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Research Record

Use of Ground Penetrating Radar to Delineate Bridge Deck Repair Areas

Final Report

Prepared in cooperation with the U.S. DOT, Federal Highway Administration

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16. Abstract

Ground penetrating radar (GPR) has emerged as a viable means of nondestructively determining the locations of deteriorated sections of bituminous-overlaid, reinforced concrete bridge decks. While prior GPR successes on such structures were traditionally limited to estimating repair quantities and had not been shown to consistently provide an accurate indication of the *location* of distressed areas, work conducted in 1998 and 1999 on several New Hampshire bridges produced predictions of deterioration that compared favorably with ground truth data and conventional (destructive) survey techniques. Recent developments in GPR technology provided high resolution images of the bridge deck structure that were used to create contour maps detailing different levels of deterioration.

This report summarizes efforts initiated and sponsored by the New Hampshire Department of Transportation (NHDOT) related to location-specific predictions of corrosion and freeze/thaw induced deterioration on existing bridge decks scheduled for rehabilitation. In 1998, twin 842-foot (257 m) interstate bridges spanning the Connecticut River between Lebanon, NH and White River Junction, VT were surveyed using a combination of horn and ground-coupled antennas. These surveys, supplemented by an underside inspection and limited coring and chloride testing, were successfully used to estimate and locate repair areas prior to a deck rehabilitation project on the structures. In 1999, four structures located along I93 in Thornton-Woodstock, NH were surveyed without the use of supplemental, destructive testing or lane closures. Contour maps were produced on all structures, showing varying degrees of predicted deterioration. Although statistical comparisons were not performed, the contour maps showed a high visual correlation with independent maps generated based on sounding, half-cell potential, and/or chloride content testing.

17. Key Words Ground penetrating radar, GPR, bridge deck, rehabilitation, maintenance, repair, patching, NDT, half-cell, potential, corrosion, chloride, sounding, delamination, freeze-thaw	**18. Distribution Statement** No Restrictions. This document is available to the public through the National Technical Information Service (NTIS), Springfield, Virginia, 22161.

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Acknowledgements

This report was prepared to fulfill the final reporting requirements of NHDOT Research Project 12323S, SPR-0004(023). Much of the data contained herein were previously presented in the following documents and presentations:

1. Romero, F.A., Roberts, G.E., and Roberts, R.L., 2000, "Evaluation of GPR Bridge Deck Survey Results Used for Delineation of Removal/Maintenance Quantity Boundaries on Asphalt-Overlaid, Reinforced Concrete Deck", *Structural Materials Tech. IV*, Technomic Publishing Co., Lancaster, PA, p. 23-30.
2. Roberts, G., Roberts, R., Tarussov, A., 2001, "Identifying Concrete Deterioration using Ground Penetrating Radar Technology", paper and presentation at the American Society for Nondestructive Testing (ASNT) Fall Conference and Quality Testing Show, Columbus, OH, October 15 – 19, 2001.

The author would like to acknowledge Roger Roberts and Francisco Romero of Geophysical Survey Systems Inc., for their many contributions to the project including GPR data collection, post processing, interpretation, and graphical reporting of results. Ken Maser of Infrasense, Inc. is acknowledged for producing similarly effective results in limited runs at the I93 sites.

Alan Rawson, Mark Whittemore, Chris Waszczuk, Scott Leslie, Steve Drouin, Joe Constant, Alan Perkins, Bill Real and Jeff Allbright, all from the New Hampshire Department of Transportation, and Dave Hall from FHWA, are acknowledged for their contributions to the research effort. Particular recognition goes to Earl Kingsbury, formerly of NHDOT, who managed to keep accurate records of the I89 rehabilitation activities during nighttime operations, in spite of many demands on the jobsite.

Additional references are included at the end of this report.

Cover photo courtesy of Geophysical Survey Systems Inc.

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EXECUTIVE SUMMARY

Ground penetrating radar (GPR) has emerged as a viable means of nondestructively determining the locations of deteriorated sections of bituminous-overlaid, reinforced concrete bridge decks. While prior GPR successes on such structures were traditionally limited to estimating repair quantities and had not been shown to consistently provide an accurate indication of the *location* of distressed areas, work conducted in 1998 and 1999 on several New Hampshire bridges produced predictions of deterioration that compared favorably with ground truth data and conventional (destructive) survey techniques. Recent developments in GPR technology provided high resolution images of the bridge deck structure that were used to create contour maps detailing different levels of deterioration.

This report summarizes efforts initiated and sponsored by the New Hampshire Department of Transportation (NHDOT) related to location-specific predictions of corrosion and freeze/thaw induced deterioration on existing bridge decks scheduled for rehabilitation. In 1998, twin 842-foot (257 m) interstate bridges spanning the Connecticut River between Lebanon, NH and White River Junction, VT were surveyed using a combination of horn and ground-coupled antennas. These surveys, supplemented by an underside inspection and limited coring and chloride testing, were successfully used to estimate and locate repair areas prior to a deck rehabilitation project on the structures. In 1999, four structures located along I93 in Thornton-Woodstock, NH were surveyed without the use of supplemental, destructive testing or lane closures. Contour maps were produced on all structures, showing varying degrees of predicted deterioration. Although statistical comparisons were not performed, the contour maps showed a high visual correlation with independent maps generated based on sounding, half-cell potential, and/or chloride content testing.

BACKGROUND

In early 1998, the New Hampshire Department of Transportation (NHDOT) prepared to advertise a bridge deck rehabilitation project on twin bridges carrying Interstate Route 89 over the Connecticut River between Lebanon, NH and White River Junction, VT. Although a more extensive and permanent restoration or replacement was anticipated for the structure several years in the future, a significant interim rehabilitation project was warranted because of the need for frequent patching and maintenance repairs on the deck.

Because of traffic concerns at the site, the rehabilitation project was designed such that all work would occur at night. The contractor would be required to perform concrete repairs and reopen the bridge to traffic within a 12-hour work-window each night. To facilitate the project and to allow for reasonable quantity estimates to be made, the Department sought to accurately delineate those areas needing repair prior to advertisement of the project. The size of the structure, traffic, and existing bituminous overlay eliminated a conventional (half-cell potential, delamination, etc.) bridge deck condition survey from consideration. Ground penetrating radar (GPR) emerged as a potential tool to meet the project objectives.

