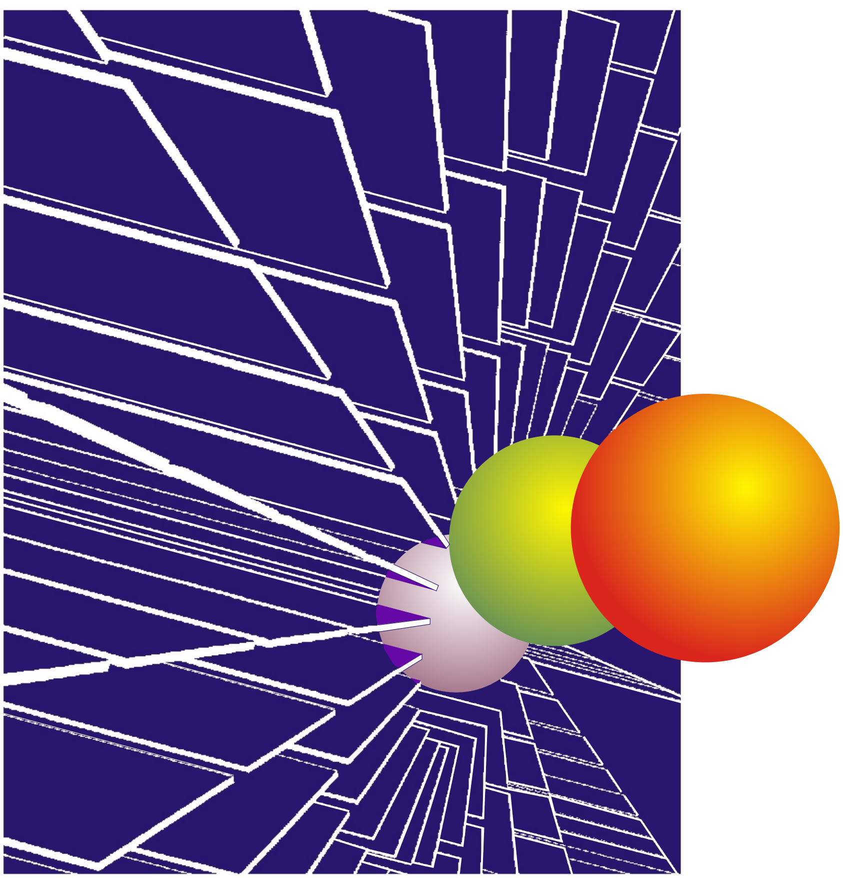
MoDOT

Research, Development and Technology

RDT 03-009

Investigation of Dowel Bar Placement Accuracy with a Dowel Bar Inserter

RI 01-049



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Dowel bar inserters (DBI) on concrete paving equipment eliminate the need for manually placing dowel bar baskets. Reduced manual labor eventually pays off the initial investment in a DBI and ultimately results in reduced PCCP costs to the roadway owner.

The purpose of this investigation was to compare the dowel bar placement accuracy of a DBI with the performance of conventional dowel baskets. Ground penetrating radar (GPR) was used to measure dowel bar skew, translation, and depth at specific joint locations on a US 60 jointed plain concrete pavement (JPCP) construction project near Van Buren.</td></tr>
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INVESTIGATION OF DOWEL BAR PLACEMENT ACCURACY WITH A DOWEL BAR INSERTER

Prepared by

MISSOURI DEPARTMENT OF TRANSPORTATION
RESEARCH, DEVELOPMENT, AND TECHNOLOGY

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JEFFERSON CITY, MISSOURI
Date Submitted: April 2003

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Wooyoung Kim and Neil Anderson at UMR for their extensive work performing the GPR measurements of dowel locations and subsequent interpretation and analysis of the data.

Stuart Reed and Andy Horstman at the Van Buren project office for their very helpful assistance in selecting test locations and keeping the author informed of paving developments.

Executive Summary

The general conclusion of the investigation was that the Gunter-Zimmerman DBI provides similar dowel bar placement accuracy to dowel baskets. The DBI performed a little better with regards to horizontal skew, while dowel baskets held a very slight edge on vertical skew performance. Both had low frequency of oppositely misaligned bars. Each method had one joint location with some excessive longitudinal translation of dowels, which was due to manmade error. Horizontal translation was visually acceptable. For depth the DBI was more consistent than baskets with respect to the surface elevation.

The general recommendation is to allow use of the Guntert-Zimmerman DBI as an acceptable dowel bar placement alternate to dowel baskets on future JPCP paving projects. Any DBI manufactured by another company should be evaluated separately on an experimental basis to determine its acceptability.

Table of Contents

page

Background …………………………………………………………… 1

Project Description …………………………………………………… 1

Investigation Procedures ……………………………………………... 5

Results …………………………………………………………………... 6

Skew ………………………………………………………. 6

Translation ………………………………………………… 8

Depth ……………………………………………………… 9

Conclusions …………………………………………………………….. 9

Recommendations ………………………………………………………… 9

References ……………………………………………………………… 11

Appendix A - Spreadsheet graphs of dowel skew and depth in joints.

Appendix B - Covermeter procedures for construction inspectors to measure dowel locations

Appendix C - Dowel Bar Inserter Special Provisions

Appendix D - UMR preliminary report for GPR procedures and data analysis

Investigation of Dowel Bar Placement Accuracy with a Dowel Bar Inserter

Background:

Dowel bar inserters (DBI) on concrete paving equipment eliminate the need for manually placing dowel bar baskets. Reduced manual labor eventually pays off the initial investment in a DBI and ultimately results in reduced PCCP costs to the roadway owner.

DBIs have been used in Europe for a quarter century. Their use in the United States dates back to the late 1980s. The Texas and Wisconsin DOTs concluded in separate investigations that DBIs were at least as accurate in dowel bar placement as baskets. In 1996 the FHWA officially encouraged the use of DBIs as an acceptable alternate means of dowel bar placement in jointed concrete construction.

Prior to the US 60 project DBIs had not been used in Missouri on any other State highway projects. They had been, however; used on airfield projects in Missouri, including one constructed last year at KCI airport by Cape and Sons.

Guntert-Zimmerman DBI on US 60 near Van Buren

Project Description:

Approximately five miles of divided four-lane JPCP on US 60 near Van Buren was scheduled for construction in the summer of 2002. The contractor, James Cape and Sons from Wisconsin, had extensive experience with DBIs (they were the contractor on the DBI projects studied by the

Wisconsin DOT over a decade ago) and broached the subject of using their DBI on this paving project. The project office agreed to allow it on an experimental basis. Consensus was reached to use the DBI on the eastbound lanes were there were fewer anticipated paving interruptions and dowel baskets on the westbound lanes.

US 60 JPCP paving on Project J9P0282E

Paving operations began in the early summer of 2002 and concluded in the early fall. The contractor, in an effort to alleviate any initial fears at the start of paving operations with the DBI, constructed a throwaway section of concrete for the first couple of joints, so that inspectors could verify dowel bars were in their approximate correct locations

Dowel bar location verification

Measuring dowel bar depths

No DBI operational problems were noted by the project office. However, in a humorous aside, project office personnel were approached by several upset citizens, including a retired MoDOT inspector, who were under the impression that the contractor either forgot or intentionally left out the 'steel' and MoDOT inspectors allowed it to happen, when they didn't notice any dowel baskets in the eastbound lanes.

Dowel bars waiting for pick up

Hoisting dowel bar bundles

Placing bars in shuttle

Waiting for shuttle to place bars in DBI slots

DBI vibrating forks and dowel slots

Shuttle dropping dowel bars in slots

DBI measuring wheel for joint locations

DBI pistons matching forward rate of paver

Marking dowel bar locations

DBI trail after insertion

Oscillating beam for finishing surface after DBI

Finished surface behind oscillating beam

Investigation Procedures:

The investigation comparing dowel bar placement accuracy for the DBI versus dowel baskets began with the selection of ten joints spaced 400 meters apart from each other in both the eastbound and westbound directions. Dowel bar placement was measured with ground penetrating radar (GPR) at each joint location. The GPR unit was operated by a University of Missouri at Rolla (UMR) doctoral student through a research contract with the university. A handheld pachometer or steel locator was used by the MoDOT investigator to measure actual dowel bar depths at one joint in each direction to provide ground truth data for GPR calibration.

Measuring dowel bar locations with GPR

Locating steel with pachometer

Procedures for a construction inspector to measure and record 1 ½" diameter dowel locations with a Micro Covermeter (pachometer) are attached in Appendix B.

The GPR unit contained a 1.5 GHz ground-coupled antenna to provide the high resolution for this study. GPR profiles were collected from edge-of-shoulder to edge-of-shoulder at 4.5" and 9" offsets from the transverse joint on both the east and west sides of all twenty joints. The data was calibrated and converted to length units of measure. A much more detailed explanation of GPR methodology and data processing is contained in the UMR preliminary report (without appendices) in Appendix D.

