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GPR Study of Imbedded Dowel Bars, Van Buren, Missouri

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16. Abstract

Objective: The intent is to determine the orientation, depth and spacing of imbedded dowel bars at specified joint locations along a newly paved segment of US 60, near Van Buren, Missouri. (Preliminary construction plans call for the symmetric emplacement of 18” dowel bars, at 15” centers and 6” depth.)

Work Plan: UMR geophysics crew will acquire 3 parallel GPR (ground penetrating radar) profiles at each of 20 specified joints along the two-lane, test section of US 60. Data will be acquired during the course of five separate site visits. These GPR data will be acquired using a 1500 monostatic mega Hz antenna. Trace spacing along each profile will be ¼ inch (or less). Profile spacing will be 9’’.

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MAPPING VARIATIONS IN THE RELATIVE SPATIAL LOCATIONS OF EMBEDDED DOWEL BARS USING GPR

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ABSTRACT

A 1.5 GHz ground penetrating radar (GPR) tool was used to determine the relative spatial locations of 2 sets of embedded dowel bars. Dowel Bar Set #1 (~360 dowel bars at 10 joint locations along west bound lane of Route US 60) was emplaced using the conventional wire basket assembly method. Dowel Bar Set #2 (~360 dowel bars at 10 joint locations along east bound lane of US Route 60) was emplaced using the automated dowel bar inserter method. The objective was to compare the accuracy and reliability of the two emplacement methods.

Four parallel GPR profiles (oriented perpendicular to the axis of the dowel bars) were acquired at each joint set. These GPR data were used to determine the relative spatial location of each embedded dowel bar. Analyses indicate that in the test areas, the conventional wire basket assembly method was more accurate than the automated inserter method in terms of the relative spatial orientations of the emplaced dowel bars. In contrast, the automated inserter method was more reliable than the wire basket assembly method depth in terms of uniformity of depth of emplacement.

INTRODUCTION

Traditionally, dowel bars have been placed in transverse pavement joints using the wire basket assembly method (Fig. 1a). However, because of increased productivity and reduced costs, an increasing number of contractors are employing the automated dowel bar inserter method (Fig. 1b). Although the automated dowel bar inserter method is less expensive than the wire basket assembly method, the relative reliability of these two techniques is debatable.

In an effort to assess the relative reliability of the two dowel bar emplacement methodologies, the Missouri Department of Transportation (MoDOT) funded a comparative study along a segment of divided highway US Route 60 near Van Buren, Missouri. The dowel bars in the twinned westbound lanes (WBL) of the test segment of US Route 60 were emplaced using the conventional wire basket assembly technique (Dowel Bar Set #1); the dowel bars in the twinned eastbound lanes (EBL) were emplaced using an automated dowel bar inserter (Dowel Bar Set #2). The geophysics crew from the University of Missouri-Rolla (UMR) used a 1.5 GHz GPR tool to determine the relative spatial location of each emplaced dowel bar in the study area.

EMBEDDED DOWEL BARS: PLACEMENT AND MAPPING

The concrete pavement in the study area was designed to include dowel bars and tie bars (Fig. 2). The dowel bars (3.8 cm diameter and 45 cm length) were spaced at 30 cm along the transverse contraction joints. The tie bars (2 cm diameter and 100 cm length) were spaced at 75 cm along the longitudinal joints. The design thickness of the concrete pavement was 30 cm; the design depth of all dowel bars was 15 cm from pavement surface.

On a GPR profile, dowel bars are characterized by an inverted U-shaped reflection/diffraction *hyperbola* (Figure 3). This characteristic signature is generated because the radiated antenna beam has the shape of a wide cone. Thus, the target is imaged not only when the antenna is immediately above, but also when the antenna is approaching yet several centimeters from the target (Daniels, 1996). If the dowel bar is near-horizontal and if the GPR survey line overlies the dowel bar, the apex of the *hyperbola* indicates the exact spatial location of the target. The groove at midpoint between transmitter and receiver on the antenna housing indicates the target position (Fig. 2).

