GROUND PENETRATING RADAR *(GPR)* EVALUATION

SPR - STP - 0010 (019)
RP 119

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INTRODUCTION

- Knowledge of pavement thickness is required to predict performance and establish load capacity
- Core sampling/test pits are destructive, expensive, time consuming and intrusive to traffic
- Idaho Transportation Department (ITD) conducted GPR surveys as NDT method to evaluate 30 miles of AC/PCC pavements and 3 bridge decks to assess the applicability of the GPR to conditions encountered in Idaho
- Results were correlated with the ground - truth data (GTD) obtained from borings
- GPR surveys employed both air coupled (A-C) and air and ground coupled (A-G-C) systems with associated equipment and software
- This presentation summarizes the findings and provides statistically based data to make recommendations for pavements and bridge decks in Idaho

GOALS OF ITD STUDY

- Evaluate, compare and assess the ability of both (A-C) and (A-G-C) systems

- Accurately measure multiple pavement layer thickness

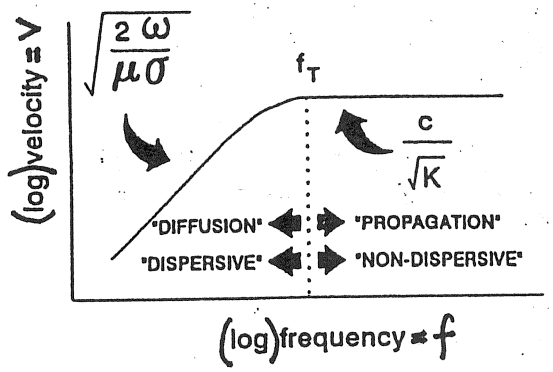
- Document the structural conditions of the selected bridge decks nondestructively

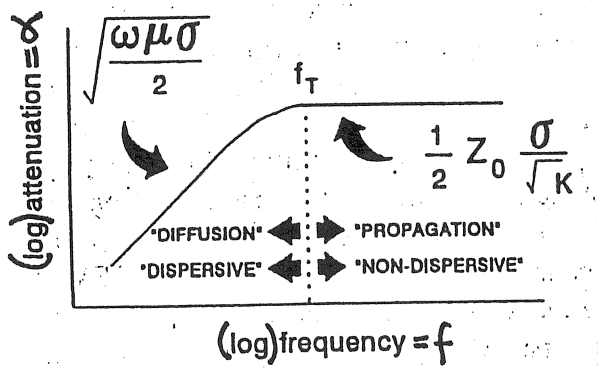
  - Two firms were contracted by ITD:
    + (A-G-C) System: Road Radar Ltd. (RRL), Edmonton, Alberta, Canada
    + (A-C) System: Infrasense, Inc. (INFRA), Arlington, Massachusetts, USA

PROJECT ACTIVITIES

- Review available reports and data by RRL and INFRA
- Establish a usable database for analyses and comparative evaluations
- Review available field notes compiled by ITD
- Correlate each consultant's data and compare results with respect to site-specific ground-truth-data (GTD)
- Summarize findings and recommend the preferred GPR survey method/technique for ITD's design, construction and maintenance operations

- RADAR is an acronym for RAdio Detection And Ranging
- GPR has been developed to investigate the internal structure of the subsurface materials by using propagated Electro Magnetic (EM) fields
- EM velocity and attenuation relationships are:



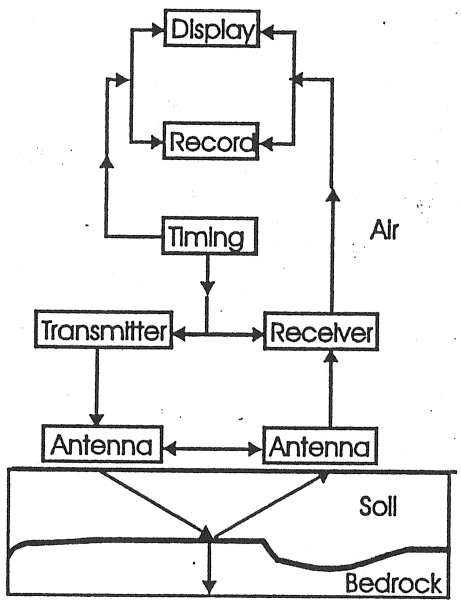


where:

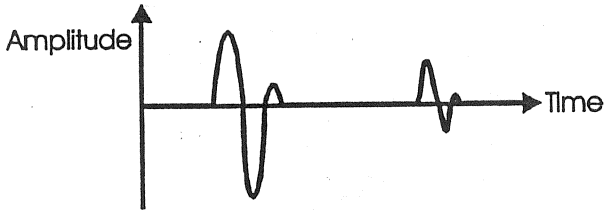
Z_0	=	free space impedance
K	=	dielectric constant or relative permitivity
σ	=	electrical conductivity
c	=	propagation velocity in air
v	=	velocity
α	=	attenuation
μ	=	permeability
ω	=	angular frequency
f	=	frequency
f_T	=	transition frequency

GPR SYSTEM ELEMENTS

- Block diagram depicting main components of a GPR system



- Typical data recorded by a GPR is an amplitude versus delay time. Events from <u>three</u> dimensional space are mapped into their <u>one</u> dimensional time record



PROBLEM DEFINITION STEPS IN GPR

- There are five fundamental questions to be asked before deciding effectiveness of the GPR survey
  - What is the target depth?
    (within the range of GPR)
  - What is the target geometry?
    (target size and orientation)
  - What are the target electrical properties?
    (target must present a contrast in electrical properties to the host environment)
  - What are the host material electrical properties?
  - What is the survey environment like?
    (presence of extensive metal structures and other radio frequency sources, accessibility, hazardous conditions)

GPR/NDT PROCEDURES

- GPR (short-pulse radar) is electromagnetic analog of sonic and ultrasonic pulse-echo methods
- Contrast in the dielectric constants of the paving materials helps to determine their thickness by measuring the transit time
- The success of thickness measurement depends on reasonably detectable reflection from the bottom of the pavement member, i.e., AC/PCC surface course, base and subbase course
- The wavelength of 1-gigahertz GPR is about 3 inches, which has a penetration depth of about 24 inches
- The penetration depth is a function of the overall dielectric constant of the pavement structure
- Materials with high dielectric constant have high signal attenuation, thereby decreasing effective depth of penetration

GPR METHODOLOGIES USED IN ITD STUDY

- Study considered whole section length (Network) and 500-foot-long section length (Project) level applications both for AC and PCC pavements

- <u>Project Level Objectives:</u>
  - Gather detailed information for rehabilitation overlay design purposes including:
    - ➢ Continuous subsurface profile of layers
    - ➢ Subgrade anomalies
    - ➢ Surface and sub-surface cracks
    - ➢ Voids
    - ➢ Weakened or stripped areas

- <u>Network Level Objectives:</u>
  - Locate pavement segment profiles
  - Check expected performance by gathering:
    - ➢ Sufficient continuous surface and subsurface information
  - Collect data for planning purposes and budget estimates

GPR METHODOLOGIES USED IN ITD STUDY

- Eight road test sections (total of 30 miles) were included in Network Level applications
- Total of 16 sections were included in Project Level applications
- Total of 3 bridge decks were included in the study
- GPR survey employed both air-coupled (A-C) and combination air and ground coupled (A-G-C) systems
- Results were correlated with the ground-truth data (GTD) obtained from ITD borings drilled at designated locations of the GPR test sections

A-C GPR SYSTEM

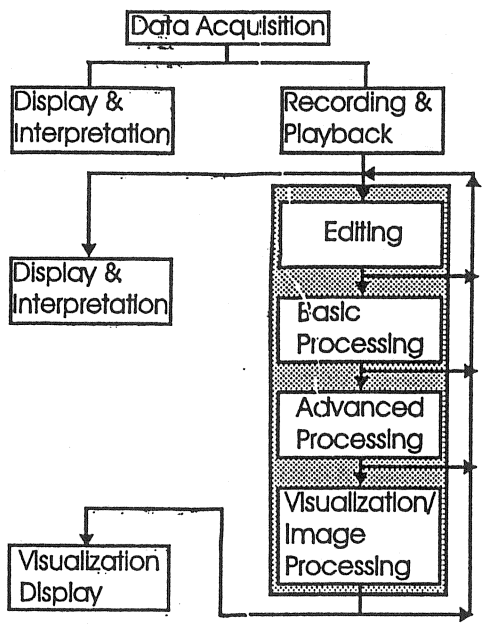
- The system employed is the Pulse Radar, Inc. RODAR™ GPR equipment, coupled with Infrasense PAVLAYER™ and DECAR™ software
- The equipment is based on a 1 gigahertz air-coupled horn antenna
- Survey was performed at driving speeds ranging from 25 mph on urban roads to 55 mph on the interstate highways
- No lane closures or traffic control was required
- Project Level survey included data collection one for each wheel path and one at the center of the lane
- Right wheel path data was used for analysis since it was where the GTD data were taken
- Project Level analysis was performed at every foot, and reported at 50 ft. intervals
- Network Level analysis was performed at every 5 feet, and reported at 250 ft. intervals

