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SD Department of Transportation
Office of Research

DOWEL BAR PLACEMENT AND DISPLACEMENT

Study SD91-09
Final Report

Prepared by
SDDOT - Office of Research
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16. Abstract

This report describes research performed by the South Dakota Department of Transportation to investigate the problem of dowel bar misalignment in PCC pavements. Over 400 dowel bars from three (3) construction projects were inspected and compared to the dowel bar alignment specifications.

This study found that the dowel bars tended to conform to the alignment specifications even though, in the opinion of the researcher , the specifications were too rigid. It was noted that sawing of the contraction joint was the governing factor for the longitudinal displacements. Although no pavement distress was observed in areas containing dowel bar misalignments, it should be noted that only two (2) years had passed between project construction and the field survey. It is the opinion of the researcher that this is insufficient time for pavement distress to manifest itself since even undoweled PCC pavement may not show distress or faulting for 5 years or more.

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I. PROBLEM STATEMENT

Misplacement of dowels and/or saw cuts is a problem that may lead to premature joint failure and a reduction in pavement life and has been well documented in numerous studies. The South Dakota Department of Transportation (SDDOT) has specified dowel bar use in PCC pavements to improve load transfer at the contraction joints since 1987. SDDOT personnel investigated projects constructed within recent years and have found that misalignment problems still exist to a serious degree. Construction tolerances are lacking and present specifications have not controlled the problem. New procedures are warranted to reduce the misalignments to acceptable limits.

II. BACKGROUND

Dowel bars are commonly used to improve load transfer at PCC pavement transverse joints. Although load transfer is the primary function of dowel bars, they must also allow free longitudinal movement of the contraction joint to relieve internal stresses. Freedom of movement and /or load transfer efficiency can be hindered should the dowel bars be installed out of alignment or move during the paving operation.

The most common methods for the installation of dowel bars is the use of dowel basket assemblies and automatic dowel bar inserters. Dowel basket assemblies consist of a simple thin steel frame which supports the desired number of dowel bars at the specified height **(Fig. 1)**. These steel frame provide a method of installing numerous dowel bars and of maintaining the proper dowel bar orientation through the paving process. Automatic dowel bar inserters place the dowels during the paving process by vibrating the dowels to the required depth through the concrete placed by the spreader.

The use of dowel bar inserters is more desirable from a constructability standpoint because less labor is involved and the sequence of paving operations is simplified. However, inserters' ability to meet alignment specifications is a concern because of reports of their varying success rates.

The need for research concerning dowel bar placement was indicated by SDDOT personnel who observed several occurrences of dowel bars being placed out of alignment.

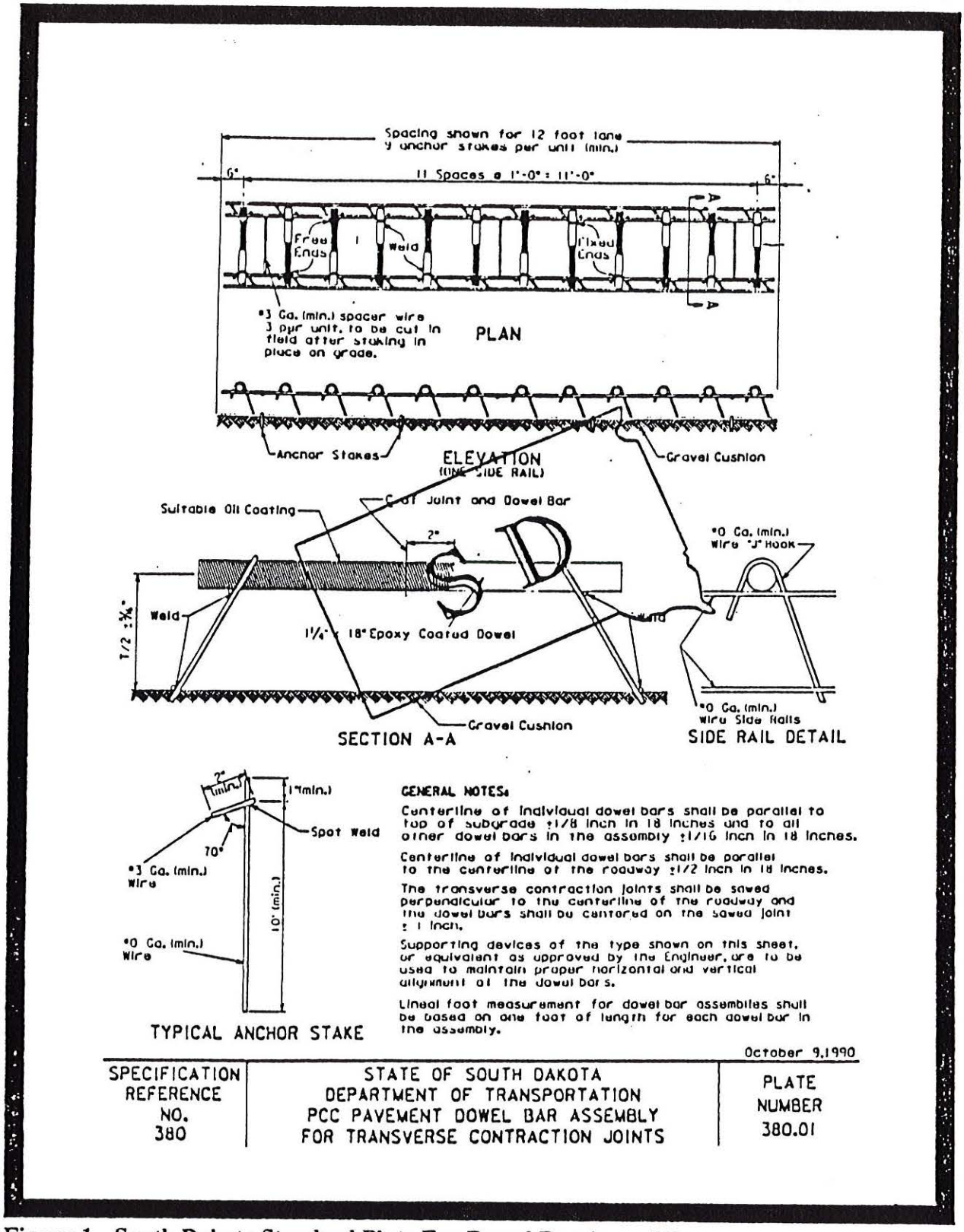

Figure 1 - South Dakota Standard Plate For Dowel Bar Assemblies

III. LITERATURE REVIEW

Dowel bar performance in PCC pavements has been a topic of much research. Information from reports and other state DOTs show that dowel bar depth, vertical and horizontal rotation, and longitudinal displacement are the evaluating criteria for dowel bar placement and displacement. For clarification, these terms are defined in **Table 1** and illustrated in **Figure 2.**

Table 1 - Dowel Placement Terms	
Vertical Translation -or- Depth (D)	Average measurement from the pavement surface to the dowel bar centerline.
Vertical Rotation (VR)	Elevation difference over the length of the bar.
Horizontal Rotation (HR)	Skew measured over the length of the bar in relation to pavement centerline or shoulder joint.
Longitudinal Displacement (LD)	Distance from dowel bar center to contraction joint.

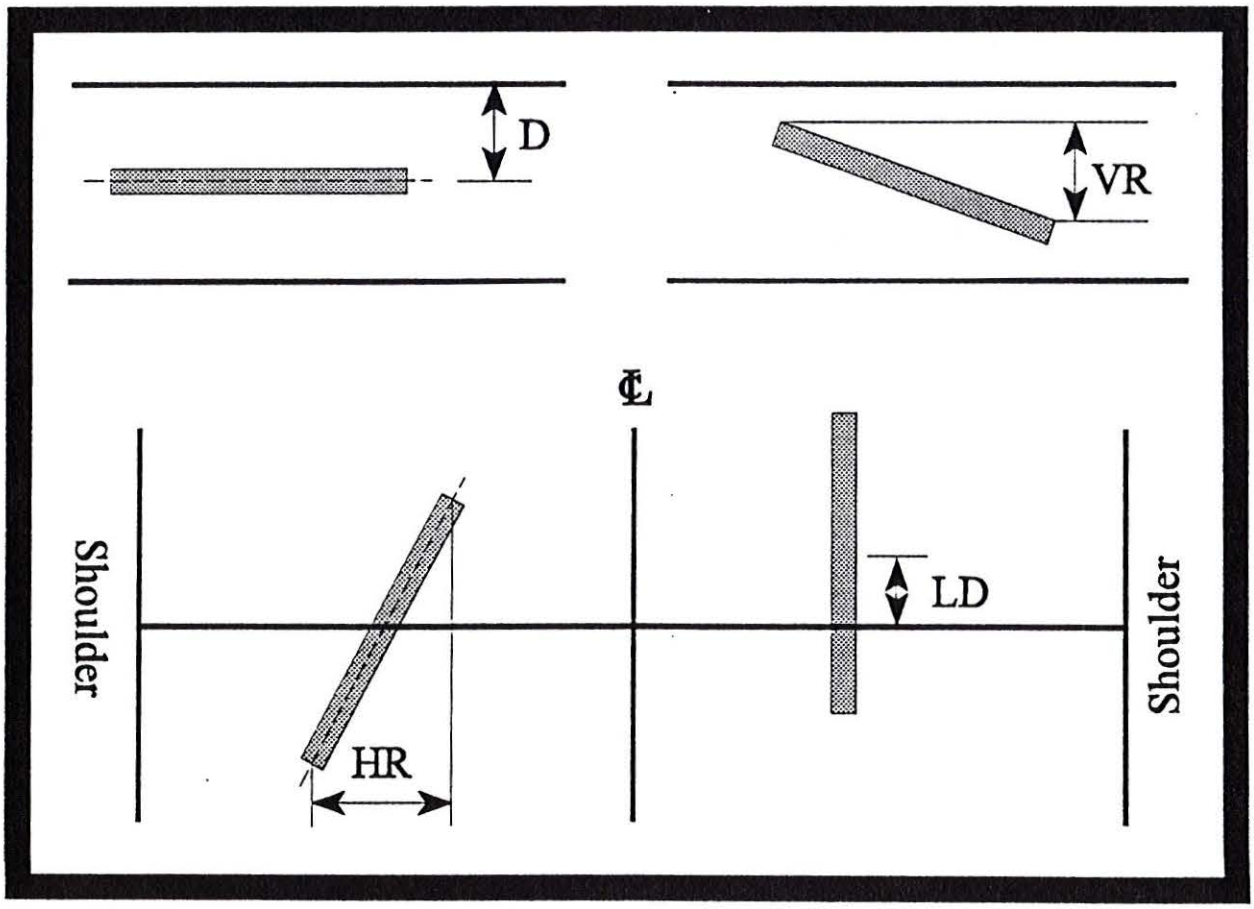

Figure 2 - Dowel Bar Alignment Definitions

It should be noted that there is no consensus as to what constitutes adequate misalignment tolerances (**5**). For example, **Table 2** shows the SDDOT's alignment specifications in relation to other states' specifications.