(a) *(b)*

Figure 1. Placing the dowel bars in concrete using wire basket assemblies
(a) and automated dowel bar inserter (b)

The hyperbolic reflection/diffraction will appear somewhat distorted if the GPR survey profile crosses the dowel bar at an oblique angle. Indeed, if the survey line parallels the dowel bar, the signature of the dowel bar will look like that of a continuous layer. If the GPR survey profile is located slightly (~several cm) beyond the outermost end of the dowel bar, the *hyperbola* will be low-amplitude and the arrival time of the apex of the *hyperbola* will be anomalously high (reflecting the true separation between the antenna and dowel bar). In this case, the apex of the hyperbola on the GPR profile will not indicate the correct location of the dowel bar because the reflection/diffraction originated out-of-the-plane of the GPR profile.

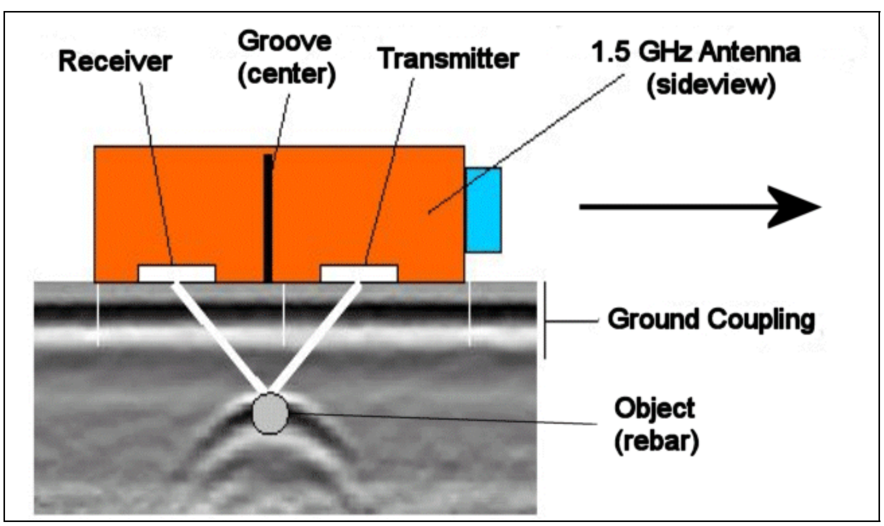

Figure 2. Locating a target using 1.5 GHz ground-coupled GPR antenna.

DATA ACQUISITION

The GPR data were acquired at twenty traverse joint locations; ten in the westbound lane (Bowel Bar Set #1) and ten in the eastbound lane (Dowel Bar Set #2) of the US Route 60 near Van Buren, Missouri (Fig. 4) using the GSSI SIR 10 B radar system equipped with the 1.5 GHz ground-coupled antenna. The survey acquisition parameters are as follows:

Antenna		1.5 GHz
Range (ns)		12
Range gain(dB)		0,40,30
	LPF	N =2
Vert IIR		F =3000 MHz
	HPF	N =2
		F =375 MHz
Samples/scan		516
Bits/sample		16
Scans/m		154 scan/m

At some locations in the eastbound and the westbound lanes, preliminary GPR tests were performed to determine optimal GPR data acquisition parameters. Estimated dowel bar depths were determined at several test locations by a MoDOT crew using Micro Covermeter (manufactured by Koelectric Research Limited in England). This device is an electromagnetic cover pachometer specifically calibrated for different rebar sizes. At MoDOT's request, these depth measurements were used as ground truth for calibrating the acquired GPR data.