Results

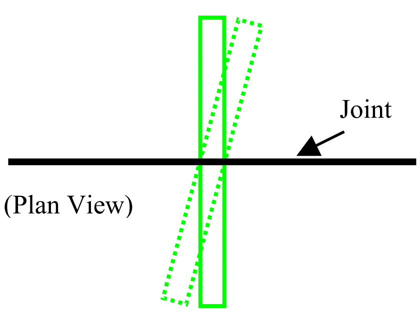
The GPR data provided accurate measurements of dowel bar horizontal skew, vertical skew, transverse translation, and depth and approximations of longitudinal translation. Horizontal and vertical skew are the two most critical indicators. Excessive skew in any direction creates potential for locked joints during normal expansion and contraction in the slabs that occur naturally from temperature and moisture changes. Longitudinal displacement is important for ensuring adequate steel length on either side of the joint for load transfer. Transverse displacement and vertical depth are less critical, but worth verifying.

Skew

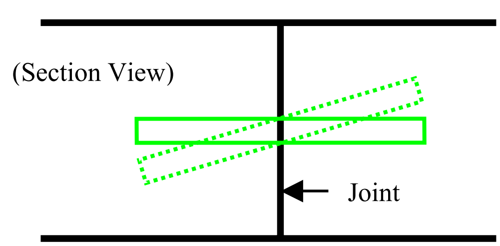
Most States that specify a skew limit for dowel alignment use ½" for 18" bars. Missouri currently specifies that the bars 'be parallel to the subgrade and perpendicular to the line of the joint' rather than use a tolerance measure. Few States, if any, conduct acceptance testing to verify dowel placement and orientation when using dowel baskets. However, some of the States that allow DBIs use a pachometer to randomly verify placement.

Limited research has been conducted in the past to understand the importance of dowel bar skew.

Laboratory pullout tests have been performed on one misaligned and two oppositely misaligned dowel bars in a joint[1]. The results showed that for two oppositely misaligned bars (i.e. skewed towards or away from each other) pullout forces were relatively low for slabs with up to 1" bar skew and ¼" joint opening. No laboratory or field tests have been performed to measure lockup forces in joints with multiple pairs of misaligned bars.



Horizontal Skew



Vertical Skew

A finite element modeling study[2] to better understand the impact of dowel skew was conducted for the Michigan DOT in 2001, because of their increased use of DBIs. The study concluded that a single misaligned dowel results in PCC stresses higher than in the case of uniformly misaligned dowels, but lower than in the case of oppositely misaligned dowels. Also, oppositely misaligned dowel bars up to ¼” skew do not cause significant restraints on joint behavior. Recommendations were made for more elaborate pullout testing to better understand dowel-PCC interaction.

Dowel skew results for the US 60 project are summarized in the two tables below. Dowels were categorized into three groupings of skew: ≤ ½”, ½” – ≤ 1”, and > 1”. Actual average horizontal and vertical skews at each joint location are shown in Appendix A.

The DBI produced slightly less average horizontal skew than the dowel baskets. Dowel baskets had a 70% higher incidence of dowels misaligned > 1” than the DBI. Overall, neither the DBI at 67.2 % nor the basket at 60.9% had impressive alignment rates within the ½” limit set by most States. This somewhat disturbing finding echoed the results of a Texas study in 1988, in which a similar comparison of a DBI and dowel baskets was made[3]. In that study, average DBI horizontal skew was 0.49”, while average basket horizontal skew was 0.51”.

Average vertical skew was closer to acceptable standards for both the DBI and dowel baskets. Both had close to 90% alignment within the ½” skew limit. Neither had significant incidence > 1”. Overall, baskets held a very slight edge over the DBI in minimizing vertical skew.

Type	Number of Dowels	Mean Horizontal Skew (in)	% ≤ ½”	½” < % ≤ 1”	% > 1”
DBI	360	0.41	67.2	23.9	8.9
Basket	368	0.48	60.9	23.9	15.2

Type	Number of Dowels	Mean Vertical Skew (in)	% ≤ ½”	½” < % ≤ 1”	% > 1”
DBI	360	0.23	88.9	10.6	0.5
Basket	368	0.27	92.7	6.8	0.5

The issue of oppositely misaligned skew was also considered. The table below summarizes the occurrence of oppositely skewed pairs where each bar is skewed > ½” toward the other within the same joint. Horizontal occurrence was moderate for each with the DBI having a slight advantage. Significantly, the DBI had no instance of pairs skewed vertically toward each other > ½” , while the baskets had only three.

Type	Horizontal Oppositely Skewed Pairs (> ½” each)	Horizontal Oppositely Skewed Pairs (> 1”)	Vertical Oppositely Skewed Pairs (> ½”)	Vertical Oppositely Skewed Pairs (> 1”)
DBI	22	5	0	0
Basket	25	5	3	0

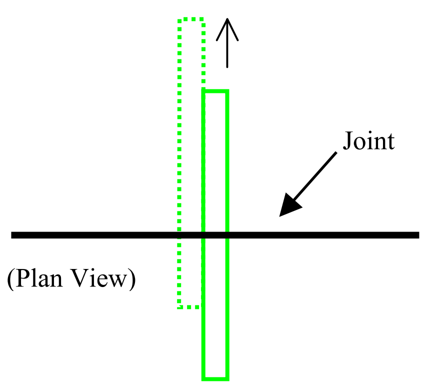
Translation

Longitudinal translation is a measure of a bar’s effective length on the approach and leave sides of two slabs. It is not realistic to expect every 18” bar to perfectly straddle a joint with 9” on either side, but it is expected that a bar have at least 6” on either side to ensure that it can adequately provide load transfer across the slabs.

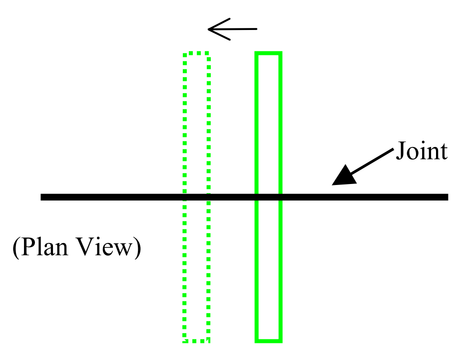
Longitudinal translation for this study was difficult to assess because of the limited number of GPR profiles. The two outer profiles were intended to detect bars at their very tips. Any slight longitudinal deviation of a bar resulted in a missing profile at that spot. This occurred many times for both the DBI and baskets. The inner two profiles were 4.5” away from the expected bar end locations, therefore all that could be known for certain in the case of a bar missing only the outer profile was that its end lie somewhere between 9” and 4.5” from the joint. Where this occurred in a joint, there was nearly always an adjacent or nearby dowel that did have all four profiles indicating that because of slight operational drift in the DBI or slight distortion of the basket placement the bar with the missing profile had near symmetry across the joint.

There was, however; one case at a joint location for each method where a dowel had both the outer and inner profiles on one side missing (EB Sta 14+700 and WB Sta 12+300) meaning that the bars were translated in the longitudinal direction beyond an acceptable tolerance. This would have been the result of manmade error in marking the midpoint of the joint location beside the slab or perhaps in sawing and not an inherent flaw in the DBI or baskets themselves.

Horizontal translation has little performance impact on load transfer, unless grossly clustered enough to possibly create load transfer gaps and air pockets. The bars are supposed to be spaced on 12” centers. Because the baskets are designed for this spacing and the DBI slots are fixed for these spacings, there is virtually no chance of the abovementioned occurring.



Longitudinal Translation



Horizontal Translation

Depth

Dowel depth is not as critical as skew, but still must be monitored to ascertain that the bars are not being placed in higher stress zones where they could be deformed or cause debonding or bearing stress failures in the PCC. One limitation of GPR testing for measuring depth in this study that had little impact on measuring other parameters is the use of a single dielectric constant for each direction. This introduced potential errors up to ± 1/8" in depth, but because the degree of error would have been constant at a single joint location, the relative accuracy of each profile with respect to one another was still very high.

Average depth placement is a little misleading when comparing the DBI with baskets, because each is fixed with respect to a different horizontal plane. The DBI places a dowel at a constant depth with reference to the finished PCC surface, while baskets fix the dowel height with reference to the base surface to which the baskets are fixed and thus, cannot adjust for undulations in paving thickness. The result of this when measuring depth from the surface is that the DBI-placed dowels should inherently be more consistent or have a lower standard deviation of measured depth. That is in fact what happened in this study. The DBI standard deviation for depth was 0.22", while the baskets were 0.37". Actual average depths at each joint location are shown in Appendix A. Because of variations in slab thickness and possible GPR error it is not possible to know how exactly close to mid-depth the center of each dowel is, however; the results indicate that both the DBI and dowel baskets are reasonably close to specification.

Conclusions

1) Both the DBI and baskets tend to have moderate horizontal skew tendencies with the DBI performing a little better.

2) Both the DBI and baskets have very good control of vertical skew with the baskets holding a slight edge in performance.