Prior to that time, GPR techniques had traditionally been limited to estimating repair quantities, and had not been shown to provide an accurate indication of the *location* of the distressed areas. More recent work performed in New Hampshire and elsewhere by Geophysical Survey Systems, Inc. (GSSI) of Salem, NH had included the use of a 1.5 GHz ground-coupled dipole antenna. This equipment appeared to yield high quality data for assessing the condition of concrete bridge decks near the top rebar mat. These investigations provided promising correlations between the reflection amplitude of the upper rebar and zones of deterioration in the deck, giving the Department hope that radar could provide an accurate delineation of areas to be repaired on the I89 rehabilitation project.

A research project was initiated to investigate and verify the ability of the GPR technology to determine deterioration limits within the parameters of the proposed rehabilitation project. By incorporating an experimental application of GPR into the project, the objectives of the research were to evaluate the current state-of-the-practice and to provide recommendations related to future applications of GPR at NHDOT.

GROUND PENETRATING RADAR (GENERAL)

Ground penetrating radar (GPR) has been a useful tool for investigating the internal structure of materials for over 30 years. GPR is typically used in a pulsed mode. A transmitting antenna radiates an impulse of electromagnetic energy that propagates through the medium and reflects, refracts, and/or diffracts at boundaries with other media possessing different electromagnetic properties than the host medium. A portion of the energy scattered at these electromagnetic property boundaries may be redirected towards another antenna that is set-up as a receiver. GPR can be described as an electromagnetic version of the acoustic fish-finder; however, GPR can be used on land as well as on water.

During the early years, GPR was utilized mainly for geological and environmental applications. The antennas that were built for these investigations were approximately a meter in length and radiated electromagnetic pulses containing wavelengths on the order of several meters. The large wavelengths were effective in locating objects such as 55-gallon barrels, but prohibited resolution of fine details, such as the internal structure of concrete. Over the past several years, very small antennas have been designed that can provide high-resolution images containing the signature of individual rebars in concrete. Figure 1 shows a schematic diagram of a cross section of an asphalt-overlaid reinforced concrete bridge deck and an example of actual GPR data obtained over such a deck. The rebar are clearly seen in the GPR data.

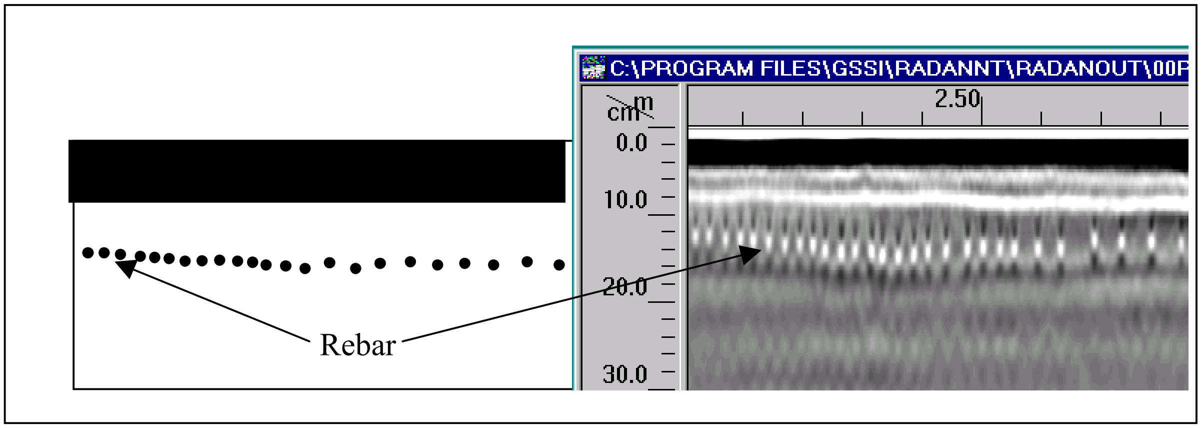


Figure 1. Schematic of asphalt-overlaid bridge deck and an example of actual GPR data collected over an asphalt-overlaid bridge deck

A great deal of GPR data can be collected in a very short period. The realization that GPR technology was capable of imaging individual rebars in concrete at a rapid rate led to a feasibility study of the usage of GPR for accurately mapping rebar depth in new NHDOT bridge decks. This work, briefly described below, influenced the direction of the later bridge deck condition assessment research.

GPR EVALUATION FOR COVER MEASUREMENT

Work in New Hampshire related to use of the GPR instrument as a new-bridge-deck inspection tool began about a year before the I89 rehabilitation project when NHDOT and GSSI cooperatively engaged in an effort related to the determination of concrete cover. The objectives of that work were to (a) collect data on new bridge deck structures, (b) develop post-processing software to calculate and display the depth to reinforcing steel, and (c) compare the resulting product with direct measurement and pachometers used to determine concrete cover [1]. The evaluation effort resulted in a modification of existing QC/QA specifications by NHDOT, requiring the exclusive measurement of this parameter by the GPR tool, based on its performance [2].

The tool's initial success as a high-resolution measuring instrument on new structures then prompted it to be investigated as a condition assessment device on an old, asphalt-overlaid deck scheduled for dismantling by the NHDOT. It was discovered that the tool's ability to isolate information from individual bars within the reinforced concrete structure allowed it to differentiate between (a) reinforcement surrounded by good concrete, and (b) reinforcement surrounded by deteriorated material, i.e. material that included delaminated zones, punky concrete, or concrete that had otherwise become compromised by corrosion and/or other deterioration mechanisms [3].

PRELIMINARY BRIDGE DECK CONDITION INVESTIGATIONS

Several other asphalt-overlaid NHDOT structures, already scheduled for replacement, were then surveyed with the intent of accurately determining deterioration quantities, relative degree of deterioration, and location of these identified deterioration zones. Each survey produced similar results, where either (a) core data supported GPR-predicted zones of deterioration (or good concrete); (b) delamination-mapping (hammer-sounding) data matched GPR-predicted deterioration; and/or (c) removed sections of the bridge deck (during dismantling) further supported the GPR predictions.

There are a number of possible physical conditions associated with concrete deterioration that could generate low rebar reflection amplitudes: (1) the concrete has a greater moisture content, thus absorbs more of the radar wave energy; (2) the rebar corrosion products increase the conductivity of the concrete in the vicinity of the rebar thus absorbing more radar wave energy; and/or, (3) the rebar size is diminished due to the effects of corrosion resulting in less reflected radar wave energy. The chloride concentration in the concrete matrix resulting from the intrusion of deicing salts may also influence the measured reflection amplitude.

INTERSTATE ROUTE 89/CONNECTICUT RIVER BRIDGES

Previously described cooperative efforts between NHDOT and GSSI just prior to the proposed I89 bridge rehabilitation project contributed to the Department's decision to enter into a contract with GSSI to perform the GPR survey associated with the research.

