

1. Report No. TX-98/2947-S		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle APPLICATIONS OF GROUND-COUPLED GPR TO PAVEMENT EVALUATION				5. Report Date November 1997	
				6. Performing Organization Code	
7. Author(s) Tom Scullion, Stacia Servos, John Ragsdale and Timo Saarenketo				8. Performing Organization Report No. Research Report 2947-S	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Study No. 7-2947	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080				13. Type of Report and Period Covered Project Summary: August 1996 - August 1997	
				14. Sponsoring Agency Code	
15. Supplementary Notes Research performed in cooperation with the Texas Department of Transportation. Research Study Title: Using Ground-Coupled and Air-Launched Radar Systems for Pavement Evaluation					
16. Abstract <p>Four case studies are presented in which ground-coupled ground-penetrating radar (GPR) was used successfully to identify subsurface problems in highway projects. These include identifying the extent of a subsurface aquifer so that a drainage system can be designed, locating underground storage tanks, locating potential sinkholes, and identifying the extent of damage caused by leaking water lines.</p> <p>Ground-coupled GPR has an advantage over air-launched systems in their depth of penetration. Low frequency units (100 MHZ) can penetrate 10-15 m (32-50 ft) in some soil types. The limitations of these systems are that the data collection speed is relatively slow 5-10 kph (3-6 mph), the data quality is severely impacted by the coupling between the antenna and the ground, and data interpretation relies heavily on expert interpretation. As with all GPR systems, the depth of penetration is severely limited in highly plastic clay soils.</p>					
17. Key Words GPR, Ground-Coupled, Pavements, UST, Highways, Sinkholes			18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161		
19. Security Classif.(of this report) Unclassified		20. Security Classif.(of this page) Unclassified		21. No. of Pages 54	22. Price

APPLICATIONS OF GROUND-COUPLED GPR TO PAVEMENT EVALUATION

by

Tom Scullion
Associate Research Engineer
Texas Transportation Institute

Stacia Servos
Graduate Student Worker
Texas Transportation Institute

John Ragsdale
Research Associate
Texas Transportation Institute

and

Timo Saarenketo
Assistant Research Scientist
Texas Transportation Institute

Research Report 2947-S
Research Study Number 7-2947
Research Study Title: Using Ground-Coupled and Air-Launched
Radar Systems for Pavement Evaluation

Sponsored by
Texas Department of Transportation

November 1997

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, TX 77843-3135

IMPLEMENTATION RECOMMENDATIONS

The purpose of this study was to determine if there are cost-effective applications of ground-coupled GPR within TxDOT operations. As the letter shows below, there are clearly some applications in which these deep penetrating systems can help. To continue to implement this technology the following steps are recommended.

1. Organize a training school focused on ground-coupled GPR applications.
2. Construct a calibration facility with several buried objects so that operators can be trained. The sand site at TTI can be used as part of this facility.
3. Develop specifications and purchase the necessary data acquisition systems and GPR antennas.
4. Sponsor additional research work to develop improved signal processing software.



P.O. BOX 6868 • FORT WORTH, TEXAS 76115-0868 • (817) 370-6500

June 16, 1997

Mr. John Ragsdale
Ms. Stacia Servos
Materials, Pavements & Construction
TTI/CE Bldg. Suite 508
College Station 77843-3135

Dear Ms. Servos and Mr. Ragsdale:

Last week our contractor excavated the tanks you found for us at the Beall Concrete plant on S.H. 199. The tanks were found right where your charts indicated. This saved the state the expense of exploring for the tanks

Thanks again for a job well done.

Sincerely,

A handwritten signature in black ink that reads "C. Carl Logan". The signature is written in a cursive, flowing style.

C. Carl Logan
R.O.W. Administrator

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Tom Scullion, P.E. #62683.

There is no invention or discovery conceived or reduced to practice in the course of or under this contract; including any art, method, process, machine, manufacture, design, or composition of matter; or any new and useful improvement thereof; or any variety of plant which is or may be patentable under the patent law of the United States of America or any foreign county.

ACKNOWLEDGMENT

Carl Bertrand of TxDOT's Pavement Design Section is acknowledged for his support of this study. Mr. Timo Saarenketo of the Finnish National Road Administration processed the data for the Mesa Road project. He also assisted by teaching a workshop at Texas Transportation Institute on processing signals from ground-coupled GPR systems.

TABLE OF CONTENTS

	Page
LIST OF FIGURES	x
SUMMARY	xiii
CHAPTER I INTRODUCTION	1
CHAPTER II USING 500 MHZ GPR TO MAP THE EXTENT OF A SUBSURFACE AQUIFER ON SH 199	3
Field Methods	9
Interpretation	10
Conclusions	18
CHAPTER III USING GPR TO IDENTIFY SINKHOLES ON I-20.....	19
Introduction	19
Area Geology	19
Observations	19
Recommendations	23
CHAPTER IV USING GRP TO LOCATE UNDERGROUND STORAGE TANKS (USTs) ON PARCEL 94	29
CHAPTER V USING GPR TO DETECT SUBSURFACE PROBLEMS ON MESA ROAD IN EL PASO, TEXAS	33
Introduction	33
Results	35
Conclusions	38

LIST OF FIGURES

	Page
1. State Highway 199, Azle, Texas, Illustrating Location of Cores, Survey Lines and Station Numbers	4
2. Cross-Section Along the East Side of State Highway 199, Azle, Texas. Refer to Figure 1 for Core Locations	5
3. Cross-Section Along West Side of State Highway 199, Azle, Texas. Refer to Figure 1 for Core Locations	6
4. Cross-Sections Perpendicular to State Highway 199, Azle, Texas (East to West). Refer to Figure 1 for Location of Cores	7
5. A Portion of the Radar Data Taken from the Median Along State Highway 199 in Azle, Texas	11
6. State Highway 199, Azle, Texas, Illustrating Locations of Possible Concern Resulting from GPR Survey	12
7. A Portion of the Radar Data Taken from the Northbound Shoulder (NSH) Along State Highway 199 in Azle, Texas	13
8. A Portion of the Radar Data Taken from the Northbound Shoulder (NSH) Along State Highway 199 in Azle, Texas	14
9. A Portion of the Radar Data Taken from the Northbound Main Lane (NTL) Along State Highway 199 in Azle, Texas	15
10. A Portion of the Radar Data Taken from the Northbound Main Lane (NTL) Along State Highway 199 in Azle, Texas	16
11. A Portion of the Radar Data Taken from the Southbound Shoulder (SSH) Along State Highway 199 in Azle, Texas	17
12. Cross-Section Along I-20 Between Ft. Worth, Abilene, and Roscoe. The Tilt of the Rocks is Greatly Exaggerated (From Texas Roadside Geology)	20
13. Sequence of Permian Rocks in Northcentral Texas. (From Texas Roadside Geology)	20

LIST OF FIGURES (Continued)

	Page
14. Example of the Holes Existing within the Grassy Median	21
15. 500 MHZ Data from Grassy Median Where Known Sinkholes are Located	21
16. The 100 MHZ (Large Rectangle) and the 500 MHZ (Small Square) Antennae Used in the Survey	22
17. 100 MHZ Data from Frontage Road 2 Adjacent to Grassy Median with Known Sinkholes	24
18. 100 MHZ Data from Frontage 2	24
19. 100 MHZ Data from Frontage 1	25
20. 500 MHZ Data from Frontage 1	25
21. 100 MHZ Data from I-20 Eastbound	26
22. Sweetwater Interstate 20	27
23. Site Layout at Beall Concrete Plant with GPR Results	30
24. GPR Data from Location of Buried Tanks (500 MHZ Data from 16 to -16)	32
25. GPR Data from Location of Buried Tanks (200 MHZ Data from 0 to 68)	32
26. The 100 MHZ Antenna Used in Mesa Road Testing	34
27. Water Seeping from Pavement Near the Intersection with Kern Street	34
28. Left Lane, 100 MHZ, Very High Moisture Content in White Areas Around 900 ft, 4 ft Below Surface. Leaking Pipe at 1100 ft	36
29. Summary of GPR Results Showing Trapped Moisture and Possible Leak Locations	39

SUMMARY

Four case studies are presented in which ground-coupled ground-penetrating radar (GPR) was used successfully to identify subsurface problems in highway projects. These include identifying the extent of a subsurface aquifer so that a drainage system can be designed, locating underground storage tanks, locating potential sinkholes, and identifying the extent of damage caused by leaking water lines.

Ground-coupled GPR has an advantage over air-launched systems in their depth of penetration. Low frequency units (100 MHZ) can penetrate 10-15 m (32-50 ft) in some soil types. The limitations of these systems are that the data is relatively slow 5-10 kph (3-6 mph), the data quality is severely impacted by the coupling between the antenna and the ground, and data interpretation relies heavily on expert interpretation. As with all GPR systems, the depth of penetration is severely limited in highly plastic clay soils.

CHAPTER I

INTRODUCTION

In the past 10 years the Texas Department of Transportation (TxDOT) has gained considerable experience in collecting and processing ground penetrating radar (GPR) data from high frequency (1 GHz) air-launched antennas. These systems operate at close to highway speed and have been found to be effective in evaluating the upper 0.5 m (1.6 ft) of the pavement structure. Implementation at the District level is proceeding within TxDOT.

However, these air-launched systems are a recent development in the GPR field. Traditional GPR systems are ground-coupled and these are used to penetrate deeper within the pavement structure. A range of different operating frequencies antennas are available, commonly ranging from low frequency 100 MHz to high frequency 1 GHz. The lower the frequency the greater the penetration depth but the less the near surface resolution. For example, under favorable soil conditions 100 MHz antennas may provide subsurface information to a depth of 15 m (50 ft). However, they will not be able to identify the presence of thin near surface layers. At the other end of the scale, high frequency ground-coupled systems may only penetrate up to 1 m but they can distinguish between thin layers close to the surface.

The drawback for the ground-coupled systems is their data acquisition speed. As these systems must stay in contact (or very close) to the surface the speed of data collection is limited to less than 10 kph (6 mph). Several signal processing techniques (filtering, clutter removal, etc.) are used to obtain sharper GPR images, however, interpretation of the final profile is performed manually by experienced operators.

Because of its success with air-launched GPR systems, TxDOT funded project 2947 to evaluate possible uses for ground-coupled GPR systems. Four case studies are presented in this report.

1. Defining the extent of a subsurface aquifer.
2. Locating sinkholes.
3. Locating underground storage tanks.
4. Failure investigation to determine the cause of a subsurface void.

CHAPTER II

USING 500 MHZ GPR TO MAP THE EXTENT OF A SUBSURFACE AQUIFER ON SH 199

On December 13, 1996, TTI conducted a ground penetrating radar survey along State Highway 199 to determine the lateral extent of a local aquifer. Figure 1 shows a schematic of the area. Water was seen flowing from a sand formation downhill, toward Denver Trail, within a drainage ditch on the east side of SH 199. An under drain, or slotted PVC pipe, was installed beneath the northbound lanes at Station 612 +25 to alleviate water buildup and damage from beneath the road surface. The driving lanes of SH 199 are constructed of 150 mm (6 ins) of select material overlain by 250 mm (10 ins) of jointed concrete and 50 mm (2 ins) of asphalt. The shoulders are constructed of 150 mm (6 ins) of roadbed material, quite possible area material, overlain by 250 mm (10 ins) of base and 50 mm (2 ins) of asphalt.

Core records were acquired through TxDOT, whereby cross-sections were then inferred. The locations of the cores are shown in Figure 1. It can be seen from the cross-sections, Figure 2, Figure 3, and Figure 4 a, b, and c, that the surface of the site dips from both the north and south towards the creek located at Station 611 +00 on the west side of SH 199 to 612 +00 on the east side. The largest topographic high is to the south. Probable groundwater flow is toward the creek from both sides.

Observation of the cross-section from south to north, beginning with the cores from the east side of SH 199 (Figure 2), revealed 1.4 m (4.6 ft) of a silty clay overlies a dense, cemented sand, in core EC1, the southern most core on the east side of SH 199. As one travels downhill, or to the north, the clay grades into 0.3 m (1.0 ft) of sandy clay overlying the same cemented sand, in core EC2. Core EC3 reveals 0.3 m (1.0 ft) of silty sand overlying 1.5 m (5 ft) of silty clay which grades into a sandy, silty clay. Ground water surfaces were measured at elevation 660 in core EC3 (near bottom of hill) and at elevation 667 in core EC2. There was no mention of existing groundwater in the core log for EC1.

