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HIGH RESOLUTION GPR BRIDGE DECK EVALUATION SURVEYS

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ABSTRACT

The use of a shielded, 1.5 GHz center frequency ground-coupled dipole antenna has been beneficial for determining the depth of the top layer of rebar in new bridge decks and assessing the condition of the concrete near the top rebar mesh in two asphalt overlaid bridge decks.

The vertical and horizontal high-resolution capability of this antenna yields data that contain isolated reflections from individual rebar spaced 15 cm between centers. Some quality assurance – quality control (QA/QC) studies required on new concrete bridge decks necessitate determination of the average depth of the top layer of rebar and the variability of the rebar depths. The 1.5 GHz antenna was investigated to assess its performance for such a task. After depth calibration, the processed 1.5 GHz antenna data resulted in calculated top layer rebar depths that were accurate to within ± 3 mm.

This 1.5 GHz antenna was also used to study two asphalt-overlaid bridge decks scheduled for disassembly and showed very promising results in assessing the condition of the concrete near the top rebar mesh that may lead to improved bridge deck evaluations in the near future.

INTRODUCTION

Ground penetrating radar (GPR) has been applied extensively to investigate the condition of concrete bridge decks (Mesher, and others, 1996; Pagnoni, 1996; Juranty, 1995; Parry and Davis, 1992). These studies all utilized air-launched, horn antennas with center frequencies varying from 1 to 2.5 GHz. Depending on the polarization direction, the horn antenna data may contain reflections from the major interfaces in the bridge: (1) the asphalt-concrete interface (if the bridge deck contains an asphalt overlay), (2) the top layer of transverse rebar, (3) the bottom layer of transverse rebar, and (4) the bottom of the bridge deck. This information has been used to assess the bridge deck condition with varying degrees of success. One significant limiting factor of air-launched horn antennas is the lack of horizontal resolution necessary to image individual rebar in any detail. The first Fresnel zone radius for 2.5 GHz horn antennas mounted 45 cm above a surface with a 6 cm asphalt overlay and 6 cm rebar depth in the concrete, assuming a spherical wavefront, is approximately 17 cm. This means rebar spaced at 15 cm intervals are indistinguishable and the top transverse rebar mesh appears as a continuous reflector in the data. Consequently, the reflection amplitudes from the rebar in the upper and lower rebar mesh cannot generally be used to infer the condition of the rebar and surrounding concrete unless the spacing and placement of the rebar is accurately known. In contrast, the use of ground-coupled antennas in the frequency range from 1 to 2.5 GHz have Fresnel zones varying from 9 to 5 cm, respectively—well within the range needed to image individual rebar with high resolution.

Research has been conducted to assess the performance of a sheilded, 1.5 GHz center-frequency ground-coupled antenna, (GSSI's Model #5100) in two types of bridge deck investigations. The first application was locating and determining the position and depth of individual transverse rebar in the top mat, beneath the concrete surface in new concrete bridge decks. The second application involved condition assessment of older asphalt-overlaid bridge decks. The results from the research are presented in the following sections.

DATA COLLECTION AND PROCESSING

The 1.5 GHz antenna used in the investigation was mounted in an enclosure on a bracket attached to a long fiberglass tube fitted with a handle and survey wheel so the person collecting the antenna could walk at normal speed. Figure 1 shows typical data collection. The distance encoder attached to the survey wheel on the mounting bracket provided distance-based scan control. All of the data presented in this paper were obtained at a density of 80 scans/meter, and the antenna was ground-coupled at all times. The antenna used to obtain the data was bistatic with a fixed separation distance of 5.8 cm between transmitting and receiving antennas.