3) Both the DBI and baskets have few serious occurrences of high opposite skew between dowel bars in the same joint.

4) Longitudinal translation was not excessive except at one joint location for both the DBI and baskets.

5) Average depth and average depth standard deviation was acceptable for both the DBI and baskets.

Recommendations

1) The Guntert-Zimmerman DBI should be allowed as an alternate method of dowel bar placement on MoDOT JPCP construction projects.

2) Use of a DBI other than the Guntert-Zimmerman should be evaluated on an experimental basis before approving as an alternate to dowel baskets. Special provisions for using a DBI in a JPCP construction project are in Appendix C.

3) MoDOT construction inspectors should be equipped with a pachometer to randomly check dowel bar placements using the procedures in Appendix B (Note: specifically for measuring 1 ½" dowels with a Micro Covermeter) when a DBI is used on a JPCP project.

References

1) Tayabji, Shiraz D., *Dowel Placement Tolerances for Concrete Pavements*, TRR 1062, 1986.

2) Khazanovich, Lev, N. Buch, A. Gotliff, *Evaluation of Alignment Tolerances for Dowel Bars and their Effects on Joint Performance*, Michigan DOT, 2001.

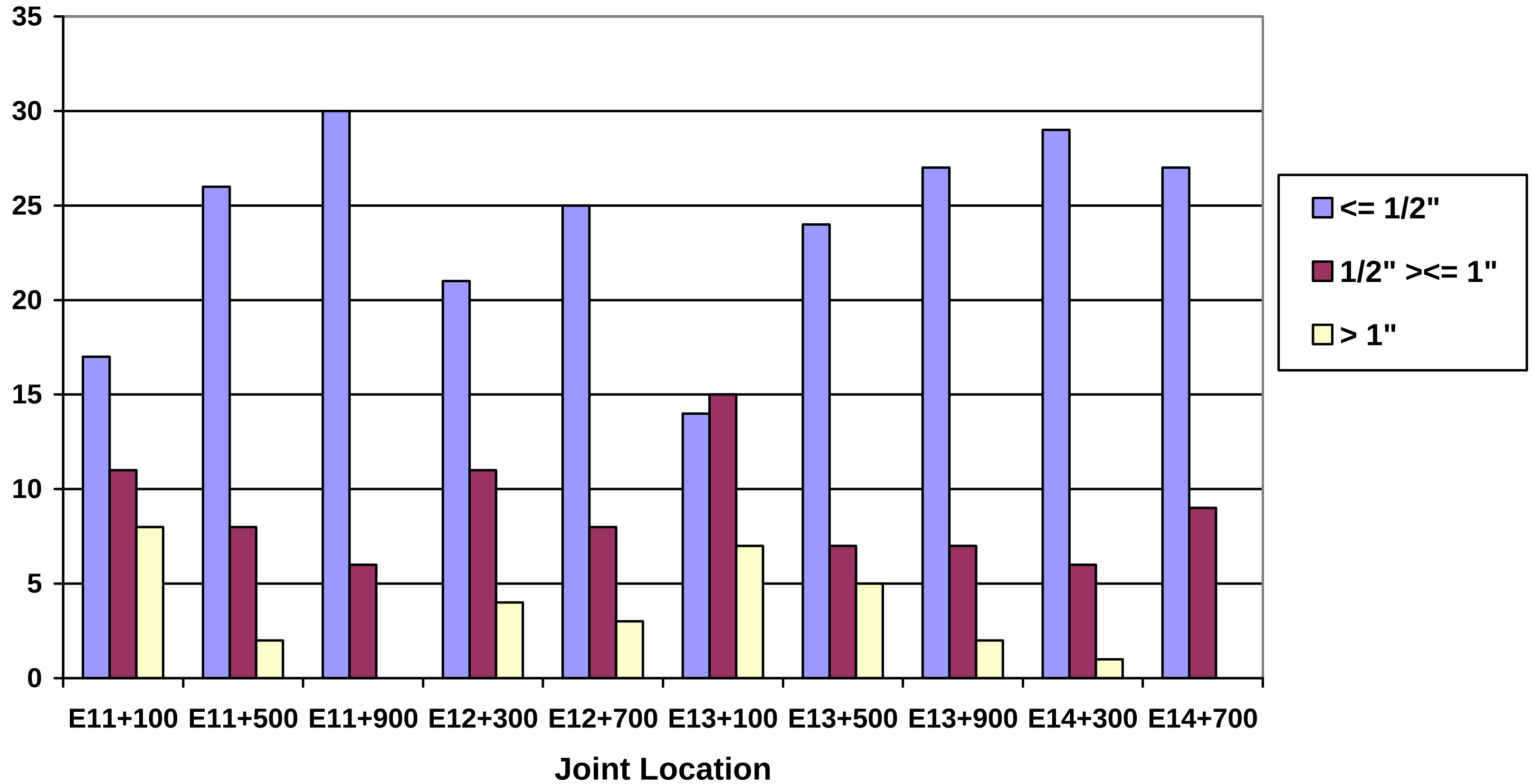
3) Okamoto, Paul A., *Field Evaluation of Dowel Placement Along a Section of Interstate 45 in Texas*, 1988.