The 842-foot (257 m), two-structure, four-lane bridge deck system spanning the Connecticut River on I-89 was evaluated by GSSI during the spring of 1998, and a rehabilitation strategy based largely on the GPR results was developed by NHDOT to repair the asphalt-overlaid bridge deck. The project goals were to simultaneously: (a) extend the service life of the structures an additional ten years or more; (b) maintain the bridge deck structures using a sequence of cut-and-patch operations, allowing unimpeded traffic flow on the structure during daytime hours; and (c) investigate the effectiveness of a new GPR technology's ability to accurately determine concrete deterioration levels and their boundaries on a plan view map of the structure.

Figure 2. Elevation view of twin bridges carrying I89 over the Connecticut River between New Hampshire and Vermont.

GPR DATA COLLECTION AND DECK UNDERSIDE SURVEY

The GPR survey was performed on the structures using a combination of horn and ground-coupled antennas within the framework of the established project goals. GPR data were supplemented by a surface and underside inspection of the deck, and by limited chloride sampling and coring of specific areas of both sound and deteriorated concrete. Information from the survey was used to delineate areas needing repair. To evaluate the accuracy of the results, the rehabilitation contract included provisions for visually inspecting and sounding the deck after the initial patching took place and prior to final membraning and paving of the structure.

Two traffic lanes in each direction were surveyed parallel to the direction of traffic flow. Each GPR profile (data collection line) was 842 feet (257 m) in length. Profiles were spaced at two-foot intervals, resulting in six profiles collected per lane. Data were spaced at one-half inch intervals (GPR scan density of 80 scans/meter) along each profile.

With data collected in this manner, a complete set of adjacent GPR scan profiles—representing each deck structure (one for East-bound lanes and one for West-bound lanes)—was assembled "side-by-side" in their respective, relative orientations and analyzed. Common features detected in adjacent GPR profiles—regions displaying evidence of concrete deterioration beneath the asphalt overlay—were then able to be contour-plotted in a plan-view map of each structure's surface [4].

High resolution data were collected using a single, shielded, ground-coupled 1.5 GHz sensor (antenna), controlled by a SIR-10H, high signal-noise ratio data acquisition unit. The spacing between each GPR profile was accurately controlled by using a forward-facing, declined laser which could be viewed on a reference line (each lane stripe) even during bright sunlight [4]. Since the laser was aligned so that it's "line-of-sight" was parallel to the vehicle's axis of symmetry, when viewed from above the survey vehicle, it could be used to control scan profile spacing as follows:

(a) Data on a single profile were collected with the laser-to-antenna spacing set at one foot (0.3 m), resulting in a survey profile collected one foot inside the right lane shoulder stripe when the vehicle was driven so that the laser was sighted at the marking stripe's centerline during travel (data collection).
(b) Next, the laser—which was mounted on a rack across the front of the vehicle's roof, perpendicular to the vehicle's axis of symmetry—was offset two feet (0.6 m) to the right (or left) of its previous position. A new GPR profile was collected, with the laser focusing on the same reference stripe (lane divider), at an interval of two feet (0.6 m) from (but parallel to) the previous GPR profile.
(c) Repeated repositioning of the laser, in two-foot (0.6 m) increments, with the laser pointing at either the left lane boundary (stripe) or the right boundary—depending on which side of the vehicle the antenna and laser were mounted—allowed for the entire lane width to be collected with parallel profile paths.

GSSI performed a deck underside survey using a camera and telephoto lens. Three spans of each structure were surveyed by motorboat. A complete photographic record of the deck structures' undersides was taken, using overlapping photos of the deck bottom—with substructure supports, beams, and girders as references for re-plotting the observed defects onto graph paper.

Individual cracks and cracked areas displaying underside efflorescence (stalactites) buildup, where usually the reinforcement grid pattern could be seen, were marked and duplicated on the graph paper. In addition, areas where the concrete underside surface displayed significant rust staining were marked. The coordinates for this underside deterioration, relative to a plan view of the deck's top surface, were entered into a database and plotted using a mapping program.

DATA POST-PROCESSING, ANALYSIS AND REPORTING

For each structure, a project file assembled all of the data profiles sequentially so that starting and ending points along the structure were aligned for all profiles. Data were processed using proprietary software that measured several GPR signals taken across each transverse bar and compared signals from every bar in the structure. The amplitude response from each sequential bar in every GPR profile was measured and compared to its neighbors, and the maximum amplitude value was output in one-foot increments along the profile. The results were output to a 3-D ASCII file so that the distance-referenced data could be plotted in a contour-mapping program.

A series of contour-plots highlighting zones displaying relative levels of deterioration were generated so that all sections of both structures could be examined. Visual indications of deck deterioration obvious in the raw data were used to establish an initial deterioration threshold. Raw data indicating zones of obviously degraded concrete and likely, good concrete were used to selectively locate cores for both strength testing and chloride content analysis.

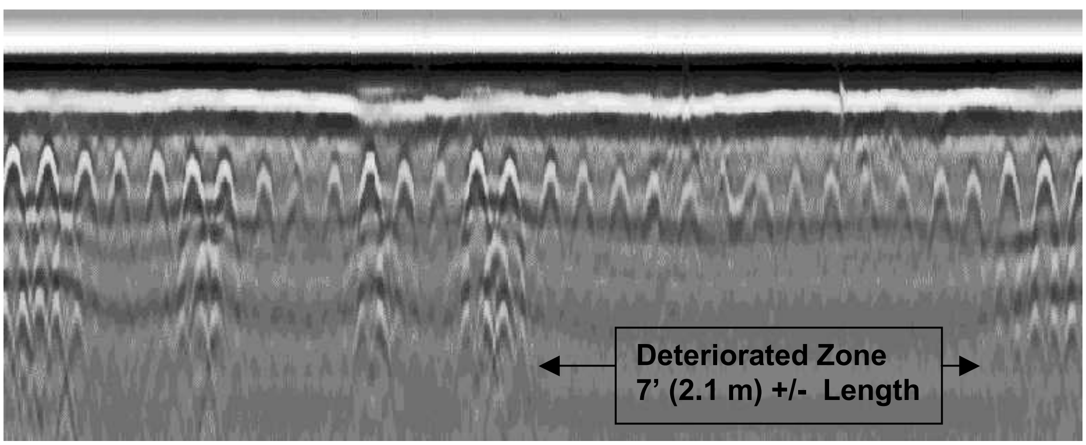


Figure 3: GPR Profile (Raw Data) Showing Four Deteriorated Zones

Figure 3 shows segments of severely deteriorated concrete on the Southbound Lanes from a single GPR profile. Final relative deterioration maps, where GSSI defined its interpretation of concrete zones requiring rehabilitation action, were produced for NHDOT as part of the final report [4]. Figure 4 illustrates a typical, 125-foot (38 m) section of deck in the graphical format supplied with the report.