Table 2 - Dowel Bar Alignment Specifications (Measured over the length of the bar)

State	D [T/2±mm (in)]	VR [± mm (in)]	HR [± mm (in)]	LD [± mm (in)]
AL	12.7 (1/2)	25.4 (1)	25.4 (1)	25.4 (1)
GA	12.7 (1/2)	25.4 (1)	25.4 (1)	14.3 (9/16)
MN	7.9 (5/16)	6.4 (1/4)	6.4 (1/4)	50.4 (2)
ND*		3.2 (1/8)	3.2 (1/8)	
SD	7.9 (5/16)	3.2 (1/8)	12.7 (1/2)	25.4 (1)
WI	25.4 (1)	12.7 (1/2)	12.7 (1/2)	50.8 (2)
WY	19.0 (3/4)	9.5 (3/8)	9.5 (3/8)	76.0 (3)

*- Measured per foot of dowel bar length

The probable reason for the differences of alignment specifications is the fact that several research studies report varying degrees of tolerable dowel bar misalignments (**1-6**). These reports also show differing pull-out loads and distress occurrence for misalignments of equal magnitude. It should be noted that the reported pull-out loads came from laboratory prepared specimens that did not have the same number of dowels as a typical contraction joint. Therefore, these pull-out loads cannot be taken as absolutes because the interaction of multiple misaligned dowels is not fully understood. Correct alignment of the dowel bars helps ensure that slab movement is accommodated at the contraction joint, but if the saw cut is misplaced or misaligned there is potential for other types of distress to occur. Slab deflections can occur if the dowels are not in the joint, eventually resulting in faulting and slab cracking. When the dowels are in part of the slab, differential support and point loading can lead to cracking.

Due to varying degrees of success, dowel bar inserters' ability to place bars within specified tolerances has been a topic of concern among state agencies. For example, Georgia DOT placed a moratorium on dowel bar inserters because of noncompliance with depth and rotation specifications while Wisconsin DOT allows inserter use because they have displayed consistent placement performance. Prior to Georgia's moratorium, a project on which an inserter was used substantially met their specifications and compared favorably to a project which used dowel basket assemblies (**3**). The major contributing factors on dowel inserted projects displaying proper alignment are probably thorough inspection and contractor experience. In Wyoming, a short moratorium was placed on inserters because of a project where depth and vertical rotation were a problem. The contractor discovered that the problem was an incorrect vibratory setting on the finishing screed which allowed

the dowels to move in the plastic concrete. After making corrections to their paving equipment, the contractor was allowed to construct another pavement in which dowel alignment was satisfactory.

Another dowel bar placement technique is the Iowa Special paving operation. **Figure 3** shows a block diagram of the paving operation's sequence of events. **Figures 4 and 5** show the hopper where the concrete is delivered, the conveyor belt that transports the concrete over the dowel basket installation area, and the dowel basket installation area. The Iowa Special is a viable dowel basket installation alternative for full-width paving because concrete haul routes are simplified. The operation allows the concrete trucks to approach the concrete hopper from the roadbed rather than from the shoulders. This is significant during wet seasons when shoulder material is weak due to excessive moisture. Basket installation on the go also alleviates the problem of having to estimate how many baskets to place and lubricate prior to the next days planned paving. However, because of the cramped and extreme working conditions of the dowel basket installers, it is possible for the quality control of the basket installation operation to drop. This problem can, however, be avoided by developing a regular work rotation for the basket installers and maintaining adequate inspection.

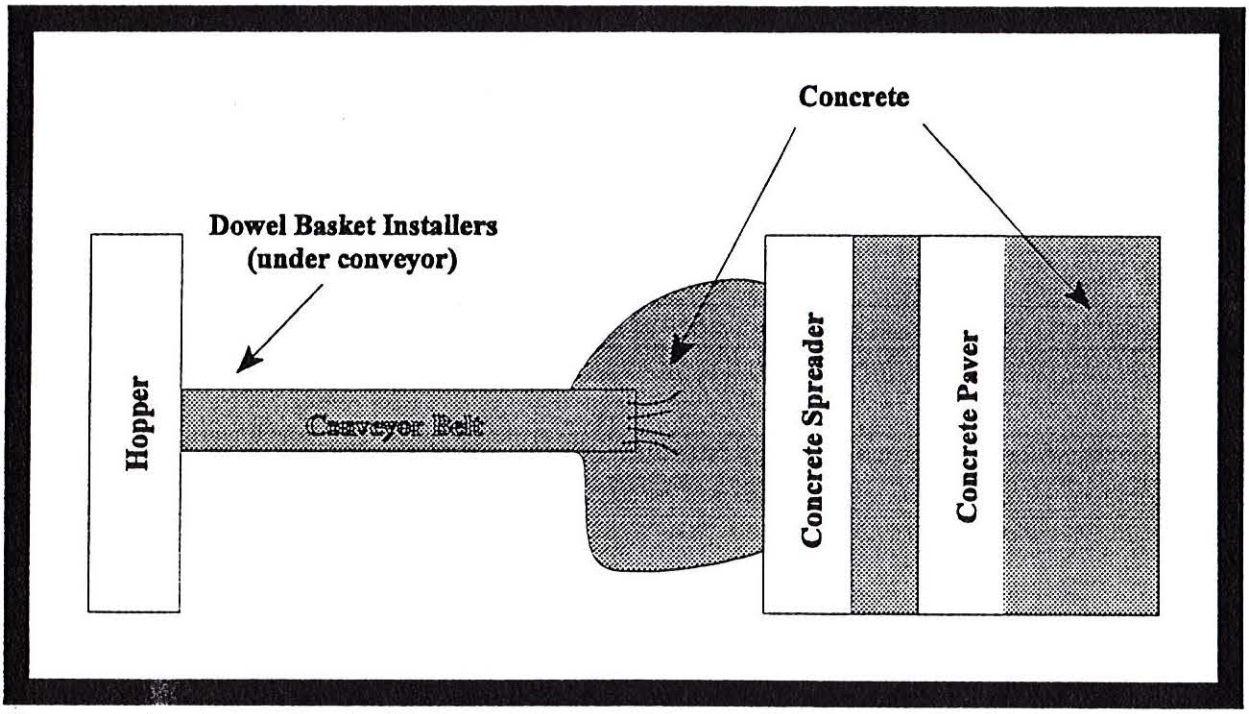

Figure 3 - Paving Operation Sequence

Figure 4 - Hopper and Conveyor Belt For Concrete Delivery

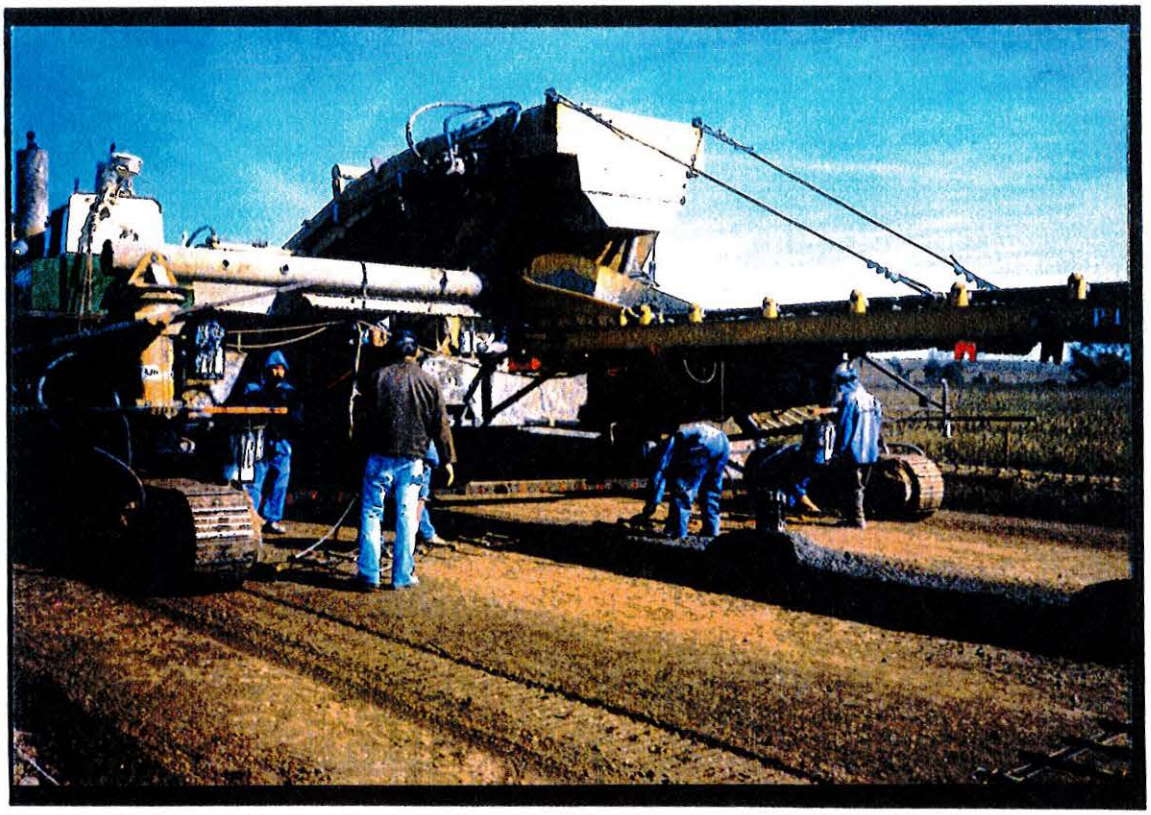

Figure 5 - Dowel Basket Installation Area (under conveyor belts)

IV. RESEARCH OBJECTIVES AND TASKS

The technical panel overseeing this research project outlined the following research objectives and tasks to be performed to address the Department's concerns:

Research Objectives

1. Develop more detailed specifications and tolerances which will provide satisfactory performance.

2. Determine necessity of in-house training and improved utilization of field personnel.

3. Determine need for design changes.

4. Explore alternative methods of dowel placement (e.g. - Iowa Special and Automated inserters).

5. Recommend policy regarding pay reductions for out of specification joints.

Research Tasks

1. Conduct complete literature search including contacting other states with potential solutions.

2. Compile results of existing in-house investigations and conduct research on problem projects to determine extent and severity of misalignments and resulting loss of performance.

3. Determine economical and structural feasibility of alternative insertion methods including automated dowel insertion and the Iowa Special system based upon other states' results.

4. Recommend construction specifications, tolerances, and design modifications based upon results of this study.

5. Recommend pay reduction policy based upon the cost of joint repair, replacement, or loss of pavement life.

6. Prepare an interim report summarizing progress and expected work plan for the upcoming year by May 1, 1991. This will be used to determine if any preliminary adjustments to construction policy should be made before the construction season.

7. Prepare a final report describing research methodology, findings, conclusions, and recommendations by May 1, 1995.

V. RESEARCH TASK METHODOLOGY

Task 1. *Conduct compete literature search including contacting other states with potential solutions.*

A complete search for relevant literature was conducted at the State Library using the Transportation Research Information System (TRIS) and 6 states were contacted by phone requesting a copy of their standard plate and any information regarding use of automated dowel bar inserters.

Task 2. *Compile results of existing in-house investigations and conduct research on problem projects to determine extent and severity of misalignments and resulting loss of performance*

The Division of Operations requested the Operations Review Team to inspect three (3) projects in 1989-90 to verify compliance with dowel bar placement specifications. The team was able to successfully measure horizontal rotation and longitudinal displacement using an R-meter and verification cores. These joints were relocated in the summer of 1993 to measure depth and vertical rotation using a new digital resteel locating meter (Soiltest CT-4950 Micro Covermeter) on loan from the Federal Highway Administration - Office of Technology Application (FHWA - OTA). The instrument's accuracy was verified in the laboratory and by drilling down to several dowel bars for direct measurement.

