NON-DESTRUCTIVE TESTING (NDT) FOR CORROSION IN BRIDGE DECKS USING GPR

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Abstract

The ground penetrating radar (GPR) tool was used to inspect Bridge A-2138 in Franklin County, Missouri. The objective was to determine whether the non-destructive, non-invasive GPR tool is an effective method for identifying and mapping zones of deterioration (corroded rebar and delaminations) within bridge decks. GPR data were collected under different weather conditions (wet, dry, warm and cold) to assess the impact of these climatic conditions on the data quality and interpretability. The GPR interpretations were compared to those of other traditional techniques, including the chain drag and half-call potential methods.

The study results confirm the GPR tool cannot be used to directly resolve delaminations and/or corroded rebar within concrete bridge decks. However, the GPR tool can be successfully used to detect and map zones of relatively high dielectric constant (low EM velocity) and high attenuation. These low-velocity/high-attenuation zones are typically zones of delamination (characterized by anomalously high moisture content and chloride ion concentration). These interpretations are consistent with results obtained from more conventional bridge deck inspection methods. It was also concluded that weather conditions did not significantly affect the overall utility of the GPR tool.

Introduction

Many factors cause or contribute to the initial disintegration (fracturing) of the top layer of concrete in bridge decks including the corrosion of steel rebar, freeze and thaw cycles, traffic loading, initial damage resulting from poor design and/or construction, and inadequate maintenance (Roddis, 1987, and Maser, 1989). Water, of variable salinity, can infiltrate the concrete through such fractures and cause and/or accelerate the corrosion of emplaced rebar. Corrosion (and the attendant increase in the size of the rebar) generates expansive pressures which can cause further delamination (minute fracturing and cracking) just above the top rebar mat (Figure 1; Krauss, 1996). Delaminations effectively decouple the concrete from rebar resulting in the loss of structural strength and increase the corrosion rate of the steel by allowing even more infiltration into the concrete.

The integrity of the concrete can vary spatially across a bridge deck (Fig. 2), however areas of extensive delamination are often difficult to find because the mechanism occurs below the concrete surface, which is mostly overlaid by asphalt. If deterioration is not identified before spallage occurs, the resulting damage is costly to repair. Often, the upper portion of concrete (in some cases the top mat reinforcement) or the entire deck is replaced (Halab, 1994; Warhus, 1995; Krauss, 1996).

Deteriorating concrete within a bridge deck can often be identified and mapped with varying degrees of success using conventional methods, including chain drag, half-call potential, chloride content, ultrasonic, pulse-echo, infrared ray testing, and visual inspection (Figure 2). More recently, the GPR tool has been employed as a non-destructive test (NDT) tool for bridge deck inspection and concrete strength evaluation (Maser and Bernhardt, 2000; Cardimona, 2001; Oota et al., 2000; and Robert and Romero, 1999). In this study, a 1.5 GHz ground-coupled antenna was used to inspect the deck of Bridge A-2138 in Franklin County, Missouri.

Principles of Using the GPR for Bridge Deck Inspection

The GPR tool is not physically capable (re: vertical and horizontal resolution) of directly imaging minute delaminations (micro-fractures) within concrete because the crack openings are too small to

generate a reflected signal. However, the 1.5 GHz GPR tool is capable of imaging the reflections/diffractions from embedded rebar, and hence can be used to indirectly detect the presence of delaminations, particularly when the fractures contain moisture and dissolved salts (Barnes, 1998).