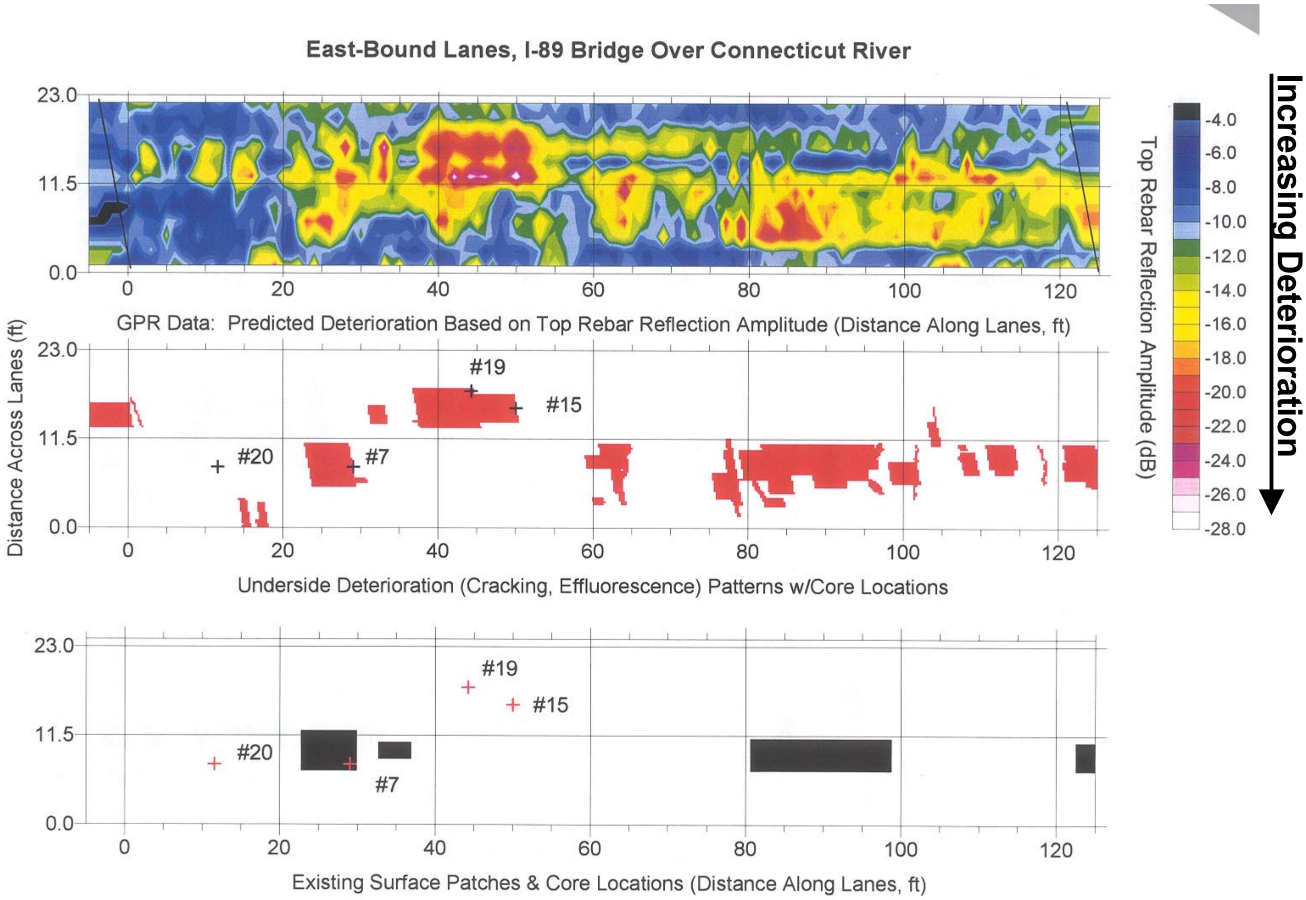


Figure 4: Plan-View Contour Map of Relative Deck Deterioration (top) and Deck Underside Deterioration (bottom)

REHABILITATION ACTIVITIES BASED ON GPR-PREDICTED RESULTS

Along with the contour maps, the following observations, interpretations, and recommendations were provided to NHDOT.

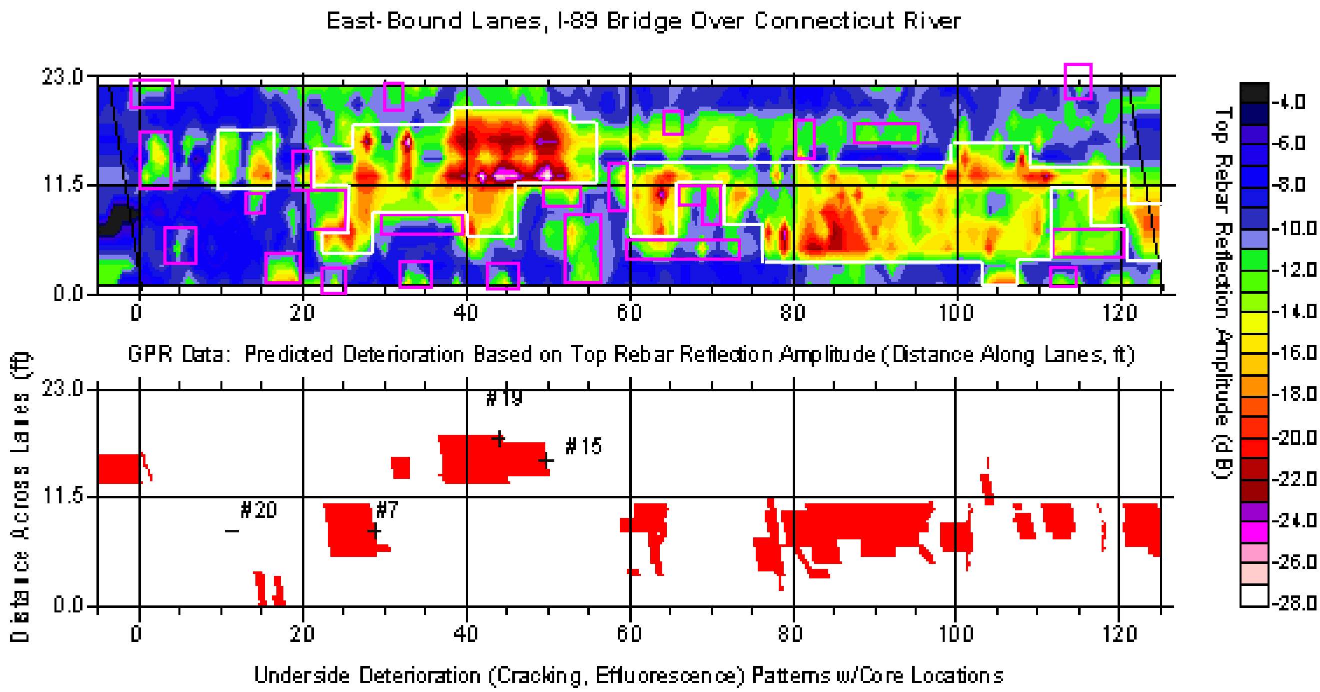
With reference to Figure 4, the probability of deterioration increases with decreasing amplitude; therefore, a –10dB to –11dB amplitude zone (light blue) on the contour map represents a region with a lower probability of deterioration than a zone falling between –19dB and –23dB (varying shades of red). Either, however, represents a region that could be of concern when classifying the bridge deck sections as deteriorated. It was recommended that all regions on the color-scaled contour plots of processed GPR data falling between –10dB and –28dB (light blue through white, on the lower end of the color scale) be treated as regions with a high probability of deterioration. Regions on the contour plots that fell between –3dB and –10dB were classified as zones displaying negligible or marginal evidence of deterioration.

