U.S. Department of Transportation

Federal Highway Administration

LTPP Seasonal Monitoring Program

Site Installation and Initial Data Collection

Section 561007
Cody Wyoming

Report No. FHWA-56-1007

February 1994

Notice

LTPP Seasonal Monitoring Program

Site Installation and Initial Data Collection
Section 561007, Cody Wyoming

Report No. FHWA-56-1007

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16. Abstract

This report contains a description of the instrumentation installation activities and initial data collection for test section 561007 which is a part of the LTPP Core Seasonal Monitoring program. This asphalt concrete surfaced pavement test section, which is located on U.S. Highway 16 just east of Cody Wyoming, was instrumented on August 10, 1993. The instrumentation installed included time domain reflectometery probes for moisture content, electrical resistivity probes for frost location, thermistor probes for temperature, tipping bucket rain gage, piezometer to monitor the ground water table, and an on-site data logger. Initial data collection was performed on August 11, 1993 which consisted of deflection measurements with a Falling Weight Deflectometer, elevation measurements, temperature measurements, TDR measurements, and electrical resistance and resistivity measurements. The report contains a description of the test site and its location, the instruments installed at the site and their locations, characteristics of the installed instruments and probes, problems encountered during installation, specific site circumstances and deviations from the standard guidelines, and a summary of the initial data collection.

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I. Introduction

The installation of instrumentation on seasonal site 561007 near Cody Wyoming was performed on August 10, 1993. Initial data collection was performed on August 11, 1993.

The site is located on eastbound U.S. Highway 16, approximately five miles east of the Cody, Wyoming (Figure A-1 in Appendix A). The test section is located on an undivided highway consisting of a 3.7m wide travel lane in each direction. The shoulder is surfaced with asphalt concrete and is approximately 1.5m wide. The test section is classified as GPS-1 and is collocated on an SPS-3 project site.

The pavement structure consists of an average of 76mm asphalt concrete (AC) over an average of 152mm granular aggregate base. The subgrade is a silty sand. Pavement structure information from the GPS material drilling log is presented in Figure A-2. Properties determined from the laboratory material tests are presented in Table 1.

Deflection profile and analysis results from the FWDCHECK program are presented in Appendix A.

The climate at this site is classified as a dry-freeze zone (cell #7). Summary data from the LTPP climate database indicates the following climatic conditions based on 11 years of data:

Freezing Index (C-Days)	574
Precipitation (mm)	229
No. of Freeze Thaw Cycles	147
Days Above 32°C	10
Days Below 0°C	175
Wet Days	78

The estimated annual average daily traffic (AADT) in 1989 was 1620 (two-way) of which 9.3% was truck traffic. The GPS lane carried about 50% of the total AADT. The truck AADT on the GPS lane was 75. The estimated annual ESAL applications in the GPS lane were 27,000.

Installation of the instrumentation was a cooperative effort between Wyoming Department of Transportation (WDOT), Nichols Consulting Engineers (NCE) LTPP Western Region Coordination Office staff, and staff from the FHWA LTPP Division.

The following personnel participated in the instrumentation installation:

Gary E. Elkins	Nichols Consulting Engineers
Mark Potter	Nichols Consulting Engineers
Jason Dietz	Nichols Consulting Engineers
Haiping Zhou	Nichols Consulting Engineers
John Klemunes	FHWA LTPP Division
Gail Beers	Wyoming Department of Transportation

Table 1. Material Properties

Description	Surface Layer	Base Layer	Subgrade
Material	AC	Aggregate	Silty Sand
Thickness (mm)	76	152	∞
In Situ Dry Density (kg/m^3)		2046	1916
In Situ Moisture Content (%)		5.4	12.8
Lab Max Dry Density (kg/m^3)	---	2243 @ 6% MC	1954 @ 12% MC
Liquid Limit	---	NP	NP
Plastic Limit	---	NP	NP
Plastic Index	---	NP	NP
% Passing #200	---	9.2	23.6

MC - Moisture Content
NP - Non Plastic

II. Instrumentation Installation

Meeting with Highway Agency and Site Visit

Planning arrangements with WDOT were handled through telephone conversations and written correspondence. No direct planning meeting were held with WDOT officials. All installation support was provided by WDOT crews.

A site inspection was performed on July 22, 1993 by Gary Elkins. Although pavement damage signs were posted on the site, the test section appeared to in good condition with sealed transverse cracks at approximate 8m intervals. The cracks appear to be related to low temperature thermal fracture. The pavement structure also appeared to have some longer wave length distortion in its longitudinal profile. The test section is located on a slight vertical upgrade in what appears to be a shallow fill. The deepest part of the drainage ditch is located approximately 9m from the edge of the shoulder. No surface features indicated a preference of which end of the test section to instrument. Since the deflection profile was more uniform on the approach end of the test section, it was selected for instrumentation.

Equipment Installed

The equipment installed at the test site included instrumentation for measuring air and subsurface temperature, subsurface moisture content, frost depth, rainfall, joint opening, bench mark and depth to water table. An equipment cabinet was installed to house cable leads, the datalogger, and battery pack. The equipment installed are shown in Table 2.

Equipment Check/Calibration

Prior to field installation, all equipment were checked or calibrated. The air temperature probe, thermistor probe, and the tipping bucket rain gauge were connected to the CR10 datalogger for calibration and function checks. The tipping bucket rain gage was calibrated using 473ml of water placed in a plastic container with a tiny hole in the bottom. The hole size was adjusted so that 45 minutes were required to drain all of the water out of the container. For the 473ml of water, the tipping bucket was found to be within the range of 100 tips $\pm$ 3 tips. The air temperature and thermistor probes were checked for proper functioning by placing them in an ice bath and in direct sun light and comparing the measured temperatures. The results indicated that the air temperature and thermistor probes were functioning properly. The spacings between the thermistor sensors in the plastic tube were measured and recorded. These measurements are shown in Table 3.

The wiring of the resistivity probe was checked by performing continuity measurements between the each electrode and to the pins in the connector. The distance between the electrodes were measured and recorded. These spacing are shown in Table 4. Electrical resistance and resistivity measurements were performed with the probe immersed in a water bath. The results of these measurements are shown in Appendix B. The checks on the resistivity probe indicated that the probe was correctly wired and functioning properly.

Table 2. Equipment installed.

Equipment	Quantity	Serial Number
Instrument Hole		
MRC Thermistor Probe	1	191 (56AT)
ABF Resistivity Probe	1	56AR
TDR Sensors	10	56A01-56A10
Equipment Cabinet		
Campbell Scientific CR10 Datalogger	1	16566
Battery Package	1	5587
Weather Station		
TE525 MM Rain Gauge	1	12065
Air Temperature Probe (Model 107)	1	421316
Radiation Shield	1	41301
Observation Well/Bench Mark	1	None

The functioning of the TDR sensors were checked by performing measurements in air, with the prongs shorted at beginning of the sensor and not shorted, and in water. The TDR measurements indicated that all sensors produced the expected traces and appeared to be functioning properly. Results of these TDR measurements are presented in Appendix B.

Equipment Installation

Installation of the instrumentation was performed on August 10, 1993. All details and responsibilities regarding the instrumentation installation were finalized with the WDOT with a phone call on the previous day. WDOT provided traffic control, pavement sawing and auguring of the instrumentation hole and Bench Mark/Observation Well, and pavement repair. The NCE and FHWA staff installed all instrumentation, the observation well, and cabinet.

Installation of the instrumentation was completed in one day. Installation activities included set-up of traffic control, site layout and marking, installation of piezometer, thermistor probe, resistivity probe, TDR sensors, air temperature probe, rain gauge, and cabinet, and site clean up. Wiring of all cables to the cabinet was also completed in the first day.

The instrumentation was installed on the approach end of the test section at approximate station 0-26. The in-pavement sensors were installed in a 508mm square hole cut into the AC surface, located in the outside wheel path, approximately 800mm from the edge of the travel lane. Cooling water was not used with the pavement saw and subsequently, the surface of the base material did not get wet during the sawing operation. A 254mm diameter hollow-stem auger was used to bore the instrument hole. The instrumentation hole was approximately 2m deep.

Table 3. Description of MRC thermistor probe and sensor spacing.

Unit	Channel Number	Distance from Top of Unit (cm)	Remarks
1	1	1.3	This unit was installed in the surface layer.
	2	15.2	
	3	29.2	
2	4	1.8	This unit was installed in the base and subgrade.
	5	9.6	
	6	17.1	
	7	24.7	
	8	32.2	
	9	47.6	
	10	62.8	
	11	78.3	
	12	93.2	
	13	108.5	
	14	123.7	
	15	139.1	
	16	154.2	
	17	169.5	
	18	184.6	

The temperature probe (Unit 2) was placed on the leave side of the hole beneath the location of the in-pavement sensor (Unit 1). The electrical resistivity probe was placed opposite the temperature probe on the approach side of the hole. The TDR probe were placed in an offset fan pattern with the lead wires positioned along the side of the hole closest to the shoulder. Stress relief S-loops were formed in all of the TDR lead wires, except one, near the connection with the probe. The S-loop was inadvertently left out of the wire for TDR No 10. The lead wires from the in-pavement instrumentation were placed in a 51mm diameter steel conduit and buried in a 76mm wide trench leading to the equipment cabinet located approximately 8.5m away from the instrument hole. The equipment cabinet was located on the side slope slightly above the drainage ditch. Wiring of all cables to the cabinet was also completed the first day.

Table 4. Resistivity probe and sensor spacing.

Connector Pin Number	Electrode Number	Continuity ✓	Measurement	Spacing (cm)			Dist. from top (cm)
				Line 1	Line 2	Avg	
36	1	✓	Top-1	2.9	3.0	2.95	3.0
35	2	✓	1-2	5.2	4.9	5.05	8.0
34	3	✓	2-3	4.9	5.1	5.00	13.0
33	4	✓	3-4	5.2	5.0	5.10	18.1
32	5	✓	4-5	5.1	5.1	5.10	23.2
31	6	✓	5-6	5.0	5.1	5.05	28.3
30	7	✓	6-7	5.0	5.1	5.15	33.4
29	8	✓	7-8	5.0	5.1	5.05	38.5
28	9	✓	8-9	5.1	5.0	5.00	43.5
27	10	✓	9-10	5.1	5.1	5.10	48.6
26	11	✓	10-11	5.1	5.1	5.10	53.7
25	12	✓	11-12	5.0	5.0	5.00	58.7
24	13	✓	12-13	5.2	5.1	5.15	63.8
23	14	✓	13-14	5.1	5.1	5.10	68.9
22	15	✓	14-15	5.0	5.1	5.05	74.0
21	16	✓	15-16	5.1	5.0	5.05	79.0
20	17	✓	16-17	5.1	5.0	5.05	84.1
19	18	✓	17-18	5.0	5.1	5.05	89.1
18	19	✓	18-19	5.2	5.1	5.15	94.3
17	20	✓	19-20	5.1	5.0	5.05	99.3
16	21	✓	20-21	5.0	5.2	5.10	104.4
15	22	✓	21-22	5.1	5.1	5.10	109.5
14	23	✓	22-23	5.1	5.0	5.05	114.6
13	24	✓	23-24	5.1	5.1	5.10	119.7
12	25	✓	24-25	5.1	4.6	4.85	124.5
11	26	✓	25-26	5.1	5.5	5.30	129.8
10	27	✓	26-27	5.1	5.1	5.10	134.9
9	28	✓	27-28	5.1	5.1	5.10	140.0
8	29	✓	28-29	5.1	5.1	5.10	145.1
7	30	✓	29-30	4.9	5.0	4.95	150.1
6	31	✓	30-31	5.2	5.1	5.15	155.2
5	32	✓	31-32	5.1	5.1	5.10	160.3
4	33	✓	32-33	5.1	5.2	5.15	165.5
3	34	✓	33-34	4.8	4.9	4.85	170.3
2	35	✓	34-35	5.2	5.1	5.15	175.5
1	36	✓	35-36	5.0	5.1	5.05	180.5
			36-End	2.8	2.8	2.80	183.3

Table 5. Installed location of TDR sensors.

Sensor #	Depth from Pavement Surface (m)	Layer
56A01	0.152	Base
56A02	0.305	Subgrade
56A03	0.457	
56A04	0.610	
56A05	0.762	
56A06	0.914	
56A07	1.067	
56A08	1.219	
56A09	1.524	
56A10	1.823	

A 152mm diameter solid stem auger was used for the observation piezometer/benchmark placed on the edge of the pavement shoulder adjacent to test section station 1+00. The sides of this hole stood open and installation of the piezometer hardware was performed with no complications.

Tables 5 presents the installed depths of the TDR probes, Table 6 the thermistor sensors, and Table 7 the electrodes of the resistivity probe. Table 8 presents the comparison between the computed moisture content from the TDR measurements and field measured moisture content during installation. The TDR traces obtained during installation are presented in Appendix C.

Upon completion of the installation, all wiring to the cabinet were carefully examined. The Version 1.0 of the ONSITE computer program was downloaded from the notebook computer to the onsite CR10 datalogger mounted in the cabinet. The datalogger was left to collect data overnight so that the results could be evaluated the next day.

Site Repair

The instrumentation hole was repaired by reinstalling the asphalt concrete block originally cut from the pavement. The concrete block was positioned and secured into the pavement using PC-7 epoxy. Self-leveling 888 crack sealant was used in the pavement surface temperature grove and around the edges of the block. The conduit trench was repaired by placing and compacting a WDOT supplied cold mix asphalt concrete patching material.

Table 6. Installed location of MRC thermistor sensors.

Unit	Channel Number	Depth from Pavement Surface (m)	Remarks
1	1	0.013	AC layer
	2	0.038	
	3	0.063	
2	4	0.164	Base
	5	0.242	Subgrade
	6	0.317	
	7	0.393	
	8	0.486	
	9	0.622	
	10	0.774	
	11	0.929	
	12	1.078	
	13	1.231	
	14	1.383	
	15	1.537	
	16	1.688	
	17	1.841	
	18	1.992	

Table 7. Location of electrodes of the resistivity probe.

Connector Pin Number	Electrode Number	Depth from Pavement Surface (m)
36	1	0.189
35	2	0.239
34	3	0.289
33	4	0.340
32	5	0.391
31	6	0.442
30	7	0.493
29	8	0.544
28	9	0.594
27	10	0.645
26	11	0.696
25	12	0.746
24	13	0.797
23	14	0.848
22	15	0.899
21	16	0.949
20	17	1.000
19	18	1.050
18	19	1.102
17	20	1.152
16	21	1.203
15	22	1.254
14	23	1.305
13	24	1.356
12	25	1.404
11	26	1.457
10	27	1.508
9	28	1.559
8	29	1.610
7	30	1.660
6	31	1.711
5	32	1.762
4	33	1.814
3	34	1.862
2	35	1.914
1	36	1.964

Table 8. Field measured moisture content during installation.

Sensor Number	Sensor Depth (m)	Layer	TDR Moisture Content (% by wt)	Measured Moisture[3] Content (% by wt)
56A01	0.152	Base[1]	3.79	4.87
56A02	0.305	Subgrade[2]	6.67	5.84
56A03	0.457		6.41	6.91
56A04	0.610		7.28	8.66
56A05	0.762		8.21	11.28
56A06	0.914		7.90	10.21
56A07	1.067		6.97	9.91
56A08	1.219		4.67	7.10
56A09	1.524		3.54	7.25
56A10	1.823		4.91	7.03

[1] Conversion factor = 2.24, determined from laboratory maximum dry density.
[2] Conversion factor = 1.95, determined from laboratory maximum dry density.
[3] Raw data are given in Appendix C

III. Initial Data Collection

The second day activities included initial data collection on the site and checks on functioning of the installed equipment. The activities consisted of examination of the data collected over the previous night by the Onsite datalogger, collection of TDR and electrical resistance data with the Mobile data acquisition system, manual electrical resistance and resistivity measurements, deflection testing, and elevation surveys.

Air Temperature, Subsurface Temperature, Rain-Fall Measurements

The air temperature, pavement and subsurface temperature profile, and rainfall data monitored and stored by the onsite CR10 datalogger overnight were examined. The equipment and datalogger appeared to be functioning properly. The battery voltages were checked and found to be acceptable. Raw data collected at the site are presented in Appendix D.

Figure D-1 presents a plot of the air temperature data collected from 5:00 p.m. (August 10) through 8:00 a.m. (August 11). In Figure D-2, the hourly average subsurface temperature for the first 5 sensors is plotted. It was found that at the end of installation on the first day, the data logger time was inadvertently set to 1:00 instead of 1700 hours. The datalogger interpreted this as 1:00 am instead of 5:00 pm and overnight its internal time did not pass 2400 hours when the average subsurface temperature for all 18 thermistor sensors are stored in secondary memory. Thus this data file did not contain the daily average temperatures for all 18 thermistors. A total amount of 0.1mm precipitation was recorded that night by the rain gage. This appears to be correct since the area experienced scattered showers that night.

TDR Measurements

TDR data were collected using the Mobile data acquisition system. The mobile system contains a CR10 datalogger, a battery pack, two multiplexers and a resistance multiplexer circuit board. The Version 1.0 of the Mobile program was used to collect and record the TDR wave form traces for each sensor.

Figures D-3 to D-12 show the TDR wave form traces collected with the Mobile data acquisition system for all 10 sensors.

Electrical Resistance Measurements

Electrical resistance data were collected in the automated and manual mode. The Mobile data acquisition system automatically performs two point contact resistance measurements and stores the results as measured millivolts between adjacent electrodes. The contact resistance measurements with the Mobile system appeared to be functioning properly in the field, since the numbers changed and were within the logical range of correct values. However after subsequent inspection and investigation of the Mobile unit in the office, it was found that the multiplexer board had been improperly wired and the measurements erroneous.

Manual contact resistance and resistivity measurements were performed using a Simpson Model 420D function generator, two Beckman HD-110 digital multi-meters and a manual switch board. The measured contact resistance data are plotted in Figure D-13. In Figure D-14 the 4-point electrical resistivity profile computed from 4-point measurements are plotted. The raw measurement data are given in Appendix D.

Deflection Measurements

Deflection measurement followed procedures described in the "LTPP Seasonal Monitoring Program: Instrumentation Installation and Data Collection Guidelines."

Elevation Surveys

One set of surface elevation surveys was performed following the guidelines. It was assumed the elevation of the well top was 1.000 meters. The survey results are presented in Appendix D.

IV. Summary

The instrumentation installation on test section 561007 was performed on August 10, 1993 and initial data collection on August 11, 1993. The instrumentation installed included time domain reflectometery probes for moisture content, electrical resistivity probes for frost location, thermistor probes for temperature, tipping bucket rain gage, piezometer to monitor the ground water table, and an on-site datalogger to collect and store data.