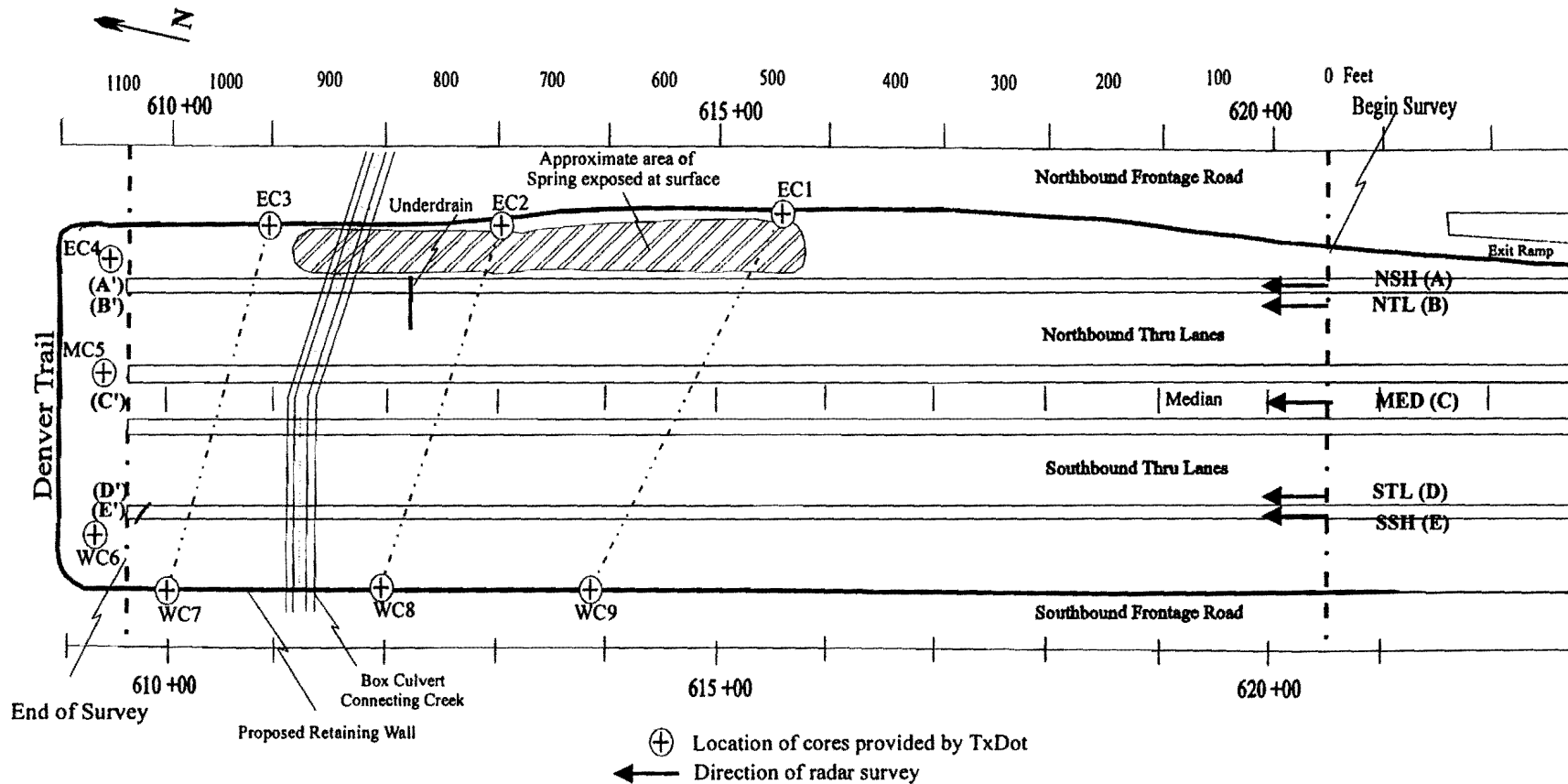


Figure 1. State Highway 199, Azle, Texas, Illustrating Location of Cores, Survey Lines and Station Numbers.
 (1 ft = 0.3 m)

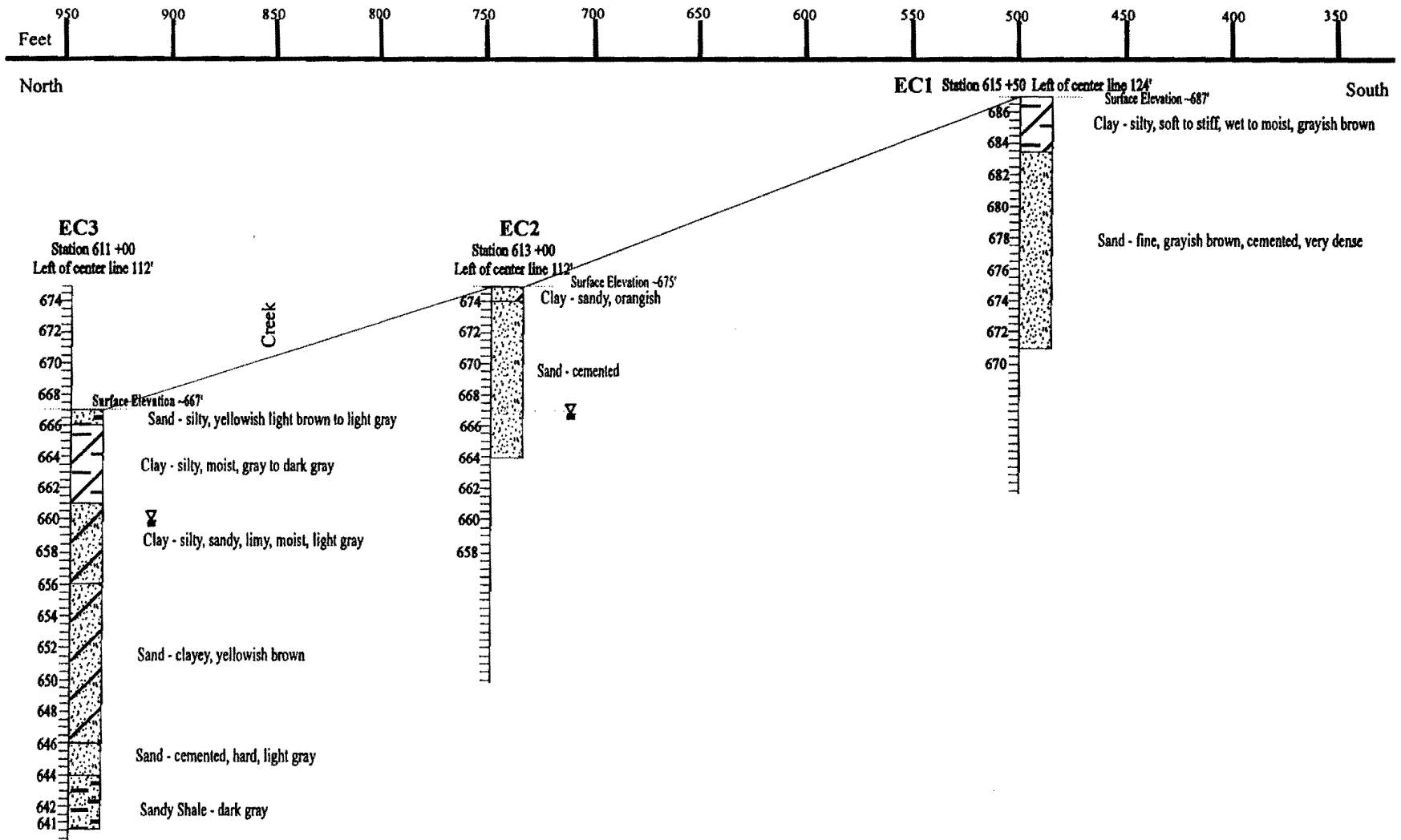


Figure 2. Cross-Section Along the East Side of State Highway 199, Azle, Texas. Refer to Figure 1 for Core Locations.
 (1 ft = 0.3 m)

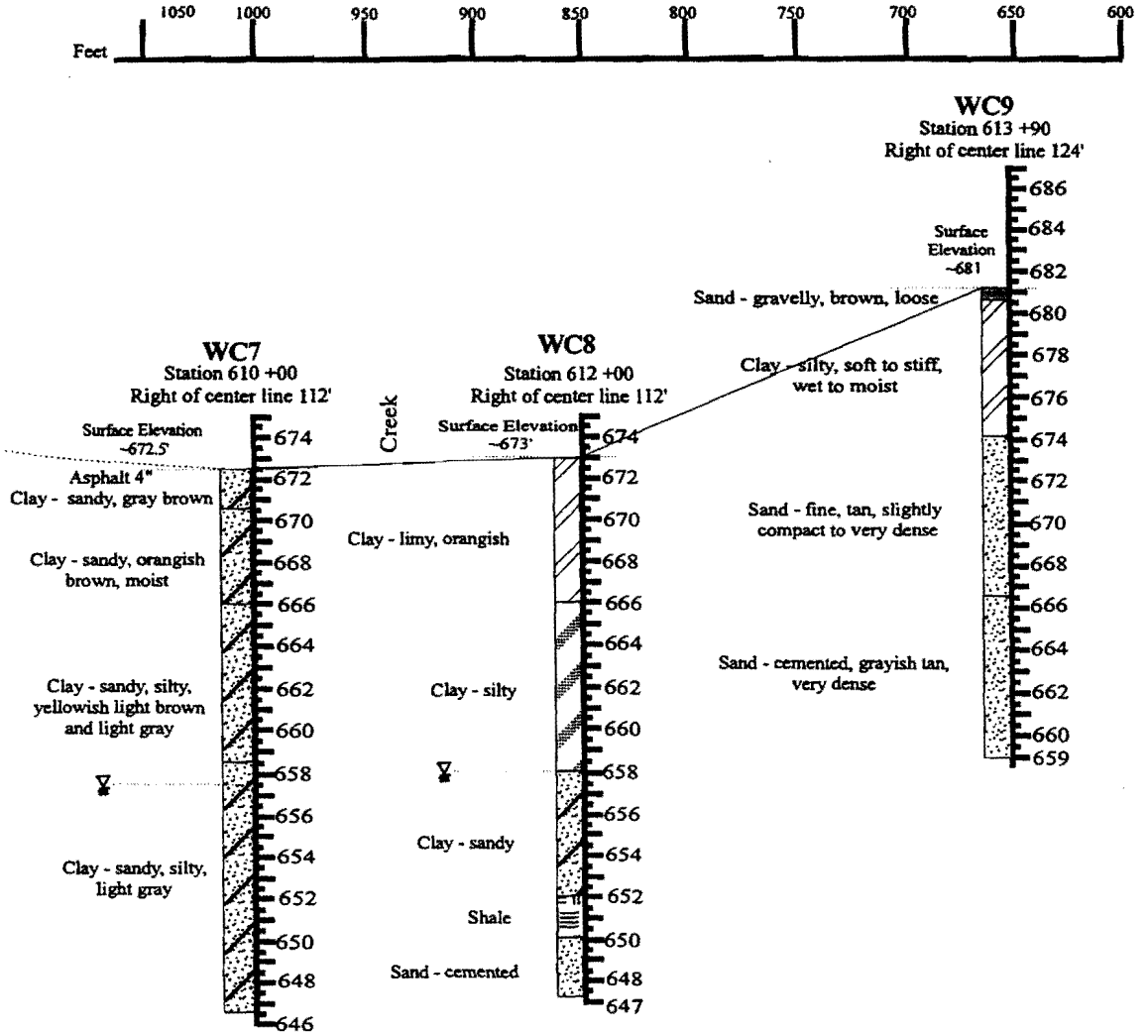


Figure 3. Cross-Section Along West Side of State Highway 199, Azle, Texas. Refer to Figure 1 for Core Locations. (1 ft = 0.3 m)

