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Ground Penetrating Radar (GPR) for Pavement Evaluation

by

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16. Abstract
In the near future the Arkansas State Highway and Transportation Department Pavement Management System (PMS) will utilize a Falling Weight Deflectometer (FWD) to collect network level pavement structural data to aid in predicting performance of pavement sections. One of the drawbacks to running the FWD is that pavement thickness is required for the tested pavement section. The standard method for obtaining pavement thickness information is coring. Coring for a network level survey would be cost prohibitive. Coring costs can run between $3,000 and $3,600 per day with a typical collection distance of 20 miles per day. The Department manages over 16,000 centerline miles of highways. Previous research has shown Ground Penetrating Radar (GPR) is a proven and reliable technology that can be used as a feasible alternative to provide pavement thickness data. GPR data collection can be costly as well; contract services for pavement thickness can cost between $50 and $100 per mile from a reputable service provider. GPR equipment has become less cumbersome, more user-friendly and more affordable in the last few years. There are GPR technologies that employ multiple antennas to provide pavement layer thickness for network level surveys. These newer technologies could provide the pavement layer thicknesses required for network level FWD data collection in a timely and cost-effective manner.

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OVERVIEW OF AIR-LAUNCHED GROUND PENETRATING RADAR METHOD	Ground penetrating radar (GPR) data are normally acquired using either a ground-coupled antenna or air-launched antennae. Usually, ground-coupled data are acquired using an antenna in monostatic-mode (transmitter/receiver housed in single case), whereas air-launched data are normally acquired using antennae in bistatic-mode (transmitter/receiver housed in separate cases). Herein, emphasis is on the use of air-launched bistatic-mode antennae for pavement investigation purposes. Generally, pavement GPR data are acquired at highway speeds and along linear traverses using air-launched antennae in bistatic mode. As the antennae are moved along the traverse of interest, short bursts (GPR pulse; little more than one wavelength in duration) of band-limited electromagnetic radiation (with central frequencies of 1 to 2 GHz) are emitted at predetermined distance intervals (typically several inches) The GPR pulse propagates away from the shielded transmitter coil in the antenna and into the pavement (or other target). When the GPR pulse intersects an interface separating materials with different electrical properties (dielectric permittivity), some of the energy is reflected back towards the receiver coil in the antenna. Typical reflectors are the top of asphalt, the top of concrete, the base of concrete, and the top of native soil. The arrival times and the magnitudes of all reflected GPR energy (within a preset time window) is recorded as a single trace every time a pulse is discharged. The time window is set such that reflections can be recorded from the base of the lowermost target (usually top of native soil). The normal output is a 2-D GPR profile (horizontal axis: distance; vertical axis: time) consisting of all acquired traces plotted at the appropriate relative location. Typically, the most prominent reflections can be identified and correlated across the entire 2-D plot (GPR profile). If transmission velocities are known or can be estimated, recorded arrival times can be converted to depths and layer thicknesses.
ACQUISITION	
Brief overview of field procedure	Pavement GPR data are normally acquired at highway speeds using a pair (or two pairs) of air-launched antennae in bistatic mode. The antennae are normally coupled to the front or rear of a vehicle with GPS capabilities. As the vehicle is driven along the segment of roadway to be surveyed, GPR data is collected at predetermined distance intervals. If the roadway is relatively long, the GPR data are often collected in manageable sections. The normal output is a 2-D GPR profile (horizontal axis: distance; vertical axis: time) consisting of all acquired traces plotted at the appropriate location. Typically, reflections from the tops of different pavement layers and the native soil can be identified and correlated along the entire GPR profile. If transmission velocities are known or can be estimated, recorded arrival times can be converted to distances and variations in unit depths and thicknesses can be estimated along the length of the 2-D GPR profile.
Field equipment	The equipment normally consists of one or two pairs of vehicle-mounted air-launched relatively high-frequency (1 or 2 GHZ) bistatic antennae and a recording unit. The vehicle is normally equipped with GPS capabilities a survey wheel (so that data can be acquired at regular intervals).
Field crew	Normally consists of 2 persons.
Considerations	
• **size of test site**	Any segment of roadway is suitable.
• **Sampling interval**	GPR data is typically acquired at distance intervals of several inches if the intent is to variations in pavement thicknesses only. Smaller sampling (distance) intervals are used if the user intends to image imbedded rebar. Smaller sampling intervals

