U.S. Department of Transportation

Federal Highway Administration

LTPP Seasonal Monitoring Program

Site Installation and Initial Data Collection

Section 491001
Bluff Utah

Report No. FHWA-49-1001

February 1994

Notice

LTPP Seasonal Monitoring Program

Site Installation and Initial Data Collection
Section 491001, Bluff Utah

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Prepared by

Nichols Consulting Engineers, Chtd.
1885 S. Arlington Ave., Suite 111
Reno, Nevada 89509

Prepared for

Federal Highway Administration
LTPP-Division, HNR-40
Turner-Fairbanks Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101

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15. Supplementary Notes

16. Abstract

This report contains a description of the instrumentation installation activities and initial data collection for test section 491001 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 191 just southwest of Bluff Utah, was instrumented on August 5, 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 6, 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.

17. Key Words	18. Distribution Statement
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I. Introduction

The installation of instrumentation on seasonal site 491001 near Bluff Utah was performed on August 5 - 6, 1993.

The site is located on northbound of U.S. Highway 191, approximately one mile southwest of the town of Bluff in southeastern Utah (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 outside shoulder is 1.8m wide. The test section is classified as a GPS-1 project and in Cell 15 of the Seasonal Monitoring Program (SMP) experiment design.

The pavement structure consists of 140mm asphalt concrete (AC) over an average of 147mm granular aggregate base. The subgrade is primarily a 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. Summary data from the LTPP climate database indicates the following climatic conditions based on 9 years of data:

Freezing Index (C-Days)	121
Precipitation (mm)	229
No Freeze Thaw Cycles	139
Days Above 32° C	75
Days Below 0° C	139
Wet Days	45

The estimated annual average daily traffic (AADT) in 1989 was 1240 (two-way) of which 38% was truck traffic. The GPS lane carried about 50% of the total AADT. The truck AADT on the GPS lane was 238. The estimated annual ESALs in the GPS lane were about 82,000.

Installation of the instrumentation was a cooperative effort between Utah Department of Transportation (UDOT), Nichols Consulting Engineers (NCE) LTPP Western Region Coordination Office staff, and staff from PCS/Law Engineering.

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
Gonzalo R. Rada	PCS/Law Engineering (TAC)
Darrell Geannonatti	Utah Department of Transportation

Table 1. Material properties.

Description	Surface Layer	Base Layer	Subgrade
Material	AC	Aggregate	Sand
Thickness (mm)	140	147	∞
Lab Max Dry Density (kg/m^3)	---	2179 @ 6% MC	1842 @ 12% MC
Liquid Limit	---	NP	NP
Plastic Limit	---	NP	NP
Plastic Index	---	NP	NP
% Passing #200	---	10.6	20.4

Key

MC - Moisture Content
NP - Non-Plastic

II. Instrumentation Installation

Meeting with Highway Agency and Site Visits

A planning meeting was held with Utah Department of Transportation (UDOT) on July 13, 1993 to discuss instrumentation installation activities. Attending the meeting were Mr. Darrell Geannonatti and Deloy Dye of UDOT and Gary Elkins of Nichols Consulting Engineers, Chtd. The plans for both seasonal monitoring sections (sites 491001 and 493011) in Utah were discussed. After discussing installation requirement, UDOT decided that it would be best to contract out the pavement coring, sawing and drilling on the two seasonal monitoring sites. UDOT personnel would provide traffic control and pavement patching materials.

The test section was inspected by Gary Elkins on July 14, 1993. The test section appeared in good condition with some minor chip loss in the wheel paths and transverse cracking, which appeared to be related to low temperature effects, at approximately 15m intervals. The old test pit location on the leave end of the section did not appear to be in very good condition with open cracks apparent around the edges. The approach end of the test section was selected for instrumentation, since this end was in a deeper part of the cut and was more representative of the test section than the leave end.