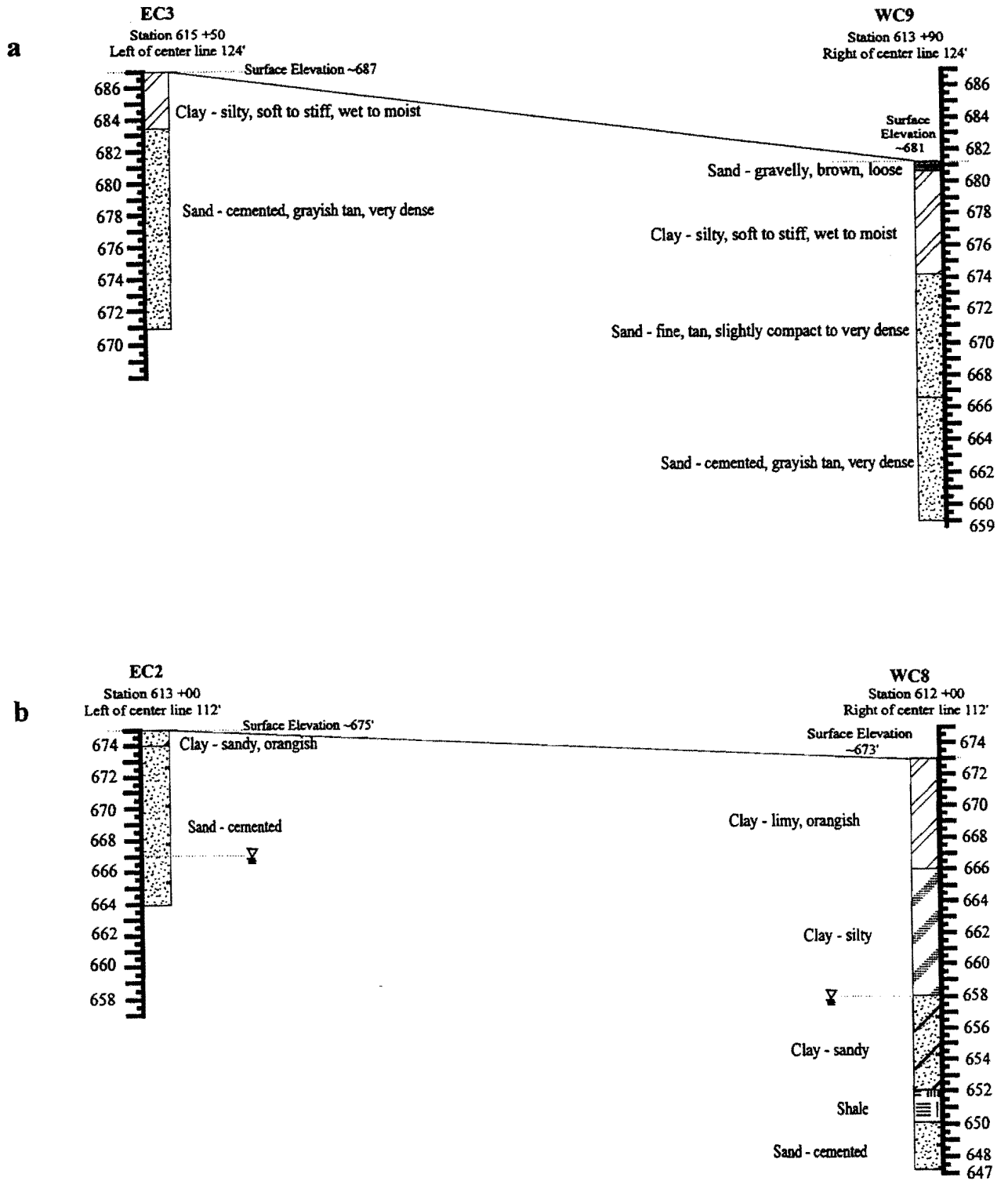


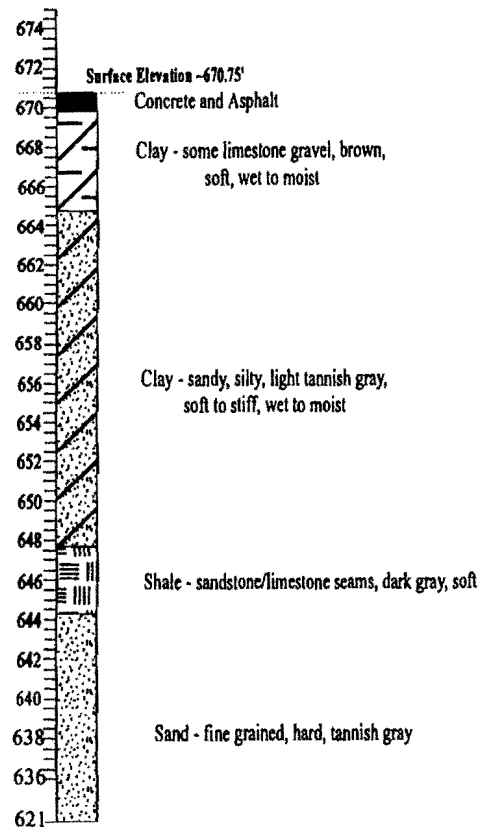
Figure 4. Cross-Sections Perpendicular to State Highway 199, Azle, Texas (East to West).

Refer to Figure 1 for Location of Cores.

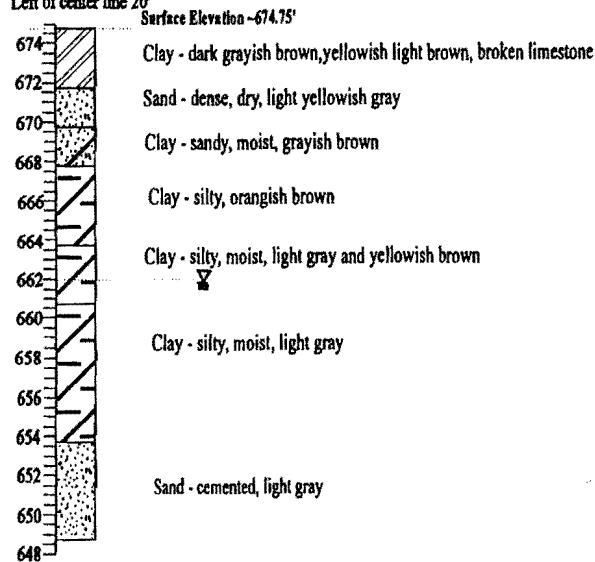
(1 ft = 0.3 m)

c

EC4
 Station 609 +45
 Left of center line 70'



MC5
 Station 609 +43
 Left of center line 20'



WC6
 Station 609 +45
 Right of center line 70'

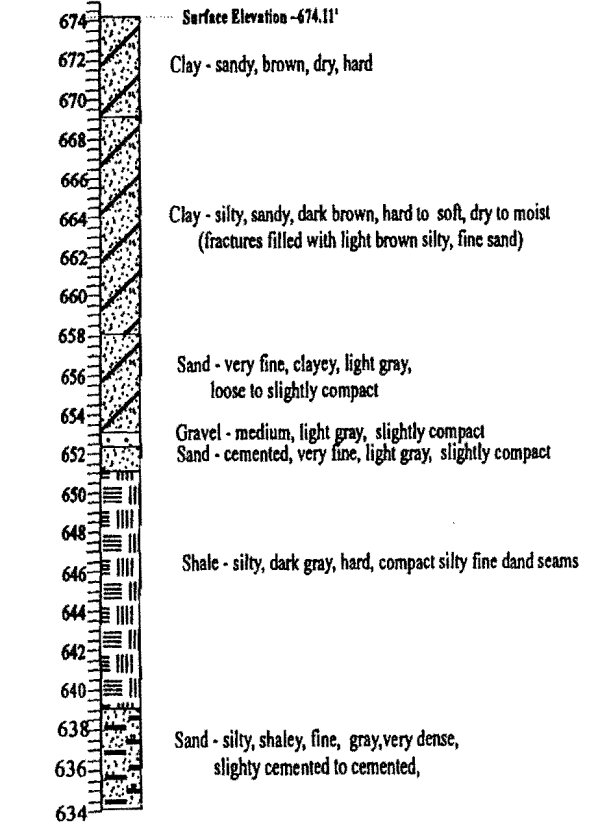


Figure 4. Cross-Sections Perpendicular to State Highway 199, Azle, Texas (East to West). Refer to Figure for Location of Cores. (Continued) (1 ft = 0.3 m)

The cross-section of the cores on the west side of SH 199 is shown in Figure 3. Core WC9 consists of a 150 mm (6 ins) of gravelly sand overlying a silty clay. The clay, 2.1 m thick, found at the surface of core WC8 overlies a silty clay, 2.4 m (8 ft) thick. Core WC7 consists mainly of sandy clay grading into a silty, sandy clay. According to the drillers groundwater was found in cores WC7 and WC8 within the sandy/silty clay, at nearly the same depth (elevation 658).

Observation of the cross-sections from east to west, began with EC1-WC9 (Figure 4a) (EC=east core; WC=west core). The surface appears to grade into a sandy soil to the west. The thickness of the clay increases to the west from 1.4 to 2.0 m (4.6 to 6.5 ft). Beneath the clay in both cores lies a dense, cemented sand. In observing cross-section EC2-WC8 (Figure 4b), 0.3 m (1 ft) of clay seen at the surface of EC2 and increasing in thickness and type towards WC8, overlies a cemented sand.

Cores EC4, MC5, WC6, run east to west across SH 199 near to Station 609 +50 (Figure 4c). Two meters of clay, either sandy or containing broken limestone, exist at the surface of these cores. Sand is only seen relatively near to the surface in core MC5.

The cores from the east side reveal that more cemented sand exists closer to the surface than on the west side. The water is not limited to just the sand. The sandy clay was also found to be holding water. There is not enough information to determine the true flow direction, however, based of the information given, an estimate would be that groundwater flows toward the creek from both the north and south.

FIELD METHODS

Due to the time constraints evoked by traffic control and the efficiency of a smaller antenna, the 500 MHZ antenna was employed at this site. Five survey lines, each 330 m (1082 ft) in length, were conducted along the northbound shoulder (NSH(A-A')), the northbound driving lane (or slow lane) (NTL(B-B')), the southbound driving lane (STL(D-D')), the southbound shoulder (SSH(E-E')), and the median separating the north and southbound traffic (MED(C-C')) (Figure 1). Markers were placed within the data every 7.5 m (25 ft). The survey from the median was expected to establish subsurface reflection

patterns for comparison with those taken atop the road surface. The survey parameters include 40 scans/sec, 512 samples/scan, and a time/depth range of 60 ns.

INTERPRETATION

The radar survey in the median separating the north and southbound lanes produced a strong, distinctive reflection pattern within the subsurface beginning around the 150 m (500 ft) mark and tapering off around the 210 m (700 ft) mark. (See Figure 5 for radar profile and Figure 6 - for location). This reflection pattern was then used to help distinguish the same sort of pattern from the surveys completed atop the roadway. It appears that around 165 m (540 ft) a layer tapers out then reappears around 210 m (700 ft). This survey in the median also exhibits some unclear areas starting around 260 m (850 ft) and just before the end of the survey it appears as if another layer joins in. The distinctive reflection pattern was also found in survey NSH (northbound shoulder) from 145 - 180 m (470 - 590 ft) (Figure 7) and from 230 - 250 m (750 - 820 ft) (Figure 8). It appears that around the 150 m (490 ft) mark, the bottom of the vase in the main lane is affected by water, as is the roadbed material and probably the base material in the shoulder. The contacts between the base material, the roadbed material and the natural geology taper in and out along the survey on the northbound shoulder. The characteristic reflection is more noticeable in the shoulder survey than the main lane, however, it can be seen in survey NTL (northbound thru lane) from 150 - 160 m (490 - 520 ft) and 210 - 250 m (700 - 820 ft) (See Figures 9 and 10, respectively). Data from the main lane entail interference as seen by the spikes approximately every 4 m (13 ft), due to the joints between the concrete slabs. It is also assumed the materials making up the shoulder are of a lower dielectric and are less compacted than the main lane. The area around the 230 m (750 ft) mark distinguished by the radar, in both the northbound shoulder and main lane, is where sand is seen close to the surface within core EC2 and might be saturated with water and/or clay layers are grading into the area.

The reflection pattern could also be seen in survey STL (southbound thru lane) from 180 - 230 m (590 - 750 ft) and 240 - 260 m (820 - 850 ft) and in SSH (southbound shoulder) from the 175 - 240 m (570 - 790 ft) mark (Figure 11). The data from the southbound main lane exhibited weak reflections, however their locations could be correlated with the other surveys.