A-G-C GPR SYSTEM

- The system employed is patent pending ROAD RADAR™ which employs a hybrid antenna system consisting of a "ground-coupled" antenna system operating at a center frequency of 1 GHz and an "air-coupled" antenna operating at a nominal 3 GHz
- The combination of antenna configuration makes the system versatile, self-calibrating and reliable under a wide range of situations
- The ROAD RADAR™ also uses a distance measuring instrument (DMI), connected to the transmission of the vehicle to trigger the radar so that the system is not speed dependent and the location of each measurement is known
- Network Level surveys were conducted at about 40-45 mph, with sampling interval of about 24 inches
- Right wheel path was surveyed since it was the track where the GTD cores were taken
- Project Level surveys were conducted at about 15 mph, with sampling interval of about 8 inches
- Each wheel path and center of lane were surveyed on a continuous basis

GPR DATA PROCESSING FLOW

- GPR data are treated as a scalar quantity while the EM fields are vector quantities
- The processing flow for GPR data is depicted below:



Note: The highlighted zone indicates looped areas of data processing and iterative activity

Table 1: ITD Roadway Test Sections for Network and Project Level GPR Surveys

Roadway	Description/Location	Mile Posts (Beginning-Ending) (miles and feet)	Survey Type	Total Length Surveyed	Miscellaneous Information	Mile Posts for ITD Core Data (Boring location) (miles and feet)
SH-16	State Highway-16, minor arterial, asphalt concrete surface, two lane rural highway, Ada County Line to Sand Hollow Road	8.359 – 11.960	N	3.601 miles	Ascending direction	9.1 + 0; 9.1 + 500; 10.0 + 0; 10.0 +250; 10.0 +500; 11.0 +0; 11.0 +250; 11.0 +500
		9.1 – 9.1 + 500 ft.	P #1	500 ft.		
		10.0 – 10.0 + 500 ft.	P #2	500 ft.		
		11.0 – 11.0 + 500 ft.	P #3	500 ft.		
US-20	US Highway-20, principal arterial, asphalt concrete surface, two lane rural highway, Canyon County Line to Junction SH-55 (State Highway-55)	32.283 – 40.229	N	7.946 miles	Ascending direction, 0.3 ft. overlay in June 1995	34.0 + 0; 34.0 + 105; 34.0 + 500; 36.0 + 0; 36.0 + 500; 38.0 + 500
		34.0 – 34.0 + 500 ft.	P #1	500 ft.		
		36.0 – 36.0 + 500 ft.	P #2	500 ft.		
		38.0 – 38.0 + 500 ft.	P #3	500 ft.		
SH-44	State Highway-44, principal arterial asphalt concrete surface, two lane rural highway, Intersection State and Knox Street to Junction SH-16.	10.771 – 12.298	N	1.527 miles	Ascending direction	11.0 + 0; 11.0 +500
		11.0 – 11.0 + 500 ft.	P #1	500 ft.		
I-84/WB	Interstate-84, six lane divided highway, west bound inside lane, Portland cement concrete surface Meridian City Limit to Ridenbaugh Canal	44.960 – 46.770	N	1.810 miles	Asphalt treated permeable base	46.0 + 0; 46.0 +500
		46.0 – 46.0 + 500 ft.	P #1	500 ft.		
I-84/EB	Interstate-84, four lane divided highway, east bound lane, asphalt concrete surface, A-Line Canal to Maintenance Cross-Over	5.968 – 12.610	N	6.642 miles	0.4 ft. overlay in 1985	8.0 + 0; 8.0 + 500; 10.0 + 0; 10.0 + 500
		8.0 – 8.0 + 500 ft.	P #1	500 ft.		
		10.0 – 10.0 + 500 ft.	P #2	500 ft.		
I-84/EB	Interstate-84, four lane divided highway east bound lane, Portland cement concrete surface, Interchange #95 to Interchange #99	96.153 – 99.570	N	3.417 miles	Open graded base	97.0 + 0; 97.0 + 500; 98.0 + 0; 98.0 + 500
		97.0 – 97.0 + 500 ft.	P #1	500 ft.		
		98.0 – 98.0 + 500 ft.	P #2	500 ft.		
I-84B/EB	Business route of Interstate, four lane divided highway, principal arterial, asphalt concrete surface, east bound outside lane, Caldwell Blvd., N. Midway to Homedale Road	53.842 – 54.468	N	0.626 miles	--	54.0 + 0; 54.0 + 130; 54.0 + 500
		54.0 – 54.0 + 500 ft.	P #1	500 ft.		
US-95	US Highway-95, principal arterial, asphalt concrete surface, two lane rural highway, Milepost Equator Marker to N. End Devils Elbow	86.600 – 90.300	N	3.700 miles	Open graded base	88 + 0; 88 + 500; 89 + 0; 89 + 500; 90 + 0; 90 + 500;
		88.0 - 88.0 + 500 ft.	P #1	500 ft.		
		89.0 – 89.0 + 500 ft.	P #2	500 ft.		
		90.0 – 90.0 + 500 ft.	P #3	500 ft.		

LEGEND:

WB – West Bound
EB – East Bound
SH – State Highway
US – United States Highway

I – Interstate
N – Network Level
P – Project Level

SUMMARY OF FINDINGS

- A-C and A-G-C system results are correlated with GTD by using linear regression analyses for bridge deck survey results and for both Project and Network Level surveys, and for both pavement surface (AC/PCC) and base course layer measurements

- Figures 1, 2 and 3 represent Project Level surveys of the pavement surface course for all project sites
  - The relationships between A-C and GTD; between A-G-C and GTD; and between A-C and A-G-C yield large correlation coefficients, indicating strong statistical reliabilities
  - Slopes of best-fit lines are close to 1, indicating direct proportional relationships
    - ➢ Both A-C and A-G-C systems match very closely to GTD data

Figure 1: ITD Core Data (Ground Truth) versus Air-coupled (A-C) Data for Surface Course Thickness (Project Survey, All Sites)

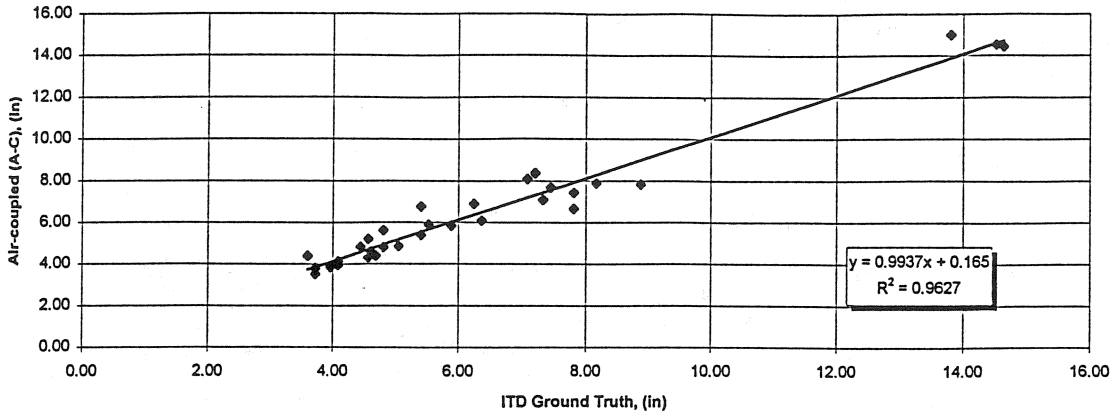


Figure 2: ITD Core Data (Ground Truth) versus Air-ground-coupled (A-G-C) Data for Surface Course Thickness (Project Survey, All Sites)