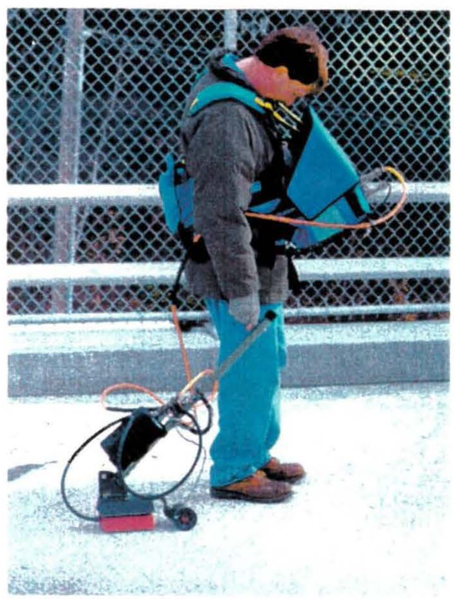


Figure 1: Data collection setup for bridge deck investigations (GSSI's SIR-2 control unit and Model 5100, 1.5 GHz ground-coupled antenna).

Figure 2 shows typical data obtained over an asphalt- overlaid bridge deck. The data were obtained over a time range of 12 ns with a straight-gain applied (i.e., same gain applied from the top to the bottom of each scan). A 3000 MHz single pole IIR low pass and 250 MHz, 1 pole IIR high pass filter were applied to the data during collection. No additional processing were performed on the data presented in this paper. The data shown in Figure 2 were obtained using GSSI's SIR-10H control unit, however, most of the data presented in this paper were obtained using GSSI's SIR-2 control unit. A scan of data corresponding to the location indicated in Figure 2 is shown in Figure 3. The time-zero for each antenna is factory-calibrated (once) using core data obtained from rebar at different depths in one bridge deck. Note the relatively high amplitudes of the reflections from the asphalt-concrete interface and one of the top transverse rebar. The high signal-to-noise ratio seen in the data are a characteristic of the data and are essential for accurate rebar depth calculations.

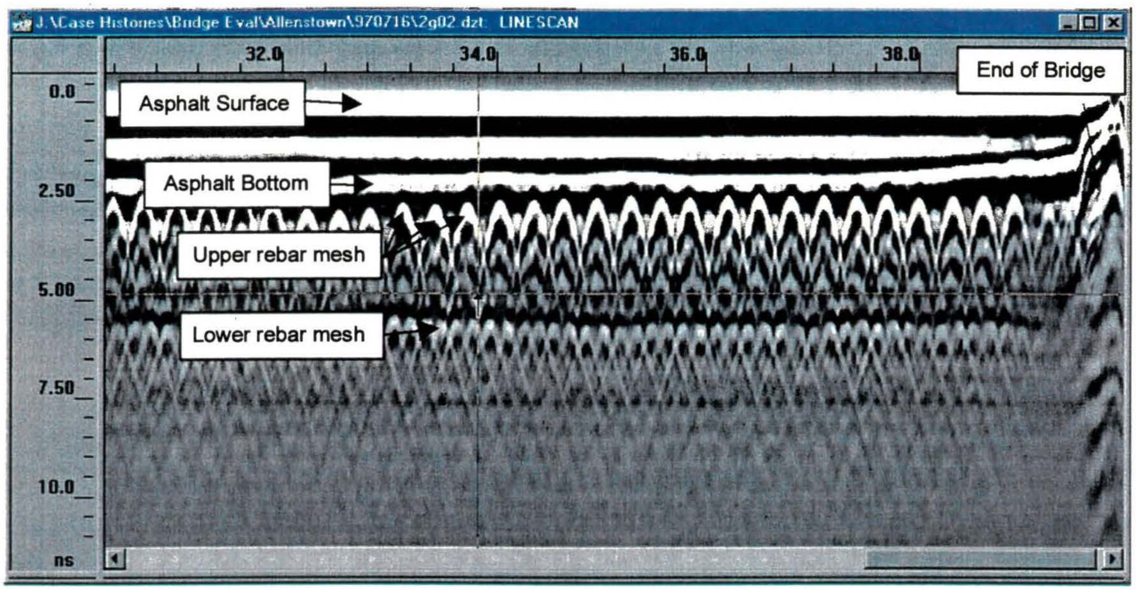


Figure 2: Typical data obtained with 1.5 GHz ground-coupled antenna on asphalt overlaid concrete bridge deck.