The predicted deterioration zones encompassed a total area that exceeded NHDOT's practicality threshold for a cut-and-patch approach. Based on the short- and long-term service life goals associated with rehabilitation of the structure, and the Department's limited previous experience with GPR as a predictive delineation tool, a decision was made to repair the deck at a less aggressive level. Sections of the contour map more negative than –15dB were used to estimate the initial deck repairs. Additionally, regions falling between –14dB and –15dB on the deterioration scale were included if they also displayed evidence of underside deterioration. Smaller, isolated regions on the deck that only the GPR had identified as deteriorated were generally not included in the Phase 1 repairs.

During the rehabilitation, repairs were made in two phases. Phase 1 consisted of repairing areas that were delineated on the plans based on the estimation protocol described above. The concrete was cut-and-patched through the existing asphalt pavement using a quickset concrete followed by a temporary asphalt patch, to match the existing section. Following Phase 1, complete removal of the temporary asphalt patches and the remaining original asphalt overlay occurred to expose the entire concrete surface. The entire deck surface was then visually inspected and sounded. Phase 2 consisted of the additional repair of any newly detected zones of deteriorated concrete. Figure 5 shows a typical, 125-foot (38 m) panel displaying both Phase 1 and Phase 2 repairs, and their correspondence to various deterioration levels predicted by the GPR survey.

Almost all repairs (both Phase 1 and Phase 2) resided within the GPR-predicted rehabilitation boundaries. A number of small, deteriorated zones were found that were not identified as deteriorated by GPR. Conversely, some of the more conservatively classified zones did not appear to be deteriorated based on sounding or visual inspection, although the corrosion potential and chloride content were not measured. In general, there was a strong visual correlation between the predicted and the actual deteriorated zones.

Which of the various thresholds is appropriate for a particular structure is always subject to debate based on the parameters of a specific project. On this project, the Department successfully utilized the GPR analysis as corroborative evidence to delineate areas for removal of substandard concrete from the deck. Using an objective NDT evaluation technique that quantified the extent of the repair zones prior to marking for concrete removal and repair, NHDOT could repair areas much more effectively than indicated strictly by visual evidence on the deck bottoms. With the exception of the limited core/chloride test locations used by GSSI for establishing a deterioration threshold, no invasive testing was performed on the deck prior to rehabilitation. In addition, no asphalt or membrane removal was required to perform the pre-construction evaluation.



White Border in Top Image: Approximate Phase I Rehabilitation Zones
Pink Border in Top Image: Approximate Phase II Rehabilitation Zones

(Note that Figure 4 and Figure 5 represent the same bridge deck plan views, except that different color palettes (grayscale levels) were used so that rehabilitation boundaries could be seen on this image.

Figure 5: Illustration of Phase I and Phase II repairs - Lebanon

I93 BRIDGES, THORNTON-WOODSTOCK

During the spring of 1999, the Department organized an informal comparison study of deterioration-mapping methods on four asphalt-overlaid bridge decks along I93 in the Thornton-Woodstock area. Half-cell corrosion potential and chloride concentration data had been collected by NHDOT in 1998, and contour maps were produced for the half-cell data. Limited radar data were collected by GSSI and Infrasense, Inc. of Arlington, MA in 1999. Hammer sounding was performed by NHDOT in 2001 on one bridge following removal of the bituminous pavement. A visual comparison of the half-cell contour maps and the processed maps from both GPR vendors showed general agreement between areas of low rebar reflection amplitudes in the GPR data and the portions of the upper bridge deck possessing high (negative) corrosion potential. Deteriorated zones detected by hammer sounding, as well as the spot-chloride data, were also generally consistent with the GPR data. Appendix A shows the comparative, visual results from each of the four bridge decks using GPR data from GSSI.

One significant difference between the radar survey work performed at the I89 site in Lebanon and the I93 sites in Thornton-Woodstock was that, at the latter site, no destructive testing or sampling was used to "calibrate" the processed data. Although the half-cell potential/chloride content surveys were conducted first, the GPR surveys were conducted "blind" without the benefit of the prior data. A minimal level of sampling to establish deterioration threshold levels is expected to greatly improve the predictive abilities of the radar survey. The work on I93 was also performed without the use of lane closures. Finally, the work at these latter bridges included the use of multiple antennas, reducing the number of passes required to fully scan the deck.

Conclusions at the I93 site are limited by the small data set, including a low density of half-cell and chloride measurements, and the time lapse between test activities. In addition, further effort would be required to evaluate the radar's ability to differentiate between various deterioration mechanisms in the field.

CONCLUSIONS AND RECOMMENDATIONS

It has been demonstrated that GPR is effective for time-efficient, high-resolution deterioration investigations of concrete structures. The advanced GPR technique described in this report was used effectively and accurately to guide the decisions for removal of deteriorated concrete prior to repair. With more experience and further refinements in GPR technology and methodology, its judicious use can save a significant amount of time and money when decisions between various rehabilitation regimes must be made.

This research project demonstrated that rehabilitation-level decisions can be made effectively using high-resolution, ground-coupled GPR evaluations supported by limited destructive testing. Underside evidence and limited sampling allows for improved calibration of predicted deterioration thresholds in the deck and serves as an additional measure of comfort when the deterioration level predicted by GPR is higher or lower than expected. Users are encouraged to consider this information to supplement any decisions that might be made based on the GPR results alone.