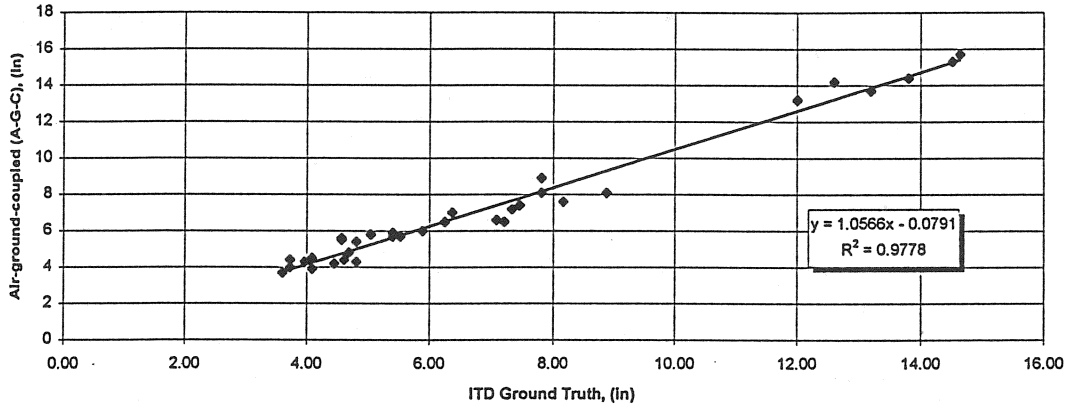
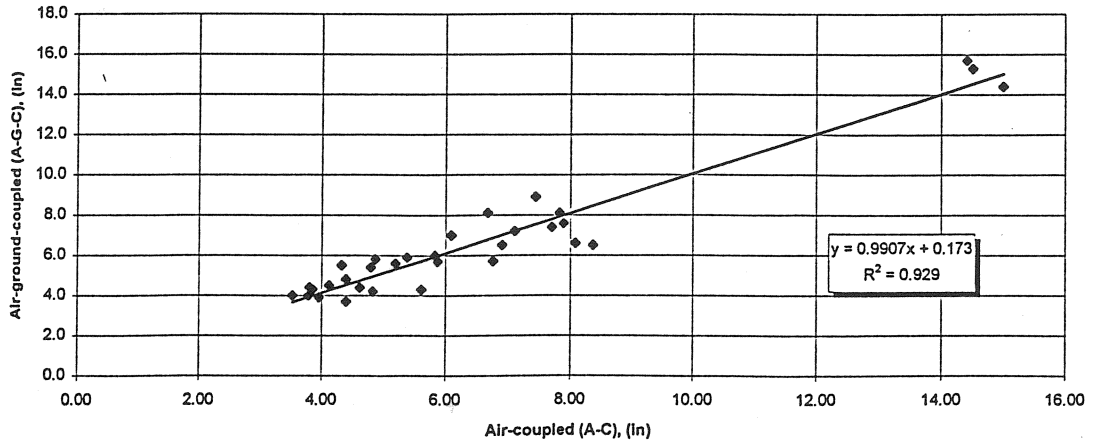


Figure 3: Air-coupled (A-C) Data versus Air-ground-coupled (A-G-C) Data for Surface Course Thickness (Project Survey, All Sites)



SUMMARY OF FINDINGS

- Figures 4, 5 and 6 represent Network Level surveys of the pavement surface course for all Network sites
  - The relationship between A-C and GTD; between A-G-C and GTD; and between A-C and A-G-C typically yield low correlation coefficients (except Figure 5), indicating minimal statistical relationships
  - Slopes of best-fit lines are not close to 1, indicating large data scatter

Figure 4: ITD Core Data (Ground Truth) versus Air-coupled (A-C) Data for Surface Course Thickness (Network Survey, All Sites)

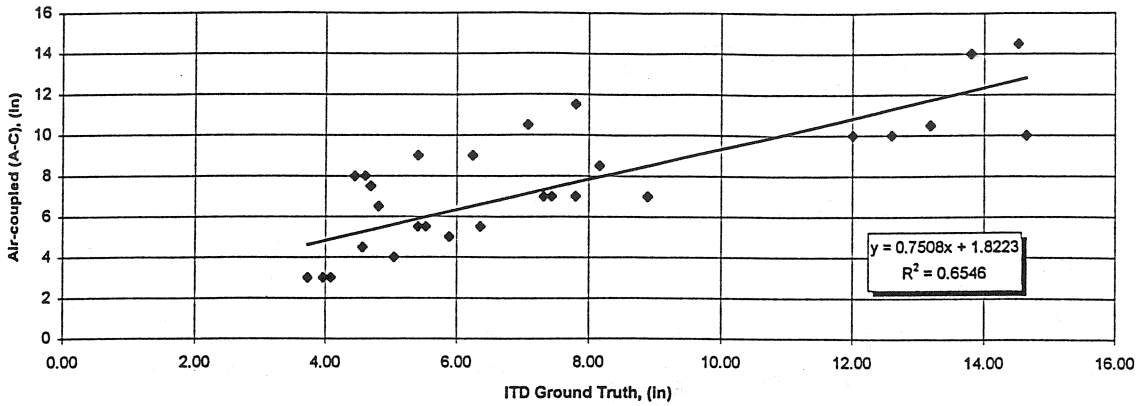


Figure 5: ITD Core Data (Ground Truth) versus Air-ground-coupled (A-G-C) Data for Surface Course Thickness (Network Survey, All Sites)

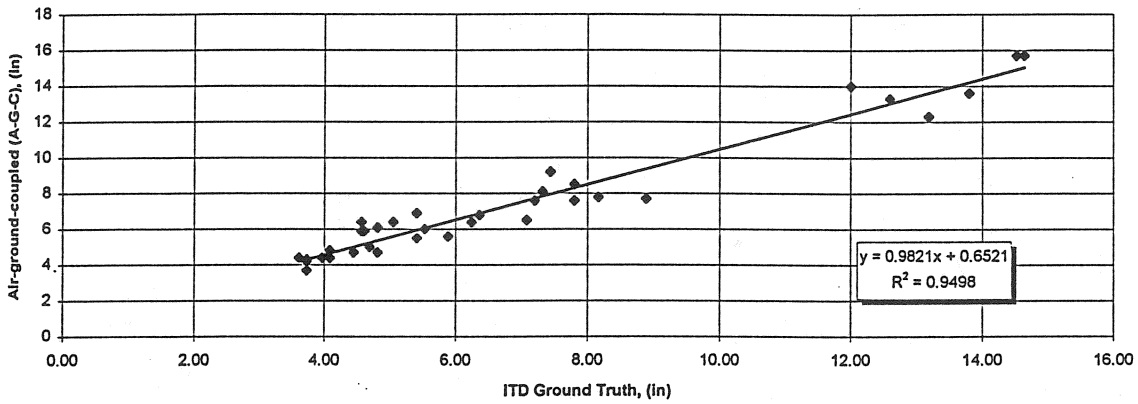
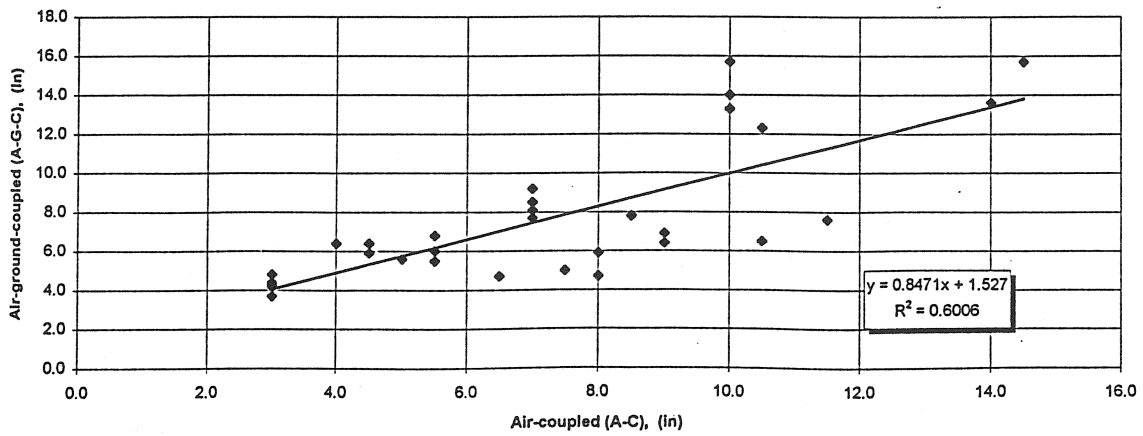


Figure 6: Air-coupled (A-C) Data versus Air-ground-coupled (A-G-C) Data for Surface Course Thickness (Network Survey, All Sites)