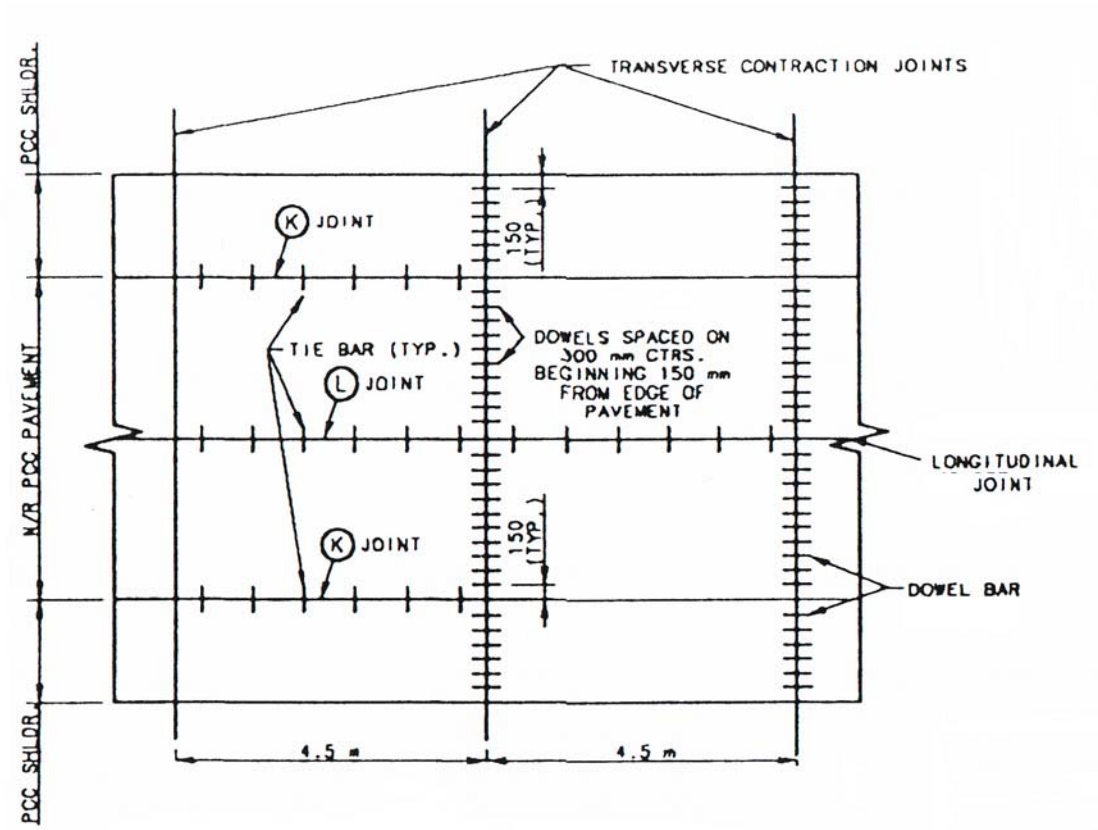

Figure 3. Joint plan and spacing for contraction joints

Four GPR profiles were acquired at each tested transverse joint (Figures 4 and 5); two GPR profiles were located to the east of the joint (11 cm and 22 cm from joint) and two were placed to the west of the joint (11 cm and 22 cm from joint). The GPR data were not acquired along the joints because the gummy joint sealing material prevents the antenna from gliding smoothly on the pavement. Each GPR profiles was 11 m in length and crossed ~36 embedded dowel bars (Figure 5).

DATA PROCESSING

Good quality field data were obtained and minimal post-acquisition processing was applied (using the GSSI RADAN software for Windows NT (GSSI, 2000). The quality of the original data did not require advanced processing techniques such as migration or deconvolution. However, basic processing and extra rearrangement were performed for easier analysis and interpretation.