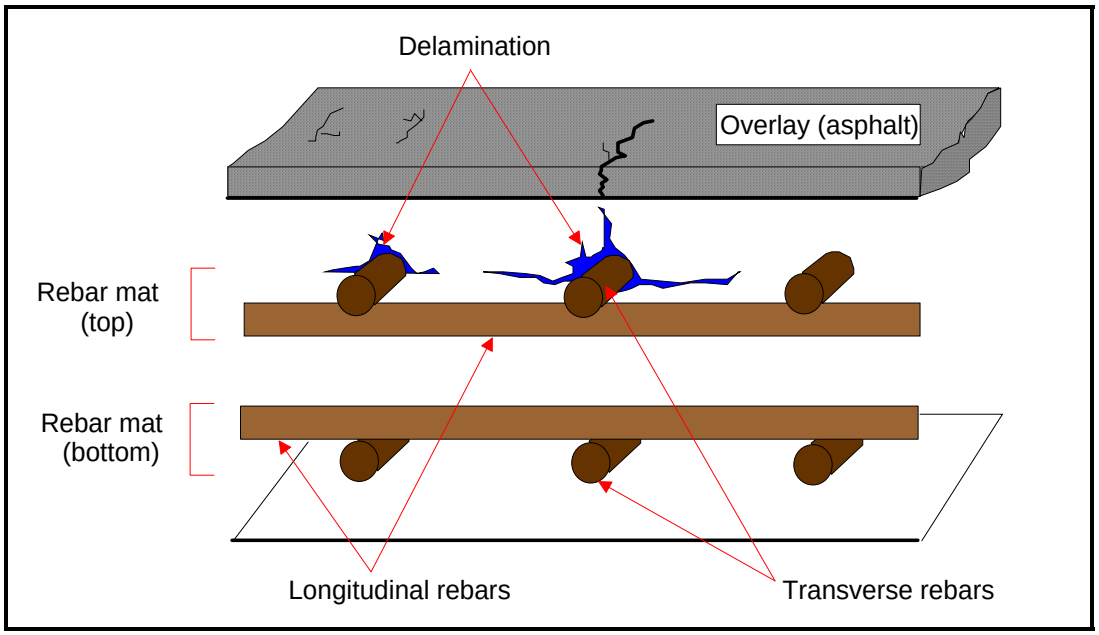

Figure 1: Concrete delaminations caused by corrosion of steel reinforcement.

Figure 2: A photographic picture shows an example of the severely deteriorated bridge deck.

The basis principle is as follows. Moisture and dissolved chlorides within the concrete attenuate the radar signals that are reflected from embedded rebar. They also decrease their average velocity of the reflected signal resulting in increased arrival times (relative to non-deteriorated sections of the bridge deck; Halabe and et al., 1994). Generally, lower relative reflection magnitudes and greater transit times are indicative of greater deterioration. Transit times and known rebar depths can be used to determine the dielectric constant of the concrete at every location where rebar is imaged. Deteriorated sections of bridge deck can be identified quantitatively on the basis of assigned dielectric constant. Deteriorated sections of the bridge deck can also be identified on the basis of the relative magnitude of the

reflections/diffractions from each imaged rebar. (Magnitudes need to be normalized relative to the reflection from the surface of the bridge deck.) The shape of the GPR wavelet reflected from corroded rebar can also be distorted relative to wavelets reflected from intact rebar (Cardimona, 2001).

Site Location and Bridge Deck Description

GPR data were acquired across the deck of Bridge A-2138, Franklin County, Missouri. Bridge A-2138 is located on Route O, about three miles southwest of the intersection of US 50 and I-44 (Figure 3). The bridge was constructed in the early 1970's. It is 141.5 feet long, 34 feet wide, and has an average daily traffic (ADT) of 1,700 (MoDOT, Bridge Deck Condition Survey Summary, 2001). According to the bridge plan map, Bridge A-2138 (MODOT, Bridge Plan Map, 1967), the concrete bridge deck is reinforced with two layers of rebar meshes (top and bottom). Each rebar mesh is comprised of transverse (5/8") and longitudinal (4/8") rebars. Rebar spacing is placed at 6 inches center-to-center and the design depth from the surface to the top of the transverse rebar of the top mesh is 15/8 inches. This depth measured by GPR and by a ruler during core sampling. The thickness of the concrete deck is 6.5 inches (Figure 4). Cracks in the thin (<3 cm thick) overlying asphalt layer were observed during a visual inspection in September 2001.