The test section is located on eastbound of U.S. Highway 16 approximately five miles east of Cody Wyoming. The pavement structure on this test section consists of 76mm asphalt concrete over an average of 152mm granular aggregate base. The subgrade is a silty sand.

A formal meeting was not held with the participating highway agency for planning of the installation activities on this site. All planning functions were handled by oral and written correspondence. This approached worked well with this agency in this circumstance. It also resulted in reduced cost to the program. This approach should be considered when circumstances dictate a high probability for success.

All equipment and instrumentation were installed with no major departures from the installation guidelines. All of the installed equipment appeared to be functioning properly. As noted in the report, the automated resistance data acquisition system did not function properly, although this was difficult to determine in the field. The malfunction was subsequently traced to a faulty wiring connection. In the future, all data acquisition systems should be thoroughly tested in the office prior to field use. In addition, a program which plots the data collected by the datalogger is also needed as a field quality control check.

APPENDIX A

Test Section Background Information

Appendix A Includes the Following Supporting Information:

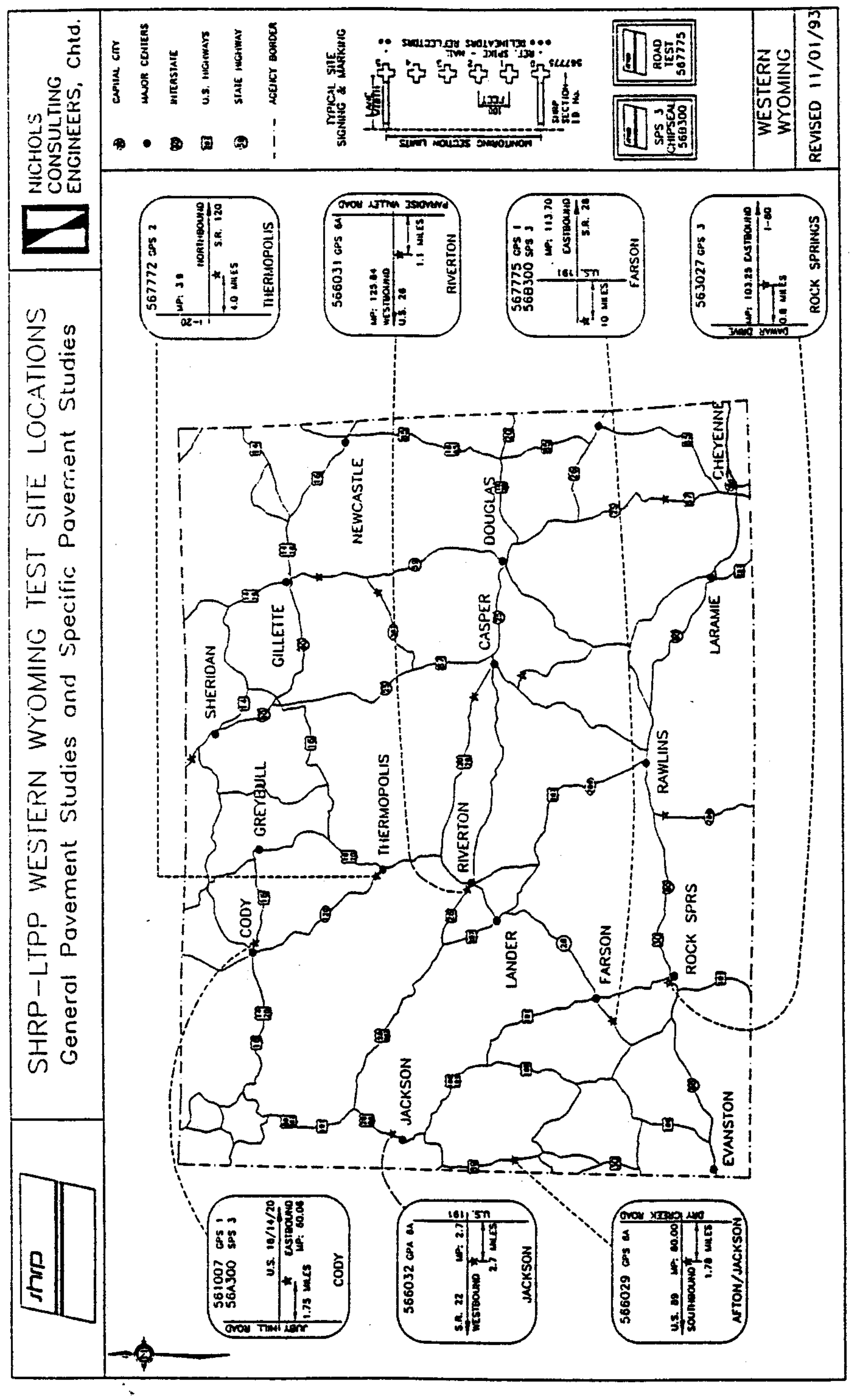


Figure A-1. Location of test site, GPS test section 561007.

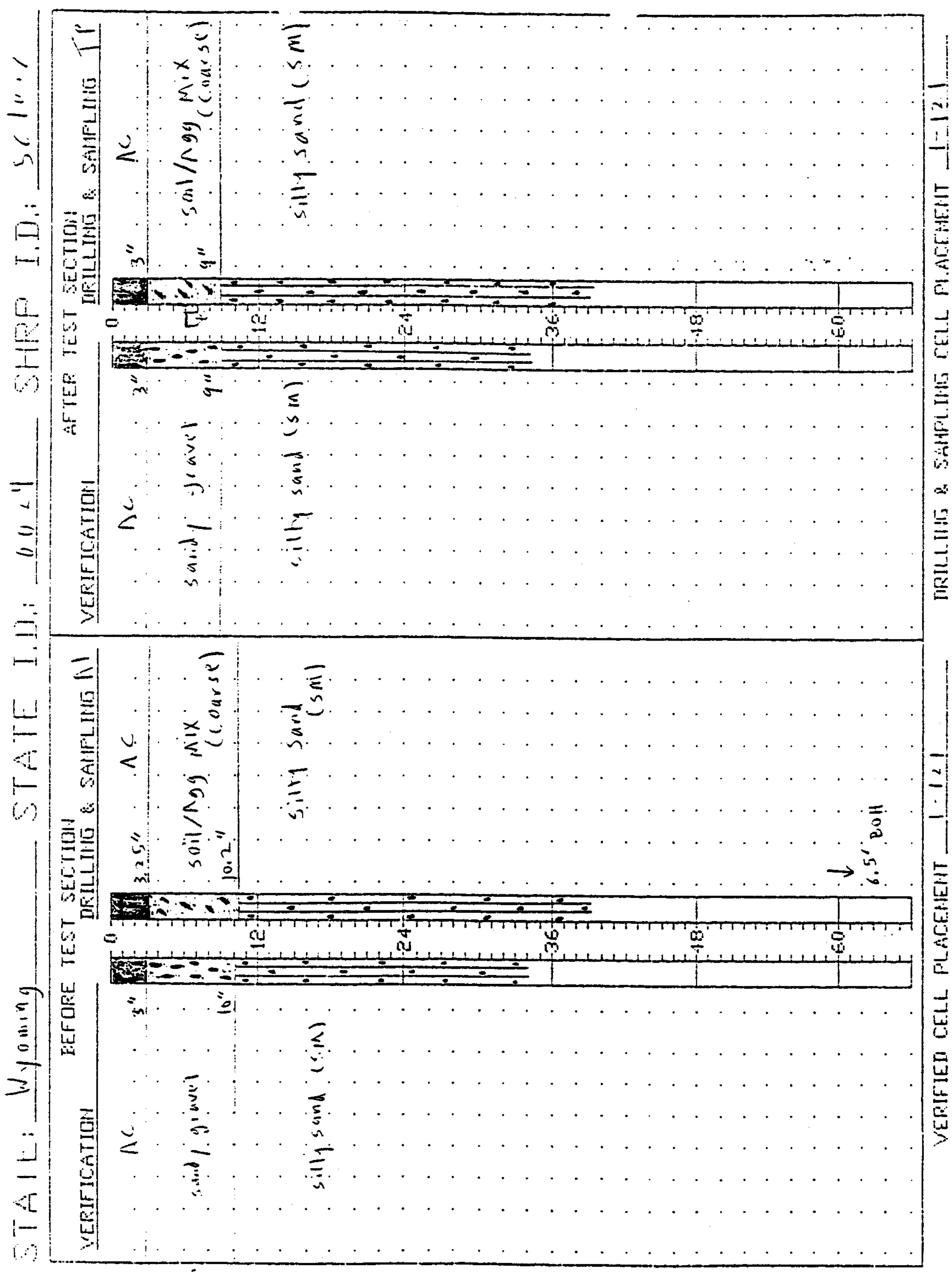


Figure A-2. Profile of test section.

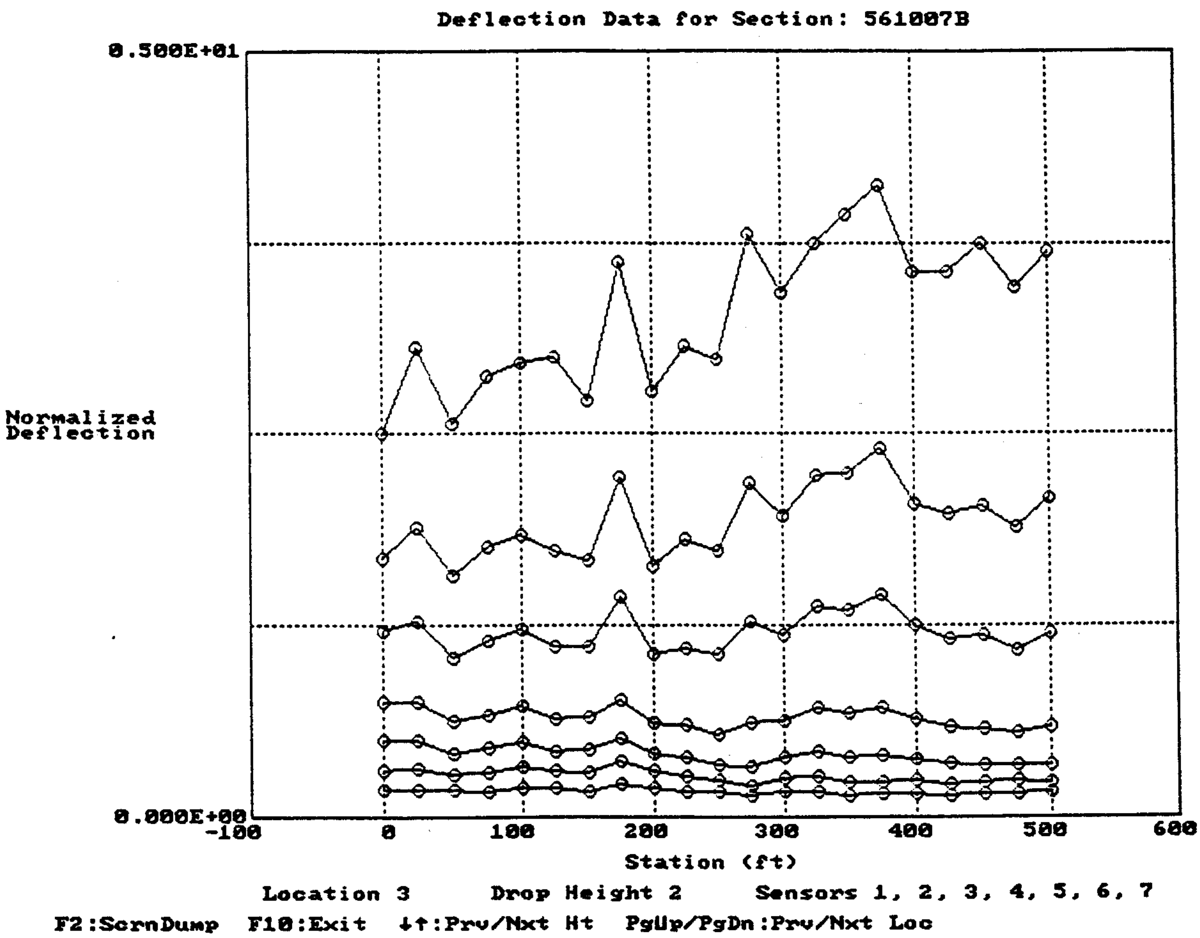


Figure A-3. Normalized deflection profile from FWDCHECK (test date 5/13/91).

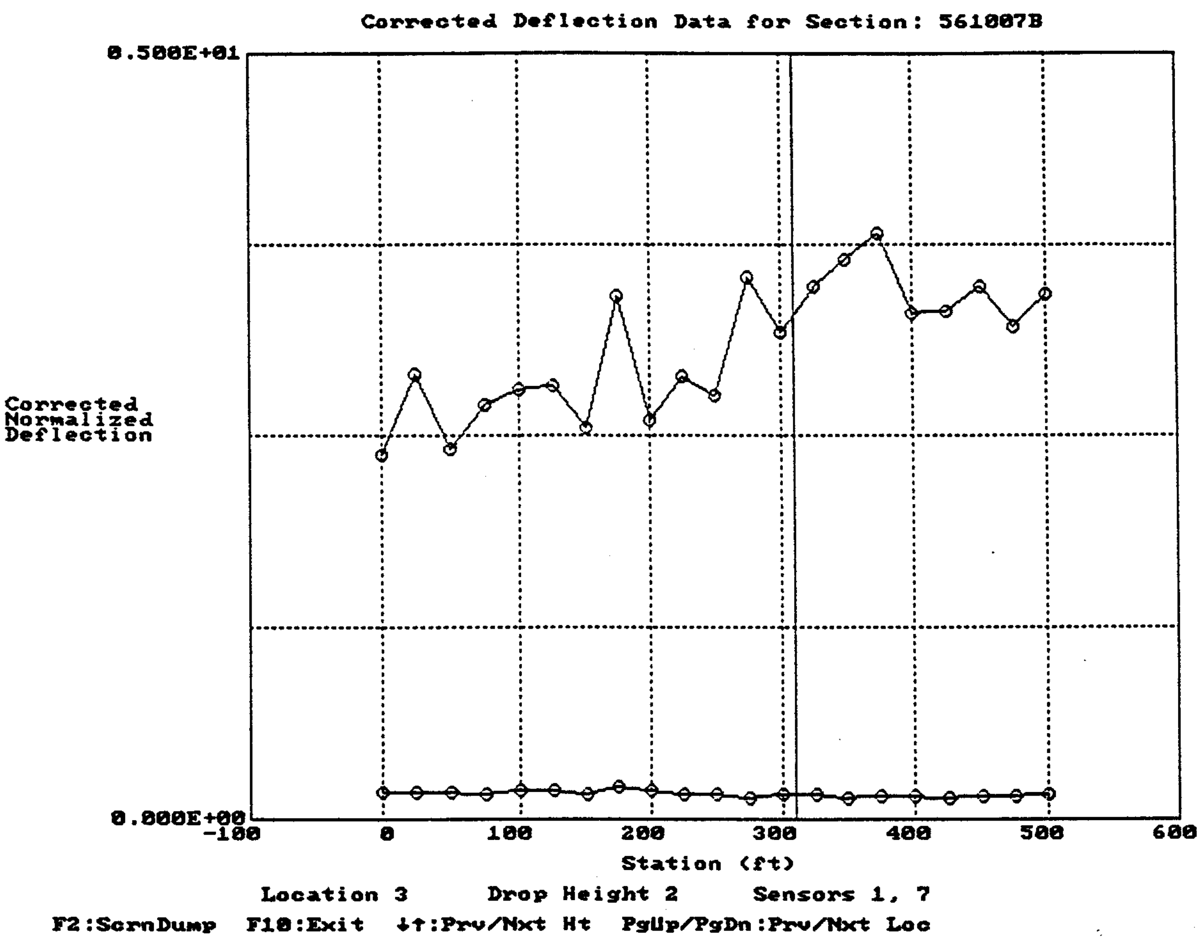


Figure A-4. Corrected normalized deflection profile from FWDCHECK.

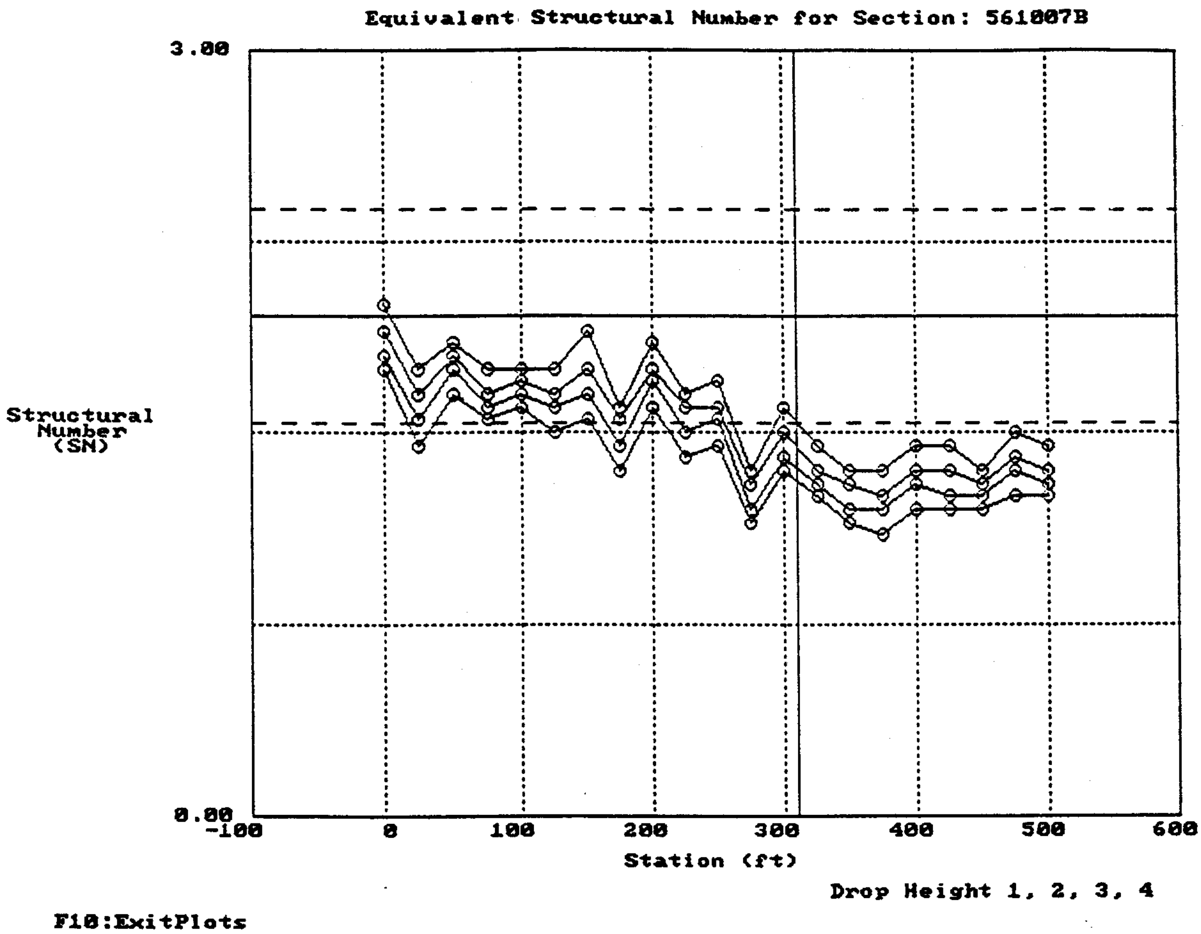


Figure A-5. Structural Number (SN) profile from FWDCHECK.