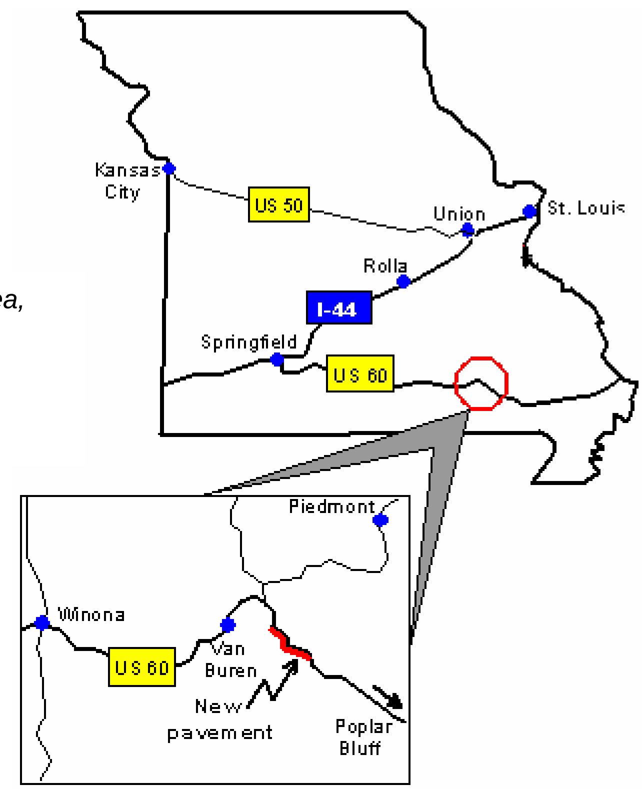

Figure 4. Study area, US Route 60, Van Buren, Missouri.

DATA PROCESSING

Good quality GPR field data were obtained and minimal post-acquisition processing was applied (using the GSSI RADAN software for Windows NT (GSSI, 2000). The quality of the original data did not require advanced processing techniques such as migration or deconvolution. However, basic processing and extra rearrangement were performed for easier analysis and interpretation.

Although a survey wheel was used during the GPR data acquisition, the lengths of the survey lines were normalized to compensate for minor differences between survey wheel distances and tape measured distances. The GPR data were filtered to eliminate high frequency noise and to remove low frequency tilt. An automatic rebar-picking software tool picked the positions of dowel bars. (Some manual corrections were made later.) The output was a set of numeric data including the spatial locations and the two-way travel times to each rebar.

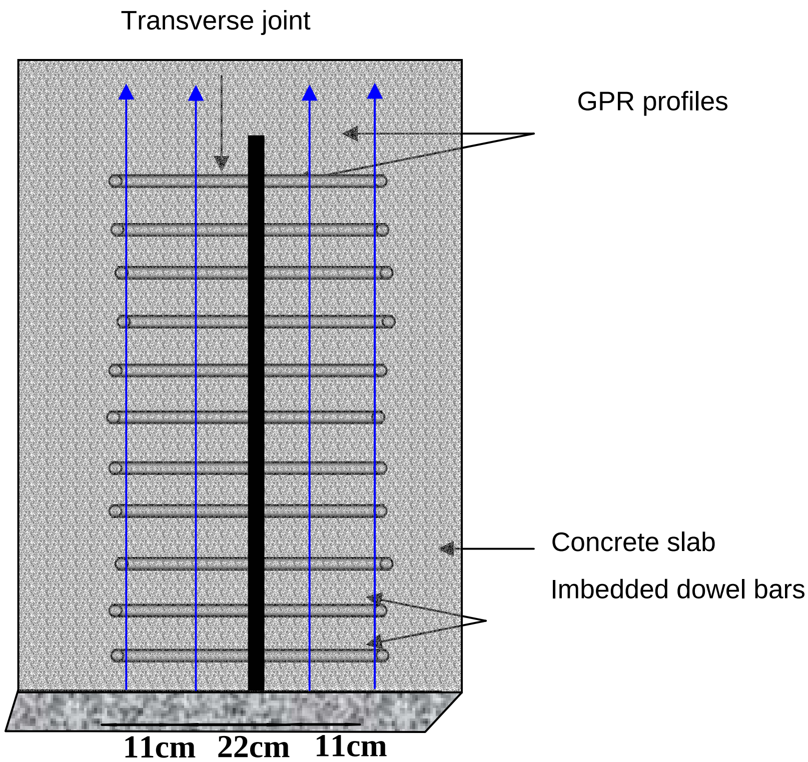

Figure 5. Locations of the GPR profiles relative to the joints and dowel bars.