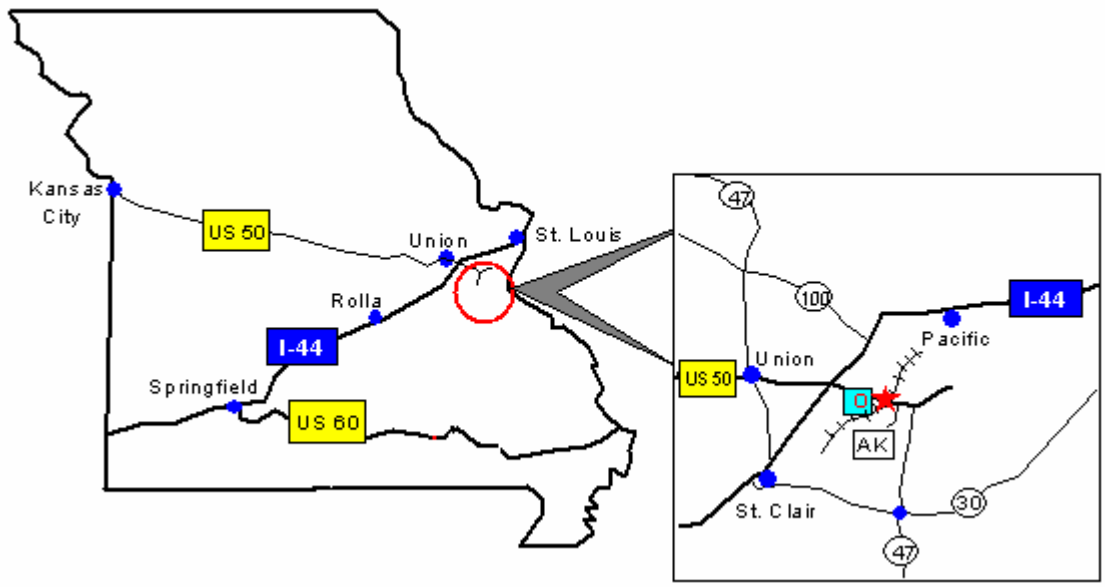

Figure 3: Location map of bridge A-2138 in Franklin County, MO.

GPR Data Acquisition

The GPR data were acquired with a GSSI SIR-10B system equipped with 1.5 GHz ground coupled antenna. A survey wheel was used in the survey to indicate reference points or fiduciary marks in the GPR digital data record. The separation between parallel GPR survey lines was 1-foot (Figures 4 and 5). Acquisition parameters were as follows:

- Time window: 12 ns
- Samples per scan: 512
- Transmit rate: 100 kHz/s
- Gain function: 2 gain points
- Filters (vertical IIR): LP 375 MHz, HP 3000 MHz

