GROUND PENETRATING RADAR (GPR)

EVALUATION

(ITD/BSU Cooperative Transportation Research Project)
SPR - STP - 0010 (019)
RP 119

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ABSTRACT

A knowledge of pavement layer thickness is needed to predict pavement performance, establish load carrying capacities and develop maintenance and rehabilitation priorities. For new construction of roadways and bridges, it is important to ensure that the thickness of materials being placed by the contractor is acceptably close to specification. Core sampling and test pits are destructive to the pavement system, expensive, time consuming and intrusive to traffic. In addition, repair and/or replacement of deteriorated bridge decks is a major expense and difficult to assess.

The Idaho Transportation Department (ITD) conducted a series of ground penetrating radar (GPR) surveys as a non-destructive testing (NDT) method to evaluate the thickness of asphalt and Portland cement concrete pavements, and assess the progressive deterioration and structural condition of bridge decks in Idaho during 1995 and 1996. GPR surveys employed both air coupled (A-C) and combination air and ground coupled (A-G-C) systems with their associated equipment and software. A total of 30 miles of pavements and three bridge decks were evaluated by GPR surveys to assess the applicability of GPR to conditions encountered in Idaho. The obtained results were correlated with the site-specific ground-truth data (GTD).

For conditions identified in Idaho, it is recommended both GPR systems could be considered to determine the pavement surface course thickness for both project and network level surveys, although it has been noticed that the A-G-C system (Road Radar™) is capable of predicting the GTD more accurately than the A-C system (Infrasense). The proper estimation of the base course layer thickness should include occasional cores to provide higher accuracy to collected data by both GPR systems. The estimation of the depth to reinforcing steel (concrete thickness) and the asphalt overlay thickness at bridge decks should include cores to provide reliability for collected GPR data. Finally, the reliability of the GPR bridge deck condition survey evaluation results can not be assessed objectively.

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1. INTRODUCTION

A knowledge of pavement layer thickness is needed to predict pavement performance, establish load carrying capacities and develop maintenance and rehabilitation priorities. For new construction of roadways and bridges, it is important to ensure that the thickness of materials being placed by the contractor is acceptably close to specification. Core sampling and test pits are destructive to the pavement system, expensive, time consuming and intrusive to traffic. In addition, repair and/or replacement of deteriorated bridge decks is a major expense and difficult to assess.

The Idaho Transportation Department (ITD) conducted a series of ground penetrating radar (GPR) surveys as a non-destructive testing (NDT) method to evaluate the thickness of asphalt and Portland cement concrete pavements, and assess the progressive deterioration and structural condition of bridge decks in Idaho during 1995 and 1996. GPR surveys employed both air coupled (A-C) and combination air and ground coupled (A-G-C) systems with their associated equipment and software. A total of 30 miles of pavements and three bridge decks were evaluated by GPR surveys to assess the applicability of GPR to conditions encountered in Idaho. The obtained results were correlated with the site-specific ground-truth data (GTD).

2. THE GOALS OF THE IDAHO TRANSPORTATION DEPARTMENT STUDY

The goals of the ITD study were to evaluate, compare and assess the ability of the A-C and A-G-C systems; to accurately measure multiple pavement layer thicknesses; and document the structural conditions of the selected bridge decks nondestructively. There appeared to be significant differences in the equipment and approaches used in conducting GPR surveys by these two systems. ITD elected to contract for comparison GPR services with two firms: Road Radar Ltd. (A-G-C system), and Infrasense, Inc. (A-C system). These firms issued their collected data, findings and conclusions in:

- "Road Radar™ Surveys, Idaho Transportation Department, Final Report, Boise Area Test Sections, 910-11370.34, October, 1996," prepared by Road Radar Ltd., Edmonton, Alberta, Canada.[1]

- "Thickness Data Gathering using Ground Penetrating Radar Technology Equipment, Final Report, February 14, 1997," prepared by Infrasense Inc., Arlington, Massachusetts, U.S.A. [2]

Both firms published preliminary reports prior to receiving the GTD. Road Radar Ltd. claimed that the obtained accuracy was adequate without GTD. Published final reports by these two consulting firms indicated that reasonably accurate determination of pavement layer thickness can be achieved by using GPR survey for conditions encountered in Idaho. Levels of bridge deck deterioration, asphalt overlay thickness and reinforcement depth can also be determined on a relative scale to complement other evaluation techniques.

3. PROJECT ACTIVITIES

The researchers at the Boise State University (BSU) proposed to review the findings of these two GPR survey types and provide statistically based data comparisons of the two methods for pavements including bridge deterioration estimates, asphalt overlay thickness and depth to location of the reinforcement from the surface (concrete thickness measurement) in bridge decks. The following activities were conducted:

- Review reports and data provided by Road Radar™ Ltd. Establish a usable database for analyses and comparative evaluations.
- Review reports and data provided by Infrasense, Inc. Establish a usable database for analyses and comparative evaluations.
- Review field notes compiled by ITD's onsite representative.
- Correlate each consultant's data and compare their results for the corresponding road and/or bridge segments.
- Evaluate all results with respect to the ITD's site-specific GTD. Establish data based trends and compare ground-truth data with the data collected from combination air-and-ground-coupled (A-G-C) method (Road Radar Ltd. technique) and the air-coupled (A-C) method (Infrasense, Inc. technique).
- Discuss the advantages and disadvantages of both systems and recommend the preferred GPR survey method/technique for ITD's design, construction and maintenance operations.
- Summarize findings of the research project in a publishable final report for the planning purposes of ITD.

4. PROJECT ORGANIZATION

The following BSU personnel were involved with this project and worked with ITD's Project Coordinator Mr. Robert Smith, P.E., Research and Assistant Materials Engineer:

Joseph C. Sener, Ph.D., P.E. Principal Investigator, Asst. Professor, Dept. of Civil Engineering
George A. Murgel, Ph.D., P.E., Co-Investigator, Asst. Professor, Dept. of Civil Engineering
Robert W. Hamilton, Ph.D., P.E., Independent Reviewer, Asst. Prof., Dept. of Civil Engineering
David R. Haws, Ph.D., P.E., Independent Reviewer, Asst. Professor, Dept. of Civil Engineering
Donald W. George, E.I.T., Civil Engineering Senior Student

5. GROUND PENETRATING RADAR NON-DESTRUCTIVE TESTING

RADAR is an acronym for "RAdio Detection And Ranging". Ground penetrating radar (GPR) is the general term applied to techniques which employ radio waves, typically in the 1 to 1000 MHz frequency range, to map structures and features buried in the ground. The development of GPR began in the late 1960's. Historically, GPR was primarily focussed on mapping structures in the ground; more recently GPR has been used in non-destructive testing of non-metallic structures. The applications are limited only by the availability of suitable instrumentation. GPR systems are typically deployed in the reflection manner. The earliest study on the use of GPR in areas related to civil engineering was reported in 1974.[3] GPR, more appropriately called short-pulse radar, is the electromagnetic analog of sonic and ultrasonic pulse-echo methods.[3]

In order to detect an object or a boundary some of the radio wave energy must be re-emitted. By detecting the scattered (re-emitted) energy, it is possible to locate and position the objects causing the energy scatter. This requires that there be a change in the electrical properties from the surrounding host material. GPR investigates the subsurface by making use of electromagnetic (EM) fields which propagate into the ground. EM fields, which are time varying, consist of coupled electric (E) and magnetic (M) fields.[4]. The manner in which the electromagnetic fields interact with natural materials controls how electromagnetic fields spread and are attenuated in the medium. In addition the variation in electrical properties gives rise to the observed subsurface reflections obtained with a GPR system.[4] In most geological situations, the electrical properties tend to be the most dominant factor controlling GPR responses. Magnetic variations are generally weak.[4]

An electric field in a material gives rise to the movement of an electric charge in that material. The charge (electric current) flow depends on the nature of the material. When an electrical field is applied, displacement of charge in a material causes an intrinsic dipole moment distribution in the material.[4] The charge separation is described in terms of a dipole moment density which is directly proportional to the applied electric field, and the proportionality constant is referred to as the "dielectric permittivity/dielectric constant" of the material.[4] The dielectric constant is always non-zero. Even in a vacuum, the permittivity takes on a finite value of 8.85×10^{-12} farads per meter.[4] The dielectric constants for common geologic materials are listed below.[4]

Material Type	Dielectric Constant
Air	1
Distilled Water	80
Fresh Water	80
Sea Water	80
Dry Sand	3-5
Saturated Sand	20-30
Limestone	4-8
Shales	5-15
Silts	5-30
Clays	5-40
Granite	4-6
Dry Salt	5-6
Ice	3-4

In geologic materials, the presence of water is one of the most important factors determining electrical properties. Water molecules have a natural intrinsic dipole moment. As a result, this gives the material a moderately high relative permittivity of 80 at low frequency, (i.e., typical geophysical application frequencies).[4] Depending on the percentage of water and air present in the pore space of the material matrix, the electrical properties of the material can be greatly varied. This strongly suggests that the presence of groundwater effects the obtained results by GPR. Organic contaminants in the ground complicate the electrical properties even further. As a result, GPR investigations which are governed by a process involving the propagation of EM energy through materials of different dielectric constants are strongly affected by the variation of dielectric constants with respect to the water content of the medium and the presence of contaminants in the host environment.

Proper design of GPR surveys is critical to success. Setting expectations and optimizing data acquisition to meet expectations requires planning. The following questions should be answered before deciding on the GPR survey implementation, or during evaluation of the effectiveness of the GPR survey:

- Within the range of GPR, what is the target depth?
- What is the anticipated target geometry, i.e., size and orientation?
- What are the anticipated target electrical properties, i.e., dielectric constants?
- What are the host material electrical properties, i.e., dielectric constants?
- What is the survey environment like, i.e., presence of metal structures, other radio frequency sources, accessibility, hazardous conditions, etc.?

6. GPR PAVEMENT APPLICATION PROCEDURES

The main components of a GPR system consist of a display/record/timing system with a transmitter and a receiver antenna. Typical data recorded by a GPR survey consists of an amplitude versus delay time. Events from three-dimensional space are mapped into their one-dimensional time record.[4] Coetzee, et al.,[5] provides the following brief description of the procedure:

> "GPR directs pulses of electromagnetic radiation into the ground/pavement structure. A portion of this energy is reflected back to the surface, and picked up by the GPR receiver, at each location in the pavement structure where a significant difference in electrical properties of the materials occur. The electrical property of interest is the material's dielectric constant. GPR is effective for pavement evaluations as long as there is sufficient contrast in the dielectric constant of the paving materials. Additionally, the dielectric constant is frequency dependent. The following dielectric ranges are typical for paving materials at a low frequency of approximately 1 GHz:

➢ Air	1
➢ Asphalt Surface / Black Base	5 to 6
➢ Concrete / Cement Stabilized Base	8 to 9
➢ Flexible Base	10 to 11 (highly moisture dependent)
➢ Water	80
➢ Steel	81

From the list above, it is evident that pavement layers composed of materials having significantly different dielectric constants can be identified. Pavement structures having multiple layers with similar dielectric constants are more difficult to evaluate, and it may not be possible to identify each individual layer and measure its thickness. Additionally, city streets often have utility patches and maintenance practices that can confuse data reduction."[5]

"The wavelength of a 1-gigahertz GPR system is approximately three inches. The thickness of layers approximately one-quarter of the width of the radar wavelength or greater can be resolved. Consequently, GPR systems cannot resolve pavement layers less than 1 inch in thickness. The 1-gigahertz system has a depth of penetration of approximately 24 inches. The penetration depth is a function of the overall dielectric constant of the pavement structure. Materials possessing a high dielectric constant tend to attenuate the radar signal, thereby decreasing its effective depth of penetration."[5]

"A 500-megahertz GPR system has a wavelength of approximately six inches. Since the signal has a longer wavelength, it can penetrate deeper into the pavement structure. The 500 MHz system is capable of measuring to depths of four to five feet, depending on the dielectric constant of the material. The trade-off is less thickness measurement capability with the 500 MHz system when compared to the 1 GHz system."[5]

Clemens, G.G.[6], after a careful review of the available GPR study results, provides the following:

"Assuming that the dielectric constant of a given material is uniform and known, the two-way transit time of microwave pulses through the material is directly proportional to the thickness of the material. The presence of observed range of errors in the results likely reflects the fallacy of the assumption inherent in this procedure that the material at all locations has the same relative dielectric constant and errors exceeding ± 0.25 inches are considered acceptable for compliance testing." [6]

"The success of thickness measurement using GPR depends on a reasonably detectable reflection from the backside (or the bottom) of the member (pavement slab), since this allows for the precise identification of the reflection and, therefore, the accurate measurement of the transit time. Conditions that would prevent the reflection from being precisely detected include the presence of the relatively high attenuation of the microwave pulses by the pavement materials, insufficient difference between the relative dielectric constants of the pavement materials (surface and base course), and pavements that are too thick. For some pavements, it is likely that there may by only small differences between the relative dielectric constants of the surface course, base course and the subgrade materials, so that this reflection would be very weak and difficult to identify. Consequently, prior to an actual inspection, it is generally difficult to predict how precise the GPR measurements will be in measuring the thickness of a particular pavement." [6]

"Short-pulse radar systems operate by transmitting a single pulse that is followed by a "dead time" in which reflected signals are returned to the receiver. A basic radar system consists of a control unit, a monostatic antenna (*i.e.*, an antenna that is used for both transmitting and receiving), an oscillographic recorder, and a power converter for direct current operation. A multi-channel instrumentation tape recorder is recommended due to the relatively fast rate at which the inspection has to be carried out. In operation, as the radiated pulses travel through the material, different reflections will occur at interfaces that represent changing dielectric properties. Each reflected electromagnetic pulse arrives back at the receiving antenna at a different time that is governed by the depth of the corresponding reflecting interface and the dielectric constant of the intervening material. A receiver circuit reconstructs the reflected pulses at an expanded time scale by a time-domain sampling technique. The resulting replicas of the received radar signals are amplified and further conditioned in the control unit before they are fed to an output. The analog output can be displayed on an oscilloscope, an oscillographic recorder, or a facsimile gray-scale graphic recorder. It can also be recorded on magnetic tape for future processing or analysis. On an oscilloscope or an oscillographic recorder, the received radar signals may appear similar to the waveform depending on the radar system used. The received signal consists of three basic components. At the top is the transmitted pulse that serves as a time reference. Immediately following the transmitted pulse is a strong surface reflection, the shape of which is indicative of the shape of the radar pulse transmitted by the antenna. Then, at a later time equal to the pulse travel time from the surface to an interface and back to the antenna, the interface reflection appears. The vertical scale is the time scale, which can be calibrated by a pulse generator that produces pulses at equally spaced time durations. If the wave speed in the material is known the time scale can be converted to a corresponding depth scale." [6]

7. GPR BRIDGE DECK CONDITION SURVEY PROCEDURES

Rehabilitation of asphalt-covered bridge decks require an accurate estimate of the asphalt overlay thickness across the bridge, the location and extent of deck scaling and delaminations, and the depth of concrete cover over the top layer of reinforcing steel. There are more than 578,000 highway bridges in the United States and more than 40 percent of them are structurally deficient or functionally obsolete.[7] The literature indicates that conventional GPR systems are capable of locating and characterizing the construction flaws and wear or age-induced damage in these structures without utilizing destructive testing methods. [8,9,10,11]

Condition assessment of asphalt overlaid bridge decks by GPR is performed at highway driving speeds ranging from 15 to 40 mph. The reflected signals from the top of the concrete is related to the concrete's dielectric constant, and the deterioration quantities are shown to be proportional to the variability of the concrete dielectric constant. [11]

"The percent deterioration is determined by first computing the dielectric constant of the concrete from the GPR data. The decks are surveyed in a series of multiple parallel passes, each at a different transverse position. For each pass of the deck, the percent of the pass which exceeds the mean dielectric constant plus a threshold is computed, and this percent is averaged for all passes. The percent deterioration is then computed from a formula which has been determined by correlation with actual deterioration conditions." [11]

Currently, bridge condition assessments are generally being done by visual inspection, tapping and chain dragging, and with a limited amount of physical testing (i.e., by taking cores.) These methods are laborious and not always reliable. In addition, the early stages of deterioration in asphalt overlaid concrete bridge decks and pavements is not detectable by traditional methods. Although core sampling provides reliable results, it also causes localized damage to the deck or pavement and hinders traffic. GPR offers a rapid and non-destructive method of measurement which is becoming increasingly popular. The results of the Ontario, Canada, Bridge Deck Condition Survey by GPR[9] showed that comparison of the GPR survey results against ground-truth data, which was collected after removal of the asphalt overlay prior to the GPR survey, revealed good reliability of results with respect to prediction of bridge deck delaminations and locating the areas of deteriorations.

8. GPR METHODOLOGIES USED IN THE IDAHO TRANSPORTATION DEPARTMENT STUDY

ITD's study considered whole-section length (Network Level), and 500-foot-long section length (Project Level) applications for pavements. Typically, the GPR system results provide pavement engineers with subsurface information for "project level" rehabilitation design or "network level" planning. The degree of detail and frequency of measurement depend on the requirements of the user. The study by ITD included both.

At the "project level", the objective was to gather detailed information for the selected segments of the project. The information included continuous subsurface profiles of the thickness of layers, including determination of base problems, subgrade anomalies, surface and sub-surface cracks, voids, debonding and weakened or stripped areas. One to three project level sections, 500 feet in length, were identified for detailed evaluation and correlation with GTD within each of the overall network level test sections. At the "network level", the objective was to locate pavement segment profiles and check expected performance by gathering sufficient continuous surface and base course thickness information for future planning purposes and budget estimates.[3]

ITD required the assessment of newly developed GPR technologies for both project and network level applications, including demonstration of the equipment operations, data analysis procedures, and comparison of the analyzed GPR data with measurements made by more traditional (destructive) means. A total of 8 road test sections and 3 bridge decks were identified and surveyed as part of this evaluation by ITD. Test sections represented a wide spectrum of network and project level applications, including interstate, principal and minor arterial in both urban and rural settings. ITD required a variety of GTD information for direct comparison between GPR and core measurements which consisted of coring road test sections at designated locations, logging the bore holes (to a maximum depth of 7 ft.) and obtaining samples from the materials encountered. [3]

GPR surveys employed either A-C or A-G-C systems, each with associated equipment and component software for interpretation of gathered pavement thickness data (i.e., pavement surface course and base course thickness). ITD provided the descriptions and locations of eight state highway test sections by functional class, route number, beginning and ending mileposts (MP), and whether the pavement type was flexible (asphalt concrete) or rigid (Portland cement concrete) pavement for the GPR technology application. The majority of the selected pavements

were asphalt concrete, except two pavement sections which were Portland cement concrete. ITD also provided a plan and procedures guide for collection of pavement thickness data at normal driving speeds, with no lane closures, for rural and urban highway sections. The plan addressed the speed limit variation from 35 mph to 55 mph on pavement surveys and 15 mph to 40 mph on bridge deck surveys. The total length of network lanes surveyed was 29.3 miles. The total number of 500-foot long sections surveyed was 16. [3]

Both GPR firms (A-C and A-G-C) were asked to provide the output and documentation of the process involved for statistical and visual validation on the highway network and project level analyses. Both GPR firms additionally had to describe their study results on pavement thickness data, and correlate the findings with the GTD obtained from ITD borings drilled in the designated locations of the GPR test sections. The correlation against the GTD was required to determine the accuracy (including both the network and project level data accuracy analyses) of these NDT systems. Both firms published preliminary reports prior to receiving the GTD.[3]

With respect to the three bridge deck studies, ITD provided plans and procedural guidelines for collection of bridge condition survey data. In addition, ITD drilled bridge decks at designated locations to collect GTD and performed chain-drag survey along with visual inspections.

The GPR Test Sections of the ITD study are provided in Appendix A. Network and Project Level GPR Surveys Roadway Test Sections are presented in Table 1, Appendix B. Location Map for GPR Road Test Sites is shown in Figure 1, Appendix C. The locations of Road Test Sites No. 1 through No. 8, inclusive, are shown in Figures 2 through 9, inclusive, in Appendix C. The location map for GPR Bridge Test Sites No. 1 through No. 4, inclusive is provided in Figure 10, Appendix C. Bridge Test Sites No. 1 and No. 2 were excluded from ITD Study prior to implementation of the study. Figure 11, Appendix C, shows the location map for GPR Bridge Test Site No. 5. Hence, Bridge Test Sites No. 3, No. 4, and No. 5 represent the bridges studied by GPR. Borehole location map for GPR bridge test sites is shown in Figure 12, Appendix C.

8.1 Air-Coupled (A-C) GPR System For Pavement Thickness Evaluation

This system employs the Pulse Radar, Inc. RODAR™ GPR equipment, coupled with Infrasense PAVLAYER™ and DECAR™ software.[2]

> "The GPR equipment used is designed for mobile applications involving the coverage of large distances and areas. The equipment is based on a 1 GHz air-coupled 'horn' antenna (called horn because of its outer appearance, and used in a non-contact manner as it is scanned over the pavement surface) positioned from 12 to 18 inches above the pavement surface. Non-contact arrangement allows for road surveys to be performed at normal driving speeds. It is claimed that for mobile applications the horn antenna is superior to the more familiar ground-coupled antenna, since it permits driving speed surveys and provides a surface reflection for calibration of the surface material dielectric constant. A typical horn antenna system generates 50 scans per second, with a pulse width of approx-

imately 1 nanosecond. The radar analog signal is transmitted to a PC-based data acquisition system where it is digitized and stored to hard disk or tape. A distance-measuring instrument, typically operated from the survey vehicle transmission, provides position pulses which are encoded into the digitized radar for location referencing. Large quantities of data are obtained quickly and processed efficiently by software programs which move sequentially through the digitized radar waveforms at a specified distance interval, computing the amplitudes and arrival times of the interface reflections which are related to pavement internal dimensions and properties. These amplitudes and arrival times are converted to layer thicknesses."[12]

"All data for this study for the project and network level surveys were collected by setting the horn antenna 18 inches above the pavement surface at normal driving speeds which ranged from 25 mph on urban roads to 55 mph on the interstate highways. No lane closures or traffic control were required. Data collection for project level survey included one at each wheel path and one in the center of the lane. The results of data analysis were presented as plots, maps and American Standard Code Information Interchange (ASCII) data files."[2]

"The pavement analysis was carried out by dividing each pavement into homogeneous sub-sections and identifying the layer boundaries and layer material types for each subsection. The data from this sub-sectioning is exported to an analysis program which automatically computes the layer thicknesses at a prescribed interval. Two output files are produced from this analysis – one for plotting, and one for database reporting. For each file, the user can specify the output data interval in feet meters, or miles, and an averaging interval around each output. For this project, the following intervals were used:"[2]

Survey Type	Basic Analysis Interval (ft.)	Plotting Interval (ft.)	Reporting Interval (ft.)
Project Level	1	5	50
Network Level	5	50	250

"Pavement thickness was analyzed for all the network surveys and for the right wheelpath data for the project level surveys. The right wheel path was used since it is where the cores were taken."[2]

8.2 Air-Ground-Coupled (A-G-C) GPR System for Pavement Thickness Evaluation

"This system employs the patent pending ROAD RADAR™ which is 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 'air-coupled' antenna is mounted on an adjustable boom above the pavement and measures thin pavement layers. The 'ground-coupled' antenna is mounted on a runner connected to the rear of the vehicle and measures deeper

layers and determines signal velocity. This combination of antenna configurations makes the system versatile, self-calibrating and reliable under a wide range of situations. All electronics are rack mounted inside the vehicle. The rack mounts include control and timing electronics for each sub-system, digitizing computer and monitor, and video sub-system. A comprehensive radar signal processing hardware and software provides the means to effectively combine the large volumes of raw data and allow automated interpretation to provide continuous multiple pavement layer thickness and velocity profiles. The data processing represents a synergism of many programming domains, effectively combining artificial intelligence, time domain digital signal processing, neural networks and pattern recognition. The patent pending approach determines signal velocity at each measurement point. The system measures the signal velocity to determine the thickness at each location by varying the geometry between the transmitter and the receiver.

Measuring the different signal travel times to a reflector at different known transducer geometries permits the signal velocity to be determined. The output of the data interpretation operation includes graphical radar profiles showing the data acquired during the survey. These profiles present the opportunity to examine the road for qualitative features as well. Such features include base course/subgrade constituent variations and anomalous areas. The Road Radar™ also uses a video system coupled with a distance measuring instrument, connected to the transmission of the vehicle to trigger the radar so that the system is not speed dependent and that the location of each measurement is very accurately known."[13]

"All network level surveys were conducted at approximately 40-45 mph. The right wheel path is surveyed since it is the track where the GTD cores were taken. The spatial sampling interval for all network level surveys was approximately 24 in., producing about 2640 samples per mile. Project level surveys were conducted at approximately 15 mph with a spatial sample interval of approximately 8 inches. This increased spatial resolution provided more details and extended automated radar data interpretation capabilities. Each wheel path and center of lane were surveyed for all project level lanes on a continuous basis."[1]

8.3 Bridge Deck Evaluation with (A-C) GPR System

"The bridge deck analysis is carried out using INFRASENSE's DECAR™ software using the following steps:

- Identification of the beginning and the end of the deck in each GPR file, and calibration of distance measurements against the known length and other markers within the deck;

- Identification of the asphalt overlay/concrete (depth to reinforcing steel) interface in the data for each survey pass;

- Setup of the analysis for all of the passes for a given bridge deck, running the analysis and checking the data;

- Computation of asphalt overlay thickness and concrete deterioration; and

- Computation of the depth of reinforcement using the passes with transverse antenna polarization.

The thickness of the asphalt overlay and the depth of reinforcing is then determined."[2]

8.4 Bridge Deck Evaluation with (A-G-C) GPR System

"All bridge surveys were conducted incorporating a sequential single lane closure methodology. Full coverage was provided with multiple transverse parallel lines, each with an offset of 20 inches and a longitudinal sampling resolution of approximately 0.5 inches. The traffic control support vehicle provided by ITD facilitated effective sequential lane closures. A laser based positioning system was used to ensure accurate lateral positioning during the multiple parallel line surveys for each structure. This technique typically produces maximum lateral deviations of less than ± 4 inches during surveys."[1]

The following were measured and/or interpreted by using the software components of the system:

- Asphalt wearing course (asphalt overlay) thickness over the bridge deck structure;

- Portland cement concrete cover over the top layer of the reinforcing steel in the bridge structure; and,

- Location and aerial extent of three separate anomaly types as detected by GPR, including surface anomalies, structural anomalies and subsurface anomalies.

9. SUMMARY OF GPR TEST RESULTS

"GPR signatures constitute those identifiable characteristic features of radar reflections which permit the classification of subsurface events and anomalies when presented with graphical GPR data. An overview is given here to address those signatures which may be considered common:

- Layer interface events, the interface between dissimilar materials, produce horizontal multicolored bands. For example: for the Road Radar™ system these interface signatures consist of three bands of opposite shading (black-white-black or white-black-white on grey scale plots). The

intensity of the band colors is indicative of the signal strength, which reflects a relative measure of the adjacent layer material dielectric contrast (very dissimilar materials produce strong contrasts).

- Transverse crack events may be identified as vertical stripes in the graphical radar data, more severe cracks appear as wider vertical stripes, and the crack depth may be determined by the depth of the vertical stripe signature into the road structure.

- Void events may be identified as localized (spatially narrow) high intensity reflectors typically coincident with a horizontal layer interface and a vertical crack. The high intensity reflector arises from a strong dissimilarity between the host layer material and either the air filled or water filled voids.

- Reinforcing steel events (bars oriented perpendicular to the direction of travel) appear as closely spaced hyperbolas (approximated by inverted V's). The apex of the inverted V identifies the actual location of the bar. Therefore, the characteristic pattern of a series of closely spaced point reflectors (i.e., a reinforcing steel mat) appears as a series of ^^^^^^^ in the graphical radar data for the Road Radar™ system."[1]

It is noted that GPR test results and their interpretation requires judgement. The interpreter must use judgement to distinguish the bound bituminous layers from the unbound base layers. This judgement could be based on past experience, familiarity with local construction practice and pavement conditions. Base course layers are typically thicker and more irregular than the asphalt layers, and asphalt/base reflection is stronger than the base/subgrade reflection. Hence, data from cores may help and assist in making layer thickness interpretations based on the material type as a function of the dielectric constant. In this study, the ITD supplied bore hole/core data was used as GTD to confirm GPR system measurements both for the pavement and bridge deck investigations. ITD also provided chain-drag data for three investigated bridges. ITD's core information is summarized and provided in Appendix A.

9.1 Pavement Thickness Results from (A-C) GPR Survey

Pavement thickness (both surface and base course) was analyzed by Infrasense, Inc. for the network and project level surveys and for the right wheel path data for each 500 foot "project" test section. The right wheel path was used since it is where the cores were taken. Plots of pavement layer thickness were provided. The core data of the ITD was incorporated into these plots. The network plots showed two different material types, asphalt and base, for the GPR analysis. The project section plots showed three different layer types as determined from the GPR analysis: asphalt, concrete, bituminous/base and granular base. The layer thicknesses are calculated from the raw data and the results are presented as ASCII files and plots.

Infrasense Inc. reported that the accuracy achieved using GPR for asphalt and concrete pavement thickness was consistent with that achieved in their previous studies. The accuracy of GPR for base layer thickness evaluation was found more difficult to assess, since GPR detects boundaries within the base layer that may not be reported in borings, and boring data for unbound material thickness may not be precise. It was pointed out that it was difficult to identify the reflection from the bottom of concrete in the GPR data, and the thickness calculation could only be made at those locations where the interface could be detected.

Test section Site No. 6 (I84EB) from MP 97 to MP 98+500 includes asphalt treated leveling course under concrete as a base course. Test section Site No. 8 (US 95) from MP 88 to MP 90+500 includes ¾ inch aggregate base course. The actual base is about 12 inches of open graded shotrock on I-84 and about 2 to 3 feet of open graded shotrock on US 95. Infrasense Inc's study did not detect the presence of the base course (open graded) material in these test sections.

Infrasense, Inc.'s evaluations and the correlation of the GPR pavement surface course data with the ITD's GTD showed high Correlation Coefficients (R^2), comparable to results obtained in their previous studies. The same was not true for the base course evaluations.

9.2 Pavement Thickness Results From (A-G-C) GPR Survey

Road Radar Ltd. analyzed the collected pavement thickness GPR data, correlated the data with the ITD's GTD, and pointed out that the core data overlaid on network and project level surveys may or may not reference the same location laterally across the roadway, and that this positional uncertainty may increase errors in the correlation between the two measurements. Road Radar Ltd. claimed that the obtained accuracy was adequate without GTD.

With some exceptions, a high correlation of core data and GPR measured surface course pavement thickness was reported by Road Radar Ltd. with good correlation results on prediction of the granular base layer thickness. Some of the GPR data was capable of detecting wear surfaces consisting of two separate lifts of asphalt. At some road sections, the GPR data indicated an extremely variable base structure with multiple base layers and a combined thickness varying between 6 and 24 inches (with sub-base layers being detected as deep as 34 inches). At certain locations it was found that the GPR accurately detected the core information for the structural interface within the granular base/sub-base layers. However, it was also reported that the GPR was not able to detect a granular base/sub-base structural layer under the Portland cement concrete pavement and asphalt treated base layers. This was reported as not unexpected due to high attenuation expectancy in the regions of Portland cement concrete. It was also reported that high attenuations also occurred at some test sections in an open graded base course or in subgrade materials which appear to be clay/till based fines. Very little signal energy was returned for depths of greater than 24 inches in such subgrade materials.

Previously mentioned test sections, Site No. 6 and Site No. 8, were detected and reported by Road Radar™ only after providing GTD and re-evaluation of the data with an applicable software adjustments to account for the discrepancies. Using the GTD provided by ITD, a number of direct comparisons between two measurements were possible after employing linear regression analysis by Road Radar Ltd. Graphical GPR versus core measurement comparisons were segregated into project and network level surveys for individual comparisons of wearing surface (surface course) and base layer (base course) measurements for reporting purposes.

9.3 Bridge Deck Study Results From (A-C) GPR Survey

The bridge deck data were analyzed by Infrasense, Inc. to determine the depth of asphalt overlay and reinforcement. The variations in concrete dielectric constant was used to plot areas of potential deterioration. The depth of asphalt overlay and concrete (depth to reinforcement) were calculated and results were presented as contour plots for 3 bridge decks. It was reported that asphalt overlay thickness as determined from GPR data agreed with the core data. The minimum thickness resolution for the GPR system used in this study was 1 inch, and the boundaries of less than 1 inch thick overlays could not be determined. It was reported that the depth of reinforcement as determined by GPR did not agree as closely with the core data. It was concluded that the results could have been improved by using a two antenna survey - one longitudinally polarized for the concrete condition assessment and one transversely polarized for the concrete condition assessment and the rebar depth evaluation.

Results from chain-drag data and cores were provided by the ITD on selected lanes of each bridge deck. In order to compare the GPR survey results with the chain drag surveys, calculations were made in terms of the percentage of the total area deteriorated. This percentage was then compared to the percentage deterioration determined from the GPR survey in the same areas of each bridge deck. It was reported that the bridge deck deterioration quantities from the GPR survey agreed closely (within 5%) with the chain-drag quantities for one of the bridge decks while the quantity agreement was not as good for the other two decks. The relative condition of the three bridge decks, as determined from GPR survey, reportedly agreed with that determined from a chain-drag survey.

9.4 Bridge Deck Study Results From (A-G-C) GPR Survey

"The reported parameters for each bridge structure surveyed as part of the ITD radar evaluation, included structural measurements (wearing surface, concrete cover over rebar) and extensive plan maps of type and areal extent of detected defects. The reported defects were: surface anomalies (occurring at the asphalt overlay wearing surface boundary) indicative of debonding or surface spalling, subsurface anomalies (at the depth of the top mat of rebar) indicative of structural delamination, and structural anomalies indicating localized variations in the radar data typically due to structural components common to bridge decks (expansion joints, web/diaphragm tie-ins, slab joints). For all bridge structures, defect area results were reported as a percentage of the total surveyed area. This was

fundamentally different from the total deck area as determined by the plan drawings for the structure. The surveyed area as defined, was calculated by subtracting from the total area of the deck (the product of the overall length and width for the structure) any areas not explicitly defined for vehicular traffic. The surveyed area included shoulders but excluded sidewalks, barriers, and medians. It was felt that defect areas to total survey area ratios would be most meaningful, however total defect area also was presented in the event that the calculation of other ratios was desired."[1]

It was reported that available core data has confirmed the GPR results with rebar cover of variable thickness for the structures with an average thickness of nominally 2 inches. GPR surveys indicated asphalt overlay wearing surface thickness below the minimum resolution of the GPR system (typically 1 inch).

The detailed anomaly maps obtained from the GPR data of the bridge deck structures revealed limited wearing surface interface anomalies, and slightly fewer subsurface anomalies. It was reported that, typically, the defects were distributed throughout the deck and correlated well with areas of diminished rebar cover. The general trends in the GPR defect plan map were found by Road Radar™ to correlate well with the available chain-drag data.

10. EVALUATION OF (A-C) AND (A-G-C) GPR RESULTS AND SUMMARY OF FINDINGS

The researchers at BSU summarized the available GPR survey data and analyzed it with the GTD obtained by the ITD. The data was grouped and summarized for easy reference in tabular forms. The data for the comparison of the surface course thickness and base course thickness measurements obtained by Infrasense and Road Radar™ for pavement test sections with the GTD are provided in Tables 2 and 3, in Appendix B, respectively.

The data for comparison of the asphalt overlay and the depth to reinforcing steel (concrete thickness) measurements obtained by Infrasense and Road Radar™ for bridge test sections with the GTD are shown in Table 4, in Appendix B.

10.1 Pavement Survey Results and Summary of Findings

The accuracy of the GPR systems can be assessed by a correlation comparison with available GTD. The comparisons included in this research study utilized linear regression analysis. All core measurements, forming the basis or the comparisons for both project and network level surveys for all sites, are presented with the corresponding GPR measurements. Graphical GPR versus core measurement comparisons have been segregated into project and network level surveys for individual statistical comparisons of surface and base course layer measurements. [3]

In compilation of the GPR data, the reported values in the final reports (References 1 and 2) were taken directly and inserted into the appropriate tables. In the event that no specific values were provided at locations where GTD data was obtained,

such as the case for the network level survey of Infrasense, appropriate GPR plots in the final report were used to obtain the corresponding GPR values for the designated GTD locations. Correspondence with the Infrasense personnel also suggested a possibility of comparing the network level GPR survey data at the 500 foot test sections with the average of the cores (there are usually 3 per section), so that the Infrasense's averages may be compared with the GTD averages. Careful review of the results of this trial indicated no significant improvement. It was then decided that the approach used in this study was indicative of the representative evaluation since both the GPR (obtained from the data plots) and the GTD values which were being compared with the network survey GPR results represented the appropriate measurements at the same locations.

Figures 13, 14 and 15 in Appendix C represent project level surveys of the surface course pavement thickness for all project sites. Figures 16, 17 and 18, in Appendix C, represent network level surveys of the pavement surface course for all project sites. Figures 19, 20 and 21, in Appendix C, represent project level surveys of the thickness of the pavement base course for all project sites. Figures 22, 23 and 24, in Appendix C, represent network level surveys of the base course pavement thickness for all project sites.