SUMMARY OF FINDINGS

- Figures 7, 8, and 9 represent Project Level and Figures 10, 11, and 12 correlate Network Level surveys of the base course for all sites
  - The relationship between A-C and GTD; between A-G-C and GTD; and between A-C and A-G-C indicate very low correlation coefficients, indicating unreliable statistical relationships
  - Slopes of best-fit lines are near 0, indicating very large data scatter

Figure 7: ITD Core Data (Ground Truth) versus Air-coupled (A-C) Data for Base Course Thickness (Project Survey, All Sites)

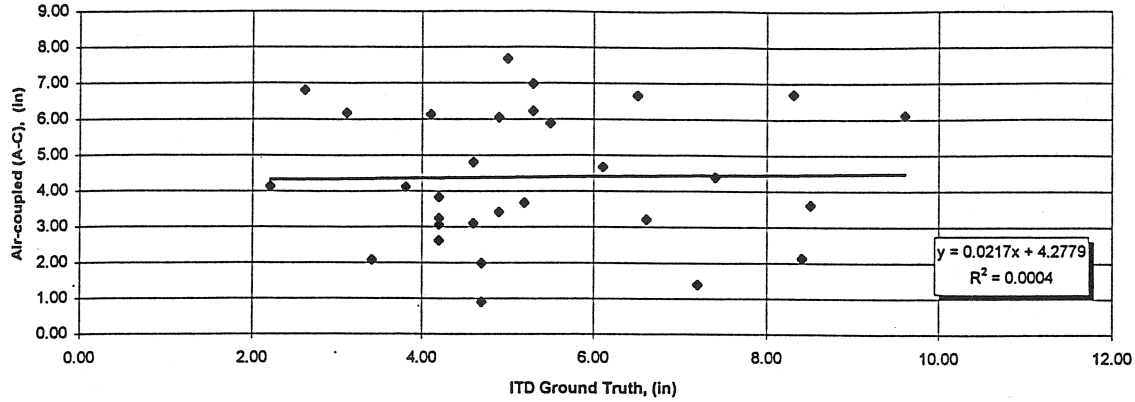


Figure 8: ITD Core Data (Ground Truth) versus Air-ground-coupled (A-G-C) Data for Base Course Thickness (Project Survey, All Sites)

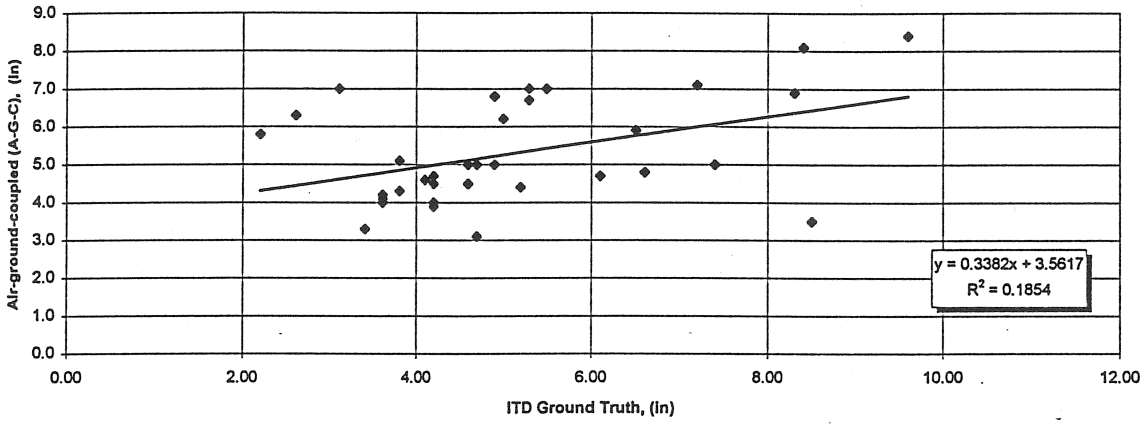


Figure 9: Air-coupled (A-C) Data versus Air-ground-coupled (A-G-C) Data for Base Course Thickness (Project Survey, All Sites)

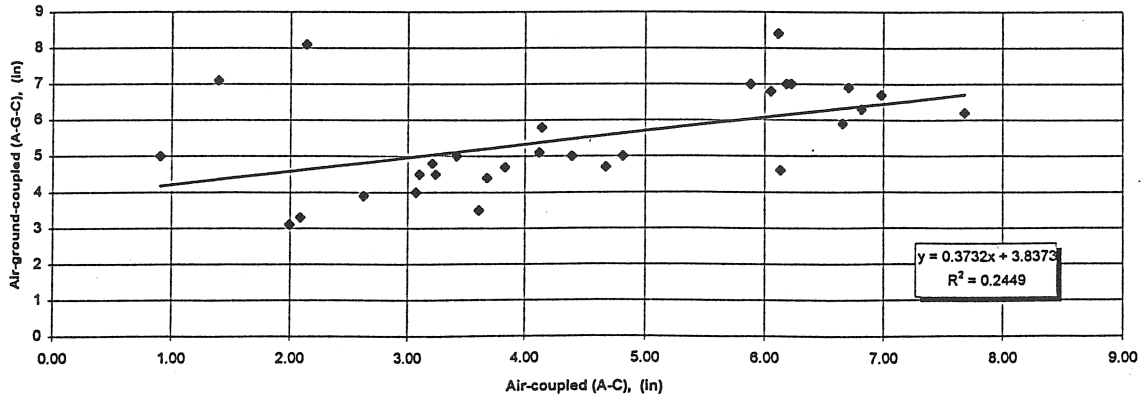


Figure 10: ITD Core Data (Ground Truth) versus Air-coupled (A-C) Data for Base Course Thickness (Network Survey, All Sites)

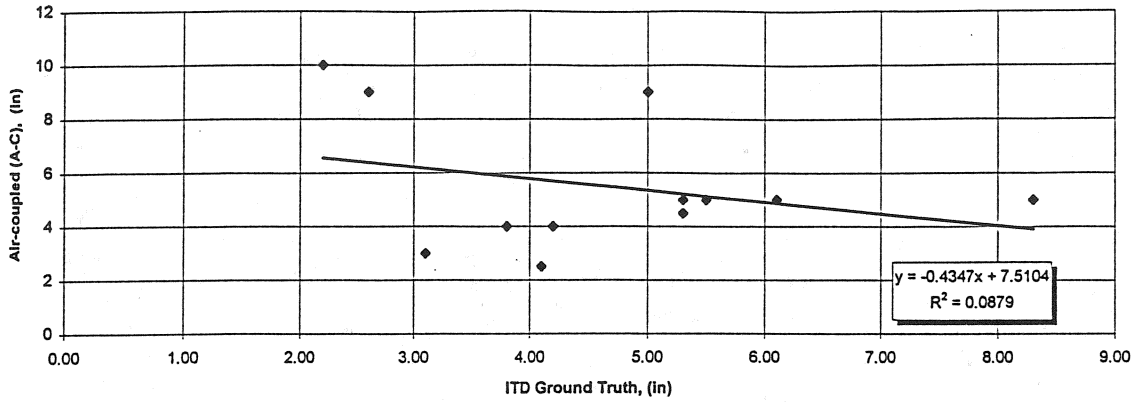


Figure 11: ITD Core Data (Ground Truth) versus Air-ground-coupled (A-G-C) Data for Base Course Thickness (Network Survey, All Sites)