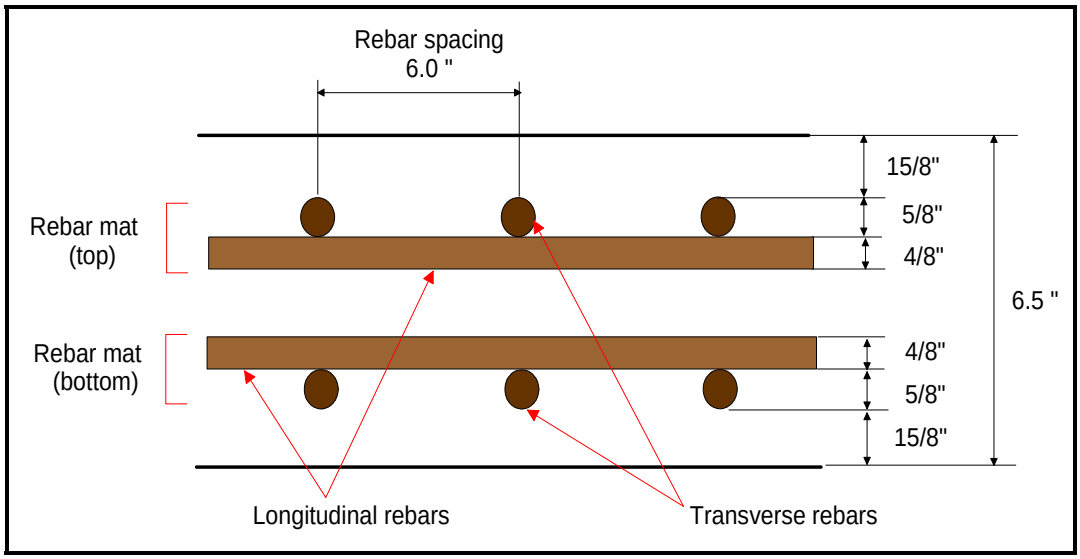

Figure 4: Cross-section of the bridge deck (Bridge A-2138).

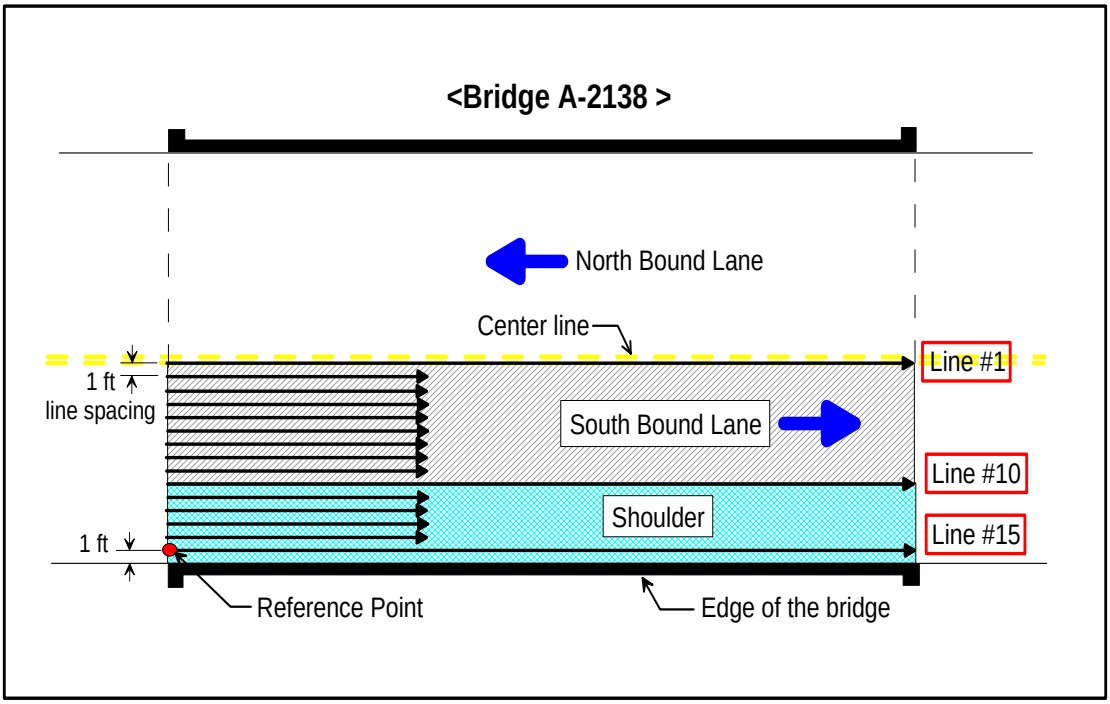

Figure 4: Survey map for the bridge deck (Bridge A-2138) showing orientation of profiles and spacing between parallel profiles.

Figure 5: GPR data acquisition on the bridge deck.