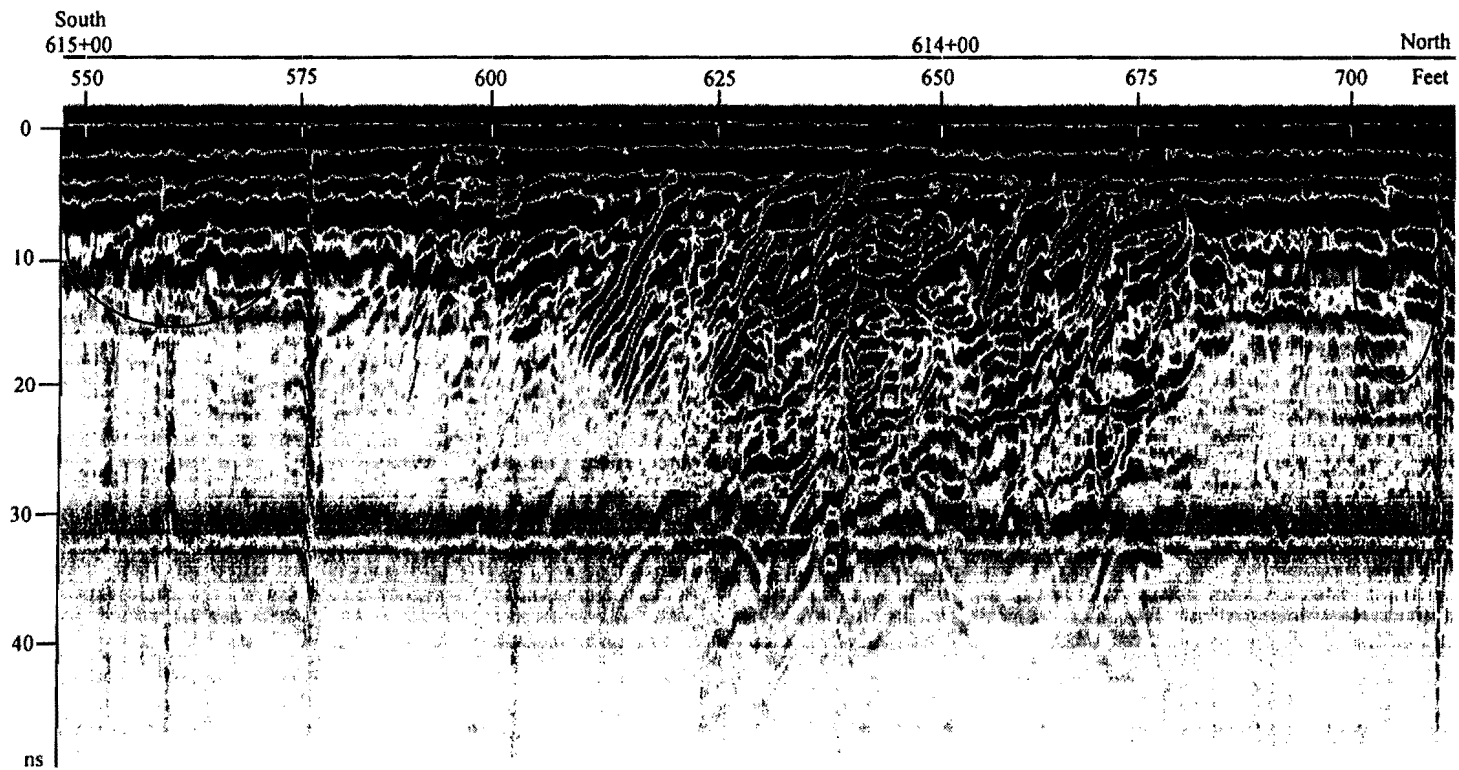


Figure 5. A Portion of the Radar Data Taken from the Median Along State Highway 199 in Azle, Texas. The Survey is Running South to North and Shows an Area of Possible Sandy Saturated Deposits. Tapering Out of Layers Can Be Seen in Between 550 ft and 575 ft as Well as After 700 ft. (1 ft = 0.3 m)

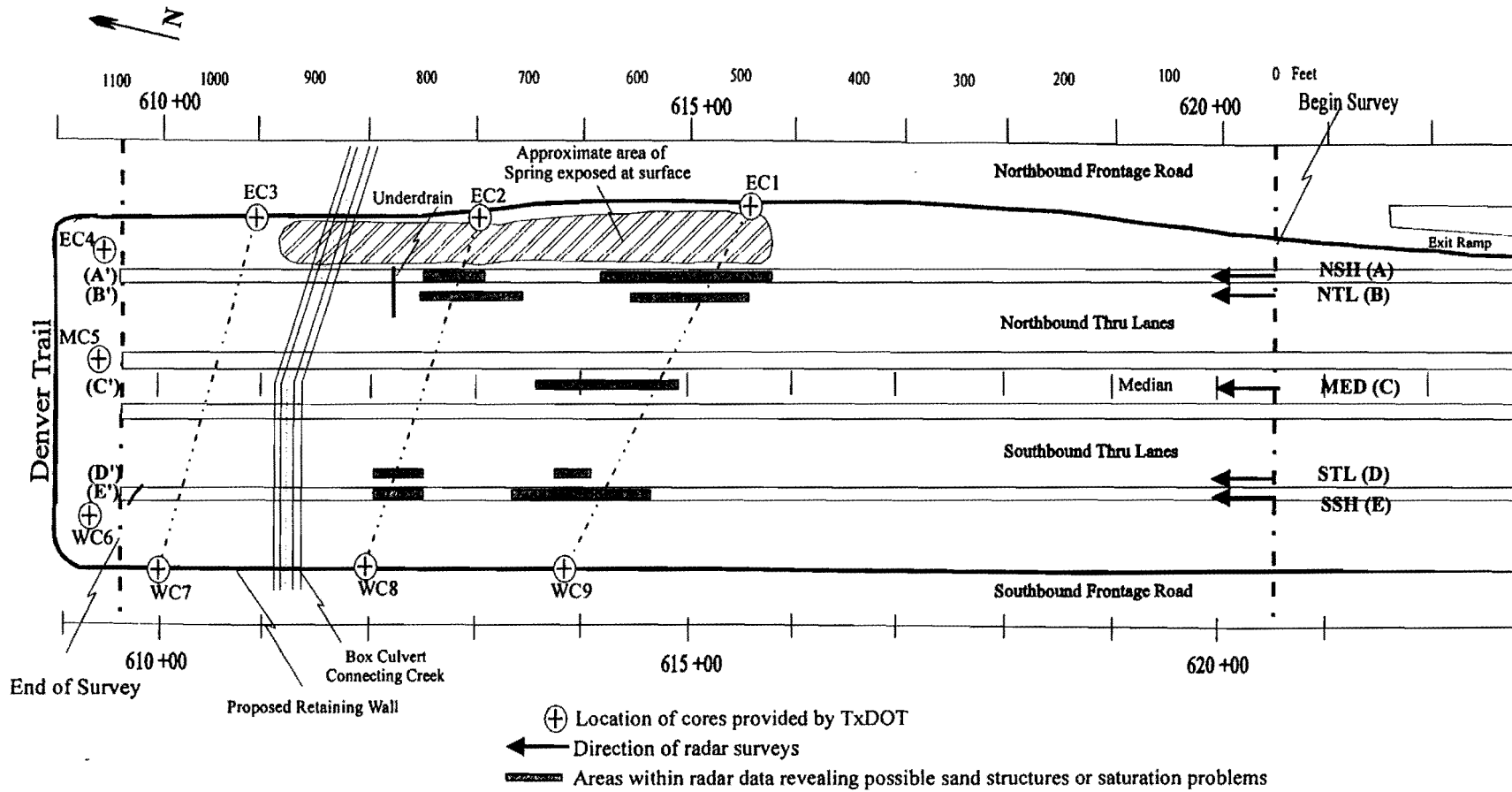


Figure 6. State Highway 199, Azle, Texas, Illustrating Locations of Possible Concern Resulting from GPR Survey.
 (1 ft = 0.3 m)

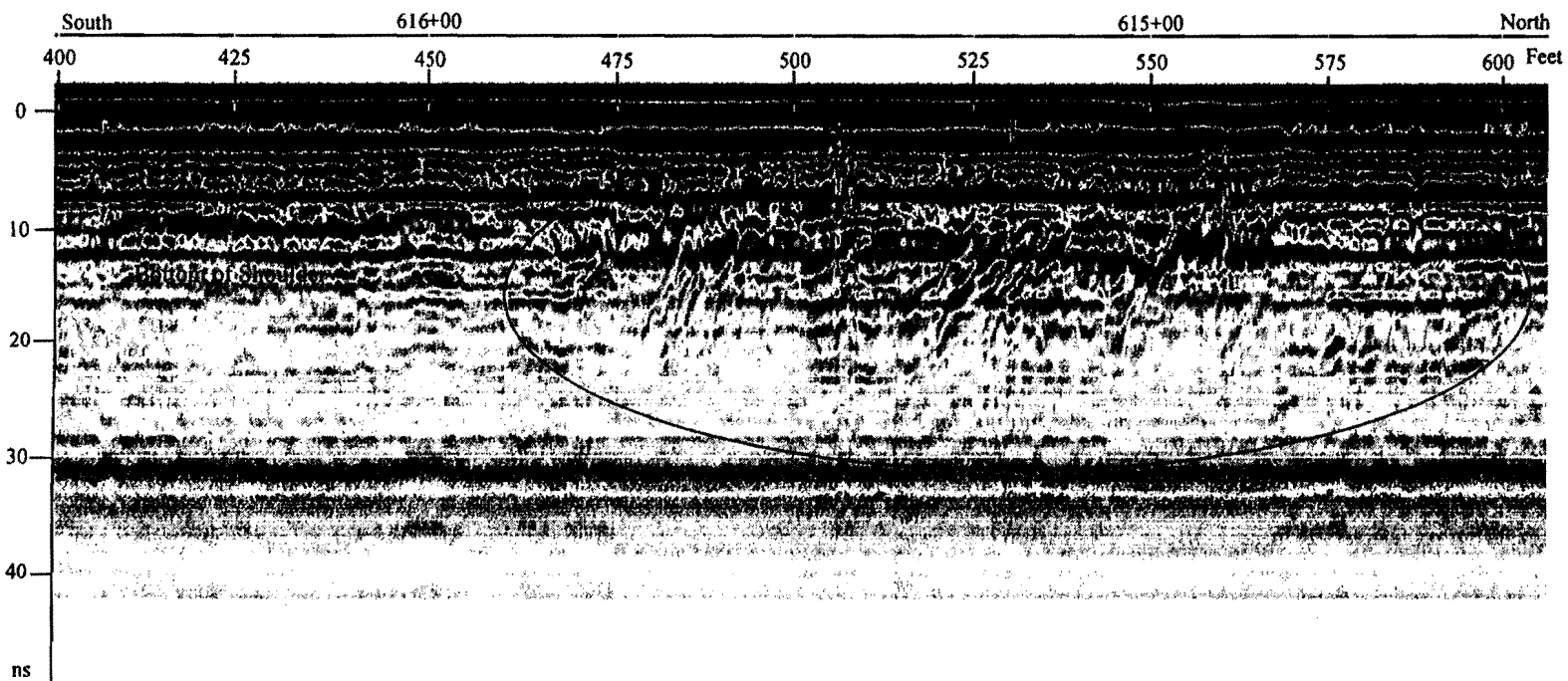


Figure 7. A Portion of the Radar Data Taken from the Northbound Shoulder (NSH) Along State Highway 199 in Azle, Texas. The Survey is Running South to North and Shows an Area of Possible Sandy Saturated Deposits Beginning at 475 ft. (1 ft = 0.3 m)

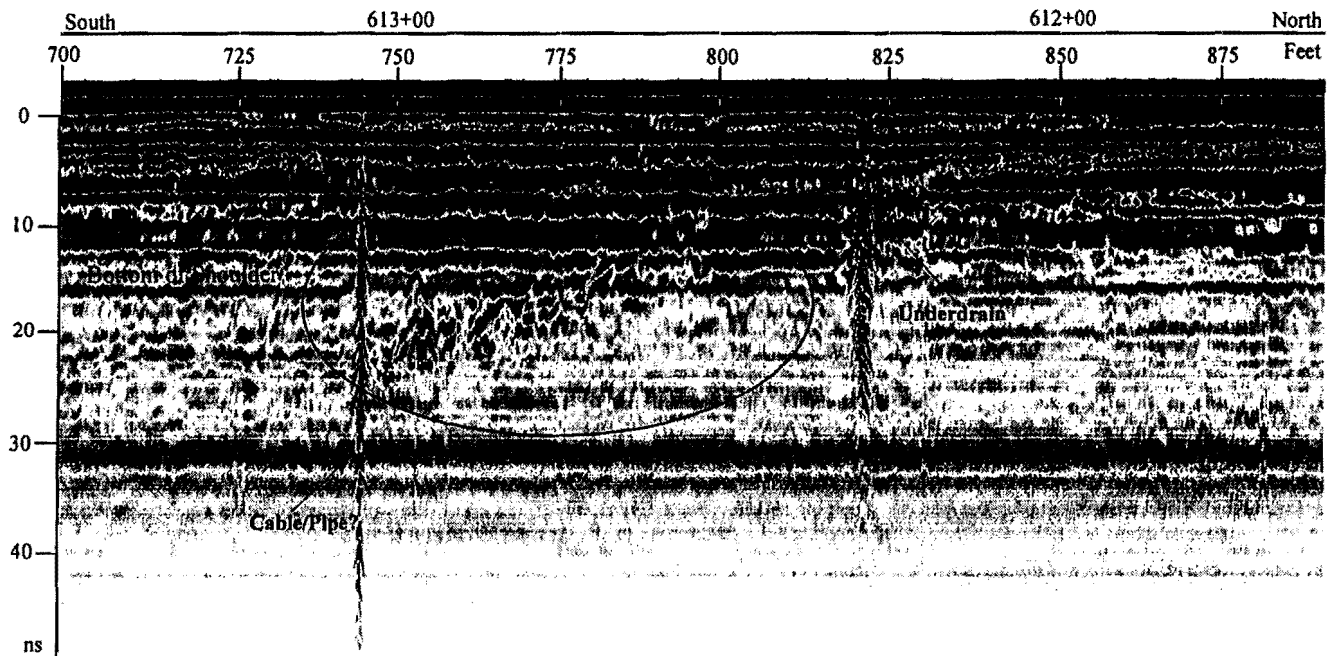


Figure 8. A Portion of the Radar Taken from the Northbound Shoulder (NSH) Along State Highway 199 in Azle, Texas. The Survey is Running South to North and Shows a Distinctive Reflector Between 750 and 800 ft Markers. The Underdrain Placed on the Northbound Side is Also Visible. (1 ft = 0.3 m)