	translate into lower acquisition speeds.
• **Vehicular access**	All equipment is loaded into the vehicle or coupled to the vehicle.
• **topography**	Data can be acquired across undulating or steeply dipping roadways.
• **vegetation**	Roadways are not usually forested.
• **background noise**	Background electrical noise can degrade signal quality.
• **anchoring requirements**	The equipment does not need to be physically anchored or coupled to the ground surface.
• **nature of ground surface**	Non-clay pavements are readily imaged. Clay-based pavements and clayey soil will attenuate GPR signal very rapidly, and is normally very difficult to image.
• **subsurface lithology or material**	The pavement and subsurface can usually be imaged to a depth of several feet unless clays are present. Conductive clays attenuate GPR signal very rapidly.
• **depth of investigation**	The maximum depth of investigation is a function mostly of the central frequency of the GPR antennae and the conductivity of the pavement/soil. A 1000 MHz antenna can normally image pavement/soil to a depth of several feet if the pavement/soil is relatively dry and non-conductive. The operator normally selects a trace length (record length) that is greater than twice the time-depth to the deepest target of interest.
• **proximity to buried structures and buried utilities**	GPR antennae are shielded and the signal is emitted in a conical pattern. Reflections from buried structures and buried utilities will be recorded if these features are within the conical zone and beneath the top of the pavement, in the pavement or beneath the pavement (but still shallow enough to image). Electrical utilities can constitute a source of noise.
• **proximity to built structures and utilities**	Reflections from built structures and above-ground utilities will be recorded only if these features are within the conical zone of signal emitted by the GPR antenna. Electrical utilities can constitute a source of noise.
• **permitting requirements**	Generally, only permission from the surface rights holder is required.
• **notification requirements**	Generally, only permission from the surface rights holder is required.
• **other**	Accurate GPS control is essential so that sampling locations can be identified with a high degree of reliability.
Brief description of field data	The field data are recorded digitally (as traces) and stored (sequentially) on the GPR control unit. One trace is generated at each sampling location.

Estimated cost to acquire field data at one test site	Basic field costs include: a) crew time plus travel time; b) equipment rental and/or depreciation; c) vehicle rental and/or depreciation plus fuel. It typically takes a 2-person crew about one hour to acquire a data along a 50 mile segment of roadway.
Potential for errors	Unless equipment malfunctions or unless the operator is careless, there is little likelihood that field errors will lead to misinterpretation.
• **human**	Human error, leading to misinterpretation, is unlikely because the only critical non-automated processes are coupling of the antenna, survey wheel, GPS unit and control unit, and the entering of field acquisition parameters.
• **equipment**	Equipment problems are unlikely to generate errors that will lead to misinterpretation.
Reproducibility of field tests	If good quality data can be recorded, field results can be reproduced with a high degree of consistency.