Data Processing and Analysis

The GPR data were processed using GSSI's RADAN post-processing software for Windows NT (GSSI, 2000). Basic processing steps included filtering to eliminate high and low frequency noise and frequency tilt. An automatic rebar-picking tool was used to pick the arrival times/lateral locations of the rebar. The two way travel times to the top of the rebar and the magnitude of the reflections from the rebars were plotted and interpreted.

Results

During the preliminary phase of data interpretation, the processed GPR data were visually examined. With suitable adjustment of the display mode such as color table, color transform and display gain, badly deteriorated zones within the bridge deck could be identified visually on the basis of rebar image magnitudes and arrival times. For example, in Figure 6, areas of intact concrete are characterized by laterally continuous rebar reflections/diffractions of uniformly high magnitude with relatively short arrival time. In contrast, areas of extensive delamination are characterized by lower magnitude reflections/diffractions with greater arrival times (Figure 6b). (Note that areas of delamination were identified on the basis of both criteria.)

Deteriorated areas of the bridge deck, as identified by MoDOT inspectors using the traditional chain drag test and the half-cell potential test bridge deck inspection methods, are plotted on plan view maps as Figures 7a and 7b, respectively. A cut-off value of -150 millivolts (mV) was selected as indicative of deteriorated concrete. Closed, dark green contours represent those areas of the bridge deck that were interpreted as deteriorated.

Deteriorated areas of the bridge deck, as interpreted during the visual inspection of the GPR data, are plotted as Figure 7c. Areas interpreted as deteriorated on the basis of two-way travel times to top of the upper rebar as determined using the automatic picking tool included in the GSSI RADAN NT software are presented as Figure 7d. Areas interpreted as deteriorated on the basis of the magnitude of the reflected radar signals from top of the upper rebar as determined using the automatic picking tool included in the GSSI RADAN NT software are highlighted in Figure 7e. A magnitude level of 72dB was used as the cut-off.

In a general sense, the interpretation based on the visual assessment of GPR magnitudes and travel times best matched the interpretations based on the traditional methods. This is not unexpected because travel times can vary as a result of the inaccurate placement of rebar (with respect to design plans). Similarly, signal magnitudes can vary because of factors other than the presence of delaminations. However, variations in both parameters are most likely due to the presence of delaminations.

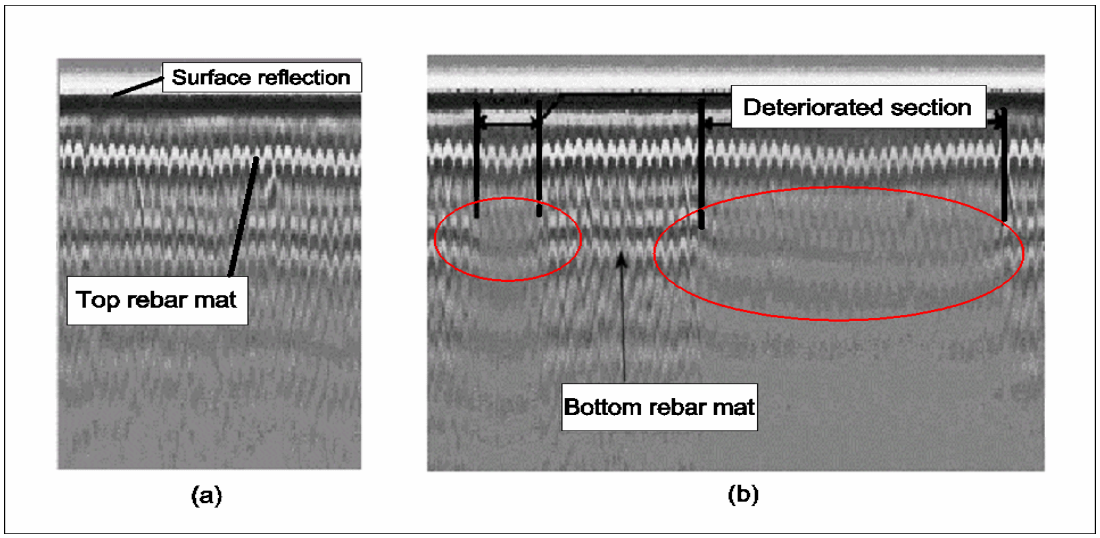

Figure 6: Example GPR data displaying sound area (a) and deteriorated area (b).