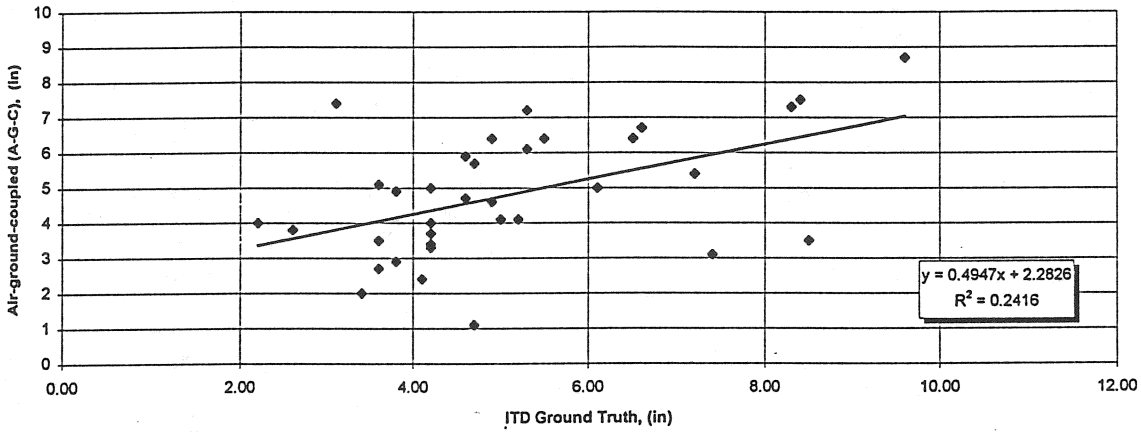
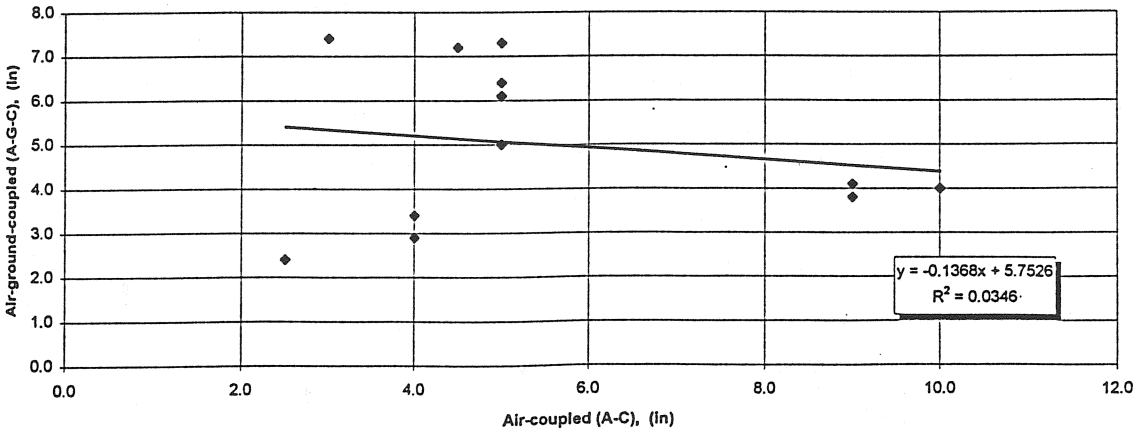


Figure 12: Air-coupled (A-C) Data versus Air-ground-coupled (A-G-C) Data for Base Course Thickness (Network Survey, All Sites)



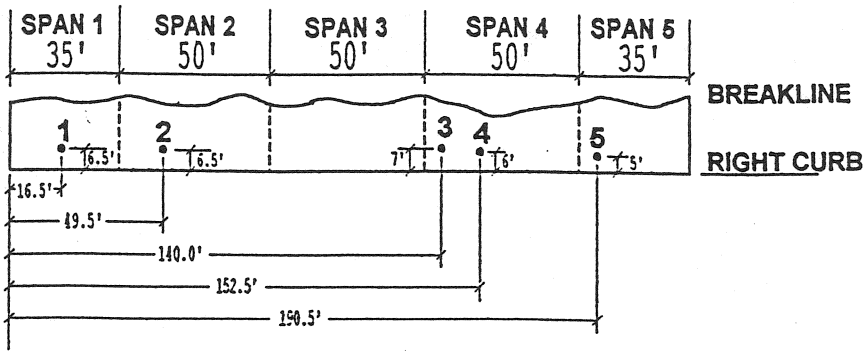
BRIDGE DECK STUDY

- CONDITION SURVEY EVALUATION
  - Both (A-G-C) and (A-C) systems claimed somewhat close agreements with the ITD's chain drag data
  - Surface anomalies occurring at the AC/PCC wearing surface boundary were assessed and reported comparatively in percentage of the total area deteriorated
  - It is an opinion that subjectively evaluated chain drag data may not be compared with the GPR assessments

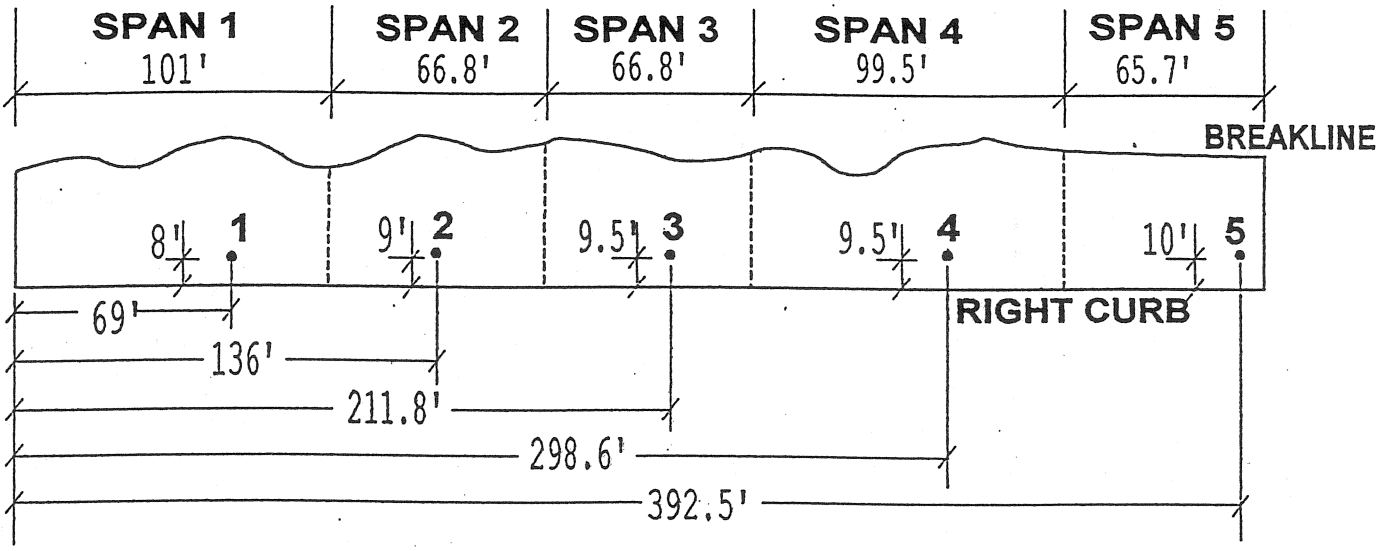
BRIDGE DECK STUDY

- <u>REBAR DEPTH AND OVERLAY THICKNESS</u>
  - Both (A-G-C) and (A-C) systems attempted to predict the ITD's GTD data
  - Following figures indicate the core locations and the data comparison between (A-G-C), (A-C), and (GTD)
  - It is an opinion that both GPR systems have limited capability predicting the (GTD)

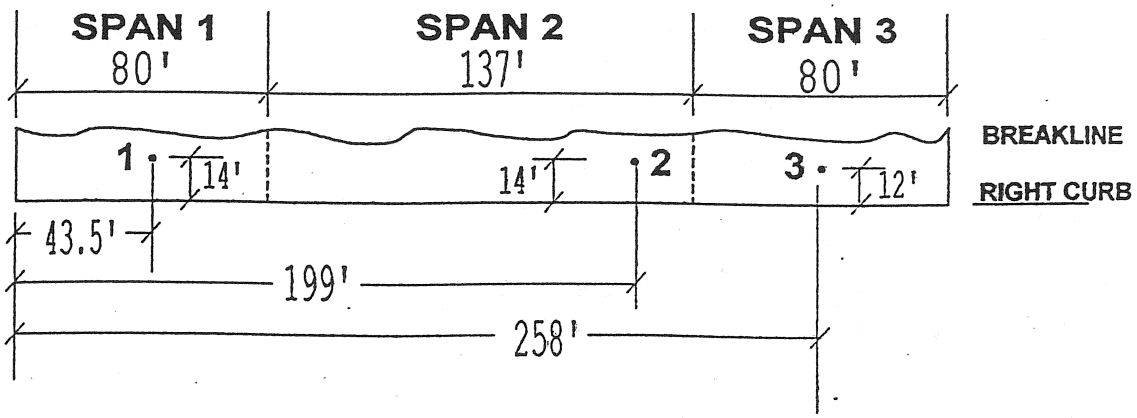
PLAN VIEW OF BRIDGE, US 20/26 over I84 (BROADWAY AVE. INTG.)



PLAN VIEW OF BRIDGE, I-184 over FRANKLIN RD. (FRANKLIN EXCHANGE)



PLAN VIEW OF BRIDGE, US 20/26 over UPRR and NY CANAL (NORTHBOUND) BROADWAY AVE.