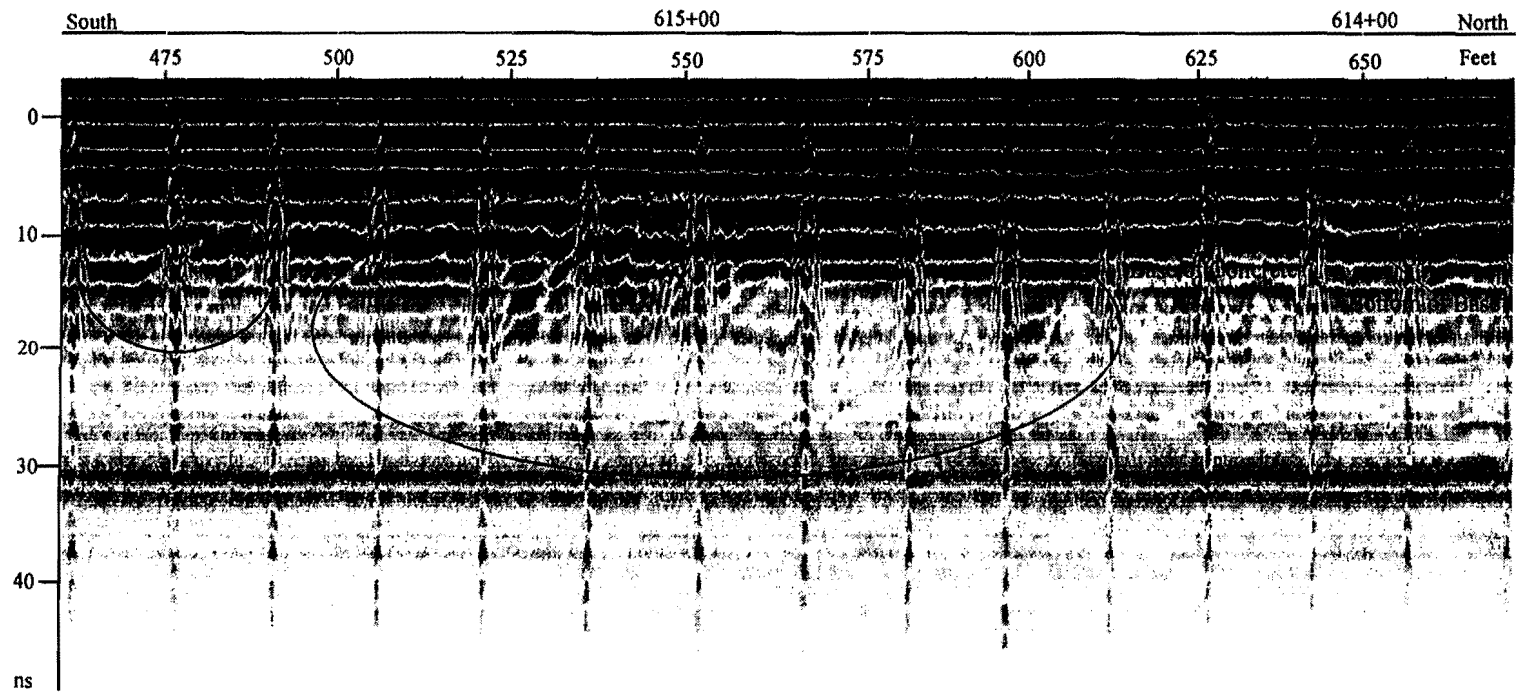


Figure 9. A Portion of the Radar Data Taken from the Northbound Main Lane (NTL) Along State Highway 199 in Azle, Texas. The survey is Running South to North and Shows an Area of Possible Sandy Saturated Deposits Between 500 and 600 ft. Possible Taping bed at 475 ft mark. Spiking Produced by Joints in Concrete.
(1 ft = 0.3 m)

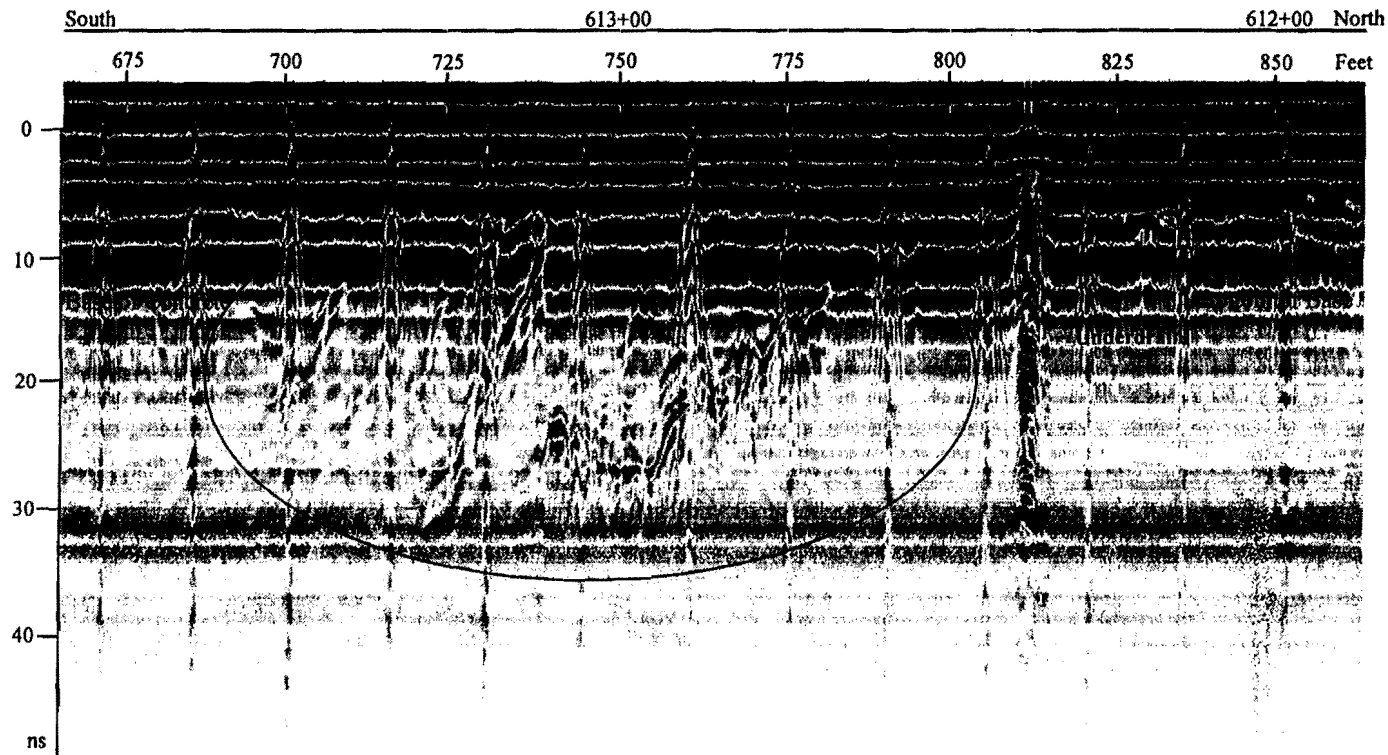
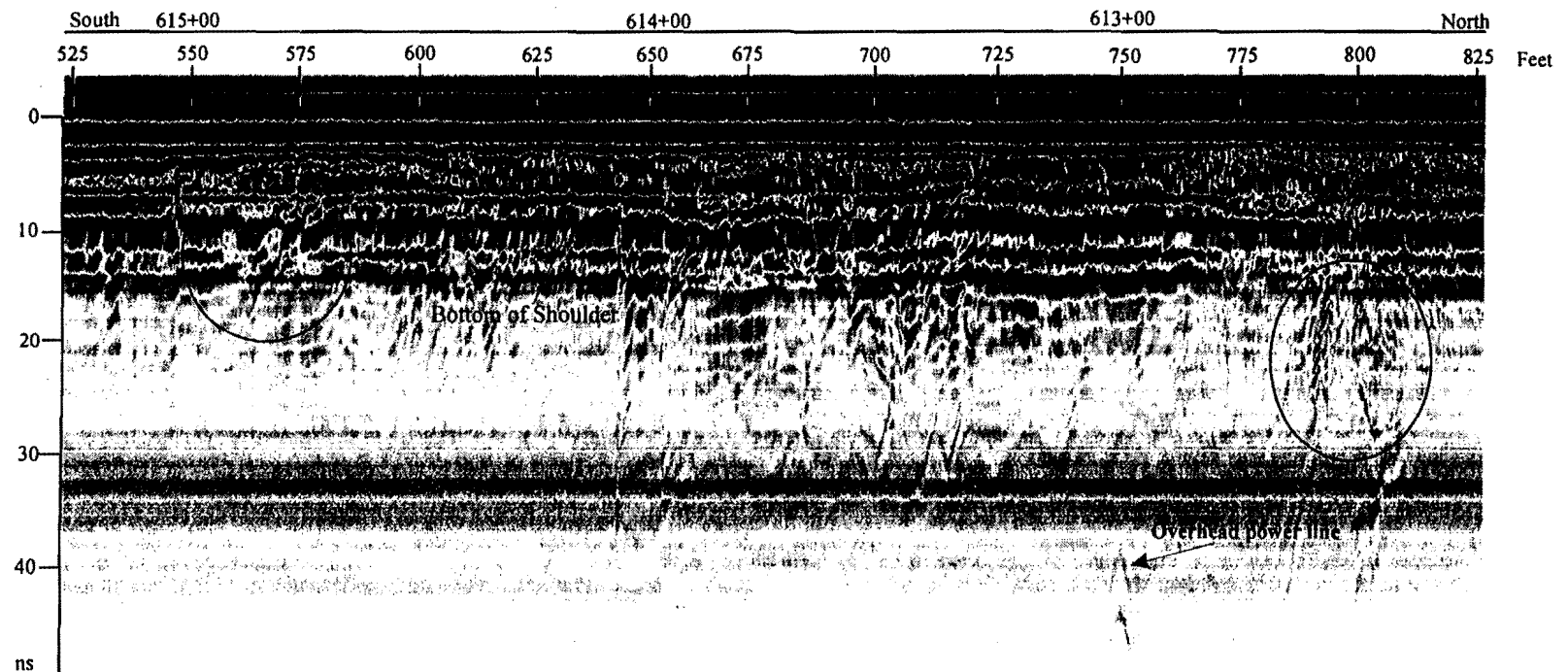


Figure 10. A Portion of the Radar Data Taken from the Northbound Main Lane (NTL) Along State Highway 199 in Azle, Texas. The survey is Running South to North and Shows a Distinctive Reflector Between 700 and 800 ft. The Underdrain Placed is also Visible. (1 ft = 0.3 m)



17

Figure 11. A Portion of the Radar Data Taken from the Southbound Shoulder (SSH) Along State Highway 199 in Azle, Texas. The survey is Running south to North and Shows a Reflection Pattern, Similar to that from the Median, Between the 525 and 825 ft Markers. Possible Tapering Bed at 575 ft and a Distinctive Reflector at 800 ft. (1 ft = 0.3 m)

Depths to any near-surface reflectors, i.e. the bottom of the asphalt or concrete, could not be accurately calculated on such a small scale with the particular antenna used in this survey.

CONCLUSIONS

Cores EC1 and EC2 are both of interest since a sand layer (cemented sand) is seen fairly close to the surface in both cores. It is believed that this sand grades into a clayey sand to the north (EC3) at least 3.2 m (10.5 ft) below the surface and is possibly still bearing water. Distinctive radar reflections were seen just to the north of EC1 within surveys NSH and NTL and on top of EC2 as well, where sand is seen 0.3 m (1 ft) below the surface. It is believed that this sand is the source of the water flowing up to the surface in the drainage ditch. This sand seems to grade into a clayey sand or sandy clay to a depth of at least 4.6 m (15 ft) from EC2 to WC8. The shale layer seen in cores WC8, WC6, EC4, and EC3 is at an elevation of no more than 652 (fairly deep) and more than likely thins and thickens randomly throughout the site. This layer was too deep to be seen in this survey.

Two possibilities exist for the apparent saturation below the bottom of the road layers. The road is either lying atop a clay layer or a sand layer. If the former, water could be trapped in between the clay and the road itself. If the latter, water, which can easily travel through the sand, may be rising to a level below the road.

Based on all observations it appears the main area of importance regarding the location of the water saturation (or the spring) on both sides of SH 199 begins before the 150 m (490 ft) mark (Station 615 +50) and extends northward toward the creek.