Data Acquired Under Different Weather Conditions:

GPR data were acquired over a six month period in an effort to determine how weather conditions (humidity and temperature) affect the utility of the GPR tool with respect to the identification of delaminated areas of the bridge deck. In a general sense, the relative magnitudes of signals reflected from the top of the rebar are similar irrespective of weather conditions. Although reflection magnitudes are slightly higher on data profiles acquired under wet conditions than that under dry condition (Fig. 8), there was no significant change (in terms of data interpretability).

The two-way travel times to the top of the upper rebar are similar irrespective of weather conditions (Fig. 9). Indeed, variations in two-way travel times (due to changing weather conditions) seem to be less significant than changes in reflections magnitudes. Although travel time differences (intact versus delaminated concrete) are slightly higher on data profiles acquired under wet conditions than that under dry condition (Fig. 8), there was no real significant change in terms of the overall interpretability of the GPR data.

Conclusions

The study results confirm that the GPR tool cannot be used to directly resolve delaminations and/or corroded rebar within concrete bridge decks. However, the GPR tool can be successfully used to detect and map zones of relatively high dielectric constant (low EM velocity) and high attenuation. These low-velocity/high-attenuation zones are typically zones of delamination (characterized by anomalously high moisture content and chloride ion concentration). The interpretations of the deck of Bridge A-2138 contained herein are consistent with the interpretations obtained from more conventional bridge deck inspection methods. It was also concluded that weather conditions did not significantly affect the overall utility of the GPR tool.

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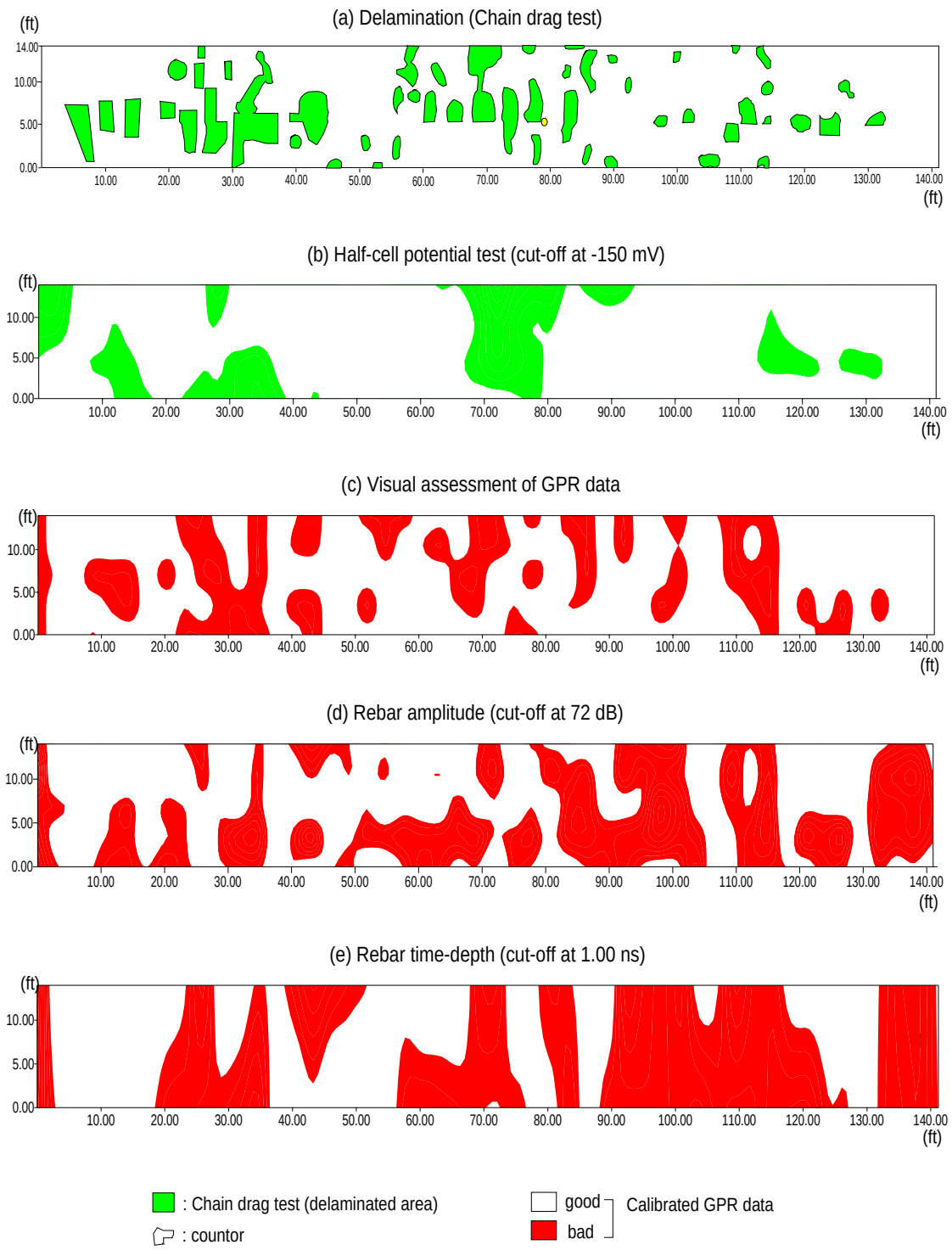