Task 3. *Determine economical and structural feasibility of alternative insertion methods including automated dowel insertion and the Iowa Special system based upon other states' results.*

Information concerning use of automated dowel bar inserters was collected through the TRIS literature search and phone conversations with 6 states.

Task 4. *Recommend construction specifications, tolerances, and design modifications based upon results of this study.*

After review of the literature, other states' specifications, and field survey data, a recommendation to revise current specifications to conform to other states' specifications is made.

Task 5. *Recommend pay reduction policy based upon the cost of joint repair, replacement, or loss of pavement life.*

Due to the lack of distress that could be solely attributed to dowel bar misalignment, a pay reduction policy based on joint repair, replacement, or loss of pavement life costs cannot be developed. Therefore, current pay reduction policies with respect to inability to adhere to current SDDOT specifications should remain in force.

Task 6. *Prepare an interim report summarizing progress and expected work plan for the upcoming year by May 1, 1991. this will be used to determine if any preliminary adjustments to construction policy should be made before the construction season.*

This task was performed by the previous investigator. However, review and revision of the interim report was not accomplished prior to his departure from the Office of Research.

VI. CURRENT DOWEL BAR INSTALLATION PRACTICES IN SOUTH DAKOTA

The SDDOT uses the dowel bar basket assembly for the installation of dowel bars in PCC pavements. Possible explanations for the misalignment of the dowel bars include:

1. Improper location of the dowel basket assemblies.
2. Improper anchoring of the dowel basket assemblies which would allow movement during the paving operations.
3. Damage to the dowel basket assembly before, during, or after placement.
4. Improper location of the contraction joint saw cut.
5. Improper sawing of the contraction joint.

Observations of some contractors' paving operation were made during the course of the field surveys. All operations conformed to standard dowel basket installation procedures that resulted in very little, if any, observable movement of the dowel basket assemblies. However, locating the initial saw cut over the center of the dowel basket assembly did prove to be a problem. Normally, the finishing crew on a paving operation places an approximately 10 cm wide (4 in) protective strip over the center of the dowel basket location to prevent tining over the area and to delineate the joint location for the saw crew. On many instances, the alignment of the strip deviated from the markers placed at the ends of the dowel baskets (**Fig. 6**) often resulting in a contraction joint skew greater than 0.3 m in 3.7 m (1 ft in 12 ft) (**Fig. 7**). Therefore, if the joint is centered over the dowel basket on one end, this would result in the dowel bar located on the other end of the basket assembly not traversing the joint. Also, there were instances where the dowel baskets were not aligned properly with the end markers (**Fig. 8**). Therefore, if the alignment of the dowel basket, protective strip, and saw cut are misplaced in the same direction, it would result in the contraction joint being 152 mm (6 in) away from the center of the dowel bars.

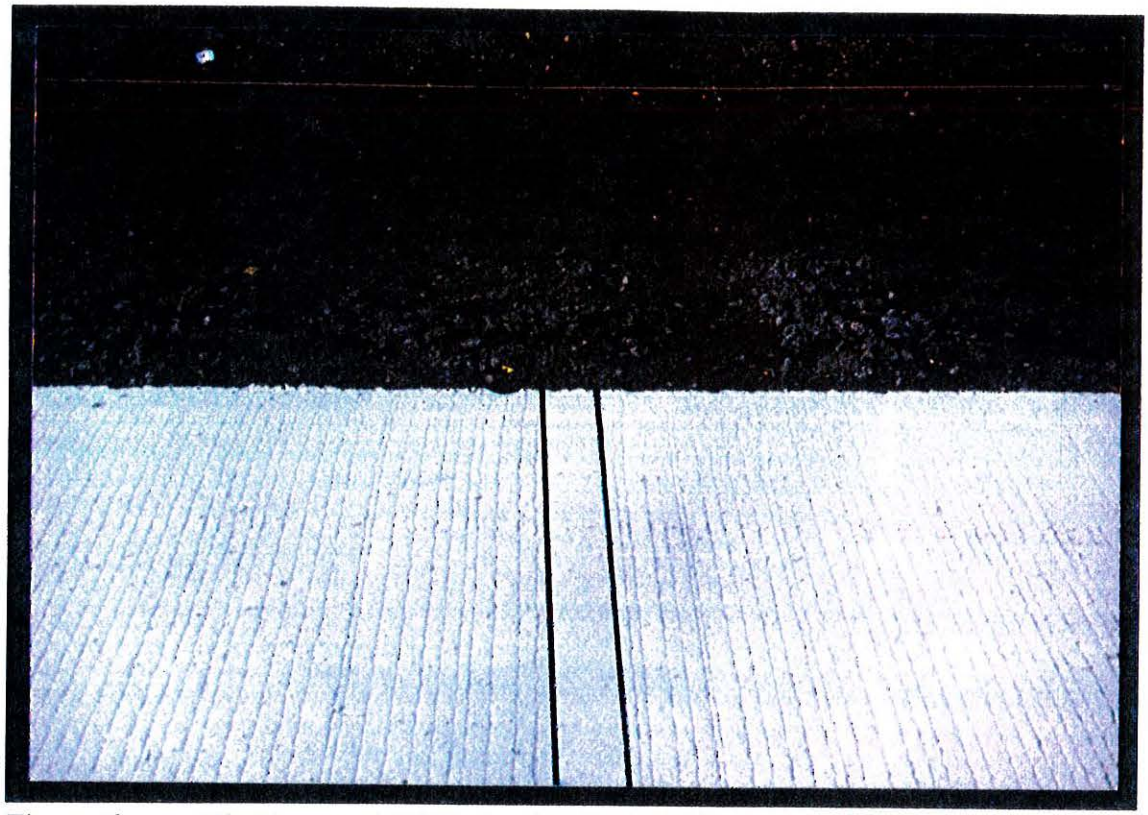

Figure 6 - Misalignment Of Protective Strip (With Respect To Yellow Marker)

Figure 7 - Skewed Contraction Joint (With Respect To Adjoining & Center Line Joints

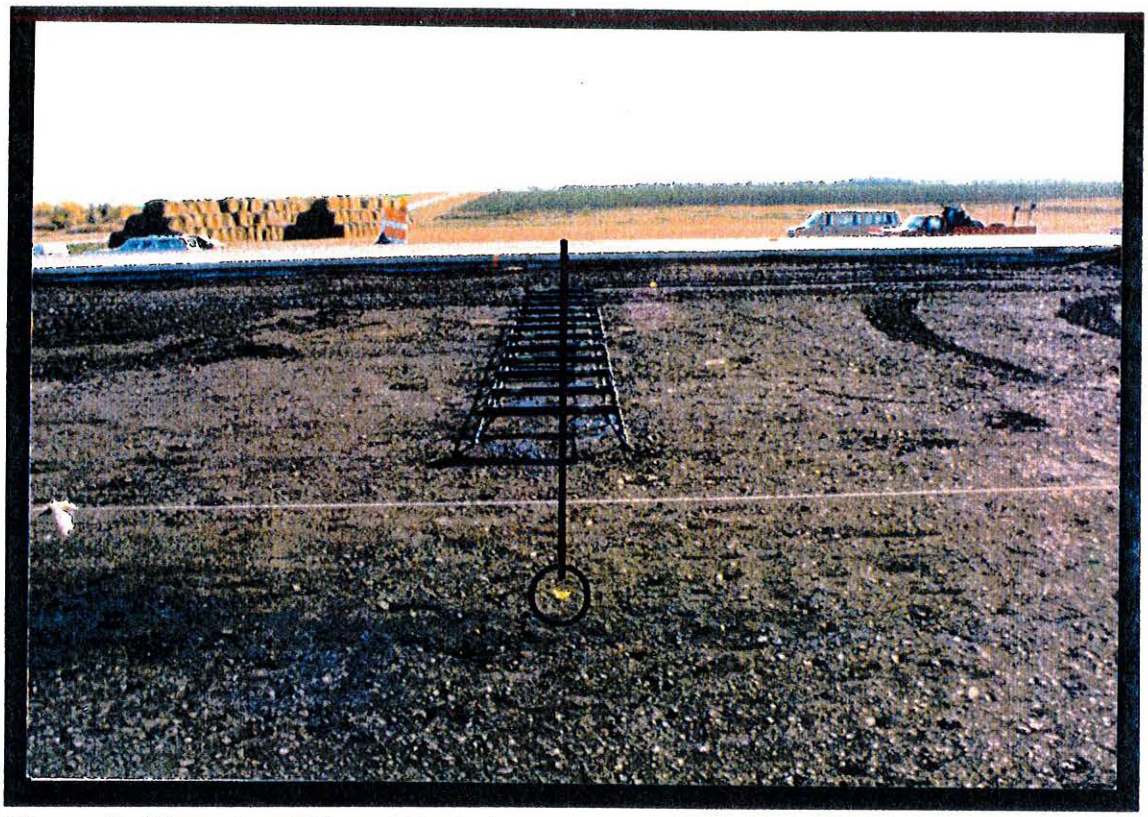

Figure 8 - Uncentered Dowel Basket

VII. DATA COLLECTION

At the request of the Division of Operations, horizontal rotation and longitudinal displacement data, as defined in the literature review, were collected in early 1990 by the Operations Review Team on the following 1989 construction projects:

Table 3 - Surveyed Projects

Designator	Project Number	County	Plan Thickness (mm / in)	Avg. Thickness (mm / in)
A	F0018(95)234	Tripp County	203 / 8.0	214 / 8.4
B	F0083(33)165	Potter & Sully Counties	203 / 8.0	213 / 8.4
C	F0212(37)218	Potter County	216 / 8.5	224 / 8.8

For ease of reference, the projects will be referred to by the designators assigned in **Table 3**. Dowel alignment surveys were taken on these projects because of obvious noncompliance with specifications concerning contraction joint construction. At each contraction joint location, the two (2) dowel bars at the ends of the basket were selected for measurement. A James Electronics Inc. R-meter was used for determining dowel bar orientation and bar end location and a hammer drill fitted with a 25.4 mm (1.0 in.) concrete drill bit was used for verifying R-meter readings. Although the R-meter was very effective at determining dowel bar orientation and bar end locations, only horizontal rotation and longitudinal displacement measurements were taken because of the inadequate vertical measurement accuracy of the R-meter (+/- 7 mm -or- ≈0.25 in) and impracticality of drilling every dowel bar end. It was at about this time that the original principal investigator (Ken Marks) transferred to another office within the SDDOT.

In the spring of 1993, the succeeding principal investigator received a new digital resteel locating meter (Soiltest CT-4950 Micro Covermeter) on loan from the FHWA - OTA. The instrument's accuracy was verified in the lab on test blocks and by measuring the depth of several dowel bars with the instrument and then drilling down to the dowel and measuring the depth directly. Comparison between the meter and direct measurements showed that the instrument's accuracy was approximately +2.0 mm (≈ +1/16 in.). The dowel bars from the original survey were relocated and measured for depth and vertical rotation.

VIII. DATA ANALYSIS

Dowel Bar Depth

The SDDOT's current specification for dowel bar depth is written as:

Pavement Thickness/2 ± 7.9 mm (5/16 in.)