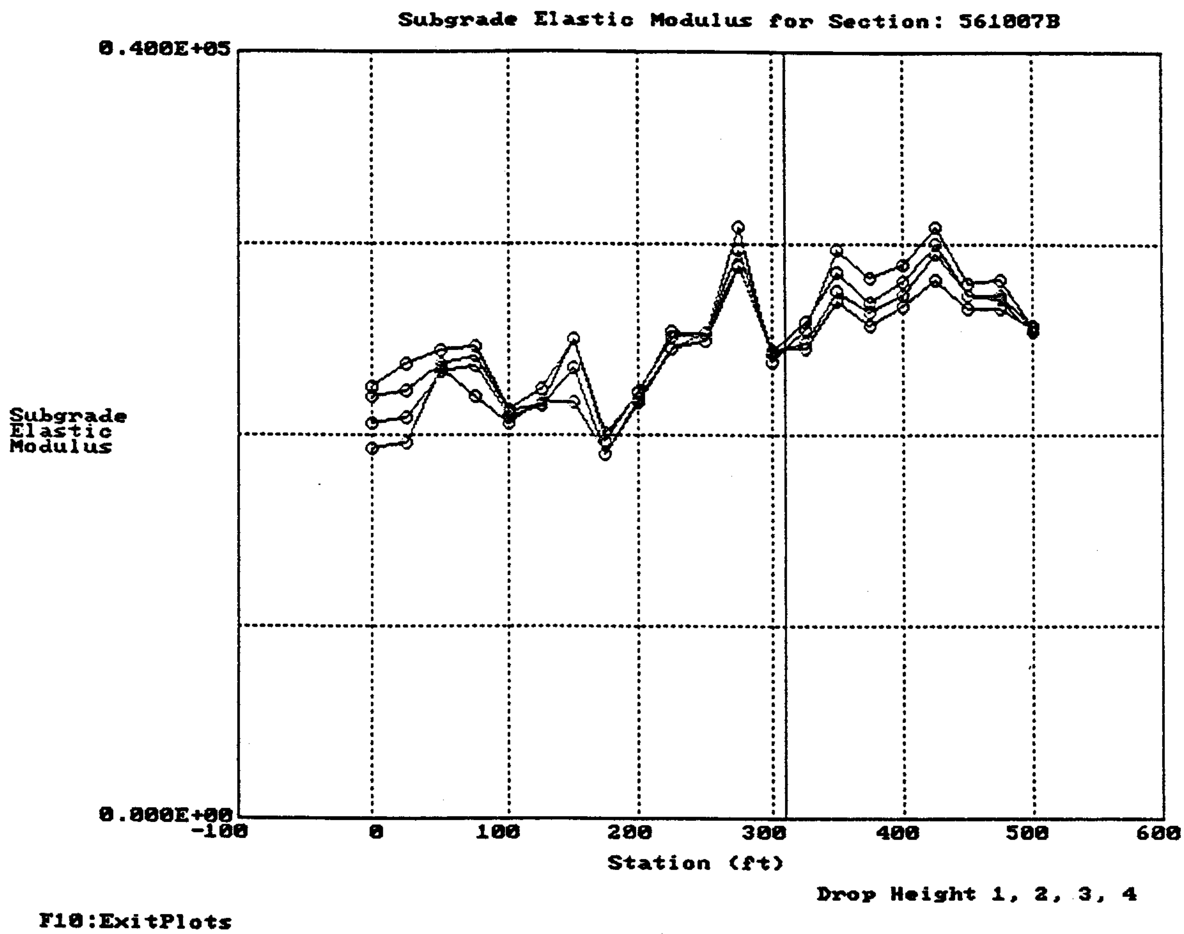


Figure A-6. Subgrade elastic modulus profile from FWDCHECK.

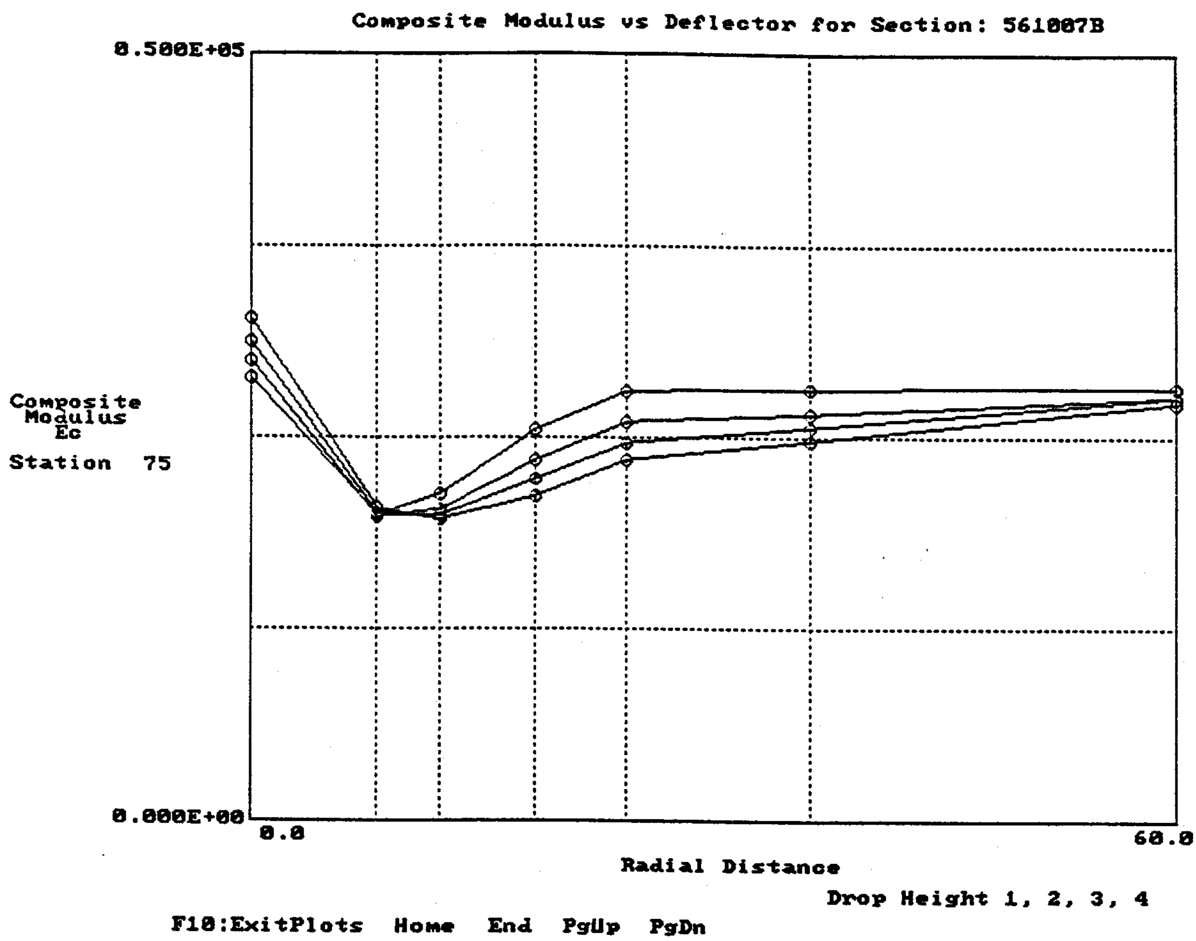


Figure A-7. Composite modulus Ec at station 75 from FWDCHECK.

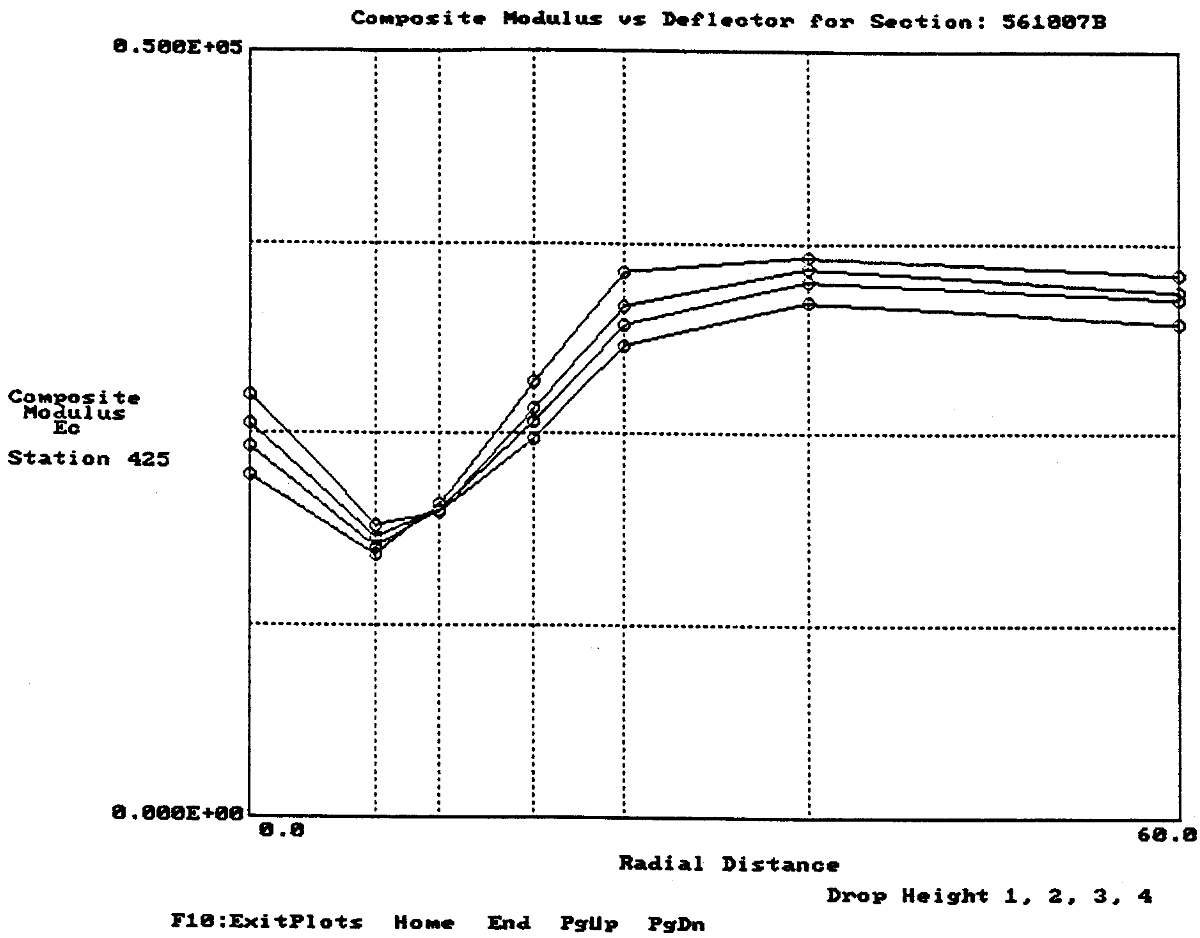


Figure A-8. Composite modulus Ec at station 425 from FWDCHECK.

APPENDIX B

Installed Instrument Information

Appendix B Includes the Following Supporting Information:

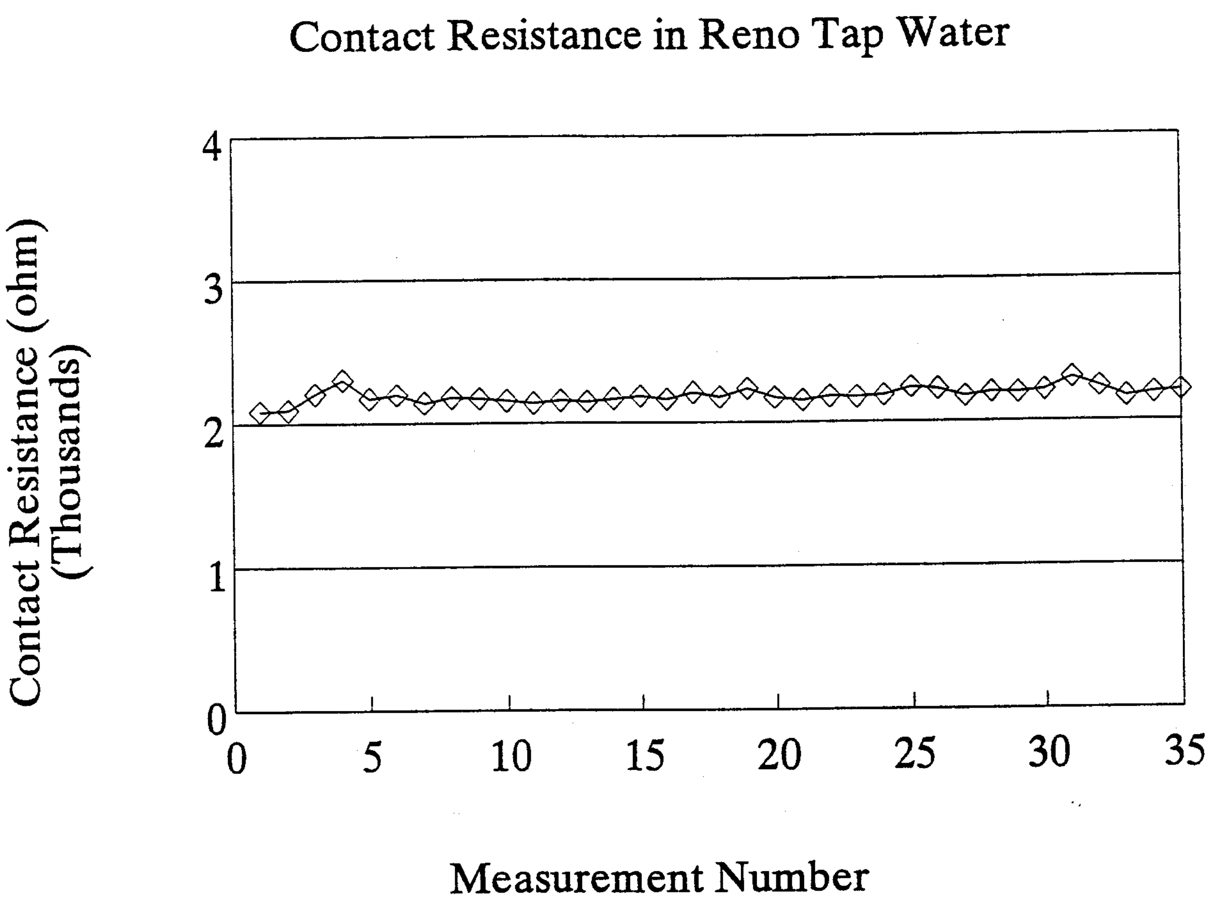


Figure B-1. Contact resistance measured in Reno tap water.

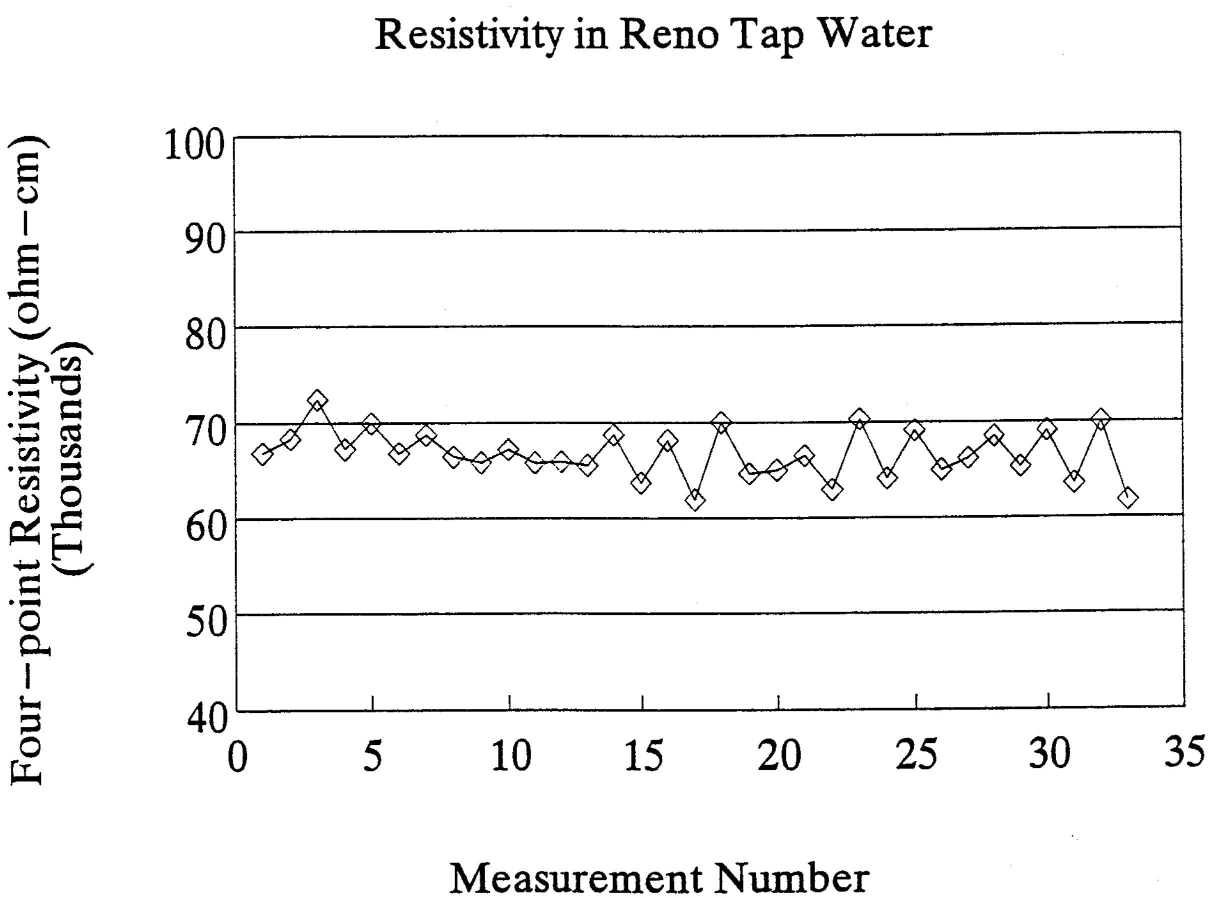


Figure B-2. Four-point resistivity measured in distilled water.