CHAPTER III

USING GPR TO IDENTIFY SINKHOLES ON I-20

INTRODUCTION

GPR data was collected by TTI from the driving lanes of I-20, eastbound and westbound, and along certain portions of the frontage roads in order to pinpoint areas of concern, mainly the identification of sinkholes.

AREA GEOLOGY

Sweetwater is located atop an outcropping of the Permian Whitehorse formation (Figure 12). The lower portion of the Whitehorse formation is comprised of gypsum rock (Figure 13). During the Permian period extensive flats acted as evaporation pans, laying down bed after bed of drying gypsum along with bright red, oxidized sand and mud layers. Gypsum, or calcium sulfate, occurs in three varieties, Alabaster is fine-grained and massive, Selenite is transparent, colorless, and crystal shape, and Satin Spar is fibrous with a silky luster. From observation and hearsay, Alabaster and Satin Spar can be found in the Sweetwater area.

OBSERVATIONS

Sinkholes along I-20 have previously been discovered in the grassy median between the eastbound lanes and the southern frontage road, where small open areas show up at the surface. These are first observed as small holes 0.3-0.6 m in diameter (Figure 14), but heavy rains cause them to enlarge. TxDOT fills these holes on a regular basis. GPR data was collected over these known existing sinkholes to establish the subsurface reflection patterns they generate. Both 500 MHZ and 100 MHZ data were collected at this site (Figure 16). Starting at the zero mark, a reference mark created by TTI on the southern frontage, the 50 MHZ and 100 MHZ data reveals sinkholes situated at the 12.2-15.2 m (40-50 ft), 24.2-32 m (80-100 ft), 38-50 m (120-160 ft), and one definitely reaching the surface at the 56 m (180 ft) mark (Figure 15).

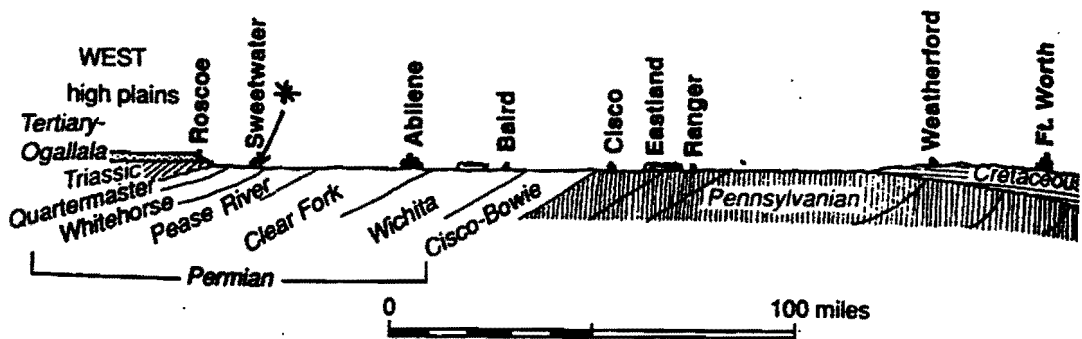


Figure 12. Cross-Section Along I-20 Between Ft. Worth, Abilene, and Roscoe. The Tilt of the Rocks is Greatly Exaggerated (From Texas Roadside Geology).

Age	Rocks	Name	Description
Permian	upper	Quartermaster	red shale, sandstone, dolomite, gypsum
		Whitehorse	
	Pease River	red dolomite, sandstone, gypsum	
	middle	Clear Fork	red shale, siltstone, some sandstone
		Wichita	reddish-brown shale, sandstone cuestas
lower	Cisco	gray-tan limestone, sandstone, shale	
Pennsylvanian			sandstone, limestone, shale

Figure 13. Sequence of Permian Rocks in Northcentral Texas. (From Texas Roadside Geology).



Figure 16. The 100 MHZ (large rectangle) and the 500 MHZ (small square) antennae used in the Survey.

The collected traces from the frontage roads and driving lanes of the highway were reviewed in order to identify locations with the same GPR signature as that found over the known sinkholes. Problem areas were identified in both the northbound and southbound frontage roads within the vicinity of where the sinkholes were observed in the median.

Frontage 2 data reveals sinkholes approximately 6 m (20 ft) before the zero mark, around the 15-23 m (50-75 ft) mark (A), 46 m (150 ft) mark (B), and approximately 7.5 m (25 ft) after the 60 m (20 ft) mark (C) (Figure 17). These observations coincide with the ones made in the grassy median. Sinkhole A encompasses an area of approximately 1.2 m (4 ft) below the surface and 10.8-14 m (36-45 ft) wide. Sinkhole C is small in size and does not seem to be greatly affecting the subsurface. One other area on Frontage 2 deserves some attention. It is located approximately 1.5-3.0 m (5-10 ft) east the 70 MPH sign and is estimated at a depth of 0.9 to 1.25 m (3-4 ft) (Figure 18).

Two areas of concern are located on Frontage 1; one approximately 0.9-1.5 m (3-5 ft) east of the Lion's Club sign (D) and one approximately 1.5-2.4 m (5-8 ft) west of the sign (E) (Figure 19 and Figure 20). Both of these problem areas seem to have originated from deeper sinkholes. A hole 4.8 m (16 ft) deep and approximately 1.5 m (5 ft) wide has propagated towards the surface affecting an area .6 -.9 m (2-3 ft) wide (D). It appears that sinkhole E, .9-1.2 m (3-4 ft) in width, is a product of a much deeper hole out of the range chosen for the survey (deeper than 5.8 m (19 ft)). The affected regions around the Lion's Club sign are approximately .3 -.9 m (1-3 ft) deep, indicating that there is a strong possibility that the frontage road will soon be affected.

One small area of possible concern is located on the I-20 eastbound driving lane between the zero mark and 15 m (50 ft) mark found on the southern frontage road Frontage 2 (Figure 21). An overall review of the potential areas of concern can be seen in Figure 22.

RECOMMENDATIONS

Areas of potential sinkholes are readily visible in the radar data from the frontage roads. TTI recommends the coring of both frontage roads in order to better support the findings from the ground penetrating radar data, along with providing precise depths to the sinkholes. We recommend that cores be taken from sinkholes D and/or E on Frontage Road 1, as well as sinkhole B and/or A on Frontage Road 2. The estimated depths to the problems are given

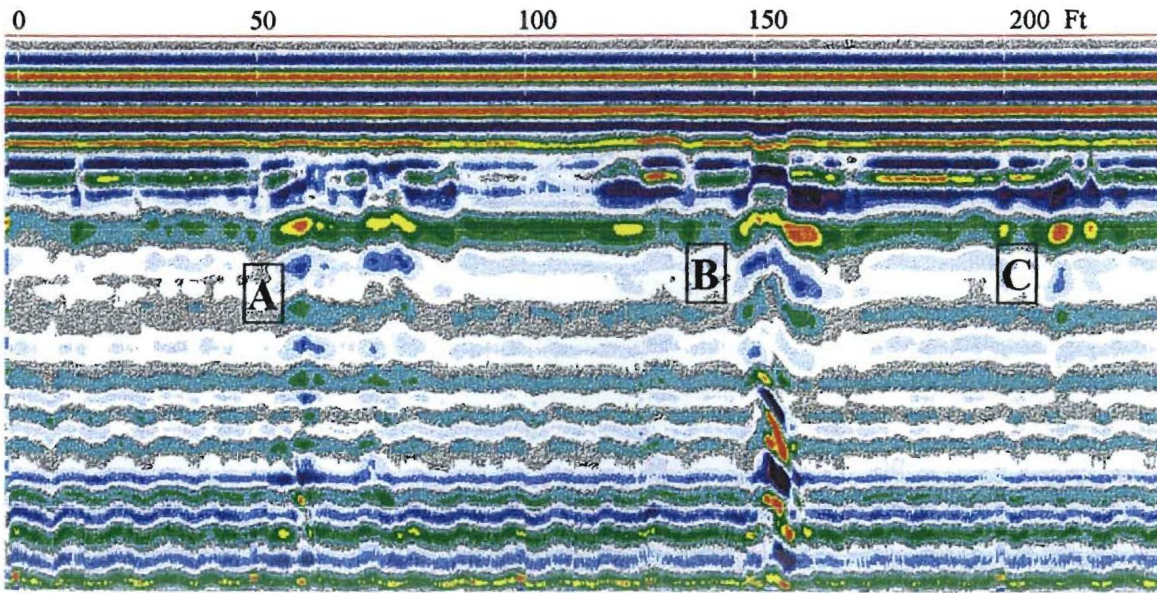


Figure 17. 100 MHz Data from Frontage Road 2 Adjacent to Grassy Median with Known Sinkholes. (1 ft = 0.3 m)

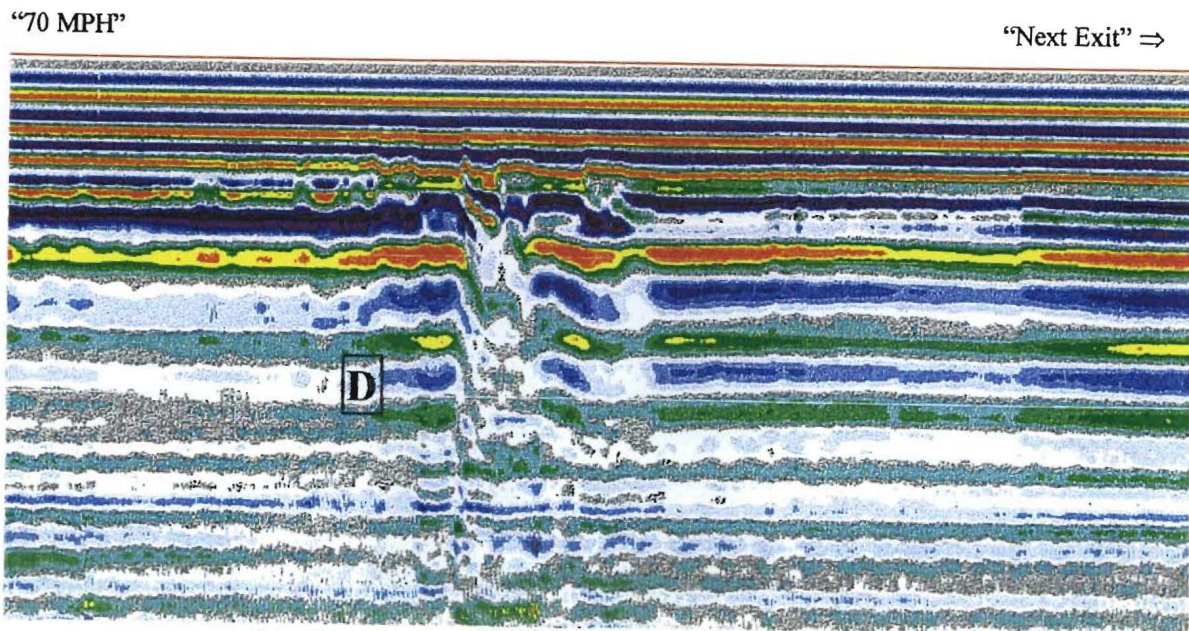


Figure 18. 100 MHz Data from Frontage 2.

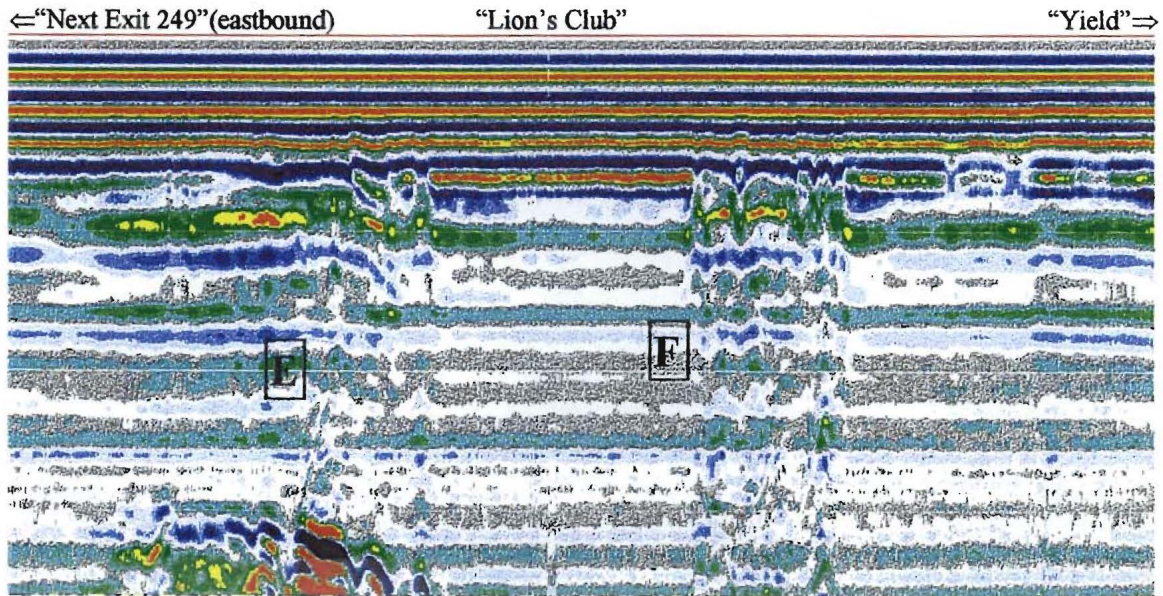


Figure 19. 100 MHz Data from Frontage 1.

