9.375		1			
9.376 - 9.875		1			
9.876 - 10.375					
Minimum-Maximum Values	3.85 - 6.32	2.60 - 9.66	3.75 - 8.06	3.87 - 5.62	3.53 - 4.88
Range (in.)	2.47	7.06	4.31	1.75	1.35
Total Number of Readings	54	60	46	60	42
* Correction for Excess Slab Thickness	-.12	-.28	-.25	-.51	-.16
Average Depth after Correction Factor	5.00	6.30	6.05	4.67	4.10
Standard Deviation of Values	.57	1.50	.84	.41	.30

* Frequency of occurrence values reflect correction factor.
All values obtained from actual core measurements.

*VERTICAL ROTATION DISTRIBUTION OF VALUES

PROJECT	A	B	C	D	E	
Rotation (in.)	Frequency of Occurrence					
0	19	15	9	21	14	↑
.125	9	9	4	18	17	
.250	6	10	9	10	8	Specification Tolerance
.375	5	9	5	4	2	
.500	4	7	6	4	1	↓
.563 -------						
.625	3	2	4	1		
.750	6	3	3			
.875			1	2		
1.000		2	2			
1.125	2	1	2			
1.250			1			
1.375		1				
1.500		1				
Total Number of Readings	54	60	46	60	42	

*All values obtained from actual core measurements.

*HORIZONTAL ROTATION DISTRIBUTION OF VALUES

PROJECT -	A		B		C		D		E		
Note (1) Measured from -	Core	Metal Detector	Core	Metal Detector	Core	Metal Detector	Core	Metal Detector	Core	Metal Detector	
Rotation (in.)	Frequency of Occurrence										
0	14	29	7	25	10	13	27	33	15	29	↑
.25	15	52	10	37	7	21	24	68	17	51	Specification Tolerance
.50	10	30	10	46	6	30	6	35	8	34	↓
.75	7	22	11	24	3	21	2	20	2	10	
1.00	3	13	6	21	11	23	1	16		2	
1.125 ------											
1.25	2	7	4	10	5	15		4			
1.50	3	4	4	5	1	6		1			
1.75		1	2	6	1	6		1			
2.00		3	1	2	2	0					
2.25			1	2		1					
2.50		1		1		1					
2.75			1								
3.00			1	2				1			
3.25			1								
3.50		1									
3.75						1					
4.00											
7.00											
Total Number of Readings	54	163	59	181	46	138	60	180	42	126	

* Horizontal rotation measured from slab edge.

NOTE 1: Core values are from actual bar measurements. Metal detector values from the three additional bar ends located only with metal detector.

* LONGITUDINAL MOVEMENT
DISTRIBUTION OF VALUES

PROJECT - Note (1) Measured from	A Core	A Metal Detector	B Core	B Metal Detector	C Core	C Metal Detector	D Core	D Metal Detector	E Core	E Metal Detector	
Longitudinal Movement (in.)	Frequency of Occurrence										
0 - 1.9			2	2			1	3			
2.0 - 3.9			1	6			1	1			
4.0 - 5.9	1	10	6	20	2	4	0	2			
6.0 - 7.9	12	32	13	30	11	26	2	4	7	14	Specification Tolerance
8.0 - 10.0	19	49	15	62	17	56	26	82	33	98	Specification Tolerance
10.1 - 11.9	16	39	10	26	7	33	17	47	2	13	
12.0 - 13.9	5	18	6	24	8	15	6	20		1	
14.0 - 15.9	1	4	2	7	1	4	4	15			
16.0 - 17.9							2	3			
18.0 - 19.9											
Number of Bars out of joint			4	3			1	3			
Total Number of Readings	54	152	59	180	46	138	60	180	42	126	

* All Longitudinal measurements were made from transverse joint forward to bar end, always in traffic flow direction.

NOTE (1) Core values are from actual core measurements. Metal detector values from the three additional bar ends, located only with metal detector.

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.