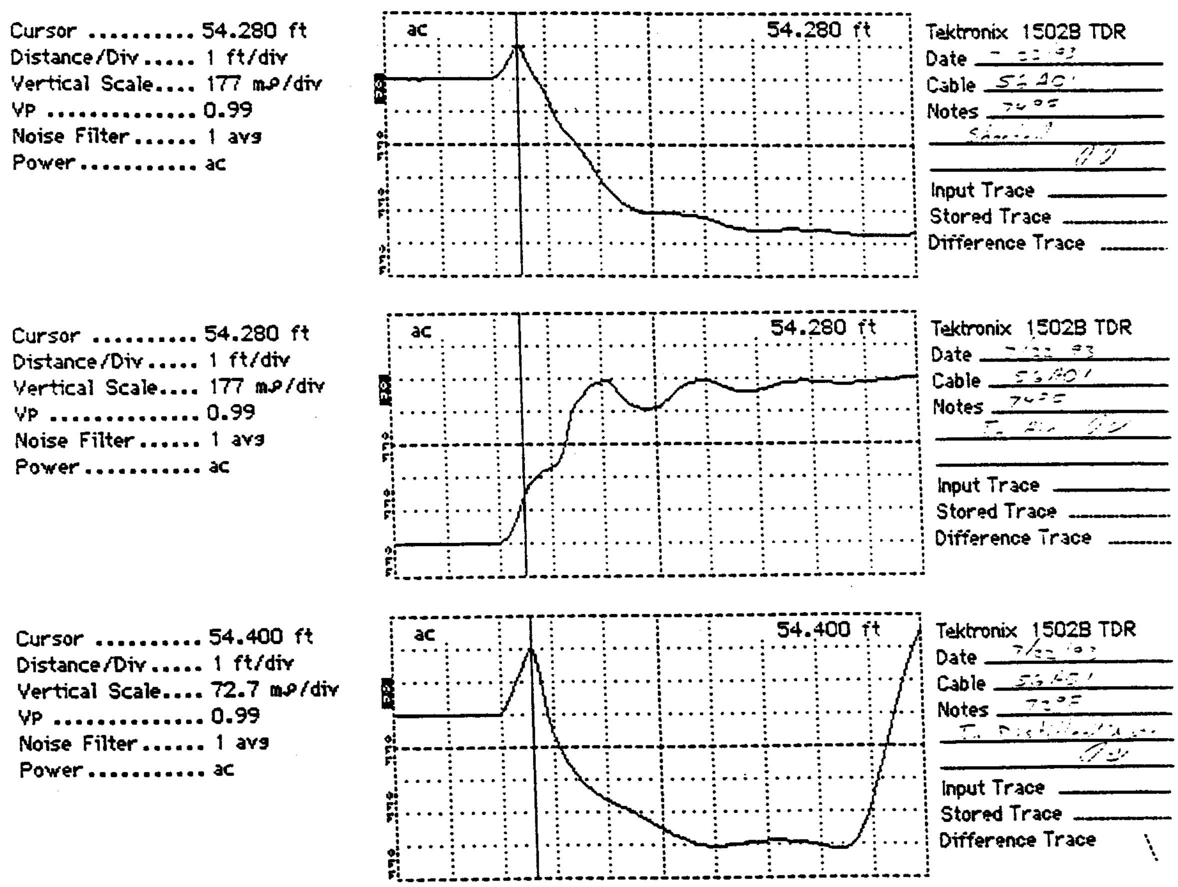
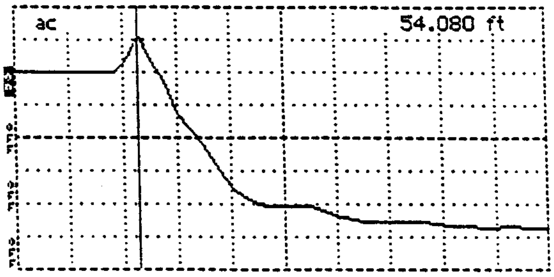


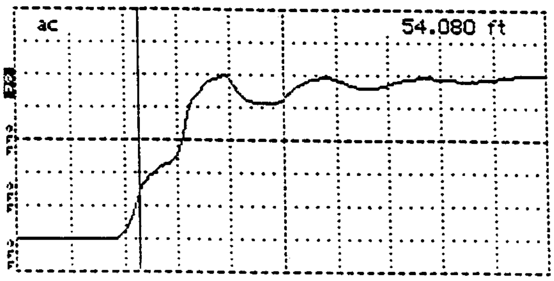
Figure B-3. TDR traces obtained during calibration.

Cursor .... 54.080 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



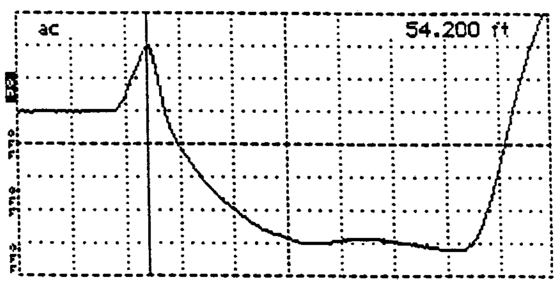
Tektronix 1502B TDR
Date
Cable
Notes
Input Trace
Stored Trace
Difference Trace

Cursor .... 54.080 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date
Cable
Notes
Input Trace
Stored Trace
Difference Trace

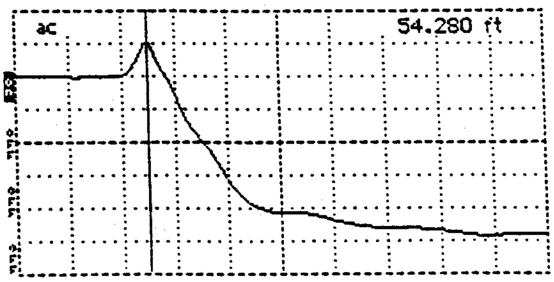
Cursor .... 54.200 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date
Cable
Notes
Input Trace
Stored Trace
Difference Trace

Figure B-3. TDR traces obtained during calibration (cont.).

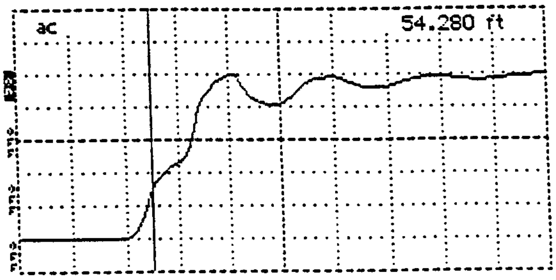
Cursor .... 54.280 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power............ ac



Tektronix 1502B TDR
Date 7/22/93
Cable
Notes

Input Trace
Stored Trace
Difference Trace

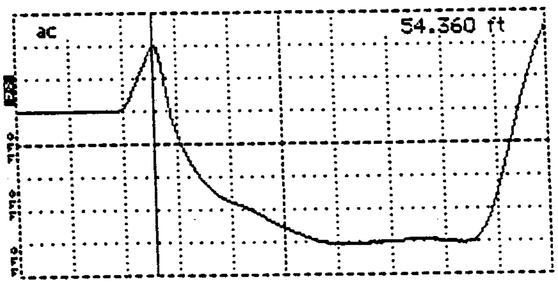
Cursor .... 54.280 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power............ ac



Tektronix 1502B TDR
Date 7/22/93
Cable
Notes

Input Trace
Stored Trace
Difference Trace

Cursor .... 54.360 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power............ ac

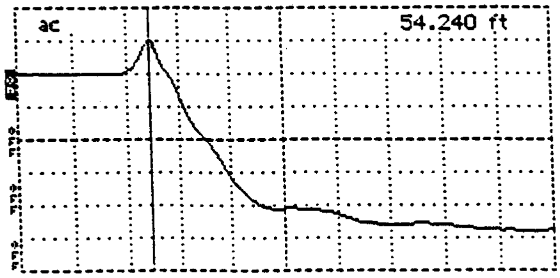


Tektronix 1502B TDR
Date 7/22/93
Cable
Notes

Input Trace
Stored Trace
Difference Trace

Figure B-3. TDR traces obtained during calibration (cont.).

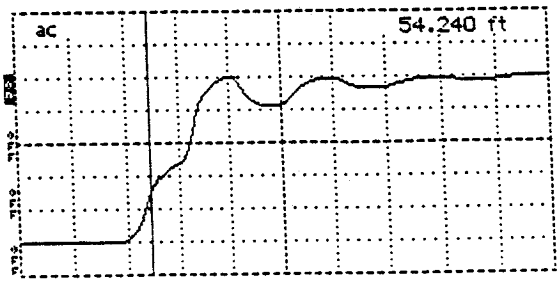
Cursor .... 54.240 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date ______
Cable ______
Notes ______

Input Trace ______
Stored Trace ______
Difference Trace ______

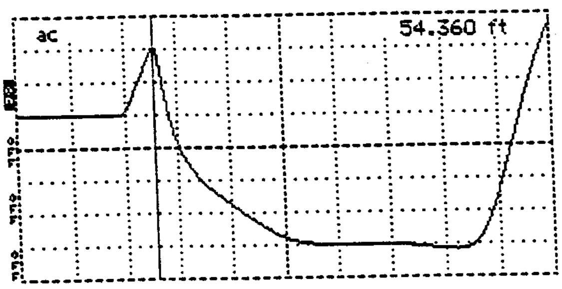
Cursor .... 54.240 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date ______
Cable ______
Notes ______

Input Trace ______
Stored Trace ______
Difference Trace ______

Cursor .... 54.360 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac

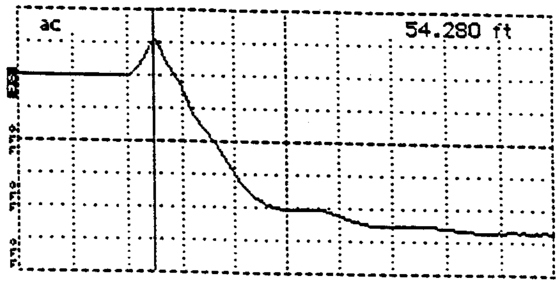


Tektronix 1502B TDR
Date ______
Cable ______
Notes ______

Input Trace ______
Stored Trace ______
Difference Trace ______

Figure B-3. TDR traces obtained during calibration (cont.).

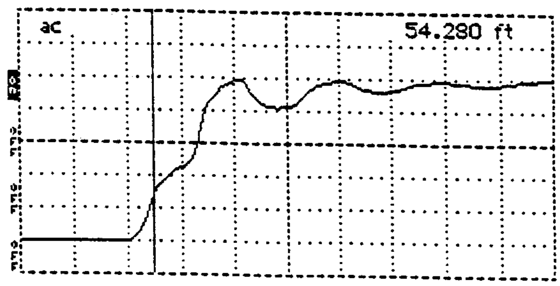
Cursor .... 54.280 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date ______
Cable ______
Notes ______

Input Trace ______
Stored Trace ______
Difference Trace ______

Cursor .... 54.280 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date ______
Cable ______
Notes ______

Input Trace ______
Stored Trace ______
Difference Trace ______

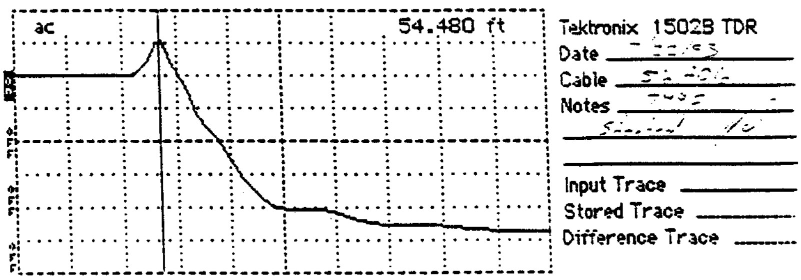
Cursor .... 54.400 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac

Tektronix 1502B TDR
Date ______
Cable ______
Notes ______

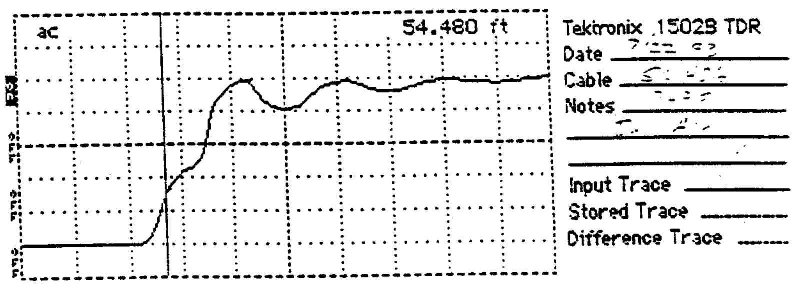
Input Trace ______
Stored Trace ______
Difference Trace ______

Figure B-3. TDR traces obtained during calibration (cont.).

Cursor .... 54.480 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power .... ac



Cursor .... 54.480 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power .... ac



Cursor .... 54.600 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power .... ac

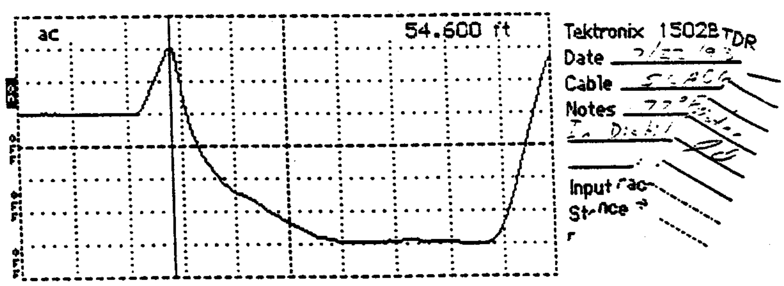


Figure B-3. TDR traces obtained during calibration (cont.).

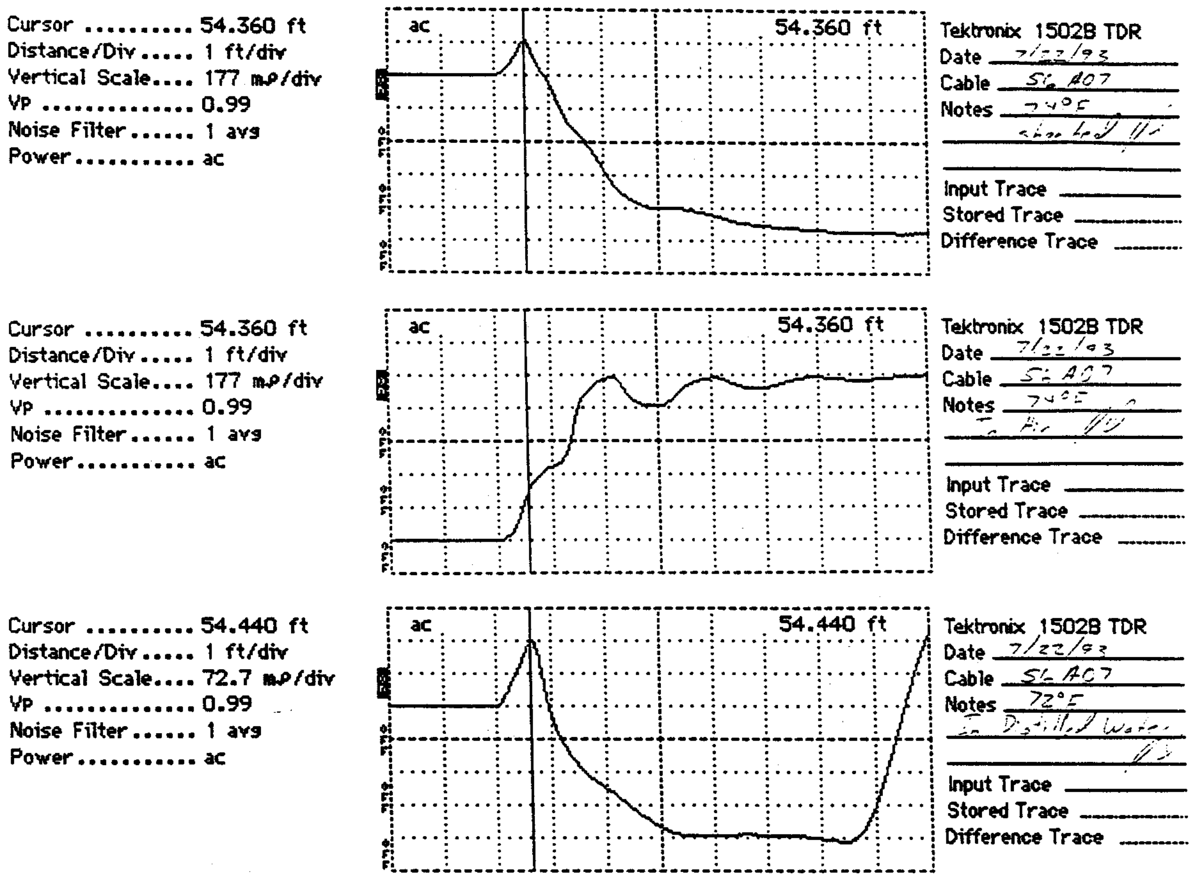
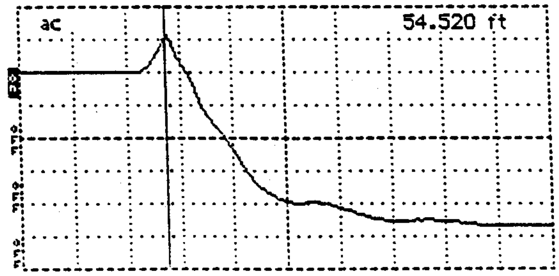


Figure B-3. TDR traces obtained during calibration (cont.).