With regards to this tolerance, the depth statistics for the projects are given in **Table 4** and the project specific data are given in **Tables 8-10, Pgs. 15-17.**

Table 4 - Dowel Bar Depth Statistics

Project	Average Depth (mm)	Std. Dev. (mm)	Allowable Range (mm)*	No. out of Spec./ No. tested	Percent out of Specification
A	108.9	9.0	99.3 - 115.1	46/132	34.8
B	108.2	8.4	98.4 - 114.2	52/160	32.5
C	108.1	7.0	104.0 - 119.8	41/116	35.3

* - Based on projects' average thickness

Dowel bar depth measurements were corrected for average pavement thicknesses based on thickness cores because most of the dowel bars not meeting specifications would be deep if plan thicknesses were used. Analysis of the data shows that roughly one-third (1/3) of the sample dowel bars do not meet standard specifications. However, the analysis showed that none of the bars varied from the average dowel bar depth by more than 25 mm (1 in). It is quite clear that variability in pavement thicknesses has a substantial bearing on whether the dowel bars meet depth specifications. Another consideration is that placing the dowel bars at mid-pavement depth becomes less critical as the pavement thickness increases. It has been discussed with the Concrete Engineer that perhaps the dowel bar depth specification should be modified to consider pavement thickness as a factor for determining tolerance levels. Therefore, the following modification to the standard specification is recommended:

(Metric Units, mm) Dowel Bar Depth = Pavement Thickness/2 ± (***Pavement Thickness/4 - 38***).
(English Units, in) Dowel Bar Depth = Pavement Thickness/2 ± (***Pavement Thickness/4 - 1.5***).

This proposed specification modification will maintain a reasonable tolerance level while taking into account the decreasing criticality as pavement thickness increases **(See Table 5)**.

Table 5 - Examples Of New Specification Tolerances

Pavement Thickness (mm/in)	± Tolerance (mm)	± Tolerance (in)
203 / 8.0	13	1/2
216 / 8.5	16	5/8
254 / 10.0	26	1

Dowel Bar Vertical Rotation

The SDDOT's current specification for dowel bar vertical rotation is written as:

> "Centerline of individual dowel bars shall be parallel to top of subgrade ± 3.2 mm (1/8 in) in 457 mm (18 in)."

With regards to this tolerance, the vertical rotation statistics for the projects are given in **Table 6** and the project specific data are given in **Tables 8-10, Pgs. 15-17.**

Table 6 - Dowel Bar Vertical Rotation Statistics					
Project	Avg. Vertical Rotation (mm)	Std. Dev. (mm)	Allowable Range (mm)	No. out of Spec./ No. tested	Percent out of Specification
A	1.1	2.4	0 - 3.2	1 / 132	0.8
B	2.4	7.8	0 - 3.2	19 / 160	11.9
C	1.0	1.2	0 - 3.2	0 / 116	0.0

Three (3) of the twenty (20) dowel bars out of specification had vertical rotations more than 25 mm (1.0 in) with the rest of the out of specification dowels averaging 6 mm (1/4 in) rotations. The other dowels in the survey substantially met the current allowable misalignment tolerances. The vertical rotation measured on the three (3) dowels in excess of 25 mm suggest that the bars may have been dislodged or that the baskets were somehow damaged before or during the paving operation. Analysis of the data does not show a statistical difference in the slope of the vertically rotated bars, giving strength to the argument that the dowel baskets are not moving during the paving operation. Although it does not appear that the vertical rotation specification is difficult to achieve with the dowel basket assemblies, discussions with the Concrete Engineer and review of the literature indicate that the current specification may be too strict. Therefore, the following modification to the standard specification is recommended:

> "Centerline of individual dowel bars shall be parallel to top of subgrade ± ***6.4 mm (1/4 in)*** in 457 mm (18 in)."

This modification to the specification will make the use of dowel bar inserters more feasible, thus providing a means to reduce construction costs because of the reduction in labor and simplification of the paving operation.

Dowel Bar Horizontal Rotation

The SDDOT's current specification for dowel bar horizontal rotation is written as:

> "Centerline of individual dowel bars shall be parallel to the centerline of the roadway ±12.7 mm (1/2 in) in 457 mm (18 in)."

With regards to this tolerance, the horizontal rotation statistics for the projects are given in **Table 6** and the project specific data are given in **Tables 11-13, Pgs. 18-20.**

Table 6 - Dowel Bar Horizontal Rotation Statistics					
Project	Avg. Horizontal Rotation (mm)	Std. Dev. (mm)	Allowable Range (mm)	No. out of Spec./ No. tested	Percent out of Specification
A	6.6	4.6	0 - 12.7	10/132	7.6
B	10.6	9.8	0 - 12.7	39/172	22.7
C	8.3	6.4	0 - 12.7	21/116	18.1

Analysis of the data shows that, of the dowel bars out of specification, most are within 25.4 mm (1.0 in). Although the time period between project construction and field survey was short, it can be speculated that horizontal rotations of this magnitude can be tolerated without acceleration of pavement deterioration since no distress was found that could be attributed to dowel bar misalignments. However, since previous research has shown that horizontal rotations can be approximately twice the magnitude of vertical rotations before spalling in test slabs occurs (7), it is recommended that the specification for horizontal rotation not be changed.

Dowel Bar Longitudinal Displacement

The SDDOT's current specification for dowel bar longitudinal displacement is written as:

> "The transverse contraction joints shall be sawed perpendicular to the centerline of the roadway and the dowel bars shall be centered on the sawed joint ± 25.4 mm (1.0 in.)"

With regards to this tolerance, the longitudinal displacement statistics for the projects are given in **Table 7** and the project specific data are given in **Tables 11-13, Pgs. 18-20.**

Table 7 - Dowel Bar Longitudinal Displacement Statistics					
Project	Avg. Longitudinal Displacement (mm)	Std. Dev. (mm)	Allowable Range (mm)	No. out of Spec./ No. tested	Percent out of Specification
A	17.1	21.2	0 - 25.4	25/132	18.9
B	27.2	36.0	0 - 25.4	59/172	34.3
C	22.0	25.4	0 - 25.4	30/116	25.9

Analysis of the data and field observations show that there may be a problem with how the centers of the dowel basket assemblies are located. The large variability in the measurements indicate that either the dowel baskets are not being installed properly or that the contraction joint is not being located properly. Since the longitudinal displacement measurements are normally distributed about the joint, it can be concluded that the dowel baskets are not moving or else the data would be skewed in the direction of the paving operation. Therefore, incorrect placement of the contraction joint is the most likely answer for the large variability of the displacement measurements. Field observations also support this conclusion. It has been indicated from the literature and discussions with the Concrete Engineer that the current specification is too strict to achieve what is generally considered to be an adequate imbedment length (≈ 6 X Dowel Diameter). Therefore, the following modification of the specification is recommended:

> "The transverse contraction joints shall be sawed perpendicular to the centerline of the roadway and the dowel bars *shall have a minimum imbedment length of: 6 x Dowel Bar Diameter"*

Table 8 - US 18 VERTICAL ALIGNMENT MEASUREMENTS

I-0018(95)234 Tripp County
Vertical Rotation Measurements

Station	Depth Measured to Top of Dowel Bar at Each End (mm) a = Approaching Joint, l = Leaving Joint: A a	A l	B a	B l	C a	C l	D a	D l	Depth to Dowel Center*: A (mm)	B (mm)	C (mm)	D (mm)	Dowel Bar Depth 0 = Within Spec. 1 = Deep -1 = Shallow: A	B	C	D	Vertical Rotation Measurements taken 248 mm o.c.: A	B	C	D	Vertical Rotation 457 mm Dowel Bar (mm): A1	B1	C1	D1	Vertical Rotation 0 = Within Spec. 1 = (+) slope -1 = (-) slope:			
-1+80	109.2	109.2	109.2	109.2	111.8	113.0	116.8	115.6	123.5	123.5	126.7	130.5	1	1	1	1	0.0	0.0	-1.3	1.3	0.0	0.0	-2.3	2.3	0	0	0	0
0+40	95.3	95.3	95.3	95.3	99.1	100.3	123.2	123.2	109.5	109.5	114.0	137.5	0	0	0	1	0.0	0.0	-1.3	0.0	0.0	0.0	-2.3	0.0	0	0	0	0
4+60	110.5	111.8	90.2	91.4	94.0	95.3	102.9	102.9	125.4	105.1	108.9	117.2	1	0	0	1	-1.3	-1.3	-1.3	0.0	-2.3	-2.3	-2.3	0.0	0	0	0	0
16+40	96.5	96.5	88.9	90.2	101.6	101.6	74.9	74.9	110.8	103.8	115.9	89.2	0	0	1	-1	0.0	-1.3	0.0	0.0	0.0	-2.3	0.0	0.0	0	0	0	0
22+40	87.6	88.9	86.4	86.4	90.2	88.9	97.8	96.5	102.6	100.6	103.8	111.4	0	0	0	0	-1.3	0.0	1.3	1.3	-2.3	0.0	2.3	2.3	0	0	0	0
30+00	105.4	105.4	83.8	83.8	78.7	80.0	90.2	88.9	119.7	98.1	93.7	103.8	1	-1	-1	0	0.0	0.0	-1.3	1.3	0.0	0.0	-2.3	2.3	0	0	0	0
55+20	114.3	115.6	102.9	102.9	101.6	102.9	92.7	91.4	129.2	117.2	116.5	106.4	1	1	1	0	-1.3	0.0	-1.3	1.3	-2.3	0.0	-2.3	2.3	0	0	0	0
73+40	86.4	86.4	86.4	86.4	86.4	87.6	94.0	94.0	100.6	100.6	101.3	108.3	0	0	0	0	0.0	0.0	-1.3	0.0	0.0	0.0	-2.3	0.0	0	0	0	0
83+15	109.2	109.2	83.8	83.8	85.1	85.1	95.3	95.3	123.5	98.1	99.4	109.5	1	-1	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
90+85	109.2	108.0	95.3	94.0	85.1	86.4	91.4	91.4	122.9	108.9	100.0	105.7	1	0	0	0	1.3	1.3	-1.3	0.0	2.3	2.3	-2.3	0.0	0	0	0	0
100+43	111.8	113.0	86.4	87.6	94.0	94.0	104.1	102.9	126.7	101.3	108.3	117.8	1	0	0	1	-1.3	-1.3	0.0	1.3	-2.3	-2.3	0.0	2.3	0	0	0	0
109+18	94.0	94.0	97.8	96.5	97.8	97.8	92.7	92.7	108.3	111.4	112.1	107.0	0	0	0	0	0.0	1.3	0.0	0.0	0.0	2.3	0.0	0.0	0	0	0	0
125+00	81.3	81.3	81.3	81.3	87.6	87.6	91.4	91.4	95.6	95.6	101.9	105.7	-1	-1	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
134+80	82.6	82.6	90.2	90.2	83.8	83.8	92.7	92.7	96.8	104.5	98.1	107.0	-1	0	-1	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
141+85	96.5	96.5	90.2	90.2	90.2	91.4	94.0	94.0	110.8	104.5	105.1	108.3	0	0	0	0	0.0	0.0	-1.3	0.0	0.0	0.0	-2.3	0.0	0	0	0	0
149+40	94.0	94.0	92.7	92.7	92.7	94.0	91.4	92.7	108.3	107.0	107.6	106.4	0	0	0	0	0.0	0.0	-1.3	-1.3	0.0	0.0	-2.3	-2.3	0	0	0	0
165+55	105.4	105.4	82.6	82.6	82.6	82.6	90.2	90.2	119.7	96.8	96.8	104.5	1	-1	-1	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
177+90	111.8	111.8	97.8	97.8	91.4	91.4	95.3	94.0	126.0	112.1	105.7	108.9	1	0	0	0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	2.3	0	0	0	0
186+35	104.1	104.1	92.7	94.0	91.4	90.2	99.1	97.8	118.4	107.6	105.1	112.7	1	0	0	0	0.0	-1.3	1.3	1.3	0.0	-2.3	2.3	2.3	0	0	0	0
199+10	86.4	86.4	90.2	90.2	105.4	105.4	105.4	105.4	100.6	104.5	119.7	119.7	0	0	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
209+15	99.1	99.1	83.8	85.1	106.7	108.0	104.1	104.1	113.3	98.7	121.6	118.4	0	-1	1	1	0.0	-1.3	-1.3	0.0	0.0	-2.3	-2.3	0.0	0	0	0	0
217+00	94.0	94.0	88.9	90.2	114.3	114.3	100.3	100.3	108.3	103.8	128.6	114.6	0	0	1	0	0.0	-1.3	0.0	0.0	0.0	-2.3	0.0	0.0	0	0	0	0
233+70	94.0	94.0	87.6	88.9	95.3	95.3	91.4	92.7	108.3	102.6	109.5	106.4	0	0	0	0	0.0	-1.3	0.0	-1.3	0.0	-2.3	0.0	-2.3	0	0	0	0
243+50	95.3	95.3	92.7	92.7	91.4	91.4	96.5	96.5	109.5	107.0	105.7	110.8	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
255+45	81.3	81.3	82.6	83.8	87.6	88.9	100.3	99.1	95.6	97.5	102.6	114.0	-1	-1	0	0	0.0	-1.3	-1.3	1.3	0.0	-2.3	-2.3	2.3	0	0	0	0
269+45	96.5	96.5	99.1	99.1	85.1	85.1	94.0	92.7	110.8	113.3	99.4	107.6	0	0	0	0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	2.3	0	0	0	0
279+05	100.3	99.1	87.6	87.6	96.5	96.5	82.6	81.3	114.0	101.9	110.8	96.2	0	0	0	-1	1.3	0.0	0.0	1.3	2.3	0.0	0.0	2.3	0	0	0	0
289+65	100.3	99.1	94.0	94.0	102.9	102.9	94.0	92.7	114.0	108.3	117.2	107.6	0	0	1	0	1.3	0.0	0.0	1.3	2.3	0.0	0.0	2.3	0	0	0	0
300+45	97.8	97.8	86.4	86.4	113.0	114.3	86.4	100.3	112.1	100.6	128.0	107.6	0	0	1	0	0.0	0.0	1.3	-14.0	0.0	0.0	2.3	-25.8	0	0	0	-1
310+25	104.1	102.9	92.7	91.4	106.7	106.7	77.5	77.5	117.8	106.4	121.0	91.8	1	0	1	-1	1.3	1.3	0.0	0.0	2.3	2.3	0.0	0.0	0	0	0	0
322+05	99.1	99.1	92.7	92.7	81.3	81.3	86.4	86.4	113.3	107.0	95.6	100.6	0	0	-1	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
336+60	96.5	97.8	87.6	88.9	92.7	92.7	100.3	101.6	111.4	102.6	107.0	115.3	0	0	0	1	-1.3	-1.3	0.0	-1.3	-2.3	-2.3	0.0	-2.3	0	0	0	0
345+40	90.2	90.2	87.6	87.6	78.7	80.0	94.0	92.7	104.5	101.9	93.7	107.6	0	0	-1	0	0.0	0.0	-1.3	1.3	0.0	0.0	-2.3	2.3	0	0	0	0