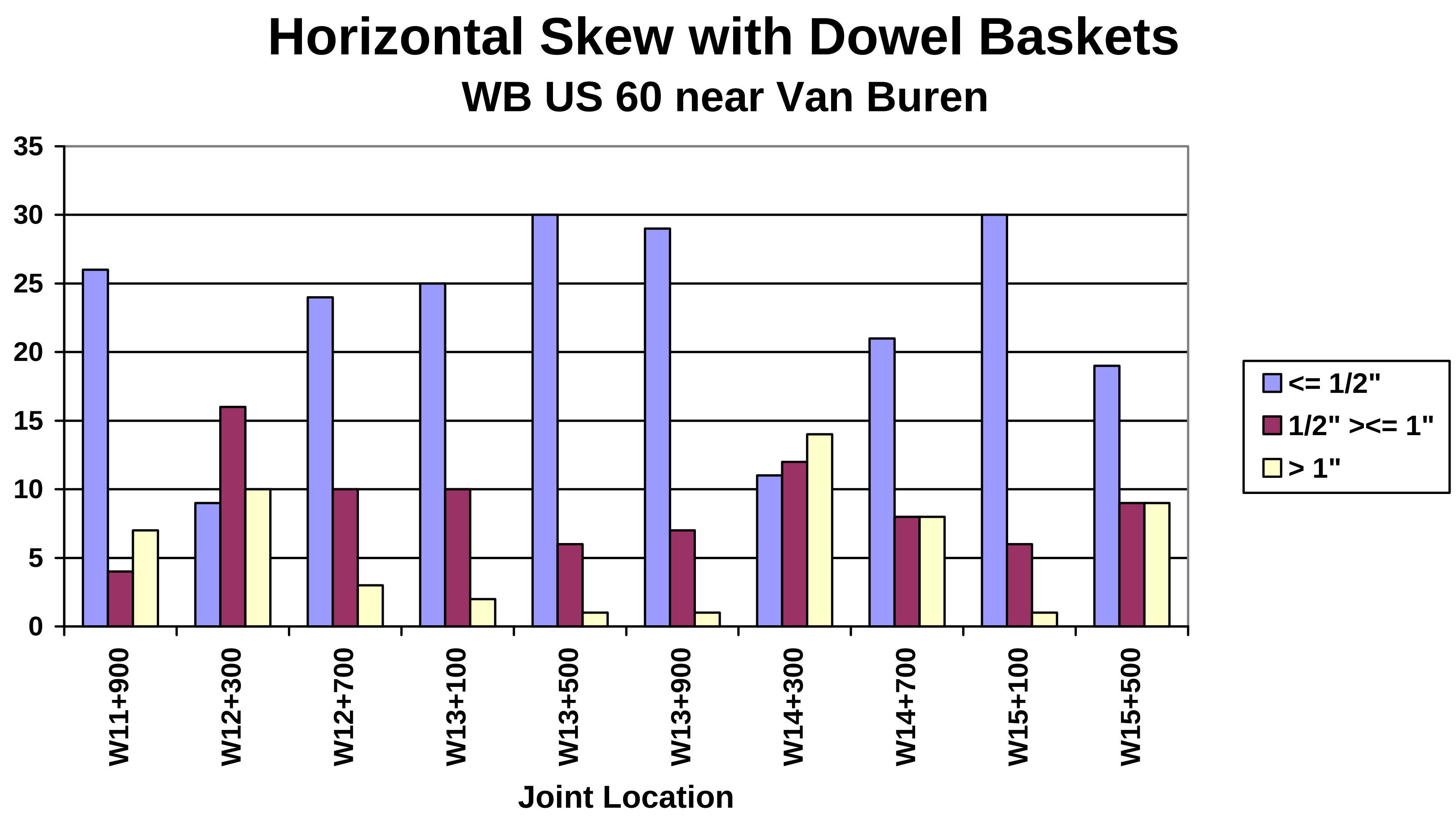
APPENDIX A

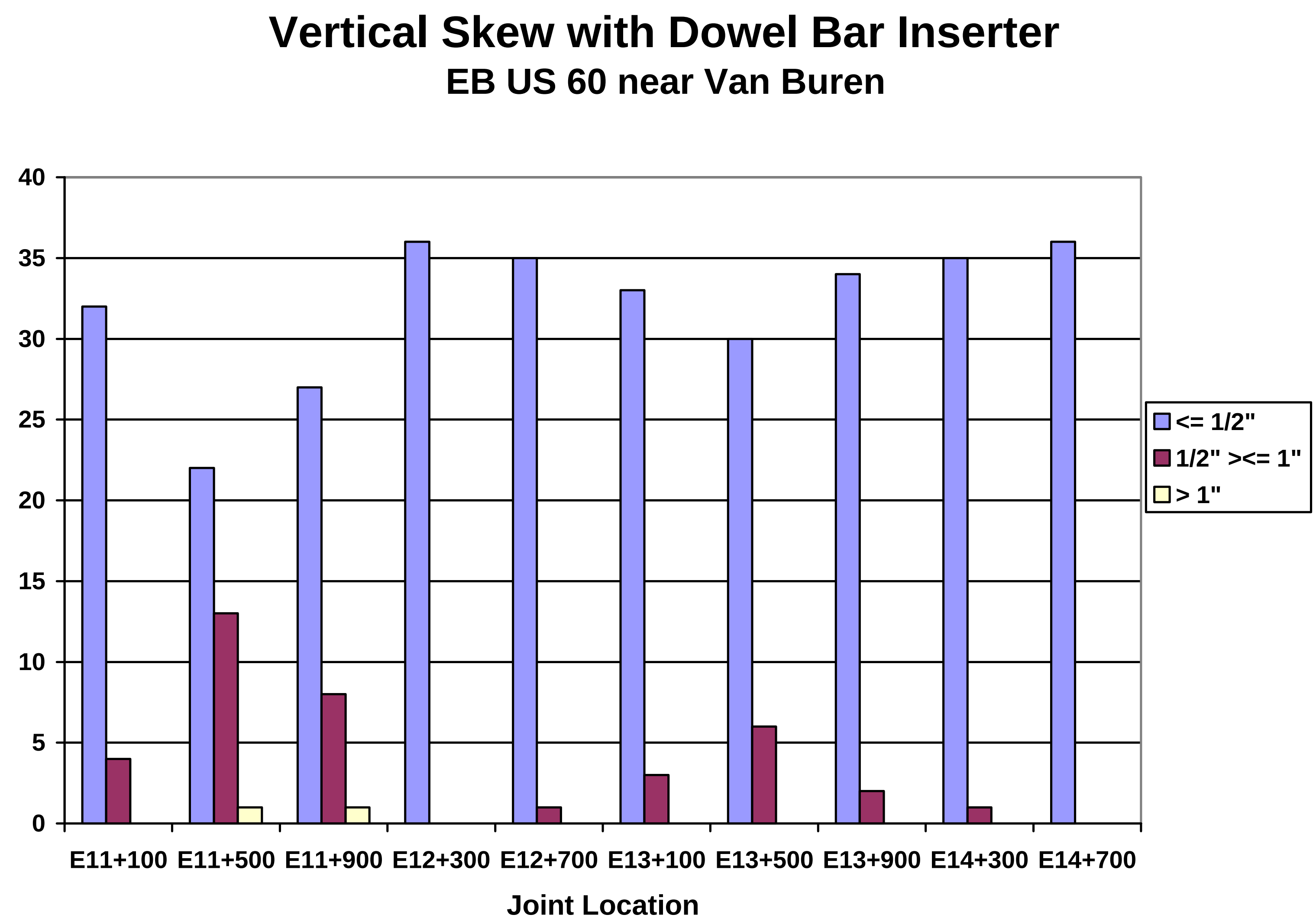
Spreadsheet graphs of dowel skew and depth in joints