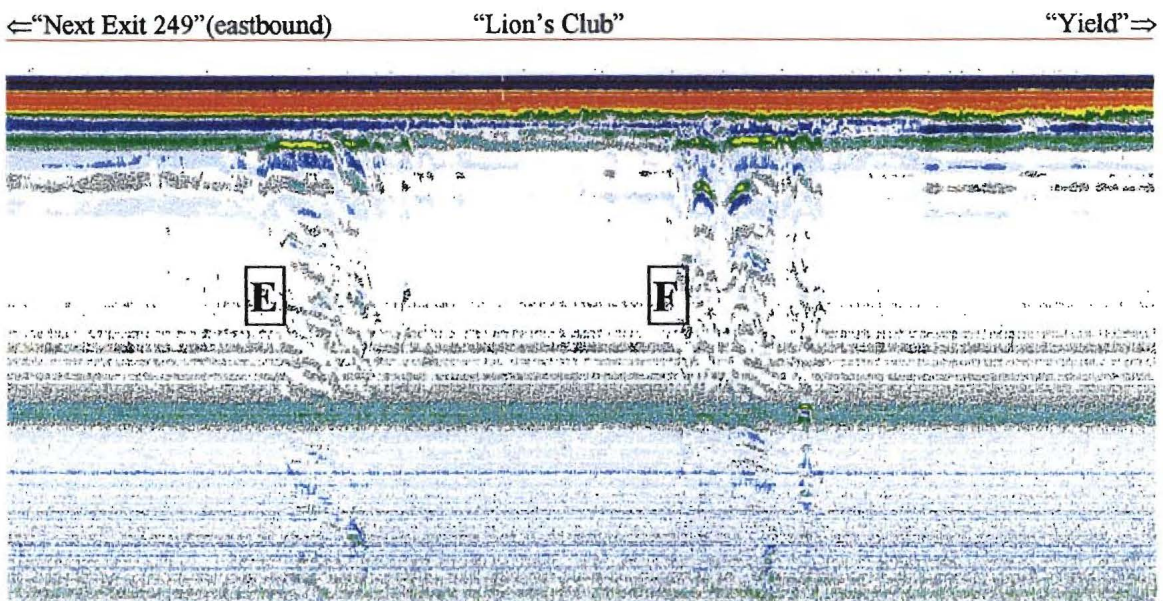
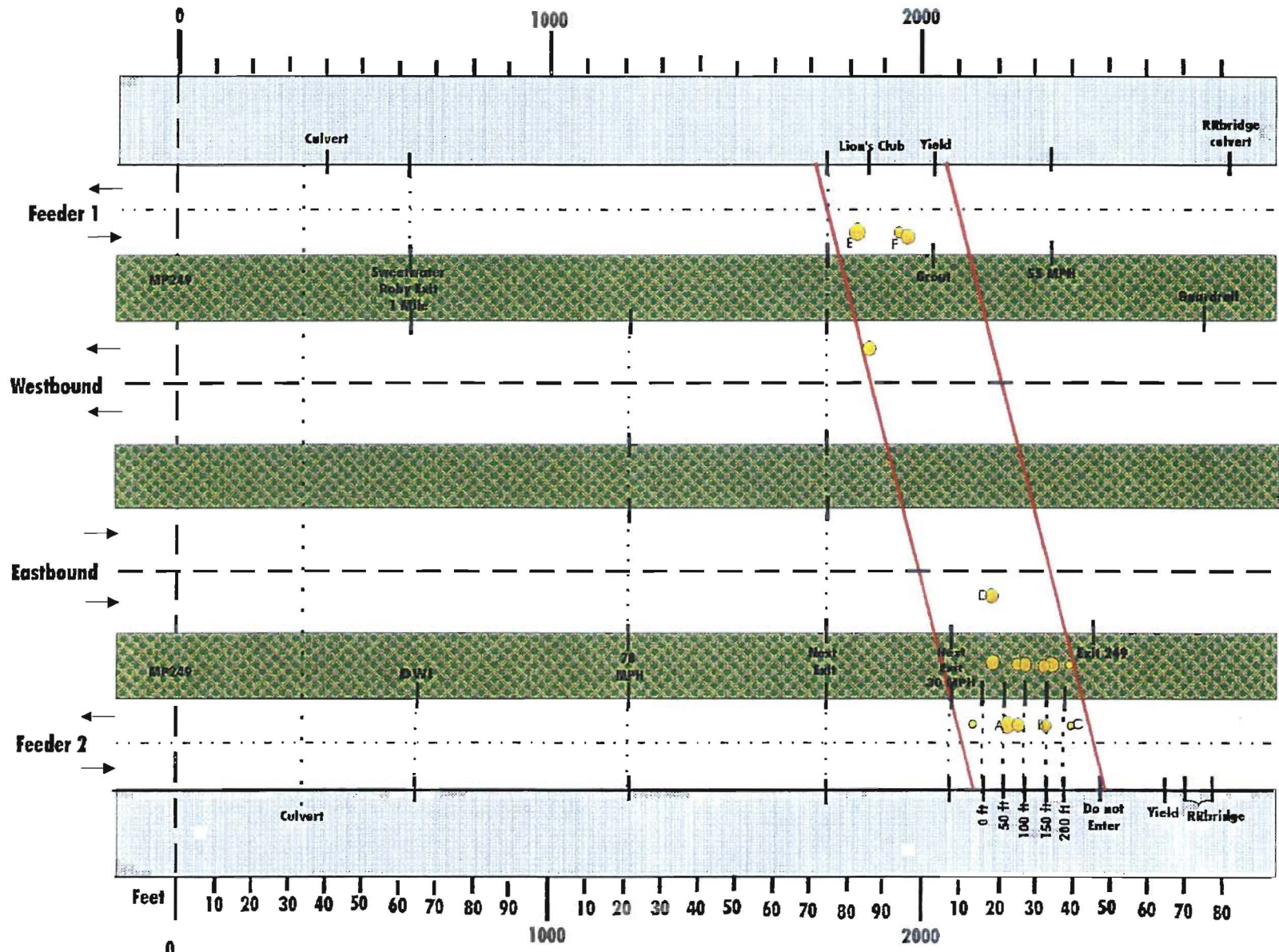


Figure 20. 500 MHz Data from Frontage 1.



— denote markers on the radar data
● denote problem areas located with around penetrating radar

Figure 22. Sweetwater Interstate 20.

above and should be used as a guideline for coring. We also recommend examination of the premises surrounding all sites with assessed sinkholes to insure that objects on or above the surface are not affecting the radar. The main highway lanes should be monitored for any deterioration, possibly due to the existence of sinkholes beneath the road. Future monitoring should include detail radar surveys in all main highway lanes and medians.

CHAPTER IV

USING GPR TO LOCATE UNDERGROUND STORAGE TANKS (USTs) ON PARCEL 94

On December 12, 1996, TTI conducted a GPR survey at the Beall Concrete Plant on State Highway 199 in Azle, Texas. Information previously gathered suggests that three underground storage tanks (USTs) exist on the property. The location of one 3,000 gallon tank was known, while the locations of two 2,500 gallon tanks was unknown. The aim of the GPR survey was to locate the two 2,500 gallon tanks for the purpose of extracting them from the ground.

The GPR survey was comprised of a grid designed by the operators in order to help better locate the USTs. Using the telephone pole located in the parking lot as a zero point, a grid was set up consisting of 1.2 m (4 ft) intervals in the x-direction and .6 m (2 ft) intervals in the y-direction (Figure 23). A 200 MHZ antenna and a 500 MHZ antenna were used to collect data in both the x- and y-direction. The radar survey revealed an estimated 230-300 mm (9-12 in) of concrete with another 300 mm (12 in) of fill overlying the tanks.

UST #1 was found within the quadrant of (8, 6) to (12, 6) to (8, 12) to (12, 12), however it is located closer to the $x = 8$ than to $x = 12$. The depth of UST #1 is approximately .52-.6 m (1.70-2 ft). This depth was calculated using a common dielectric constant for concrete, 7. If the exact dielectric constant of the concrete at the site was known, a more accurate depth could be calculated.

The estimated location of UST #2 is in the quadrant of (12, 8) to (16, 8) to (12, 12) to (16, 12), yet being located closer to the $x = 16$ line. A depth to UST #2 could not be calculated, but it is assumed to be at a similar depth as that of UST #1.

An assumption is made in this survey with respect to the orientation of the USTs. It is assumed that they are laying lengthwise in the y-direction. This assumption is based on the reflection characteristics within the radar data. When a radar antenna crosses perpendicular over the axis of a cylindrical tank, a hyperbolic shape is seen in the data. Hyperbolic reflections were only seen in the survey lines running in the x-direction (with the exception of those produced by the water pipes in the y-direction) resulting in the assumption that the tanks are

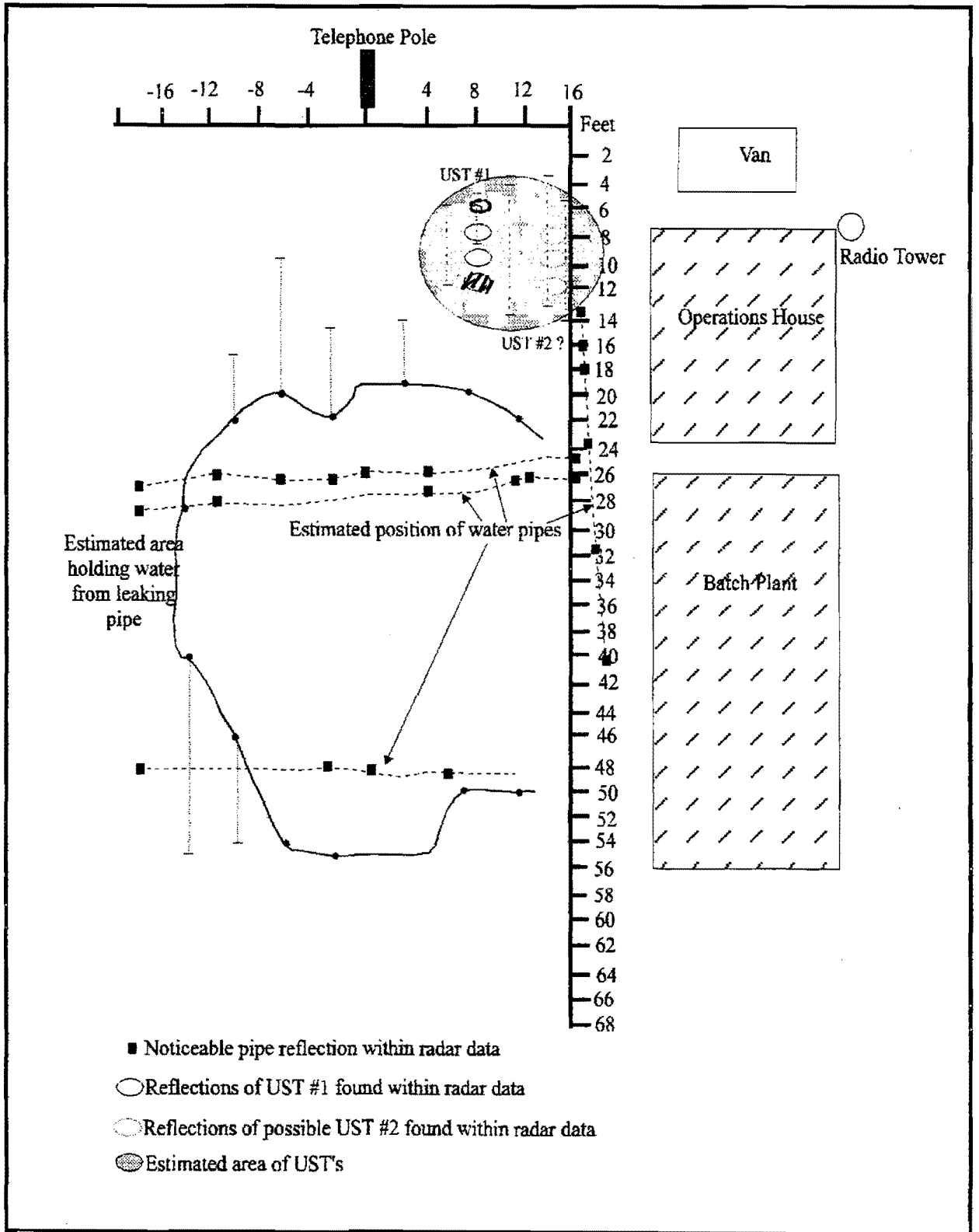


Figure 23. Site Layout at Beall Concrete Plant with GPR Results.

oriented in the y-direction. See Figures 24 and 25 for examples of the characteristics radar reflection for a UST. In the 500 MHz data, clear hyperbolas are observed in the data (see markers A and B).