Figures 13, 16, 19, and 22 represent comparisons of the GTD with Infrasense's GPR data. Figures 14, 17, 20, and 23 represent comparisons of GTD with Road Radar's GPR data. Figures 15, 18, 21, and 24 represent comparisons of Infrasense's GPR data with Road Radar's GPR data. The data plotted in each figure was subjected to a best-fit linear regression analysis and calculation of a coefficient of correlation (R^2).

The variations of the GPR surface course thickness measurements from the GTD, both for the project and the network level roadway test section surveys are provided in Tables 5 and 6 in Appendix B, respectively. Histograms of variations between: Infrasense and GTD, Road Radar™ and GTD, and Infrasense and Road Radar™ for project level surface course thickness measurements for all sites are respectively shown in Figures 25, 26, and 27 in Appendix C. Histograms of variations between: Infrasense and GTD, Road Radar™ and GTD, and Infrasense and Road Radar™ for network level surface course thickness measurements for all sites are provided in Figures 28, 29, and 30 in Appendix C, respectively.

The variations of the GPR base course thickness measurements from the GTD, both for the project and the network level roadway test section surveys are provided in Tables 7 and 8 in Appendix B, respectively. Histograms of variations between: Infrasense and GTD, Road Radar™ and GTD, and Infrasense and Road Radar™ for project level base course thickness measurements for all sites are shown in Figures 31, 32, and 33 in Appendix C respectively. Histograms of variations between: Infrasense and GTD, Road Radar™ and GTD, and Infrasense and Road Radar™ for network level base course thickness measurements for all sites are provided in Figures 34, 35, and 36 in Appendix C, respectively.

The summary of the calculated correlation coefficients (R^2) and their evaluations follow. Correlation coefficients are calculated from the linear regression analyses of the data obtained by GPR methods used in this study and their correlations with the GTD of ITD, as shown in Figures 13, 14, 16, 17, 19, 20, 22 and 23. The results are presented below:

Figure No.	Measured Thickness	Survey Level	GPR Method	Correlation Coefficient (R^2)	Evaluation of Correlation
13	SC	P	(A-C)	0.9627	Very High
14	SC	P	(A-G-C)	0.9778	Very High
16	SC	N	(A-C)	0.6546	High
17	SC	N	(A-G-C)	0.9498	Very High
19	BC	P	(A-C)	0.0004	Negligible
20	BC	P	(A-G-C)	0.1854	Low
22	BC	N	(A-C)	0.0879	Negligible
23	BC	N	(A-G-C)	0.2416	Moderate

Legend: SC = Surface Course BC = Base Course A-C = Air Coupled
P = Project Level N = Network Level A-G-C = Air-Ground-Coupled

Negligible = $R^2 < 0.1$
Low = $0.1 < R^2 \leq .2$
Moderate = $0.2 < R^2 \leq .6$
High = $0.6 < R^2 \leq .9$
Very High = $R^2 > 0.9$

The summary of calculated average deviations, in percent and in inches, between the compared pairs of GTD and GPR measurements are shown below:

Figure No.	Measured Thickness	Survey Level	Compared Relations ( ) minus ( )	Average Deviation	
				Percent	Inch
13	SC	P	(A-C) - (ITD/GTD)	2.5	0.13
14	SC	P	(A-G-C) - (ITD/GTD)	4.7	0.31
15	SC	P	(A-C) - (A-G-C)	--	-0.11
16	SC	N	(A-C) - (ITD/GTD)	4.5	0.06
17	SC	N	(A-G-C) - (ITD/GTD)	9.8	0.53
18	SC	N	(A-C) - (A-G-C)	--	-0.44
19	BC	P	(A-C) - (ITD/GTD)	-6.7	-0.92
20	BC	P	(A-G-C) - (ITD/GTD)	13.2	0.19
21	BC	P	(A-C) - (A-G-C)	--	-1.08
22	BC	N	(A-C) - (ITD/GTD)	45.9	0.88
23	BC	N	(A-G-C) - (ITD/GTD)	0.02	-0.29
24	BC	N	(A-C) - (A-G-C)	--	0.50

Legend: SC = Surface Course BC = Base Course A-C = Air Coupled
P = Project Level N = Network Level A-G-C = Air-Ground-Coupled

Figures 13, 14, and 17, with average deviations of 2.5, 4.7, and 9.8 percent respectively, were found to have high correlation coefficients (R^2) indicating statistical reliability of the best-fit regression. The level of accuracy achieved by using GPR for surface course pavement thickness measurements is consistent with that reportedly achieved in previous studies.[2] Figure 15 was also found to have a relatively high correlation coefficient confirming the statistical reliability of the correlation.

Figures 13, 14, 15, and 16 have line slope values close to 1.0, indicating an almost direct proportional relationship between the compared relations, i.e., the GPR-based results match very closely to the GTD data obtained by coring. The remaining figures, 18 through 24, indicate large data scatter with low coefficients of correlations, suggesting low statistical relationships between the compared values. [3]

The comparison of results from Figures 13 and 14 indicate that both A-C and A-G-C GPR systems are equally capable of predicting GTD for project level surface course thickness measurements. Figure 15 also suggests almost equal capability between A-C and A-G-C GPR systems in estimating the thickness of the surface course as obtained during project level GPR survey. However, results from both GPR systems at the network level surveys of the pavement surface course, as shown in Figures 16 and 17, appear to indicate an overestimation (between 4.5 and 9.8 percent) of the thickness of surface course pavement,[3] although A-G-C system detects GTD of network level surface course pavement thickness with much higher reliability than the A-C system. Figure 18 shows that the A-G-C GPR system slightly overestimates the surface course thickness obtained from the network level survey compared to the A-C GPR system-based surface course results.[3]

The evaluations of Figures 19, 20, and 21 for project level, and Figures 22, 23, and 24 for network level, base course pavement thickness measurements indicate that both GPR systems appear not to be accurately predicting the GTD within the expected ranges.[3] These results seem inconsistent with the values reported in previous studies. [2]

As previously explained, GPR systems used in this study did not detect the open graded base course material beneath the concrete slab pavement. However, the A-G-C system was able to report the detection after providing the GTD, and re-analyzing the collected data upon making software adjustments to account for discrepancies. The comparison of the A-C and the A-G-C system base course results suggests that the A-G-C system predicts the GTD with more reliability than the A-C system.

Additional statistical analyses of the data was performed using Pearson's Correlation Coefficient (r).[14] The results are summarized in Table 9, Appendix B. The interpretation of the Table 9 results is also presented in Table 10, Appendix B. The evaluation of the data suggests good, dependable (high to very high) relationships between GPR and GTD for measurements of the thickness of the surface course. Base course thickness measurements appear to have only a minimal (negligible to moderate) relationship between GPR and GTD. [3] It should be noted that (R^2) values indicated on Figures 13 through 24 are correlation coefficients used in linear regression analysis. The correlation coefficient (R^2) is same as the Coefficient of Determination (r^2) as used in Table 9. More information is available in Reference 14 (pp. 224 – 225) about Pearson's Correlation Coefficient (r) and the Coefficient of Determination (r^2) which is the square of the Pearson's Correlation Coefficient (also known as the Correlation Coefficient in some other references).

10.2 Bridge Deck Survey Results and Summary of Findings

The bridge deck GPR survey results are analyzed in a manner similar to the pavement survey. The variations of the GPR asphalt overlay thickness measurements from the GTD for bridge test sections are provided in Table 11 in Appendix B. The histogram of variations between: Infrasense and GTD, Road Radar™ and GTD, and Infrasense and Road Radar™ for asphalt overlay thickness measurements for all bridge sites are shown in Figures 37, 38, and 39, in Appendix C, respectively.

The variations of concrete thickness (depth to reinforcing steel) measurements from the GTD for bridge test sections are provided in Table 12 in Appendix B. The histogram of variations between : Infrasense and GTD, Road Radar™ and GTD, and Infrasense and Road Radar™ for depth to reinforcing steel (concrete) measurements for all bridge sites are shown in Figures 40, 41, and 42, in Appendix C, respectively.

The bore hole location maps for three investigated bridge sites are shown in Figure 12. The core data obtained from boreholes (GTD) by ITD are compared with the GPR bridge deck survey results of both Infrasense and Road Radar™. These comparisons are presented in Figures 43 through 48 inclusive. The profiles of asphalt overlay thickness measurements for all bridge deck sites as obtained by ITD, Infrasense and Road Radar™ are shown in Figures 43, 44, and 45, in Appendix C. The profiles of depth to reinforcing steel (concrete) measurements for three bridge deck sites as obtained by ITD, Infrasense and Road Radar™ are shown in Figures 46, 47, and 48, in Appendix C.

It is observed that both (A-C) and (A-G-C) systems attempted to predict the ITD's GTD with respect to asphalt overlay thickness and depth to reinforcing steel measurements. However, it must be noted that both GPR systems have a limited capability in matching the GTD.

With respect to bridge deck condition survey evaluations, both GPR systems claimed somewhat close agreements with the ITD's chain-drag data. Surface anomalies occurring at the wearing surface boundary were assessed and reported comparatively in percentage of the total area deteriorated. The researchers of this study made every effort to match the reported values. It is noted that subjectively evaluated chain-drag data may not be reliably compared with the GPR assessments. It is also expected that the chain-drag information may be misleading and can be influenced by delamination of the asphalt wearing surface and the concrete deck, and unless the asphalt overlay is removed the bridge deck deterioration data may not be accurately obtained by using GPR systems.

11. CONCLUSIONS AND RECOMMENDATIONS

The research objective of this project was to evaluate the effectiveness of GPR as a NDT method component of a highway-pavement and bridge deck structural evaluation system in Idaho. The knowledge of pavement layer thickness is needed for highway network analysis to establish load carrying capacities and develop rehabilitation and maintenance priorities. Previously, the acceptable methods for pavement-thickness measurements include test pits and

borings to obtain core samples. These methods are time consuming, intrusive to traffic and destructive to the pavement system. The GPR systems provide a relatively low-cost, and reasonably reliable alternative to coring.[3]

The study has shown that reasonably accurate, dependable determination of pavement surface course layer thickness can be achieved using a normal driving speed data collection method by either A-C or A-G-C based GPR NDT systems.[3] The results indicate that, for both systems, project level surveys provide higher quality and more accurate data in comparisons to the network level GPR surveys. Base course thickness measurement results of both the project and the network level surveys indicate that both GPR technologies are capable of providing similar results.[3] The reported base course pavement thickness values appear to deviate significantly from the GTD, suggesting that the proper estimation between surface and unbounded base course layers will require occasional cores for conditions encountered in Idaho.[3] This study indicates that the A-G-C system predicts the base course GTD with more reliability than the A-C system, although predicted values deviate from the GTD. The difficulty in measuring base course thickness with GPR in Idaho may have been due to the nature of the subgrade. In many instances it has been standard practice to replace deteriorated areas in the subgrade with predominantly granular open graded material, which could affect the dielectric contrast between the base course and the subgrade. This will result in interpretations either as the full base course thickness, or conversely, the real bottom of the base course may not produce a repeatably clear contrast with the subgrade, suggesting that inaccuracies in the base course thickness data could be more of a data interpretation problem, and could only be confirmed by periodic GTD. On the other hand, it should also be remembered that, while obtaining GTD, removal of an intact core from base course material may also be difficult due to auguring and change in material color and texture which could also affect the process of obtaining accurate GTD.

With regard to bridge deck test section survey results, it can be concluded that objective comparisons with technical reliability can not be made between GPR data of the two systems used and the chain-drag data collected in the determination of the bridge deck condition survey. The chain-drag data may be misleading since it may be influenced by delaminations between asphalt overlay and the concrete deck. In addition, depth to reinforcing steel and asphalt overlay thickness measurements obtained by both GPR systems are not reliable and indicate deviations from the GTD which is considered sufficiently accurate for comparison purposes.

The GPR data processing and the interpretation techniques used are still in their infancy and are being continuously revised and upgraded. It is the opinion of this report's researchers that the approach to use GPR systems should be flexible and calibrated with GTD to increase the reliability and the relative accuracy of the collected 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. Typically, 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, although it has been noticed that the A-G-C system (Road Radar™) is capable of predicting the GTD more accurately than the A-C system (Infrasense).

- 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 depth to reinforcing steel (concrete thickness) and the asphalt overlay thickness at bridge decks should include cores to provide reliability for collected GPR data.

- The reliability of the GPR bridge deck condition survey evaluation results can not be assessed objectively.

12. ACKNOWLEDGEMENT

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APPENDICES

APPENDIX A:	**GROUND PENETRATING RADAR TEST SECTIONS OF THE IDAHO TRANSPORTATION DEPARTMENT STUDY AND CORE DATA**
APPENDIX B:	**TABLES**
APPENDIX C:	**FIGURES**

APPENDIX A

GROUND PENETRATING RADAR

TEST SECTIONS

OF

THE IDAHO TRANSPORTATION DEPARTMENT STUDY AND

BORING DATA

GROUND PENETRAING RADAR TEST SECTIONS OF ITD STUDY

BRIDGE DECKS:

3.) **US 20/26 (Broadway Ave.) over UPRR and New York Canal.**
Structure No. 02020D 52.54
US 20/26 Milepost 52.54
Concrete Deck with2 inch asphalt overlay
Length - 302 ft. Width - 83.7 ft.

4.) **US 20/26 (Broadway Ave.) over I-84 (Broadway Interchange)**
Structure No. 02020D 52.72
US 20/26 Milepost 52.72
Concrete Deck with 1 inch asphalt overlay
Length - 220 ft. Width - 74.3 ft.

5) **I-184 over Franklin Rd. (Franklin Interchange) - WBL Only**
Structure No. 18070A 1.04
I-184 Milepost 1.04
Concrete Deck with 1 inch asphalt overlay
Length - 400 ft. Width - 55.1 ft.

NOTE:

- All structures are within the City of Boise, District 3, Idaho Transportation Department.
- BRIDGE TEST SITE NOS. 1 AND 2 WERE EXCLUDED FROM THIS STUDY.

ROADWAY TEST SECTIONS:

1. **SH 16, Ada County Line to Sand Hollow Rd.**
   Mileposts 8.359 to 11.960, (Ascending Direction)
   Minor Arterial, Asphalt Surface
   Includes 3, 500 ft. long "Project Level" Sections.

2. **US 20, Canyon County Line to Jct SH-55**
   Mileposts 32.283 to 40.229, (Ascending Direction)
   Principal Arterial, Asphalt Surface (0.3' Overlay, June, 1995)
   Includes 3, 500 ft. long "Project Level" Sections

3. **SH 44, Intersection State and Knox Street to Jct SH-16**
   Mileposts 10.771 to 12.298, (Ascending Direction, Traffic Lane)
   Minor Arterial, Asphalt Surface
   Includes 1, 500 ft. long "Project Level" Section

4. **I-84, Meridian City Limit to Ridenbaugh Canal**
   Mileposts 44.960 to 46.770. (Westbound, Inside Lane only)
   Interstate, Concrete Surface w/Asphalt-Treated Permeable Base
   Includes 1, 500 ft long "Project Level" Section

5. **I-84, "A" Line Canal to Maintenance Cross-over**
   Mileposts 5.968 to 12.610, (Eastbound Traffic Lane)
   Interstate, Asphalt Surface, 0.4' Overlay, 1985
   Includes 2, 500 ft long "Project Level" Sections

6. **I-84, Interchange #95 to Interchange #99**
   Mileposts 96.153 to 99.570, (Eastbound Traffic Lane)
   Interstate, Concrete Surface, Open graded base
   Includes 2, 500 ft long "Project Level" Sections

7. **I-84B, Caldwell Blvd, N. Midway to Homedale Rd.**
   Mileposts 53.842 to 54.468, (Eastbound, Outside Lane)
   Principal Arterial Business Rt., Asphalt Surface.
   Includes 1, 500 ft long "Project Level" Sections

8. **U.S. 95, Milepost Eq. Marker to N. End Devils Elbow**
   Mileposts 86.600 to 90.300 (Northbound Traffic Lane)
   Principal Arterial, Asphalt Surface, Open Graded Base
   Includes 3, 500 ft. long "Project Level" Sections

Total Lane Miles - 29.27 Network Level Total Project Level Sections - 16

BORING DATA FOR GROUND PENETRATING RADAR TEST SECTION PROJECT # SPR-STP-0010(018) KEY # 5961 FUNCTION CODE-RT, RESEARCH PROJECT 119

Roadway	Mile Post	Offset	Depth to Bottom	Layer Thickness	Description	Moisture Content	Remarks
US – 95	88 + 0′	9.5′ RT	0.34′	0.34′	Plantmix		
			0.75′	0.41′	Crushed Aggregate Base		
			3.10′	2.35′	Open Graded Shot Rock Base		
			7.00′	BOH	Silty Clay	27.0%	Moist Test @ 3.5′
US – 95	88 + 500′	10.1′ RT	0.33′	0.33′	Plantmix		
			0.87′	0.54′	Crushed Aggregate Base		
			3.00′	2.13′	Open Graded Shot Rock Base		
			7.00′	BOH	Silty Clay	23.8%	Moist Test @ 3.2′
US – 95	89 + 0′	16.7′ RT	0.31′	0.31′	Plantmix		
			1.00′	0.69′	Crushed Aggregate Base		
			3.00′	2.00′	Open Graded Shot Rock Base		
			7.00′	BOH	Silty Clay	23.7%	Moist Test @ 3.3′
US – 95	89 +500′	16.8 RT	0.34′	0.31′	Plantmix		
			0.80′	0.46′	Crushed Aggregate Base		
			3.00′	2.20′	Open Graded Shot Rock Base		
			7.00′	BOH	Clay	67.5%	Moist Test @ 3.3′
US – 95	90 + 0′	10.2′ RT	0.31′	0.31′	Plantmix		
			0.75′	0.44′	Crushed Aggregate Base		
			2.20′	2.55′	Open Graded Shot Rock Base		
			7.00′	BOH	Clay	42.4%	Moist Test @ 3.5′
US – 95	90 + 500′	10.3′ RT	0.31′	0.31′	Plantmix		
			0.75′	0.44′	Crushed Aggregate Base		
			3.00′	2.25′	Open Graded Shot Rock Base		
			7.00′	BOH	Silty Clay	25.6%	Moist Test @ 3.4′

NOTE: Open Graded Shot Rock Base is 3 inch minus - #4 plus quarried crushed or screened rock, part of Pavement Section.

BOH = Bottom of Hole

BORING DATA FOR GROUND PENETRATING RADAR TEST SECTIONS

Roadway	Mile Post	Offset	Depth to Bottom	Layer Thickness	Description	Moisture Content	Remarks
I – 84 B	54 + 0′	20.2′ RT	0.60′	0.60′	Plantmix		
			1.30′	0.70′	Crushed Aggregate Base		
			1.60′	0.30′	Caliche		
			5.00′	BOH	Silt	20.1%	Moist Test @ 2.1′
I – 84B	54 + 130′	19.9′ RT	0.30′	0.30′	Plantmix		
			1.10′	0.80′	Crushed Aggregate Base		
			1.90′	0.80′	Granular Sub-base		
			5.00′	BOH	Sandy Silt	12.4%	Moist Test @ 2.2′
I – 84 B	54 + 500′	19.6′ RT	0.40′	0.40′	Plantmix		
			1.00′	0.60′	Crushed Aggregate Base		
			2.40′	1.40′	Granular Sub-base		
			5.00′	BOH	Sandy Silt	11.0%	Moist Test @ 2.6′
SH – 44	11 + 0′	10.2′ RT	0.40′	0.40′	Plantmix		
			0.95′	0.55′	Crushed Aggregate Base		
			1.25′	0.30′	Granular Sub-base		
			5.00′	BOH	Silty Gravel	8.8%	Moist Test @ 1.6′
SH – 44	11 + 500′	10.6′ RT	0.45′	0.45′	Plantmix		
			0.80′	0.35′	Crushed Aggregate Base		
			1.10′	0.30′	Granular Sub-base		Moist Test @ 1.8′
			3.30′	2.20′	Silty Gravel	7.9%	Refusal @ 3.3′

BORING DATA FOR GROUND PENETRATING RADAR TEST SECTIONS

Roadway	Mile Post	Offset	Depth to Bottom	Layer Thickness	Description	Moisture Content	Remarks
I – 84 EBL	97 + 0′	7.6′ RT	1.10′	1.10′	Concrete		
			1.40′	0.30′	Permeable Plantmix Base (1)		
			2.20′	0.80′	Open Graded Shot Rock Base		Geotextile @ 2.2′
			4.80′	BOH	Silty Gravel – Small < 1″	9.7%	Moist Test @ 2.5′
I – 84 EBL	97 + 500′	8.2′ RT	1.15′	1.15′	Concrete		
			1.50′	0.35′	Permeable Plantmix Base (1)		
			2.20′	0.70′	Open Graded Shot Rock Base		
			3.80′	1.60′	Silty Sand w/ Caliche	14.5%	Refusal @ 3.8″
I – 84 EBL	98 + 0′	8.4′ RT	1.05′	1.05′	Concrete		
			1.35′	0.30′	Permeable Plantmix Base (1)		
			2.20′	0.85′	Open Graded Shot Rock Base		Refusal @ 3.2′
			3.20′	1.00′	Silty Sand w/ Caliche	15.4%	Moist Test @ 2.5′
I – 84 EBL	98 + 500′	8.4′ RT	1.00′	1.00′	Concrete		
			1.30′	0.30′	Permeable Plantmix Base (1)		
			2.30′	1.00′	Open Graded Shot Rock Base		Refusal @ 3.4′
			3.40′	1.10′	Silty Sand	7.7%	Moist Test @ 2.6′
I – 84 WBL	46 + 0′	29.4′ L	1.21′	1.21′	Concrete		
			1.60′	0.39′	Asphalt Treated Perm Base		
			1.80′	0.20′	Crushed Aggregate Sub-base		
			5.00′	BOH	Gravel	5.6%	Moist Test @ 2.5′
I – 84 WBL	46 + 500′	29.5′ L	1.22′	1.22′	Concrete		
			1.50′	0.28′	Asphalt Treated Permeable Base		
			1.80′	0.30′	Crushed Aggregate Sub-base		
			5.00′	BOH	Gravel	10.0%	Moist Test @ 2.4′

BORING DATA FOR GROUND PENETRATING RADAR TEST SECTIONS

Roadway	Mile Post	Offset	Depth to Bottom	Layer Thickness	Description	Moisture Content	Remarks
I – 84	8 + 0′	8.8′ RT	0.65′	0.65′	Plantmix		Core Broken
			1.00′	0.35′	Crushed Aggregate Base		
			1.50′	0.50′	Granular Sub-base		
			5.00′	BOH	Fine Sand w/ Clay Nodules	14.5%	Moist Test @ 2.4′
I – 84	8 + 500′	8.4′ RT	0.74′	0.74′	Plantmix		
			1.04′	0.30′	Crushed Aggregate Base		
			1.40′	0.40′	Granular Sub-base		
			2.40′	1.00′	Clayey Sand	14.5%	Moist Test @ 2.0′
			5.00′	BOH	Fine Sand w/ Clay Nodules	15.3%	Moist Test @ 2.6′
I – 84	10 + 0′	8.9′ RT	0.62′	0.62′	Plantmix		
			1.00′	0.38′	Crushed Aggregate Base		
			1.60′	0.60′	Granular Sub-base		
			5.00′	BOH	Clayey Sand (Fine)	6.1%	Moist Test @ 1.9′
I – 84	10 + 500′	?	0.61′	0.61′	Plantmix		Core Broken
			1.00′	0.39′	Crushed Aggregate Base		
			1.50′	0.50	Granular Sub-base		
			5.00′	BOH	Clayey Sand	7.7%	Moist Test @ 1.8′

BORING DATA FOR GROUND PENETRATING RADAR TEST SECTIONS

Roadway	Mile Post	Offset	Depth to Bottom	Layer Thickness	Description	Moisture Content	Remarks
SH 20	34 + 0′	9.6′ RT	0.38′	0.38′	Plantmix		
			0.60′	0.22′	Crushed Aggregate Base		
			4.00′	3.40′	Granular Sub-base		
			5.00′	BOH	Silt	17.8%	Moist Test @ 4.2′
SH 20	34 + 105′	9.6′ RT	0.38′	0.38′	Plantmix		
			0.80′	0.42′	Crushed Aggregate Base		
			4.00′	3.40′	Granular Sub-base		
			5.00′	BOH	Silt	20.1%	Moist Test @ 4.3′
SH 20	34 + 500′	9.3′ RT	0.42′	0.42′	Plantmix		
			0.60′	0.18′	Crushed Aggregate Base		
			3.00′	2.40′	Granular Sub-base		
			5.00′	BOH	Silt	21.2%	Moist Test @ 3.2′
SH 20	36 + 0′	9.2′ RT	0.46′	0.46′	Plantmix		
			0.80′	0.34′	Crushed Aggregate Base		
			5.00′	BOH	Granular Sub-base	13.7%	Moist Test @ 3.0′
SH 20	36 + 500′	9.3′ RT	0.53′	0.53′	Plantmix		
			0.85′	0.32′	Crushed Aggregate Base		
			3.00′	2.15′	Granular Sub-base		
			5.00′	BOH	Silt	17.1%	Moist Test @ ?
SH 20	38 + 500′	9.4′ RT	0.49′	0.49′	Plantmix		
			1.00′	0.51′	Crushed Aggregate Base		
			3.70′	2.70′	Granular Sub-base		
			5.00′	BOH	Silt	18.0%	Moist Test @ 4.0′

BORING DATA FOR GROUND PENETRATING RADAR TEST SECTIONS

Roadway	Mile Post	Offset	Depth to Bottom	Layer Thickness	Description	Moisture Content	Remarks
SH 16	9.1 + 0′	9.2′ RT	0.38′	0.38′	Plantmix		
			1.00′	0.62′	Crushed Aggregate Base		
			6.00′	BOH	Fine Silty Sand	15.8%	Moist Test @ 1.4′
SH 16	9.1 + 500′	9.2′ RT	0.37′	0.37′	Plantmix		
			0.80′	0.43′	Crushed Aggregate Base		
			5.00′	BOH	Fine Silty Sand	15.5%	Moist Test @ 0.5′
SH 16	10 + 0′	8.2′ RT	0.39′	0.39′	Plantmix		
			1.10′	0.71′	Crushed Aggregate Base		
			5.00′	BOH	Fine Silty Sand	15.9%	Moist Test @ 1.4′
SH 16	10 + 250′	8.6′ RT	0.52′	0.52′	Plantmix		
			0.90′	0.38′	Crushed Aggregate Base		
			5.00′	BOH	Fine Silty Sand	13.7%	Moist Test @ 1.3′
SH 16	10 + 500′	8.3′ RT	0.59′	0.59′	Plantmix		
			1.00′	0.41′	Crushed Aggregate Base		
			3.60′	2.60′	Fine Silty Sand		
			5.00	BOH	Silty Sand (med. to coarse)	13.7%	Moist Test @ 1.3′
SH 16	11 + 0′	8.0′ RT	0.65′	0.65′	Plantmix		
			1.00′	0.35′	Crushed Aggregate Base		
			5.00′	BOH	Fine Silty Sand	16.3%	Moist Test @ 1.3′
SH 16	11 + 250′	8.0′ RT	0.68′	0.68′	Plantmix		
			1.00′	0.32′	Crushed Aggregate Base		
			5.00′	BOH	Clayey Sand (Fine – Med.)	14.9%	Moist Test @ 1.3′
SH 16	11 + 500′	8.2′ RT	0.45′	0.45′	Plantmix		
			0.80′	0.35′	Crushed Aggregate Base		
			3.20′	2.40′	Fine Silty Sand		
			5.00′	BOH	Silty Sand (Fine to Coarse)	15.4%	Moist Test @ 1.1′

SUMMARY OF CORES

SPAN 1 --	0.00 to 0.17'	Plantmix
	0.17' to 0.34'	Concrete
	0.34'	Rebar
SPAN 2 --	0.00 to 0.32'	Plantmix
	0.32' to 0.39'	Concrete
	0.39'	Rebar
SPAN 3 --	0.00 to 0.28'	Plantmix
	0.28' to 0.36'	Concrete
	0.35'	Rebar

SUMMARY OF CORES

SPAN 1 --	0.00 to 0.02'	Plantmix
	0.02' to 0.13'	Concrete
	0.13'	Rebar
SPAN 2 --	0.00 to 0.02'	Plantmix
	0.02' to 0.15'	Concrete
	0.15'	Rebar
SPAN 3 --	0.00 to 0.02'	Plantmix
	0.02' to 0.18'	Concrete
	0.18'	Rebar
SPAN 4 --	0.00 to 0.03'	Plantmix
	0.03' to 0.20'	Concrete
	0.20'	Rebar
SPAN 5 --	0.00 to <0.01'	Plantmix
	<0.01' to 0.14'	Concrete
	0.13'	Rebar

SUMMARY OF CORES

SPAN 1 --	0.00 to 0.04'	Plantmix
	0.04' to 0.16'	Concrete
	0.16'	Rebar
SPAN 2 --	0.00 to 0.05'	Plantmix
	0.05' to 0.16'	Concrete
	0.16'	Rebar
SPAN 3 --	0.00 to 0.05'	Plantmix
	0.05' to 0.17'	Concrete
	0.17'	Rebar
SPAN 4 --	0.00 to 0.04'	Plantmix
	0.04' to 0.15'	Concrete
	0.15'	Rebar
SPAN 5 --	0.00 to 0.03'	Plantmix
	0.03' to 0.23'	Concrete
	0.23'	Rebar

APPENDIX B

TABLES

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; I – Interstate; US – United States Highway; SH – State Highway; P – Project Level; N – Network Level

Table 2: Comparison of Surface Course (Asphalt and Portland Cement Concrete) Thickness Measurements for Roadway Test Sections, Obtained by Infrasense and Road Radar, with the Core Data (Ground Truth)

Test Site	Road Name	Section	Location (MP)	ITD Ground Truth (in)	INFRASENSE Project Survey As reported by Infra. (Report, pg 17) (in)	INFRASENSE Network Survey ** (in)	ROAD RADAR Project Survey RWP (in)	ROAD RADAR Project Survey COL (in)	ROAD RADAR Project Survey LWP (in)	ROAD RADAR Project Survey As reported by RRL (Report, pg 20) (in)	ROAD RADAR Network Survey As reported by RRL (Report, pg 20) (in)
1	SH16	1	9.1	4.60	4.61	8.0	4.4	4.3	3.7	4.4	5.9
1	SH16	1	9.1+ 500	4.44	4.82	8.0	4.3	3.8	4.2	4.2	4.7
1	SH16	2	10	4.68	4.39	7.5	4.8	3.7	4.3	4.8	5.0
1	SH16	2	10 + 250	6.24	6.90	9.0	6.4	6.0	5.5	6.5	6.4
1	SH16	2	10 + 500	7.08	8.08	10.5	6.7	6.6	5.2	6.6	6.5
1	SH16	3	11	7.80	6.67	11.5	8.0	7.6	6.9	8.1	7.6
1	SH16	3	11 + 250	8.16	7.88	8.5	7.6	7.3	6.7	7.6	7.8
1	SH16	3	11 + 500	5.40	6.76	9.0	5.7	5.5	5.4	5.7	6.9
2	SH20	1	34	4.56	5.19	4.5	5.6	5.6	5.6	5.6	6.4
2	SH20	1	34 + 105	4.56	4.32	4.5	5.6	5.3	5.4	5.5	5.9
2	SH20	1	34 + 500	5.04	4.86	4.0	5.7	5.8	5.4	5.8	6.4
2	SH20	2	36	5.52	5.87	5.5	5.7	6.1	5.8	5.7	6.0
2	SH20	2	36 + 500	6.36	6.09	5.5	7.0	7.2	7.2	7.0	6.8
2	SH20	3	38 + 500	5.88	5.83	5.0	5.9	6.7	7.3	6.0	5.6
3	SH44	1	11	4.80	4.79	6.5	5.4	6.1	4.9	5.4	4.7
3	SH44	1	11 + 500	5.40	5.38	5.5	5.9	6.1	5.4	5.9	5.5
4	I84WB	1*	46	14.52	14.51	14.5	14.9	14.6	15.3	15.3	15.7
4	I84WB	1*	46 + 500	14.64	14.42	10.0	15.4	15.0	15.7	15.7	15.7
5	I84EB	1	8	7.80	7.43	7.0	8.9	7.7	8.4	8.9	8.5
5	I84EB	1	8 + 500	8.88	7.82	7.0	8.1	7.8	7.8	8.1	7.7
5	I84EB	2	10	7.44	7.69	7.0	7.5	9.0	10.4	7.4	9.2
5	I84EB	2	10 + 500	7.32	7.10	7.0	7.2	7.9	8.6	7.2	8.1

LEGENDS/EXPLANATIONS:

RWP = Right Wheel Path

COL = Center of Lane

LWP = Left Wheel Path

As reported by Road Radar = The data in this column has been arrived at subjectively by RRL.

* - Portland Cement Concrete Pavement

** - Network GPR data is obtained at the core location from Attachment 4 of the Report where the network level pavement thickness plots are summarized.

Table 2: Comparison of Surface Course (Asphalt and Portland Cement Concrete) Thickness Measurements for Roadway Test Sections, Obtained by Infrasense and Road Radar, with the Core Data (Ground Truth)
(Continued)

Test Site	Road Name	Section	Location (MP)	ITD Ground Truth (in)	INFRASENSE Project Survey As reported by Infra. (Report, pg 17) (in)	INFRASENSE Network Survey ** (in)	ROAD RADAR Project Survey RWP (in)	ROAD RADAR Project Survey COL (in)	ROAD RADAR Project Survey LWP (in)	ROAD RADAR Project Survey As reported by RRL (Report, pg 20) (in)	ROAD RADAR Network Survey As reported by RRL (Report, pg 20) (in)
6	I84EB	1*	97	13.20	ND	10.5	13.6	12.9	12.6	13.7	12.3
6	I84EB	1*	97 + 500	13.80	15.00	14.0	14.4	11.7	12.8	14.4	13.6
6	I84EB	2*	98	12.60	ND	10.0	14.1	12.7	12.9	14.2	13.3
6	I84EB	2*	98 + 500	12.00	ND	10.0	13.2	13.1	13.6	13.2	14.0
7	I84B/EB	1	54	7.20	8.37	ND	6.5	6.8	6.1	6.5	7.6
7	I84B/EB	1	54 + 130	3.60	4.39	ND	3.8	4.1	4.5	3.7	4.4
7	I84B/EB	1	54 + 500	4.80	5.61	ND	4.3	4.3	4.3	4.3	6.1
8	US95	1	88	4.08	3.95	3.0	3.9	4.2	4.0	3.9	4.4
8	US95	1	88 + 500	3.96	3.85	3.0	4.4	4.3	4.0	4.3	4.4
8	US95	2	89	3.72	3.80	3.0	4.4	4.2	3.9	4.4	4.3
8	US95	2	89 + 500	4.08	4.12	3.0	4.5	4.6	5.3	4.5	4.8
8	US95	3	90	3.72	3.78	3.0	4.0	4.8	4.5	4.0	4.2
8	US95	3	90 + 500	3.72	3.52	3.0	4.0	4.1	3.9	4.0	3.7

LEGENDS/EXPLANATIONS:

RWP = Right Wheel Path

COL = Center of Lane

LWP = Left Wheel Path

As reported by Road Radar = The data in this column has been arrived at subjectively by RRL.

ND = Pavement thickness Not Detected (ND) by GPR test method used at these locations.

* - Portland Cement Concrete Pavement

** - Network GPR data is obtained at the core location from Attachment 4 of the Report where the network level pavement thickness plots are summarized.

Table 3: Comparison of Base Course Thickness Measurements for Roadway Test Sections, Obtained by Infrasense and Road Radar, with the Core Data (Ground Truth)

				ITD	INFRASENSE		ROAD RADAR				
					Project Survey	Network Survey	Project Survey				Network Survey
Test Site	Road Name	Section	Location (MP)	Ground Truth (in)	As reported by Infra. (Report, pg 17) (in)	** (in)	RWP (in)	COL (in)	LWP (in)	As reported by RRL (Report, pg 20) (in)	As reported by RRL (Report, pg 20) (in)
1	SH16	1	9.1	7.40	4.39	N/A	5.0	4.6	4.8	5.0	3.1
1	SH16	1	9.1+ 500	5.20	3.68	N/A	4.4	4.4	4.2	4.4	4.1
1	SH16	2	10	8.50	3.61	N/A	3.5	4.1	4.4	3.5	3.5
1	SH16	2	10 + 250	4.60	3.10	N/A	4.5	3.7	3.9	4.5	4.7
1	SH16	2	10 + 500	4.90	3.42	N/A	4.9	4.7	5.2	5.0	4.6
1	SH16	3	11	4.20	3.83	N/A	4.8	2.9	4.6	4.7	4.0
1	SH16	3	11 + 250	3.80	4.12	N/A	5.2	5.2	5.0	5.1	4.9
1	SH16	3	11 + 500	4.20	3.24	N/A	4.5	4.7	5.0	4.5	3.3
2	SH20	1	34	2.60	6.81	9.0	6.3	5.9	6.1	6.3	3.8
2	SH20	1	34 + 105	5.00	7.68	9.0	5.9	6.0	5.9	6.2	4.1
2	SH20	1	34 + 500	2.20	4.14	10.0	6.0	6.8	8.2	5.8	4.0
2	SH20	2	36	4.10	6.13	2.5	4.6	5.3	5.1	4.6	2.4
2	SH20	2	36 + 500	3.80	N/A	4.0	4.2	5.5	4.1	4.3	2.9
2	SH20	3	38 + 500	6.10	4.67	5.0	4.7	4.1	3.6	4.7	5.0
3	SH44	1	11	6.60	3.21	N/A	4.9	4.8	6.0	4.8	6.7
3	SH44	1	11 + 500	4.20	2.62	N/A	3.9	3.7	2.9	3.9	3.7
4	I84WB	1	46	4.70	1.99	N/A	3.8	2.4	3.1	3.1	1.1
4	I84WB	1	46 + 500	3.40	2.08	N/A	3.9	2.9	3.3	3.3	2.0
5	I84EB	1	8	4.20	3.07	4.0	4.0	4.8	3.3	4.0	3.4
5	I84EB	1	8 + 500	3.10	6.18	3.0	7.0	7.7	5.8	7.0	7.4
5	I84EB	2	10	4.60	4.81	N/A	4.9	4.5	3.9	5.0	5.9
5	I84EB	2	10 + 500	4.70	0.90	N/A	5.0	5.2	5.1	5.0	5.7

LEGENDS/EXPLANATIONS:

RWP = Right Wheel Path

COL = Center of Lane

LWP = Left Wheel Path

As reported by Road Radar = The data in this column has been arrived at subjectively by RRL.