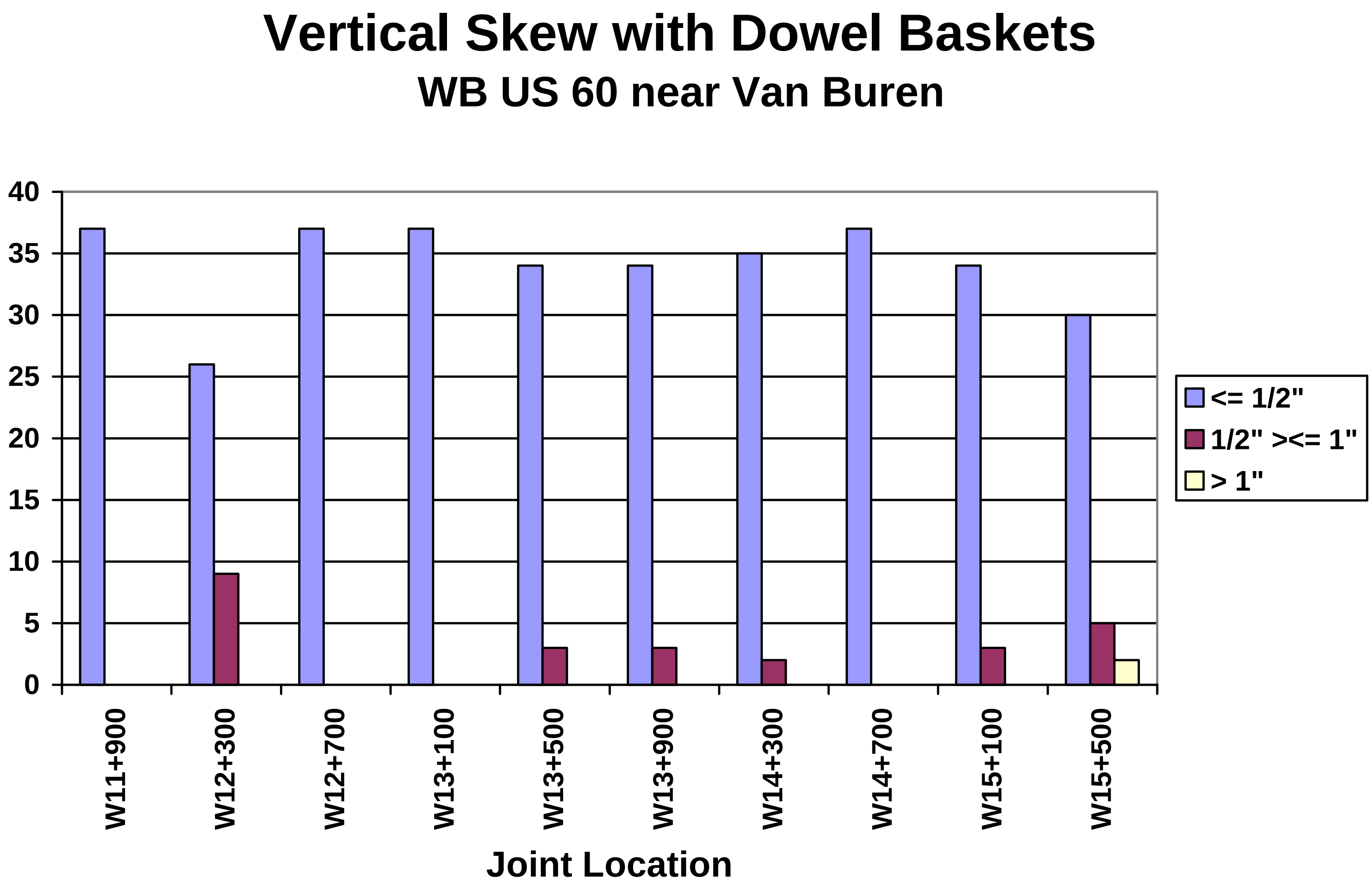
Horizontal Skew with Dowel Bar Inserter

EB US 60 near Van Buren

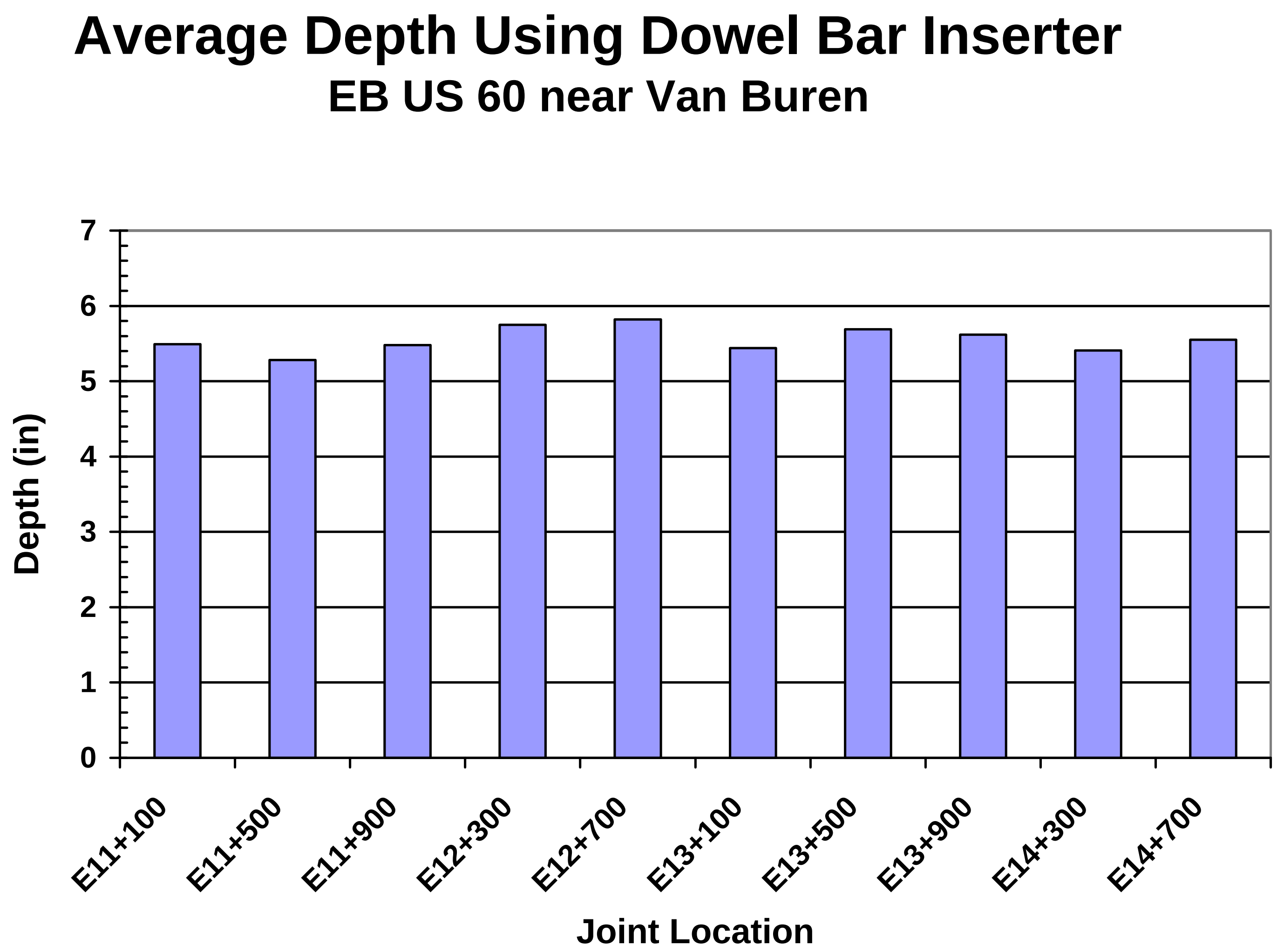



Horizontal Skew with Dowel Baskets
WB US 60 near Van Buren
35
30
25
20
15
10
5
0
W11+900
W12+300
W12+700
W13+100
W13+500
W13+900
W14+300
W14+700
W15+100
W15+500
Joint Location
<= 1/2"
1/2" ><= 1"
> 1"

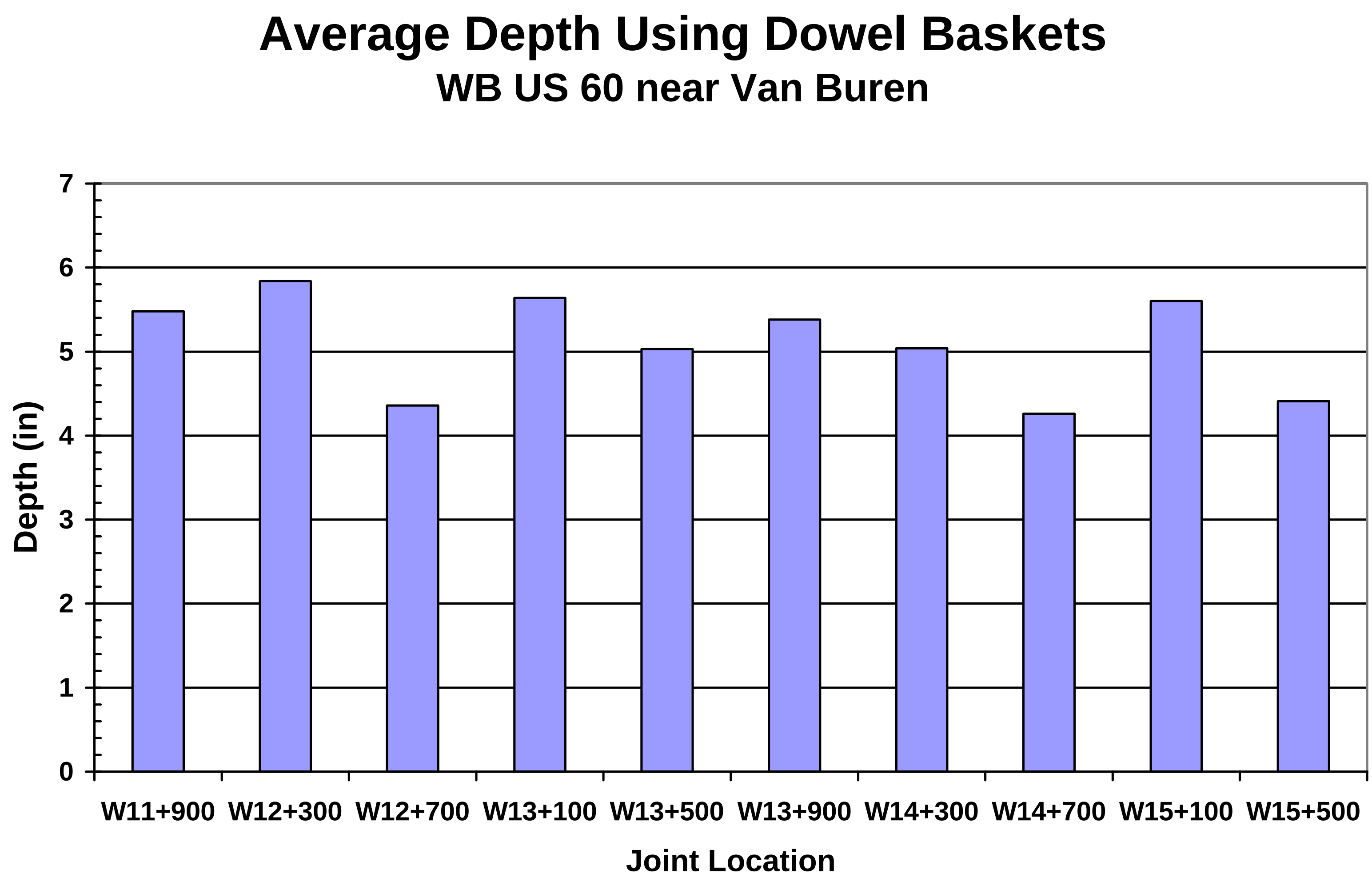

Vertical Skew with Dowel Bar Inserter
EB US 60 near Van Buren
40
35
30
25
20
15
10
5
0
E11+100
E11+500
E11+900
E12+300
E12+700
E13+100
E13+500
E13+900
E14+300
E14+700
Joint Location
<= 1/2"
1/2" ><= 1"
> 1"



Vertical Skew with Dowel Baskets
WB US 60 near Van Buren
40
35
30
25
20
15
10
5
0
W11+900
W12+300
W12+700
W13+100
W13+500
W13+900
W14+300
W14+700
W15+100
W15+500
Joint Location
<= 1/2"
1/2" ><= 1"
> 1"



Average Depth Using Dowel Bar Inserter
EB US 60 near Van Buren
Depth (in)
0
1
2
3
4
5
6
7
E11+100
E11+500
E11+900
E12+300
E12+700
E13+100
E13+500
E13+900
E14+300
E14+700
Joint Location


Average Depth Using Dowel Baskets
WB US 60 near Van Buren
Depth (in)
0
1
2
3
4
5
6
7
W11+900
W12+300
W12+700
W13+100
W13+500
W13+900
W14+300
W14+700
W15+100
W15+500
Joint Location