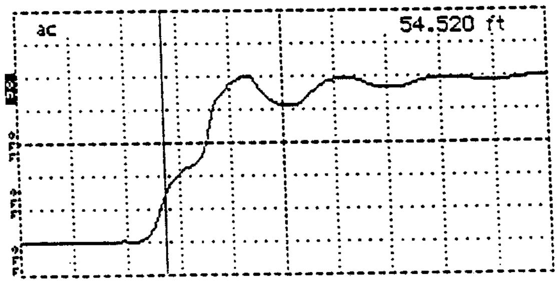
Cursor .... 54.520 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date
Cable
Notes

Input Trace
Stored Trace
Difference Trace

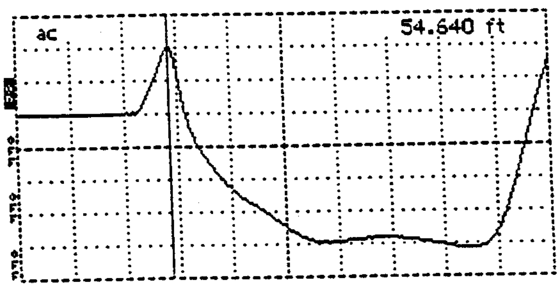
Cursor .... 54.520 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date
Cable
Notes

Input Trace
Stored Trace
Difference Trace

Cursor .... 54.640 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac

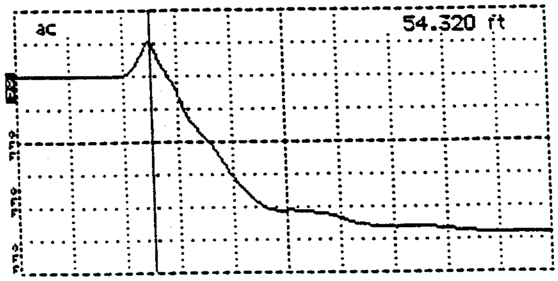


Tektronix 1502B TDR
Date
Cable
Notes

Input Trace
Stored Trace
Difference Trace

Figure B-3. TDR traces obtained during calibration (cont.).

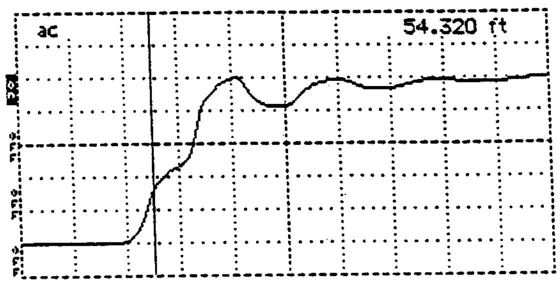
Cursor .... 54.320 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter ...... 1 avg
Power .... ac



Tektronix 1502B TDR
Date [illegible]
Cable [illegible]
Notes [illegible]

Input Trace
Stored Trace
Difference Trace

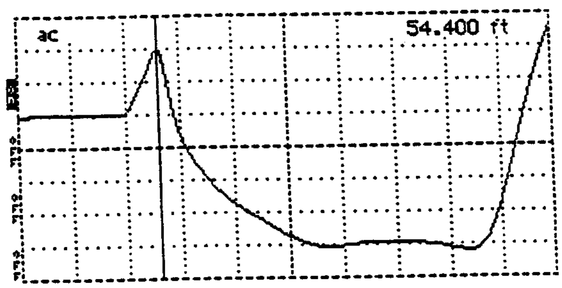
Cursor .... 54.320 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter ...... 1 avg
Power .... ac



Tektronix 1502B TDR
Date [illegible]
Cable [illegible]
Notes [illegible]

Input Trace
Stored Trace
Difference Trace

Cursor .... 54.400 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
VP 0.99
Noise Filter ...... 1 avg
Power .... ac

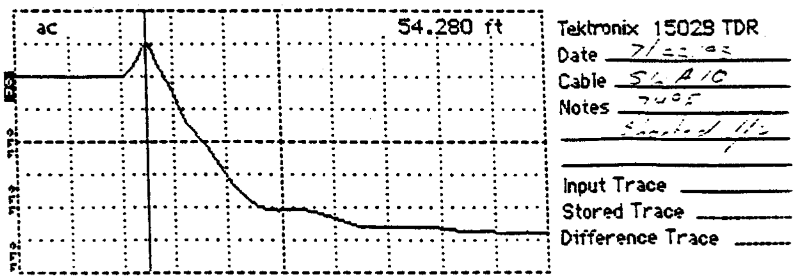


Tektronix 1502B TDR
Date [illegible]
Cable [illegible]
Notes [illegible]

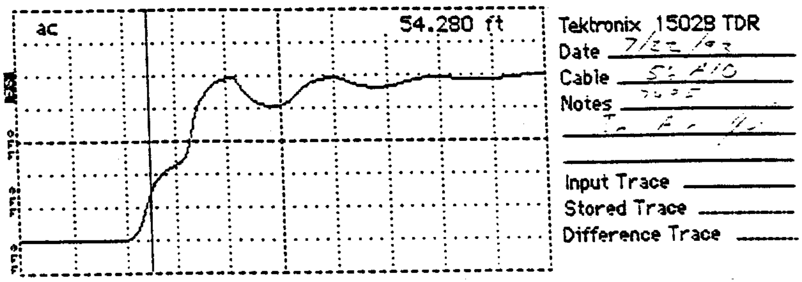
Input Trace
Stored Trace
Difference Trace

Figure B-3. TDR traces obtained during calibration (cont.).

Cursor .... 54.280 ft
Distance/Div..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



Cursor .... 54.280 ft
Distance/Div..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



Cursor .... 54.400 ft
Distance/Div..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac

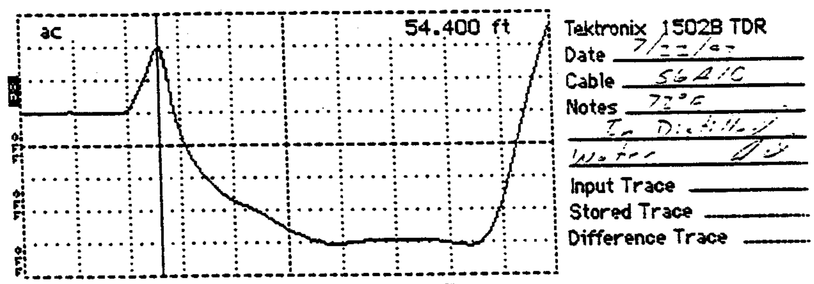


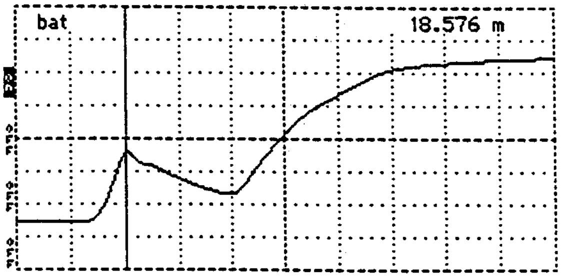
Figure B-3. TDR traces obtained during calibration (cont.).

APPENDIX C

Supporting Instrumentation Installation Information

Appendix C Includes the Following Supporting Information:

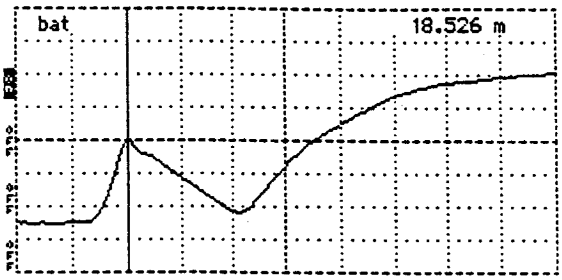
Cursor .... 18.576 m
Distance/Div ..... .25 m/div
Vertical Scale.... 100 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... bat



Tektronix 1502B TDR
Date 8/10/93
Cable #1
Notes Site 561007

Input Trace
Stored Trace
Difference Trace

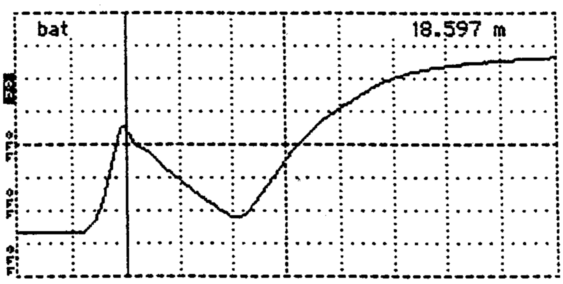
Cursor .... 18.526 m
Distance/Div ..... .25 m/div
Vertical Scale.... 81.6 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... bat



Tektronix 1502B TDR
Date 8/10/93
Cable #2
Notes Site 561007

Input Trace
Stored Trace
Difference Trace

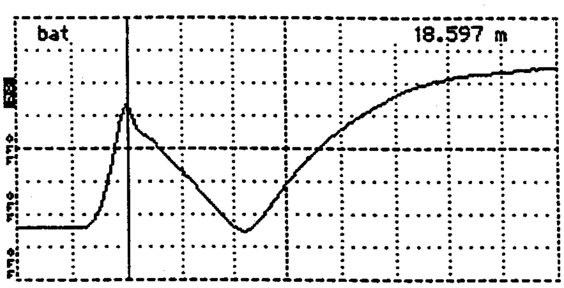
Cursor .... 18.597 m
Distance/Div ..... .25 m/div
Vertical Scale.... 64.8 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... bat



Tektronix 1502B TDR
Date 8/10/93
Cable #3
Notes Site 561007

Input Trace
Stored Trace
Difference Trace

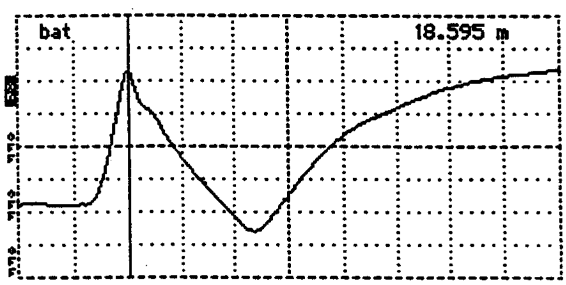
Cursor .... 18.597 m
Distance/Div ..... .25 m/div
Vertical Scale.... 54.5 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... bat



Tektronix 1502B TDR
Date 8/10/93
Cable #4
Notes Site 561007

Input Trace
Stored Trace
Difference Trace

Cursor .... 18.595 m
Distance/Div ..... .25 m/div
Vertical Scale.... 48.6 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... bat

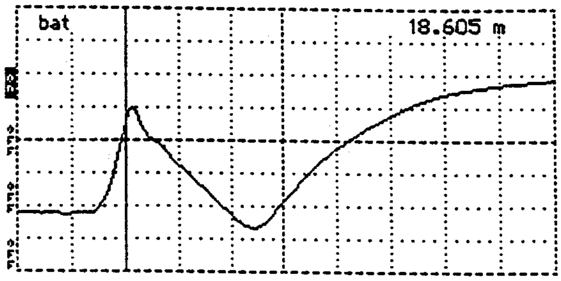


Tektronix 1502B TDR
Date 8/10/93
Cable #5
Notes Site 561007

Input Trace
Stored Trace
Difference Trace

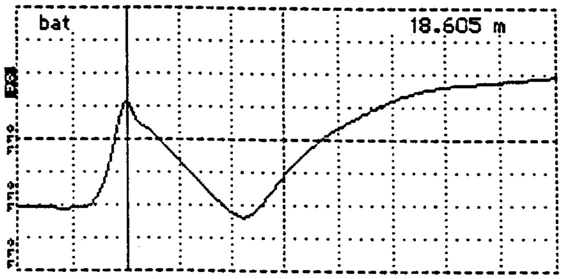
Figure C-1. TDR traces measured during installation.

Cursor .... 18.605 m
Distance/Div ..... .25 m/div
Vertical Scale.... 61.2 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... bat



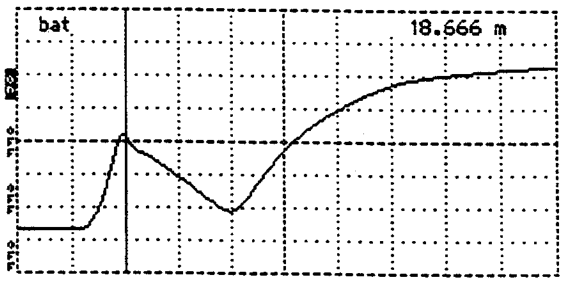
Tektronix 1502B TDR
Date 8/10/93
Cable #6
Notes Site 561007
Input Trace
Stored Trace
Difference Trace

Cursor .... 18.605 m
Distance/Div ..... .25 m/div
Vertical Scale.... 61.2 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... bat



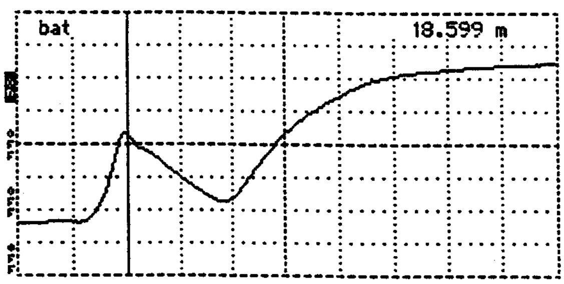
Tektronix 1502B TDR
Date 8/10/93
Cable #7
Notes Site 561007
Input Trace
Stored Trace
Difference Trace

Cursor .... 18.666 m
Distance/Div ..... .25 m/div
Vertical Scale.... 70.6 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... bat



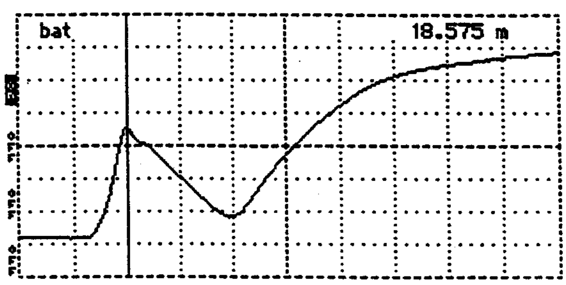
Tektronix 1502B TDR
Date 8/10/93
Cable #8
Notes Site 561007
Input Trace
Stored Trace
Difference Trace

Cursor .... 18.599 m
Distance/Div ..... .25 m/div
Vertical Scale.... 77.0 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... bat



Tektronix 1502B TDR
Date 8/10/93
Cable #9
Notes Site 561007
Input Trace
Stored Trace
Difference Trace

Cursor .... 18.575 m
Distance/Div ..... .25 m/div
Vertical Scale.... 64.8 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... bat



Tektronix 1502B TDR
Date 3/10/93
Cable #10
Notes Site 561007
Input Trace
Stored Trace
Difference Trace

Figure C-1. TDR traces measured during installation (cont.).

LTPP Seasonal Monitoring Study Moisture Contents (%)	* State Code [56] * Test Section Number [1007]

Personnel : Jason M. Dietz
Date : 8/10/93
Start Time : 12:30 PM
Finish Time : 2:00 PM
Surface Type : Asphalt Concrete
Weather Conditions : Clear 26.7°C
Unusual Conditions : None

TDR Probe #	Moisture Content (%)
10	7.03
9	7.25
8	7.10
7	9.91
6	10.21
5	11.28
4	8.66
3	6.91
2	5.84
1	4.87

Figure C-2. Field measured moisture content.

APPENDIX D

Initial Data Collection

Appendix D Includes the Following Supporting Information:

Table D-1	Raw data from the onsite datalogger during initial data collection
Figure D-1	Measured air temperature during initial data collection
Figure D-2	Measured hourly average subsurface temperature for the first 5 sensors during initial data collection
Fig. D-3 - 12	TDR traces measured with the mobile system during initial data collection
Figure D-13	Manually collected contact resistance
Figure D-14	Manually collected 4-point resistivity
Table D-2	Contact resistance measurement data sheet
Table D-3	Four-point resistivity measurement data sheet
Table D-4	Surface elevation measurement data sheet

Table D-1 Data fron the onsite datalogger during initial data collection, August 10-11, 1993

```
4,0,100,27.16,0
5,0,100,39.79,37.86,34.75,28.68,26.54
4,0,200,26.89,0
5,0,200,38.03,37.25,35.15,29.4,27.06
4,0,300,25.35,0
5,0,300,33.77,34.38,33.88,29.98,27.59
4,0,400,23.22,0
5,0,400,30.12,31.16,31.69,30.14,28.02
4,0,500,22.47,0
5,0,500,27.76,28.85,29.79,29.9,28.25
4,0,600,21.94,0
5,0,600,26.36,27.36,28.35,29.4,28.3
6,0,601,214.4,-249.3,-701,-1143,-1568,-1914,-2131,-2246,-2300,-2323,-2334,-2338,-2339,-2339,-2340,-2338,-2342,-2340,-2338,-2338,-2338,-2339,-2340,-2342,-2341,-234
0,-2338,-2338,-2340,-2338,-2338,-2336,-2336,-2338,-2338
4,0,700,21.67,0
5,0,700,24.93,26.03,27.15,28.82,28.2
4,0,800,21.96,0
5,0,800,23.98,25.01,26.08,28.23,28
4,0,900,20.04,0
5,0,900,22.79,23.96,25.15,27.66,27.75
4,0,1000,19.59,0
5,0,1000,21.67,22.85,24.13,27.1,27.47
4,0,1100,19.12,0
5,0,1100,20.97,22.08,23.32,26.54,27.17
4,0,1200,18.22,0
5,0,1200,20.37,21.47,22.66,25.98,26.85
6,0,1201,-459.2,-927,-1381,-1796,-2089,-2250,-2328,-2360,-2375,-2381,-2384,-2385,-2388,-2390,-2390,-2389,-2389,-2389,-2389,-2387,-2386,-2387,-2388,-2389,-2387,-23
88,-2386,-2385,-2387,-2387,-2386,-2387,-2386,-2387,-2386
4,0,1300,15.39,0
5,0,1300,19.23,20.49,21.86,25.48,26.52
4,0,1400,15.82,0
5,0,1400,18.89,19.91,21.14,24.97,26.19
4,0,1500,16.55,0
5,0,1500,19.69,20.3,21.09,24.49,25.86
4,0,1600,16.36,.1
5,0,1600,19.49,20.29,21.08,24.12,25.53
```

Note: The time 100 was 1700 on August 10, 1993.