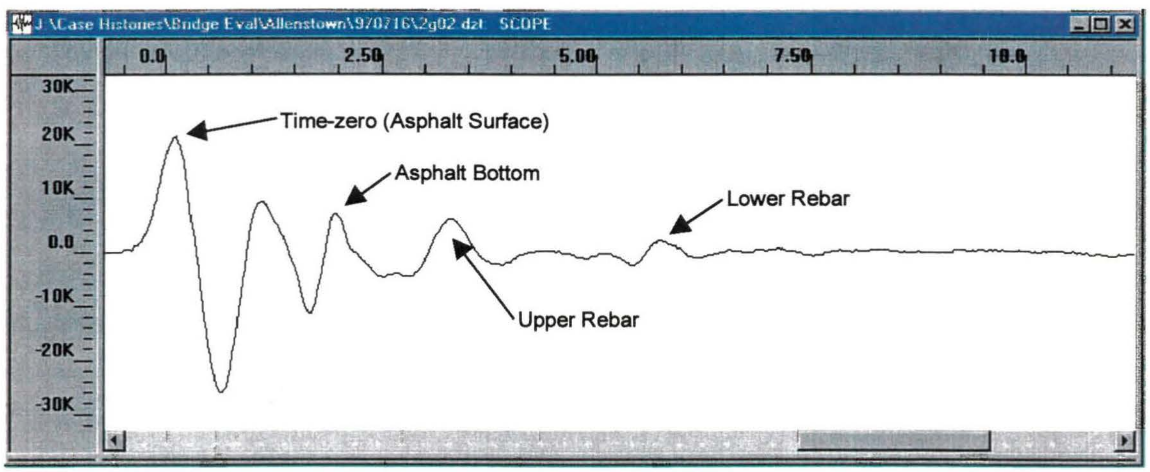


Figure 3: Scan of data from location denoted by the cross-hairs in Figure 2.

REBAR DEPTH DETERMINATION – NEW BRIDGE DECKS

Quality assurance – quality control (QA/QC) regulations in the state of New Hampshire, USA, affect the level of the contractor's pay scale when new bridges are built outside certain tolerances. One QA/QC regulation specifies the acceptable limits of variability in a new deck's concrete cover over the top transverse rebar. It has been the experience of the New Hampshire Department of Transportation (NHDOT) that previous instruments used to measure depth to rebar (concrete cover) are viewed, by contractors and NHDOT personnel, to perform at less than desirable levels of satisfaction.

Data were obtained over 3 new bridge decks to determine the accuracy of the rebar depths calculated from Model 5100 antenna data. In each case, one calibration core was drilled to a rebar for the purpose of calculating the propagation velocity in the concrete. The data were automatically interpreted by a GSSI RADAN NT software module using the calculated velocity to yield the locations and calculated depths of all of the other rebar. The calculated depths were then compared to actual (measured) depths obtained from additional verification cores.

Figure 4 shows data obtained from one of the new bridge decks with circles overlaying the interpreted location of the rebar. The scan corresponding to the location of each rebar was determined by a software algorithm that searches for the peak of each hyperbolic reflection in the data corresponding to a transverse rebar location. The arrival time of the rebar reflection was calculated based on the time difference between the time-zero position in the scan and the arrival time of the positive peak of the rebar reflection. The depth of each rebar was then calculated according to the following equation:

$$D = \sqrt{v^2\left(\frac{t_1 - t_0}{2}\right)^2 - \left(\frac{a}{2}\right)^2}$$

where:

D = depth to top of rebar,
= calculated propagation velocity through concrete determined from calibration core,
t_1 = arrival time of positive peak from rebar reflection.
t_0 = time corresponding to time-zero.
a = bistatic separation distance between transmit and receive antennas.

