Feasibility of Using Ground Penetrating Radar (GPR) for Pavements, Utilities, and Bridges

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The work was performed in cooperation with the United States Department of Transportation, Federal Highway Administration.
The objective of the project was to evaluate the feasibility and benefit of using Ground Penetrating Radar (GPR) for the evaluation of pavements, bridges, and utilities. The evaluation was carried out through a literature review, a survey of SDDOT personnel, a survey of the use of GPR by other state agencies, a series of demonstration projects, a cost/benefit analysis, and a utilization plan. The literature review and surveys indicated that the most common and effective transportation applications of GPR are for pavement thickness and bridge deck condition evaluations. The demonstration projects focused on these two applications, and on geotechnical applications for fault detection and evaluation of subgrade moisture content. The bridge deck evaluation showed that the GPR technology worked well for determining corrosion-induced delamination in overlaid decks with slab-on-girder construction, but was less effective on one-way slab bridges. The pavement evaluations, conducted on two AC and one PCC section, demonstrated the ability to accurately measure and plot pavement layer thickness. The subgrade moisture evaluation showed good correlation between GPR and boring data, and demonstrated the ability of GPR to map out variations of subgrade moisture content. The fault evaluation did not produce positive results, due to the attenuation caused by the high clay content in South Dakota soil. A cost-benefit analysis has been conducted for different scenarios shows benefit/cost ratios range from 1.98 for the bare deck delamination evaluation (GPR vs. sounding) to 113 for thickness quality assurance of new pavement. The analysis also shows the tradeoffs between using outside consultants vs. doing the work in-house. A utilization and equipment plan recommends that SDDOT initially use consultants for the lower volumes of startup work, and then move into owning and operating equipment and analyzing data when then volume increase warrants the additional investment.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE OF CONTENTS</td>
<td>i</td>
</tr>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>1</td>
</tr>
<tr>
<td>OBJECTIVES</td>
<td>1</td>
</tr>
<tr>
<td>GPR TECHNOLOGY ASSESSMENT</td>
<td>1</td>
</tr>
<tr>
<td>COST/BENEFIT EVALUATION</td>
<td>2</td>
</tr>
<tr>
<td>UTILIZATION AND EQUIPMENT PLAN</td>
<td>3</td>
</tr>
<tr>
<td>FINDINGS AND CONCLUSIONS</td>
<td>4</td>
</tr>
<tr>
<td>IMPLEMENTATION RECOMMENDATIONS</td>
<td>5</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

OBJECTIVES

The objectives of this project were to (1) provide the SDDOT a comprehensive assessment of GPR technologies for transportation infrastructure; (2) develop a cost-benefit appraisal of the applicability and merit of acquiring GPR capabilities for routine applications; and (3) develop an implementation plan including costs and recommendations for equipment, application, training, and personnel requirements.

GPR TECHNOLOGY ASSESSMENT

LITERATURE REVIEW AND SURVEYS OF STATE PERSONNEL

The project was carried out by initially conducting a literature review, and supplementing this review with a survey of GPR practices of other state highway agencies. The primary applications reported in the literature and by other states are measurement of pavement thickness, bridge deck delamination, and depth of reinforcing steel. The reported advantages of GPR are the ability to scan large areas quickly, the ability to minimize coring and traffic control, the detection of conditions not detectable by other means, and the discovery of unknown subsurface conditions prior to construction. The reported disadvantages include the set up time required, need for experienced operators for optimal results, and the complexity of equipment and data analysis. Five of the twelve state agencies responding to the survey perform GPR studies using state forces. The remaining agencies contract the work to consultants and state universities.

In order to customize the results of the project to the SDDOT needs, members of the SDDOT staff were interviewed to assess their needs, interests, concerns, and preferences. The primary interests were to provide layer thickness for backcalculation, determine layer thickness and representative sections with fewer cores at network level, categorize pavement type (thick vs. thin), determine pavement thickness for design of process-in-place (PIP) rehabilitation, determine (salvage) quantities for plans, detect bridge deck deterioration at reasonable speed, reduce exposure of coring crews, detect subgrade moisture and sinkholes, and identify pavement stripping, air voids, and reinforcement location. The preference for SDDOT implementation of the technology is to train SDDOT staff to perform the data collection and analysis, provided it is feasible to obtain sufficient use of the technology to justify the investment in personnel and equipment.