* - Portland Cement Concrete Pavement

** - Network GPR data is obtained at the core location from Attachment 4 of the Report where the network level pavement thickness plots are summarized.

Table 3: Comparison of Base Course Thickness Measurements for Roadway Test Sections, Obtained by Infrasense and Road Radar, with the Core Data (Ground Truth)
(Continued)

Test Site	Road Name	Section	Location (MP)	ITD Ground Truth (in)	INFRASENSE Project Survey As reported by Infra. (Report, pg 17) (in)	INFRASENSE Network Survey ** (in)	ROAD RADAR Project Survey RWP (in)	ROAD RADAR Project Survey COL (in)	ROAD RADAR Project Survey LWP (in)	ROAD RADAR Project Survey As reported by RRL (Report, pg 20) (in)	ROAD RADAR Network Survey As reported by RRL (Report, pg 20) (in)
6	I84EB	1*	97	3.60	(ND)	(ND)	4.1	3.9	6.7	4.1	5.1
6	I84EB	1*	97 + 500	4.20	(ND)	(ND)	4.0	4.9	3.7	4.0	5.0
6	I84EB	2*	98	3.60	(ND)	(ND)	4.0	5.9	5.9	4.0	3.5
6	I84EB	2*	98 + 500	3.60	(ND)	(ND)	4.2	5.0	5.8	4.2	2.7
7	I84B/EB	1	54	8.40	2.13	(ND)	5.7	5.2	5.1	8.1	7.5
7	I84B/EB	1	54 + 130	9.60	6.11	(ND)	5.9	6.2	4.8	8.4	8.7
7	I84B/EB	1	54 + 500	7.20	1.39	(ND)	7.1	6.7	6.9	7.1	5.4
8	US95	1	88	4.90	6.05	(ND)	6.8	5.0	4.3	6.8	6.4
8	US95	1	88 + 500	6.50	6.65	(ND)	5.8	5.5	7.4	5.9	6.4
8	US95	2	89	8.30	6.70	5.0	7.0	3.6	6.6	6.9	7.3
8	US95	2	89 + 500	5.50	5.88	5.0	6.9	5.6	5.6	7.0	6.4
8	US95	3	90	5.30	6.22	5.0	7.0	4.9	5.5	7.0	6.1
8	US95	3	90 + 500	5.30	6.98	4.5	6.7	6.2	6.8	6.7	7.2

LEGENDS/EXPLANATIONS:

RWP = Right Wheel Path

COL = Center of Lane

LWP = Left Wheel Path

As reported by Road Radar = The data in this column has been arrived at subjectively by RRL.

* - Portland Cement Concrete Pavement

** - Network GPR data is obtained at the core location from Attachment 4 of the Report where the network level pavement thickness plots are summarized.

(ND) = Evaluation of the data and the report prepared by Infrasense indicated that base course pavement thickness at the designated test sites were not detected by GPR test method used at these locations. See the appropriate section of this report for discussions.

Table 4: Comparison of Asphalt and Concrete Thickness Measurements for Bridge Test Sections, Obtained by Infrasense and Road Radar, with the Core Data (Ground Truth)

Bridge Location	Span No.	Span Length (ft)	Core No.	ITD Ground Truth				INFRASENSE		ROAD RADAR	
				Core Locations		Overlay Thickness					
				(ft from Span 1)	(ft from right curb)	Asphalt (in)	Concrete (in)	Asphalt (in)	Concrete (in)	Asphalt (in)	Concrete (in)
US 20/26 over I 84 (Broadway Avenue Interchange)	1	35.0	1	16.5	6.5	0.24	1.32	*	0.85	<1**	2 to 3
	2	50.0	2	49.5	6.5	0.24	1.56	*	0.99	<1**	2 to 3
	3	50.0	3	140.0	7.0	0.24	1.92	*	0.84	<1**	2 to 3
	4	50.0	4	152.5	6.0	0.36	2.04	*	0.92	<1**	2 to 3
	5	35.0	5	190.5	5.0	0.12	1.56	*	0.85	<1**	2 to 3
I-184 over Franklin Rd. (Franklin Interchange)	1	101.0	1	69.0	8.0	0.48	1.44	~	~	<1**	2
	2	66.8	2	136.0	9.0	0.60	1.32	~	~	<1**	2
	3	66.8	3	211.8	9.5	0.60	1.44	~	~	<1**	2
	4	99.5	4	298.6	9.5	0.48	1.32	~	~	<1**	2
	5	65.7	5	392.5	10.0	0.36	2.40	~	~	<1**	2
US 20/26 over UPRR & NY Canal (northbound) Broadway Avenue	1	80.0	1	43.5	14.0	2.04	2.04	2.42	2.75	<1**	<2
	2	137.0	2	199.0	14.0	3.84	0.84	3.47	1.94	<1**	<2
	3	80.0	3	258.0	12.0	3.36	0.96	3.16	2.24	<1**	<2

LEGENDS/EXPLANATIONS:

The word "Concrete" as used above in this table means "depth to reinforcing steel".

* Too thin to be measured by Infrasense's GPR (Report pg. 18)

** Below minimum resolution of Road Radar's GPR (Report pg. 18)

Table 5: Variations of Surface Course Thickness Measurements for Roadway Test Sections (Project Survey) from the Core Data (Ground Truth)

Test Site	ITD	INFRASENSE	ROAD RADAR	Variations between			Percent Difference between (with respect to ground truth)	
	Ground Truth (in)	Project Survey (Report, pg 17) (in)	Project Survey As used by RRL (Report, pg 20) (in)	Infrasense and ITD	RR and ITD	Infrasense and RR	Infrasense and ITD	RR and ITD
1	4.60	4.61	4.4	0.01	-0.20	0.21	0.22	-4.35
1	4.44	4.82	4.2	0.38	-0.24	0.62	8.56	-5.41
1	4.68	4.39	4.8	-0.29	0.12	-0.41	-6.20	2.56
1	6.24	6.90	6.5	0.66	0.26	0.40	10.58	4.17
1	7.08	8.08	6.6	1.00	-0.48	1.48	14.12	-6.78
1	7.80	6.67	8.1	-1.13	0.30	-1.43	-14.49	3.85
1	8.16	7.88	7.6	-0.28	-0.56	0.28	-3.43	-6.86
1	5.40	6.76	5.7	1.36	0.30	1.06	25.19	5.56
2	4.56	5.19	5.6	0.63	1.04	-0.41	13.82	22.81
2	4.56	4.32	5.5	-0.24	0.94	-1.18	-5.26	20.61
2	5.04	4.86	5.8	-0.18	0.76	-0.94	-3.57	15.08
2	5.52	5.87	5.7	0.35	0.18	0.17	6.34	3.26
2	6.36	6.09	7.0	-0.27	0.64	-0.91	-4.25	10.06
2	5.88	5.83	6.0	-0.05	0.12	-0.17	-0.85	2.04
3	4.80	4.79	5.4	-0.01	0.60	-0.61	-0.21	12.50
3	5.40	5.38	5.9	-0.02	0.50	-0.52	-0.37	9.26
4	14.52	14.51	15.3	-0.01	0.78	-0.79	-0.07	5.37
4	14.64	14.42	15.7	-0.22	1.06	-1.28	-1.50	7.24
5	7.80	7.43	8.9	-0.37	1.10	-1.47	-4.74	14.10
5	8.88	7.82	8.1	-1.06	-0.78	-0.28	-11.94	-8.78
5	7.44	7.69	7.4	0.25	-0.04	0.29	3.36	-0.54
5	7.32	7.10	7.2	-0.22	-0.12	-0.10	-3.01	-1.64
6	13.20	*	13.7	N/A	0.50	N/A	N/A	3.79
6	13.80	15.00	14.4	1.20	0.60	0.60	8.70	4.35
6	12.60	*	14.2	N/A	1.60	N/A	N/A	12.70
6	12.00	*	13.2	N/A	1.20	N/A	N/A	10.00

Reference: See Table 2

Table 5: Variations of Surface Course Thickness Measurements for Roadway Test Sections (Project Survey) from the Core Data (Ground Truth)
(Continued)

Test Site	ITD Ground Truth (in)	INFRASENSE Project Survey (Report, pg 17) (in)	ROAD RADAR Project Survey As used by RRL (Report, pg 20) (in)	Variations between: Infrasense and ITD	Variations between: RR and ITD	Variations between: Infrasense and RR	Percent Difference between (with respect to ground truth): Infrasense and ITD	Percent Difference between (with respect to ground truth): RR and ITD
7	7.20	8.37	6.5	1.17	-0.70	1.87	16.25	-9.72
7	3.60	4.39	3.7	0.79	0.10	0.69	21.94	2.78
7	4.80	5.61	4.3	0.81	-0.50	1.31	16.88	-10.42
8	4.08	3.95	3.9	-0.13	-0.18	0.05	-3.19	-4.41
8	3.96	3.85	4.3	-0.11	0.34	-0.45	-2.78	8.59
8	3.72	3.80	4.4	0.08	0.68	-0.60	2.15	18.28
8	4.08	4.12	4.5	0.04	0.42	-0.38	0.98	10.29
8	3.72	3.78	4.0	0.06	0.28	-0.22	1.61	7.53
8	3.72	3.52	4.0	-0.20	0.28	-0.48	-5.38	7.53
						Σ =	79.47	165.39

	Infrasense and ITD	RR and ITD	Infrasense and RR
Mean	0.13	0.31	-0.11
Standard Deviation	0.5860	0.5685	0.8308
sample size, n	32	35	32
Student's t	1.2067	3.2409	-0.7660
Probability associated with student's t-test	0.2367	0.0027	0.4489
Pearson's r	0.9812	0.9888	0.9638
Pearson's r^2	0.9627	0.9778	0.9290

Average % Difference (Infrasense and ITD)	Average % Difference (RR and ITD)
2.48	4.73

Reference: See Table 2

Table 6: Variations of Surface Course Thickness Measurements for Roadway Test Sections (Network Survey) from the Core Data (Ground Truth)

Test Site	ITD Ground Truth (in)	INFRASENSE Network Survey (Report, pg 17) (in)	ROAD RADAR Network Survey As used by RRL (Report, pg 20) (in)	Variations between: Infrasense and ITD	Variations between: RR and ITD	Variations between: Infrasense and RR	Percent Difference between (with respect to ground truth): Infrasense and ITD	Percent Difference between (with respect to ground truth): RR and ITD
1	4.60	8.0	5.9	3.4	1.30	2.10	73.91	28.26
1	4.44	8.0	4.7	3.6	0.26	3.30	80.18	5.86
1	4.68	7.5	5.0	2.8	0.32	2.50	60.26	6.84
1	6.24	9.0	6.4	2.8	0.16	2.60	44.23	2.56
1	7.08	10.5	6.5	3.4	-0.58	4.00	48.31	-8.19
1	7.80	11.5	7.6	3.7	-0.20	3.90	47.44	-2.56
1	8.16	8.5	7.8	0.3	-0.36	0.70	4.17	-4.41
1	5.40	9.0	6.9	3.6	1.50	2.10	66.67	27.78
2	4.56	4.5	6.4	-0.1	1.84	-1.90	-1.32	40.35
2	4.56	4.5	5.9	-0.1	1.34	-1.40	-1.32	29.39
2	5.04	4.0	6.4	-1.0	1.36	-2.40	-20.63	26.98
2	5.52	5.5	6.0	0.0	0.48	-0.50	-0.36	8.70
2	6.36	5.5	6.8	-0.9	0.44	-1.30	-13.52	6.92
2	5.88	5.0	5.6	-0.9	-0.28	-0.60	-14.97	-4.76
3	4.80	6.5	4.7	1.7	-0.10	1.80	35.42	-2.08
3	5.40	5.5	5.5	0.1	0.10	0.00	1.85	1.85
4	14.52	14.5	15.7	0.0	1.18	-1.20	-0.14	8.13
4	14.64	10.0	15.7	-4.6	1.06	-5.70	-31.69	7.24
5	7.80	7.0	8.5	-0.8	0.70	-1.50	-10.26	8.97
5	8.88	7.0	7.7	-1.9	-1.18	-0.70	-21.17	-13.29
5	7.44	7.0	9.2	-0.4	1.76	-2.20	-5.91	23.66
5	7.32	7.0	8.1	-0.3	0.78	-1.10	-4.37	10.66
6	13.20	10.5	12.3	-2.7	-0.90	-1.80	-20.45	-6.82
6	13.80	14.0	13.6	0.2	-0.20	0.40	1.45	-1.45
6	12.60	10.0	13.3	-2.6	0.70	-3.30	-20.63	5.56
6	12.00	10.0	14.0	-2.0	2.00	-4.00	-16.67	16.67

Reference: See Table 2

Table 6: Variations of Surface Course Thickness Measurements for Roadway Test Sections (Network Survey) from the Core Data (Ground Truth)
(Continued)

Test Site	ITD Ground Truth (in)	INFRASENSE Network Survey (Report, pg 17) (in)	ROAD RADAR Network Survey As used by RRL (Report, pg 20) (in)	Variations between: Infrasense and ITD	Variations between: RR and ITD	Variations between: Infrasense and RR	Percent Difference between (with respect to ground truth): Infrasense and ITD	Percent Difference between (with respect to ground truth): RR and ITD
7	7.20	N/A	7.6	N/A	0.40	N/A	N/A	5.56
7	3.60	N/A	4.4	N/A	0.80	N/A	N/A	22.22
7	4.80	N/A	6.1	N/A	1.30	N/A	N/A	27.08
8	4.08	3.0	4.4	-1.08	0.32	-1.40	-26.47	7.84
8	3.96	3.0	4.4	-0.96	0.44	-1.40	-24.24	11.11
8	3.72	3.0	4.3	-0.72	0.58	-1.30	-19.35	15.59
8	4.08	3.0	4.8	-1.08	0.72	-1.80	-26.47	17.65
8	3.72	3.0	4.2	-0.72	0.48	-1.20	-19.35	12.90
8	3.72	3.0	3.7	-0.72	-0.02	-0.70	-19.35	-0.54
						Σ =	145.21	342.21
			Mean	0.06	0.53	-0.44		
			Standard Deviation	2.0678	0.7618	2.2644	Average % Difference	Average % Difference
			sample size, n	32	35	32	4.54	9.78
			Student's t	0.1710	4.1048	-1.0929		
			Probability associated with student's t-test	0.86525	0.00024	0.28210		
			Pearson's r	0.8091	0.9746	0.7750		
			Pearson's r^2	0.6546	0.9498	0.6006		

Reference: See Table 2

Table 7: Variations of Base Course Thickness Measurements for Roadway Test Sections (Project Survey) from the Core Data (Ground Truth)

Test Site	ITD Ground Truth (in)	INFRASENSE Project Survey (Report, pg 17) (in)	ROAD RADAR Project Survey As used by RRL (Report, pg 20) (in)	Variations between: Infrasense and ITD	Variations between: RR and ITD	Variations between: Infrasense and RR	Percent Difference between (with respect to ground truth): Infrasense and ITD	Percent Difference between (with respect to ground truth): RR and ITD
1	7.4	4.39	5.0	-3.01	-2.40	-0.61	-40.68	-32.43
1	5.2	3.68	4.4	-1.52	-0.80	-0.72	-29.23	-15.38
1	8.5	3.61	3.5	-4.89	-5.00	0.11	-57.53	-58.82
1	4.6	3.10	4.5	-1.50	-0.10	-1.40	-32.61	-2.17
1	4.9	3.42	5.0	-1.48	0.10	-1.58	-30.20	2.04
1	4.2	3.83	4.7	-0.37	0.50	-0.87	-8.81	11.90
1	3.8	4.12	5.1	0.32	1.30	-0.98	8.42	34.21
1	4.2	3.24	4.5	-0.96	0.30	-1.26	-22.86	7.14
2	2.6	6.81	6.3	4.21	3.70	0.51	161.92	142.31
2	5.0	7.68	6.2	2.68	1.20	1.48	53.60	24.00
2	2.2	4.14	5.8	1.94	3.60	-1.66	88.18	163.64
2	4.1	6.13	4.6	2.03	0.50	1.53	49.51	12.20
2	3.8	N/A	4.3	N/A	0.50	N/A	N/A	13.16
2	6.1	4.67	4.7	-1.43	-1.40	-0.03	-23.44	-22.95
3	6.6	3.21	4.8	-3.39	-1.80	-1.59	-51.36	-27.27
3	4.2	2.62	3.9	-1.58	-0.30	-1.28	-37.62	-7.14
4	4.7	1.99	3.1	-2.71	-1.60	-1.11	-57.66	-34.04
4	3.4	2.08	3.3	-1.32	-0.10	-1.22	-38.82	-2.94
5	4.2	3.07	4.0	-1.13	-0.20	-0.93	-26.90	-4.76
5	3.1	6.18	7.0	3.08	3.90	-0.82	99.35	125.81
5	4.6	4.81	5.0	0.21	0.40	-0.19	4.57	8.70
5	4.7	0.90	5.0	-3.80	0.30	-4.10	-80.85	6.38
6	3.6	(ND)	4.1	N/A	0.50	N/A	N/A	13.89
6	4.2	(ND)	4.0	N/A	-0.20	N/A	N/A	-4.76
6	3.6	(ND)	4.0	N/A	0.40	N/A	N/A	11.11
6	3.6	(ND)	4.2	N/A	0.60	N/A	N/A	16.67

Reference: See Table 3

Table 7: Variations of Base Course Thickness Measurements for Roadway Test Sections (Project Survey) from the Core Data (Ground Truth)
(Continued)

Test Site	ITD Ground Truth (in)	INFRASENSE Project Survey (Report, pg 17) (in)	ROAD RADAR Project Survey As used by RRL (Report, pg 20) (in)	Variations between: Infrasense and ITD	Variations between: RR and ITD	Variations between: Infrasense and RR	Percent Difference between (with respect to ground truth): Infrasense and ITD	Percent Difference between (with respect to ground truth): RR and ITD
7	8.4	2.13	8.1	-6.27	-0.30	-5.97	-74.64	-3.57
7	9.6	6.11	8.4	-3.49	-1.20	-2.29	-36.35	-12.50
7	7.2	1.39	7.1	-5.81	-0.10	-5.71	-80.69	-1.39
8	4.9	6.05	6.8	1.15	1.90	-0.75	23.47	38.78
8	6.5	6.65	5.9	0.15	-0.60	0.75	2.31	-9.23
8	8.3	6.70	6.9	-1.60	-1.40	-0.20	-19.28	-16.87
8	5.5	5.88	7.0	0.38	1.50	-1.12	6.91	27.27
8	5.3	6.22	7.0	0.92	1.70	-0.78	17.36	32.08
8	5.3	6.98	6.7	1.68	1.40	0.28	31.70	26.42
						Σ =	-202.25	461.44

	Infrasense and ITD	RR and ITD	Infrasense and RR
Mean	-0.92	0.19	-1.08
Standard Deviation	2.5716	1.7103	1.6902
sample size, n	30	35	30
Student's t	-1.9531	0.6720	-3.5117
Probability associated with student's t-test	0.0591	0.5061	0.0013
Pearson's r	0.0211	0.4306	0.4948
Pearson's r^2	0.0004	0.1854	0.2449

Average % Difference	Average % Difference
-6.74	13.18

Reference: See Table 3

Table 8: Variations of Base Course Thickness Measurements for Roadway Test Sections (Network Survey) from the Core Data (Ground Truth)

Test Site	ITD Ground Truth (in)	INFRASENSE Network Survey (Report, pg 17) (in)	ROAD RADAR Network Survey As used by RRL (Report, pg 20) (in)	Variations between: Infrasense and ITD	Variations between: RR and ITD	Variations between: Infrasense and RR	Percent Difference between (with respect to ground truth): Infrasense and ITD	Percent Difference between (with respect to ground truth): RR and ITD
1	7.4	N/A	3.1	N/A	-4.30	N/A	N/A	-58.11
1	5.2	N/A	4.1	N/A	-1.10	N/A	N/A	-21.15
1	8.5	N/A	3.5	N/A	-5.00	N/A	N/A	-58.82
1	4.6	N/A	4.7	N/A	0.10	N/A	N/A	2.17
1	4.9	N/A	4.6	N/A	-0.30	N/A	N/A	-6.12
1	4.2	N/A	4.0	N/A	-0.20	N/A	N/A	-4.76
1	3.8	N/A	4.9	N/A	1.10	N/A	N/A	28.95
1	4.2	N/A	3.3	N/A	-0.90	N/A	N/A	-21.43
2	2.6	9.0	3.8	6.40	1.20	5.20	246.15	46.15
2	5.0	9.0	4.1	4.00	-0.90	4.90	80.00	-18.00
2	2.2	10.0	4.0	7.80	1.80	6.00	354.55	81.82
2	4.1	2.5	2.4	-1.60	-1.70	0.10	-39.02	-41.46
2	3.8	4.0	2.9	0.20	-0.90	1.10	5.26	-23.68
2	6.1	5.0	5.0	-1.10	-1.10	0.00	-18.03	-18.03
3	6.6	N/A	6.7	N/A	0.10	N/A	N/A	1.52
3	4.2	N/A	3.7	N/A	-0.50	N/A	N/A	-11.90
4	4.7	N/A	1.1	N/A	-3.60	N/A	N/A	-76.60
4	3.4	N/A	2.0	N/A	-1.40	N/A	N/A	-41.18
5	4.2	4.0	3.4	-0.20	-0.80	0.60	-4.76	-19.05
5	3.1	3.0	7.4	-0.10	4.30	-4.40	-3.23	138.71
5	4.6	N/A	5.9	N/A	1.30	N/A	N/A	28.26
5	4.7	N/A	5.7	N/A	1.00	N/A	N/A	21.28
6	3.6	(ND)	5.1	N/A	1.50	N/A	N/A	41.67
6	4.2	(ND)	5.0	N/A	0.80	N/A	N/A	19.05
6	3.6	(ND)	3.5	N/A	-0.10	N/A	N/A	-2.78
6	3.6	(ND)	2.7	N/A	-0.90	N/A	N/A	-25.00

Reference: See Table 3

Table 8: Variations of Base Course Thickness Measurements for Roadway Test Sections (Network Survey) from the Core Data (Ground Truth)
(Continued)

Test Site	ITD Ground Truth (in)	INFRASENSE Network Survey (Report, pg 17) (in)	ROAD RADAR Network Survey As used by RRL (Report, pg 20) (in)	Variations between: Infrasense and ITD	Variations between: RR and ITD	Variations between: Infrasense and RR	Percent Difference between (with respect to ground truth): Infrasense and ITD	Percent Difference between (with respect to ground truth): RR and ITD
7	8.4	(ND)	7.5	N/A	-0.90	N/A	N/A	-10.71
7	9.6	(ND)	8.7	N/A	-0.90	N/A	N/A	-9.38
7	7.2	(ND)	5.4	N/A	-1.80	N/A	N/A	-25.00
8	4.9	(ND)	6.4	N/A	1.50	N/A	N/A	30.61
8	6.5	(ND)	6.4	N/A	-0.10	N/A	N/A	-1.54
8	8.3	5.0	7.3	-3.30	-1.00	-2.30	-39.76	-12.05
8	5.5	5.0	6.4	-0.50	0.90	-1.40	-9.09	16.36
8	5.3	5.0	6.1	-0.30	0.80	-1.10	-5.66	15.09
8	5.3	4.5	7.2	-0.80	1.90	-2.70	-15.09	35.85
						$\Sigma =$	551.31	0.73

	Infrasense and ITD	RR and ITD	Infrasense and RR
Mean	0.88	-0.29	0.50
Standard Deviation	3.3621	1.7842	3.3131
sample size, n	12	35	12
Student's t	0.9015	-0.9568	0.5228
Probability associated with student's t-test	0.3866	0.3592	0.6115
Pearson's r	-0.2965	0.4915	-0.1859
Pearson's r^2	0.0879	0.2416	0.0346

Average % Difference	Average % Difference
45.94	0.02

Reference: See Table 3

Table 9: Pearson's Correlation Coefficient (r) and Coefficient of Determination (r^2) for GPR and ITD's Ground-Truth Data

Type of Pavement Thickness Measurement	Survey Type	(A-C) GPR versus ITD Data				(A-G-C) GPR versus ITD Data				(A-C) GPR versus (A-G-C) GPR Data				Data used in Figure Numbers
		Sample Size	r^2	r	Interpre-tation*	Sample Size	r^2	r	Interpre-tation*	Sample Size	r^2	r	Interpre-tation*	
Surface Course	Project	32	0.9627	0.9812	Very high correlation, very dependable relationship	35	0.9778	0.9888	Very high correlation, very dependable relationship	32	0.9290	0.9638	Very high correlation, very dependable relationship	13, 14, 15
	Network	32	0.6546	0.8091	High correlation, marked relationship	35	0.9498	0.9746	Very high correlation, very dependable relationship	32	0.6006	0.7750	High correlation, marked relationship	16, 17, 18
Base Course	Project	30	0.0004	0.0211	Slight negligible relationship	35	0.1854	0.4306	Moderate correlation, substantial relationship	30	0.2449	0.4948	Moderate correlation, substantial relationship	19, 20, 21
	Network	12	0.0879	-0.2965	Negligible Relation-ship	35	0.2416	0.4915	Moderate correlation, substantial relationship	12	0.0346	-0.1859	Negligible Relationship	22, 23, 24

* Reference 14, pp. 224, Table 10.3 (Guilford's suggested Interpretations for Values of r).

Note: (R^2) values indicated on Figures 13 through 24 are correlation coefficients used in linear regression analysis. The correlation coefficient (R^2) is same as the Coefficient of Determination (r^2) as shown in this table. See the Reference 14, pp. 224-225 for more information about Pearson's Correlation Coefficient (r) and the Coefficient of Determination (r^2) which is the square of the Pearson's correlation coefficient (also known as Correlation Coefficient in some other references).

Table 10: Statistical Analyses Results of GPR and ITD's Ground Truth Data

Type of Pavement Thickness Measurement	Survey Type	Variations (Differences) Between:														
		(A-C) GPR and ITD Data					(A-G-C) GPR and ITD Data					(A-C) GPR and (A-G-C) GPR Data				
		Sample Size	Mean (in.)	Std. Deviation	Student's (t)	Probability Associated with Student's (t)	Sample Size	Mean (in.)	Std. Deviation	Student's (t)	Probability Associated with Student's (t)	Sample Size	Mean (in.)	Std. Deviation	Student's (t)	Probability Associated with Student's (t)
Surface Course	Project	32	0.13	0.586	1.2067	0.2367	35	0.31	0.568	3.2409	0.0027	32	-0.11	0.831	-0.7660	0.4489
	Network	32	0.06	2.068	0.1710	0.86525	35	0.53	0.762	4.1048	0.00024	32	-0.44	2.264	-1.0929	0.28210
Base Course	Project	30	-0.92	2.572	-1.9531	0.0591	35	0.19	1.710	0.6720	0.5061	30	-1.08	1.690	-3.5117	0.0013
	Network	12	0.88	3.362	0.9015	0.3866	35	-0.29	1.784	-0.9568	0.3592	12	0.50	3.313	0.5228	0.6115

Table 11: Variations of Asphalt Overlay Thickness Measurements for Bridge Test Sections from the Core Data (Ground Truth)

Bridge Location	Span No.	Core No.	ITD (Ground Truth) Asphalt (in)	INFRASENSE Asphalt (in)	ROAD RADAR Asphalt (in)	Variations between			Percent Difference between (with respect to ground truth)	
						Infrasense and ITD	RR and ITD	Infrasense and RR	Infrasense and ITD	RR and ITD
US 20/26 over I 84 (Broadway Avenue Interchange)	1	1	0.24	~	1	N/A	0.76	N/A	N/A	316.67
	2	2	0.24	~	1	N/A	0.76	N/A	N/A	316.67
	3	3	0.24	~	1	N/A	0.76	N/A	N/A	316.67
	4	4	0.36	~	1	N/A	0.64	N/A	N/A	177.78
	5	5	0.12	~	1	N/A	0.88	N/A	N/A	733.33
I-184 over Franklin Rd. (Franklin Interchange)	1	1	0.48	~	1	N/A	0.52	N/A	N/A	108.33
	2	2	0.60	~	1	N/A	0.40	N/A	N/A	66.67
	3	3	0.60	~	1	N/A	0.40	N/A	N/A	66.67
	4	4	0.48	~	1	N/A	0.52	N/A	N/A	108.33
	5	5	0.36	~	1	N/A	0.64	N/A	N/A	177.78
US 20/26 over UPRR and NY Canal (northbound) Broadway Avenue	1	1	2.04	2.42	1	0.38	-1.04	1.42	18.63	-50.98
	2	2	3.84	3.47	1	-0.37	-2.84	2.47	-9.64	-73.96
	3	3	3.36	3.16	1	-0.20	-2.36	2.16	-5.95	-70.24
								Σ=	3.04	2193.71
					Mean	-0.06	0.00	2.02	Average % Difference	Average % Difference
					Standard Deviation	0.3932	1.2551	0.5395	0.76	168.75
					sample size, n	3	13	3		
					Student's t	-0.2790	0.0088	6.4748		
					Probability associated with student's t-test	0.80647	0.9931	0.0230		
					Pearson's r	0.9995	N/A	N/A		
					Pearson's r^2	0.9604	N/A	N/A		

Reference: Table 4

Table 12: Variations of Concrete Thickness Measurements for Bridge Test Sections from the Core Data (Ground Truth)

Bridge Location	Span No.	Core No.	ITD (Ground Truth) Concrete (in)	INFRASENSE Concrete (in)	ROAD RADAR Concrete (in)	Variations between			Percent Difference between (with respect to ground truth)	
						Infrasense and ITD	RR and ITD	Infrasense and RR	Infrasense and ITD	RR and ITD
US 20/26 over I 84 (Broadway Avenue Interchange)	1	1	1.32	0.85	2.5	-0.47	1.18	-1.65	-35.61	89.39
	2	2	1.56	0.99	2.5	-0.57	0.94	-1.51	-36.54	60.26
	3	3	1.92	0.84	2.5	-1.08	0.58	-1.66	-56.25	30.21
	4	4	2.04	0.92	2.5	-1.12	0.46	-1.58	-54.90	22.55
	5	5	1.56	0.85	2.5	-0.71	0.94	-1.65	-45.51	60.26
I-184 over Franklin Rd. (Franklin Interchange)	1	1	1.44	~	2	N/A	0.56	N/A	N/A	38.89
	2	2	1.32	~	2	N/A	0.68	N/A	N/A	51.52
	3	3	1.44	~	2	N/A	0.56	N/A	N/A	38.89
	4	4	1.32	~	2	N/A	0.68	N/A	N/A	51.52
	5	5	2.40	~	2	N/A	-0.40	N/A	N/A	-16.67
US 20/26 over UPRR and NY Canal (northbound) Broadway Avenue	1	1	2.04	2.75	2	0.71	-0.04	0.75	34.80	-1.96
	2	2	0.84	1.94	2	1.10	1.16	-0.06	130.95	138.10
	3	3	0.96	2.24	2	1.28	1.04	0.24	133.33	108.33
								Σ=	70.28	671.27
					Mean	-0.11	0.64	-0.89	Average % Difference	Average % Difference
					Standard Deviation	0.9806	0.4563	1.0187	8.79	51.64
					sample size, n	8	13	8		
					Student's t	-0.3101	5.0698	-2.4711		
					Probability associated with student's t-test	0.7655	0.0003	0.0428		
					Pearson's r	-0.2153	0.2390	-0.9565		
					Pearson's r^2	0.0464	0.0571	0.9149		

Note: The word "Concrete" as used above in this table means "depth to reinforcing steel".

Reference: Table 4

APPENDIX C

FIGURES

GPR Road Test Sites

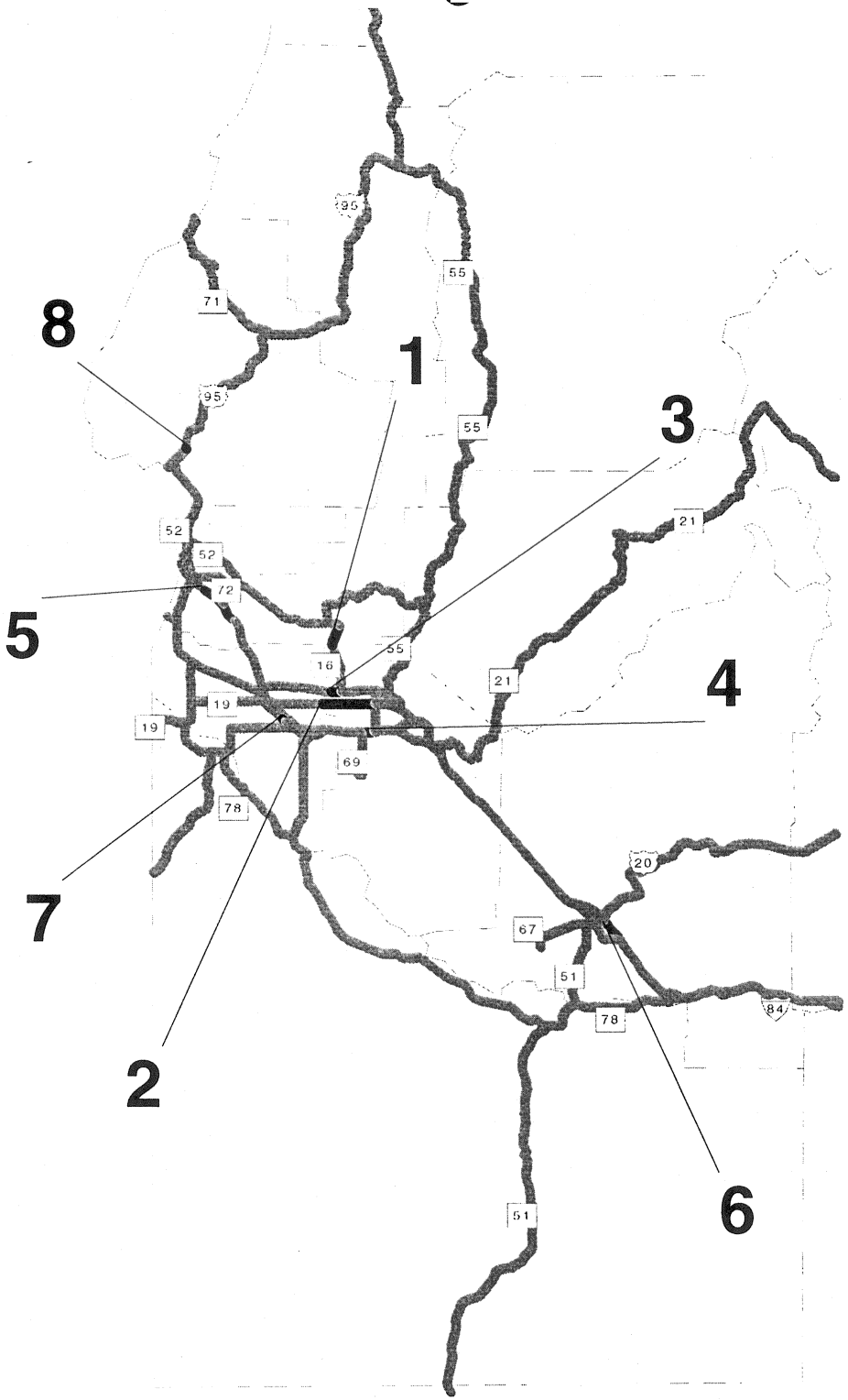
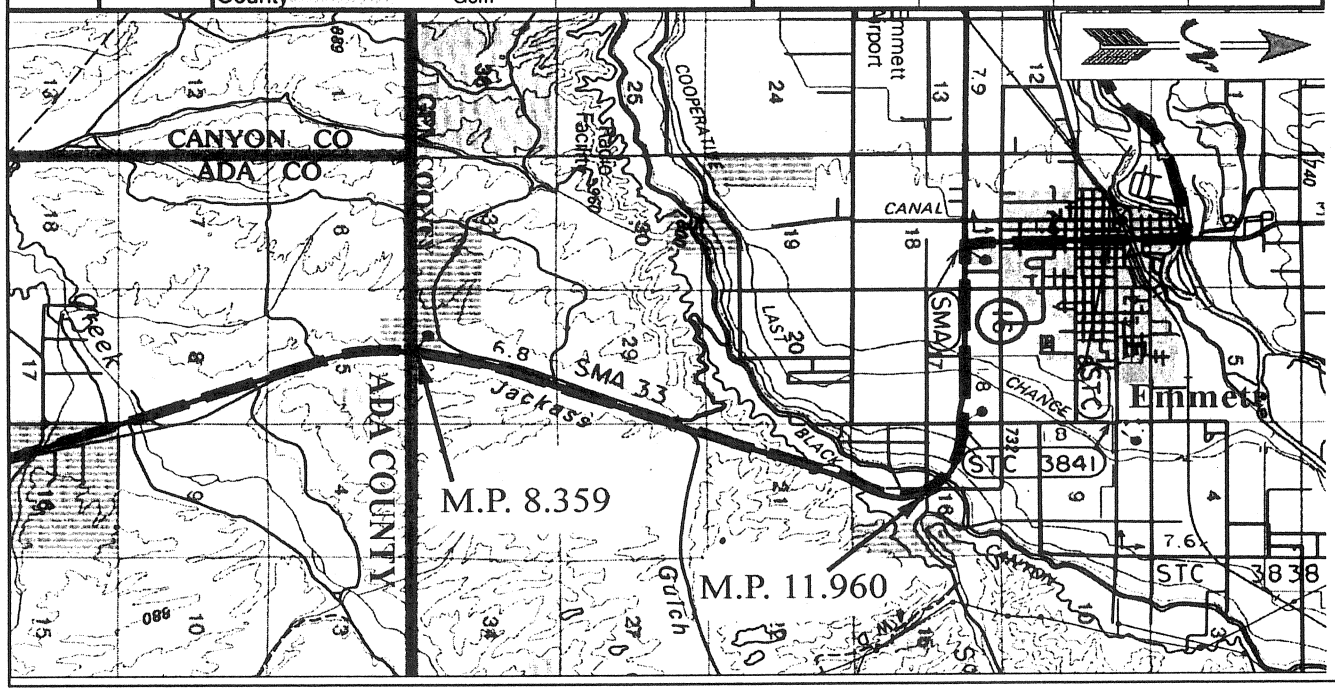


Figure 1 - Location Map for GPR Road Test Sites.