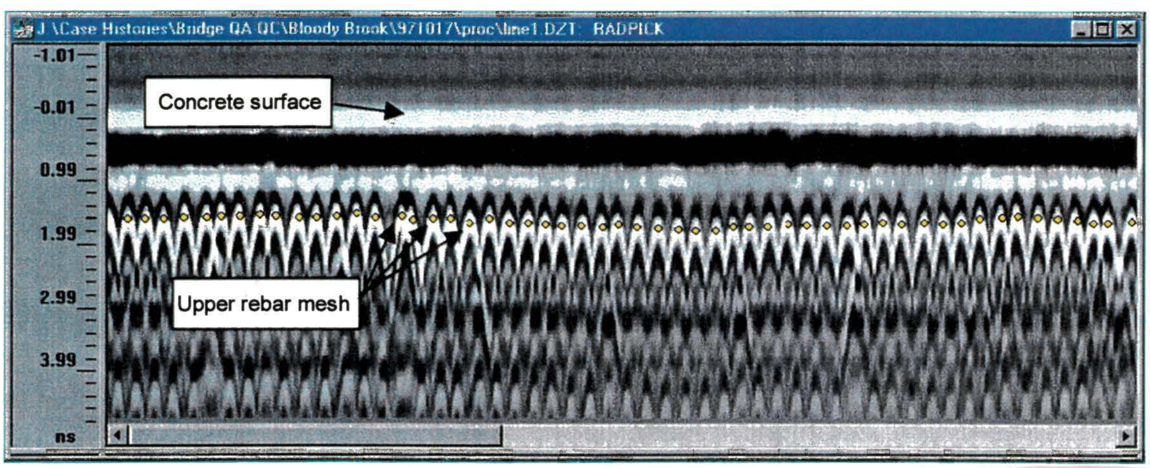
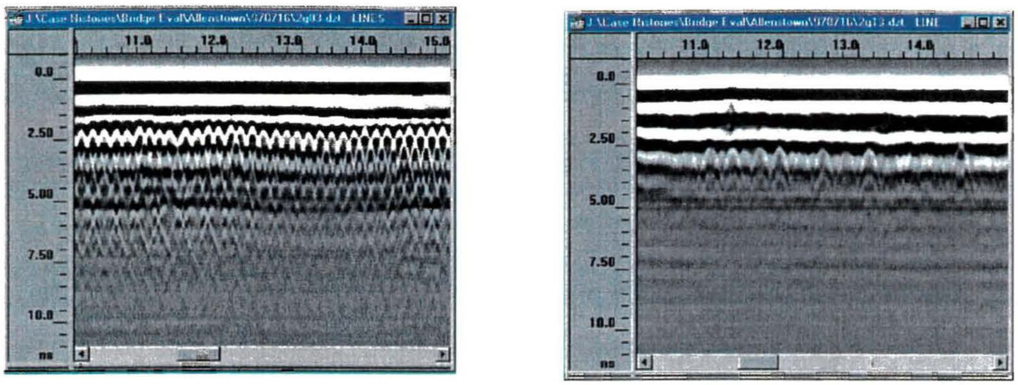


Figure 4. Processed data from new bridge-deck surface. Circles overlay the rebar reflection picks, which are located automatically by the RADAN software module used for QA/QC measurements in newly constructed decks.