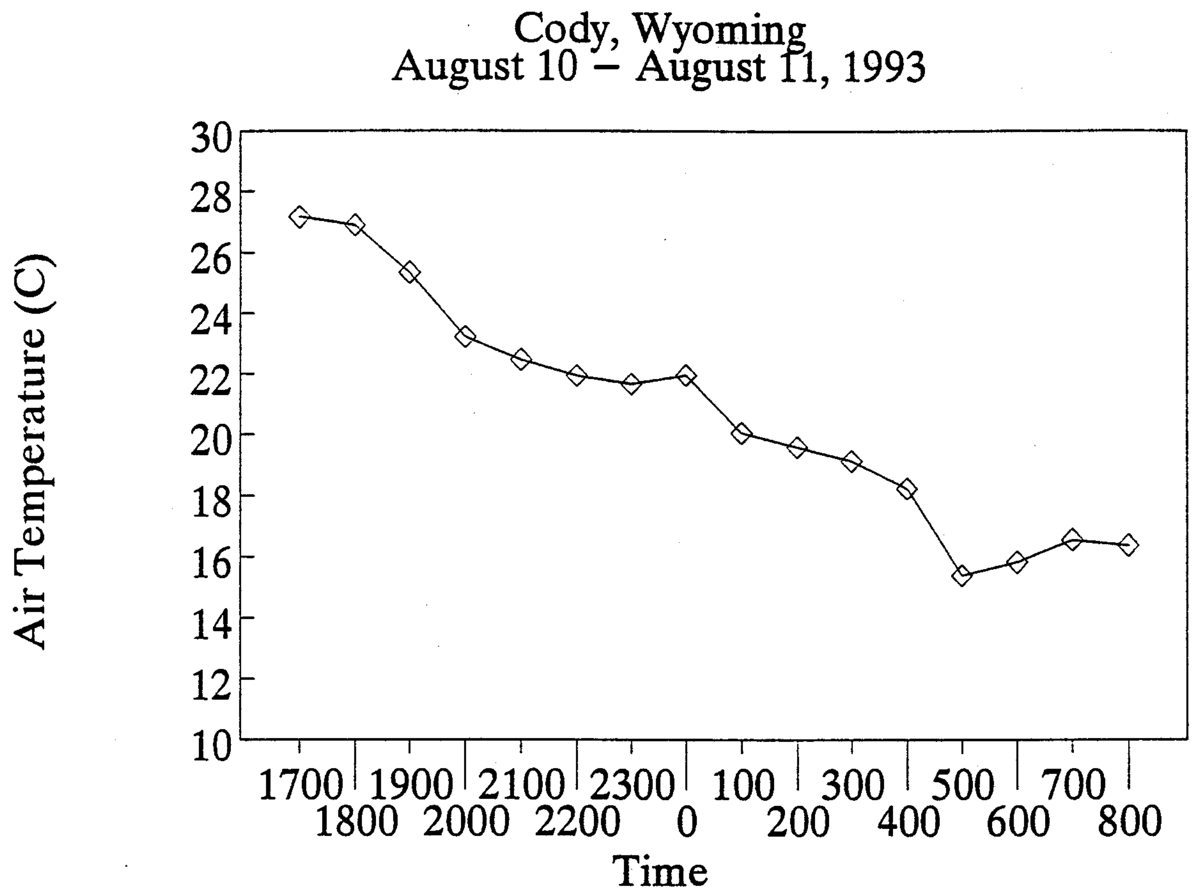


Figure D-1. Measured air temperature during initial data collection.

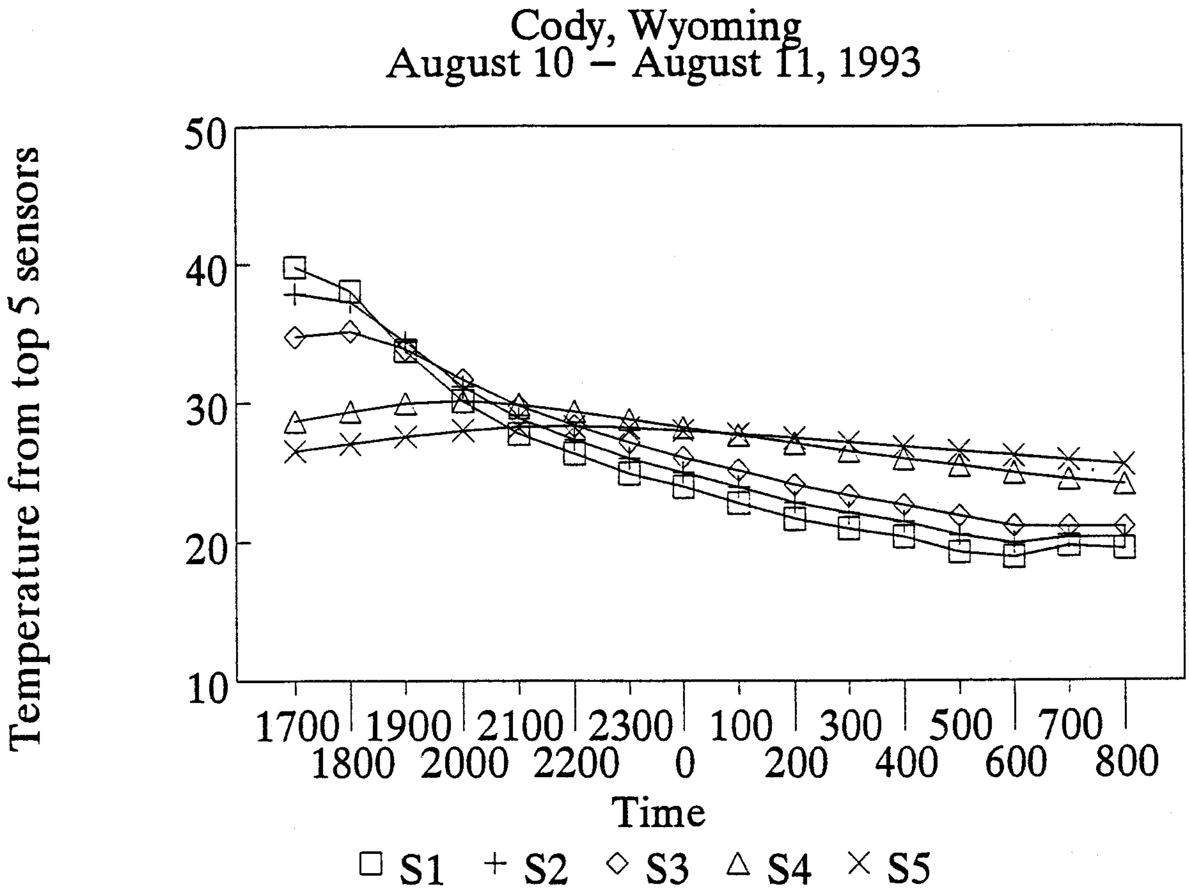


Figure D-2. Measured hourly average subsurface temperature for the first 5 sensors during initial data collection.

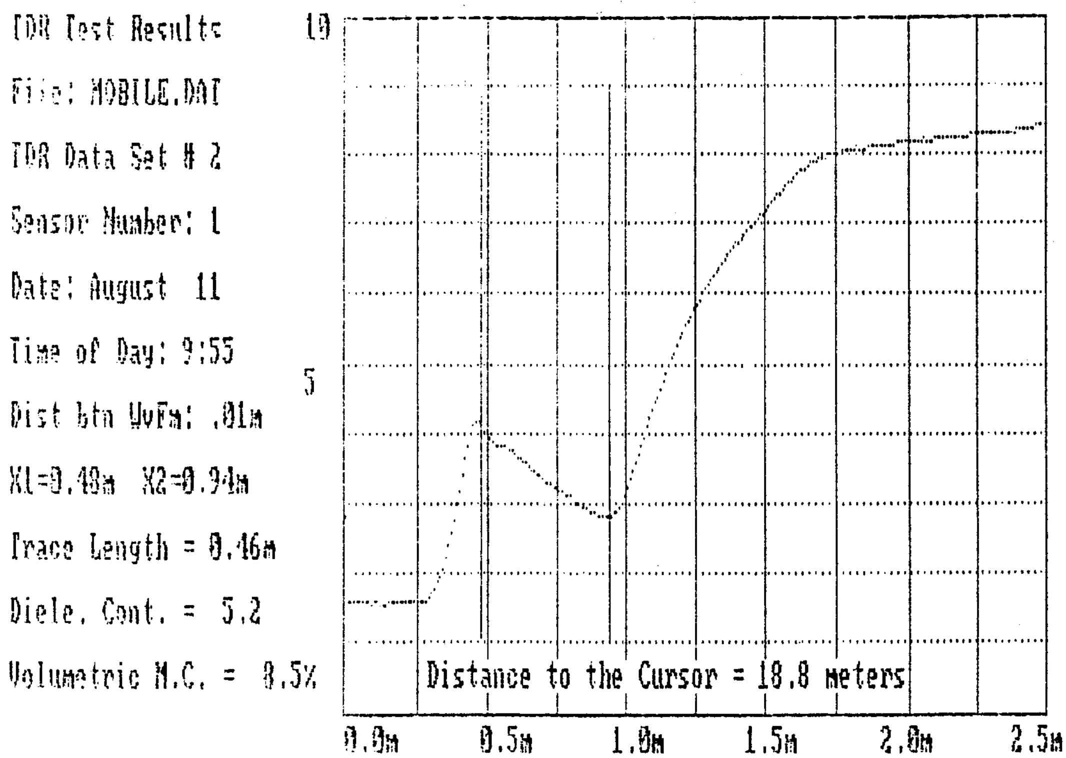


Figure D-3. Trace from TDR sensor 1.

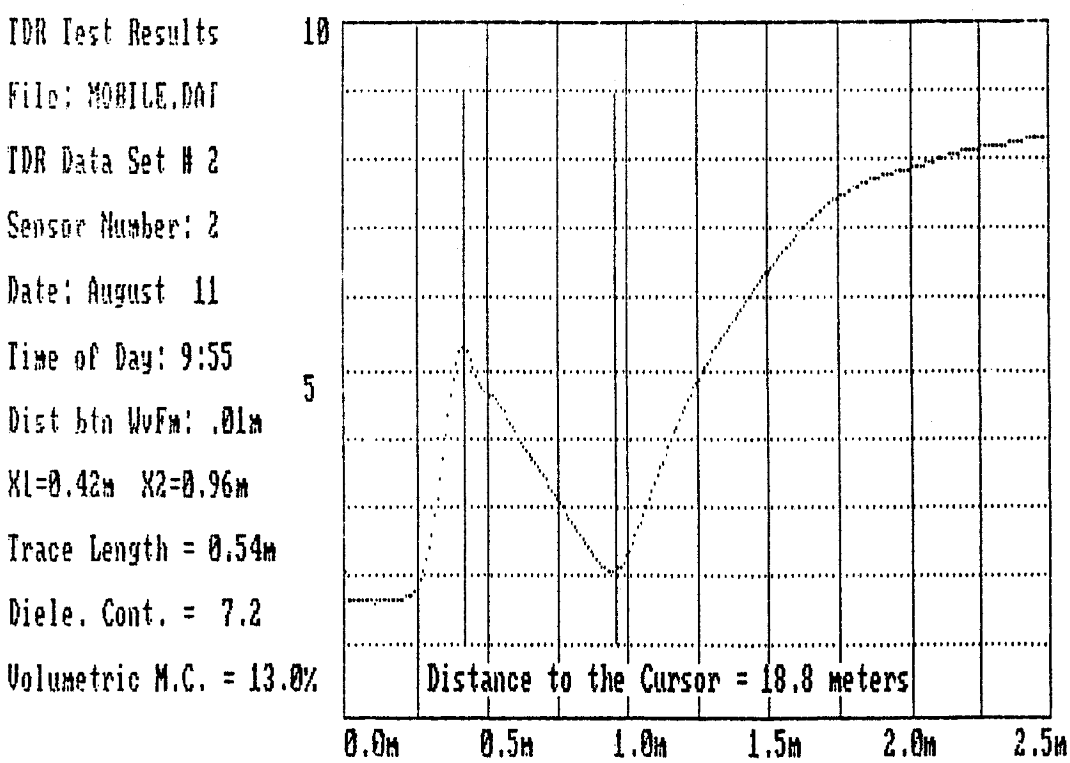


Figure D-4. Trace from TDR sensor 2.

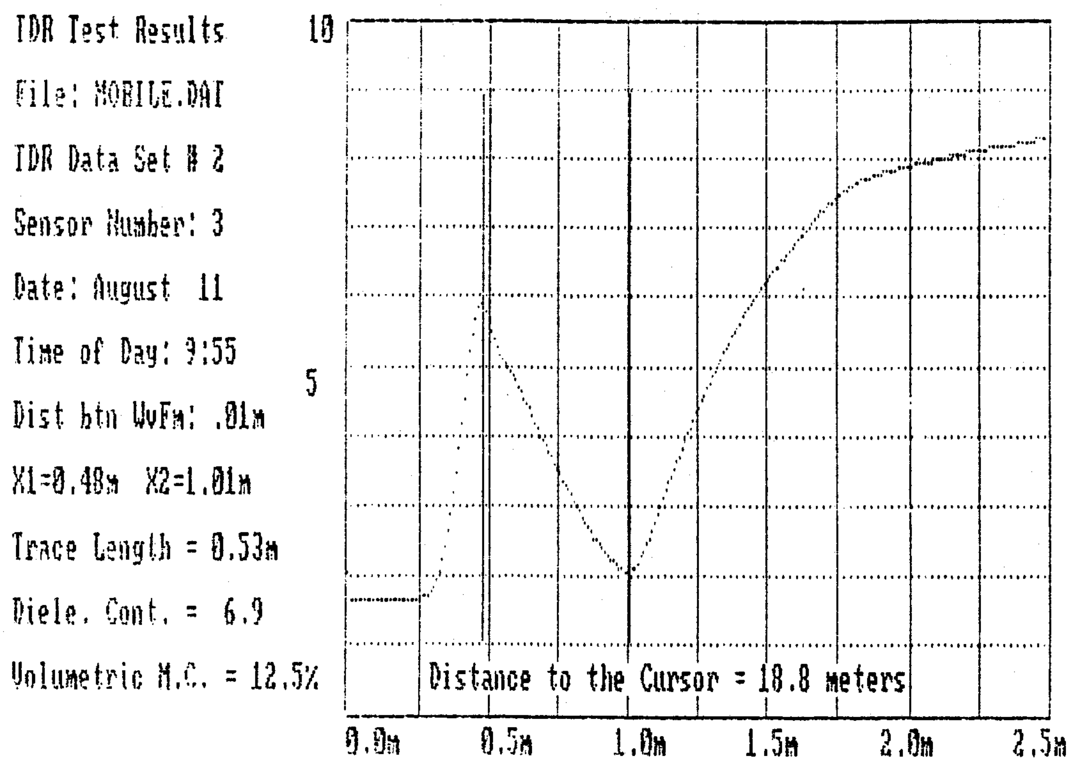


Figure D-5. Trace from TDR sensor 3.

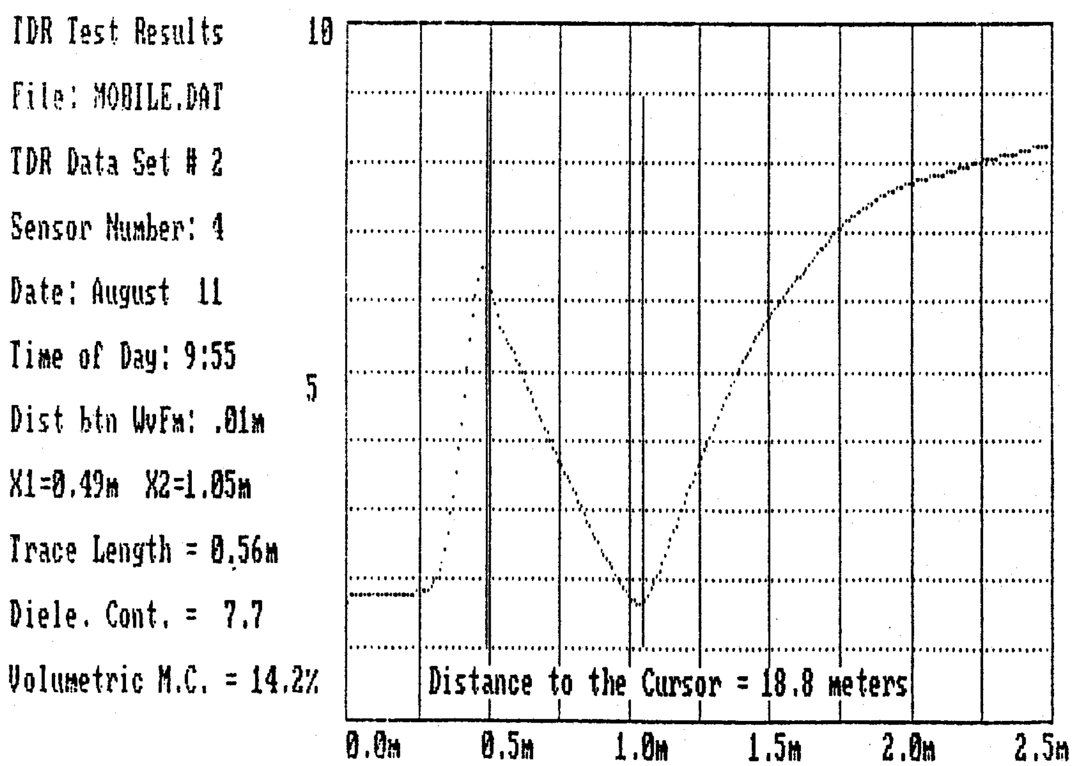


Figure D-6. Trace from TDR sensor 4.

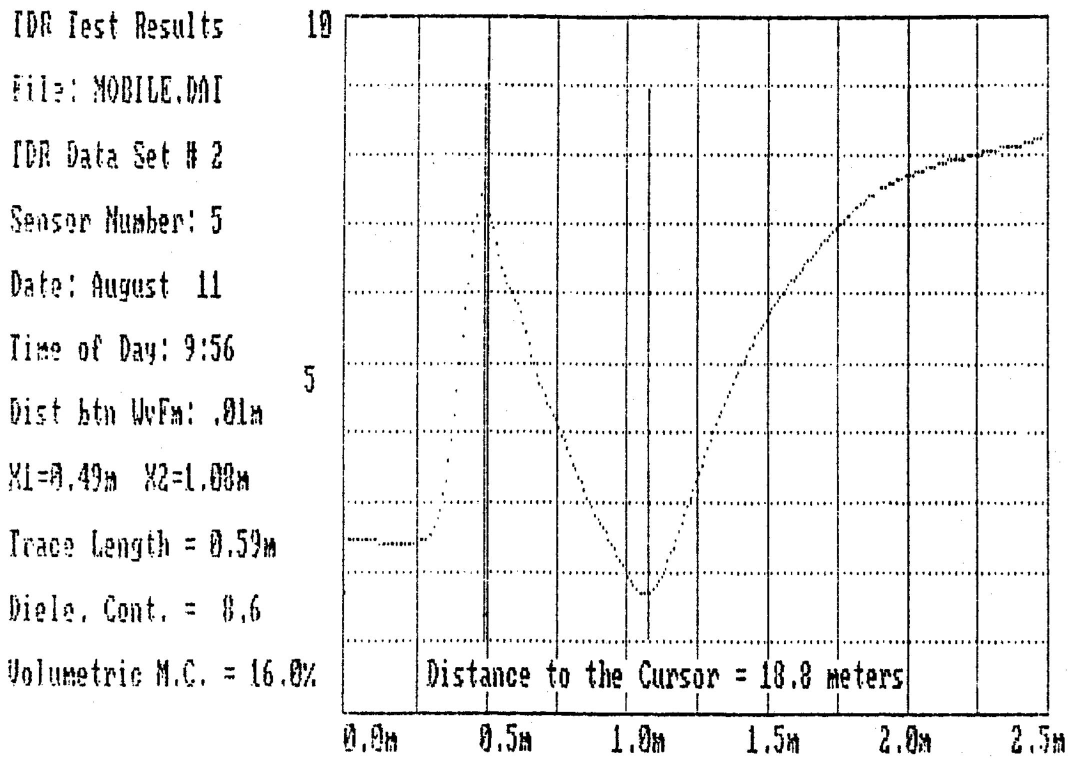


Figure D-7. Trace from TDR sensor 5.