Pavement Test Site #1

SH-16, Minor Arterial
M.P. 8.359 - 11.960

Route	Segment	Test Area	Data	Description	Break Points	Data Base		
SH-16	1390	Begin M.P.	8.359	Ada County Line		Pavement	Base	Subbase
		End M.P.	11.96	Sand Hollow Rd.	Mile Post	Thickness (in)	Thickness (in)	Thickness (in)
		Length (mi)	3.601	** Ascending **	0 - 8.359	2.4	9.6	0
		Func. Class	Minor Art.	** Direction **	9.019 - 11.960	2.4	4.8	0
		Pavement Type	Asphalt					
		Base Type	Granular					
		City	rural					
		County	Gem					



Gem County

Figure 2 -- Location map for GPR Road Test Site No. 1

Pavement Test Site #2

US-20, Principal Arterial
M.P. 32.283 - 40.229

Route	Segment	Test Area	Data	Description	Break Points			
US-20	2070	Begin M.P.	32.283	Canyon County Line		Pavement	Base	Subbase
		End M.P.	40.229	Jct. SH-55	Mile Post	Thickness (in)	Thickness (in)	Thickness (in)
		Length (mi)	7.946		32.283 - 35.200	2	6	0
		Func. Class	Princ. Artr.		35.255 - 39.200	5.4	9.6	0
		Pavement Type	Asphalt		39.200 - 40.229	2.4	9.6	0
		Base Type	Granular					
		City	rural					
		County	Ada					

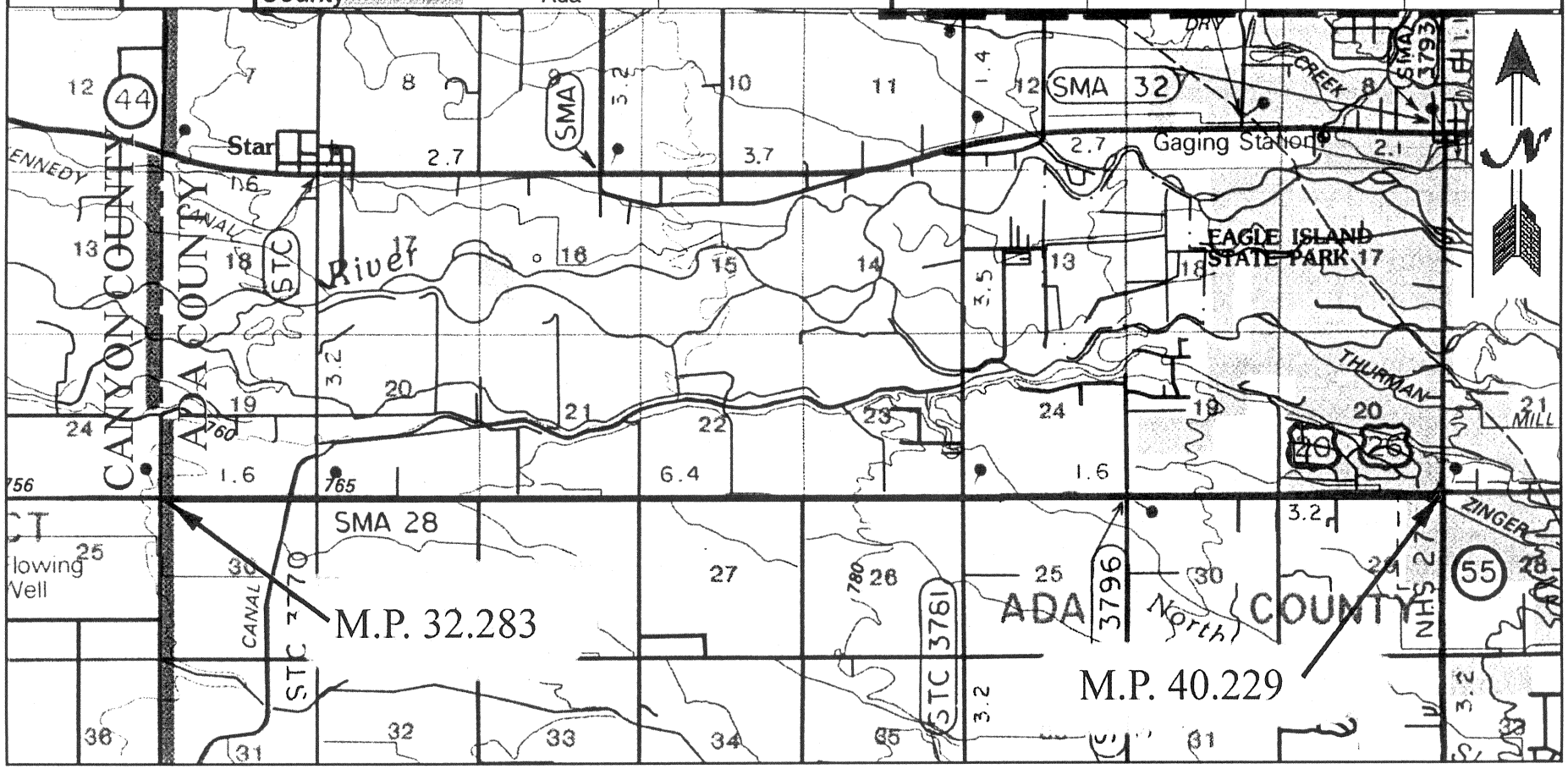


Figure 3 -- Location map for GPR Road Test Site No. 2

Pavement Test Site #3

SH-44, Minor Arterial
M.P. 10.771 - 12.298

Route	Segment	Test Area	Data	Description	Break Points	Data Base			Core Samples			
SH-44	2130	Begin M.P.	10.771	State St. & Knox		Pavement	Base	Subbase	Mile Post	Pavement	Base	Subbase
		End M.P.	12.298	Jct. SH-16	Mile Post	Thickness (in)	Thickness (in)	Thickness (in)	Location	Thickness (in)	Thickness (in)	Thickness (in)
		Length (mi)	1.527	** Ascending **	10.771 - 12.298	2.4	9.6	0	11.44	3.1	19.7	68.4
		Func. Class	Minor Artr.	** Direction **					12.35	3.0	17.4	38.4
		Pavement Type	asphalt									
		Base Type	granular									
		City	rural									
		County	Ada									

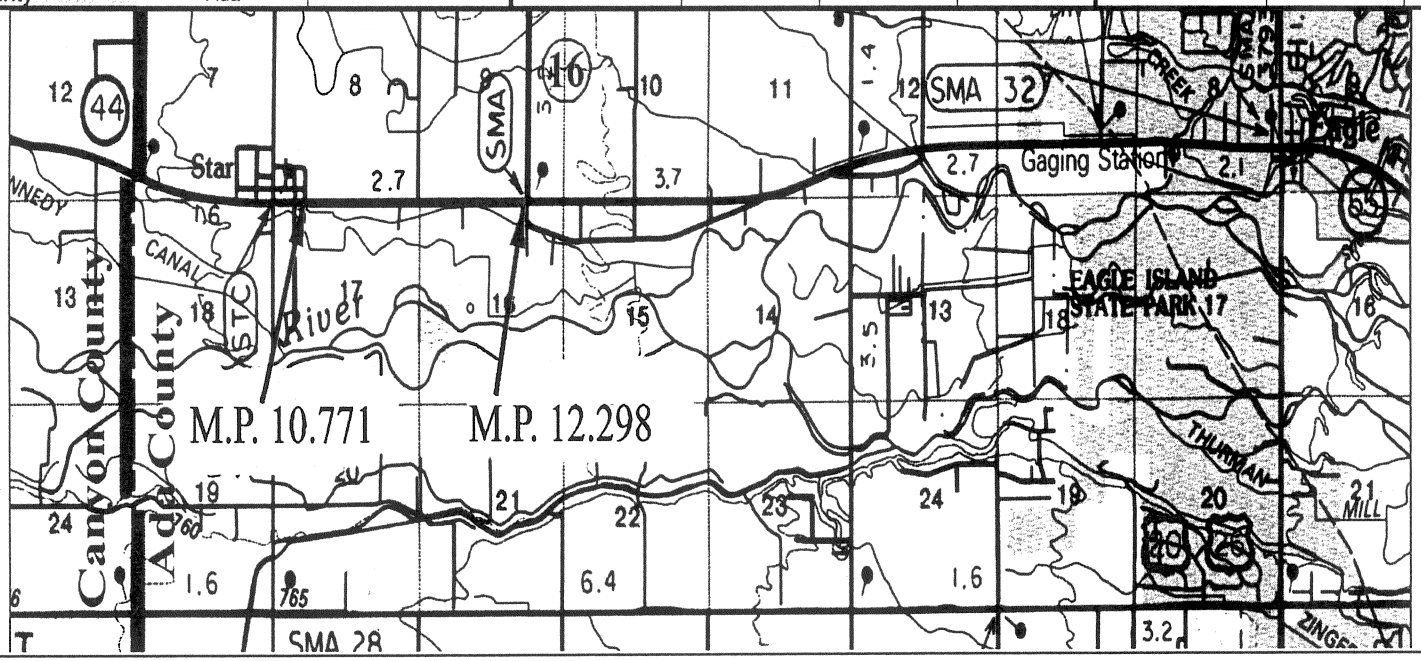


Figure 4 -- Location map for GPR Road Test Site No. 3

Pavement Test Site #4

I-84, Interstate
M.P. 44.960 - 46.770

Route	Segment	Test Area	Data	Description	Break Points			
I-84	1010	Begin M.P.	44.960	Meridian City Limit		Pavement	Base	Subbase
		End M.P.	46.770	Ridenbaugh Canal	Mile Post	Thickness (in)	Thickness (in)	Thickness (in)
		Length (mi)	1.810	**Inside Lane**	44.960 - 44.689	13	3.6	3
		Func. Class	Interstate	**Westbound**	45.940 - 46.770	13	3.6	3
		Pavement Type	concrete					
		Base Type	granular					
		City	rural					
		County	Ada					

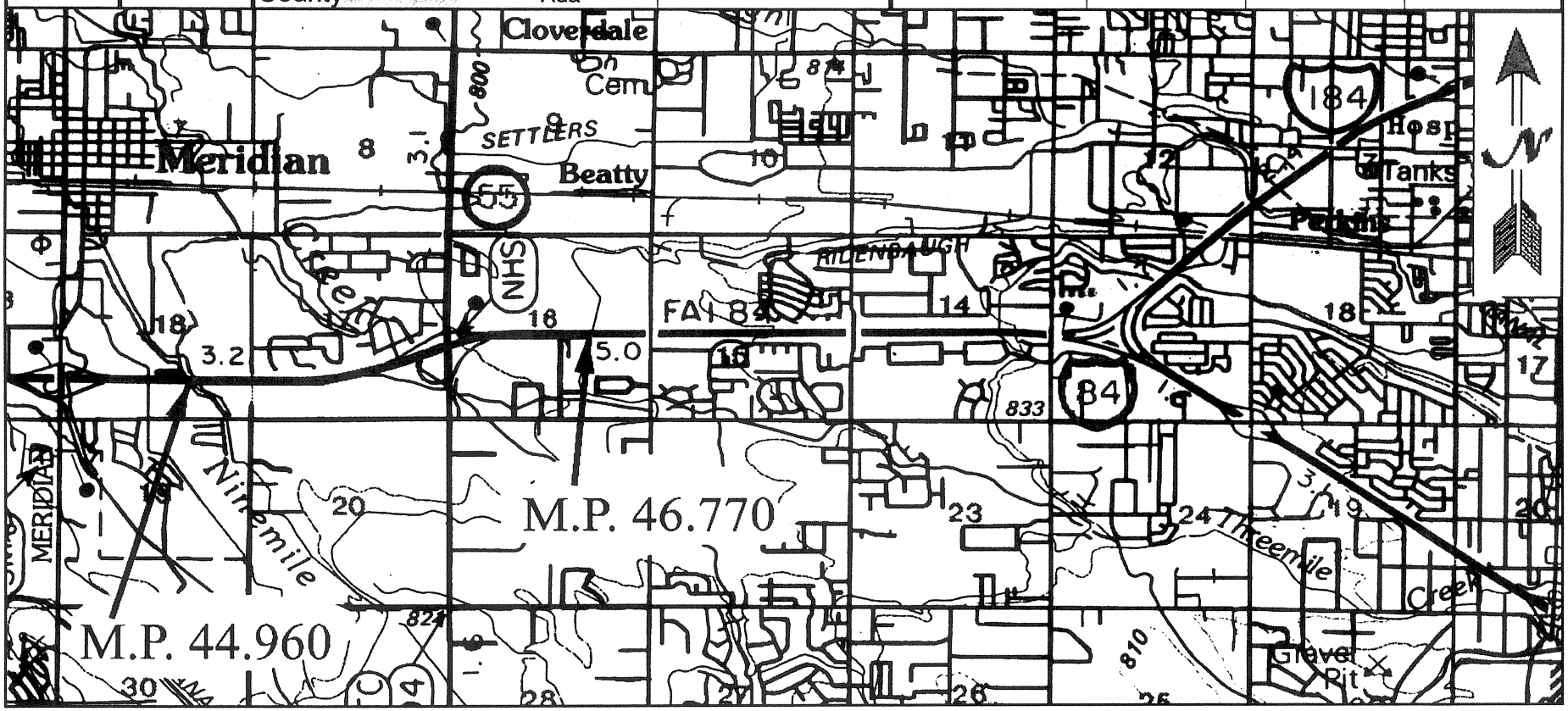


Figure 5 -- Location map for GPR Road Test Site No. 4

Pavement Test Site #5

I-84, Interstate
M.P. 5.698 - 12.610

Route	Segment	Test Area	Data	Description	Break Points			
I-84	1010	Begin M.P.	5.968	Begin 'A' Line canal		Pavement	Base	Subbase
		End M.P.	12.61	Maintenance cross	Mile Post	Thickness (in)	Thickness (in)	Thickness (in)
		Length (mi)	6.642	**Eastbound**	5.968 - 6.570	6	9.6	9.6
		Func. Class	Interstate		7.780 - 9.450	6	9.6	9.6
		Pavement Type	asphalt		9.450 - 9.540	3.6	9.6	9.6
		Base Type	granular		9.540 - 12.600	6	9.6	9.6
		City	rural		12.600 - 12.610	9	4.8	4.8
		County	Payette					

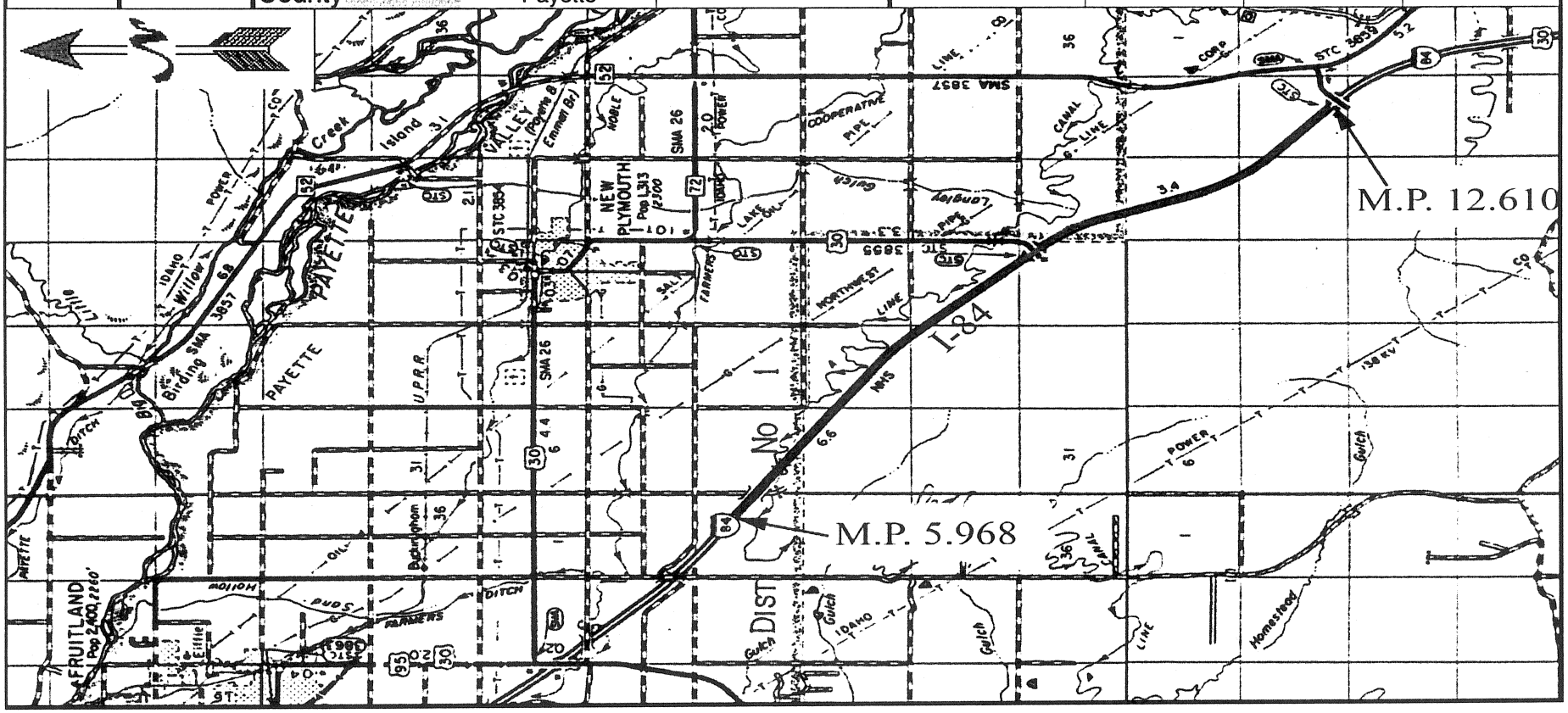


Figure 6 -- Location map for GPR Road Test Site No. 5

Pavement Test Site #6

I-84, Interstate
M.P. 96.153 - 99.570

Route	Segment	Test Area	Data	Description	Break Points			
I-84	1010	Begin M.P.	96.153	Mntn. Home Urban Limit		Pavement	Base	Subbase
		End M.P.	99.57	Center of I-84B Underpass	Mile Post	Thickness (in)	Thickness (in)	Thickness (in)
		Length (mi)	3.417	**Eastbound Direction**	96.153 - 99.570	11.5	13.8	0
		Func. Class	Interstate					
		Pavement Type	concrete					
		Base Type	granular					
		City	rural					
		County	Elmore					

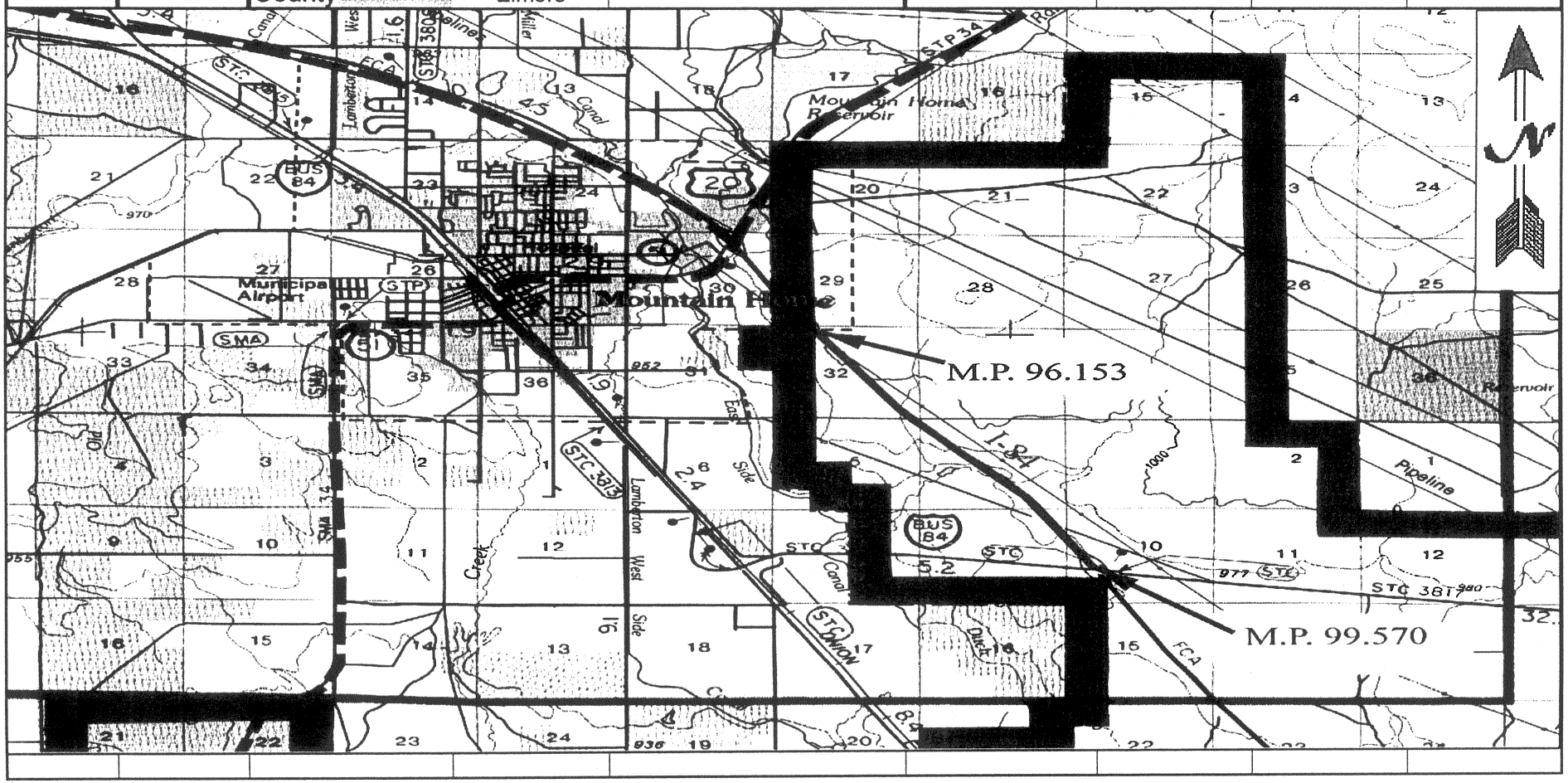


Figure 7 -- Location map for GPR Road Test Site No. 6

Pavement Test Site #7

I-84B, Principal Arterial
M.P. 53.842 - 54.468

Route	Segment	Test Area	Data	Description	Break Points			
I-84B	2040	Begin M.P.	53.842	N. Midway & Caldwell Blvd		Pavement	Base	Subbase
		End M.P.	54.468	Caldwell Bvd&Homedale Rd	Mile Post	Thickness (in)	Thickness (in)	Thickness (in)
		Length (mi)	0.626		53.842 - 54.468	7.9	40	0
		Func. Class	Princ. Artr.					
		Pavement Type	asphalt					
		Base Type	granular					
		City	rural					
		County	Canyon					

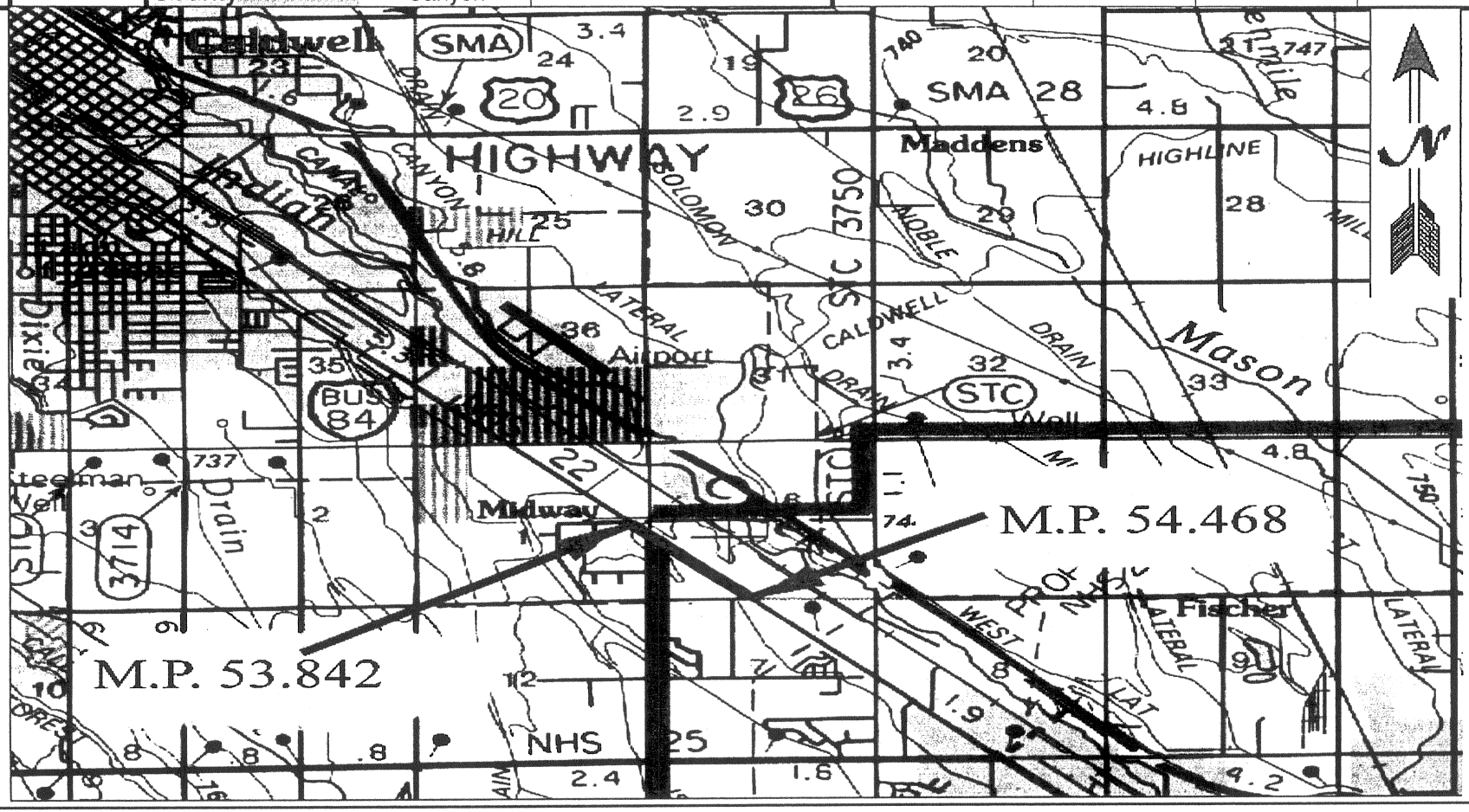


Figure 8 -- Location map for GPR Road Test Site No. 7

Pavement Test Site #8

US-95, Principal Arterial
M.P. 86.600 - 90.300

Route	Segment	Test Area	Data	Description	Break Points			
US-95	1540	Begin M.P.	86.6	Milepost Eq. Marker		Pavement	Base	Subbase
		End M.P.	90.3	N. end of Devil's Elbow Rd.	Mile Post	Thickness (in)	Thickness (in)	Thickness (in)
		Length (mi)	3.7		87.523 - 91.176	3.6	6	0
		Func. Class	Princ. Artr.					
		Pavement Type	asphalt					
		Base Type	granular					
		City	rural					
		County	Washington					

Note: M.P. 86.600 (Segment 1540) = 87.523 (Segment 8641)

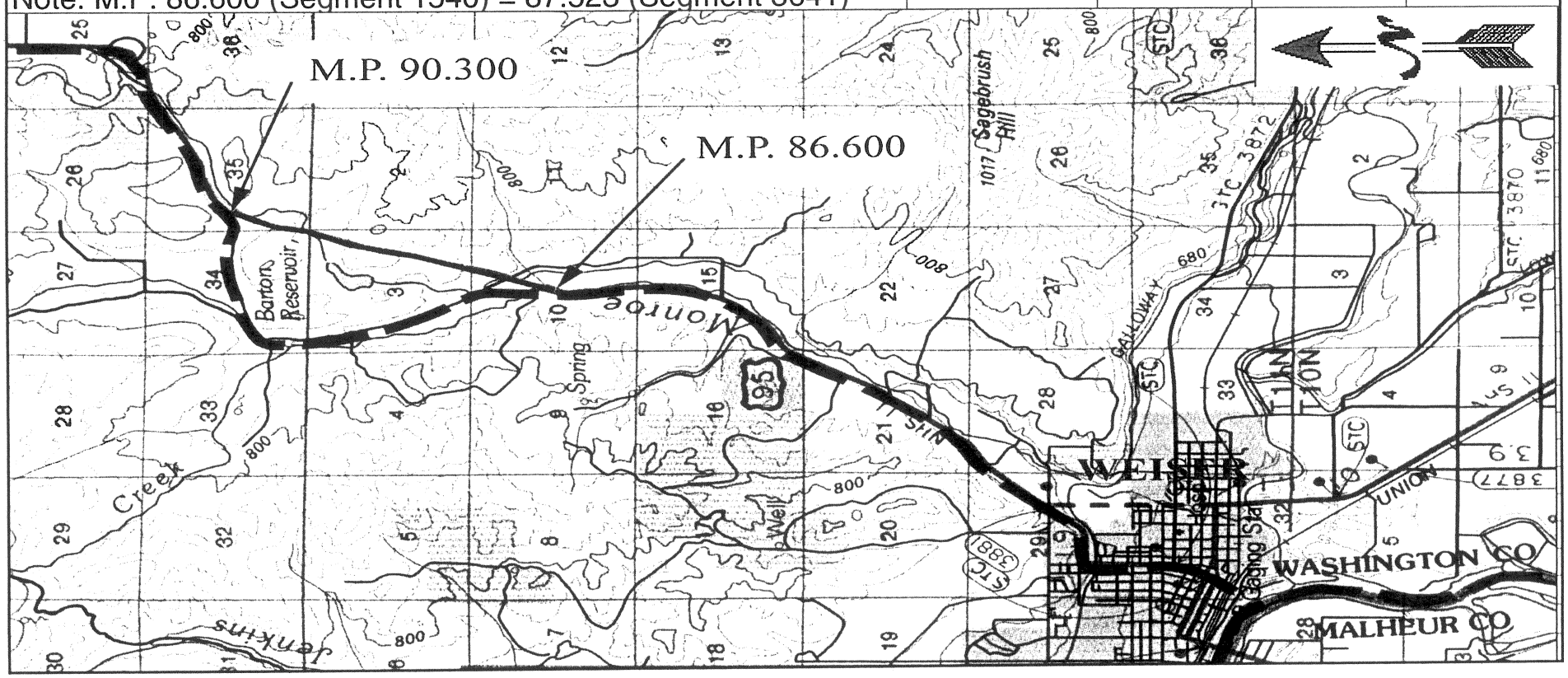
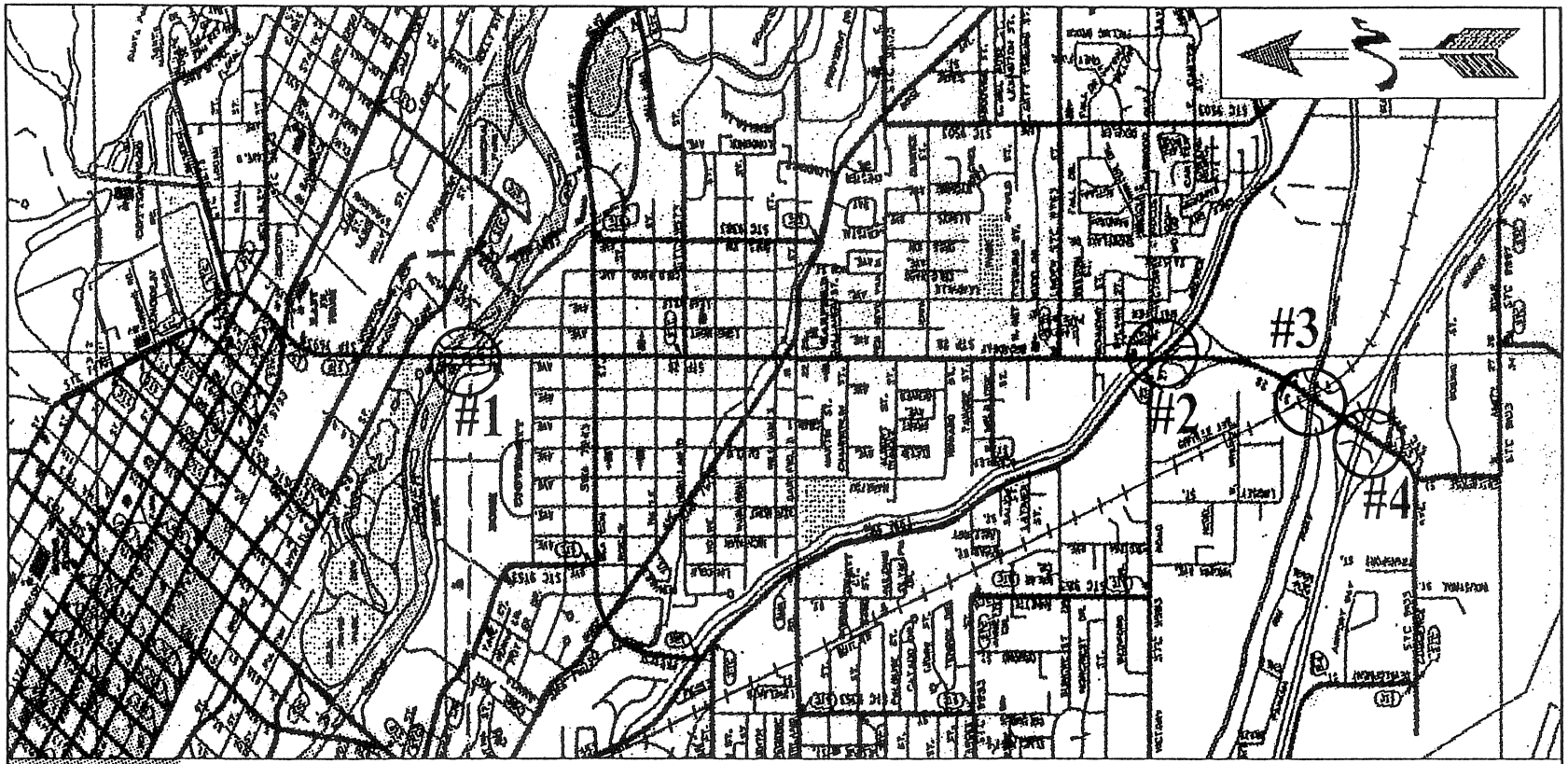