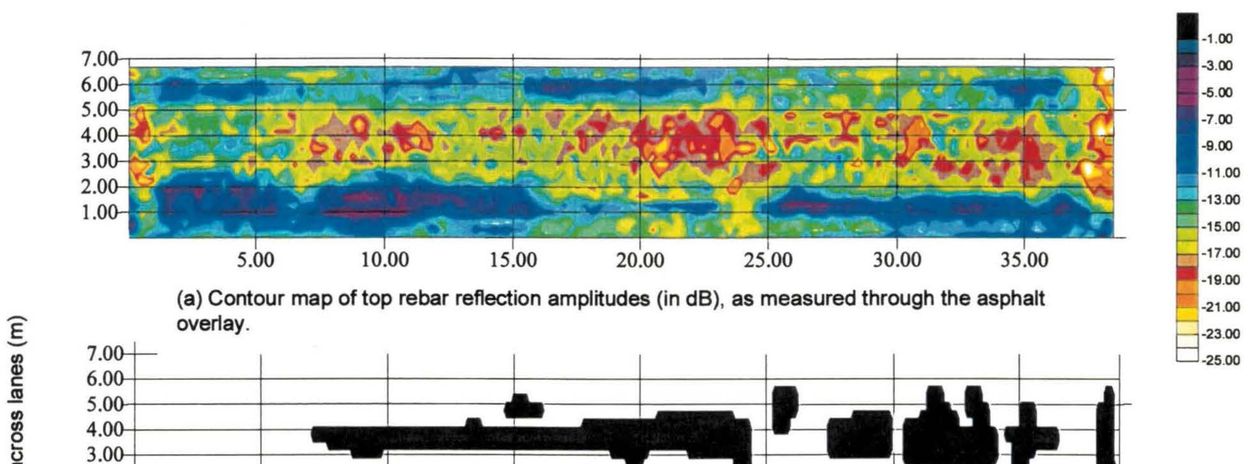
Table 1 shows the results of the calculated depths versus actual depths from data obtained on the three new bridges investigated.

Figure 5. Picture of Allenstown Bridge prior to asphalt removal.



(a) Non-deteriorated section (b) Deteriorated section

Figure 6. Data from Allenstown Bridge from (a) non-deteriorated section, and (b) deteriorated section of the bridge-deck surface.



(a) Contour map of top rebar reflection amplitudes (in dB), as measured through the asphalt overlay.

(b) Plot of deteriorated areas mapped after the asphalt was stripped from the bridge deck.

Figure 7: Comparison of relative rebar reflection amplitudes and visually detected deteriorated portions of the Allenstown bridge deck after stripping the asphalt from the reinforced concrete deck. Note: visually deteriorated and non-deteriorated locations were supported by limited core data.

DOT investigating the deterioration level on an 840-foot reinforced concrete deck structure, as well as other research efforts in related areas.

CONCLUSIONS

The use of high-frequency ground-coupled antennas is necessary for resolving individual rebar in bridge decks. A shielded, ground-coupled antenna with a center-frequency of approximately 1.5 GHz has been successful in two types of bridge deck investigations. Studies of three new bridge decks have shown that depths to the rebar in the upper transverse mesh can be resolved to within $\pm$ 3 mm, provided a calibration core is obtained to determine the propagation velocity of the radar through the concrete. Investigations of two bridge decks scheduled for dismantling have demonstrated good correlation between the reflection amplitude of the individual rebar in the upper rebar mesh and zones of deterioration.

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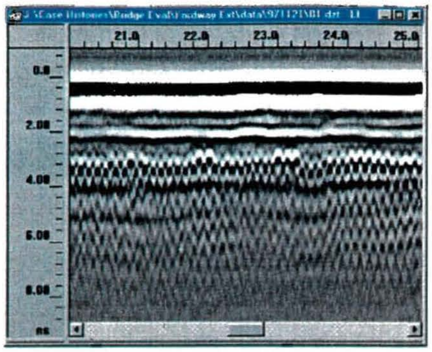
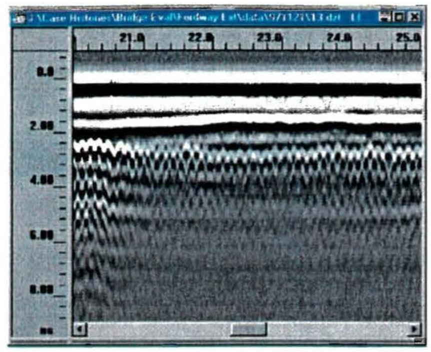
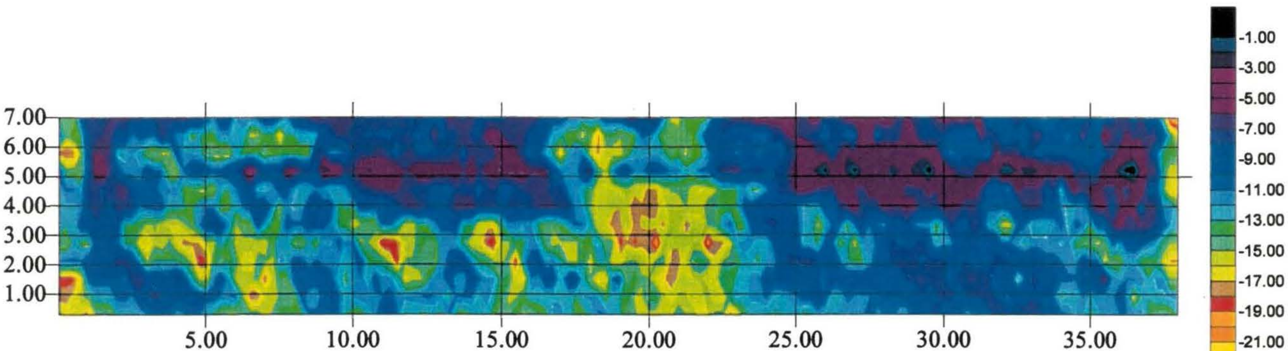