Pavement Depth: 214.38 mm (8.44 in)

Dowel Bar Depth Specification: D/2 + or 7.94 mm -or- 0.31 in

Vertical Rotation Specification: 3.18 mm -or- 0.13 in

Number of Bars for a 95% Confidence Interval with 2% Error: 29 Bars Tested: 132

Number of Bars Out of Specification:

Dowel Bar Depth:	46	=>	34.8 %	Mean:	108.9 mm	Std. Dev.: 9.0 mm
Vertical Rotation:	1	=>	0.8 %	Mean:	1.1 mm	Std. Dev.: 2.4 mm

Additional Dowel Bar Infonmantion:

Number of Bars - Deep:	29	=>	22.0 %
Shallow:	17	=>	12.9 %
Positive Slope:	22	=>	16.7 %
Negative Slope:	30	=>	22.7 %
No Slope:	80	=>	60.6 %

* - Adjusted to dowel bar center and for resteel locator accuracy of + 1.5 mm

NOTE: Written Specifications

HWMP.XLS: 3-20-95

Table 9 - US 83 VERTICAL ALIGNMENT MEASUREMENTS

I-0083(33)165: Potter & Sully Counties
Vertical Measurements

Station	Depth Measured to Top of Dowel Bar at Each End (mm) a = Approaching Joint, l = Leaving Joint: A a	A l	B a	B l	C a	C l	D a	D l	Depth to Dowel Center*: A (mm)	B (mm)	C (mm)	D (mm)	Dowel Bar Depth 0 = Within Spec., 1 = Deep, -1 = Shallow: A	B	C	D	Vertical Rotation, Measurements taken 248 mm o.c.: A	B	C	D	Vertical Rotation, 457 mm Dowel Bar (mm): A1	B1	C1	D1	Vertical Rotation, 0 = Within Spec., 1 = (+) slope, -1 = (-) slope: A	B	C	D
29+10	88.9	88.9	85.1	86.4	81.3	86.4	82.6	85.1	103.2	100.0	98.1	98.1	0	0	-1	-1	0.0	-1.3	-5.1	-2.5	0.0	-2.3	-9.4	-4.7	0	0	-1	-1
49+90	83.8	83.8	86.4	85.1	81.3	78.7	83.8	85.1	98.1	100.0	94.3	98.7	-1	0	-1	0	0.0	1.3	2.5	-1.3	0.0	2.3	4.7	-2.3	0	0	1	0
61+05	94.0	95.3	91.4	90.2	100.3	100.3	86.4	87.6	108.9	105.1	114.6	101.3	0	0	1	0	-1.3	1.3	0.0	-1.3	-2.3	2.3	0.0	-2.3	0	0	0	0
69+78	99.1	99.1	102.9	101.6	95.3	94.0	85.1	85.1	113.3	116.5	108.9	99.4	0	1	0	0	0.0	1.3	1.3	0.0	0.0	2.3	2.3	0.0	0	0	0	0
70+80	104.1	105.4	109.2	109.2	102.9	101.6	94.0	95.3	119.1	123.5	116.5	108.9	1	1	1	0	-1.3	0.0	1.3	-1.3	-2.3	0.0	2.3	-2.3	0	0	0	0
84+15	97.8	97.8	102.9	102.9	88.9	87.6	91.4	87.6	112.1	117.2	102.6	103.8	0	1	0	0	0.0	0.0	1.3	3.8	0.0	0.0	2.3	7.0	0	0	0	1
98+00	100.3	99.1	92.7	94.0	72.4	74.9	74.9	73.7	114.0	107.6	87.9	88.6	0	0	-1	-1	1.3	-1.3	-2.5	1.3	2.3	-2.3	-4.7	2.3	0	0	-1	1
111+85	102.9	101.6	91.4	90.2	86.4	85.1	82.6	83.8	116.5	105.1	100.0	97.5	1	0	0	-1	1.3	1.3	1.3	-1.3	2.3	2.3	2.3	-2.3	0	0	0	0
115+45	101.6	101.6	99.1	100.3	95.3	95.3	97.8	97.8	115.9	114.0	109.5	112.1	1	0	0	0	0.0	-1.3	0.0	0.0	0.0	-2.3	0.0	0.0	0	0	0	0
125+65	110.5	109.2	94.0	94.0	81.3	81.3	80.0	80.0	124.1	108.3	95.6	94.3	1	0	-1	-1	1.3	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0	0	0	0
132+45	90.2	92.7	92.7	92.7	76.2	77.5	111.8	110.5	105.7	107.0	91.1	125.4	0	0	-1	1	-2.5	0.0	-1.3	1.3	-4.7	0.0	-2.3	2.3	-1	0	0	0
171+95	105.4	105.4	95.3	96.5	97.8	97.8	92.7	92.7	119.7	110.2	112.1	107.0	1	0	0	0	0.0	-1.3	0.0	0.0	0.0	-2.3	0.0	0.0	0	0	0	0
177+95	68.6	67.3	78.7	78.7	95.3	94.0	106.7	108.0	82.2	93.0	108.9	121.6	-1	-1	0	1	1.3	0.0	1.3	-1.3	2.3	0.0	2.3	-2.3	0	0	0	0
180+55	90.2	90.2	95.3	95.3	99.1	97.8	106.7	106.7	104.5	109.5	112.7	121.0	0	0	0	1	0.0	0.0	1.3	0.0	0.0	0.0	2.3	0.0	0	0	0	0
184+95	92.7	92.7	87.6	87.6	92.7	92.7	104.1	104.1	107.0	101.9	107.0	118.4	0	0	0	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
196+00	94.0	94.0	92.7	92.7	92.7	94.0	91.4	92.7	108.3	107.0	107.6	106.4	0	0	0	0	0.0	0.0	-1.3	-1.3	0.0	0.0	-2.3	-2.3	0	0	0	0
215+45	101.6	99.1	94.0	95.3	85.1	86.4	100.3	101.6	114.6	108.9	100.0	115.3	1	0	0	1	2.5	-1.3	-1.3	-1.3	4.7	-2.3	-2.3	-2.3	1	0	0	0
219+45	111.8	111.8	97.8	97.8	91.4	91.4	95.3	94.0	126.0	112.1	105.7	108.9	1	0	0	0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	2.3	0	0	0	0
223+25	104.1	104.1	92.7	94.0	91.4	90.2	99.1	97.8	118.4	107.6	105.1	112.7	1	0	0	0	0.0	-1.3	1.3	1.3	0.0	-2.3	2.3	2.3	0	0	0	0
242+25	86.4	86.4	90.2	90.2	105.4	105.4	105.4	105.4	100.6	104.5	119.7	119.7	0	0	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
247+85	99.1	99.1	83.8	85.1	106.7	108.0	104.1	104.1	113.3	98.7	121.6	118.4	0	0	1	1	0.0	-1.3	-1.3	0.0	0.0	-2.3	-2.3	0.0	0	0	0	0
269+90	94.0	94.0	88.9	90.2	114.3	114.3	100.3	100.3	108.3	103.8	128.6	114.6	0	0	1	1	0.0	-1.3	0.0	0.0	0.0	-2.3	0.0	0.0	0	0	0	0
275+10	94.0	94.0	87.6	88.9	95.3	95.3	91.4	92.7	108.3	102.6	109.5	106.4	0	0	0	0	0.0	-1.3	0.0	-1.3	0.0	-2.3	0.0	-2.3	0	0	0	0
286+32	95.3	95.3	92.7	92.7	91.4	91.4	96.5	96.5	109.5	107.0	105.7	110.8	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
288+92	81.3	81.3	82.6	83.8	87.6	88.9	100.3	99.1	95.6	97.5	102.6	114.0	-1	-1	0	0	0.0	-1.3	-1.3	1.3	0.0	-2.3	-2.3	2.3	0	0	0	0
289+95	88.9	96.5	91.4	91.4	92.7	92.7	105.4	105.4	107.0	105.7	107.0	119.7	0	0	0	1	-7.6	0.0	0.0	0.0	-14.0	0.0	0.0	0.0	-1	0	0	0
329+58	100.3	99.1	87.6	87.6	96.5	96.5	82.6	81.3	114.0	101.9	110.8	96.2	0	0	0	-1	1.3	0.0	0.0	1.3	2.3	0.0	0.0	2.3	0	0	0	0
329+78	96.5	95.3	94.0	144.8	91.4	87.6	97.8	97.8	110.2	133.7	103.8	112.1	0	1	0	0	1.3	-50.8	3.8	0.0	2.3	-93.7	7.0	0.0	0	-1	1	0
330+18	97.8	97.8	86.4	86.4	113.0	114.3	86.4	100.3	112.1	100.6	128.0	107.6	0	0	1	0	0.0	0.0	-1.3	-14.0	0.0	0.0	-2.3	-25.8	0	0	0	-1
330+38	104.1	102.9	92.7	91.4	106.7	106.7	77.5	77.5	117.8	106.4	121.0	91.8	1	0	1	-1	1.3	1.3	0.0	0.0	2.3	2.3	0.0	0.0	0	0	0	0
330+58	95.3	94.0	87.6	85.1	78.7	80.0	99.1	96.5	108.9	100.6	93.7	112.1	0	0	-1	0	1.3	2.5	-1.3	2.5	2.3	4.7	-2.3	4.7	0	1	0	1
330+78	99.1	96.5	88.9	88.9	87.6	88.9	96.5	95.3	112.1	103.2	102.6	110.2	0	0	0	0	2.5	0.0	-1.3	1.3	4.7	0.0	-2.3	2.3	1	0	0	0
330+98	96.5	95.3	87.6	88.9	87.6	87.6	96.5	92.7	110.2	102.6	101.9	108.9	0	0	0	0	1.3	-1.3	0.0	3.8	2.3	-2.3	0.0	7.0	0	0	0	1
331+18	99.1	96.5	81.3	83.8	86.4	85.1	94.0	95.3	112.1	96.8	100.0	108.9	0	-1	0	0	2.5	-2.5	1.3	-1.3	4.7	-4.7	2.3	-2.3	1	-1	0	0
371+40	96.5	96.5	87.6	87.6	82.6	82.6	92.7	94.0	110.8	101.9	96.8	107.6	0	0	-1	0	0.0	0.0	0.0	-1.3	0.0	0.0	0.0	-2.3	0	0	0	0
380+00	90.2	90.2	91.4	92.7	94.0	95.3	88.9	90.2	104.5	106.4	108.9	103.8	0	0	0	0	0.0	-1.3	-1.3	-1.3	0.0	-2.3	-2.3	-2.3	0	0	0	0
380+80	96.5	97.8	90.2	90.2	94.0	94.0	88.9	90.2	111.4	104.5	108.3	103.8	0	0	0	0	-1.3	0.0	0.0	-1.3	-2.3	0.0	0.0	-2.3	0	0	0	0
384+40	90.2	90.2	94.0	94.0	104.1	101.6	97.8	96.5	104.5	108.3	117.2	111.4	0	0	1	0	0.0	0.0	2.5	1.3	0.0	0.0	4.7	2.3	0	0	1	0
392+20	92.7	94.0	96.5	97.8	94.0	95.3	96.5	99.1	107.6	111.4	108.9	112.1	0	0	0	0	-1.3	-1.3	-1.3	-2.5	-2.3	-2.3	-2.3	-4.7	0	0	0	-1
408+25	102.9	101.6	100.3	99.1	106.7	106.7	105.4	105.4	116.5	114.0	121.0	119.7	1	0	1	1	1.3	1.3	0.0	0.0	2.3	2.3	0.0	0.0	0	0	0	0