Figure 9 -- Location map for GPR Road Test Site No. 8

Bridge Test Sites
#1-4

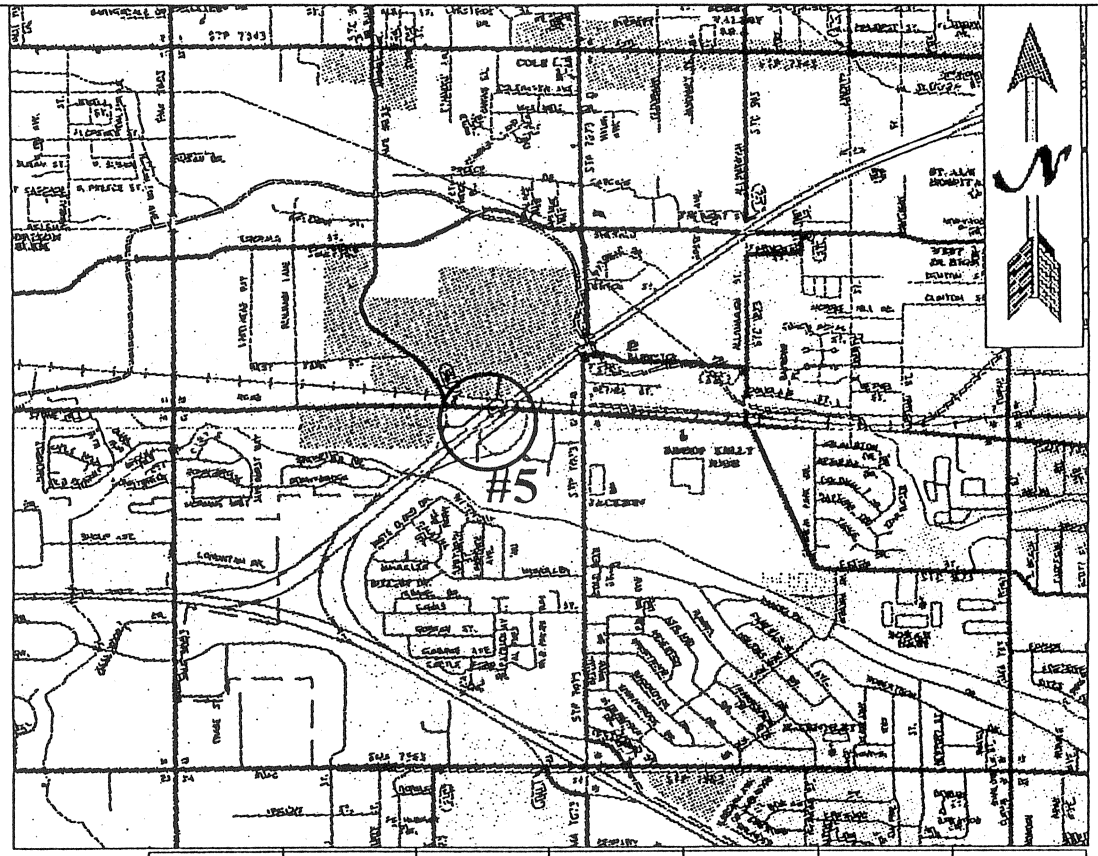


Test Site	#1	#2	#3	#4
Route No.	US-20/26	US-20/26	US-20/26	US-20/26
Description	Boise river, Broadway	Federal Way I.C.	Broadway, N.Y. canal	Broadway I.C.
Mile Post	50.07	52.11	52.54	52.72
Str. No.	02020D	02020D	02020D	02020D
Length (ft)	447	339	302	220
Width (ft)	68	72.8	83.7	74.3
Pavement	Concrete Deck with 0.5" asphalt overlay	Concrete Deck with 0.5" asphalt overlay	Concrete Deck with 2" asphalt overlay	Concrete Deck with 1" asphalt overlay

Figure 10 - Location Map for GPR Bridge Test Sites No. 1, No. 2, No.3 and No. 4

Explanation:
Bridge Test Sites No. 1 and No. 2 were excluded from this study

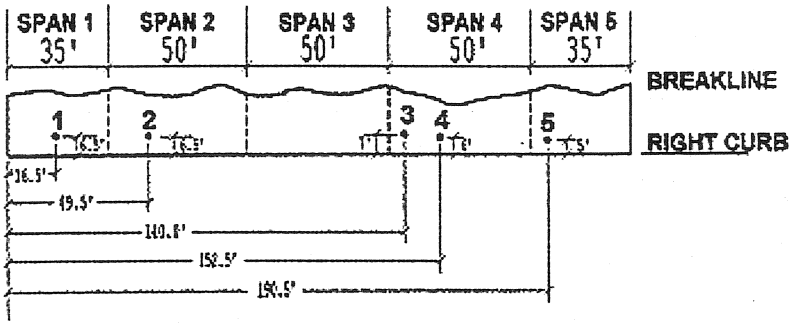
Bridge Test Sites
#5



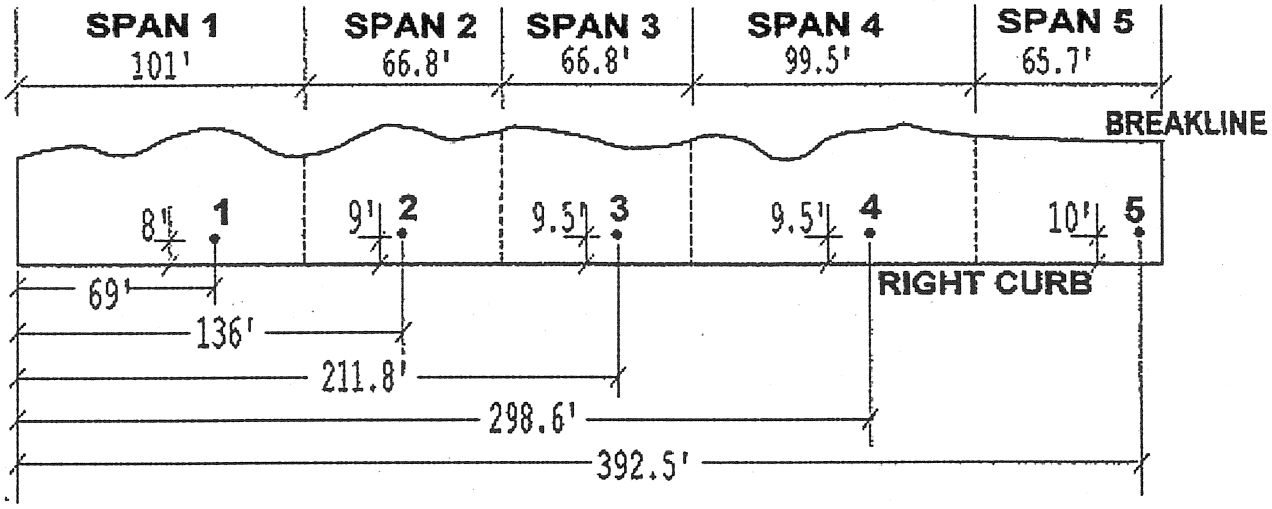
Test Site	#5
Route No.	I-84 WBL
Description	Franklin I.C.
Mile Post	1.04
Str. No.	18070A
Length (ft)	400
Width (ft)	55.1
Pavement	Concrete deck with
	1" asphalt overlay

Figure II - Location Map for GPR Bridge Test Site No. 5

PLAN VIEW OF BRIDGE, US 20/26 over I-84 (BROADWAY AVENUE INTERCHANGE)



PLAN VIEW OF BRIDGE, I-184 over FRANKLIN ROAD (FRANKLIN INTERCHANGE)



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

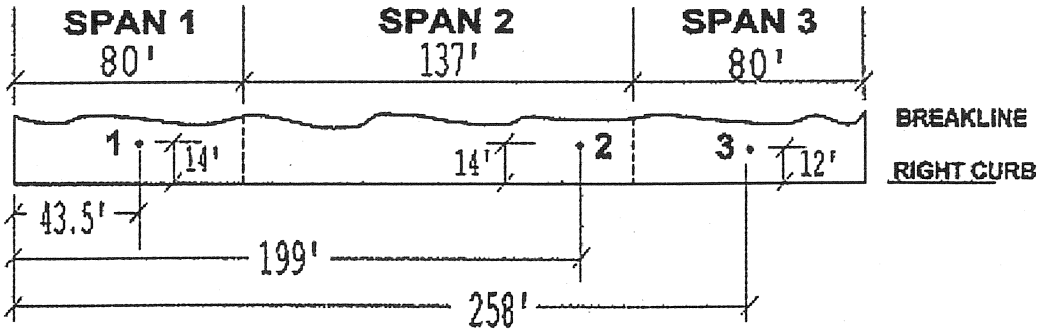
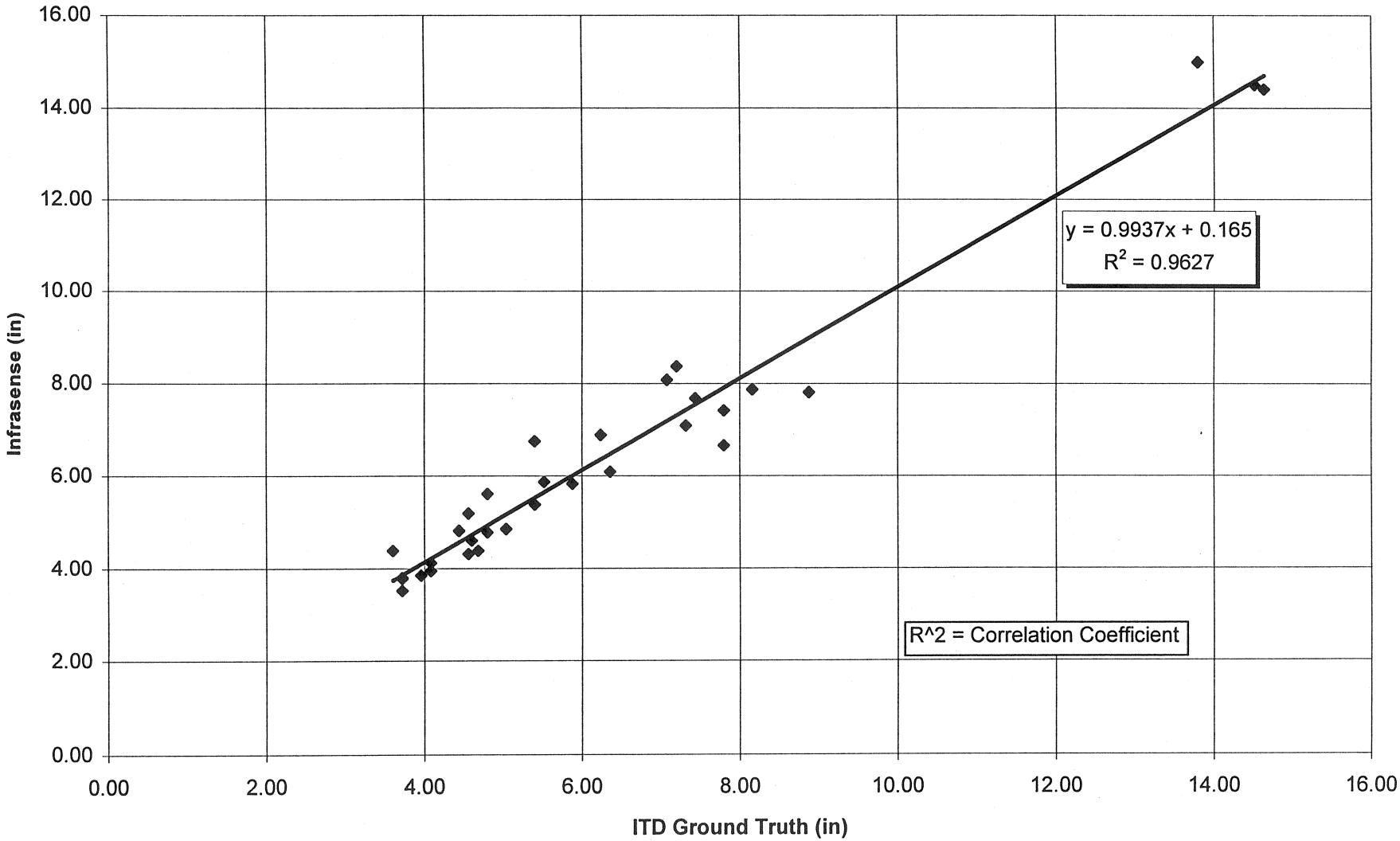


Figure 12 – Borehole Location Map for GPR Bridge Test Sites

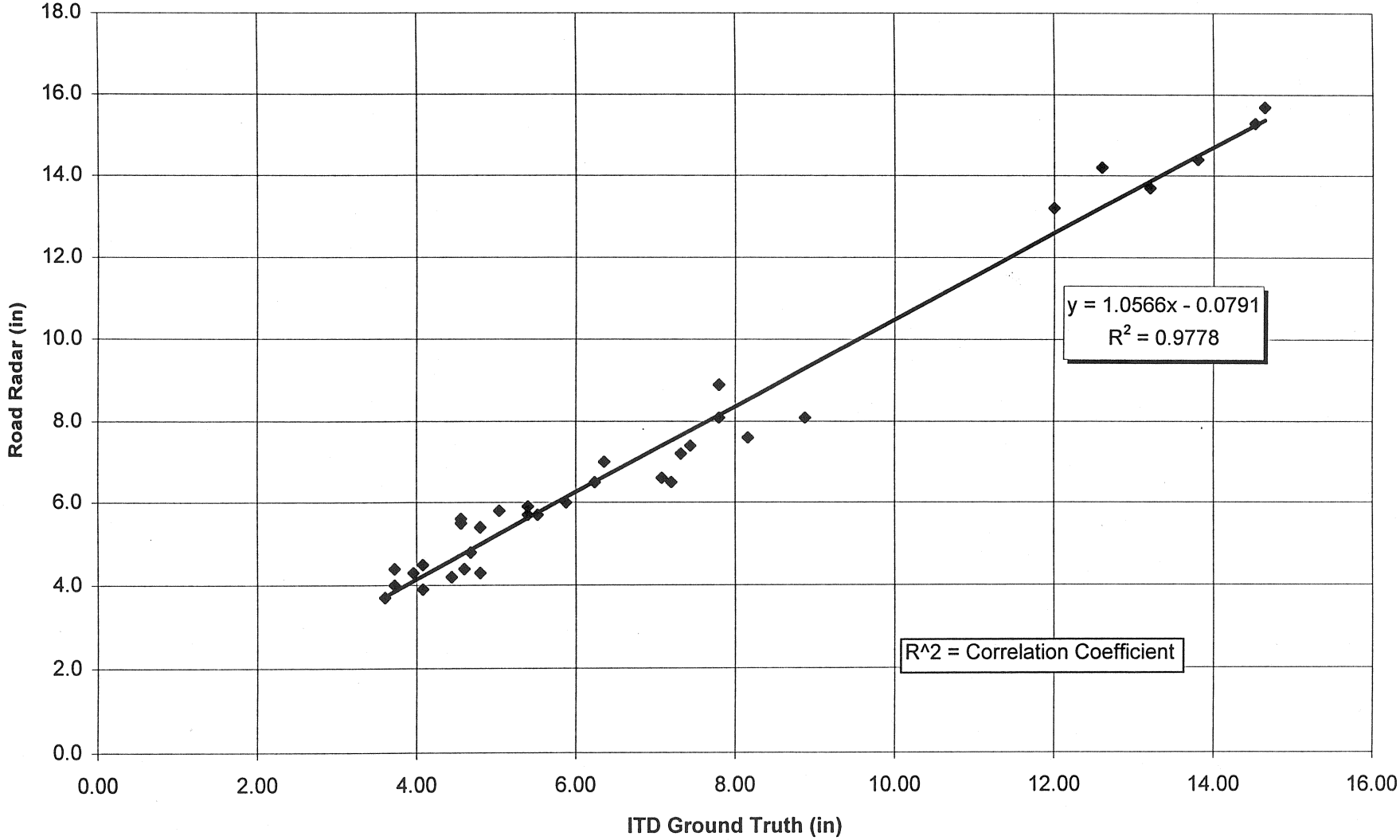
REFERENCE: TABLE 4

Figure 13 - ITD Core Data (Ground Truth) versus Infrasense Data for Surface Course Thickness (Project Survey, All Sites)



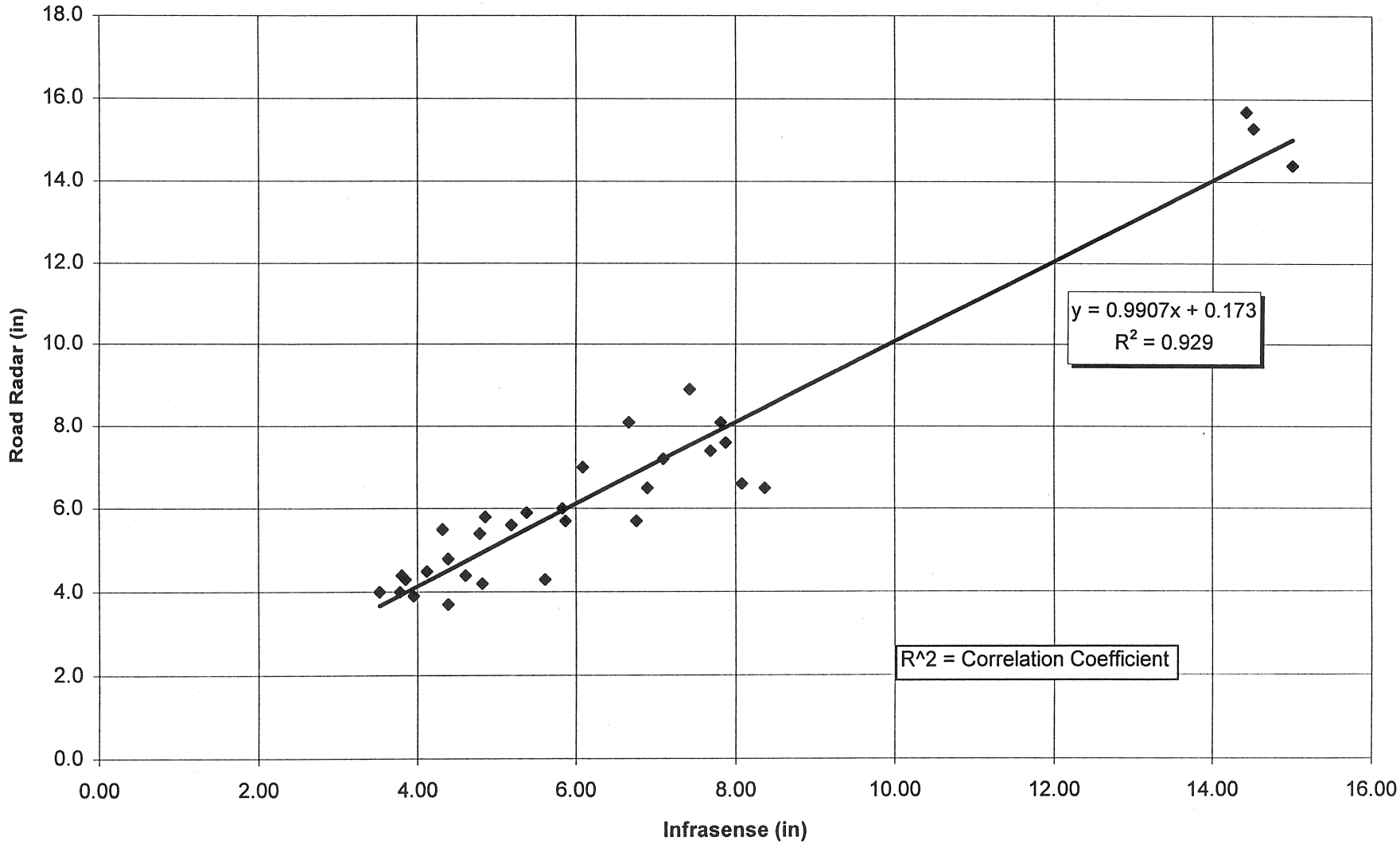
Reference: Table 2

Figure 14 - ITD Core Data (Ground Truth) versus Road Radar Data for Surface Course Thickness (Project Survey, All Sites)



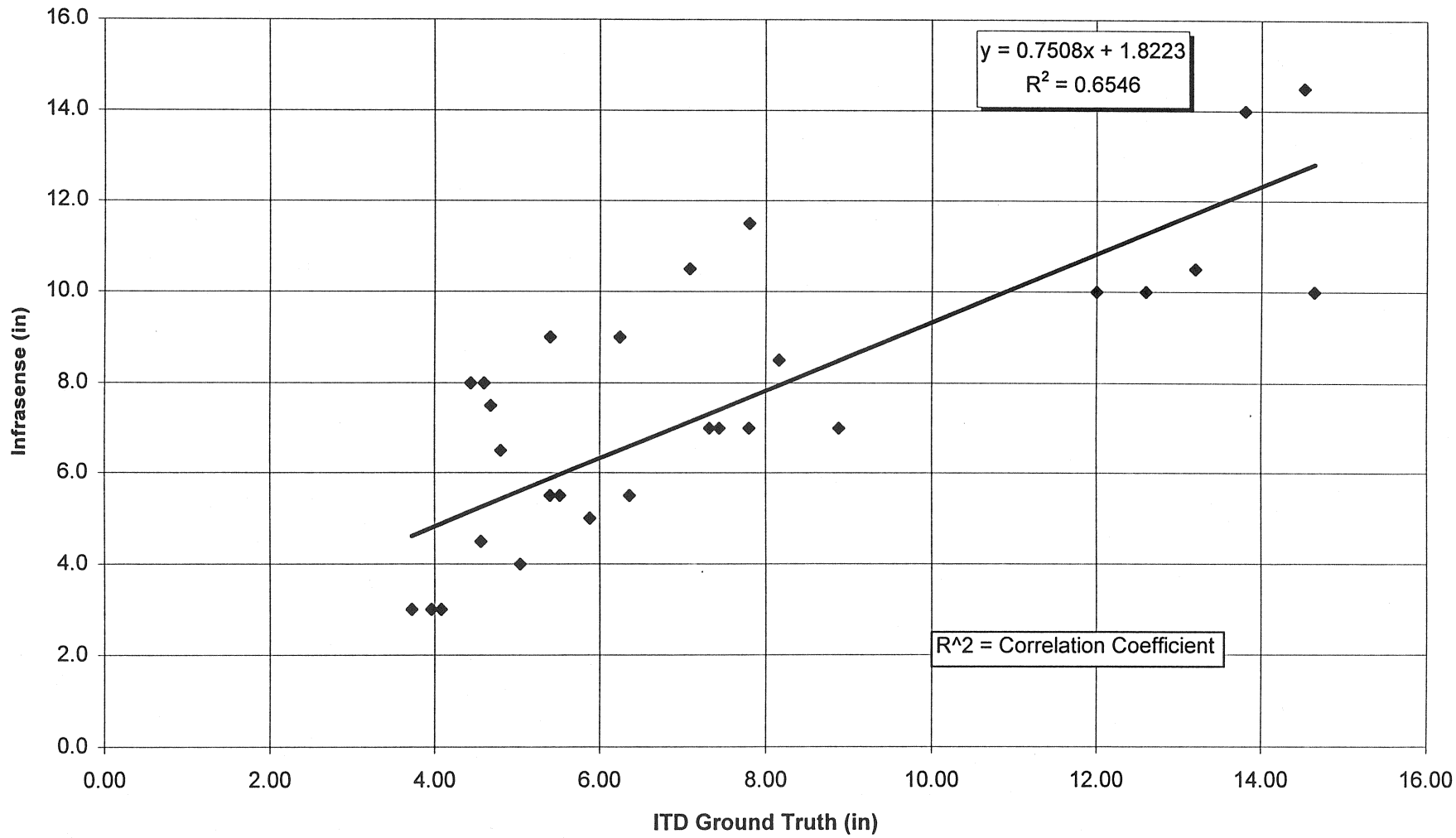
Reference: Table 2

Figure 15 - Infrasense Data versus Road Radar Data for Surface Course Thickness (Project Survey, All Sites)



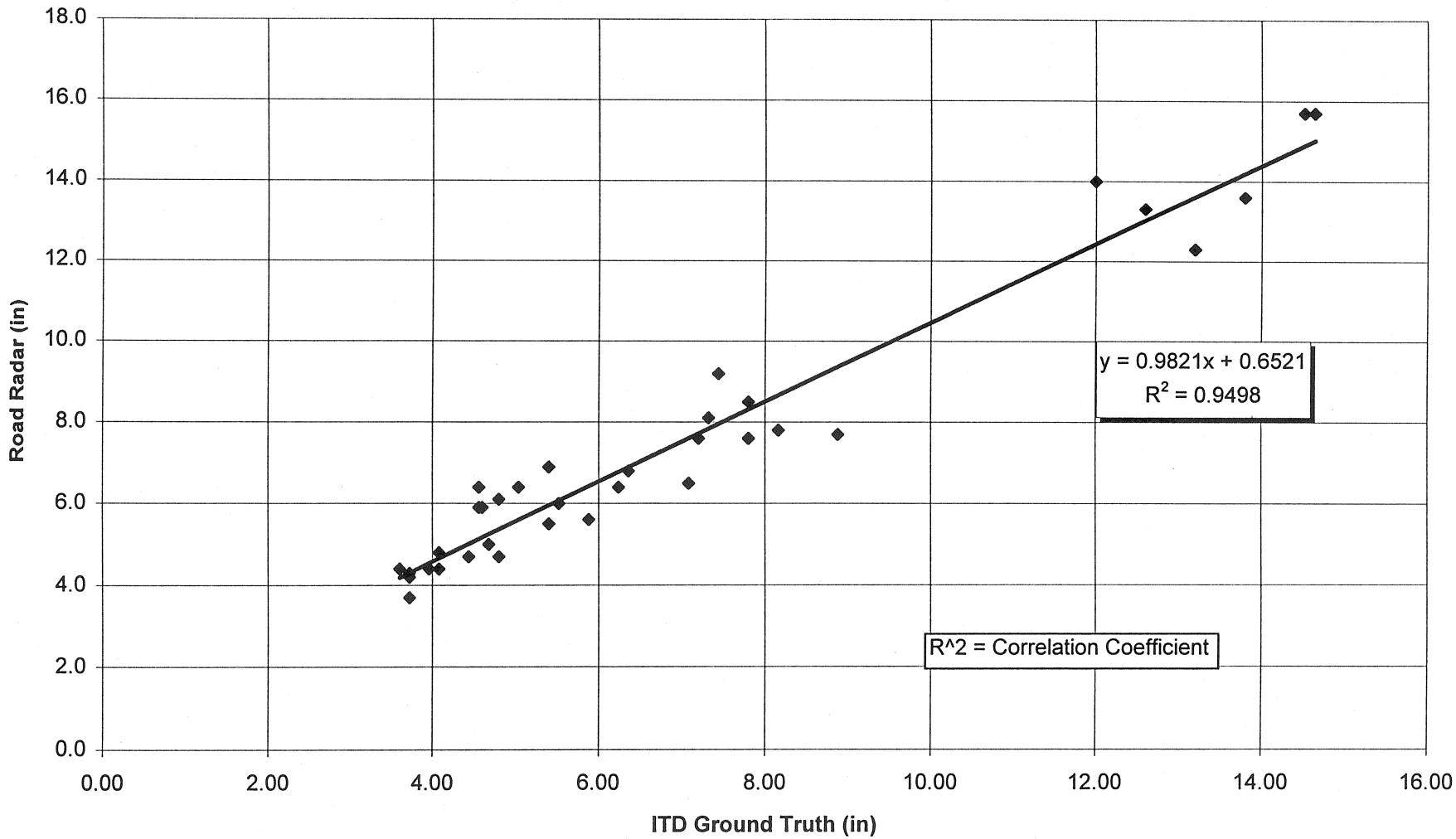
Reference: Table 2

Figure 16 - ITD Core Data (Ground Truth) versus Infrasense Data for Surface Course Thickness (Network Survey, All Sites)



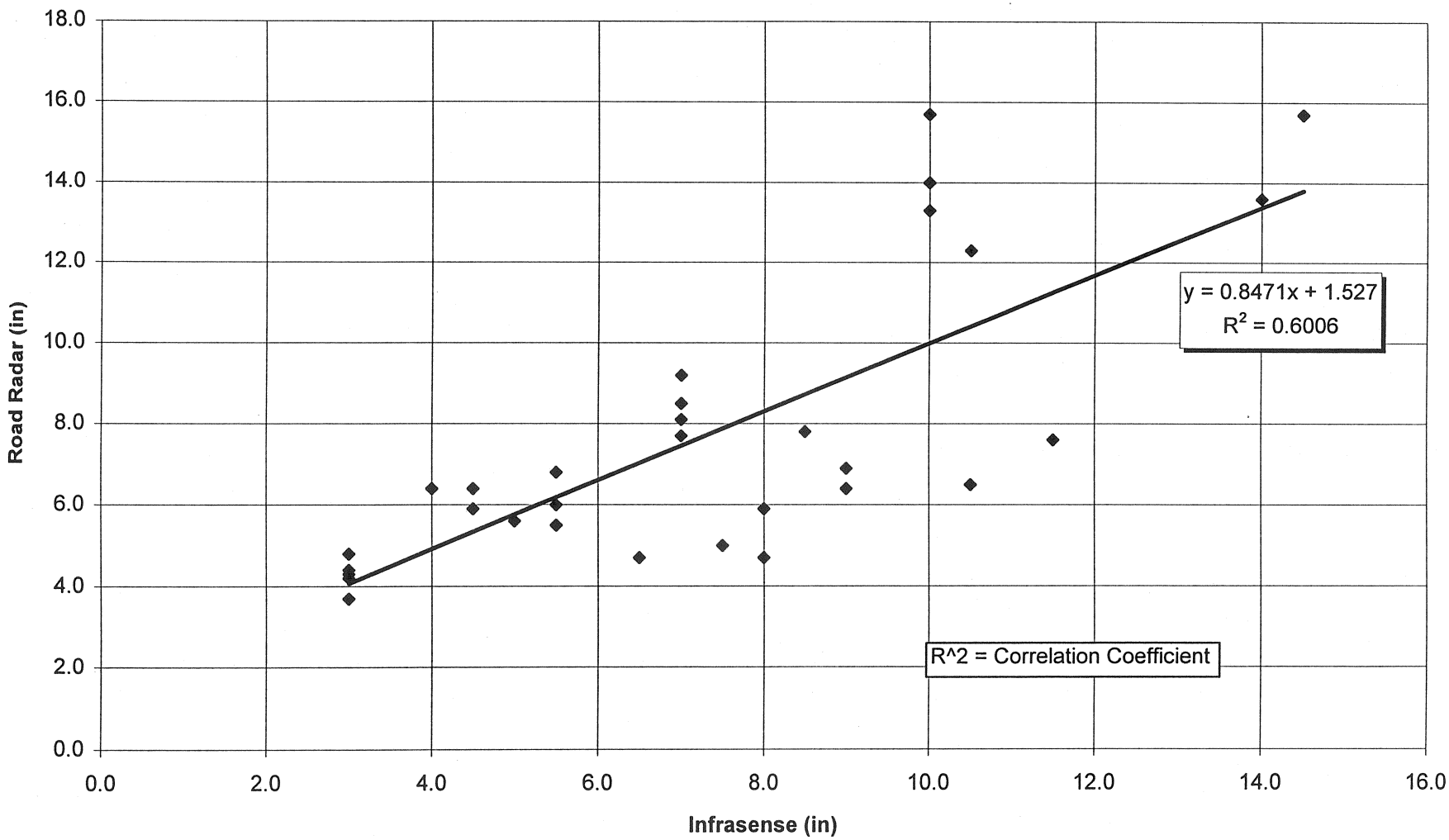
Reference: Table 2

Figure 17 - ITD Core Data (Ground Truth) versus Road Radar Data for Surface Course Thickness (Network Survey, All Sites)



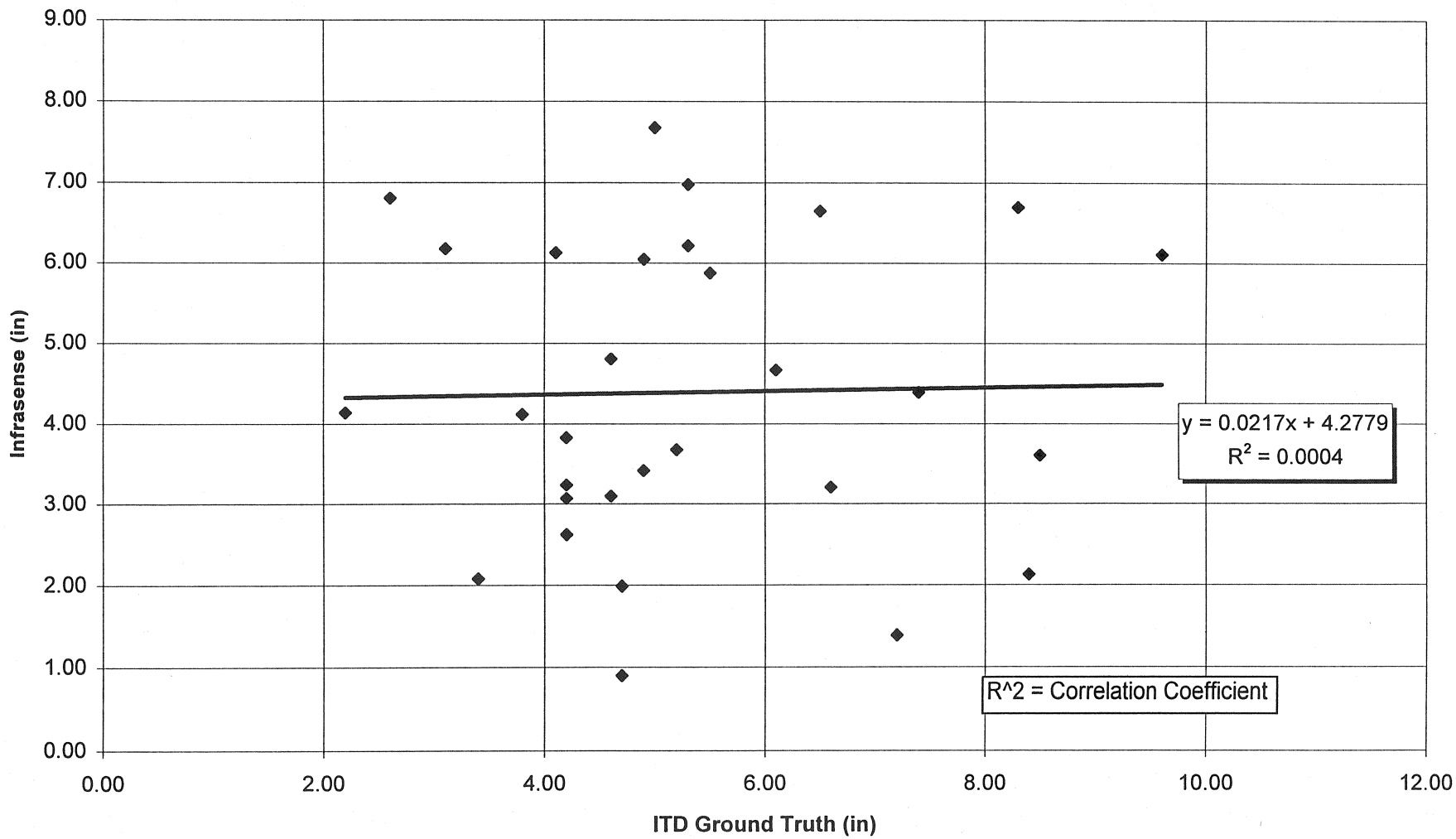
Reference: Table 2

Figure 18 - Infrasense Data versus Road Radar Data for Surface Course Thickness (Network Survey, All Sites)



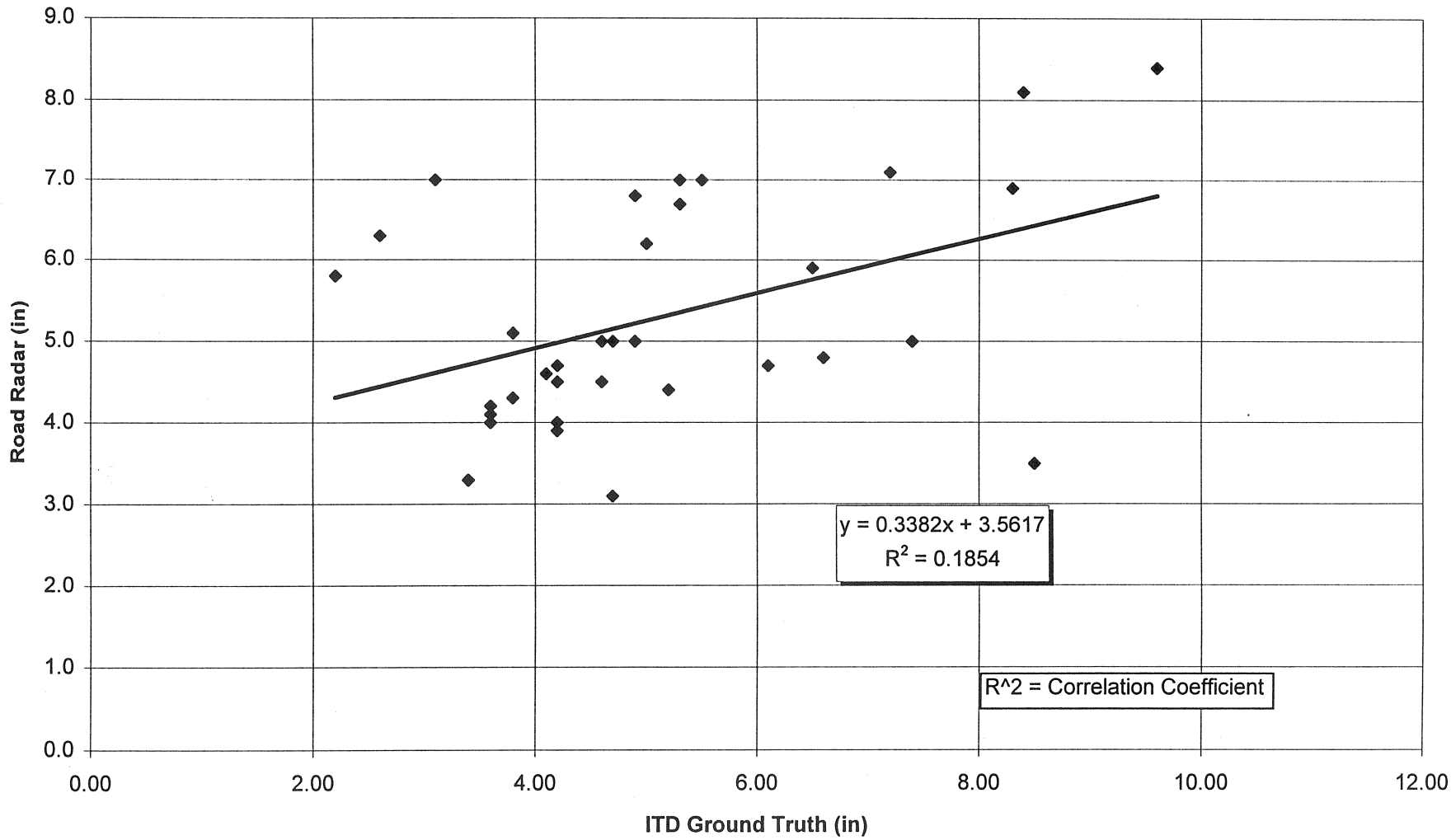
Reference: Table 2

Figure 19 - ITD Core Data (Ground Truth) versus Infrasense Data for Base Course Thickness (Project Survey, All Sites)