APPENDIX B

Covermeter procedures for construction inspectors to measure dowel locations

Procedures for Measuring Dowel Bar Locations with Micro Covermeter

1. Attach maxi-probe to covermeter.
2. Press ON key on covermeter.
3. Press SIZE key till bar size #11 is shown.
4. Press CAL (calibration) key while holding maxi-probe at arm’s length away from any metal object and verify that covermeter reads 14”.
5. Select random dowel bar location using a plan design offset distance from edge of pavement. Set probe on concrete surface (at joint if already sawed) in expected dowel bar location with longer probe side parallel to roadway direction.
6. Move probe from side to side until centered over lowest depth reading position.
7. Rotate probe, using the letter “O” in the word “TOP” as the pivot point, until aligned in direction of lowest depth reading position.
8. Record offset distance from edge of pavement on worksheet.
9. Use chalk or lumber crayon and draw tick mark on concrete at the center of each probe face in the bar direction.
10. Remove probe from surface and draw straight line through tick marks. Extend line on either side of tick marks by 12” or more.
11. Place probe back in previous position on concrete.
12. Slowly move probe forward along line until depth reading starts to increase more rapidly than bar gradient change (if any is noticed). Keep probe in position before the onset of rapid increase and record the depth of cover on the worksheet.
13. Draw tick mark across line approximately 1” in front of probe face.
14. Turn probe around in opposite direction on line.
15. Repeat steps 12 and 13. The line between the two tick marks is the approximate bearing and location of the dowel bar.
16. If the joint has been sawed, record the lengths of the dowel bar on either side of it on the worksheet.
17. Adjust the recorded depth measurements using the calibration formula for three dowel bars at 12” centers on the attached graph.
18. Calculate the vertical skew on the datasheet.
19. If the joint has been sawed, use a carpenter’s square or some other tool to measure the lateral offsets from the line-joint intersection at both ends of the line. Record and add these together on the worksheet. The total is the horizontal skew of the dowel bar.

Dowel Bar Location Measurement with Micro Covermeter Worksheet

Project:		*Route:*		*Direction:*		*County:*			Date:		
Station	Lateral offset (in)	Measured approach side depth (in)	Corrected approach side depth (in)	Measured leave side depth (in)	Corrected approach side depth (in)	Vertical skew (in)	Approach side bar length (in)	Approach side lateral offset (in)	Leave side bar length (in)	Leave side lateral offset (in)	Horizontal skew (in)

Using Covermeter to detect dowel location

Marking orientation of dowel

Marking dowel bar ends

Approximate location of dowel bar

APPENDIX C

Dowel Bar Inserter Special Provisions

Mechanical Dowel Bar Insertion

Amend Sec. 502.8 to include the following:

A mechanical device or dowel bar inserter may be used during placement of the concrete, subject to the following requirements:

1. The pavement shall be placed and consolidated to full depth prior to insertion of the dowel bars
2. Dowel bars shall be inserted into the plastic concrete ahead of the finishing beam or screed
3. The installing device shall consolidate the concrete so that no voids exist around the dowel bars
4. Dowel bars shall be located within 1 inch of the planned transverse and depth locations
5. Dowel bars shall be placed within 2 inches of the planned longitudinal locations
6. Dowel bars shall be parallel to the pavement surface and centerline within a tolerance of ½ inch per bar length
7. Forward movement of the finishing beam or screed shall not be interrupted by insertion of the dowel bars
8. A positive method of marking transverse joint locations shall be provided

Dowel bar location tolerances shall be randomly checked by the Engineer. Deviance from the tolerance shall result in suspension of paving operations until the problem is corrected. Significant and/or multiple deviances from dowel bar location tolerances may result in removal of the affected concrete section(s) at the Contractor's expense.

APPENDIX D

UMR preliminary report for GPR procedures and data analysis

Preliminary Report: GPR Study of Imbedded Dowel Bars, Van Buren, Missouri

Report prepared for:
Missouri Department of Transportation

Report prepared by: Wooyoung Kim and Neil Anderson
Department of Geology and Geophysics
University of Missouri-Rolla

Overview

In August and September, 2002, a ground penetrating radar (GPR) survey was conducted along two newly paved segments (east and west bound lanes, respectively) of Route US 60, near Van Buren, Missouri. The objective was to image imbedded dowel bars at twenty test sites (joint sites) with the goal of determining the relative spatial location (orientation and depth) of each dowel bar. The dowel bars in the west bound lane were emplaced using conventional techniques. The dowel bars in the east bound lane were emplaced using an automated dowel bar inserter.

A total of ten joints in each lane (east and west bound) were investigated. Four parallel GPR profiles were acquired at each study site (joint). Two GPR profiles were acquired parallel and to the east of the each joint (11 cm and 22 cm from joint, respectively), and two GPR profiles were acquired parallel and to the west of the each joint (11 cm and 22 cm from joint, respectively). GPR data were not acquired along the joint.

Project deliverables include a plan view map of each joint studied (ten joints per lane) and a suite of cross-sections. The plan view maps show the relative locations, depths and spacing of dowel bars (relative to joints and edge of pavement). The suite of cross-sections show the depths to tops of dowel bars along each acquired GPR profile.

Background and Methodology

The ground penetrating radar tool uses a radio wave source to transmit a pulse of electromagnetic energy into a subsurface (in this case, the concrete roadway). The amplitude and arrival time of the reflected EM pulse (which originates from the top of rebar), is recorded for analysis (determination of spatial location of rebar). The GPR signal is characterized primarily by changes in reflection amplitude and changes in the arrival time of specific reflections.

The GPR record consists of a continuous graphic display of reflected energy over a pre-set time interval. The pre-set time interval is two-way travel time (measured in nanoseconds; equal to 1×10^{-9} seconds). The depth to the rebar can be determined if the propagation velocity electromagnetic energy (V_m) through the concrete is known or estimated. V_m through a particular material is calculated as follows:

$$V_m = \frac{c}{\sqrt{E_r}}$$

where: V_m = velocity of electromagnetic energy (m/ns),

c = speed of light in free space (0.2998 m/ns), and

E_r = relative dielectric permittivity (dimensionless ratio).

E_r is a measure of the capacity of a material to store a charge when an electric field is applied relative to the same capacity in a vacuum. The depth to a reflector can be calculated using the following equation:

$$D = V\frac{t}{2}$$

where: D = depth to the object (m),
V = velocity of wave through medium (m/ns), and
t = two-way travel time (ns).

The resolution and depth penetration of the GPR tool is a function of the frequency of the antenna employed and the conductance of material imaged. Higher frequency antenna provide for better resolution, but less depth penetration. The GPR signal can penetrate resistive materials, but can not be transmitted through highly conductive materials (such as dowel bars).

The1.5 GHz ground-coupled antenna (Figure1) is often used for concrete, pavement, and bridge decks investigations. This antenna provides relatively high vertical resolution, but is generally capable of imaging the subsurface to depths of no more than 0.5 m, Collecting data with a ground-coupled 1.5 GHz antenna is relatively slow; however, this tools provide for very high-resolution, and the very accurate positioning of surveyed lines when towed by hand.

When the GPR antenna crosses a dowel bar at right angles, the resulting GPR image looks (visually) like an inverted U (*hyperbola* is the descriptive term for its characteristic shape). This characteristic signature is generated because the radiated antenna beam has the shape of a wide cone; thus the dowel bar is imaged not only when the antenna is immediately above, but also when the antenna is approaching (yet several centimeters from) the dowel bar. The hyperbolic shape indicates when the GPR antenna is approaching the dowel bar, when it is immediately above the dowel bar, and when it is moving away from the dowel bar. The apex of the hyperbola indicates the exact spatial location of the dowel bar. The groove at midpoint between transmitter and receiver on the Model 5100 housing indicates the target position (see Figure 1).

The hyperbolic reflection will appear somewhat distorted if the GPR profile crosses a dowel bar diagonally. As the survey line direction becomes nearly parallel to the dowel bar, the reflection appears as a slightly curved line. If the antenna is moves parallel to the dowel bar, the target looks like a continuous layer. If the GPR profile is located slightly (several cm) beyond the outermost end of a dowel bar, the hyperbola will be low amplitude and anomalously deep. If the GPR profile is more than several cm from the end of the dowel bar, the event can be absent.

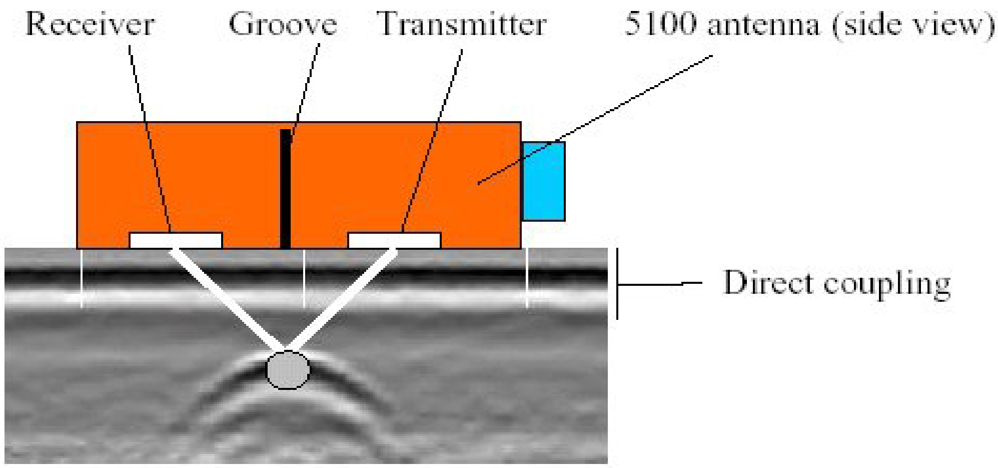


Figure 1. Locating a target using 1.5 GHz ground-coupled GPR antenna.