DEPTH ESTIMATION TO THE REBARS

Dowel bar depths at specific test locations (as provided by MoDOT) were used to calculate average GPR velocities and appropriate dielectric constants for each lane. The older, drier concrete of the eastbound lane (GPR Data Set #2) was assigned a dielectric constant of 8.8; the newer concrete (with higher moisture content) of the westbound lane (Data Set #1) was assigned a dielectric constant of 9.5.

The dielectric constants assigned to each lane were used to calculate the depths (and variations therein) to each dowel bar. The calculated depths to each dowel bar are undoubtedly inaccurate in an absolute sense. However, it is our opinion that dowel bar depth estimates along any single joint are accurate in a relative sense. The calculated depths are believed to be accurate in a relative sense to within $\pm$ 0.3 cm.

LOCATING THE SPATIAL LOCATIONS OF THE DOWEL BAR

The arrival times and locations of the apex of each dowel bar *hyperbola* on each GPR profile was automatically picked (Figures 6 and 7). These travel times were converted to depths using the assigned dielectric constants. The depth and position of each dowel bar (along each of the four GPR profiles) was then plotted on plan view joint maps (Figure 8 and 9). These plan view maps (Figures 8 and 9) depict some inappropriately placed dowel bars. Such inappropriate placement can be categorized by one or more of the following parameters:

- *Vertical Rotation, defined as the difference in depth (vertical position) between the opposite ends of the individual dowel bar.*
- *Relative Vertical Depth Variation, defined as the variation in the average depth to the top of the dowel bars along a specific joint.*

- *Absolute Vertical Depth Deviation, defined as the difference between the planned depth of emplacement and the actual depth (average) of emplacement of a specific dowel bar.*
- *Horizontal Rotation, defined as the difference in lateral position (relative to joint) between the opposite ends of the dowel.*
- *Longitudinal Translation, defined as the longitudinal offset of the midpoint of the dowel bar relative to the traverse joint.*
- *Missing Dowel Bars, defined as the absence of a dowel bar.*

DATA INTERPRETATION

The images of the dowel bars were readily identified on the GPR profiles. Figure 6 depicts two parallel GPR profiles acquired at the same joint. The upper profile was acquired 22 cm to the east of the joint; the lower profile was acquired 22 cm to the west of the joint. The two GPR profiles show a missing dowel bar, the location of which location is marked with red circle on both profiles. Horizontal Rotation is also depicted in Figure 6, as demarcated by the three vertical red lines. The vertical red line crossing the two GPR profiles shows a slight difference in the horizontal position of the opposite ends of individual dowel bar. Minor Vertical Rotation is also observed on this data set.