DATA AND/OR LABORATORY PROCESSING	
Brief overview of data processing	The acquired GPR traces (time-depth) acquired at each sampling location are used to generate a 2-D time-depth image along the length of the traverse. Normally, time "zero" (time = 0 nanoseconds) on a 2-D GPR profile is adjusted so that it conforms to the arrival of the reflection from the surface of the pavement (so that time-depths and estimated depths are relative to the uppermost pavement surface). GPR data can be filtered (including deconvolution and migration, if necessary) to improve resolution and enhance the interpretability of the acquired data. If the roadway is relatively long, the data are often processed in sections.
Output of data processing	The output from a survey of a segment of roadway (assuming one pair of antennae was used) is a single 2-D GPR profile (distance versus time-depth) that extends the length of the tested segment of roadway. Typically, reflections from the tops of different pavement layers and the native soil can be identified and correlated along the entire GPR profile. If transmission velocities are known or can be estimated, recorded arrival times can be converted to depths and thicknesses can be estimated along the length of the 2-D GPR profile.
Estimated cost to process field data from one test site	Basic processing costs include: a) several hours of processor's time; b) hardware/ software rental and/or depreciation.
Potential for error	
• **human**	In many instances, reflections from the layers of interest are easily identified (reflections from the tops of different pavement layers and the native soil can be identified and correlated along the entire GPR profile). In such interests only minimal processing of the GPR data is required. If the reflections of interest are not easily identified, expert processing is required.
• **equipment**	The GPR processing software should not be defective.
Reproducibility of field tests	If the field data are good quality, trained processors will generate consistent 2-D GPR profiles.
INTERPRETATION	
Brief overview of interpretation of processed data	The output of data processing is a 2-D GPR profile that extends the length of the segment of roadway. During data interpretation, reflections from the tops of different pavement layers and the native soil are identified and correlated along the entire GPR profile using interactive semi-automated software. The time-depths and time-thicknesses of the different layers can then be calculated automatically using interpretation software. If transmission velocities are known or can be estimated, interpreted arrival times (time-depths) can be converted to depths and calculated time-thicknesses can be converted to thicknesses. The determination of reliable transmission velocities is usually the most difficult part of the interpretation process. Even slight variations in pavement type, condition and/or moisture content can cause significant changes in transmission velocities. Generally, ground truth (typically core control) is used to constrain and verify interpretations.

Deliverable(s)	Pavement layer depth and thickness models. In some instances, pavement quality can be estimated based on lateral variations in the amplitude of identified reflections. GPR signal is attenuated more rapidly in moist poor quality pavement than in dry

	good quality pavement.
Depth range (top/bottom)	The maximum depth of investigation is a function mostly of the central frequency of the GPR antennae and the conductivity of the pavement/soil. A 1000 MHz antenna can normally image pavement/soil to a depth of several feet if the pavement/soil is relatively dry and non-conductive. The operator normally selects a trace length (record length) that is greater than twice the time-depth to the deepest target of interest.
Lateral resolution	Lateral resolution (for pavement investigations) is usually mostly a function of the lateral sampling interval. Lateral sampling intervals are usually on the order of several inches. However, if smaller sampling intervals are used (multiple traces per inch), greater lateral resolution can be achieved.
Vertical resolution	Theoretically, vertical resolution (for pavement investigations) is usually assumed to be one-quarter of a wavelength. However, the presence of microfractures (with widths much less than one-quarter wavelength) is often inferred based on the apparent attenuation of the GPR signal.
Time required to interpret processed data	If good quality data are acquired, if ground truth is available and if velocity/lithologic relationships can be established, the interpretation of the GPR pavement data is normally relatively rapid and straightforward.
Potential for error	
• **human**	If sufficient ground truth is not available and/or if pavement quality (and hence pavement velocity) varies, depth and thickness estimates may be less accurate than desired.
• **equipment**	There is little potential for error.
Reproducibility of deliverable	If ground truth is available and if good quality data are acquired, different experienced interpreters should come up with similar interpretations. If ground truth is not available, interpretations may be less accurate than desired.
DELIVERABLES	
Brief overview of deliverable(s)	2-D layered pavement model and qualitative information regarding lateral changes in pavement quality.
Utility of deliverable(s)	Reliable pavement layer thickness data is often required if remediation is planned and is essential where falling weight deflectometer (FWD) control is acquired. Indeed, some operators couple a GPR unit to their FWD vehicle to ensure reliable location-specific pavement thickness information is available. Estimates of variation in pavement quality is often required for planning (remediation) purposes.
Accuracy	The final interpretations are generally reliable if good quality field data are recorded and if ground truth is available. Use of an experienced interpreter is essential.
ADVANTAGES	Advantages include portability of equipment, rapid data acquisition and rapid semi-automated data processing and interpretation, non-invasive, limited potential for human error, reproducibility of field data, processing and interpretation results.
DISADVANTAGES	The determination of reliable transmission velocities is usually the most difficult part of the interpretation process. Even slight variations in pavement type, condition and/or moisture content can cause significant changes in transmission velocities. Generally, ground truth (typically core control) is necessary to constrain and verify

	interpretations.

Tabularized Overview of the Ground Penetrating Radar Method with Emphasis on Pavement Investigations.