DEMONSTRATION PROJECTS

Three demonstration projects were designed based on the interview feedback. The projects were classified as bridge deck evaluations, pavement evaluations, and geotechnical evaluations. The bridge deck evaluations consisted of one bare concrete deck, one concrete overlaid deck, and one asphalt overlaid deck. The bare deck and the concrete-overlaid decks were one-way slabs, and the asphalt-overlaid deck was a slab on steel girders. The bridge deck evaluation produced results showing concrete deterioration due to corrosion and ASR, rebar depth, concrete overlay delamination, and concrete and asphalt overlay thickness. ASR and concrete overlay delamination results were compared to results obtained by SDDOT staff using chain drag.
The bridge deck evaluation showed that the GPR technology worked well for determining corrosion-induced delamination in overlaid decks with slab-on-girder construction. The evaluation capability is diminished with one-way slab bridges due to the lack of a uniform mat of transverse steel for reference. The evaluation for ASR damage showed agreement with chain drag results in overall quantity estimates, but discrepancies in the location of the damaged areas. The GPR evaluation of PCC overlay delamination did not appear to agree with chain drag results. The GPR data was used to map the overlay thicknesses for the two overlaid decks and the rebar cover for all three decks, and the results appeared to agree with expected conditions.

The pavement evaluation consisted of two asphalt pavements over granular base, and one concrete pavement over a bituminous base. The object of the evaluation was to determine the thickness of pavement layers. Cores were taken from each section for correlation with the GPR data, and FWD data was collected as well. The pavement evaluations demonstrated the ability to accurately measure and plot pavement layer thickness. The evaluation showed that the average difference between GPR and core results to be between 0.75, 0.40, and 0.45 inches for the two AC and one PCC section, respectively. The mean deviation between the GPR and core results for the AC base on the PCC section was 1.69 inches. In general, where there were large deviations between GPR and core values, the GPR gave the larger values, and the difference appeared to be due to portions of the core that remained in the hole.

The geotechnical evaluation consisted of a subgrade moisture study on two adjacent pavement sections, and a subsurface fault evaluation. The subgrade moisture evaluation demonstrated the ability of GPR to map out variations of subgrade moisture content. The GPR data correlated well with boring data, and the correlation was used to calibrate the GPR data for moisture content. The fault evaluation did not produce positive results. It appears that the high clay content in South Dakota soil attenuates the GPR signal to the point that no useful data can be returned below 3 to 4 feet.

**COST/BENEFIT EVALUATION**

A cost-benefit evaluation of the application of GPR has been conducted. The analysis first looked into the costs of implementing a GPR survey program using both SDDOT equipment and labor and the alternative of using an outside consultant. These cost figures were then used to determine benefit/cost ratios for three scenarios: (1) pavement thickness evaluation for rehabilitation design; (2) bridge deck delamination evaluation for bare and overlaid decks; and (3) pavement thickness evaluation for quality assurance in newly constructed pavements. The results are shown below.

<table>
<thead>
<tr>
<th>GPR Application Scenario</th>
<th>Benefit/Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness Evaluation for Pavement Rehab</td>
<td>34.4</td>
</tr>
<tr>
<td>Condition Evaluation for M&amp;R of Bridge Decks</td>
<td></td>
</tr>
<tr>
<td>Bare Concrete Decks</td>
<td>1.98</td>
</tr>
<tr>
<td>Overlaid Decks</td>
<td>8.9</td>
</tr>
<tr>
<td>Thickness Evaluation for QA of New Pavement</td>
<td>57-113</td>
</tr>
</tbody>
</table>
UTILIZATION AND EQUIPMENT PLAN

A utilization and equipment plan has been prepared with recommendations regarding the method of implementation of the GPR technology. The cost analysis carried out under the Cost-Benefit evaluation has been applied to quantify the tradeoff between the using state forces vs. outside consultants. The results are shown in the figures below.

Figure 1 – GPR Survey Costs vs. Annual Quantity of Work
(for different SDDOT overhead rates)
The figures show the quantity of work above which it is economical to employ state forces and equipment if the volume of contracted work exceeds $70,000-100,000/year. The dollar range depends on the agencies internal cost structure, and on the type of surveys conducted. Use of a consultant at lower quantities of work is recommended because of economy, and as a startup strategy prior to making the commitment to equipment, personnel, and training. Once the level of work is anticipated to exceed the break point, it is recommended that SDDOT purchase a GPR system and implement a training program.