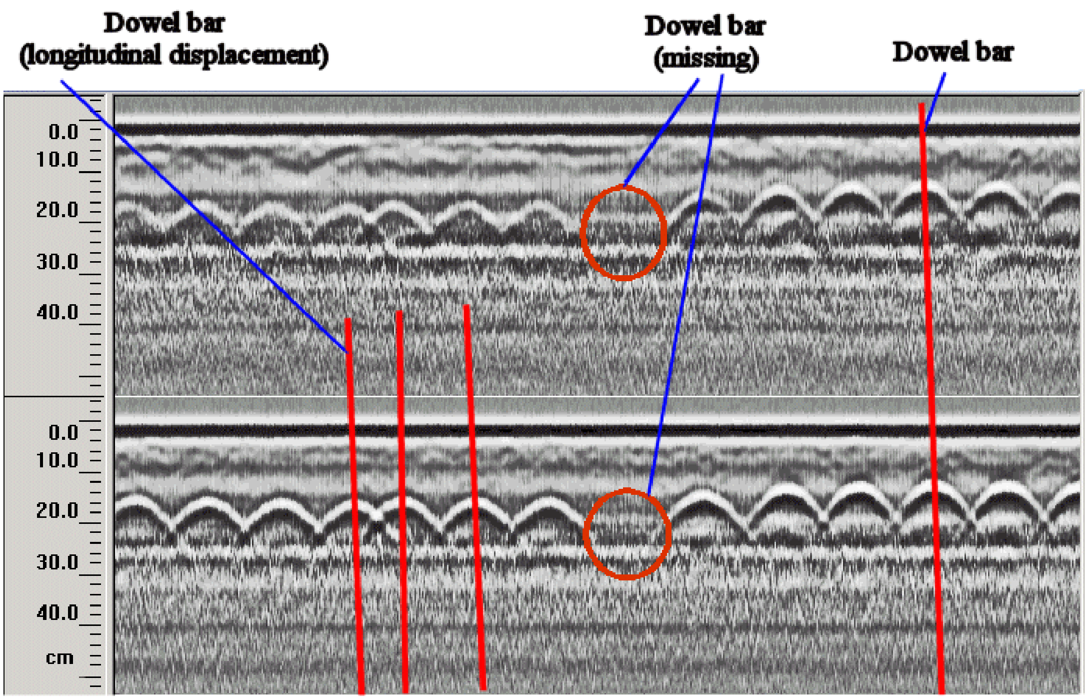

Figure 6. Example GPR profile from a westbound lane (WBL) joint site.

Figure 7 represents a GPR profile acquired 22 cm from the joint. Relative Vertical Depth Variation and Absolute Depth Deviation are clearly observed (Fig. 7). The depth to the dowel bars varies along the length of the GPR profile. The depths to the apex of the dowel bars on the right hand side of the radar profile is about 5 cm less than on the left most side (Fig. 7).

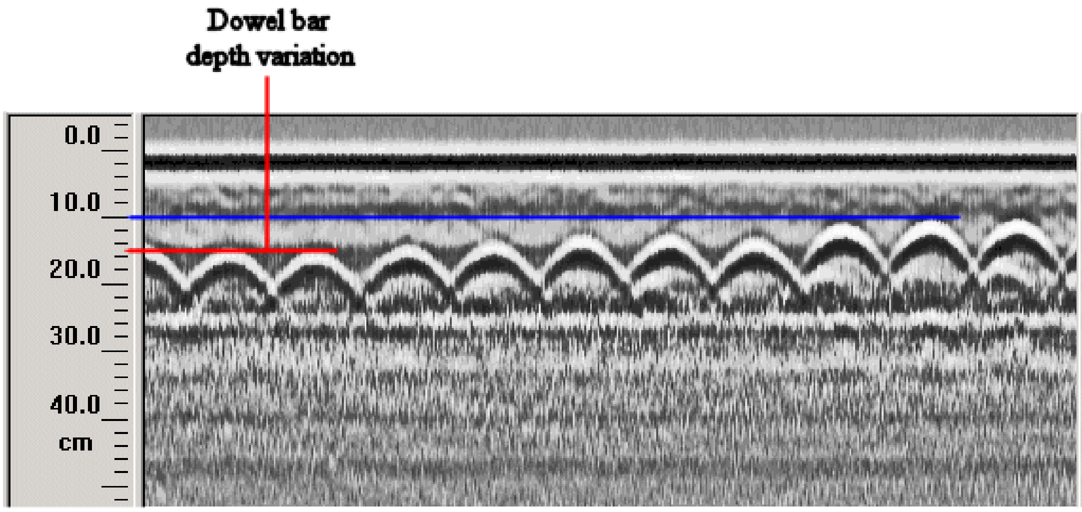

Figure 7. Example of GPR profile showing variations in the depth to the dowel bars (depth variation ~ 5 cm)

The lateral location of each dowel bar was plotted on a plan view map of the respective joint (Figures 8 and 9). The estimated depths to the dowel bar were placed next each measurement location. These plan view maps are useful in that they depict Vertical Rotation, Relative Vertical Depth Variation, Absolute Vertical Depth Deviation, Horizontal Rotation, Longitudinal Translation, and Missing Dowel Bars. Absolute Vertical Depth Deviations are also summarized in Figures 10 and 11.