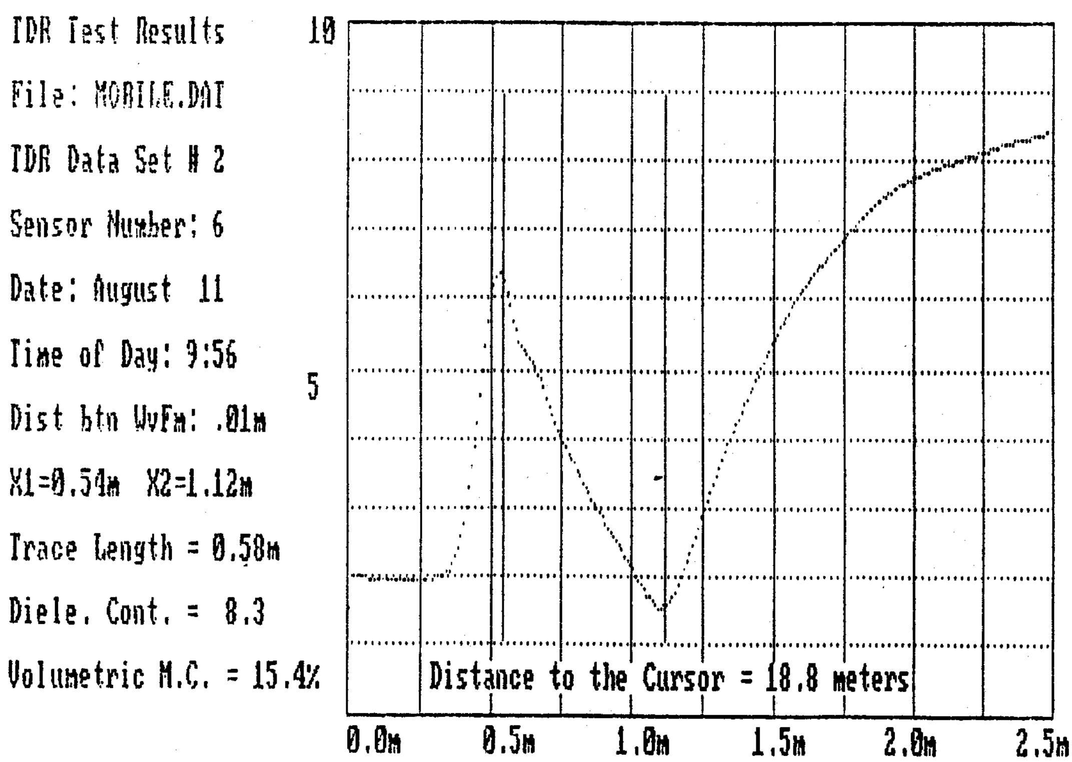


Figure D-8. Trace from TDR sensor 6.

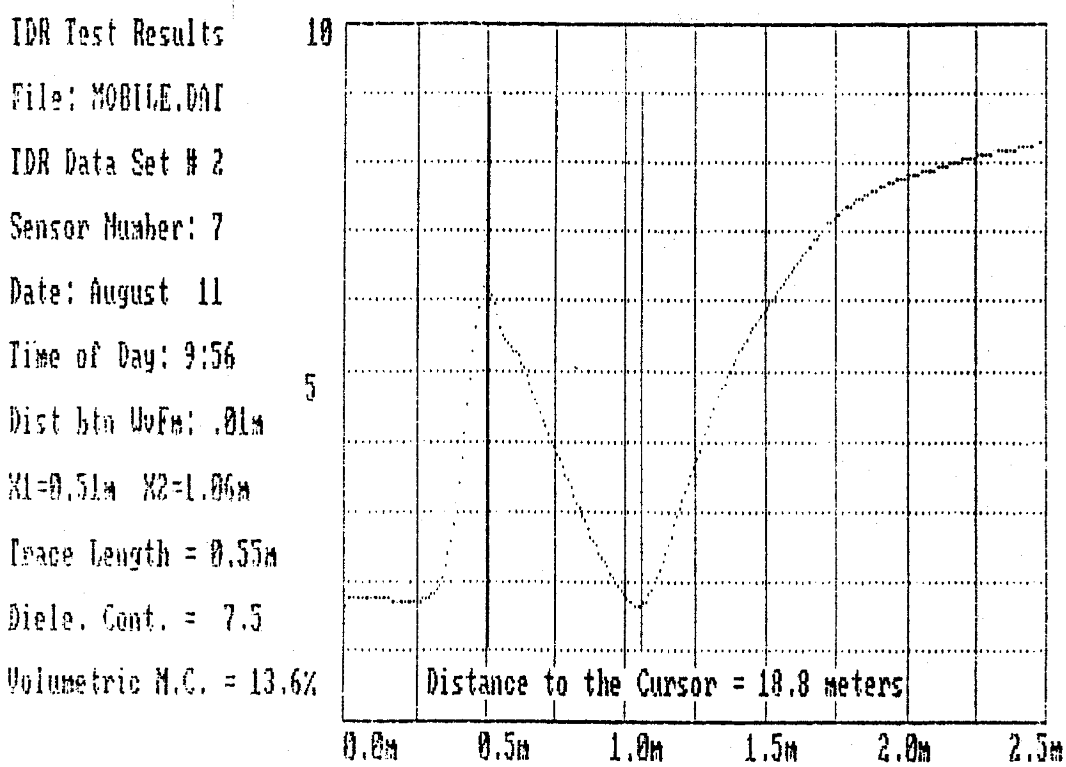


Figure D-9. Trace from TDR sensor 7.

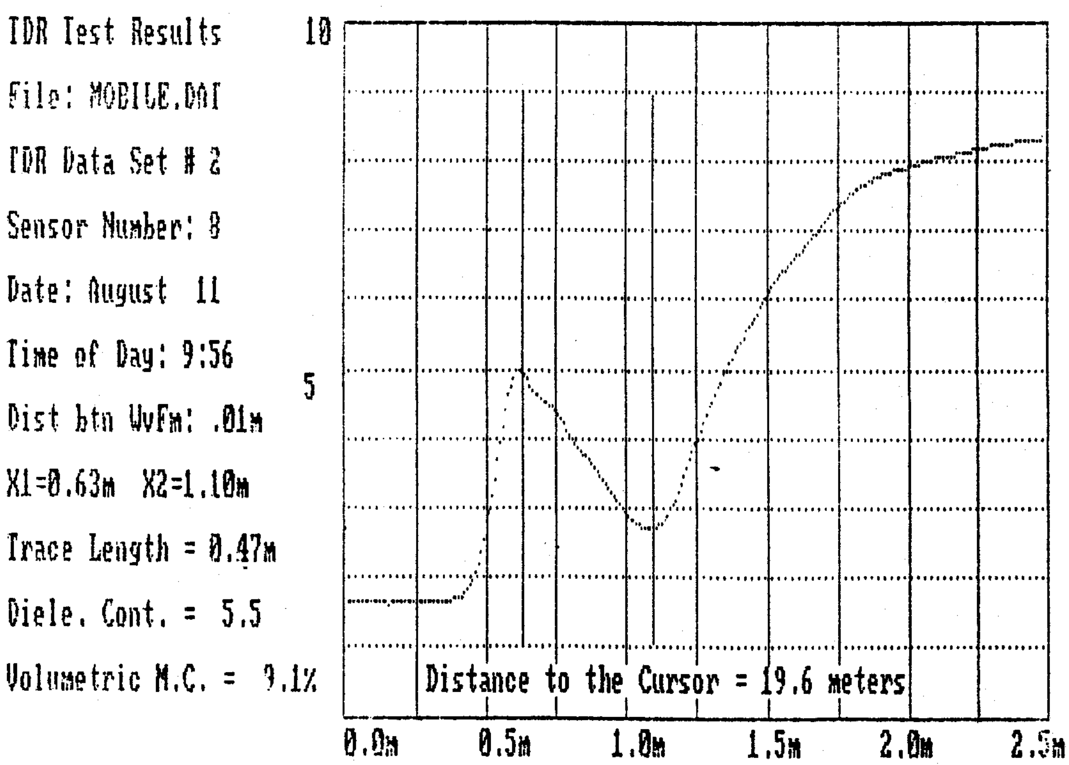


Figure D-10. Trace from TDR sensor 8.

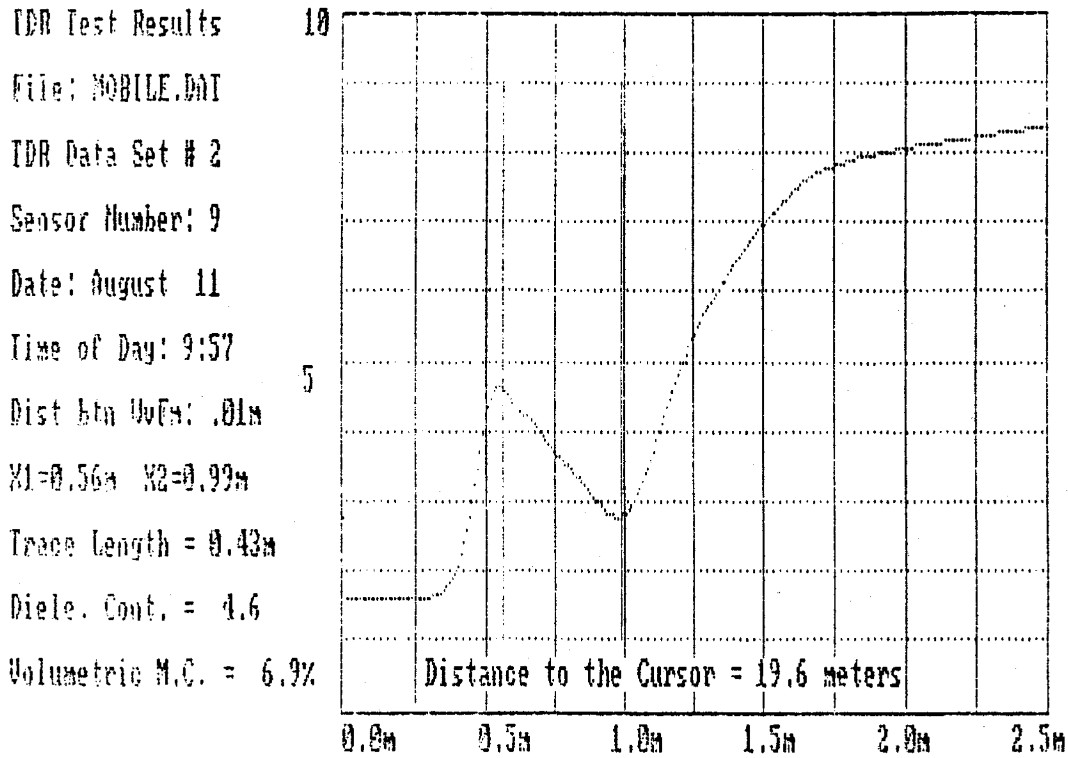


Figure D-11. Trace from TDR sensor 9.

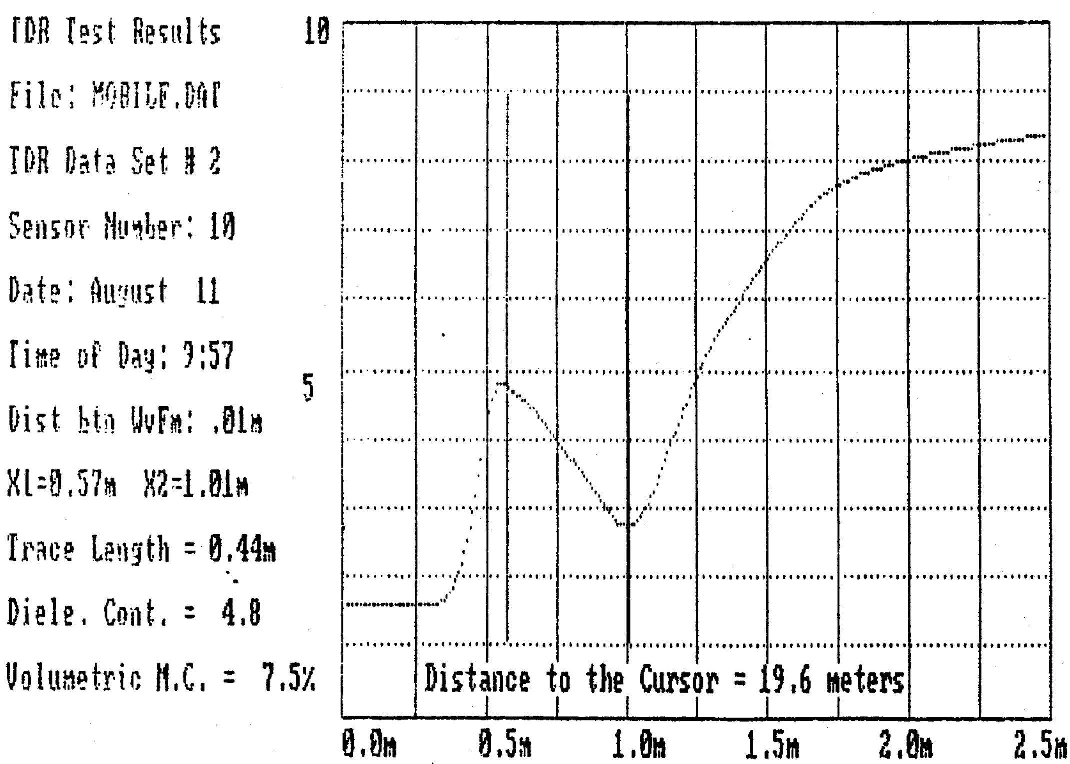


Figure D-12. Trace from TDR sensor 10.

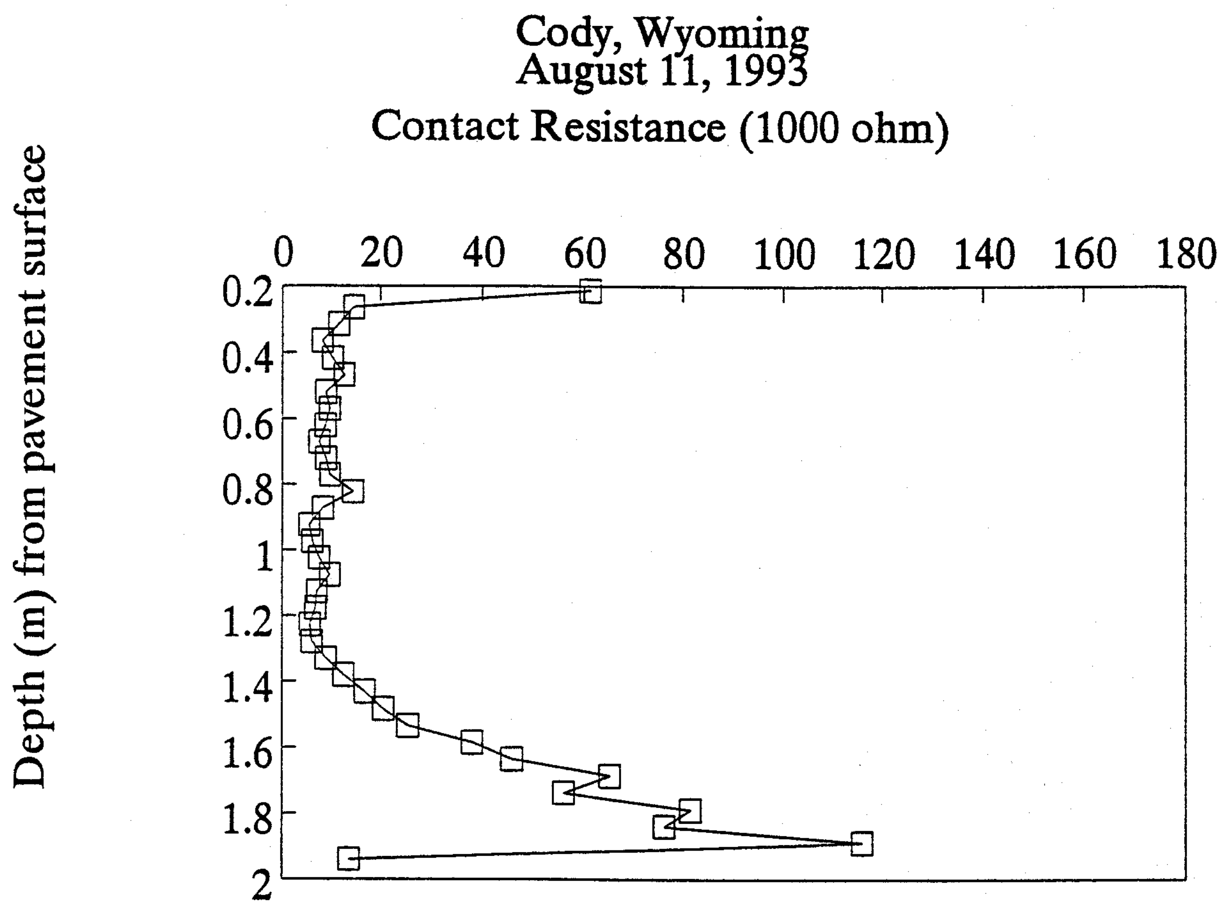


Figure D-13. Manually collected contact resistance.