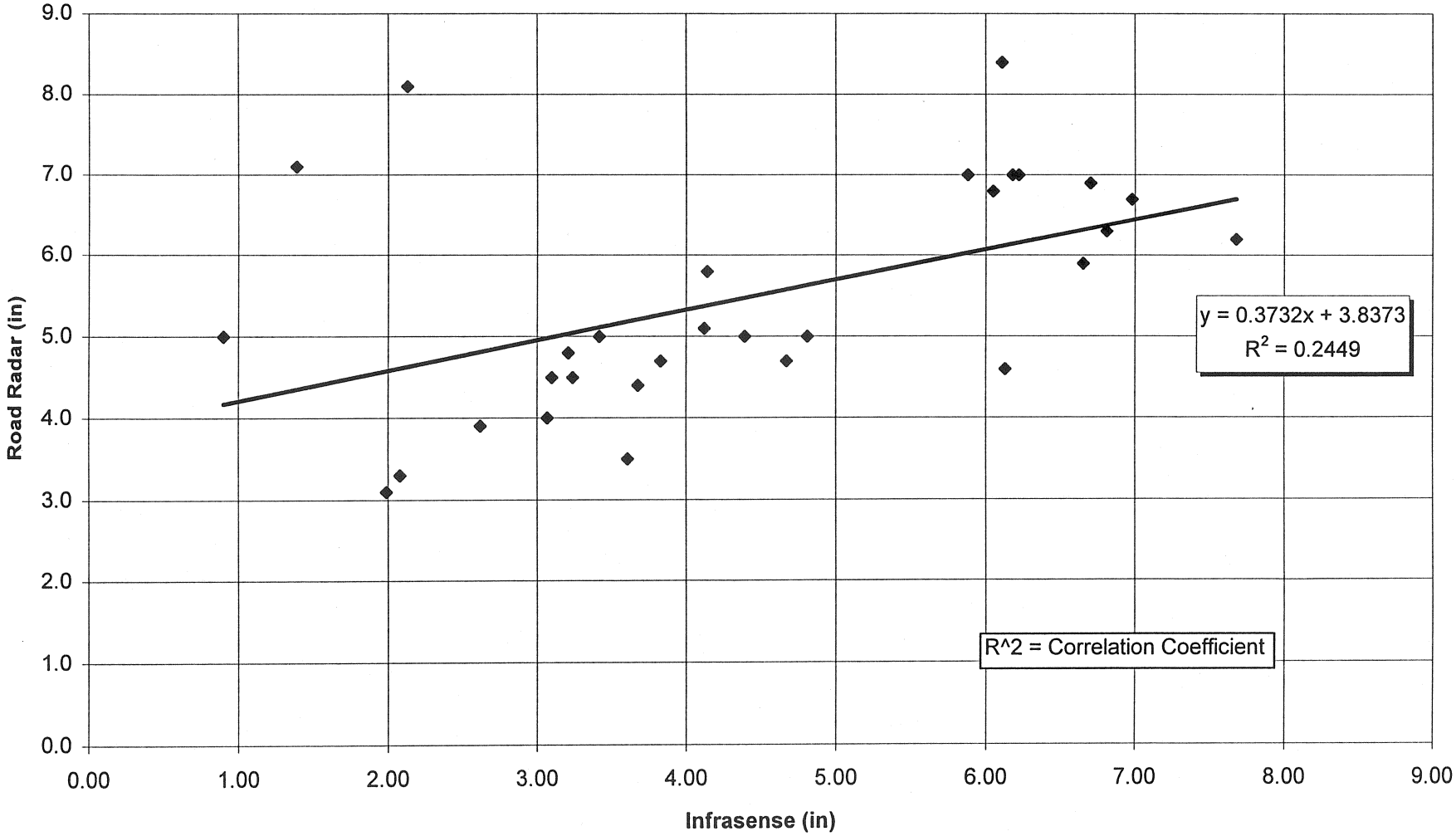
Reference: Table 3

Figure 20 - ITD Core Data (Ground Truth) versus Road Radar Data for Base Course Thickness (Project Survey, All Sites)



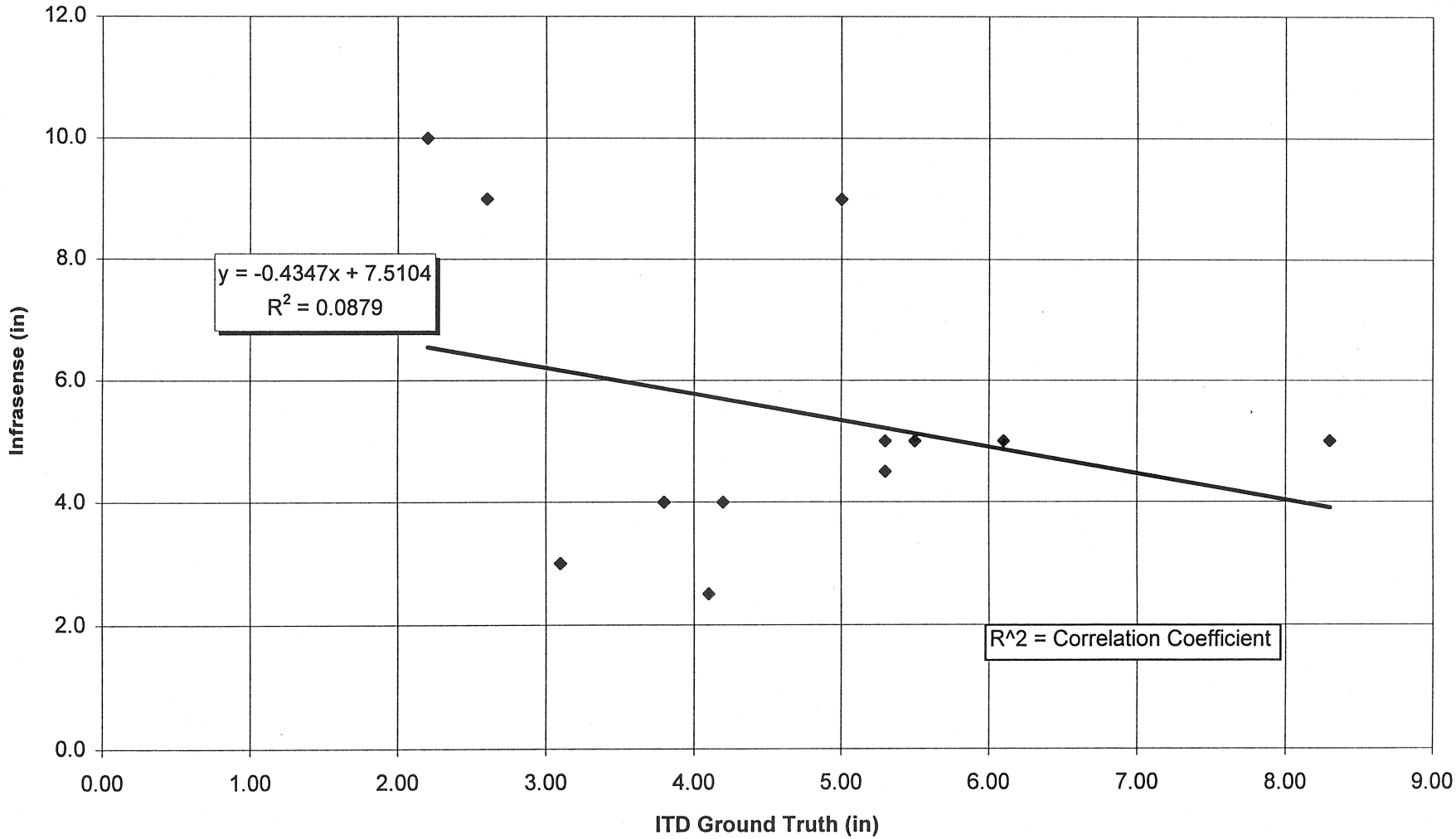
Reference: Table 3

Figure 21 - Infrasense Data versus Road Radar Data for Base Course Thickness (Project Survey, All Sites)



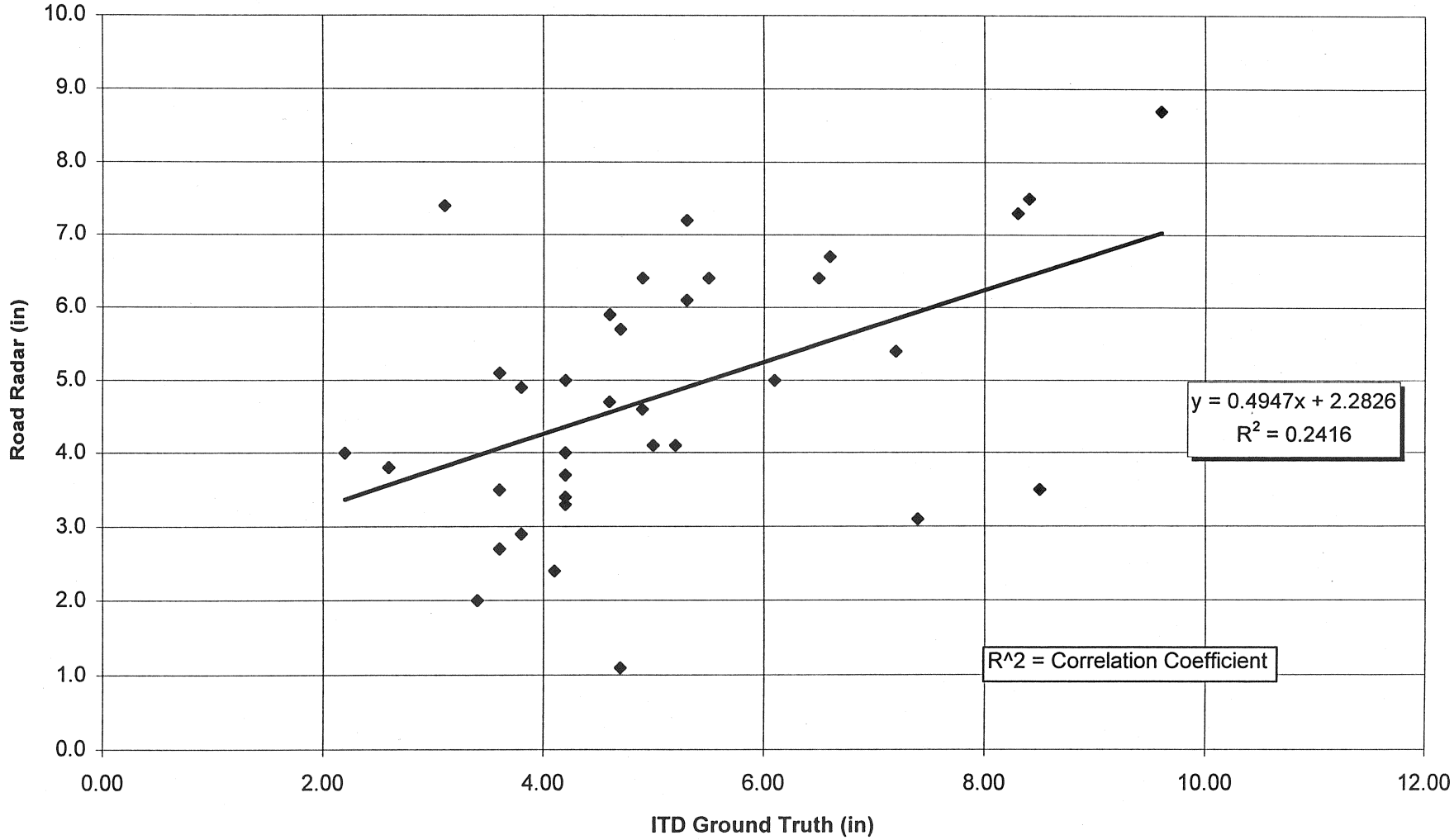
Reference: Table 3

Figure 22 - ITD Core Data (Ground Truth) versus Infrasense Data for Base Course Thickness (Network Survey, All Sites)



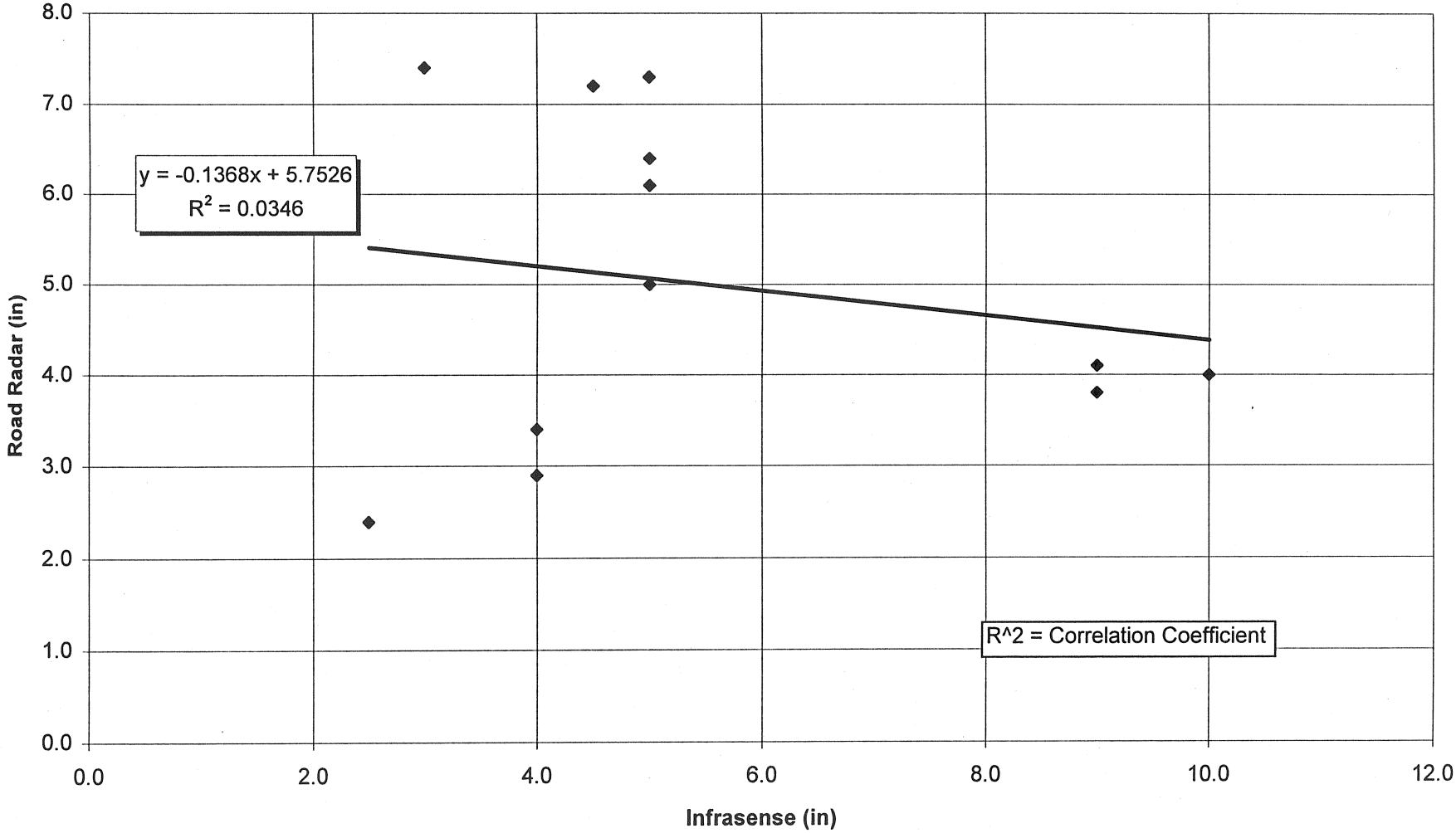
Reference: Table 3

Figure 23 - ITD Core Data (Ground Truth) versus Road Radar Data for Base Course Thickness (Network Survey, All Sites)



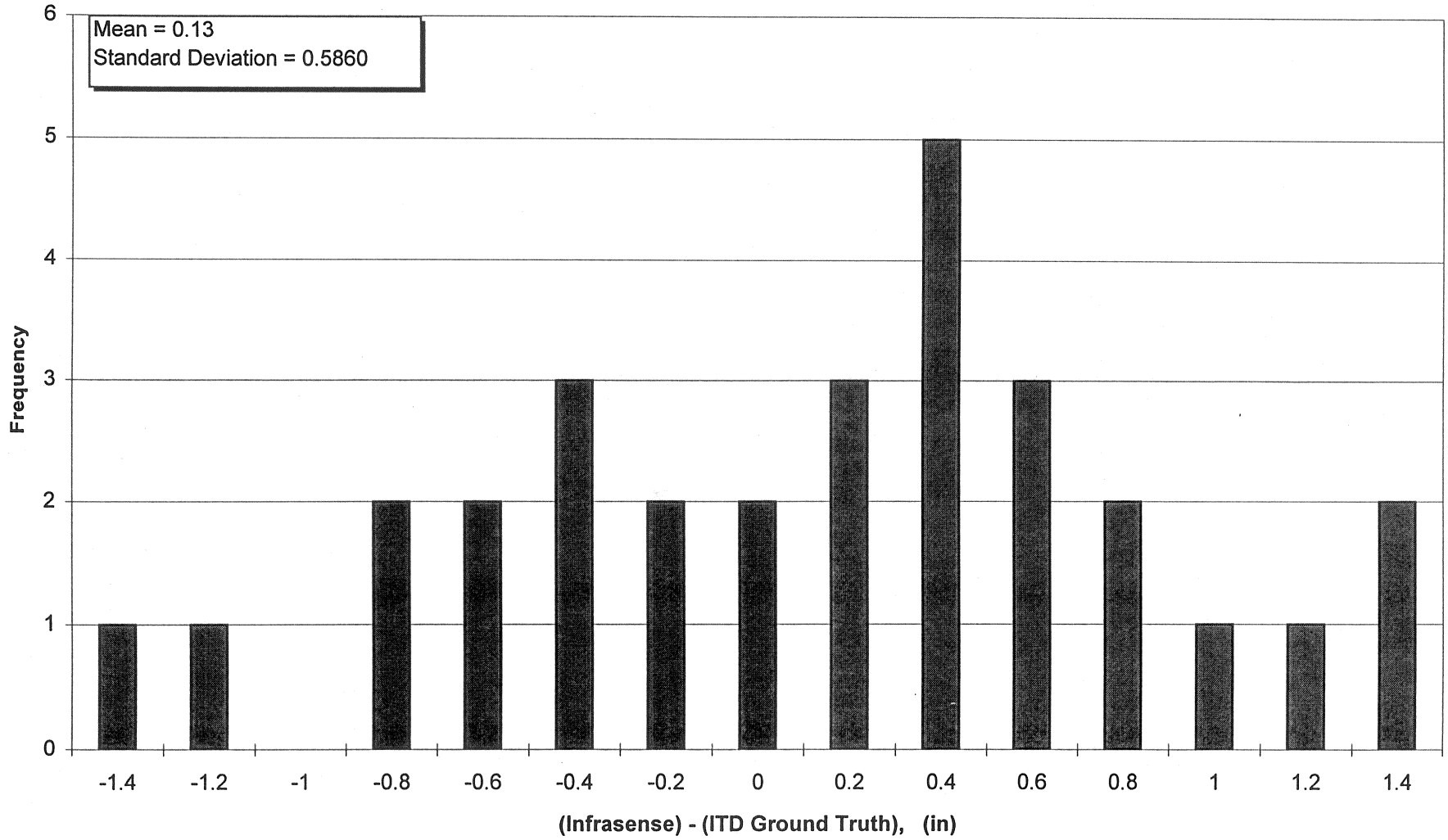
Reference: Table 3

Figure 24 - Infrasense Data versus Road Radar Data for Base Course Thickness (Network Survey, All Sites)



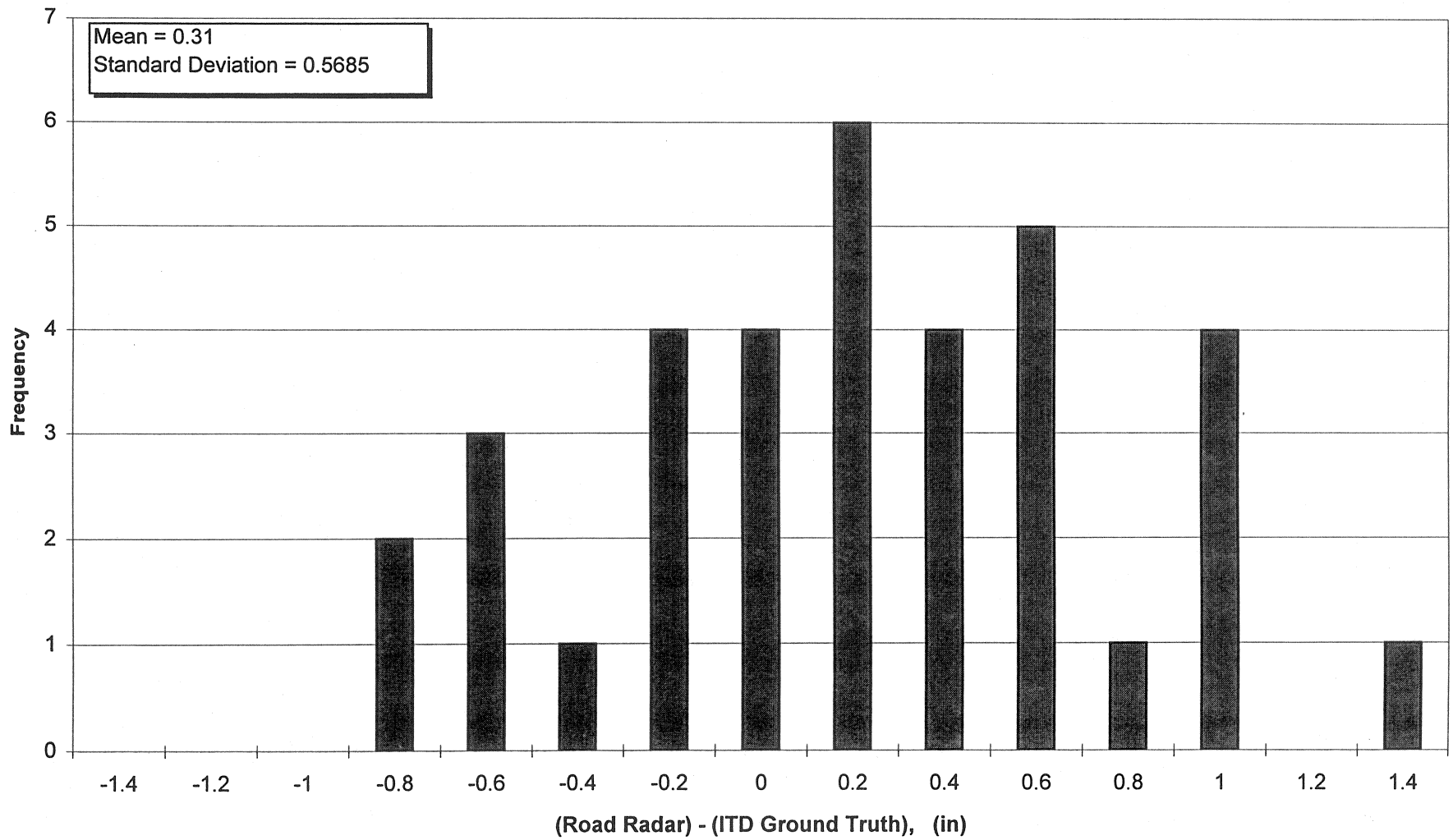
Reference: Table 3

Figure 25 - Histogram of Variations between Infrasense and ITD Core Data (Ground Truth) of Surface Course Thickness for Roadway Test Sections (Project Survey, All Sites)



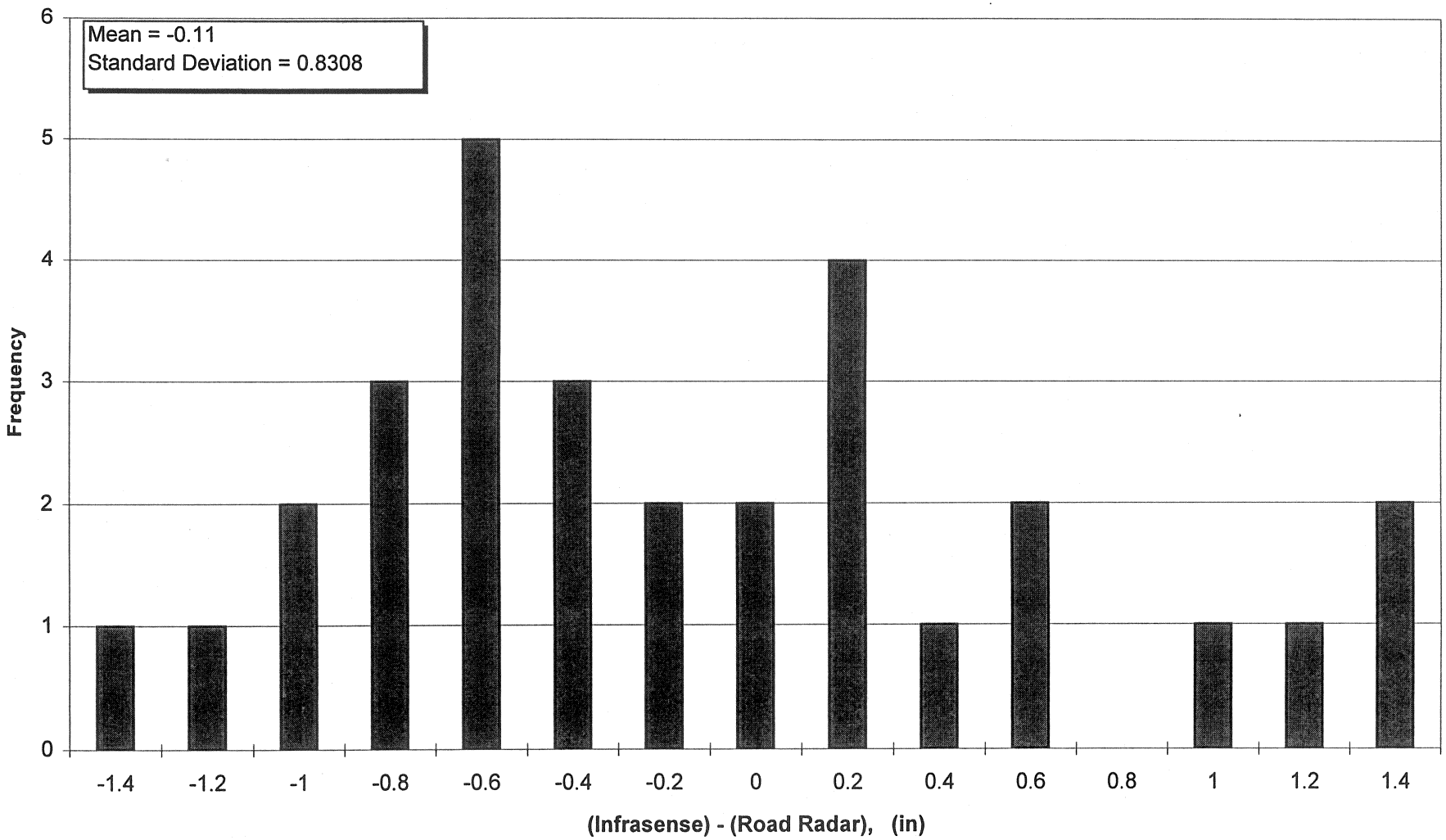
Reference: Table 5

Figure 26 - Histogram of Variations between Road Radar and ITD Core Data (Ground Truth) of Surface Course Thickness for Roadway Test Sections (Project Survey, All Sites)



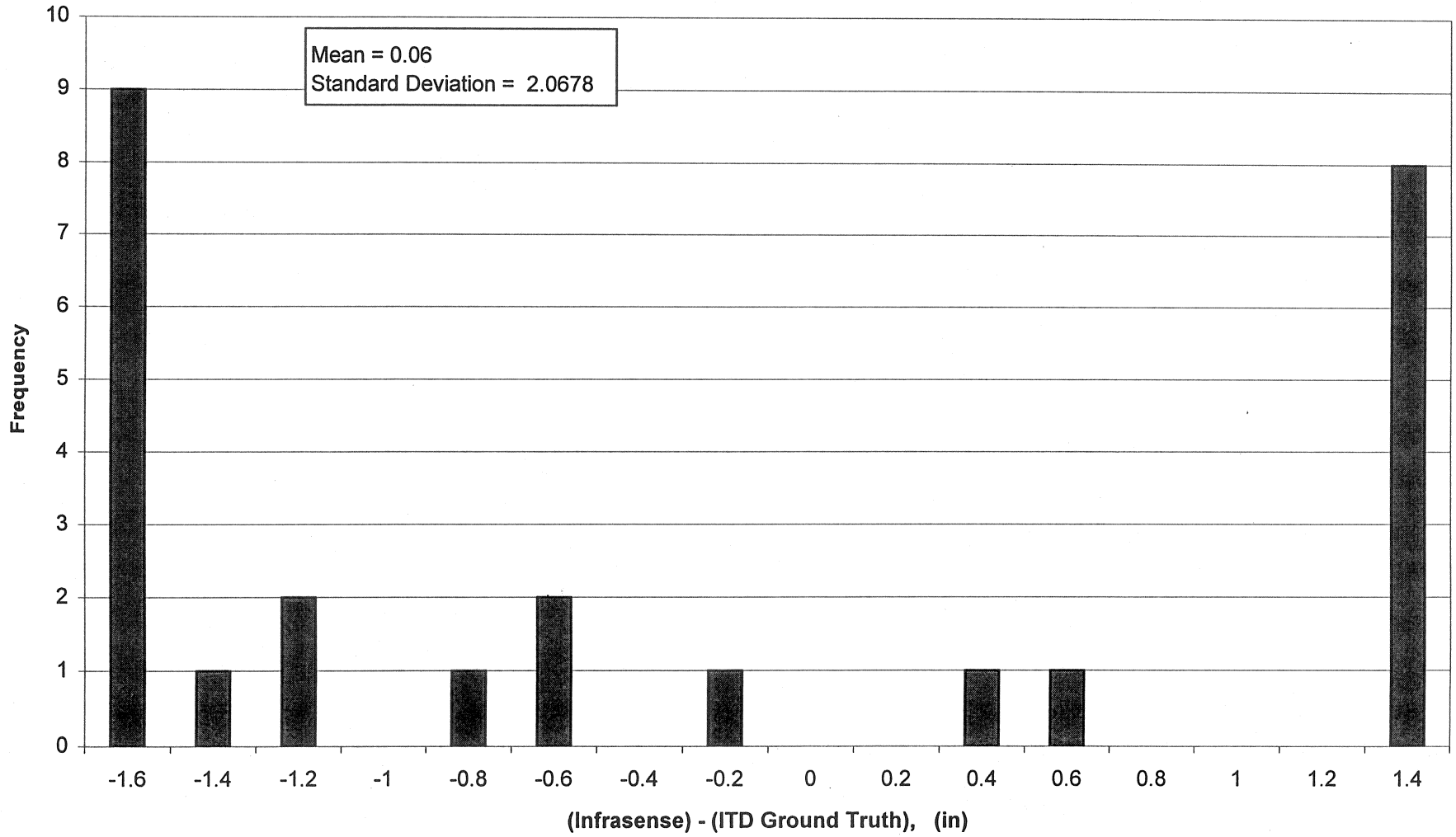
Reference: Table 5

Figure 27 - Histogram of Variations between Infrasense and Road Radar Data of Surface Course Thickness for Roadway Test Sections (Project Survey, All Sites)



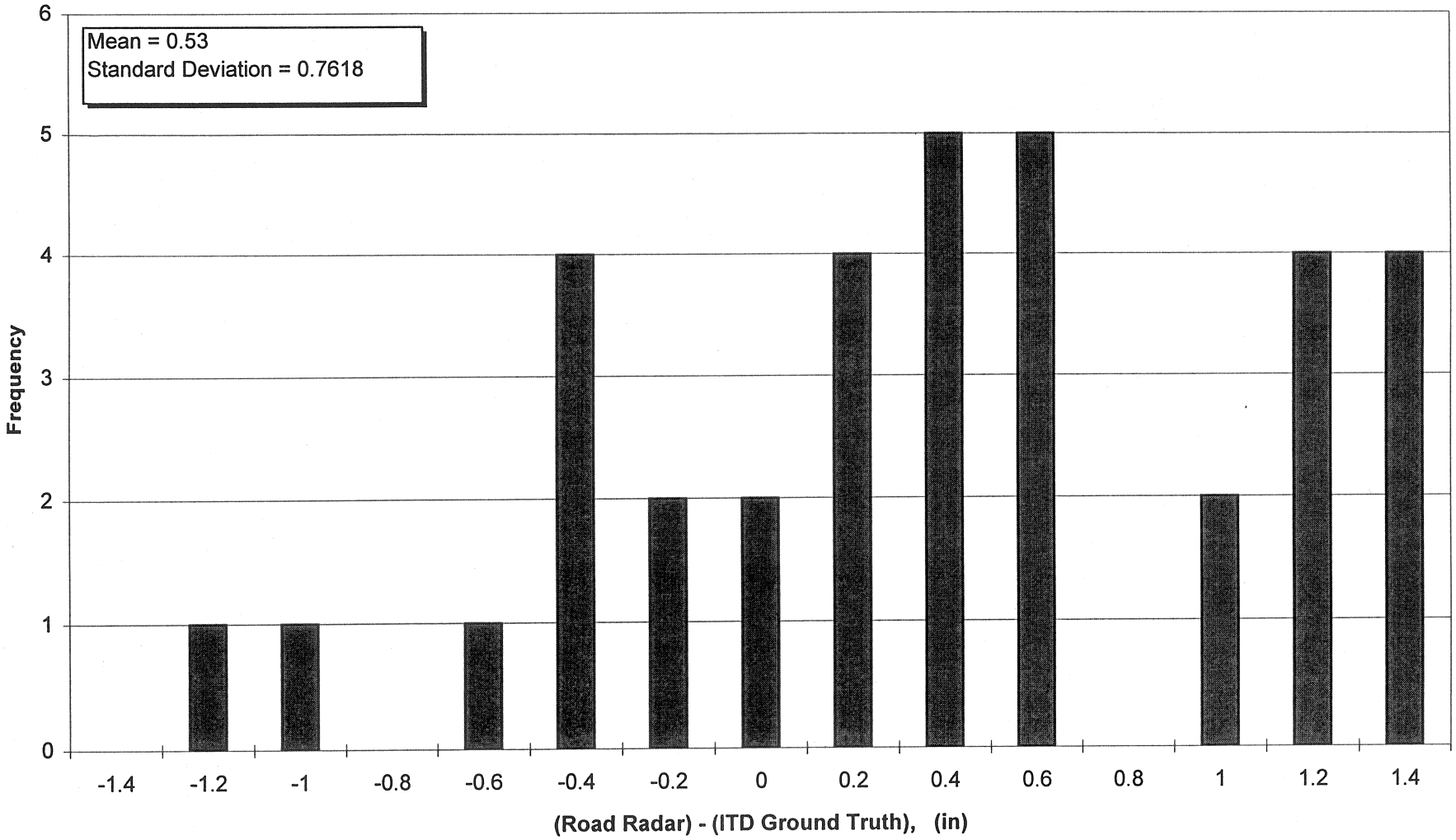
Reference: Table 5

Figure 28 - Histogram of Variations between Infrasense and ITD Core Data (Ground Truth) of Surface Course Thickness for Roadway Test Sections (Network Survey, All Sites)