Analysis of the plan view joint maps indicates that the wire basket assembly method was more accurate than the automated dowel bar inserter method in terms of Horizontal Rotation and Vertical Rotation. Indeed, the dowel bars emplaced using the automated dowel bar inserter method appear to dip in the direction the inserter was moving. Longitudinal displacement (as evidenced by absence of hyperbolic reflections or low amplitudes/anomalously high time depths) ranged from near-zero to about 11 cm with both tools.

In contrast, the automated dowel bar inserter method appears to have been superior in terms of Relative Vertical Depth Variations and Absolute Vertical Depth Deviations (Figures 10 and 11).

Figure 8. Orientation and depth of the dowel bars, EBL of US 60 (cont'd), the red dashed line represents the joint, the short lines connected the points perpendicular to the joint is the rebar position, the number at each rebar represents the estimated depth to the rebar.

Figure 9. Orientation and depth of the dowel bars, WBL of US 60 (cont'd), the red dashed line represents the joint, the short lines connected the points perpendicular to the joint is the rebar position, the number at each rebar represents the estimated depth to the rebar

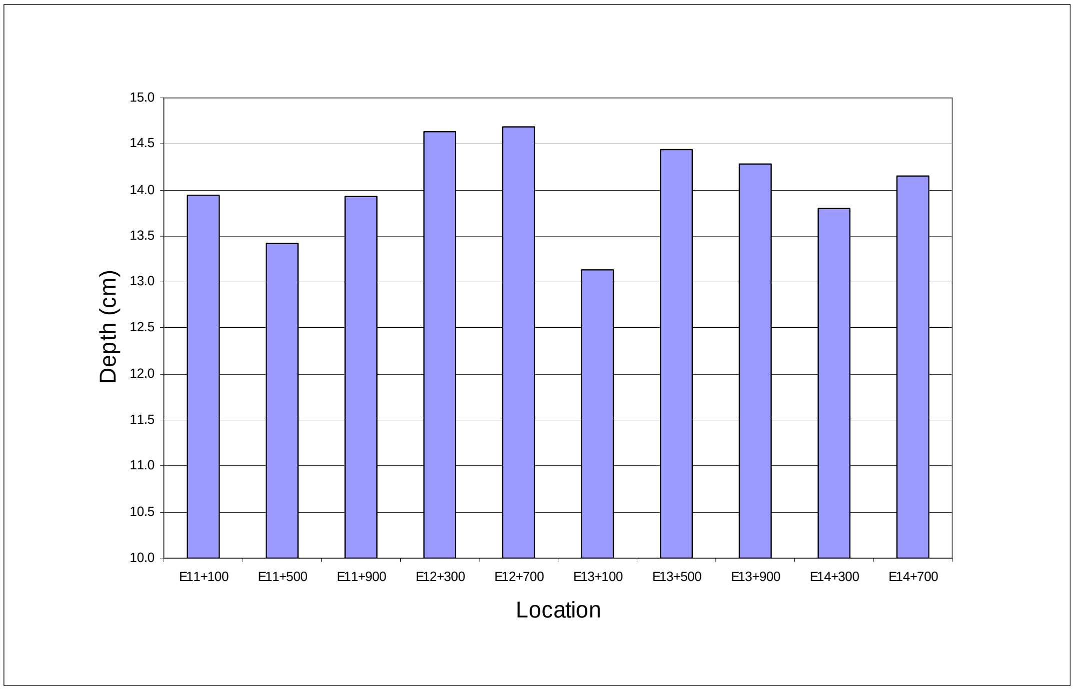

Figure 10. Average depth for dowel bar inserter (EBL of US 60)