The I89 project represented the first time NHDOT had used GPR as a rehabilitation-level tool. As such, the decision database associated with the emerging technology was small. The appropriate contour level to use for concrete replacement was difficult to assess at the time by either GSSI or NHDOT. The "correct" threshold for a project will be based on a number of factors, including the cost of various rehabilitation and maintenance regimes and the required life expectancy of the structure. On the I89 site, one might argue that a more aggressive repair level should have been used. However, the originally recommended threshold would have yielded a design repair quantity exceeding the threshold for a cut-and-patch approach to repairing the deck, which was beyond the scope and intent of the rehabilitation project. The amount of Phase II work suggests that the best-fit interpretation for that project probably resided somewhere between the interpreted GPR prediction and the design limits chosen for the rehabilitation contract. This project therefore provided valuable information related to the interpretation of GPR contour data for future delineation of repair areas.

The strengths and limitations of GPR for NDT will be further defined as more investigations are performed using GPR alongside alternative test methods and more ground-truth comparisons are performed. More work, including other non-destructive and destructive testing, should be performed to investigate the absolute ability of this technique to accurately define deterioration threshold boundaries on other deck evaluation projects, given that visual and/or traditional techniques do not yield more than subjective estimates of concrete condition. Improvements in commercially available equipment, software, and interpretative techniques have already occurred since the time of this project as radar technology rapidly evolves.

IMPLEMENTATION PLAN

It is recommended that NHDOT staff from the Bureaus of Bridge Design, Bridge Maintenance, Construction, and Materials & Research, along with the FHWA, meet to discuss the potential initiation of a Statewide contract for GPR-based bridge deck condition surveys. This non-destructive condition assessment tool would supplement, and perhaps eventually replace, existing contracts for conventional bridge deck evaluations.

Any implementation efforts undertaken by the Department should proceed with an eye toward current and future regulations imposed by the FCC regarding the use of GPR.

REFERENCES

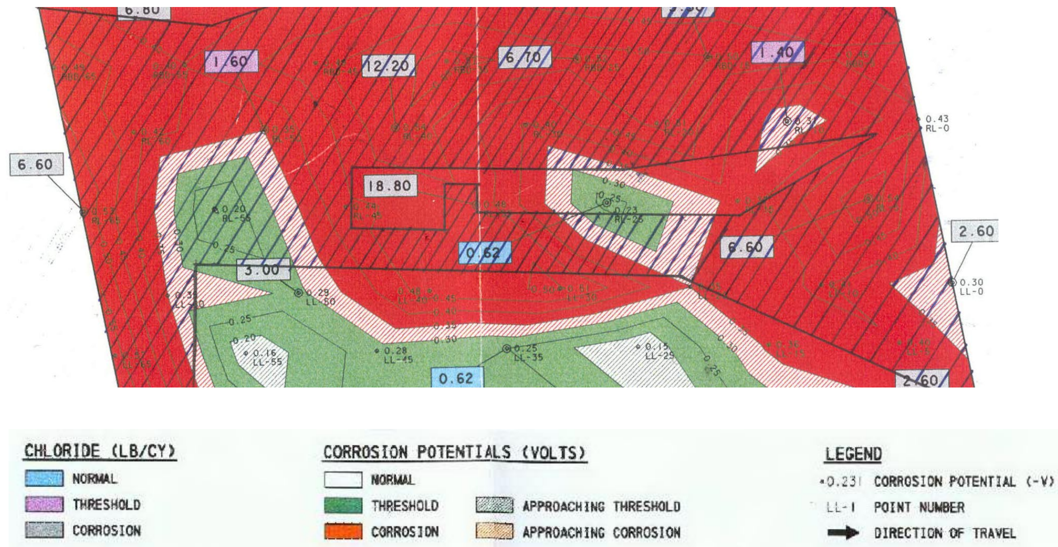
(See Acknowledgements on page i for additional references)

1. Roberts, Glenn E., Amrol, James J. 1999. "Concrete Cover Determination Using Ground Penetrating Radar (GPR)", *United States Department of Transportation (Federal Highway Administration—FHWA) Priority Technology Program, Project No. NH1997-01*, State of New Hampshire Department of Transportation, Bureau of Materials & Research Final Report; August, 1999.
2. Perkins, Alan D., Amrol, James J., Romero, Francisco A., Roberts, Roger L. 2000. "DOT Specification Development Based on Evaluation of Ground-Penetrating Radar System Performance in Measuring Concrete Cover (Reinforcement Depth) on New Bridge Deck Construction", presented at the *Structural Materials Technology—NDT Conference 2000,* February 28 – March 3, 2000 and published in *Structural Materials Tech. IV*, Technomic Publishing Co., Lancaster, PA, p. 53-60.
3. Roberts, Roger L., Romero, Francisco A. 1998. "High Resolution GPR Bridge Deck Evaluation Surveys", *Highway Applications of Engineering Geophysics with an Emphasis on Previously Mined Ground,* Missouri Department of Transportation—publishers, Jefferson City, Missouri, 1998.
4. Romero, Francisco A., Roberts, Roger L. "Interstate 89 Bridge Deck Evaluation Project, I-89 Bridge Over Connecticut River, Lebanon, NH / White River Junction, VT", GSSI Internal Document #9834, GSSI Report: 0522—I-89 Bridge Over Connecticut River (NHDOT), 1998.