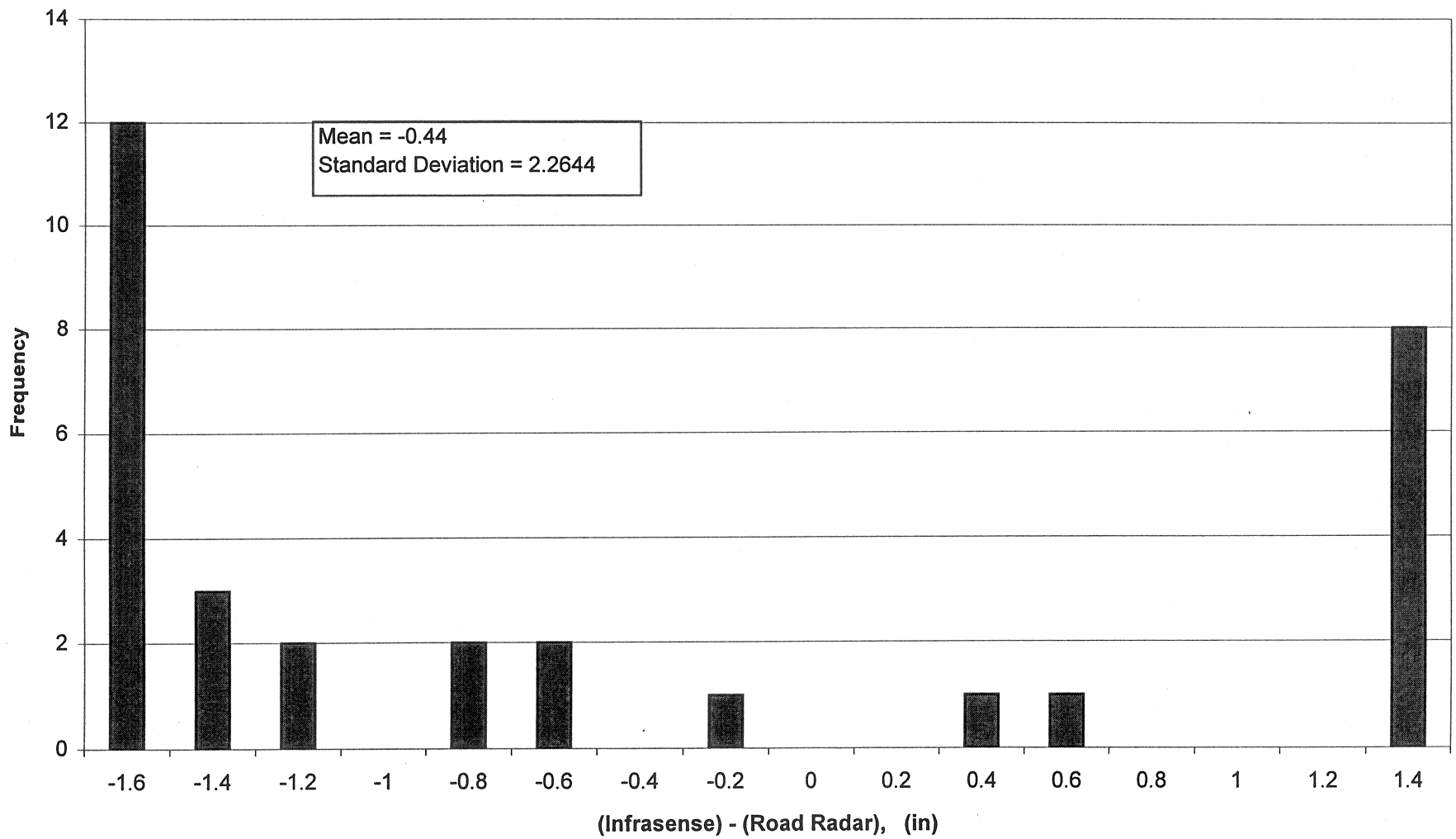
Reference: Table 6

Figure 29 - Histogram of Variations between Road Radar and ITD Core Data (Ground Truth) of Surface Course Thickness for Roadway Test Sections (Network Survey, All Sites)



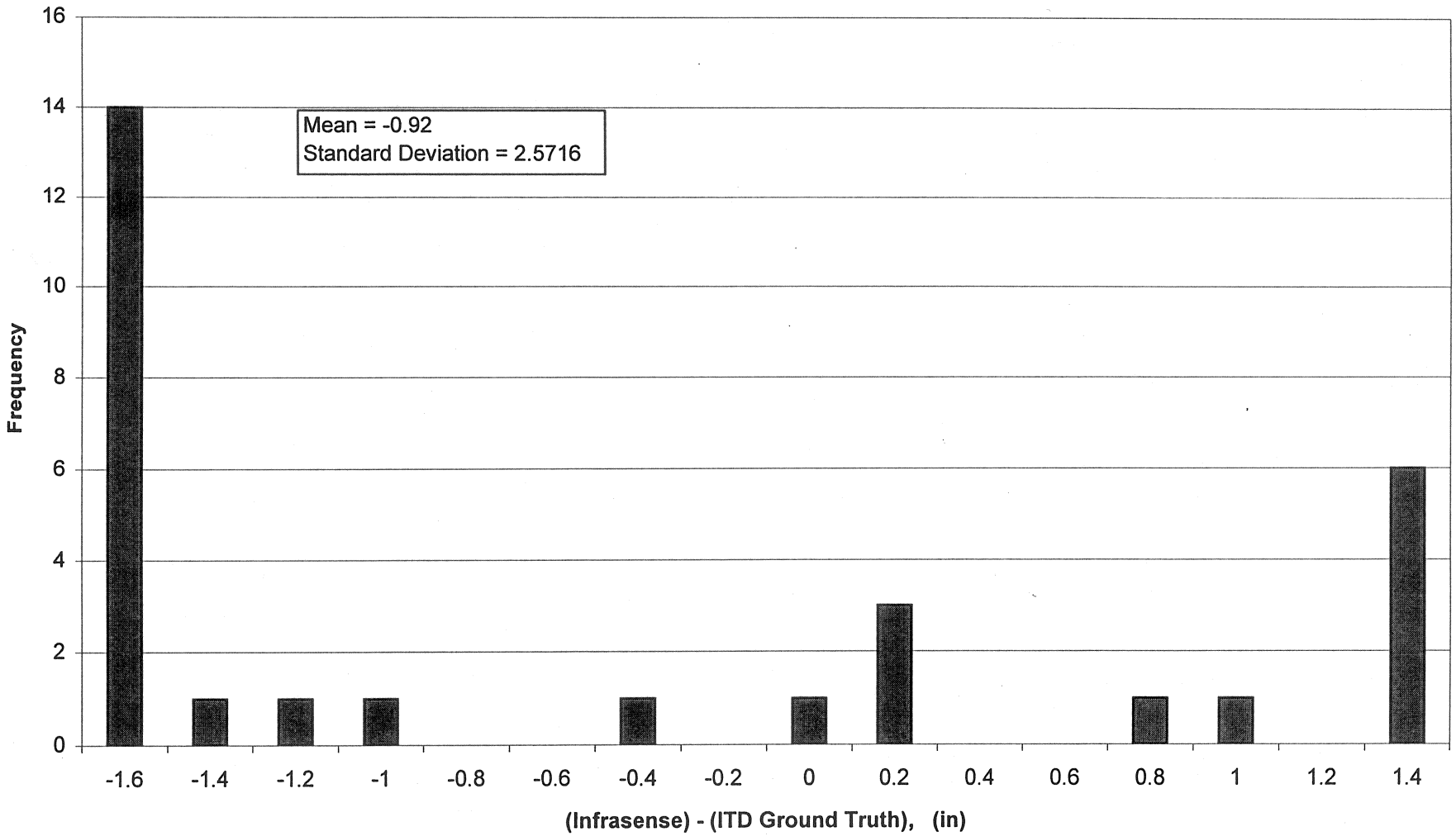
Reference: Table 6

Figure 30 - Histogram of Variations between Infrasense and Road Radar of Surface Course Thickness for Roadway Test Sections (Network Survey, All Sites)



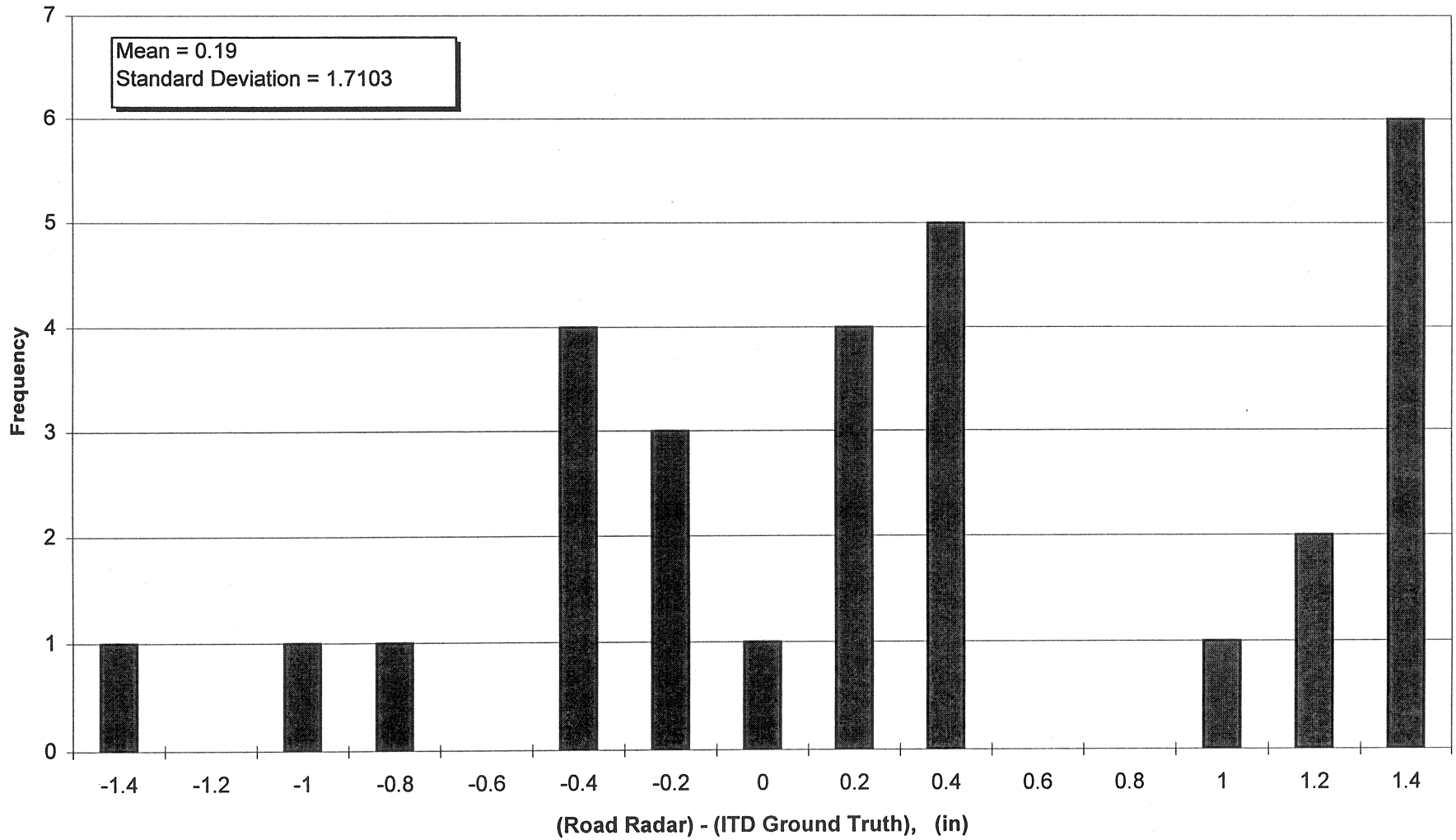
Reference: Table 6

Figure 31 - Histogram of Variations between Infrasense and ITD Core Data (Ground Truth) of Base Course Thickness for Roadway Test Sections (Project Survey, All Sites)



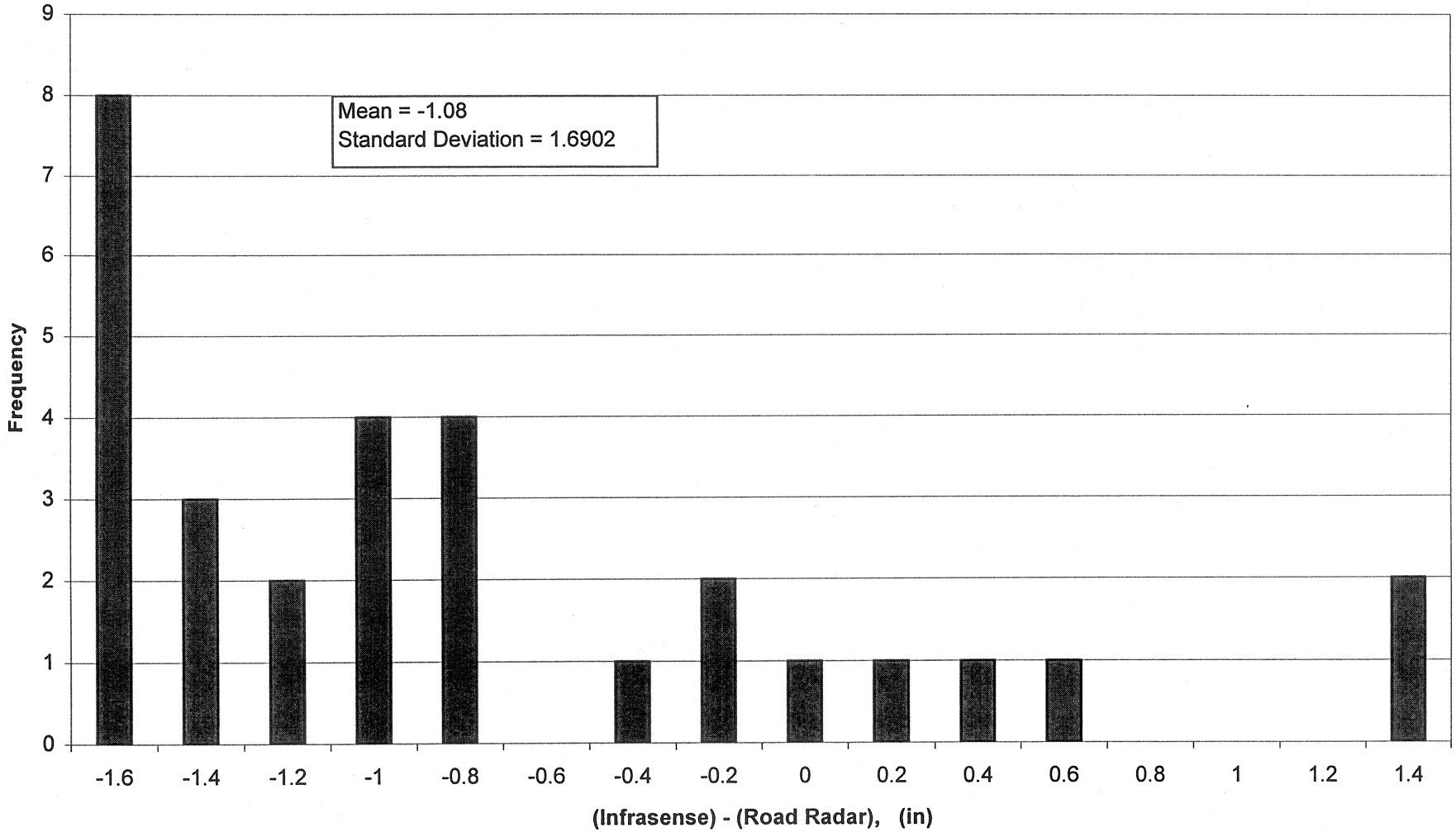
Reference: Table 7

Figure 32 - Histogram of Variations between Road Radar and ITD Core Data (Ground Truth) of Base Course Thickness for Roadway Test Sections (Project Survey, All Sites)



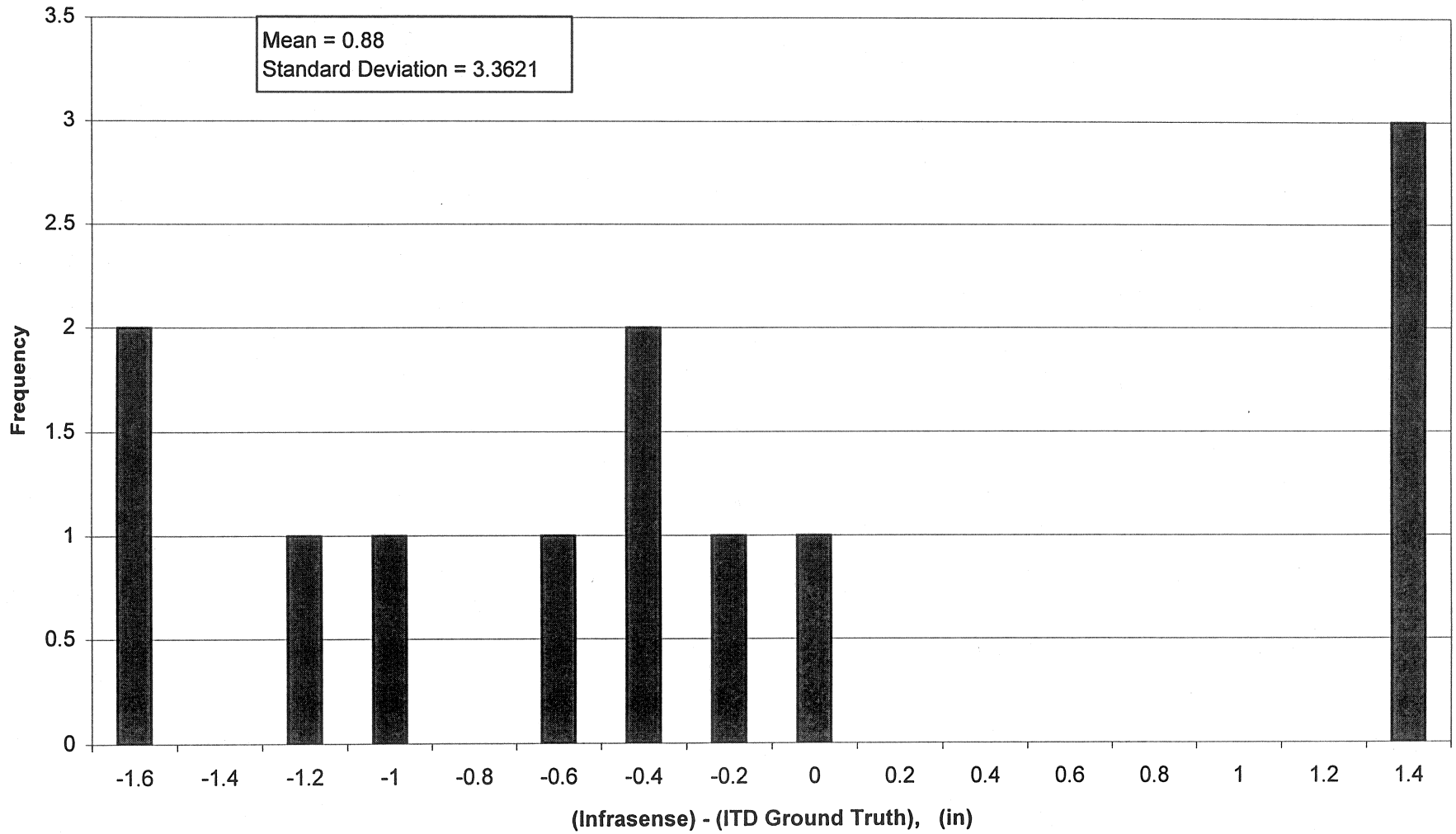
Reference: Table 7

Figure 33 - Histogram of Variations between Infrasense and Road Radar of Base Course Thickness for Roadway Test Sections (Project Survey, All Sites)



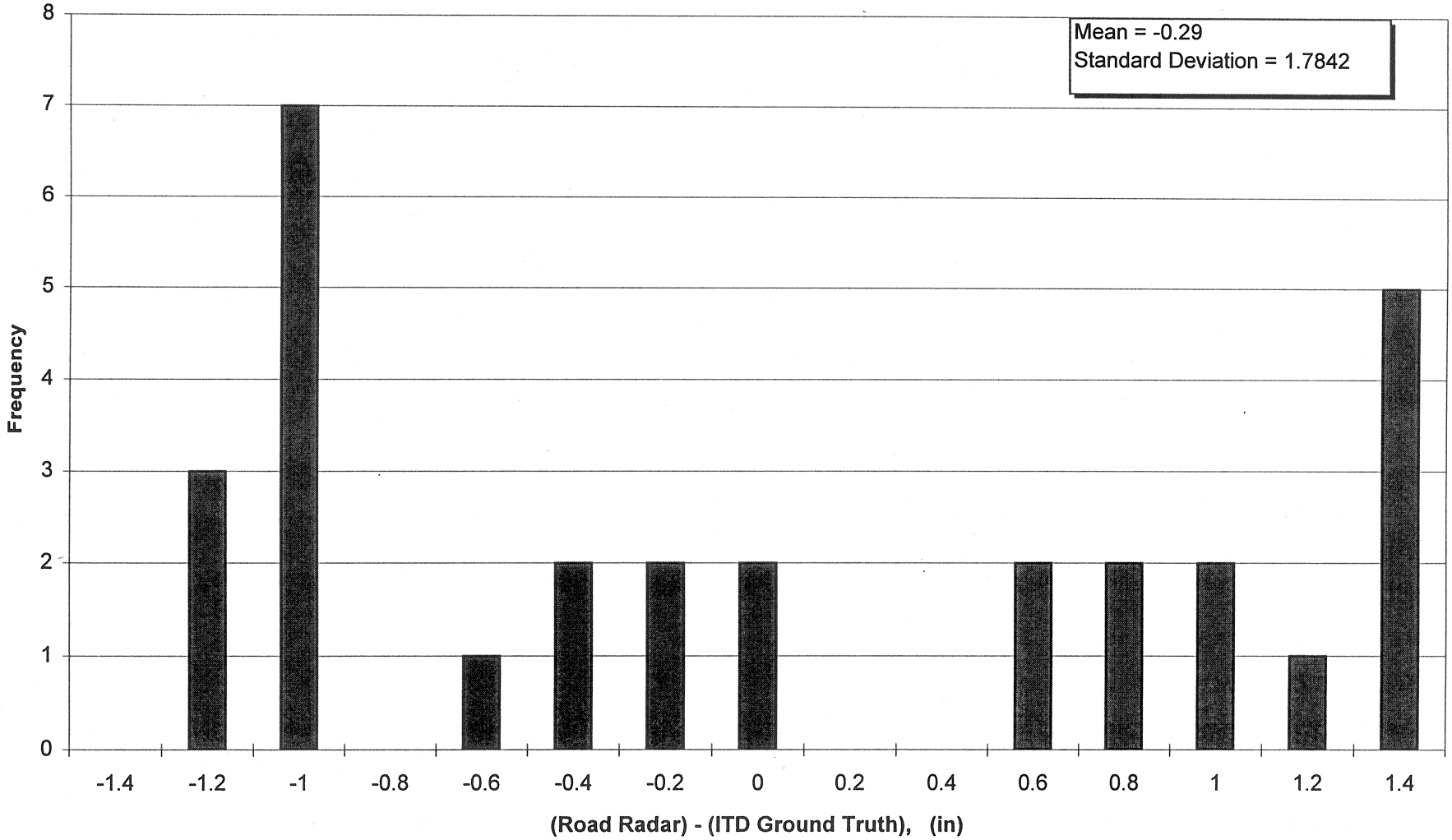
Reference: Table 7

Figure 34 - Histogram of Variations between Infrasense and ITD Core Data (Ground Truth) of Base Course Thickness for Roadway Test Sections (Network Survey, All Sites)



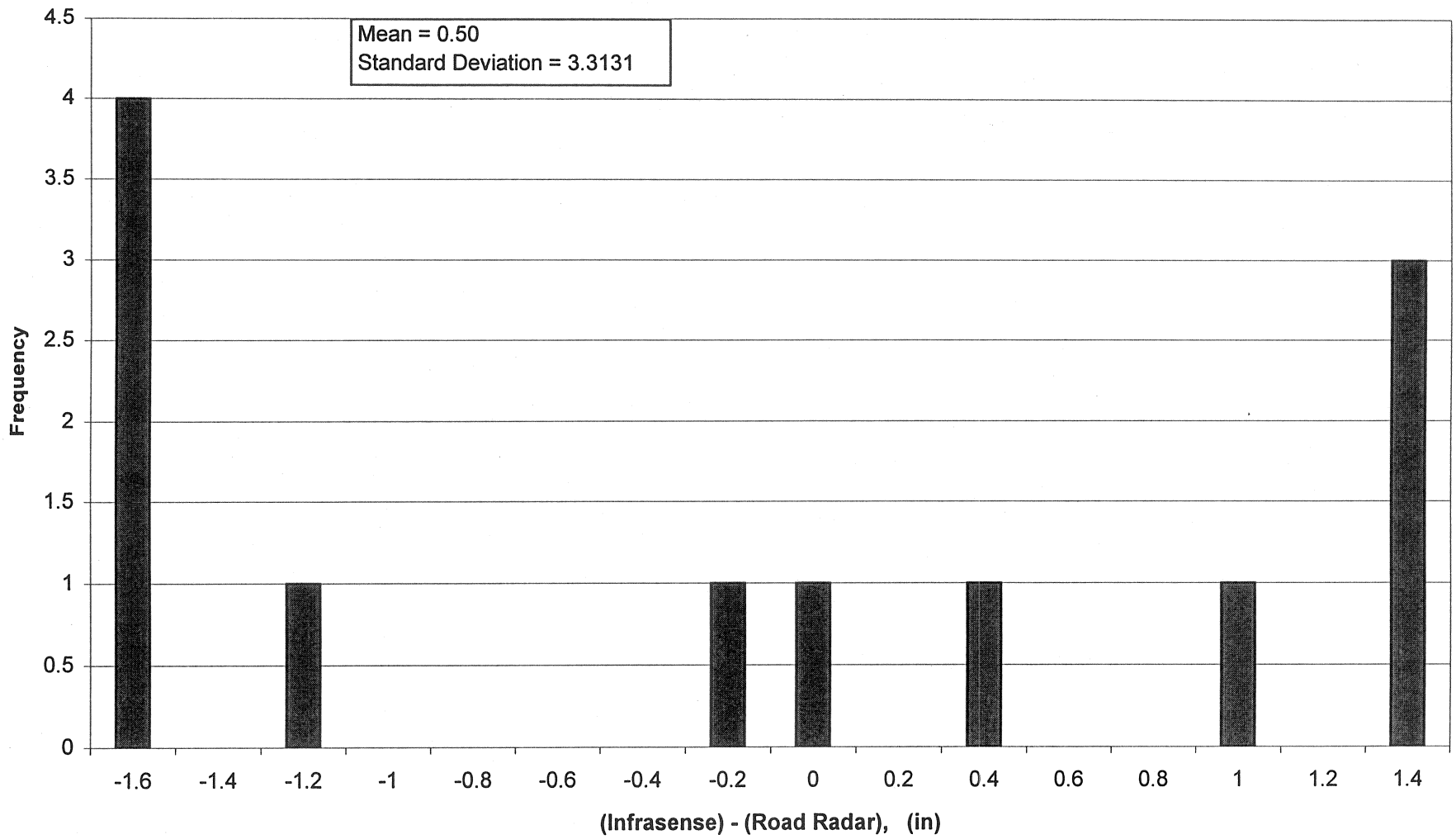
Reference: Table 8

Figure 35 - Histogram of Variations between Road Radar and ITD Core Data (Ground Truth) of Base Course Thickness for Roadway Test Sections (Network Survey, All Sites)



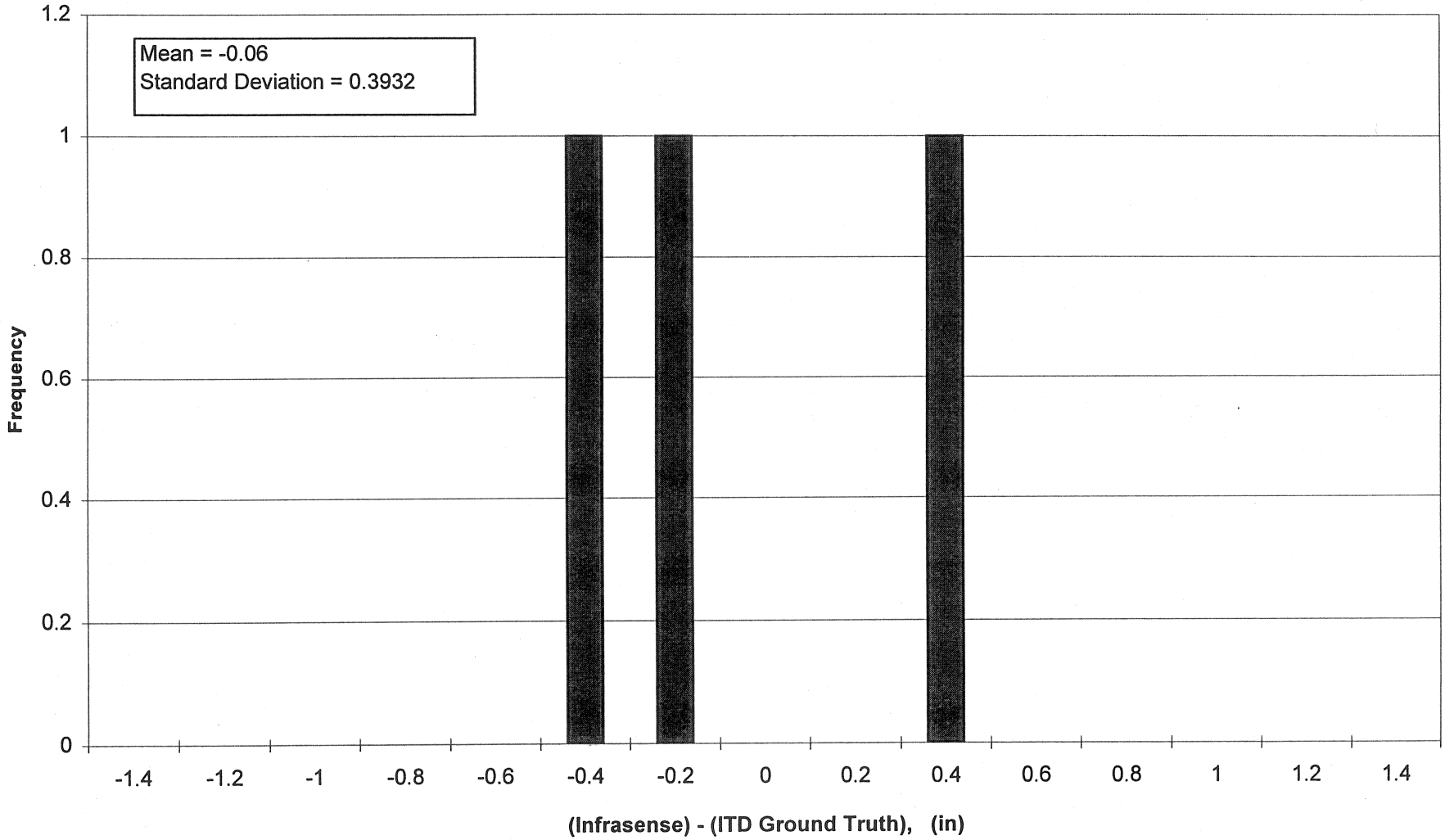
Reference: Table 8

Figure 36 - Histogram of Variations between Infrasense and Road Radar of Base Course Thickness for Roadway Test Sections (Network Survey, All Sites)



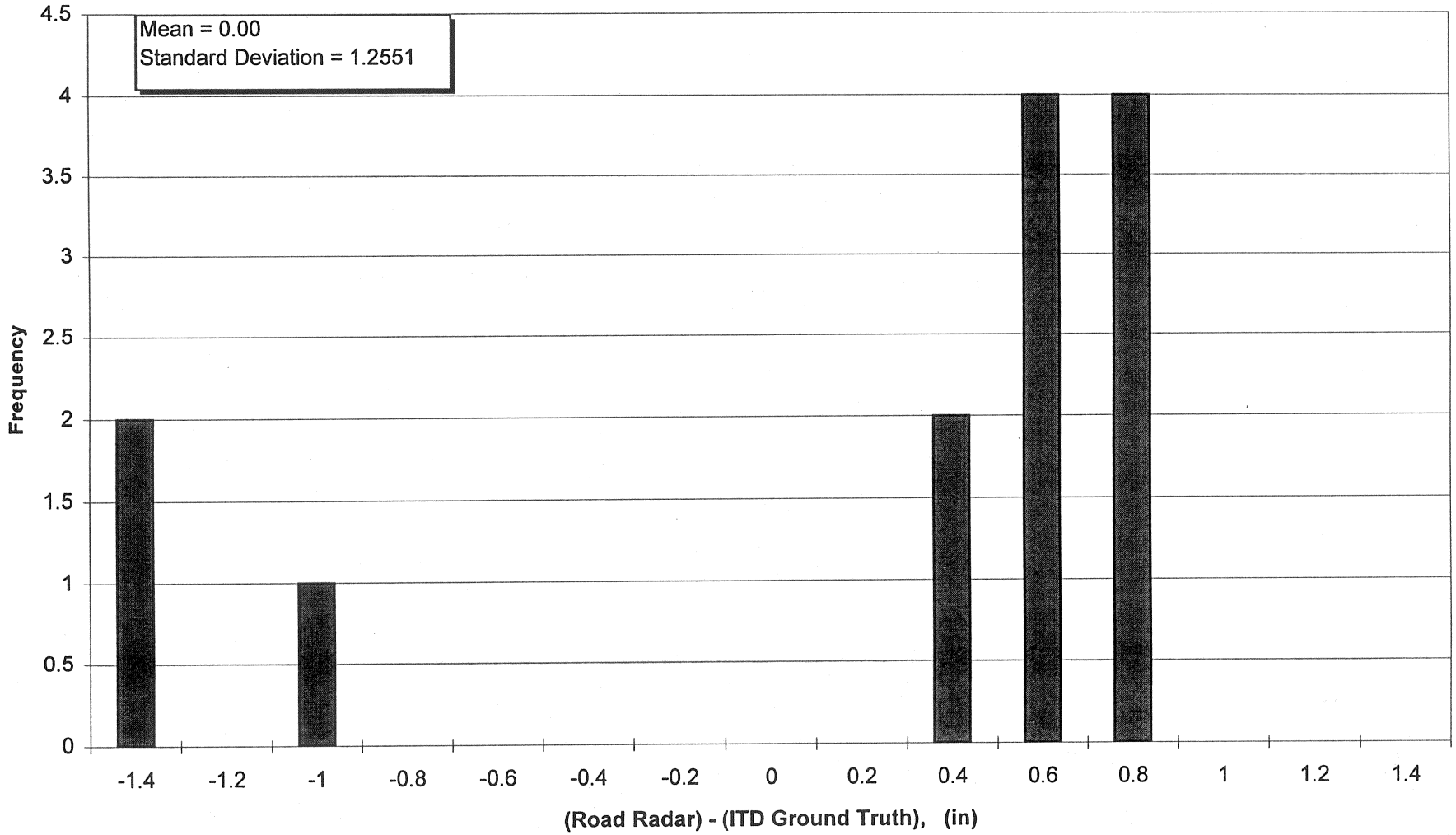
Reference: Table 8

Figure 37 - Histogram of Variations between Infrasense and ITD Core Data (Ground Truth) of Asphalt Overlay Thickness for Bridge Test Sections



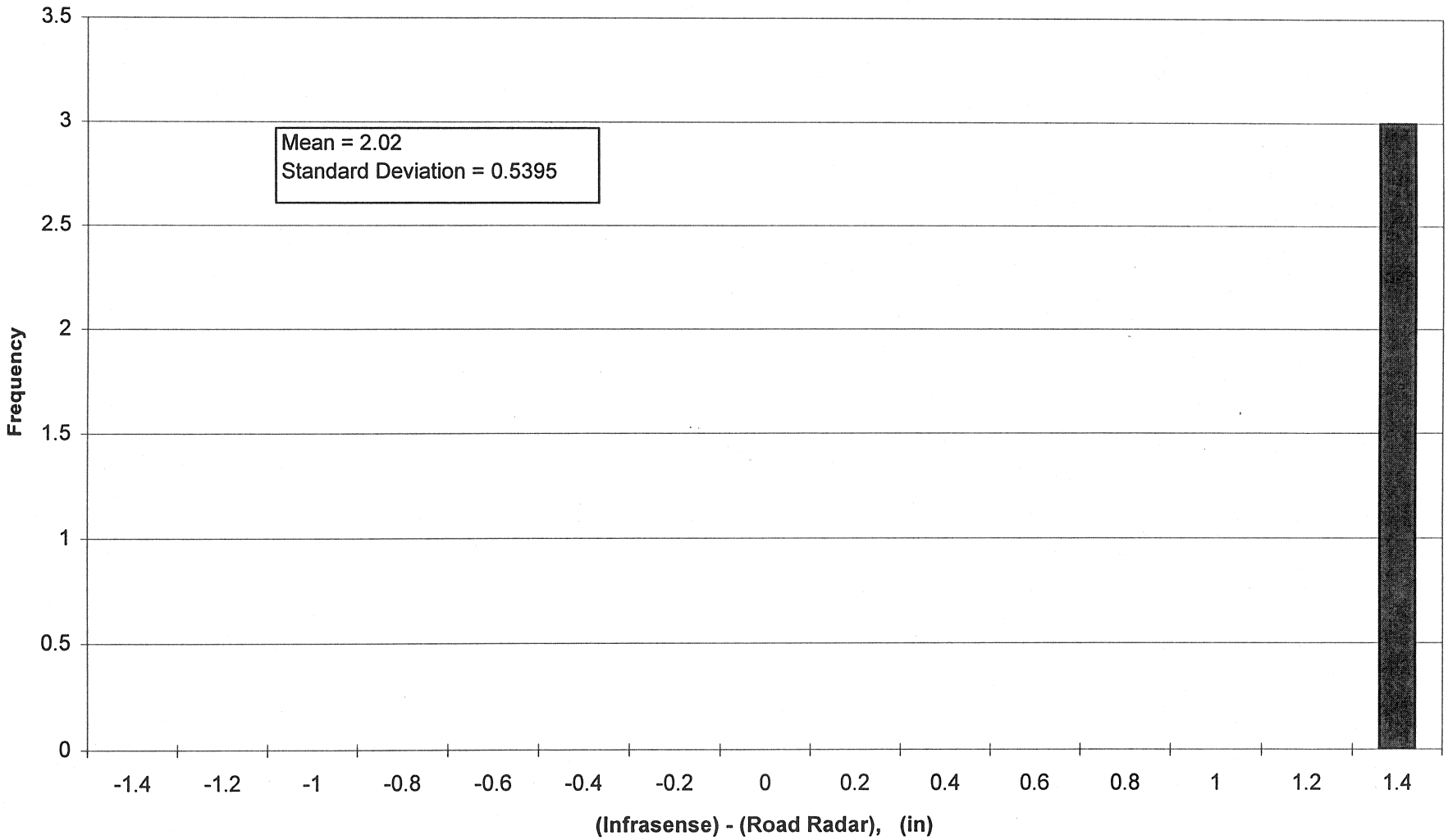
Reference: Table 11

Figure 38 - Histogram of Variations between Road Radar and ITD Core Data (Ground Truth) of Asphalt Overlay Thickness for Bridge Test Sections (All Sites)