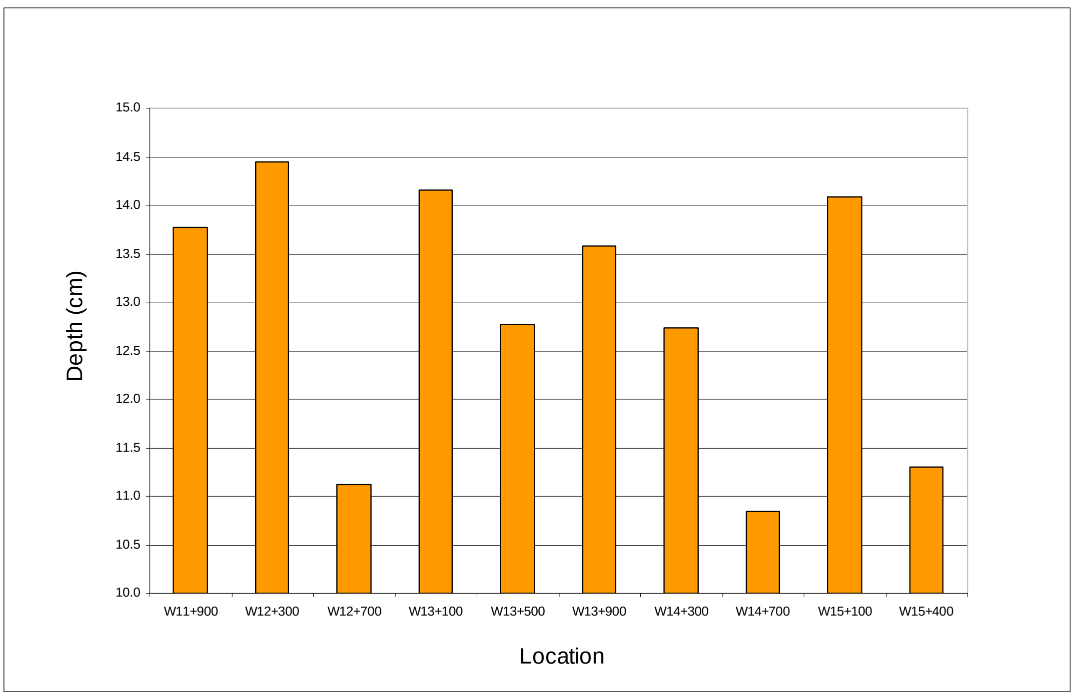

Figure 11 Average depth for dowel bar basket assemblies (WBL of US 60)

CONCLUSIONS

The interpretation of the acquired GPR data indicates that the wire basket assembly method was more accurate than the automated dowel bar inserter method in terms of dowel bar orientation (Horizontal Rotation and Vertical Rotation). Indeed, the dowel bars emplaced using the automatic dowel bar inserter method appear to dip in the direction the inserter was moving. Longitudinal Displacement (as evidenced by absence of hyperbolic reflections or low amplitudes/anomalously high time depths) ranged from near-zero to about 11 cm with both tools.

The automated dowel bar inserter method appears to have been superior in terms of depth of emplacement (Relative Vertical Depth Variation and Absolute Vertical Depth Deviation).

These study results indicate the high frequency 1.5 MHz GPR antenna can be successfully used to accurately determine the spatial orientation and depth of embedded rebar in concrete.

REFERENCES

Daniels, D.J., 1996. Subsurface-Penetrating Radar, The Institute of Electrical Engineers, pp. 1 – 62.

Geophysical Survey Systems, Inc., 2000. GSSI Manual #MN43-132 A, RADAN for Windows NT Version 2.0, April 2000. Geophysical Survey Systems, Inc., New Hampshire.