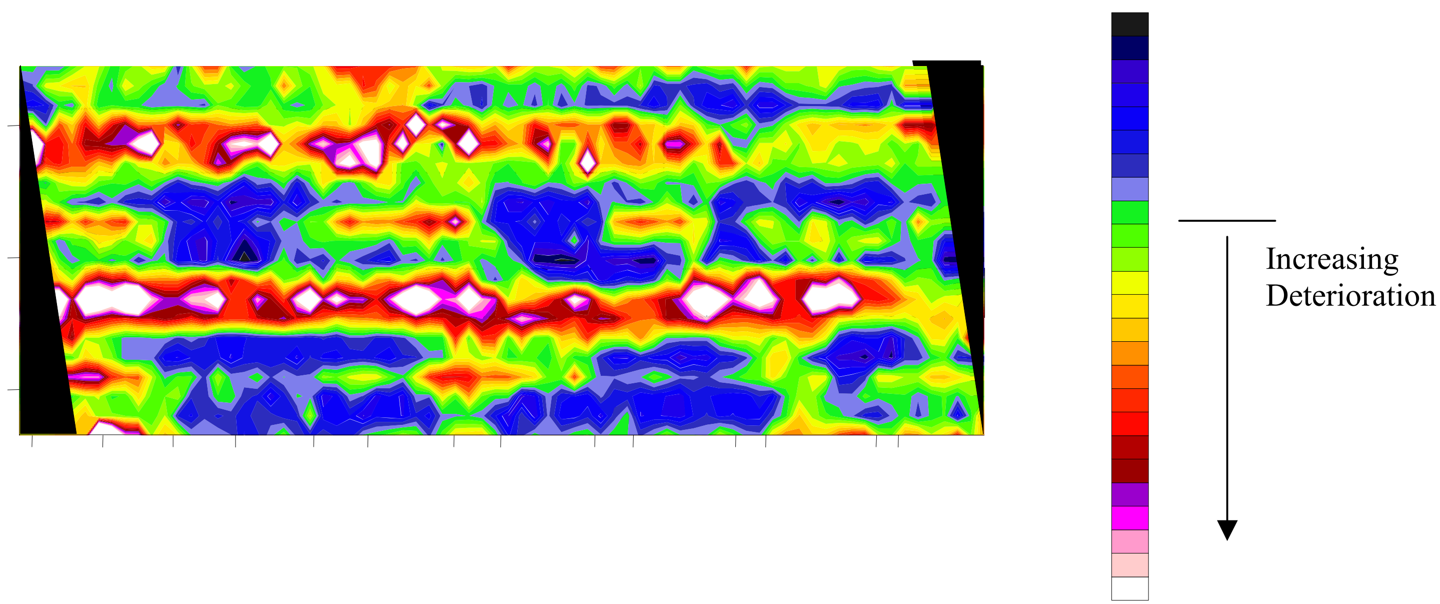
Half-Cell Potential (Red Shading = Active)

Chloride Content (Gray Box = Active)

Hammer Sounding (Black Crosshatch = unsound)



GPR

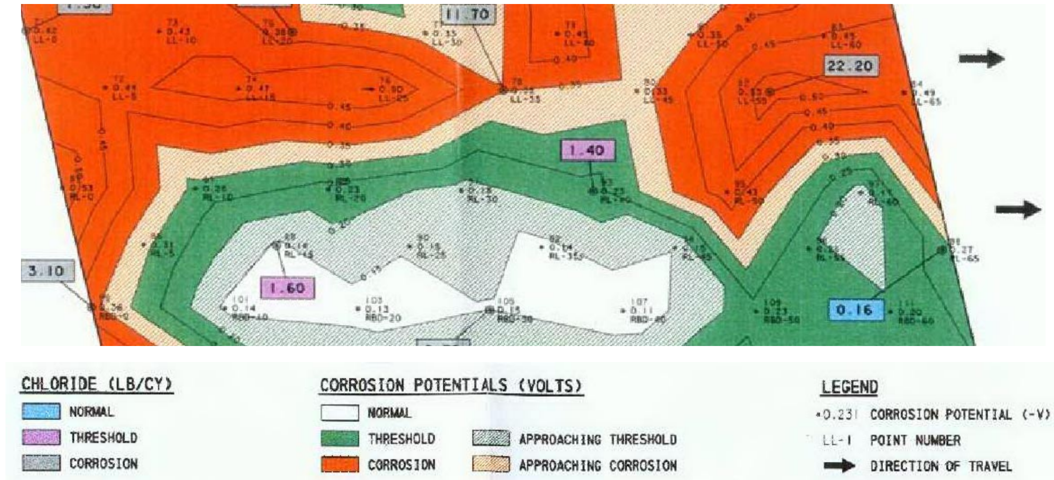


I93 SB over Merrill Road

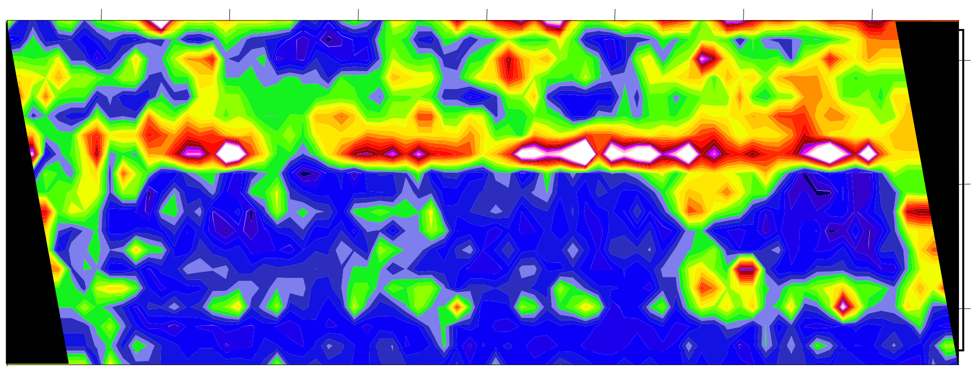
Appendix A
Page A-1

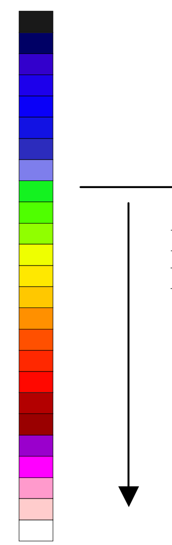
Half-Cell Potential
(Red Shading = Active)

Chloride Content (Gray
Box = Active)