As shown in Figure 23 the GPR survey also predicted the presence of some buried water pipes which appeared from the GPR traces to be leaking. An estimation of the extent of the leakage was also given.

CHAPTER V

USING GPR TO DETECT SUBSURFACE PROBLEMS ON MESA ROAD IN EL PASO, TEXAS

INTRODUCTION

GPR tests were performed in order to investigate if radar techniques could be used to detect sinkholes under the pavement on Mesa Road in El Paso. TxDOT noted that several major surface cavities had recently been repaired. These were dangerous to traffic and needing immediate repair. The cause of the cavities was unknown although it was suggested that they may be related to:

- sinkholes caused by the falling ground water table,
- underground springs causing wash outs, or
- leaking utility pipes.

Utility pipe problems are the most common cause of cavities in cities all around the world and in some countries there are special GPR systems to detect them. This type of leak enables water to escape and wash the surrounding soil into the pipes. Alternatively, the water finds a channel to flow around the pipes. A void is frequently formed and its size increases progressively until the surrounding material collapses.

In this survey, TTI used ground-coupled radar systems made by GSSI. The antennae used were the 100 MHZ and 500 MHZ units, the former one to give good depth penetration and sensitivity against moisture variations and the latter one to give more detailed information from 0 -.9 m (0-3 ft) beneath the surface, which is a “blind spot” for the 100 MHZ antenna. The 100 MHZ ground-coupled antenna is also very effective in locating transverse pipes and cables and for detecting areas of high moisture concentrations. The 100 MHZ antenna used is shown in Figure 26.

The surveys consisted of three short detailed surveys sections where earlier failures had occurred and two long runs from Kern Plaza and Alto Mesa. In the short detailed surveys, several lanes were tested with both the 100 MHZ and 500 MHZ antennae. Positioning within

Figure 26. The 100 MHz Antenna Used in Mesa Road Testing.

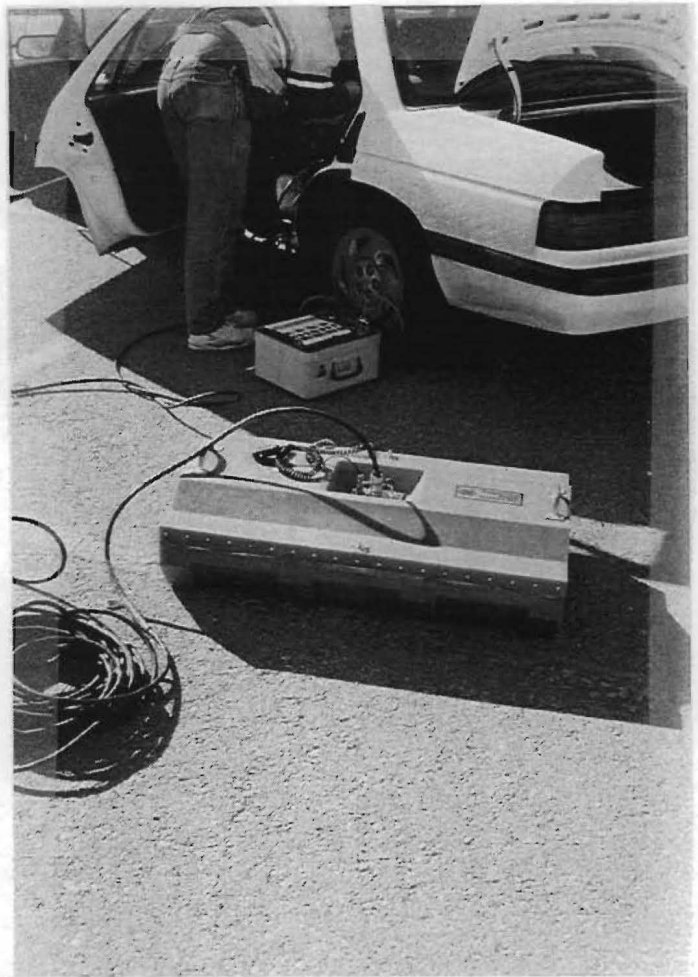


Figure 27. Water Seeping from Pavement Near the Intersection with Kern Street.

the survey was made by painting a mark at 30 m (100 ft) intervals on the curb and entering a marker into the GPR data file when passing that mark. When conducting the long surveys, markers were placed in the data at each street intersection and at other major permanent reference locations, such as the beginning of a bridge. These markers were placed in the data file to assist in tying observed anomalies to physical location in the section.

After the field surveys, the data processing and interpretation were made at TTI. This work included scale normalization, filtering, background noise removal, printing the radar profiles, and interpreting them. Because no reference core data were available to backcalculate the dielectric constant of the soil which determines the depth scale of the profile, an estimated value based on previous experience was used.

RESULTS

Sunbowl Test Site

General

The first radar passes were performed on Mesa Road between Sunbowl and Kern, where several large cavities had previously appeared at the surface. A 420 m (1400 ft) test section was established starting at the traffic lights at the Sunbowl intersection. A special observation could be made during the measurement: in the section between 318-321 m (1040-1050 ft), several surface cracks were noted to be leaking water and the flow rate peaked at around 10 a.m. and then slowly decreased. Figure 27 shows the leaking cracks. The 100 MHZ antenna was used to test all three lanes. The 500 MHZ was used on the right and center lanes only.

Results

The 100 MHZ data, with interpretation, is presented in Figure 28. The profile has been marked with white paint showing the structural interfaces between a) the road structure/subgrade soil, b) the subgrade soil/bedrock interfaces and c) any anomolous moisture areas. Also cables and pipelines that could be identified were noted in the GPR profiles.

The road structure in this section of Mesa Street consisted of a thick pavement approximately 300 mm (12 ins) thick, over a 300 mm (12 ins) thick sub base layer. The subgrade thickness over the bedrock is approximately 1 m (3 ft). However, the estimate of the bedrock depth is not reliable because no reference data were available.

Nothing in the GPR surveys results indicated that there could be a major sinkhole or cavity in the Sunbowl test section, but in the section there were two major moisture anomalies under the road these being 1) section 60-90 m (200-300 ft) and 2) section 275-475 m (900-1550 ft) shown in Figure 28. Both of these can severely impact the performance of the road structure. Some other small moisture anomalies were also located under the road in other lanes, and they were identified on the GPR profiles.

The first moisture anomaly which was located between 60 and 90 m (200-300 ft) was located in the low spot of the section. It is clear that the drainage system of the road is not working and the structure is trapping water. The consequences of this trapped moisture were also apparent on the surface of the road, where the pavement has been repeatedly repaired. From the GPR profile it is apparent that there have been several attempts to repair the problem but they have not been successful.

The second moisture anomaly is located on a sloping hillside between marks 900 and 1150 (Figure 28). The area of the moisture varies under each lane. In the right (outer) lane the moisture area is between 300 and 352 m (985 and 1155 ft), in the center lane the moisture area is narrowest and only from 306 to 342 m (1000 to 1120 ft) and in the left (inner) lane the moisture was observed to be from 290 to 358 m (950 to 1175 ft). All of these moisture anomalies were in close proximity to an underground water pipeline. The water appears to be flowing downhill from the pipe and ponding below the surface then leaching out of surface cracks. The water flow mechanism can be seen especially in the center lane radar profiles where a part of the water starts to flow down to the subgrade soil while part of the water finds its way up to the surface through the pavement structure (see arrows). In the left (inner lane) the water appears to flow around the pipe and then flow down above the bedrock. The only reflection that might indicate that there is also moisture in the bedrock can be found under this lane between 330 and 360 m (1080 and 1180 ft). It is clear that at this location the water is not coming up to the surface but flowing down through cracks.

As a conclusion it is proposed that the water is coming from leaking water or sewer pipes. This interpretation is also supported by the fact that the amount of leaking water varied during the day. The greatest amount of water was coming to the surface a couple of hours after the morning water consumption peaks.

The exact origination of the water could not be pinpointed because the GPR survey network was not tight enough, but in Figure 29 the possible source areas are sketched.

CONCLUSIONS

The water seeping from the pavement on Mesa Road in the southbound lane near the intersection with Kern appears to be coming from a leaking utility line. A major line runs longitudinally along the center median and a smaller line runs transversely across the pavement at approximately 236 m (775 ft) from the start of the section. Our best guess is that the transverse pipe is leaking. It was noted that a repair has recently been made to the longitudinal pipe in this area and it may well be that this pipe is also leaking.

At the moment we do not see any major voids or sinkholes occurring, however, continuing seepage and pumping will eventually lead to a pavement failure. These results should be forwarded to the responsible utility company.

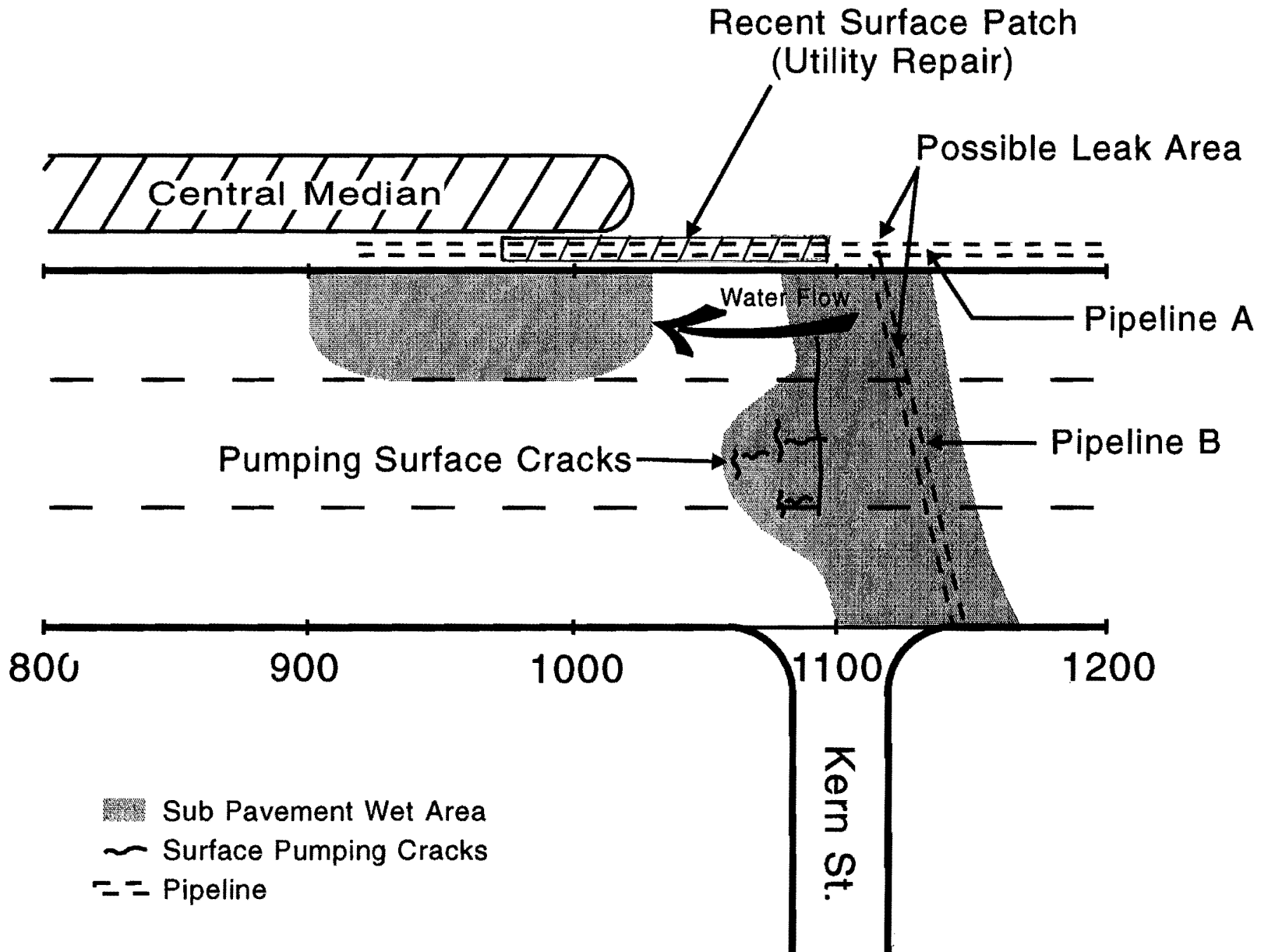


Figure 29. Summary of GPR Results Showing Trapped Moisture and Possible Leak Locations.