Pavement Depth: 212.6 mm (8.37 in <--)

Dowel Bar Depth Specification: Dowel (D/2) +/- 7.9 mm -or- 0.31 in <--

Vertical Rotation Specification: 3.2 mm -or- 0.13 in <--

Number of Bars for a 95% Confidence Interval with 2% Error: 29 Bars Tested: 160

Number of Bars Out of Specification:
- Dowel Bar Depth: 52 => 32.5 % Mean: 108.2 mm Std. Dev.: 8.4 mm
- Vertical Rotation: 19 => 11.9 % Mean: 2.4 mm Std. Dev.: 7.8 mm

Additional Dowel Bar Information:
- Number of Bars -
- Deep: 33 => 20.6 %
- Shallow: 19 => 11.9 %
- Positive Slope: 42 => 26.3 %
- Negative Slope: 48 => 30.0 %
- No Slope: 70 => 43.8 %

* - Adjusted to dowel bar center and for rested locator accuracy of + 1.5 mm

NOTE: Written Specifications

H83VERT.XLS: 3-20-95

Table 10 - US 212 VERTICAL ALIGNMENT MEASUREMENTS

F0212(37)218: Potter County
Vertical Measurements

	Depth Measured to Top of Dowel Bar at Each End (mm)								Depth to Dowel Center*				Dowel Bar Depth				Vertical Rotation				Vertical Rotation				Vertical Rotation			
	a = Approaching Joint				1 = Leaving Joint				A	B	C	D	0 = Within Spec.				Measurements taken 248 mm o.c.				457 mm Dowel Bar (mm)				0 = Within Spec.			
Station	A a	A 1	B a	B 1	C a	C 1	D a	D 1	(mm)	(mm)	(mm)	(mm)	1 = Deep		-1 = Shallow		A	B	C	D	A1	B1	C1	D1	1 = (+) slope		-1 = (-) slope	
2+54	101.6	101.6	106.7	105.4	85.1	85.1	105.4	106.7	115.9	120.3	99.4	120.3	0	1	-1	1	0.0	1.3	0.0	-1.3	0.0	2.3	0.0	-2.3	0	0	0	0
9+10	101.6	101.6	106.7	105.4	85.1	85.1	105.4	106.7	115.9	120.3	99.4	120.3	0	1	-1	1	0.0	1.3	0.0	-1.3	0.0	2.3	0.0	-2.3	0	0	0	0
34+22	94.0	95.3	85.1	83.8	91.4	91.4	95.3	96.5	108.9	98.7	105.7	110.2	0	-1	0	0	-1.3	1.3	0.0	-1.3	-2.3	2.3	0.0	-2.3	0	0	0	0
53+75	109.2	109.2	92.7	91.4	92.7	91.4	96.5	96.5	123.5	106.4	106.4	110.8	1	0	0	0	0.0	1.3	1.3	0.0	0.0	2.3	2.3	0.0	0	0	0	0
62+42	100.3	100.3	92.7	91.4	97.8	97.8	106.7	106.7	114.6	106.4	112.1	121.0	0	0	0	1	0.0	1.3	0.0	0.0	0.0	2.3	0.0	0.0	0	0	0	0
64+78	101.6	101.6	97.8	99.1	96.5	95.3	104.1	104.1	115.9	112.7	110.2	118.4	0	0	0	0	0.0	-1.3	1.3	0.0	0.0	-2.3	2.3	0.0	0	0	0	0
91+80	88.9	88.9	96.5	97.8	94.0	92.7	95.3	96.5	103.2	111.4	107.6	110.2	-1	0	0	0	0.0	-1.3	1.3	-1.3	0.0	-2.3	2.3	-2.3	0	0	0	0
92+20	86.4	87.6	88.9	87.6	87.6	87.6	91.4	91.4	101.3	102.6	101.9	105.7	-1	-1	-1	0	-1.3	1.3	0.0	0.0	-2.3	2.3	0.0	0.0	0	0	0	0
95+44	87.6	86.4	97.8	97.8	90.2	90.2	88.9	90.2	101.3	112.1	104.5	103.8	-1	0	0	-1	1.3	0.0	0.0	-1.3	2.3	0.0	0.0	-2.3	0	0	0	0
97+92	88.9	88.9	92.7	92.7	92.7	92.7	96.5	96.5	103.2	107.0	107.0	110.8	-1	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
120+40	97.8	97.8	99.1	100.3	88.9	88.9	96.5	97.8	112.1	114.0	103.2	111.4	0	0	-1	0	0.0	-1.3	0.0	-1.3	0.0	-2.3	0.0	-2.3	0	0	0	0
136+84	91.4	91.4	94.0	95.3	86.4	87.6	97.8	97.8	105.7	108.9	101.3	112.1	0	0	-1	0	0.0	-1.3	-1.3	0.0	0.0	-2.3	-2.3	0.0	0	0	0	0
137+64	94.0	94.0	94.0	95.3	87.6	86.4	95.3	95.3	108.3	108.9	101.3	109.5	0	0	-1	0	0.0	-1.3	1.3	0.0	0.0	-2.3	2.3	0.0	0	0	0	0
145+04	100.3	99.1	104.1	104.1	85.1	83.8	95.3	95.3	114.0	118.4	98.7	109.5	0	0	-1	0	1.3	0.0	1.3	0.0	2.3	0.0	2.3	0.0	0	0	0	0
147+04	99.1	97.8	96.5	96.5	83.8	83.8	100.3	100.3	112.7	110.8	98.1	114.6	0	0	-1	0	1.3	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0	0	0	0
169+34	92.7	91.4	92.7	92.7	90.2	88.9	105.4	106.7	106.4	107.0	103.8	120.3	0	0	-1	1	1.3	0.0	1.3	-1.3	2.3	0.0	2.3	-2.3	0	0	0	0
187+56	91.4	91.4	90.2	90.2	78.7	77.5	91.4	90.2	105.7	104.5	92.4	105.1	0	0	-1	0	0.0	0.0	1.3	1.3	0.0	0.0	2.3	2.3	0	0	0	0
188+36	106.7	106.7	102.9	102.9	81.3	81.3	95.3	94.0	121.0	117.2	95.6	108.9	1	0	-1	0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	2.3	0	0	0	0
197+54	97.8	96.5	95.3	95.3	90.2	90.2	105.4	105.4	111.4	109.5	104.5	119.7	0	0	0	0	1.3	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0	0	0	0
223+54	90.2	90.2	95.3	95.3	82.6	82.6	96.5	95.3	104.5	109.5	96.8	110.2	0	0	-1	0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	2.3	0	0	0	0
224+14	94.0	94.0	91.4	91.4	83.8	83.8	94.0	95.3	108.3	105.7	98.1	108.9	0	0	-1	0	0.0	0.0	0.0	-1.3	0.0	0.0	0.0	-2.3	0	0	0	0
242+12	82.6	82.6	86.4	86.4	77.5	76.2	96.5	96.5	96.8	100.6	91.1	110.8	-1	-1	-1	0	0.0	0.0	1.3	0.0	0.0	0.0	2.3	0.0	0	0	0	0
244+12	94.0	95.3	97.8	99.1	82.6	82.6	95.3	95.3	108.9	112.7	96.8	109.5	0	0	-1	0	-1.3	-1.3	0.0	0.0	-2.3	-2.3	0.0	0.0	0	0	0	0
263+56	97.8	96.5	92.7	91.4	80.0	80.0	87.6	87.6	111.4	106.4	94.3	101.9	0	0	-1	-1	1.3	1.3	0.0	0.0	2.3	2.3	0.0	0.0	0	0	0	0
276+02	87.6	87.6	94.0	95.3	77.5	77.5	87.6	87.6	101.9	108.9	91.8	101.9	-1	0	-1	-1	0.0	-1.3	0.0	0.0	0.0	-2.3	0.0	0.0	0	0	0	0
284+38	92.7	94.0	86.4	86.4	88.9	87.6	97.8	97.8	107.6	100.6	102.6	112.1	0	-1	-1	0	-1.3	0.0	1.3	0.0	-2.3	0.0	2.3	0.0	0	0	0	0
292+44	91.4	91.4	94.0	94.0	95.3	94.0	96.5	96.5	105.7	108.3	108.9	110.8	0	0	0	0	0.0	0.0	1.3	0.0	0.0	0.0	2.3	0.0	0	0	0	0
302+10	88.9	90.2	99.1	99.1	91.4	92.7	104.1	104.1	103.8	113.3	106.4	118.4	-1	0	0	0	-1.3	0.0	-1.3	0.0	-2.3	0.0	-2.3	0.0	0	0	0	0
307+28	109.2	109.2	97.8	97.8	99.1	99.1	99.1	100.3	123.5	112.1	113.3	114.0	1	0	0	0	0.0	0.0	0.0	-1.3	0.0	0.0	0.0	-2.3	0	0	0	0