GPR

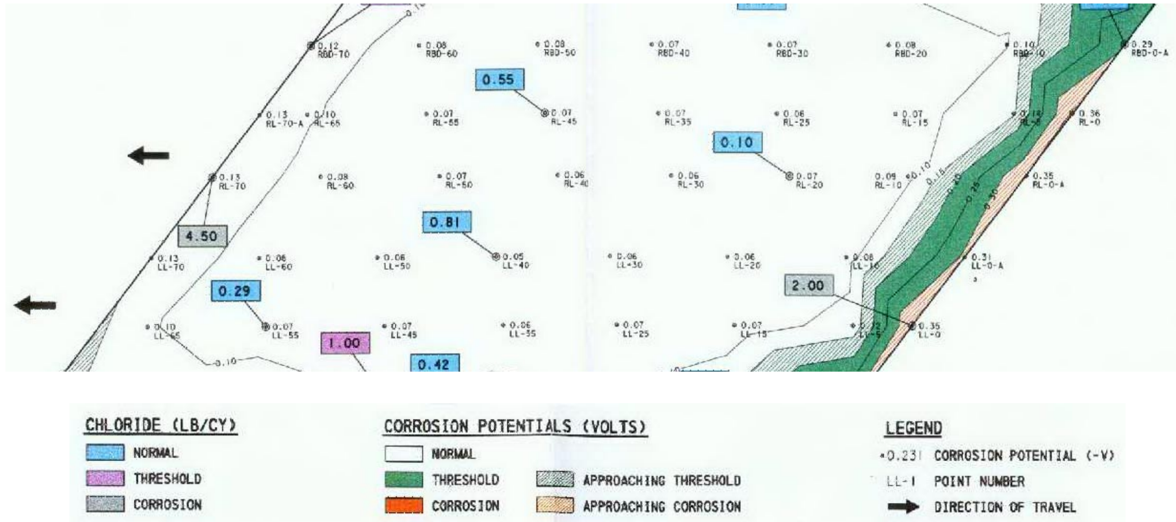




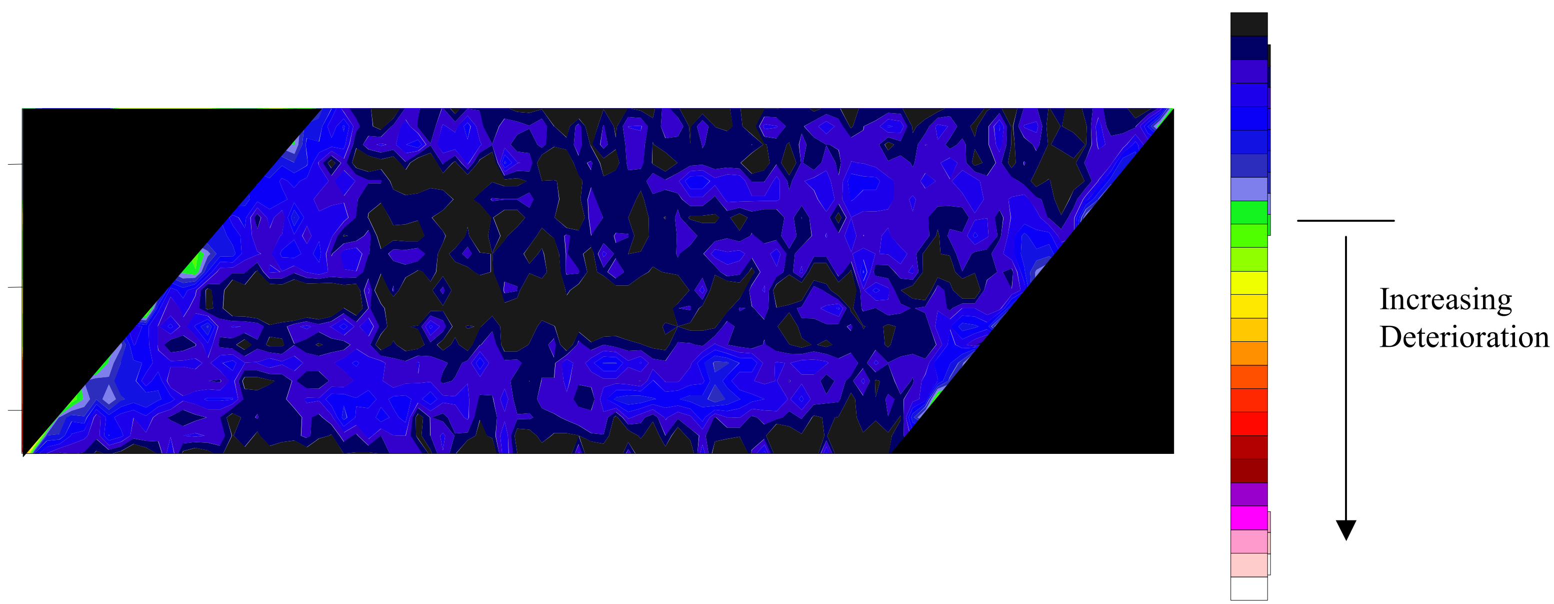
I93 NB over Merrill Road

Half-Cell Potential
(Red Shading = Active)

Chloride Content (Gray
Box = Active)



GPR

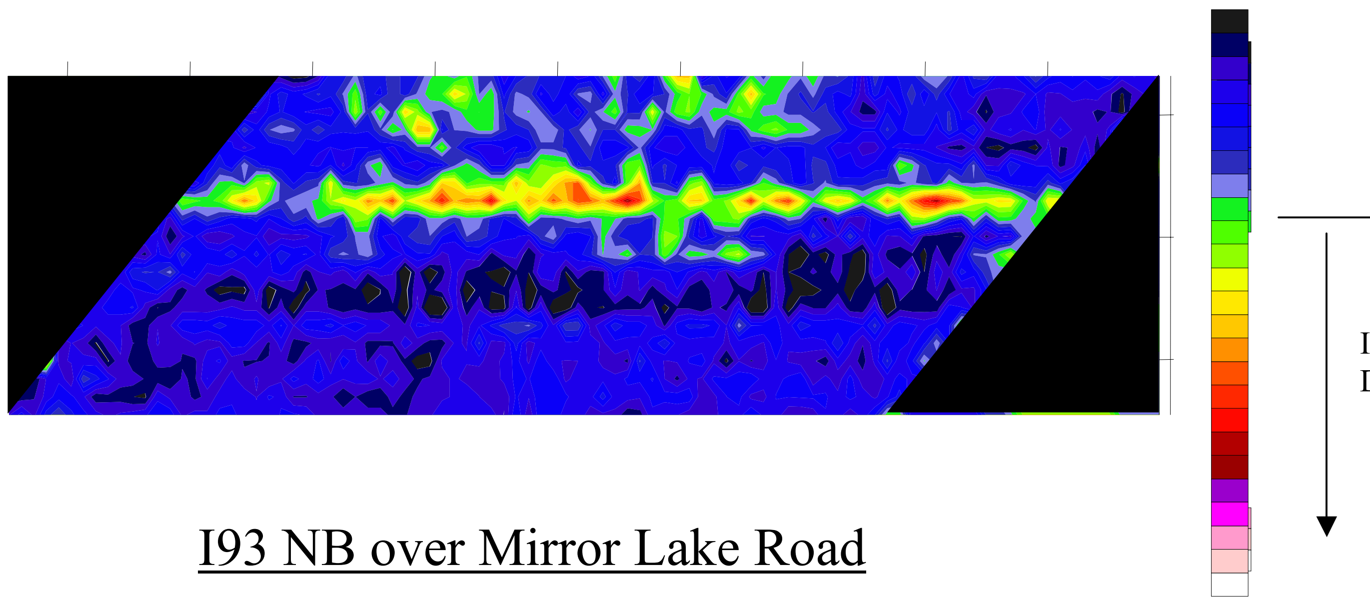


I93 SB over Mirror Lake Road

Half-Cell Potential (Red Shading = Active)

Chloride Content (Gray Box = Active)

GPR



I93 NB over Mirror Lake Road