FINDINGS AND CONCLUSIONS

Based on the work described above, the following summarizes the findings and conclusions of this study:

1. The most common application interest for GPR, both within SDDOT and for other transportation agencies, is towards evaluation of pavement thickness and assessment of bridge deck deterioration. GPR has also been used for various geotechnical applications.

2. The GPR equipment most suited to both the pavement and bridge deck application is a vehicle-mounted horn antenna coupled with a vehicle-based data acquisition and storage system.

3. GPR produces accurate pavement layer thickness data. Discrepancies between GPR and core data on older pavement can sometimes be related to incomplete core recovery.

4. GPR can measure overlay thickness, rebar depth, and corrosion-induced concrete deterioration on bridge decks. GPR is most effective for slab-on-girder decks. The evaluation capability is diminished with one-way slab bridges due to the increased thickness and the lack of a uniform mat of transverse steel for reference. The ability for GPR to detect ASR damage is not clear. Overall damage quantities were similar when GPR was compared to chain drag findings, but the locations did not coincide. GPR did not appear to be effective in detecting debonding of PCC overlays.

5. GPR can be used to evaluate variations in subgrade moisture. Calibration to direct moisture content measurement is necessary.

6. Geotechnical applications in natural soil environments are limited in South Dakota. The high clay content in South Dakota soil attenuates the GPR signal to the point that in many locations no useful data can be returned below 3 to 4 feet.

7. Implementation of GPR by state forces requires a significant investment in equipment and personnel. Although SDDOT personnel would prefer an in-house system and capability, a utilization analysis shows that it becomes economical to use state forces and equipment once volume of contracted work exceeds $70,000-$100,000/year. This threshold depends on the type of surveys (bridge deck or pavement) and the SDDOT overhead rate assumed in the analysis. This dollar value range is equivalent to 60-70 bridge decks, 400-500 lane miles of pavement, or some combination of bridge decks and pavements.

8. The benefit/cost ratio of using GPR for pavement and bridge deck evaluations can range from 2 to 117, depending on the scenario being considered. The higher benefit ratios are achieved when GPR provides information leading to better decisions and more timely responses.
IMPLEMENTATION RECOMMENDATIONS

Based on the Utilization and Equipment Plan presented in Section 9, the following are the implementation recommendations.

1. Use of SDDOT forces vs. Consultants

It is recommended that SDDOT use of a consultant initially to develop experience with the work product, the equipment, and the methodology. Once consultant survey costs exceed $70,000 – 100,000 per year, it is recommended that SDDOT acquire and operate their own equipment, and carry out their own data analysis.

2. Equipment and Software

It is recommended that SDDOT utilize a horn antenna GPR system. One such system that is currently available in the US is the GSSI Model 4105 horn antenna used with the SIR-20 acquisition and control system. Data analysis software such as "BridgeScan" and RoadScan" should also be acquired with this equipment.

3. Personnel Requirements

Should SDDOT purchase GPR equipment and software, it is recommended that at least one FTE be assigned to the operation of the equipment and the data analysis. The total number of FTE's assigned to the GPR system operation will ultimately depend on the utilization of the system.

4. Training

It is recommended that SDDOT initially utilize the full amount of training offered by the manufacturer, and that they supplement this training with ongoing analysis training and procedure reviews. The manufacturer's training generally encompasses the use of the equipment and an introduction to the software. It is recommended that at least two members of the SDDOT staff be directly involved in this training, so that there is there is backup if someone is not available. Once SDDOT personnel becomes familiar with the GPR system, it is recommended that a consultant be brought in for data analysis training and periodic reviews of methods and procedures. It is important to recognize that it takes some time to be fully functional with highway GPR, and that training is a critical part of this functionality.

5. Combining FWD and GPR

Since SDDOT currently owns and operates an FWD, it is recommended that the GPR data used for FWD backcalculation be collected independently of the FWD vehicle. This approach provides more flexibility and does not require an integrated vehicle. Care must be exercised to ensure that GPR thicknesses used for FWD analysis are at the correct locations.