Field Work and Acquisition Parameters

GPR data were acquired in the west bound lane on August 8 and 9, 2002, and in east bound lane on September 27 and 28, 2002, using a 1.5 GHz ground-coupled antenna and a SIR 10B radar system. Table 1 summarizes the acquisition parameters and survey designs for the west bound and east bound lanes. A survey wheel was used to measure the exact horizontal location from the edge of pavement. Metal straight edges were used for distance calibration.

Table 1. Specifications for SIR-10B and two antennae.

	1st Field Work				2nd Field Work
Site	Westbound		Eastbound (Test)		Eastbound
Antenna	1.5 GHz	900MHz	1.5 GHz	900MHz	1.5 GHz
date	Aug.8.2002	Aug.9.2002	Aug.9.2002	Aug.9.2002	Sep.28.2002
Vert IIR LP	N =2 F =3000 MHz	N =2 F =1800 MHz	N =2 F =3000 MHz	N =2 F =1800 MHz	N =2 F =3000 MHz
Vert IIR HP	N =2 F =375 MHz	N =2 F =225 MHz	N =2 F =375 MHz	N =2 F =225 MHz	N =2 F =375 MHz
Scans/sec	100	100	100	100	100
samples/scan	516	516	516	516	516
bits/sample	16	16	16	16	16
range (ns)	12	12	12	12	12
scans/m	154 scan/m		154 scan/m		154 scan/m
Range gain(dB)	0,40,30	10	0,40,30	19	-2, 47,40

Ten joints in each lane were investigated. The interval between adjacent tested joints was 400 meters (Table 2). However, because of construction activities, the last station in the west bound lane was 300 m from the 9th joint studied.

<table>
<tr><th>Station No.</th><th colspan="2">Lane</th><th>Remarks</th></tr>
<tr><td>10+800</td><td>E</td><td></td><td rowspan="13">* Inspected joint;
- 1st joint west of each station,
- 2nd joint east of the station 10+800 (test joint)

* Station distance;
- every 400 m
- 300 m between 15+100 and 15+400 (due to under-construction at station 15+500).</td></tr>
<tr><td>11+100</td><td>E</td><td></td></tr>
<tr><td>11+500</td><td>E</td><td></td></tr>
<tr><td>11+900</td><td>E</td><td>W</td></tr>
<tr><td>12+300</td><td>E</td><td>W</td></tr>
<tr><td>12+700</td><td>E</td><td>W</td></tr>
<tr><td>13+100</td><td>E</td><td>W</td></tr>
<tr><td>13+500</td><td>E</td><td>W</td></tr>
<tr><td>13+900</td><td>E</td><td>W</td></tr>
<tr><td>14+300</td><td>E</td><td>W</td></tr>
<tr><td>14+700</td><td></td><td>W</td></tr>
<tr><td>15+100</td><td></td><td>W</td></tr>
<tr><td>15+400</td><td></td><td>W</td></tr>
</table>

Table 2. Test joint stations along US 60.

Four GPR profiles were acquired at each joint site (Figure 2). Two GPR profiles were acquired parallel and to the east of the each joint (11 cm and 22 cm from joint), and two GPR profiles were acquired parallel and to the west of the each joint (11 cm and 22 cm from joint). (GPR data were not acquired along the joints; Figure 2). GPR profile number increase to the east in the east bound lane and to the west in the west bound lane. GPR scanning started from the inner edge of the roadway (median) ended at the outer edge (shoulder). Survey profiles were 11m (36 feet) in length and extended across 36-37 imbedded dowel bars.

Data Processing

The quality of the acquired GPR data was excellent, and minimal post-acquisition processing was applied. The key steps were the automatic “picking” (with manual editing for quality assurance) of the reflection from the top of the dowel bar (arrival time), and the determination of the depth to each dowel bar (on the basis of event arrival time and concrete velocity). Note that concrete velocities were estimated on the basis of measured reflection arrival times (determined from test GPR profiles) and corresponding dowel bar depth estimates (the later were provided by MoDOT) at select dowel bar study sites.

On the basis of the dowel bar depth estimates provided by MoDOT and corresponding dowel bar reflection arrival times (as determined from GPR profiles), dielectric constants were assigned (8.8 for east bound lane and 9.5 for west bound lane). It is recognized that the dielectric constant of concrete varies as a function of moisture content, temperature, antenna frequency, etc. It is also recognized that the use of a single (and constant) dielectric constant for all dowel bar sites along a segment of roadway will introduce minor depth estimate errors (in an absolute sense). However, it is our opinion that depth estimates at any single joint study site will be accurate in a relative sense. Depth estimates are believed to be accurate to within ± 0.3 cm.

In order to estimate the depth and position of each dowel bar from the analyses of the GPR profiles, the arrival time of the apex of each dowel bar hyperbola was automatically picked, and converted to a depth estimate using the assigned dielectric constants. The two-way travel times (2WTT) calculated for each dowel bar (along each of the four parallel GPR profiles) was converted to real depth using the dielectric constant assigned to the appropriate lane. The depth and position of each dowel bar along each of the four GPR profiles was plotted. The positions of each dowel bar on each survey line were connected to represent the dowel bar on the plan map. The lateral spatial locations of the dowel bars are believed to be accurate to within ± 1 cm.

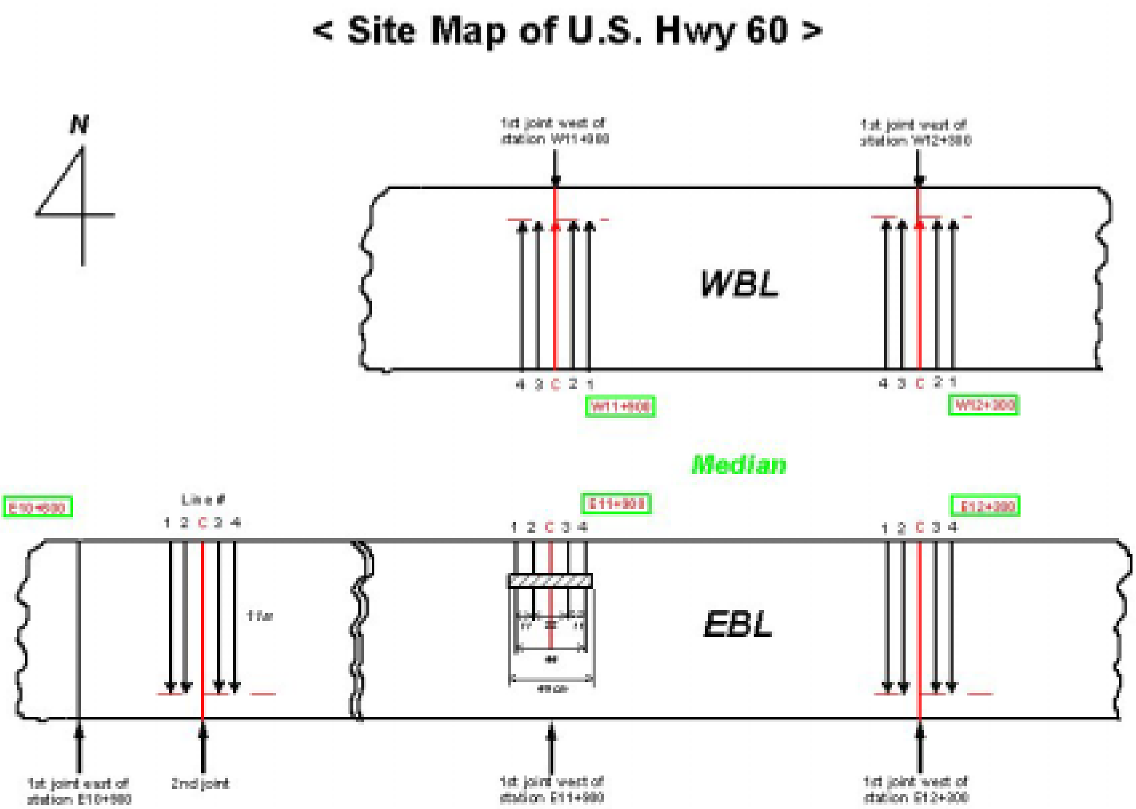


Figure 2. Location of GPR profiles (1-4) relative to joints and dowel bars.

Analysis of Example Radar Profile

The characteristic GPR signature of a dowel bar was readily identified on all 1.5 GHz ground-coupled antenna data, however the reflection from the base of the concrete was difficult to identify everywhere with confidence. In the following discussion, a few example figures and brief descriptions of the acquired GPR profiles are presented.