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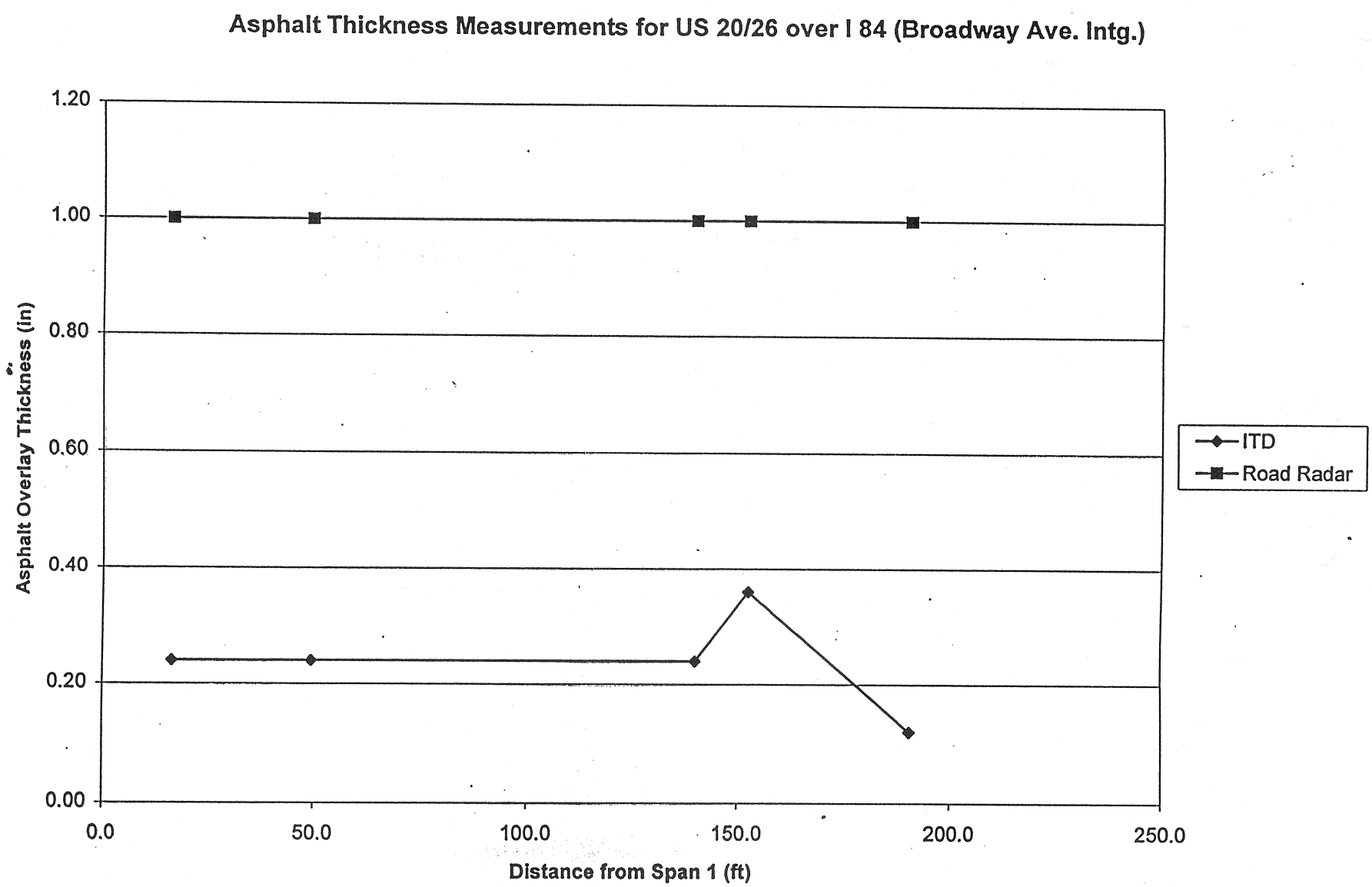

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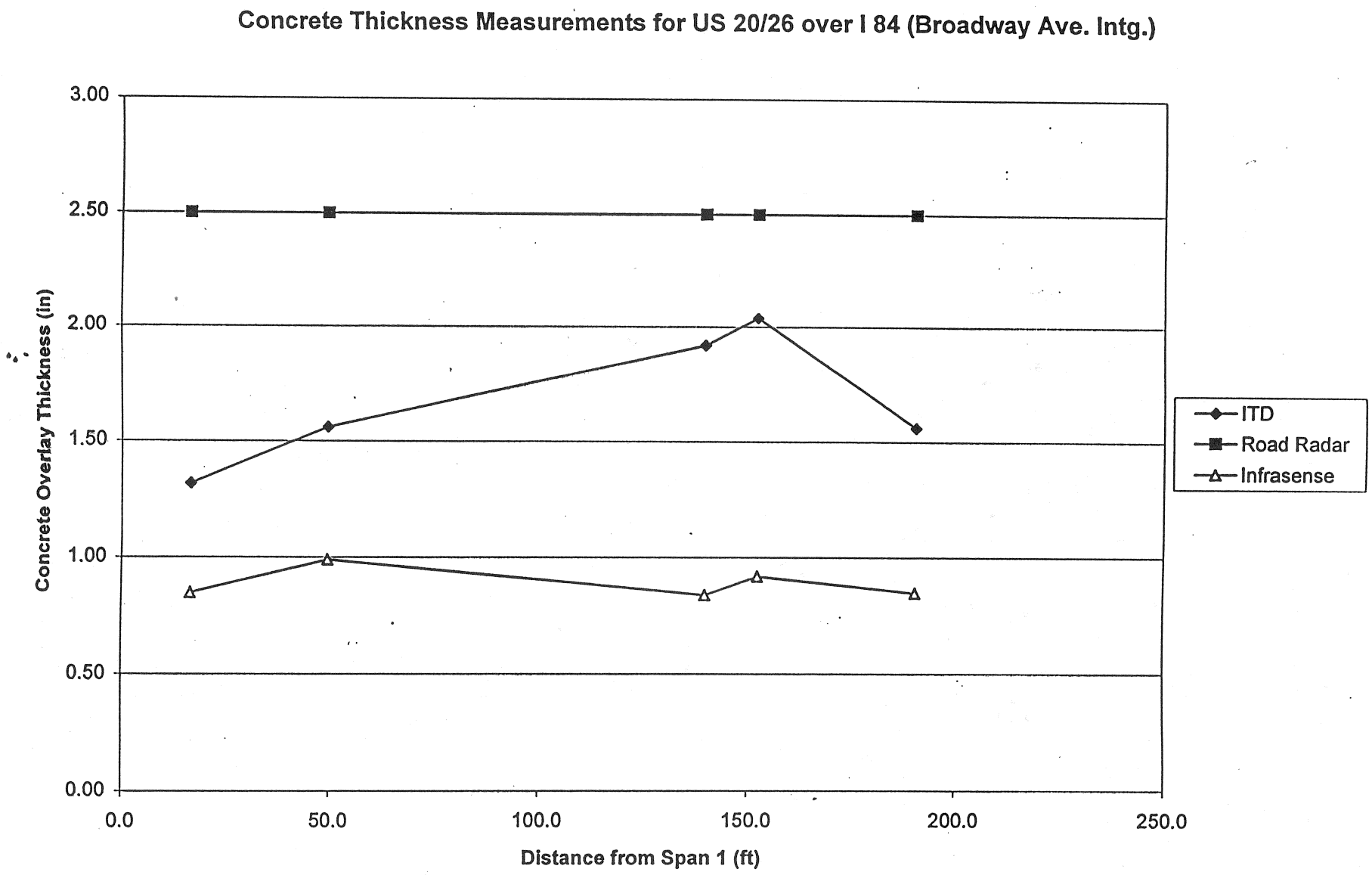
profile1.xls