(a) Non-deteriorated section.

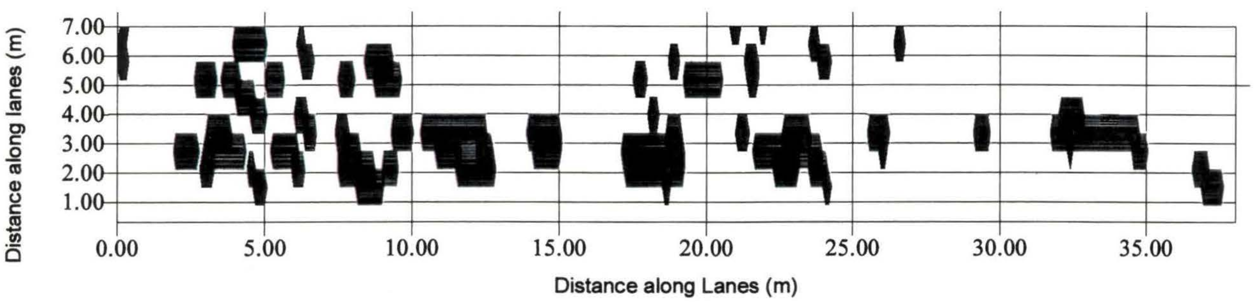


(b) Section containing deteriorated zone.

Figure 8: Examples of data from (a) non-deteriorated section and (b) deteriorated zone of the Fordway Extension Bridge.



(a) Contour map of top rebar reflection amplitudes (in dB), based on GPR data collected through asphalt overlay.



(b) Plot of delaminated areas independently identified (through hammer-sounding) and mapped after the asphalt was stripped from the bridge deck.

Figure 9: Comparison of relative rebar reflection amplitudes measured through the asphalt overlay and delaminated portions of the Fordway Extension bridge deck identified after concrete deck was exposed.

Table 1. Comparison of calculated rebar depths versus measured rebar depths (ascertained via cores).

Bridge	Core #	Depth (cm)	Calculated Depth (cm)	Depth Difference (cm)
A	1	5.875	-------*	-------
A	2	7.300	7.40	0.100
A	3	6.670	6.60	-0.070
A	4	6.035	6.30	0.265
A	5	6.350	6.10	-0.250
A	6	5.875	5.90	0.025
A	7	6.905	7.20	0.295
A	8	6.350	6.30	-0.050
B	1	6.510	------*	------
B	2	7.140	7.30	0.160
B	3	4.290	4.40	0.110
B	4	5.870	6.10	0.230
B	5	5.080	5.30	0.220
C	1	8.250	-------*	--------
C	2	7.540	7.10	-0.340
C	3	6.350	6.10	-0.250
C	4	7.700	7.80	0.100

*Used for propagation velocity calculation.