Figure 3 represents typical east bound lane GPR profile. The metal straightedge was intentionally placed on the pavement for distance control. Figure 4 is a good example of two parallel GPR profiles (joint WB12+300) that cross a missing dowel bar. Note also that the dowel bars are slightly skewed (not aligned exactly parallel to roadway). Note also that the depth to the dowel bars can vary across the length of the GPR profile (Figures 4 and 5).

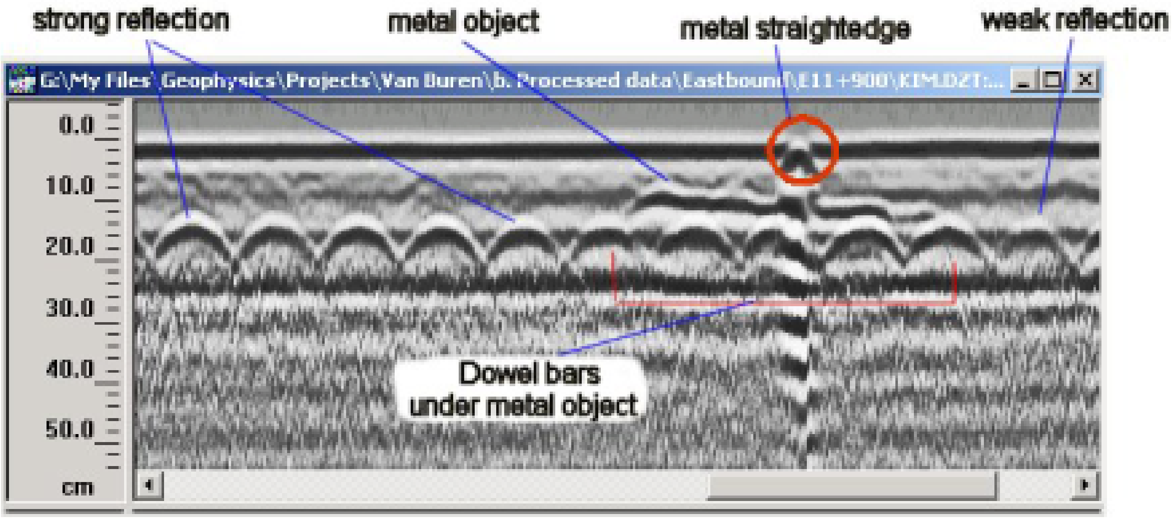


Figure 3. Example GPR profile from an east bound lane joint site.

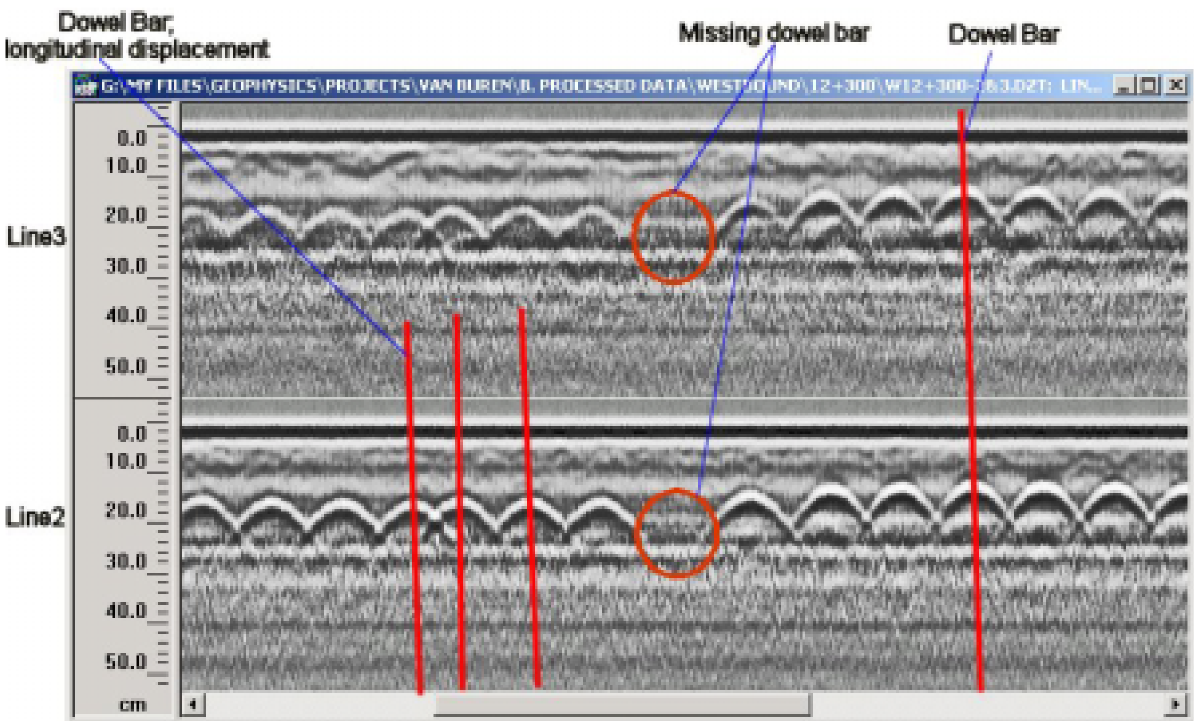


Figure 4. Example GPR profile from a west bound lane joint site.

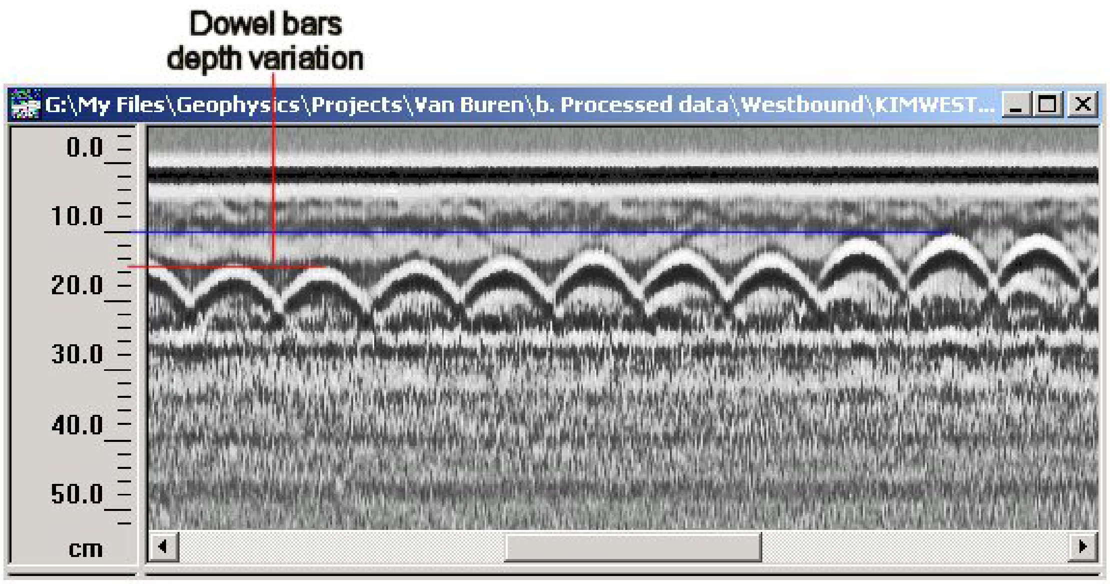


Figure 5. Example GPR profile showing variations in the depth
to the dowel bars (Profile 3; station 13+900; 4.5cm).

Results and Conclusions

The 1.5GHz ground-coupled antenna was successfully used to determine the orientation and relative depth of the dowel bars at twenty joint sites. Plots showing the orientation and depth to the dowel bars are presented in Appendix 1. Cross-sectional images are presented in Appendix 2. (All data are listed in the spread sheet presented in Appendix 3.)

Generally speaking, the dowel bars in the east bound lane dip to the east (which is the direction the dowel inserter moved). Longitudinal displacement of the dowel bars (as evidenced by absence of hyperbolic reflections or low amplitude/anomalous time depth) is generally less than several centimeters, however at a few sites (e.g., E14+700), longitudinal displacement could be in excess of 11 cm.

Appendix

Appendix 1: Position maps of the dowel bar (20 surfer files)
Appendix 2: GPR profiles of concrete road (20 jpeg. files)
Appendix 3: Dowel bar positioning data (20 MS excel files)

References

1.*GSSI Handbook For Radar Inspection of Concrete*, Geological Survey System, Inc.

2. Cardimona, S., Willeford, B., Wenzlick, J., and Anderson, N., *Bridge Decks Condition Studies in Missouri Utilizing Ground Penetrating Radar*, RDT 01-012, Report for MoDOT, September, 2001.

3. Maser, K.R., and Bernhardt, M., *Statewide Bridge Deck Survey Using Ground Penetrating Radar*, Non-destructive testing in civil engineering 2000 , SEIKEN Symposium No. 26, 2000, pp491 - 498.