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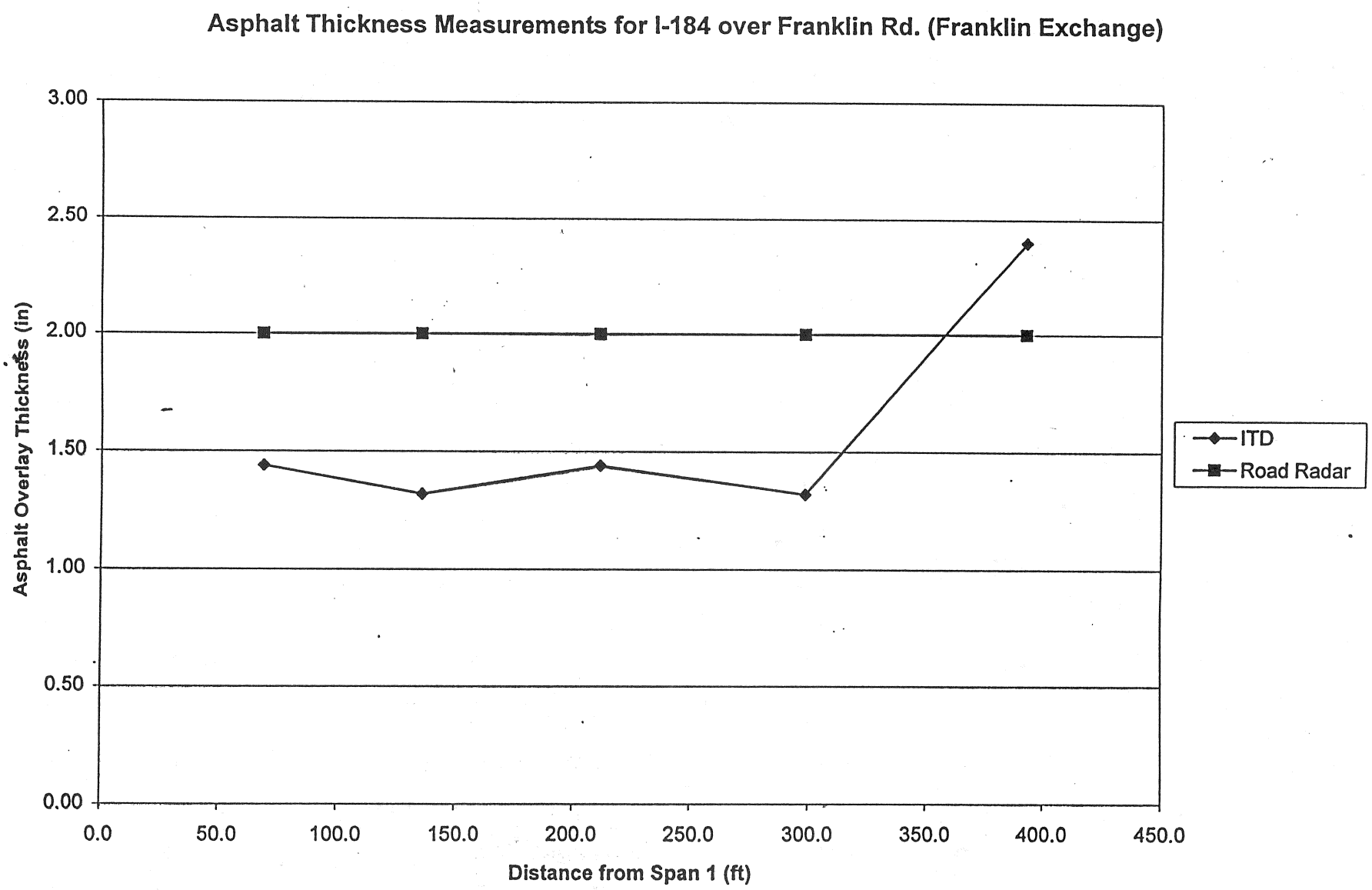

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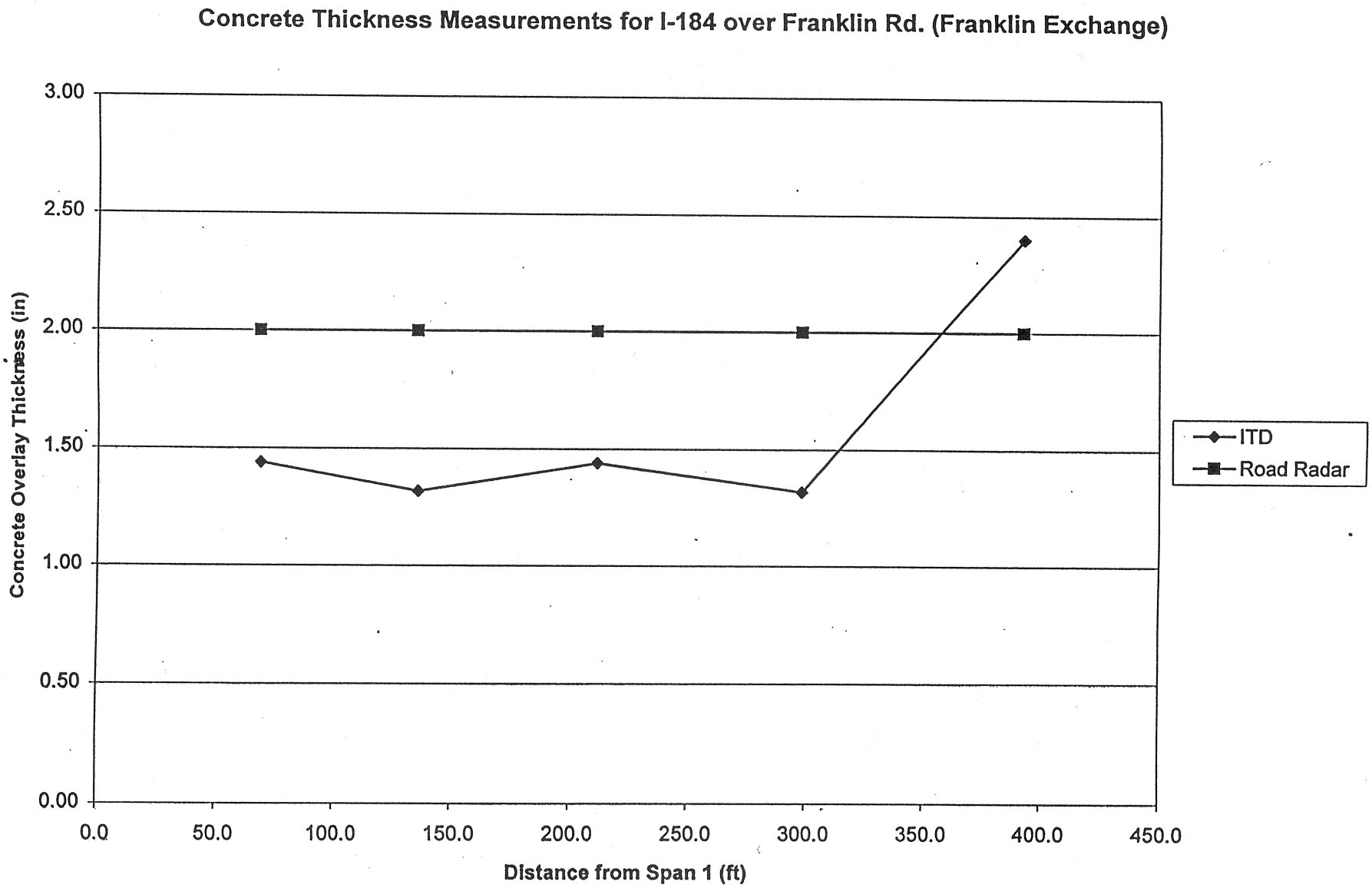