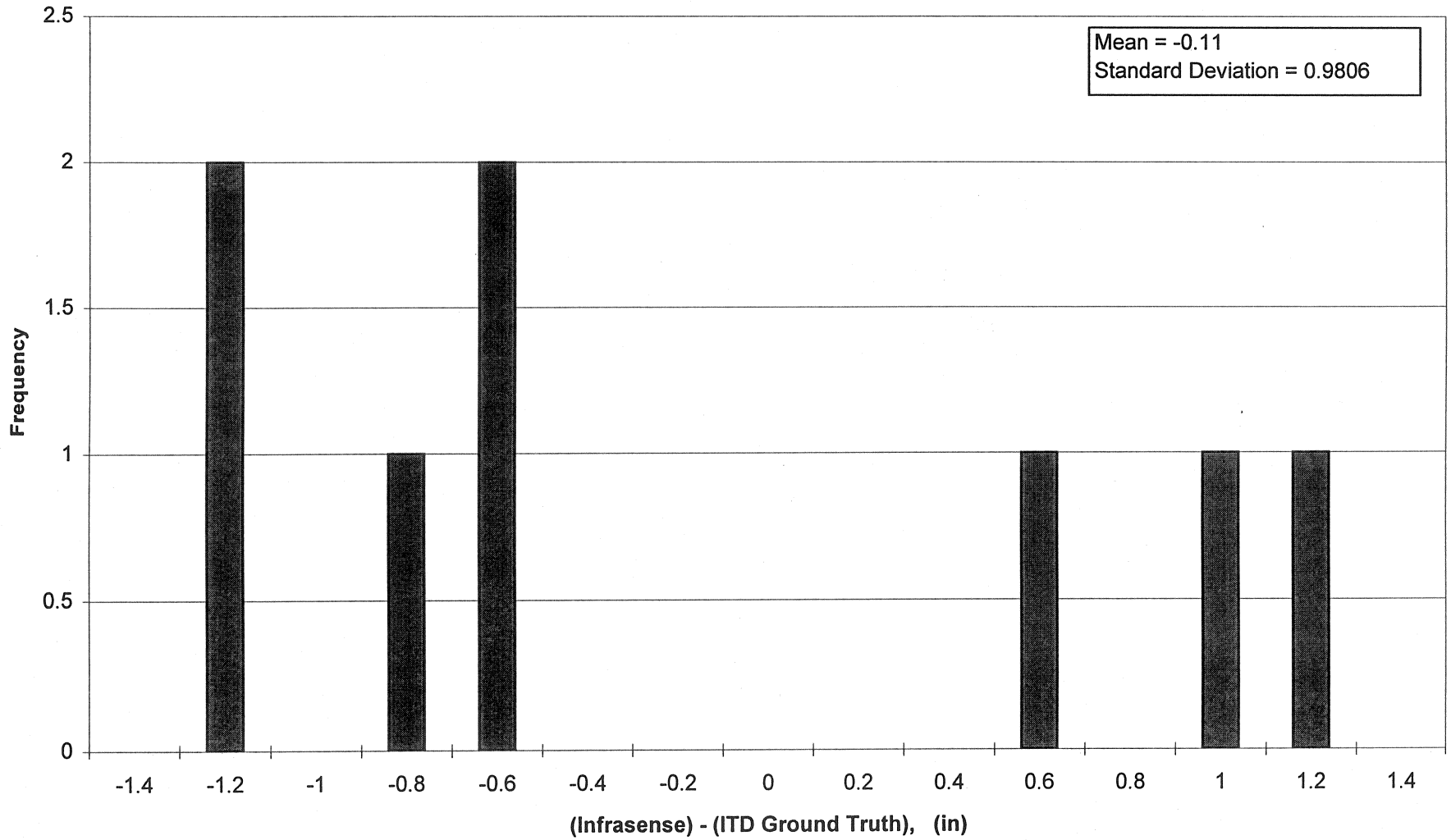
Reference: Table 11

Figure 39 - Histogram of Variations between Infrasense and Road Radar Data of Asphalt Overlay Thickness for Bridge Test Sections (All Sites)



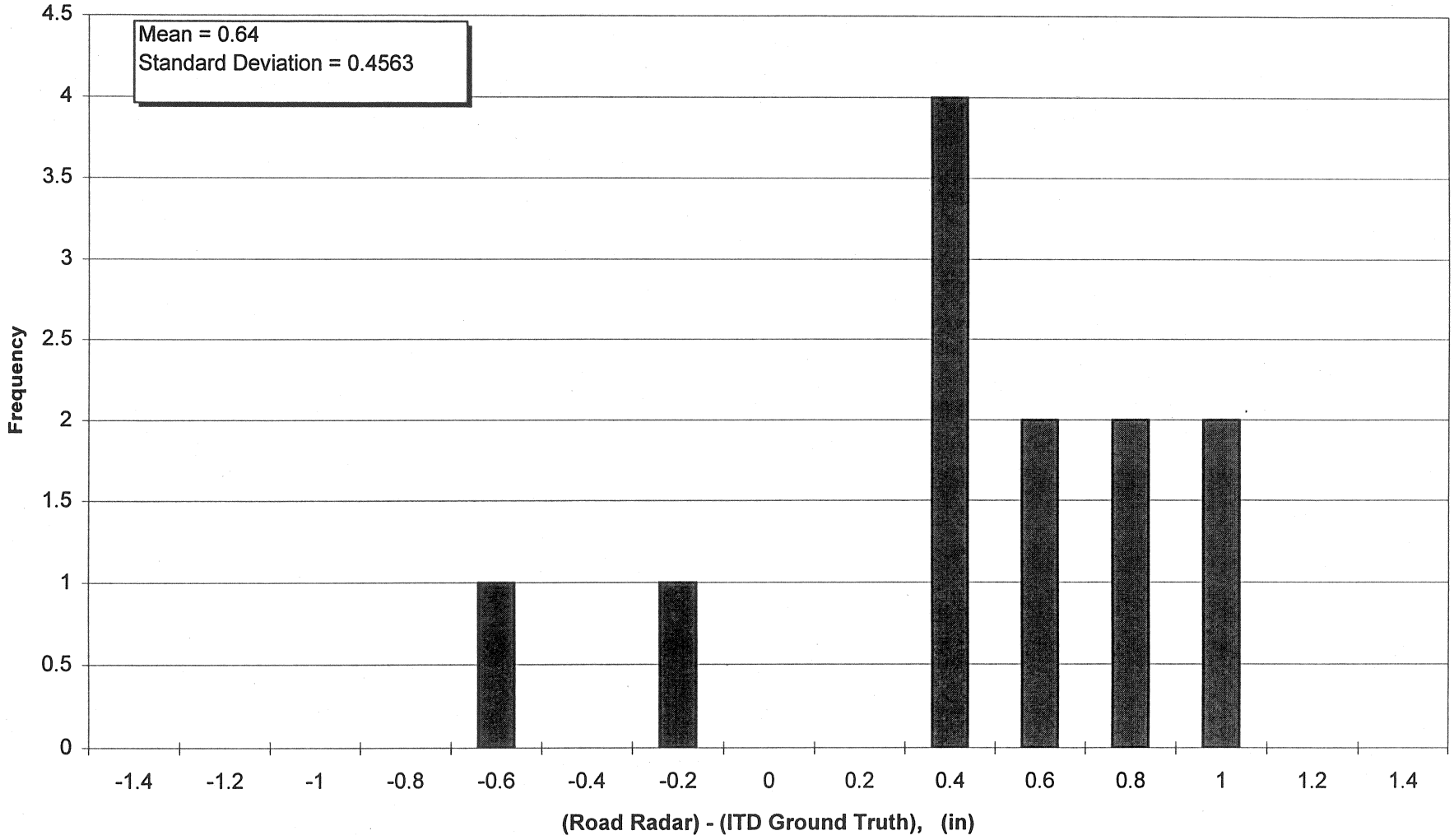
Reference: Table 11

Figure 40 - Histogram of Variations between Infrasense and ITD Core Data (Ground Truth) of Concrete Thickness for Bridge Test Sections (All Sites)



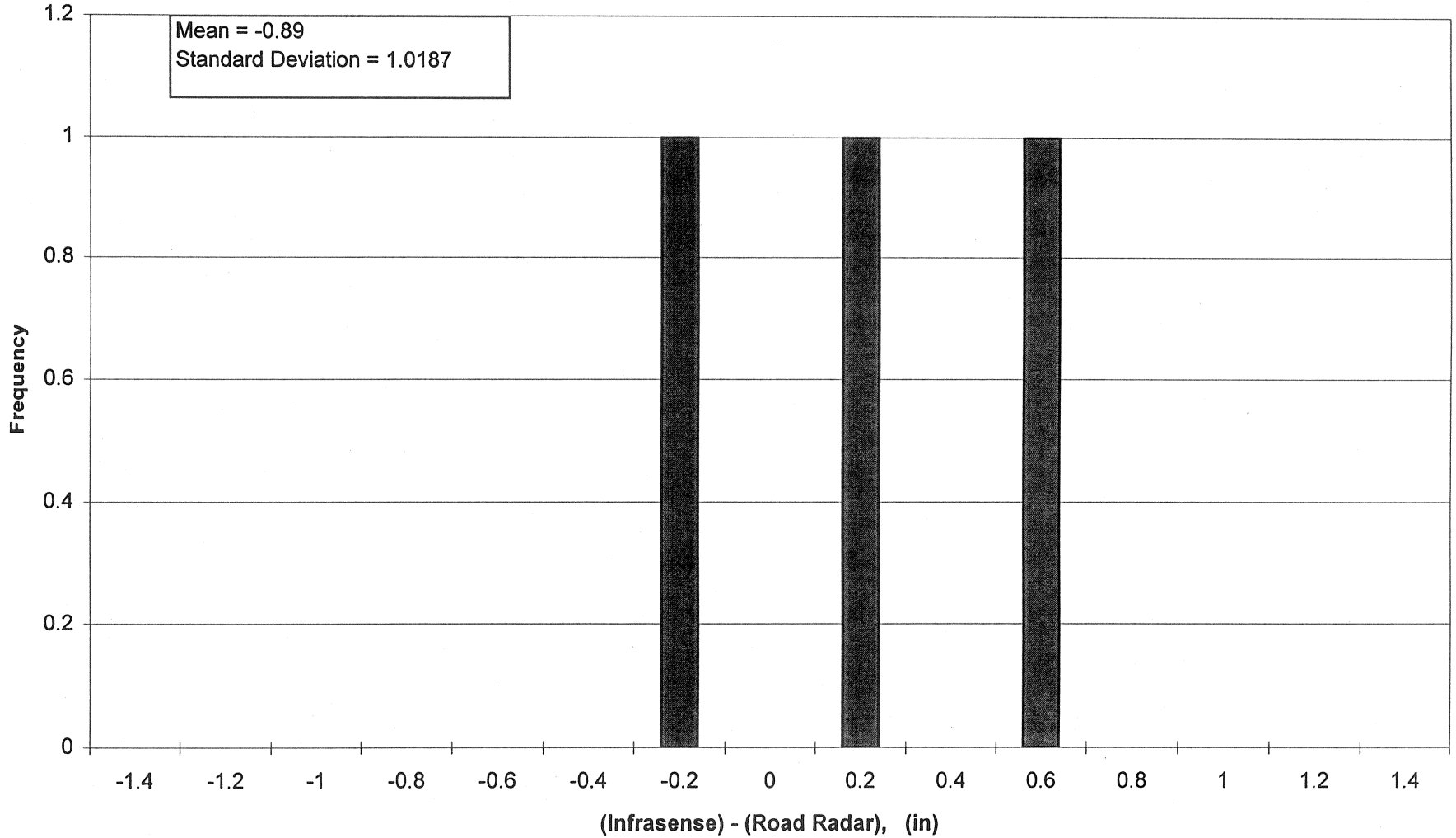
Reference: Table 12

Figure 41 - Histogram of Variations between Road Radar and ITD Core Data (Ground Truth) of Concrete Thickness for Bridge Test Sections (All Sites)



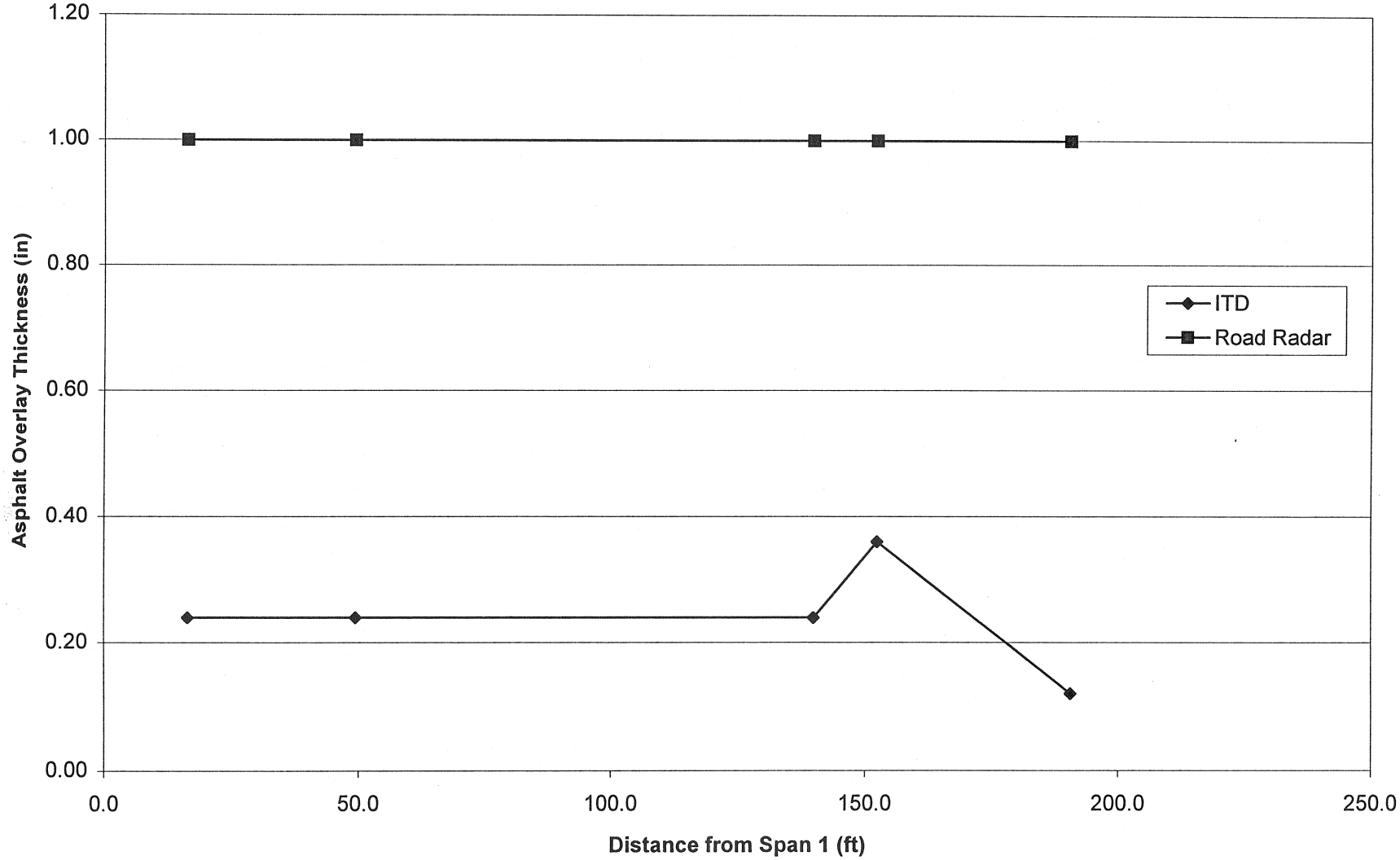
Reference: Table 12

Figure 42 - Histogram of Variations between Infrasense and Road Radar of Concrete Thickness for Bridge Test Sections (All Sites)



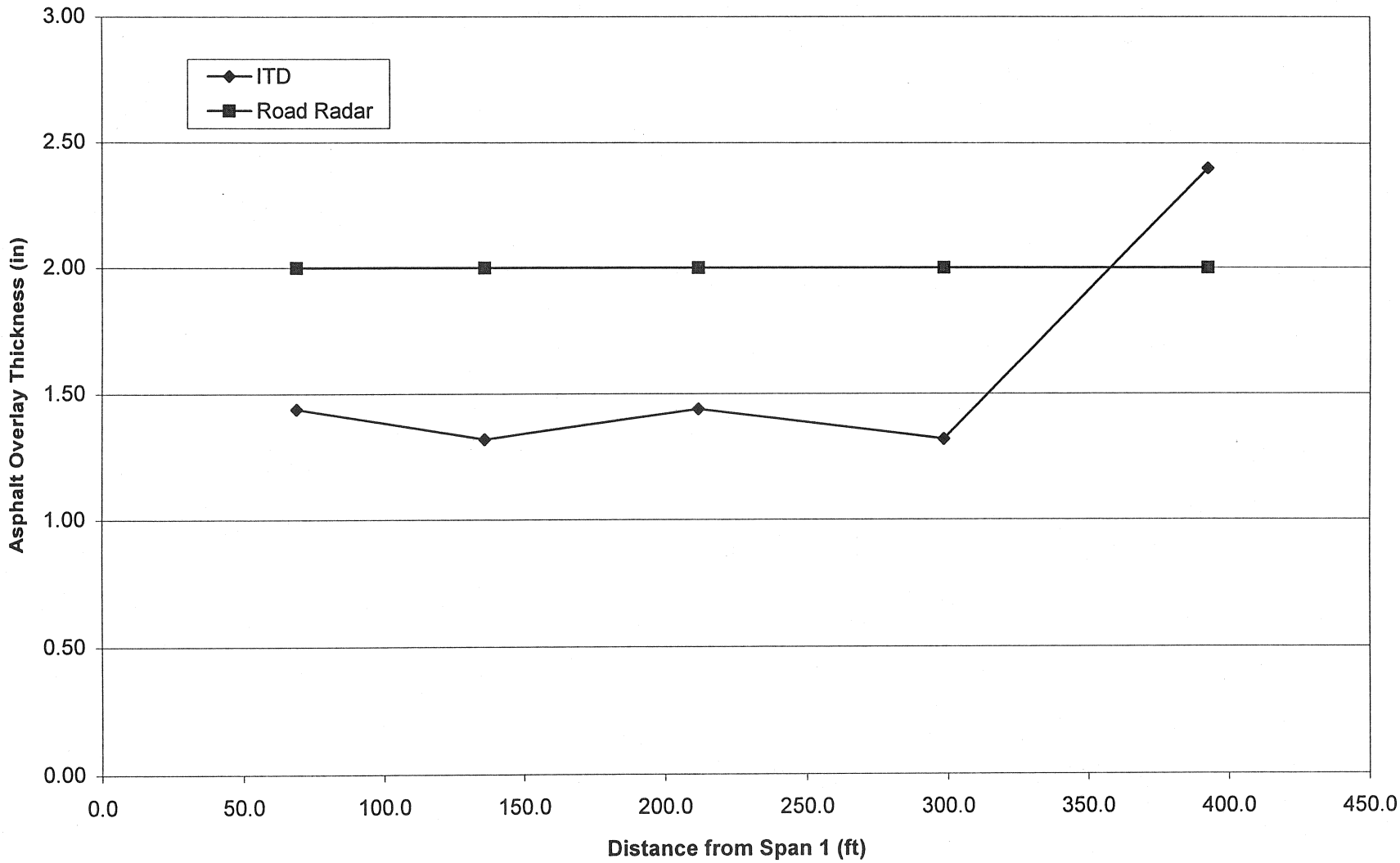
Reference: Table 12

Figure 43 - Profile of Asphalt Overlay Thickness Measurements for US 20/26 over I 84 (Broadway Avenue Interchange)



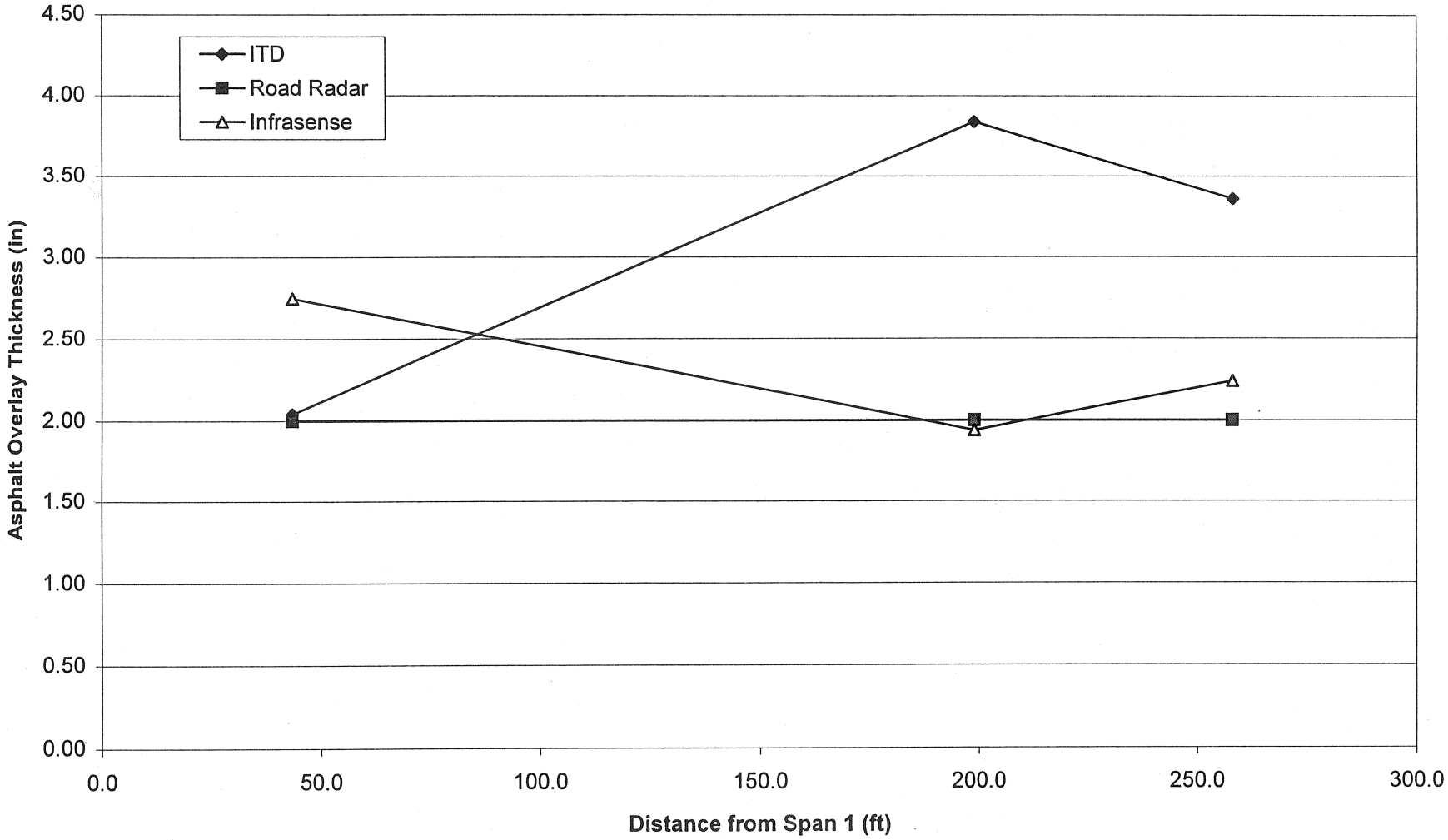
Reference: Table 4

Figure 44 - Profile of Asphalt Overlay Thickness Measurements for I-184 over Franklin Rd. (Franklin Interchange)



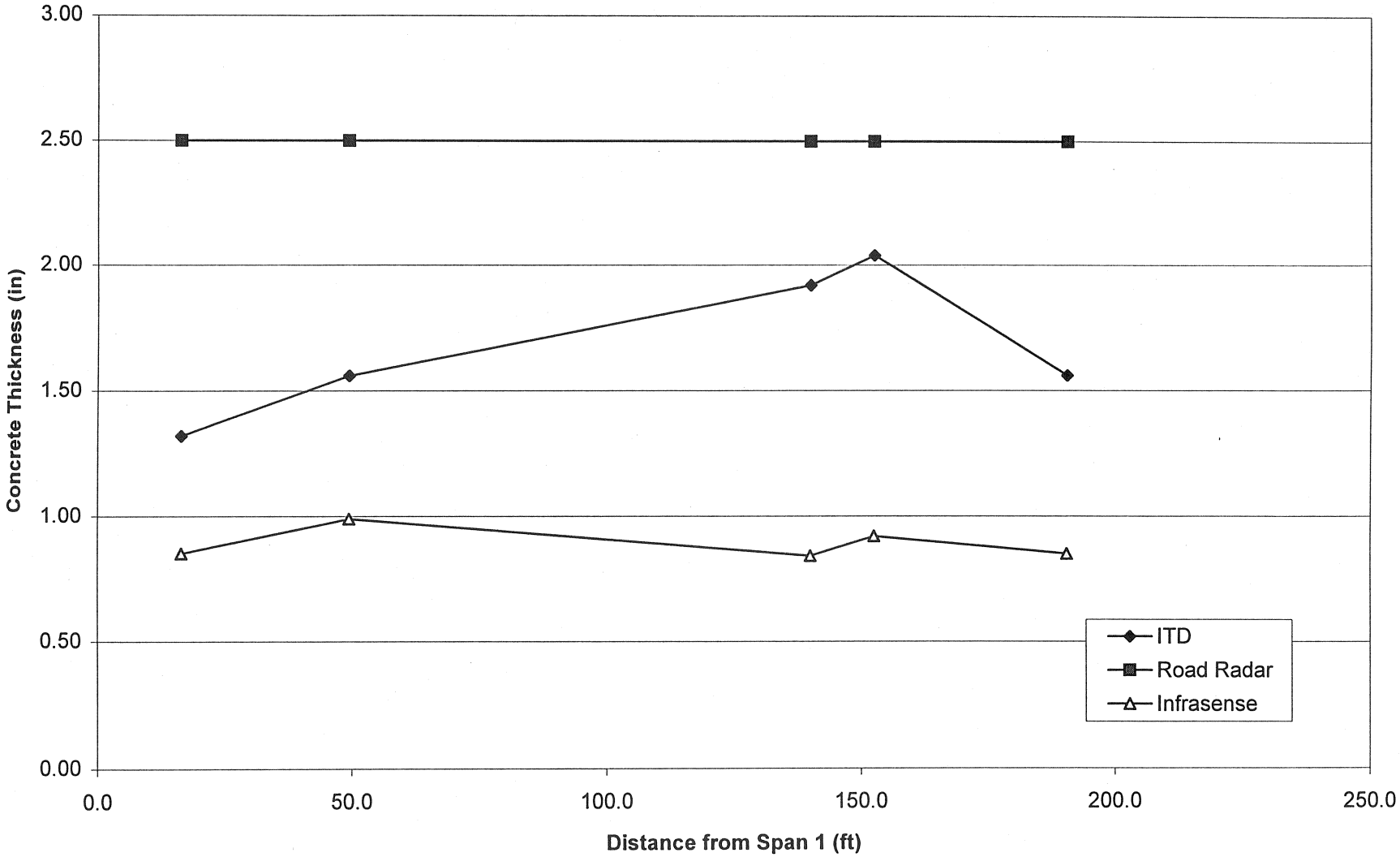
Reference: Table 4

Figure 45 - Profile of Asphalt Overlay Thickness Measurements for US 20/26 over UPRR and NY Canal (northbound) Broadway Avenue



Reference: Table 4

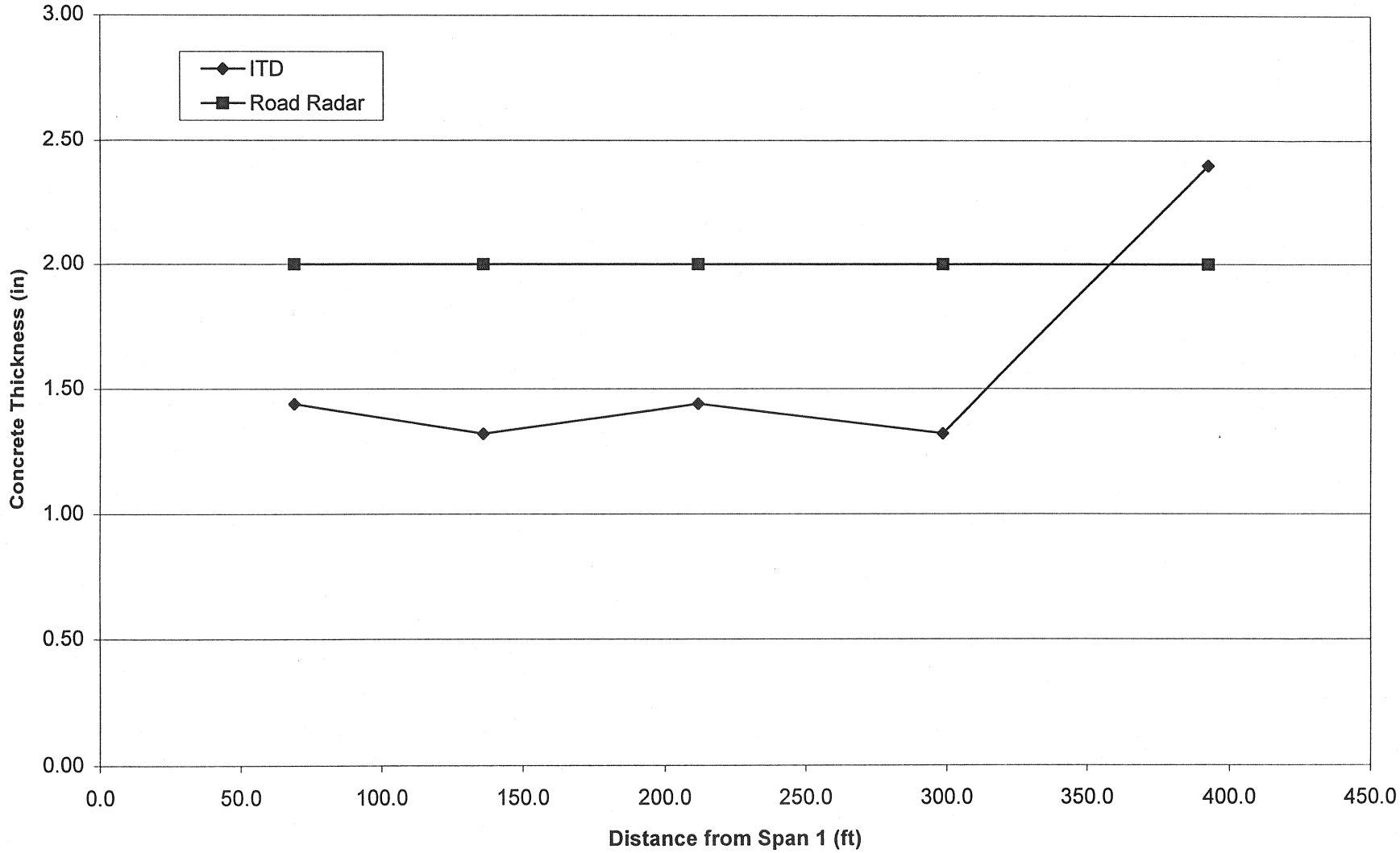
Figure 46 - Profile of Concrete Thickness Measurements for US 20/26 over I 84 (Broadway Avenue Interchange)



Reference: Table 4

Note: Concrete thickness indicates depth to reinforcing steel

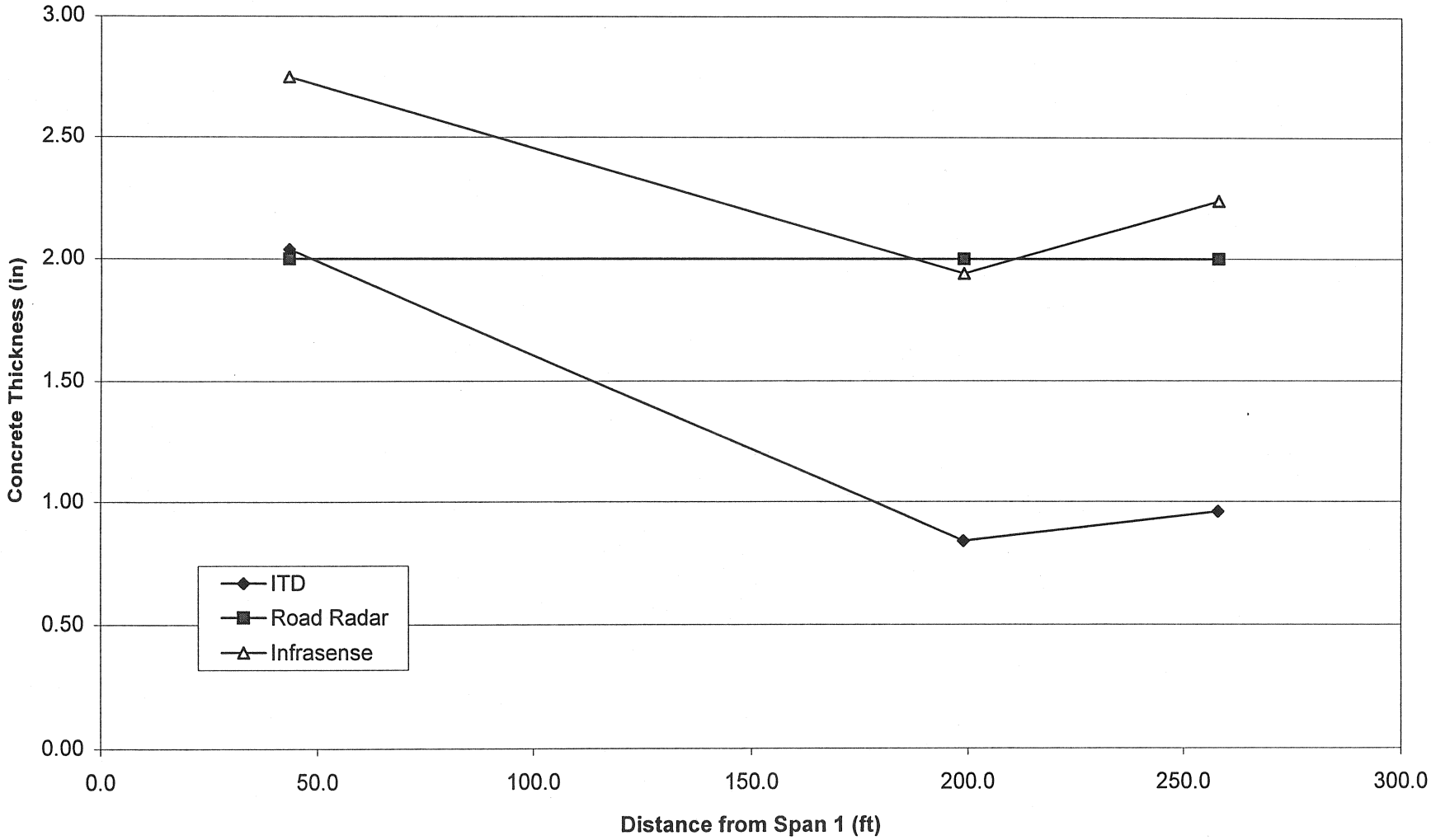
Figure 47 - Profile of Concrete Thickness Measurements for I-184 over Franklin Road (Franklin Interchange)



Reference: Table 4

Note: Concrete thickness indicates depth to reinforcing steel

Figure 48 - Profile of Concrete Thickness Measurements for US 20/26 over UPRR and NY Canal (northbound) Broadway Avenue



Reference: Table 4

Note: Concrete thickness indicates depth to reinforcing steel