A = New Rt. 101 Bridge near Exeter, NH, USA
B = New Rt. 3 Bridge over Merrimack River, Concord, NH, USA
C = New Rt. 101 Bridge over Bloody Brook, near Exeter, NH, USA

The accuracy of the depth determination is dependent on the assumption that there is no significant variation in the propagation velocity of the radar from one region to another over the bridge deck surface. The good correlation between calculated core depths and measured core depths indicates that the concrete velocity does not vary significantly over the recently poured bridge deck surface.

BRIDGE DECK CONDITION ASSESSMENT ON OLDER BRIDGE DECKS

Condition studies are periodically performed on older bridges to assess the state of concrete and reinforcement deterioration in reinforced bridge decks. The term "deterioration" in terms of a bridge deck encompasses many internal mechanisms which diminish the integrity, strength and durability of the deck as a structural unit. Bridge deck deterioration involves a combination of these and other different deterioration mechanisms. These problems include: (1) delamination – where the concrete detaches from the rebar mesh, (2) loss of compressive strength due to concrete decomposition, (3) loss of concrete tensile strength due to significant rebar corrosion, and (4) increased chloride ion content which contributes to acceleration of each of the previous mechanisms.

The data obtained by the ground-coupled antenna yield three important types of information: (1) the reflection strength from the asphalt/concrete interface, (2) the amplitudes of reflections from individual rebar in the upper rebar mesh, (3) the amplitudes of the reflections from the lower rebar mesh, and (4) the level of signal attenuation in both the good and deteriorated zones within the reinforced concrete deck.

GPR studies, using this 1.5 GHz ground-coupled antenna, were conducted on two asphalt-overlaid bridges scheduled for dismantling. Interpretation of the data showed good correlation between the reflection amplitudes of the individual rebar in the upper transverse rebar mesh and deterioration zones on the deck. In both studies GPR data were obtained prior to asphalt removal and subsequent sounding and/or coring.

Allenstown Bridge

The first study was performed on a 2-lane bridge crossing over Rt. 28 in Allenstown, NH, USA. Figure 5 shows the bridge deck condition during the survey. A series of one or more longitudinal cracks extended along the centerline of the bridge. These cracks evidently provided a means for air and water to penetrate the concrete surface. After stripping (removing) the asphalt, the concrete surface along the center portion of the bridge was found—visually and through limited core confirmation—to be extremely deteriorated. Twelve core locations were selected at locations where cracks in the asphalt overlay and/or GPR profiles indicated evidence of deterioration.

Comparison of data shown in Figure 6, obtained along profiles 1m and 4 m from the bridge sides, respectively, shows a significant difference in rebar reflection amplitudes. A contour plot of the individual rebar reflection amplitudes from the upper mesh is shown in Figure 7a. The reflection strengths vary by up to 20 dB. The large section of decreased reflection amplitude along the centerline of the bridge corresponds well with the zone of deterioration (visually-determined) plotted in Figure 7b. Unfortunately, this bridge was not sounded with a chain-drag or hammer to locate non-visually detectable deterioration such as delamination, other than what was verified through limited coring.

Fordway Extension Bridge

The Fordway Extension Bridge, located in Derry, NH, USA, was studied in the same manner as the Allenstown Bridge. There were no surface cracks in the asphalt. After asphalt removal, the concrete surface showed very little visible deterioration. Consequently, the deck was thoroughly sounded with a rock hammer to map out delaminated zones, and a number of delaminated areas were detected.

Figure 8 gives a comparison of data from profile lines 0.3 m and 4 m from the lane edge, respectively. The weaker upper rebar reflections from the deteriorated zones are visually evident. A contour plot of the amplitudes of the reflections from the upper rebar, shown in Figure 9a, reveals variability of approximately 20 dB. The zones of weak upper rebar reflections are in good agreement with the mapped delaminated areas, shown in Figure 9b. It is also suspected that zones containing other deterioration mechanisms surround delaminated regions or exist independently on the deck.

Discussion

The initial positive results in locating the deteriorated zones of the bridge deck based on the variation in reflection amplitudes of individual rebar are very encouraging and provide incentive to continue active research in this area. Currently, GSSI is involved with the New Hampshire