Reference: Table III

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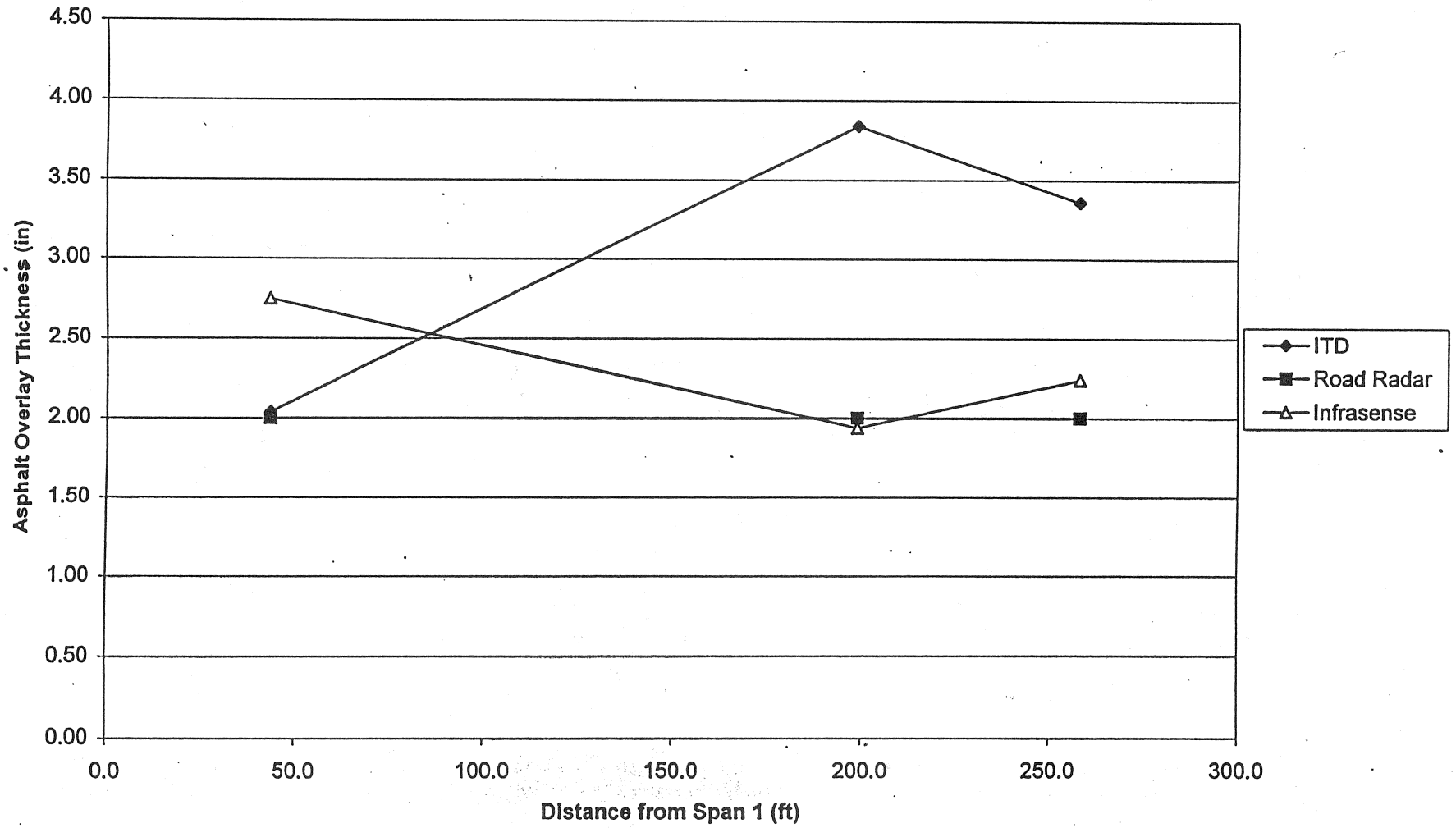
Asphalt Thickness Measurements for US 20/26 over UPRR and NY Canal (northbound)
Broadway Ave.



Reference: Table III

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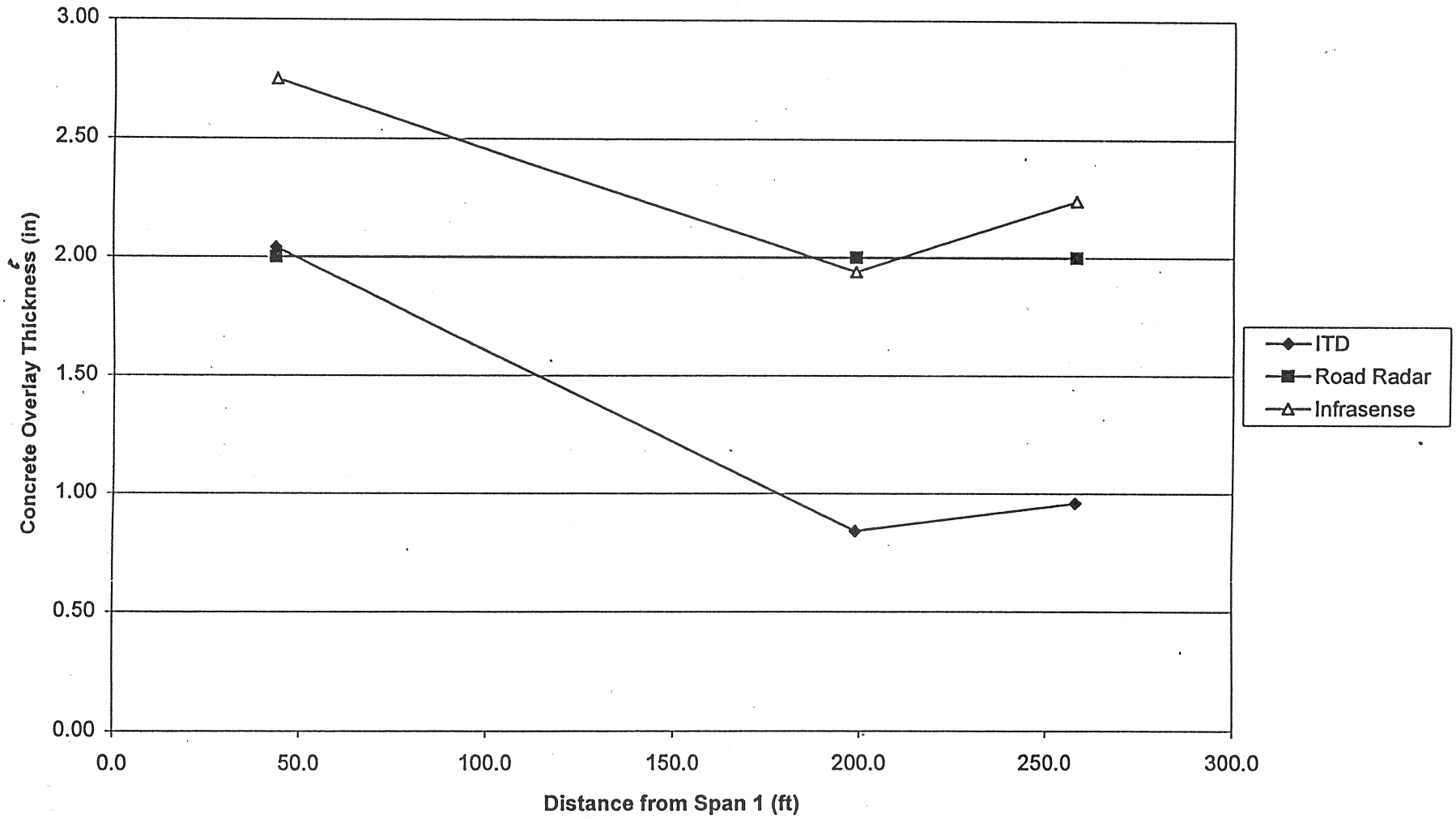
Concrete Thickness Measurements for US 20/26 over UPRR and NY Canal (northbound) Broadway Ave.



Reference: Table III

profile6.xls

CONCLUSIONS

- Both A-C and A-G-C systems are capable of predicting GTD as obtained from Project Level pavement surface course thickness measurements
- Both A-C and A-G-C systems have equal capability in estimating pavement surface course thickness for Project Level surveys
- Both A-C and A-G-C systems overestimates the pavement surface course thickness for Network Level surveys
- Both A-C and A-G-C systems appear not to be predicting GTD within the expected ranges as obtained from both Project and Network Level surveys for base course thickness measurements
- Project Level surveys provide higher quality and more accurate data in comparison to Network Level surveys
- Reasonably accurate, dependable determination of the pavement surface course (AC/PCC) layer thickness can be achieved at normal driving speeds by either A-C and A-G-C based systems
- Base course thickness measurement results indicate deviations from GTD for both GPR NDT systems

CONCLUSIONS

- Objective comparisons with technical reliability can not be made between GPR data and chain drag data collected in determination of the bridge deck condition survey

- Reinforcing steel depth (concrete) and overlay (asphalt) thickness measurements obtained by GPR indicate deviations from GTD for both GPR NDT systems

RECOMMENDATIONS

- GPR systems provide a relatively low-cost, and reasonably reliable alternative to destructive testing, such as coring

- For conditions encountered in Idaho, it is recommended that:
  - Both GPR systems could be considered to determine the pavement surface course thickness for both Project and Network Level surveys
  - Proper estimation of the base course layer thickness should include occasional cores to provide higher accuracy to collected data by both GPR systems
  - Estimation of the rebar (concrete) and the overlay (asphalt) thickness at bridge decks should include cores to provide reliability to collected GPR data
  - The reliability of the GPR bridge deck condition survey evaluation results can not be assessed objectively

FINAL WORDS

- GPR data processing is still in its infancy
- Occasional (as determined by project needs) site-specific GTD must be obtained for reliability and higher accuracy of the GPR data
- GPR data processing has to have a cost benefit; and for many GPR projects, processing is cost limited rather than technology or methodology limited

THANK YOU