APPLICATION OF GROUND PENETRATING RADAR TO PAVEMENT EVALUATION

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ABSTRACT

A computer program, called TERRA (**T**hickness **E**valuation of **R**oads by **Ra**dar) was recently developed for estimating pavement layer thicknesses from Ground Penetrating Radar (GPR) data. This program incorporates decision criteria for automated detection of layer interfaces, computation of layer thicknesses and a segmentation algorithm for delineating segments based on layer thicknesses.

The Florida Department of Transportation (FDOT) initiated the present field study for an initial assessment of TERRA. Radar and core data were collected from several flexible pavement sections of Florida's roadway system. These sites were selected to represent the present Florida in-place mixes (Superpave and Marshall mixtures) and different asphalt layer thicknesses (these thicknesses varied from approximately 50 to 300 mm (2 to 12 inches)). Radar data were collected at both highway speeds and in the stationary mode. This paper presents a description of the data collection effort as well as the subsequent analysis and findings.

INTRODUCTION

Reliable measurements of the in situ condition of pavement systems are a quintessential aspect of effective pavement evaluation and management programs. Among a number of available state-of-the-art nondestructive testing techniques, in recent years considerable attention has been focused on the use of Ground Penetrating Radar (GPR). It is a particularly well-suited technology for surveying the subsurface condition and assessing the adequacy of pavement sections while operating at highway speed. Of particular interest to highway agencies is the GPR potential for generating continuous pavement layer thicknesses useful in developing more appropriate rehabilitation and reconstruction strategies.

Traditionally, pavement layer measurements have been obtained through coring or from historical records. Core sampling is destructive and time consuming while the records are, at times, inaccurate, out of date, or difficult to access. In addition, both means only provide data at the location of the test, therefore ignoring any variations that may exist along the pavement segment between the test locations. The need for faster and non-destructive methods of pavement thickness determination prompted the consideration of ground-penetrating radar (GPR) as a possible alternative. A GPR system, combining air-launch antenna equipment with appropriate data interpretation software, has the potential for estimating pavement thicknesses while operating at highway speed. In recent years, a considerable amount of research has been conducted for further understanding of the factors affecting GPR testing from both the analytical and experimental points of view. Still some problems have not fully been resolved, particularly in the interpretation of the measured data. To address this need for improved GPR data interpretation, a computer program, called TERRA (**T**hickness **E**valuation of **R**oads by **Ra**dar) was recently developed. This program incorporates decision criteria for automated detection of layer interfaces, computation of layer thicknesses and a segmentation algorithm for delineating pavement segments based on layer thicknesses.

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PRINCIPLES OF GROUND-PENETRATING RADAR

GPR operates by transmitting short pulses of electromagnetic energy into the pavement using an antenna attached to a survey vehicle. These pulses are reflected back to the antenna. The reflected energy is captured to form, when displayed, a series of pulses that are referred to as the radar waveform. The waveform contains a record of the characteristics of the layers within the pavement. The travel time and amplitude of the waveform peaks are related to the location and nature of dielectric discontinuities in the material. A layer thickness is determined using the travel time of the transmit pulse within the layer and its dielectric constant. The dielectric constant may be calculated by measuring the amplitude of the waveform peaks corresponding to the reflections from the pavement layer interfaces.

EXPERIMENTAL PROGRAM AND DATA COLLECTION

FDOT GPR System Description

FDOT-owned GPR system consists of a specially configured van, a computer controlled radar data acquisition system, an audio/video data record/playback system and a personal computer for radar data analysis. The van is also equipped with an air suspension system to improve the rideability and minimize antenna “bounce”. The radar data acquisition system consists of a Pulse Radar, Inc., transceiver and antenna operating at a frequency of 1.0 GHz. The system is controlled with a software provided by the radar system manufacturer. When testing in the dynamic mode (at highway speed), a distance-measuring instrument triggers the data collection at pre-selected intervals. The data is stored on the PC’s internal hard drive or on an external ZIP drive.

A color camera is mounted at the rear of the van for recording the surface condition of the test site. A 300-mm (12-in.) CRT monitor is mounted in the electronics system console and a 75-mm (3-in.) LCD monitor is provided at the driver’s position. Microphones for voice annotation of the video record are provided both at the electronics console and at the driver’s position.

Data Collection

Radar data were collected, in both static and dynamic modes, using the van-mounted horn antenna illustrated in Figure 1. When testing in the dynamic mode, the data were acquired at longitudinal intervals of 1.5 m (5 ft) and approximate speed of 70 to 90 km/h (45 to 55 mph). Each site was tested with the antenna positioned in the left wheel path of the travel lane. All radar data were continuously digitized and stored in the van-housed computer. The data were subsequently analyzed at the FDOT State Materials Office using TERRA software.