Figure 7: Plots of the suggested deteriorated areas in the bridge deck; (a) based on the chain drag test; (b) based on the half-cell potential test; (c) based on the visual assessment of the radar data, (d) based on the measuring the reflection amplitudes of the radar reflections from the rebars and (d) based on the two-way travel time from the top of the rebars on the radar data.

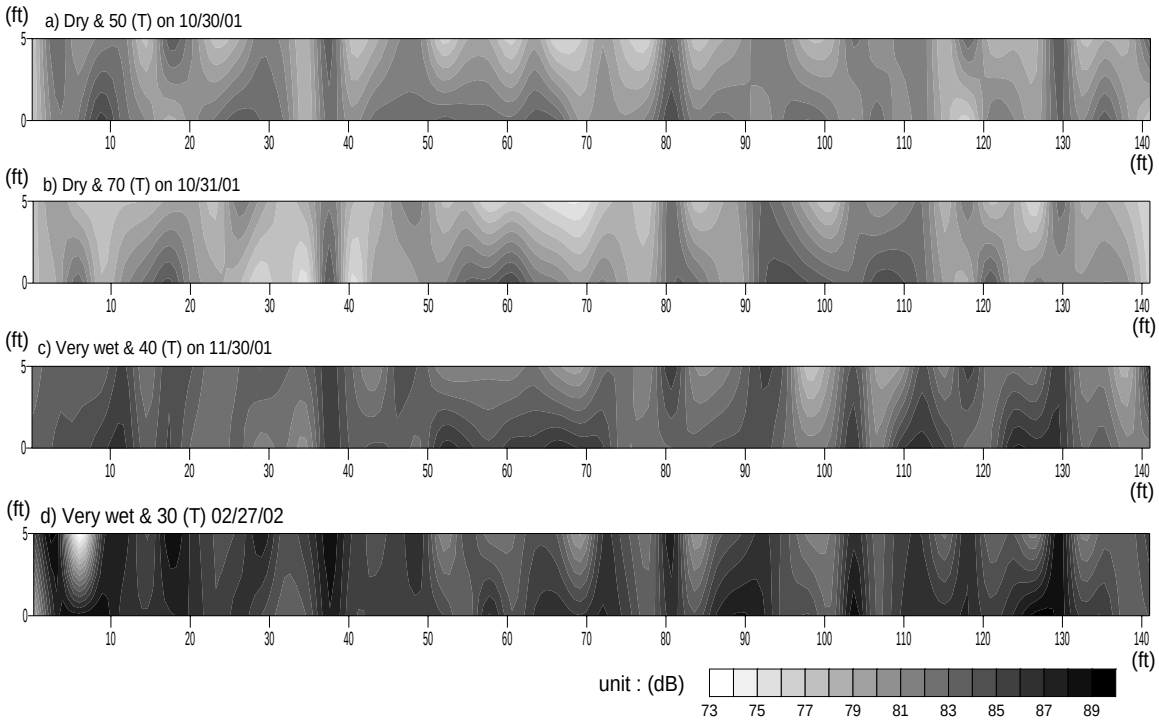

Figure 8: Contour map of amplitudes of reflected signals from the top of the rebars and different weather conditions.

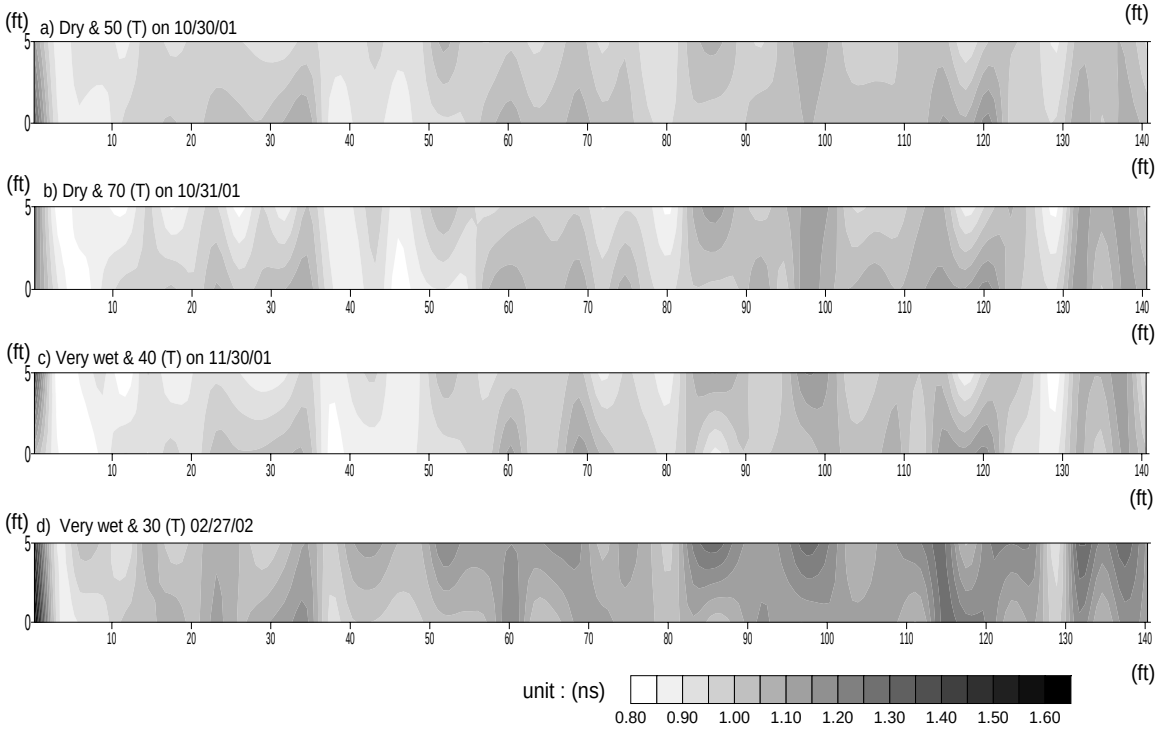

Figure 9: Contour map of the two-way travel time to the top of the rebar mat in the concrete of the bridge deck under different weather conditions.