Pavement Depth: 223.8 mm
8.81 in <==

Dowel Bar Depth Specification: (D/2) +/- 7.9 mm -or- 0.31 in <==

Vertical Rotation Specification : 3.2 mm -or- 0.13 in <==

Number of Bars for a 95% Confidence Interval with 2% Error: 29 Bars Tested: 116

Number of Bars Out of Specification:

Dowel Bar Depth:	41	=>	35.3 %	Mean:	108.1 mm	Std. Dev.: 7.0 mm
Vertical Rotation:	0	=>	0.0 %	Mean:	1.0 mm	Std. Dev.: 1.2 mm

Additional Dowel Bar Infonmantion:

Number of Bars - Deep:	9	=>	7.8 %
Shallow:	32	=>	27.6 %
Positive Slope:	26	=>	22.4 %
Negative Slope:	23	=>	19.8 %
No Slope:	67	=>	57.8 %

* - Adjusted to dowel bar center and for resteel locator accuracy of + 1.5 mm

NOTE: Written Specifications
H212VERT.XLS: 3-20-95

Table 11 - US 18 HORIZONTAL AND LONGITUDINAL ALIGNMENT MEASUREMENTS

F0018(95)234 Tripp County
Horizontal Rotation and Longitudinal Translation Measurements

Station	Horizontal Rotation in Millimeters				Longitudinal Diplacement in Millimeters				Horizontal Rotation 0 = Within Spec. 1=Right Skew -1= Left Skew				Long. Displacement 0 = Within Spec. 1=Forward -1=Backward			
	A	B	C	D	A1	B1	C1	D1	A	B	C	D	A1	B1	C1	D1
1+80	21.3	-3.0	-6.1	3.0	30.5	-27.4	-9.1	-6.1	1	0	0	0	1	-1	0	0
0+40	-12.2	9.1	12.2	15.2	-9.1	21.3	30.5	-3.0	0	0	0	1	0	0	1	0
4+60	3.0	-9.1	6.1	-15.2	21.3	15.2	-6.1	21.3	0	0	0	-1	0	0	0	0
16+40	-6.1	0.0	9.1	-9.1	-3.0	-6.1	30.5	54.9	0	0	0	0	0	0	1	1
22+40	-12.2	0.0	0.0	3.0	-6.1	21.3	-6.1	15.2	0	0	0	0	0	0	0	0
30+00	3.0	9.1	-3.0	-3.0	-45.7	-12.2	0.0	0.0	0	0	0	0	-1	0	0	0
55+20	-6.1	-3.0	-15.2	9.1	0.0	-15.2	-15.2	-91.4	0	0	-1	0	0	0	0	-1
73+40	-6.1	15.2	0.0	-6.1	24.4	15.2	24.4	45.7	0	1	0	0	0	0	0	1
83+15	6.1	6.1	-3.0	0.0	-3.0	0.0	24.4	21.3	0	0	0	0	0	0	0	0
90+85	0.0	-12.2	-3.0	-9.1	-9.1	-15.2	0.0	-33.5	0	0	0	0	0	0	0	-1
100+43	6.1	-3.0	-15.2	-9.1	0.0	-24.4	-6.1	-79.2	0	0	-1	0	0	0	0	-1
109+18	3.0	9.1	9.1	9.1	6.1	3.0	33.5	45.7	0	0	0	0	0	0	1	1
125+00	-3.0	6.1	6.1	-9.1	-76.2	9.1	76.2	3.0	0	0	0	0	-1	0	1	0
134+80	12.2	0.0	-12.2	9.1	6.1	-6.1	0.0	-30.5	0	0	0	0	0	0	0	-1
141+85	3.0	3.0	6.1	-15.2	0.0	0.0	0.0	-6.1	0	0	0	-1	0	0	0	0
149+40	9.1	-3.0	0.0	-18.3	-15.2	18.3	39.6	-30.5	0	0	0	-1	0	0	1	-1
165+55	6.1	0.0	-9.1	9.1	0.0	6.1	0.0	-152.4	0	0	0	0	0	0	0	-1
177+90	-3.0	-6.1	-6.1	0.0	-21.3	15.2	15.2	15.2	0	0	0	0	0	0	0	0
186+35	-18.3	-12.2	0.0	9.1	0.0	-3.0	15.2	39.6	-1	0	0	0	0	0	0	1
199+10	-9.1	6.1	0.0	6.1	-6.1	27.4	15.2	9.1	0	0	0	0	0	1	0	0
209+15	-6.1	-6.1	-9.1	-6.1	-6.1	54.9	-3.0	0.0	0	0	0	0	0	1	0	0
217+00	-9.1	9.1	6.1	-3.0	48.8	21.3	1.5	6.1	0	0	0	0	1	0	0	0
233+70	9.1	-3.0	6.1	-6.1	-9.1	-9.1	0.0	9.1	0	0	0	0	0	0	0	0
243+50	-12.2	12.2	-6.1	0.0	-6.1	-9.1	-6.1	18.3	0	0	0	0	0	0	0	0
255+45	-12.2	6.1	-3.0	-9.1	0.0	-24.4	9.1	6.1	0	0	0	0	0	0	0	0
269+45	0.0	-3.0	6.1	-12.2	-3.0	21.3	27.4	6.1	0	0	0	0	0	0	1	0
279+05	0.0	-6.1	-9.1	-15.2	-67.1	-6.1	15.2	6.1	0	0	0	-1	-1	0	0	0
289+65	3.0	-3.0	-9.1	0.0	-12.2	-3.0	0.0	3.0	0	0	0	0	0	0	0	0
300+45	-12.2	-6.1	-3.0	0.0	-24.4	-6.1	0.0	9.1	0	0	0	0	0	0	0	0
310+25	-6.1	-3.0	6.1	6.1	-9.1	18.3	-9.1	30.5	0	0	0	0	0	0	0	1
322+05	-3.0	-3.0	0.0	6.1	21.3	-12.2	21.3	-3.0	0	0	0	0	0	0	0	0
336+60	12.2	-6.1	-3.0	0.0	9.1	6.1	-15.2	3.0	0	0	0	0	0	0	0	0
345+40	6.1	12.2	-3.0	9.1	-3.0	24.4	9.1	6.1	0	0	0	0	0	0	0	0

Horizontal Rotation Specification :	12.7 mm	0.50 in
Longitudinal Displacement Specification :	25.4 mm	1.00 in

Number of Bars for a 95% Confidence Interval with 2% Error: 29 Bars Tested: 132

Number of Bars Out of Specification:

Horizontal Rotation (HR):						
Skewed Right:	3	=>	2.3 %	Mean:	6.6 mm	SD: 4.6 mm
Skewed Left:	7	=>	5.3 %			
Longitudinal Displacement (LD):						
Forward Displacement:	15	=>	11.4 %	Mean:	17.1 mm	SD: 21.2 mm
Backward Displacement:	10	=>	7.6 %			

NOTE: Written Specifications

H18HORIZ.XLS: 3-20-95

Table 12 - US 83 HORIZONTAL AND LONGITUDINAL ALIGNMENT MEASUREMENTS

P0083(33)165 & P0212(37)218 Potter & Sully Cos.
Horizontal Rotation and Longitudinal Translation Measurements