To determine the actual asphalt layer thickness and pavement layer structure, cores, 100 mm (4 in.) in diameter, were obtained from each test site. The locations for coring were randomly selected in an effort to achieve an unbiased test sample distribution. The cores were processed at the State Materials Office to determine the asphalt layer thicknesses. Three height measurements were taken from each sample and averaged.

Test Sites

Five separate roadway sections were selected to represent the Marshall mix portion of the study. The first was a section of State Road 24 (SR 24) near the town of Fairbanks. SR 24 is a four-lane divided highway in a primarily rural area with limited heavy truck traffic. On this section, the radar data were collected in the static mode, with the transceiver operating in the continuous mode and all returns being stored on the computer’s hard disk for analysis. Within this site, four locations were selected for testing. At each location, a core sample was taken directly under the radar antenna immediately after radar reading. The second test site was a portion of US 441, near Micanopy. US 441 is also a four-lane divided highway in a primarily rural area, but with moderate heavy truck traffic. Radar and core data were taken as for the SR 24 test site on a total of five locations. The third test site was part of US 441 crossing Paynes Prairie, in Gainesville. On this area, radar data were collected in the dynamic mode at approximately 90 km/h (55 mph) with the data acquisition system set to save a data point every 1.5 m (5 ft) for analysis. The test section was approximately 1 km (two thirds of a mile) long. After the radar data collection, ten core samples were obtained along the test site in the same wheel path as that of the radar antenna. The last two sites were sections of State Road 5 and State Road 15 in Brevard and Volusia Counties, respectively. On both of these sites, Radar data was taken in the dynamic mode. Furthermore, because of the size of the sections, a larger number of cores was obtained.

In addition to the above sites, 3 Superpave sections were also considered. All are part of the Interstate Highway System, thus subjected to significant heavy truck traffic (1 section on I-10, Madison County and 2 sections on I-75, Hamilton County, North and South directions). On all these sites, Radar data was taken in the dynamic mode. A large number of cores was also obtained as part of another study under contract. Core measurements could not all be verified for the purpose of this investigation.

All the surveyed test sections were essentially surface-on-grade flexible pavement sections in good condition. At each location, both coring and radar testing were completed concurrently on the left wheel path of the travel lane, with the exception of the Superpave sections. For the latter, a Consultant performed the coring separately. It has also to be noted that the Marshall mixes were dense graded, while Superpave mixes were coarse graded with relatively larger in-place air voids.

DATA ANALYSIS

If GPR data are to be considered for thickness prediction purposes, it is essential to assess their level of correlation with core measurements. The radar data collected during this investigation were first analyzed to predict asphalt layer thicknesses using TERRA program. In this analysis, within each site, the asphalt layers were treated as a single monolithic layer. Both core and radar data are summarized in Table 1. Differences between measured and predicted thicknesses of approximately 1 to 20 mm (0.06 to 0.8 in.) were observed on Marshall sections while much larger differences were obtained on Superpave sections. These large differences may be attributed to the high level of in-place air voids (such voids have a tendency to be more water permeable) and the greater thickness of Superpave layers. In these cases, the proposed thickness prediction model and analysis may not have been accurately considering the increasing moisture and dielectric constant with depth. In addition, the core measurements from these sections, being part of a separate research study, were not all verified for the purposes of this investigation.

Figure 2 also illustrates the level of agreement between the measured and predicted asphalt layer thicknesses. This plot shows that all the measurements lower than about 180 mm (7 in.) fall near a straight line with relatively little dispersion about the equality line. Otherwise, the thickness data are, relatively, more scattered above the equality line. Such an observation, as well the regression curve, suggest that, within the same test site, the proposed GPR procedure would generally result in comparable measurements to core sampling when the asphalt layer is less that 180-mm (7 in.) thick. Above the 180-mm (7 in.) mark, the GPR method would over-predict the layer thickness. Incidentally, the more scattered data are those obtained on Superpave sections. Again, as stated earlier, not all Superpave core values were verified as most samples were already processed and destructively tested for different purposes.

Figure 3 shows all the measurements as obtained on Marshall sections only. The core measurements, in this case, ranged from 55 to 175 mm (2 to 7 in.). The plot indicates that there is a good correlation between the two methods as reflected by the R-square value of 0.95. In this case, the regression curve is closer to the equality line. As previously stated, this Figure also suggests that, within this test range, the proposed prediction method would generally generate comparable thicknesses as those of coring sampling for dense graded mixes. The predicted values were, on average less than 10 percent higher.

The data presented herein correspond to the initial field assessment of the TERRA program. The results of the analysis performed on Marshall data suggest that the proposed GPR system is a promising alternative to core sampling for pavement thickness determination. TERRA is currently being revised and enhanced for added accuracy and practicality.