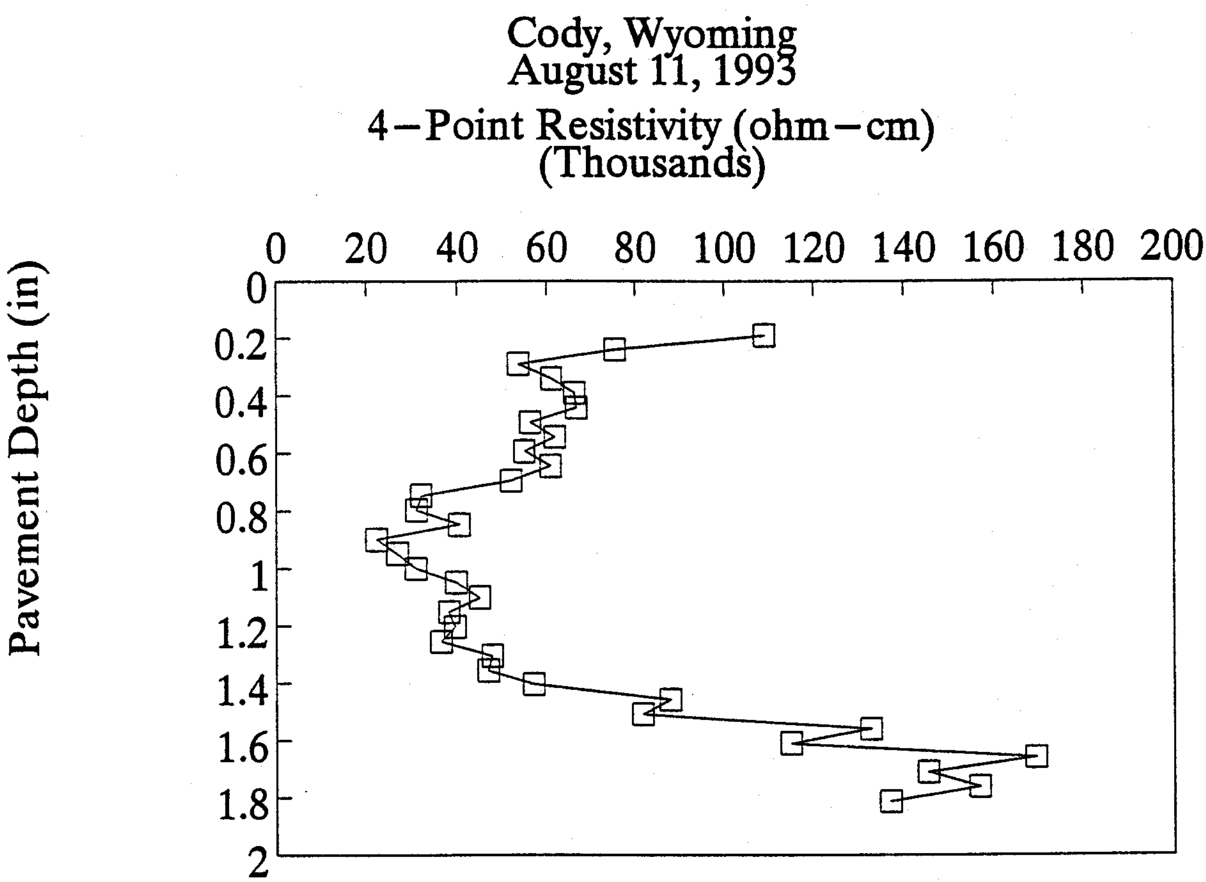


Figure D-14. Manually collected 4-point resistivity.

Table D-2. Contact resistance measurement data sheet.

LTPP Seasonal Monitoring Study Data Sheet R1 Contact Resistance Measurements	* State Code [56] * Test Section Number [1007]

1. Date (Month - Day - Year) [08-11-93]
2. Time Measurements Began (Military) [__:__]
3. Comments ____

add 3 rows

Test Position	Connections I_1 V_1	Connections I_2 V_2	Voltage (ACV) Range Setting	Voltage (ACV) Reading	Current (ACA) Range Setting	Current (ACA) Reading	Notes
1	1	2	20 ACV	7.35	2m	.120	
2	3	2		7.31		.502	
3	3	4		5.80		.504	
4	5	4		5.83		.717	
5	5	6		6.33		.614	
6	7	6		6.72		.551	
7	7	8		5.66		.631	
8	9	8		5.77		.602	
9	9	10		5.29		.606	
10	11	10		5.32		.708	
11	11	12		5.60		.631	
12	13	12		5.70		.589	
13	13	14		6.64		.460	
14	15	14		6.66		.799	
15	15	16		5.36		.975	
16	17	16		5.43		.887	
17	17	18		6.09		.809	
18	19	18		6.15		.635	
19	19	20		5.62		.789	
20	21	20		5.66		.824	
21	21	22		5.42		.955	
22	23	22		5.46		.895	
23	23	24		6.45		.728	
24	25	24		6.56		.525	
25	25	26		7.39		.438	
26	27	26		7.78		.364	
27	27	28		7.93		.307	
28	29	28		7.95		.210	
29	29	30		5.77		.155	
30	31	30		8.61		.132	
31	31	32		8.06		.144	
32	33	32		8.22		.101	
33	33	34		8.15		.107	
34	35	34		8.23		.071	
35	35	36		9.46		0.62	
36	37	38	20 ACV	11.61	200μ	16.7	
37	38	39		7.19	20m	7.22	
38	39	40	200m	20.6	"	18.94	

Preparer ____ Employer ____

Figure III-5 - Contact Resistant Measurements - Data Sheet R1

Table D-3. Four point resistivity measurement data sheet.

LTPP Seasonal Monitoring Study Data Sheet R2 Four-Point Resistivity Measurements	* State Code [6] * Test Section Number [1 0 2 7]

1. Date (Month - Day - Year) [08 - 11 - 93]

2. Time Measurements Began (Military) [__ : __]

3. Comments ______

Test Position	Connections				Voltage (ACV)		Current (ACA)		Notes
	I_1	V_1	V_2	I_2	Range Setting	Reading	Range Setting	Reading	
1	1	2	3	4	200 m	112.8	200 u	75.3	
2	2	3	4	5	2 ACV	.205		171.7	
3	3	4	5	6		.164		146.0	
4	4	5	6	7		.177		136.0	
5	5	6	7	8		.197		190.8	
6	6	7	8	9		.169		160.0	
7	7	8	9	10		.168		193.6	
8	8	9	10	11		.187		191.1	
9	9	10	11	12		.158		181.8	
10	10	11	12	13		.180		191.6	
11	11	12	13	14		.129		~~[illegible]~~ 155.6	
12	12	13	14	15		.230	2 m	.461	
13	13	14	15	16		.176		.359	
14	14	15	16	17		.195		.312	
15	15	16	17	18		.181		.507	
16	16	17	18	19		.181		.445	
17	17	18	19	20		.253		.505	
18	18	19	20	21		.228		.378	
19	19	20	21	22		.303		.426	
20	20	21	22	23		.272		.458	
21	21	22	23	24		.243		.396	
22	22	23	24	25		.245		.412	
23	23	24	25	26		.201		.287	
24	24	25	26	27		.209		.268	
25	25	26	27	28		.150		.174	
26	26	27	28	29		.193		.141	
27	27	28	29	30		.151		.117	
28	28	29	30	31		.170		.083	
29	29	30	31	32		.158		.087	
30	30	31	32	33		.138		.053	
31	31	32	33	34		.158		.066	
32	32	33	34	35		.115		.050	
33	33	34	35	36		.103		.045	

fine

switch → contact resistance

~~Prepared~~ ______ Employer ______

Figure III-6 - Four-Point Resistivity Measurements - Data Sheet R2

Table D-4. Surface elevation measurement data sheet.

LTPP Seasonal Monitoring Study Surface Elevation Measurements	* State Code * Test Section Number	[56] [1007]

Surveyed : Jason M. Dietz
Date : 8/11/93
Start Time : 10:30 PM
Finish Time : 12:00 PM
Surface Type : Asphalt Concrete
Weather Conditions : Clear 26.7°C
Unusual Conditions : None

Beginning Elevation of Frost Free Bench Mark : 1.000 meters
Ending Elevation of Frost Free Bench Mark : 1.000 meters

STATION		OLE 0.000 m	OWP 0.762 m	ML 1.829 m	IWP 2.591 m	ILE 3.658 m
0+00	3+00	0.182	0.176	0.164	0.156	0.137
0+25	3+25	0.034	0.033	0.018	0.014	1.006
0+50	3+50	1.101	1.108	1.120	1.124	1.137
0+75	3+75	1.231	1.236	1.247	1.249	1.262
1+00	4+00	BM	1.350	1.364	1.363	1.376
1+25	4+25	1.453	1.459	1.473	1.472	1.483
1+50	4+50	1.557	1.563	1.577	1.577	1.589
1+75	4+75	1.662	1.667	1.685	1.688	1.702
2+00	5+00	1.771	1.781	1.794	1.800	1.816

OLE : Outside Lane Edge
OWP : Outer Wheel Path
ML : Mid Lane
IWP : Inner Wheel Path
ILE : Inside Lane Edge

→ Eastbound Direction. US 14 east of Cody, WY

0+00 1+00 5+00

o

(Bench Mark)
Observation Well
@ 4.04 m from OLE

APPENDIX E

Photographs

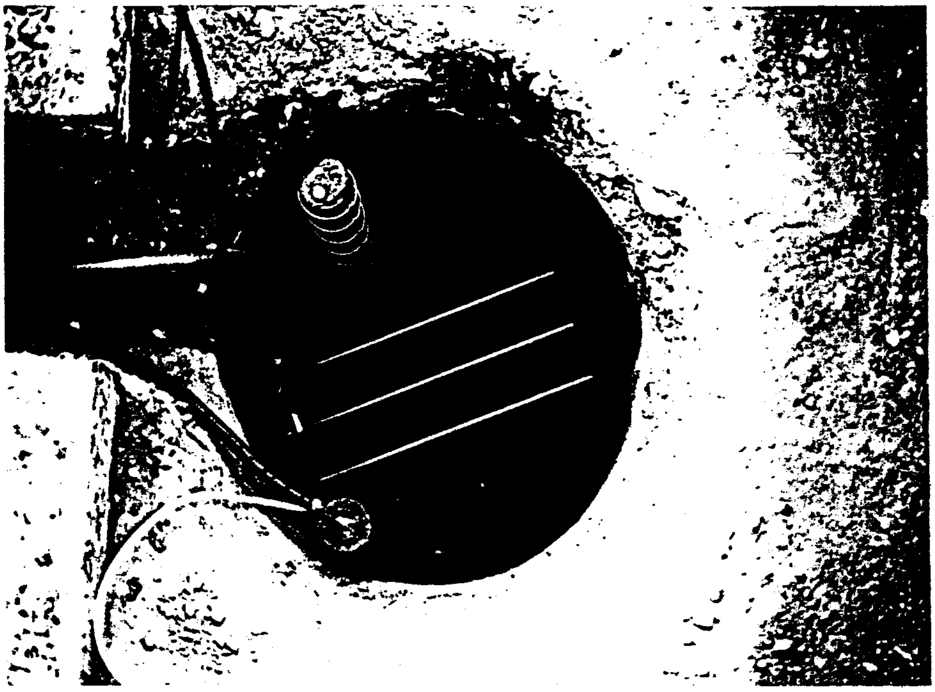


Figure E-1. Position of in-pavement sensors.

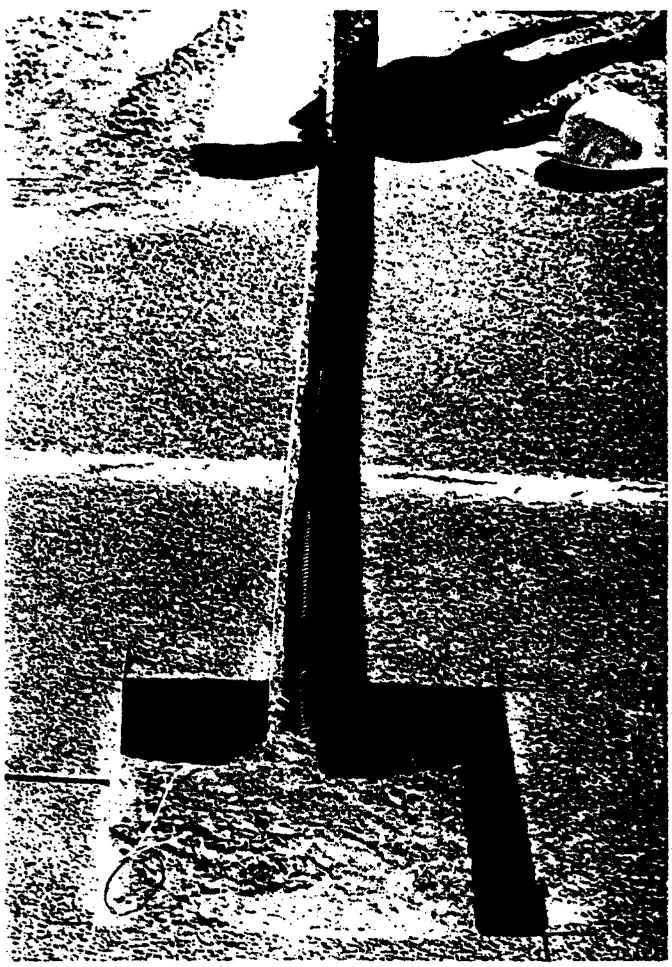


Figure E-2. Condition of instrumentation hole prior to pavement repair.

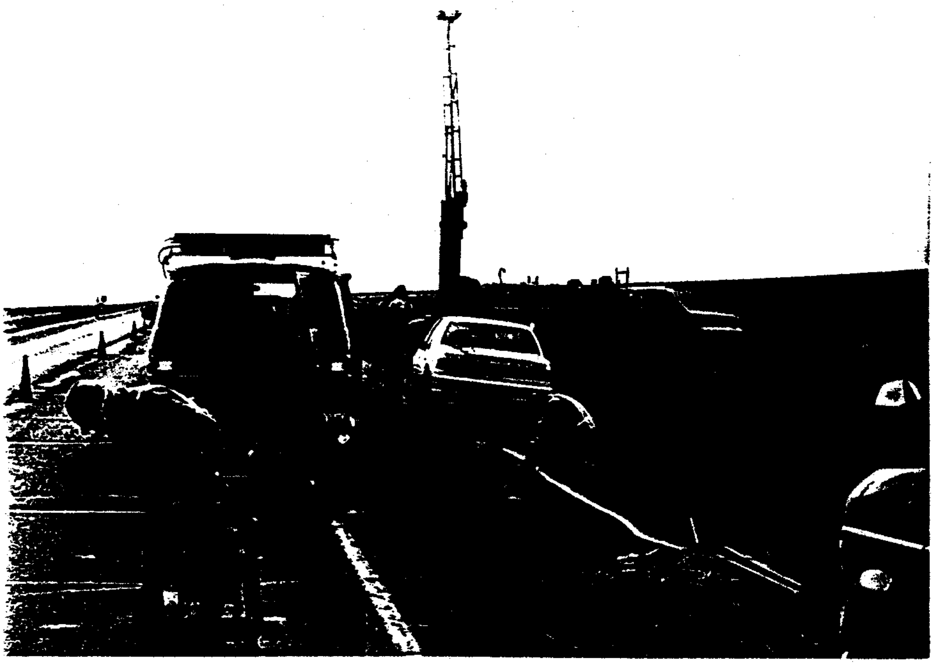


Figure E-3. Installation operations.

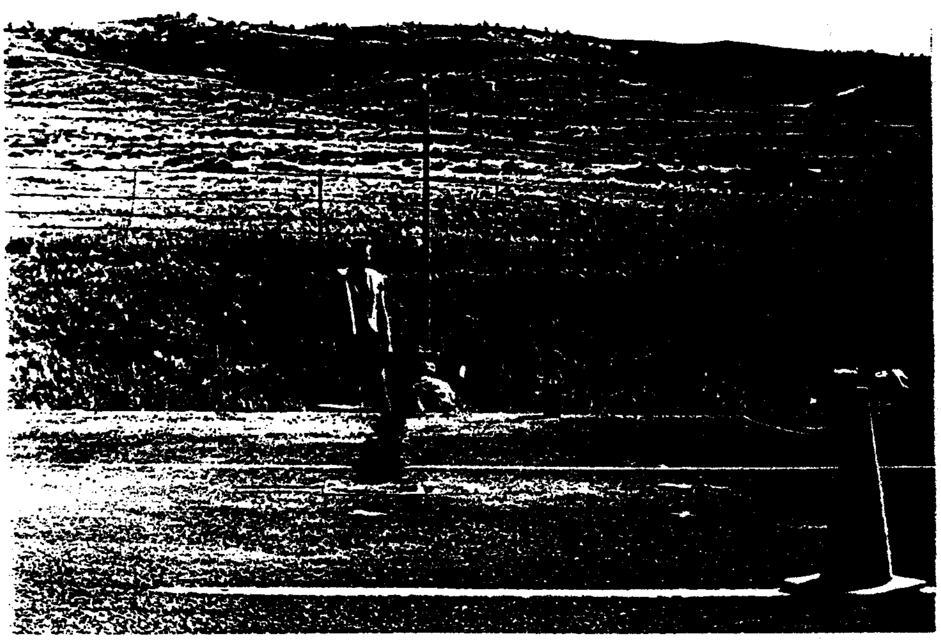


Figure E-4. Condition of pavement after repair of the instrumentation hole.

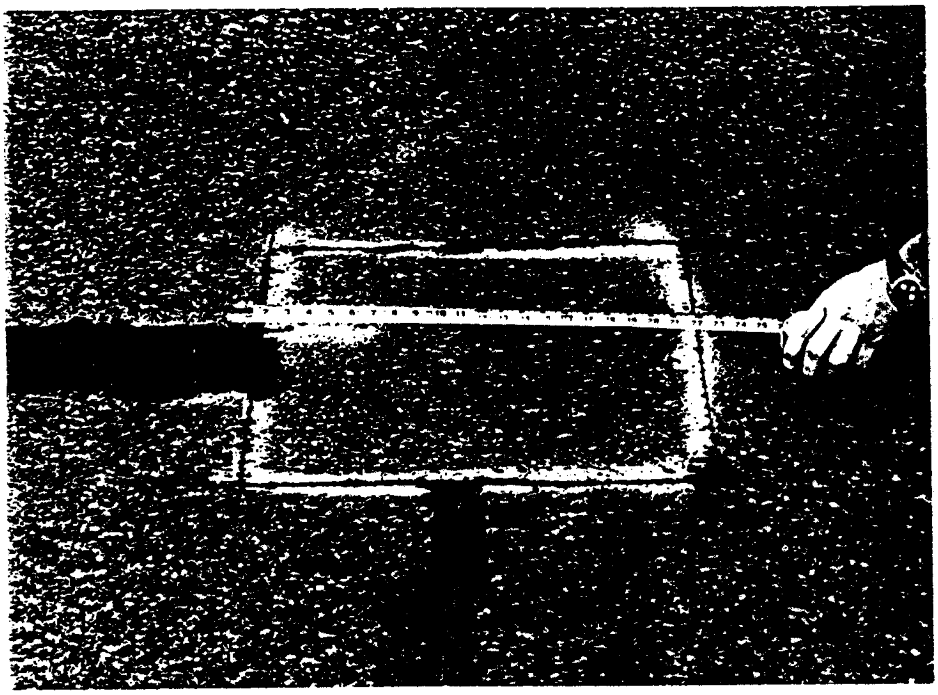


Figure E-5. Close-up of instrumentation hole after repair.