Station	Horizontal Rotation In Millimeters				Longitudinal Diplacement In Millimeters				Horizontal Rotation 0 = Within Spec. 1=Right Skew -1= Left Skew				Long. Displacement 0 = Within Spec. 1=Forward -1=Backward			
	A	B	C	D	A1	B1	C1	D1	A	B	C	D	A1	B1	C1	D1
29+10	0.0	6.1	-12.2	-3.0	-6.1	-91.4	12.2	27.4	0	0	0	0	0	-1	0	1
49+90	-9.1	6.1	-6.1	-12.2	-36.6	-18.3	30.5	3.0	0	0	0	0	-1	0	1	0
61+05	0.0	6.1	-9.1	-6.1	-3.0	30.5	3.0	158.5	0	0	0	0	0	1	0	1
69+78	-6.1	-6.1	-3.0	0.0	-9.1	-6.1	0.0	3.0	0	0	0	0	0	0	0	0
70+80	18.3	-12.2	-6.1	-9.1	30.5	-15.2	-6.1	-3.0	1	0	0	0	1	0	0	0
84+15	-12.2	-9.1	6.1	-12.2	57.9	51.8	-3.0	-6.1	0	0	0	0	1	1	0	0
98+00	-12.2	0 0	0.0	9.1	24.4	9.1	6.1	3.0	0	0	0	0	0	0	0	0
111+85	9.1	3.0	-9.1	-12.2	-24.4	-18.3	-6.1	3.0	0	0	0	0	0	0	0	0
115+45	27.4	12.2	6.1	0.0	6.1	-9.1	3.0	-15.2	1	0	0	0	0	0	0	0
125+65	-9.1	12.2	3.0	12.2	-24.4	-70.1	-12.2	3.0	0	0	0	0	0	-1	0	0
132+45	15.2	15.2	0.0	-6.1	-9.1	-91.4	-9.1	-27.4	1	1	0	0	0	-1	0	-1
171+95	12.2	-9.1	6.1	3.0	-12.2	-30.5	-15.2	-6.1	0	0	0	0	0	-1	0	0
177+95	-15.2	15.2	6.1	-18.3	9.1	-70.1	-9.1	-15.2	-1	1	0	-1	0	-1	0	0
180+55	-12.2	-6.1	6.1	6.1	24.4	-15.2	0.0	198.1	0	0	0	0	0	0	0	1
184+95	-12.2	3.0	3.0	6.1	6.1	-9.1	-21.3	0.0	0	0	0	0	0	0	0	0
196+00	18.3	-3.0	12.2	-3.0	-21.3	-61.0	-21.3	6.1	1	0	0	0	0	-1	0	0
215+45	15.2	-3.0	6.1	-12.2	-9.1	-45.7	-39.6	3.0	1	0	0	0	0	-1	-1	0
219+45	9.1	-6.1	-3.0	12.2	6.1	9.1	6.1	143.3	0	0	0	0	0	0	0	1
223+25	-12.2	6.1	-6.1	0.0	-18.3	-67.1	-15.2	-24.4	0	0	0	0	0	-1	0	0
242+25	9.1	-3.0	-15.2	0.0	-91.4	-228.6	-42.7	-30.5	0	0	-1	0	-1	-1	-1	-1
247+85	-12.2	-9.1	0.0	-9.1	6.1	-39.6	0.0	213.4	0	0	0	0	0	-1	0	1
269+90	12.2	-3.0	-3.0	-6.1	-6.1	-6.1	-6.1	12.2	0	0	0	0	0	0	0	0
275+10	6.1	-6.1	0.0	9.1	-9.1	-45.7	-36.6	9.1	0	0	0	0	0	-1	-1	0
286+32	6.1	12.2	-6.1	6.1	0.0	-18.3	0.0	15.2	0	0	0	0	0	0	0	0
288+92	-12.2	-9.1	6.1	15.2	-27.4	48.8	0.0	30.5	0	0	0	1	-1	1	0	1
289+95	-21.3	-9.1	9.1	9.1	70.1	6.1	-45.7	-3.0	-1	0	0	0	1	0	-1	0
329+58	6.1	-6.1	-3.0	-6.1	12.2	-6.1	6.1	-24.4	0	0	0	0	0	0	0	0
329+78	6.1	-21.3	3.0	0.0	-6.1	-9.1	-9.1	76.2	0	-1	0	0	0	0	0	1
330+18	27.4	18.3	-18.3	-27.4	-39.6	-64.0	9.1	9.1	1	1	-1	-1	-1	-1	0	0
330+38	42.7	15.2	-18.3	-9.1	-45.7	6.1	-6.1	6.1	1	1	-1	0	-1	0	0	0
330+58	24.4	24.4	-6.1	-24.4	-30.5	6.1	-3.0	-51.8	1	1	0	-1	-1	0	0	-1
330+78	24.4	18.3	-18.3	-54.9	-61.0	-12.2	15.2	-39.6	1	1	-1	-1	-1	0	0	-1
330+98	27.4	-21.3	-21.3	12.2	15.2	27.4	-9.1	-15.2	1	-1	-1	0	0	1	0	0
331+18	-15.2	30.5	-6.1	-12.2	-30.5	-9.1	0.0	-12.2	-1	1	0	0	-1	0	0	0
371+40	9.1	-9.1	-3.0	18.3	24.4	-3.0	-9.1	15.2	0	0	0	1	0	0	0	0
380+00	9.1	-3.0	9.1	6.1	0.0	-45.7	-36.6	30.5	0	0	0	0	0	-1	-1	1
380+80	12.2	6.1	-9.1	24.4	27.4	0.0	-24.4	36.6	0	0	0	1	1	0	0	1
384+40	-6.1	6.1	3.0	0.0	-12.2	-30.5	-6.1	36.6	0	0	0	0	0	-1	0	1
392+20	9.1	15.2	3.0	12.2	0.0	-91.4	-21.3	-6.1	0	1	0	0	0	-1	0	0
408+25	-9.1	24.4	-9.1	-3.0	-15.2	-79.2	-91.4	24.4	0	1	0	0	0	-1	-1	0
4+00	0.0	-6.1	-85.3	6.1	-24.4	-15.2	-30.5	3.0	0	0	-1	0	0	0	-1	0
13+07	-12.2	-9.1	-12.2	18.3	33.5	-70.1	-79.2	18.3	0	0	0	1	1	-1	-1	0
13+87	6.1	9.1	-18.3	6.1	3.0	-9.1	-39.6	36.6	0	0	-1	0	0	0	-1	1

Horizontal Rotation Specification :	12.70 mm	0.50 in
Longitudinal Displacement Specification :	25.40 mm	1.00 in

Number of Bars for a 95% Confidence Interval with 2% Error: 29 Bars Tested: 172

Number of Bars Out of Specification:

Horizontal Rotation (HR):
Skewed Right: 23 => 13.4 % Mean: 10.6 mm SD: 9.8 mm
Skewed Left: 16 => 9.3 %

Longitudinal Displacement (LD):
Forward Displacement: 21 => 12.2 % Mean: 27.2 mm SD: 36.0 mm
Backward Displacement: 38 => 22.1 %

NOTE: Written Specifications

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Table 13 - US 212 HORIZONTAL AND LONGITUDINAL ALIGNMENT MEASUREMENTS

F0212(37)218 Potter County
Horizontal Rotation and Longitudinal Translation Measurements

Station	Horizontal Rotation In Millimeters				Longitudinal Diplacement In Millimeters				Horizontal Rotation 0 = Within Spec. 1=Right Skew -1= Left Skew				Long. Displacement 0 = Within Spec. 1=Forward -1=Backward			
	A	B	C	D	A1	B1	C1	D1	A	B	C	D	A1	B1	C1	D1
2+54	9.14	24.38	-6.10	-18.29	-76.20	-9.14	12.19	3.05	0	1	0	-1	-1	0	0	0
9+10	-12.19	-3.05	-9.14	-6.10	100.58	3.05	-9.14	18.29	0	0	0	0	1	0	0	0
34+22	9.14	0.00	3.05	9.14	-21.34	9.14	6.10	3.05	0	0	0	0	0	0	0	0
53+75	-21.34	3.05	-6.10	-9.14	39.62	12.19	24.38	15.24	-1	0	0	0	1	0	0	0
62+42	15.24	0.00	-15.24	0.00	-9.14	15.24	33.53	9.14	1	0	-1	0	0	0	1	0
64+78	12.19	3.05	6.10	21.34	12.19	3.05	4.57	0.00	0	0	0	1	0	0	0	0
91+80	15.24	6.10	6.10	6.10	-57.91	54.86	15.24	-27.43	1	0	0	0	-1	1	0	-1
92+20	15.24	-6.10	-6.10	6.10	-30.48	-15.24	-15.24	-6.10	1	0	0	0	-1	0	0	0
95+44	3.05	-9.14	3.05	0.00	3.05	0.00	-15.24	-9.14	0	0	0	0	0	0	0	0
97+92	6.10	6.10	0.00	-6.10	6.10	0.00	0.00	-30.48	0	0	0	0	0	0	0	-1
120+40	0.00	-9.14	0.00	9.14	6.10	-12.19	-21.34	-15.24	0	0	0	0	0	0	0	0
136+84	12.19	0.00	6.10	0.00	15.24	-9.14	-15.24	-6.10	0	0	0	0	0	0	0	0
137+64	12.19	6.10	-9.14	9.14	82.30	3.05	-12.19	30.48	0	0	0	0	1	0	0	1
145+04	-6.10	-6.10	-6.10	-12.19	3.05	-27.43	3.05	39.62	0	0	0	0	0	-1	0	1
147+04	0.00	6.10	-21.34	-6.10	0.00	0.00	91.44	15.24	0	0	-1	0	0	0	1	0
169+34	-9.14	0.00	-6.10	-9.14	-12.19	-15.24	-9.14	-15.24	0	0	0	0	0	0	0	0
187+56	-6.10	27.43	-12.19	-18.29	-9.14	-9.14	27.43	6.10	0	1	0	-1	0	0	1	0
188+36	0.00	15.24	-6.10	-6.10	-36.58	0.00	167.64	-15.24	0	1	0	0	-1	0	1	0
197+54	0.00	27.43	-18.29	12.19	21.34	-6.10	-30.48	-21.34	0	1	-1	0	0	0	-1	0
223+54	9.14	6.10	-9.14	-9.14	45.72	0.00	60.96	15.24	0	0	0	0	1	0	1	0
224+14	0.00	-6.10	24.38	-9.14	33.53	-15.24	-24.38	21.34	0	0	1	0	1	0	0	0
242+12	0.00	15.24	-12.19	-12.19	70.10	-18.29	-9.14	15.24	0	1	0	0	1	0	0	0
244+12	12.19	0.00	3.05	6.10	15.24	-36.58	76.20	-15.24	0	0	0	0	0	-1	1	0
263+56	6.10	0.00	0.00	0.00	33.53	-6.10	0.00	0.00	0	0	0	0	1	0	0	0
276+02	15.24	15.24	-3.05	-9.14	70.10	-15.24	-9.14	15.24	1	1	0	0	1	0	0	0
284+38	3.05	6.10	-9.14	15.24	21.34	9.14	-76.20	9.14	0	0	0	1	0	0	-1	0
292+44	3.05	15.24	12.19	0.00	0.00	-21.34	-15.24	-24.38	0	1	0	0	0	0	0	0
302+10	9.14	9.14	12.19	12.19	54.86	-9.14	0.00	-15.24	0	0	0	0	1	0	0	0
307+28	-9.14	18.29	-9.14	6.10	15.24	15.24	-67.06	30.48	0	1	0	0	0	0	-1	1

Horizontal Rotation Specification :	12.70 mm	0.50 in
Longitudinal Displacement Specification :	25.40 mm	1.00 in

Number of Bars for a 95% Confidence Interval with 2% Error: 29 Bars Tested: 116

Number of Bars Out of Specification:

Horizontal Rotation (HR):
Skewed Right: 15 => 12.9 % Mean: 8.3 mm SD: 6.4 mm
Skewed Left: 6 => 5.2 %

Longitudinal Displacement (LD):
Forward Displacement: 19 => 16.4 % Mean: 22.0 mm SD: 25.4 mm
Backward Displacement: 11 => 9.5 %

NOTE: Written Specifications

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IX. CONCLUSIONS

Field survey data analysis and field observations support the following conclusions:

- Dowel basket assemblies do not move significantly during the paving operation if they are installed properly.

- The Soiltest CT-4950 Micro-Covermeter is an accurate instrument that can be used for the inspection of dowel bars.

- The SDDOT can modify its alignment specifications to coincide with results from previous research studies and other DOT's alignment specifications.

- The Iowa Special paving operation is a viable alternative for full-width paving because it simplifies the concrete hauling operation.

- Automated dowel bar inserters can be used provided:

    1. The modifications for the dowel bar alignment specifications are accepted.

    2. The automated dowel bar inserters meet the dowel bar alignment specifications.

- Because of the short time period between project construction and the field surveys, a policy regarding pay reductions for out of specifications joints is not provided since there was no pavement distress that could be attributed to misaligned dowel bars.

X. RECOMMENDATIONS

1. The Department should modify the dowel bar alignment specifications to read as follows:

Depth	**(Metric Units, mm)**	Dowel Bar Depth = Pavement Thickness/2 ± ***(Pavement Thickness/4 - 38).***
	(English Units, in)	Dowel Bar Depth = Pavement Thickness/2 ± ***(Pavement Thickness/4 - 1.5).***
Vertical Rotation	Centerline of individual dowel bars shall be parallel to top of subgrade ± ***6.4 mm (1/4 in)*** in 457 mm (18 in).	
Horizontal Rotation	Centerline of individual dowel bars shall be parallel to the centerline of the roadway ± 12.7 mm (1/2 in).	
Longitudinal Displacement	The transverse contraction joints shall be sawed perpendicular to the centerline of the roadway and the dowel bars ***shall have a minimum imbedment length of: 6 x Dowel Bar Diameter"***	

2. The Office of Research should work with the Training Activity to develop an inspection methodology using the Soiltest CT-4950 Micro-Covermeter.

3. The Department should use dowel bar inserters where applicable.

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DISCLAIMER

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