CONCLUSIONS AND RECOMMENDATIONS

FDOT initiated the present investigation to assess the feasibility of using a GPR system as an alternative to core sampling for pavement thickness determination. Radar and core data were collected from several flexible pavement sections of Florida’s roadways. These sites were selected to represent the existing Florida in-place bituminous mixtures (coarse graded Superpave and dense graded Marshall mixtures) and different layer thicknesses. Radar data were collected at both highway speeds and in the stationary mode. In most cases, both coring and radar testing were completed concurrently on the left wheel path of the travel lane in most cases. The radar data collected were analyzed to predict asphalt layer thicknesses using a program called TERRA. In this analysis, the asphalt layers were treated as a single monolithic layer. Based on the findings of this investigation, the following conclusions can be drawn:

- Differences between measured and predicted thicknesses of approximately 1 to 20 mm were observed on Marshall sections while much larger differences were obtained on Superpave sections.
- A regression analysis indicated that, within the same test site, the proposed GPR procedure would generally result in comparable measurements to core sampling when the asphalt layer is less that 180-mm thick. Above the 180-mm mark, the GPR method would over-predict the layer thickness.
- A good correlation between the measured and predicted thickness values, as reflected by the R-square value of 0.95, was obtained when only data from Marshall sections were considered. The predicted values were, on average 10 percent higher. The core measurements, in this case, ranged from 55 to 175 mm.
- The results of the analysis performed on Marshall data suggest that the proposed GPR system is a promising alternative to core sampling for pavement thickness determination.

  Furthermore, in evaluating the accuracy of the predicted thicknesses, it is recommended to consider the following as possible sources of error:

1) Calibration of the GPR system with respect to noise to signal ratio, and long and short-term stability. FDOT system was calibrated prior to the present investigation and was found to be within specifications to be a source of error.
2) With the exception of static data analysis, errors in tying exact core locations with radar data will affect the accuracy of the comparisons. Specifically, location discrepancies may arise due to:
   a) Differences between the first marker in the radar data file and the beginning milepost of the test section.
   b) Accumulation of Distance Measuring Instrumentation (DMI) data errors. It is advisable to have several markers in the radar data that are tied to known physical milepost locations. In this way, a core could be located with reference to its closest marker. It the evaluation presented herein, all cores were tied to the location of the first marker in the data file.
   c) Differences between the DMI used to locate the core sites and the DMI used in the radar van.
3) Radar data were taken at five-foot intervals in the dynamic mode. Therefore, predictions of layer thickness were made at a much higher frequency compared to the number of core locations taken. It is logical to expect radar predictions may show more variations in layer thickness along a given section than can be observed from the limited number of cores taken.

Table 1 Summary of Radar and Core Data

Mix Type	Site	Testing Mode	Location	Layer Thickness, mm		Diff., mm
				Core	Radar	
Marshall	SR24	Static	1	55	66.5	11.5
			2	57	61.2	4.2
			3	54	66.5	12.5
			4	55	65.4	10.4
	US441 Micanopy	Static	1	99	109.6	10.6
			2	105	114	9
			3	99	104.9	5.9
			4	94	115.1	21.1
			5	90	105.1	15.1
	US441 Prairie	Dynamic	10 locations	104.4	113.8	9.4
	SR5 Brevard Co.	Dynamic	1	104.1	103.3	0.8
			2	80	92.6	12.6
			3	138.4	148.6	10.2
			4	104.1	110.1	6
			5	101.6	113.3	11.7
			6	144.8	152.6	7.8
			7	116.9	126.4	9.5
			8	167.6	170	2.4
			9	109.2	115.4	6.2
			10	101.6	96.3	5.3
			11	109.2	112.2	3
	SR15 Volusia Co.	Dynamic	1	111.8	119.6	7.8
			2	124.5	116.8	7.7
			3	129.5	136.2	6.7
			4	134.6	127.2	7.4
			5	175.3	163.8	11.5
			6	122.5	137.3	14.8
Superpave	I-10 Madison Co.	Dynamic	1	211.6	305.2	93.6
			2	228.1	300.4	72.3
			3	222.3	241.4	19.1
			4	211.6	275.8	64.2
	I-75 Hamilton Co.	Dynamic	1	263.9	301.3	37.4
			2	269.5	306.4	36.9
			3	246.1	284.8	38.7
			4	272.5	326.1	53.6
			5	265.7	308.6	42.9
			6	247.1	278.4	31.3
			7	261.6	284.7	23.1
			8	261.1	301.6	40.5
	I-75 Hamilton Co.	Dynamic	1	299.7	316.4	16.7
			2	295.9	326.3	30.4
			3	278.1	341.1	63

Figure 1 Photographic Illustration of FDOT GPR van

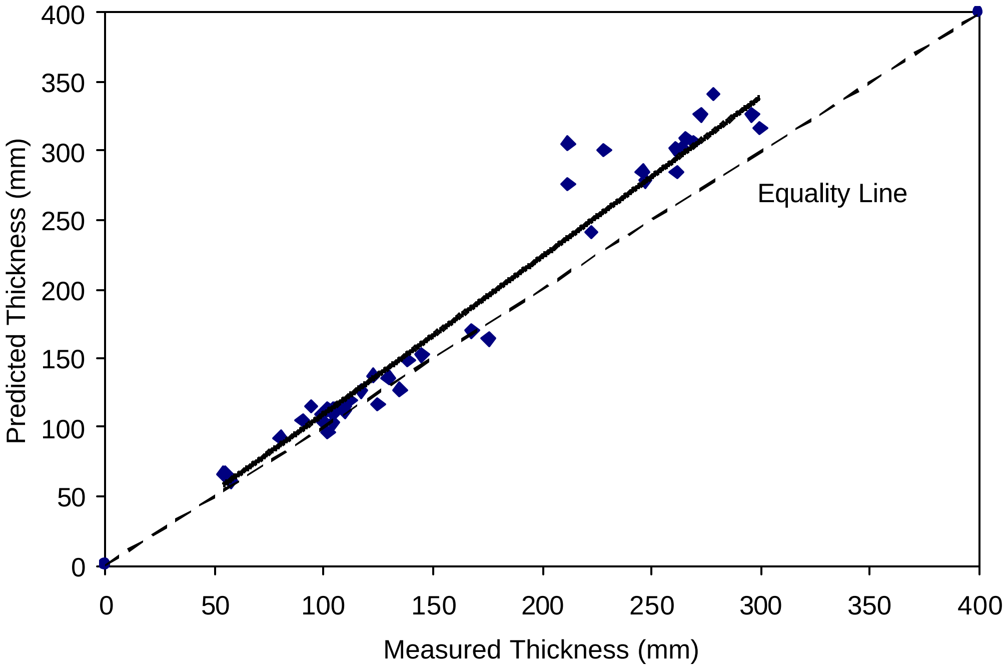

Figure 2 Illustrative comparison of measured and predicted thicknesses (all sections)

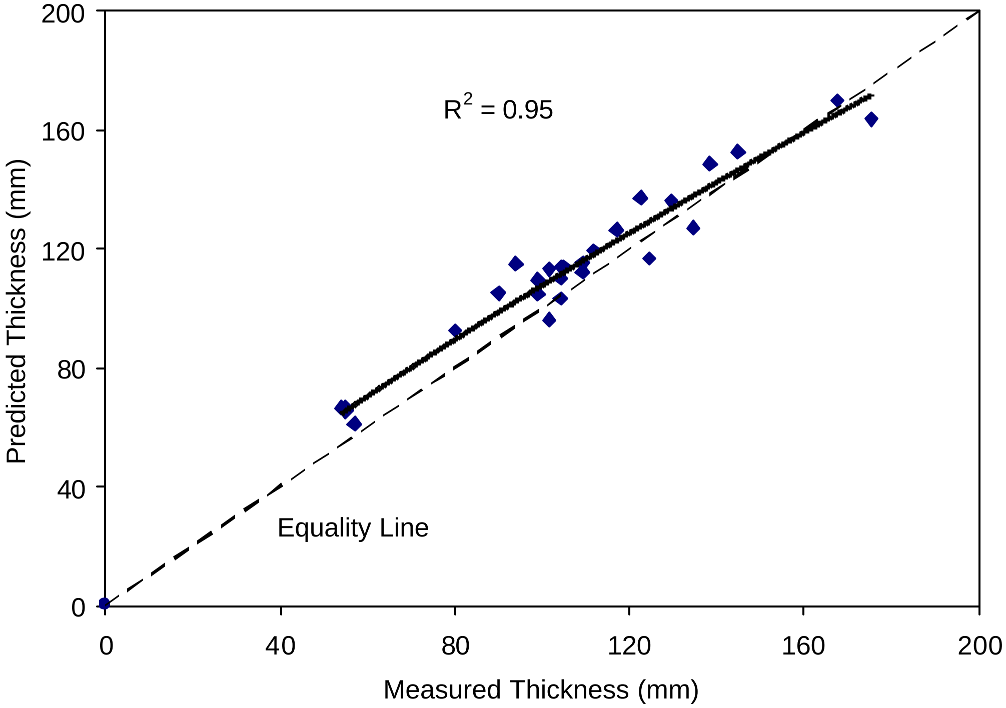

Figure 3 Illustrative comparison of measured and predicted thicknesses (Marshall sections)