Equipment Installed

The equipment installed at the test site included instrumentation for measuring air and subsurface temperature, subsurface moisture content, frost depth, rainfall, and depth to the water table. An equipment cabinet was installed to house cable leads from the instrumentation, 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 calibration results indicated that the air temperature probe and thermistor probe were working and the tipping bucket measurement was also within the manufacturer's specification. 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 measurement results showed both 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 using continuity measurements between the each electrode and the pins in the connector. The distance between each electrode was

Table 2. Equipment installed.

Equipment	Quantity	Serial Number
Instrument Hole		
MRC Thermistor Probe	1	177 (49BT)
ABF Resistivity Probe	1	49BR
TDR Sensors	10	49B01-49B10
Equipment Cabinet		
Campbell Scientific CR10 Datalogger	1	16514
Battery Package	1	5654
Weather Station		
TE525 MM Rain Gauge	1	12064
Air Temperature Probe (Model 107)	1	421316
Radiation Shield	1	41301
Observation Well/Bench Mark	1	None

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 all electrodes were functioning.

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 5, 1993. Ambient air temperatures during the installation exceeded 38° C. The same contractor coring/sawing and drilling crews that were used on the SMP site in Nephi, Utah, were used on this site. Traffic control and pavement trench repair were provided by the local UDOT maintenance crew from the yard located in Bluff, Utah. The NCE and PCS/Law Engineering staff installed all instrumentation and measurement equipment, 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.

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	9.7	
	6	17.2	
	7	24.9	
	8	32.3	
	9	47.7	
	10	63.0	
	11	78.2	
	12	93.3	
	13	108.6	
	14	123.8	
	15	139.0	
	16	154.2	
	17	169.5	
	18	184.6	

The instrumentation was installed on the approach end of the test section at approximate station 0-20. The in-pavement sensors were installed in a 356mm square hole cut into the AC surface, located in the outside wheel path, 914mm away from the edge of the travel lane. A worn 229mm diameter hollow-stem auger, which created a 216mm diameter hole, was used to bore the instrument hole. The instrumentation hole was approximately 2.1m deep. Wires from the 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. Sine the test section was located in a cut section, the equipment cabinet was located partially up the cut face, above the slight drainage ditch near the edge of the pavement. 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.

Table 4. Resistivity probe and sensor spacing.

Connector Pin Number	Electrode Number	Continuity ✓	Measurement	Spacing (cm) Line 1	Line 2	Avg	Dist. from top (cm)
36	1	✓	Top-1	2.9	2.9	2.90	2.9
35	2	✓	1-2	5.1	5.1	5.10	8.0
34	3	✓	2-3	5.0	4.9	4.95	13.0
33	4	✓	3-4	4.9	5.0	4.95	17.9
32	5	✓	4-5	5.2	5.2	5.20	23.1
31	6	✓	5-6	5.0	5.1	5.05	28.2
30	7	✓	6-7	5.2	5.1	5.15	33.3
29	8	✓	7-8	5.0	5.0	5.00	38.3
28	9	✓	8-9	5.1	5.3	5.20	43.5
27	10	✓	9-10	5.0	5.0	5.00	48.5
26	11	✓	10-11	5.2	5.0	5.10	53.6
25	12	✓	11-12	5.0	5.1	5.05	58.7
24	13	✓	12-13	5.2	5.2	5.20	63.9
23	14	✓	13-14	5.0	5.0	5.00	68.9
22	15	✓	14-15	5.1	5.1	5.10	74.0
21	16	✓	15-16	5.0	5.0	5.00	79.0
20	17	✓	16-17	5.0	5.1	5.05	84.0
19	18	✓	17-18	5.2	5.1	5.15	89.2
18	19	✓	18-19	4.9	5.1	5.00	94.2
17	20	✓	19-20	5.2	5.1	5.15	99.3
16	21	✓	20-21	5.0	5.1	5.05	104.4
15	22	✓	21-22	5.2	5.1	5.15	109.5
14	23	✓	22-23	5.1	5.0	5.05	114.6
13	24	✓	23-24	4.6	5.0	4.80	119.4
12	25	✓	24-25	5.2	5.3	5.25	124.6
11	26	✓	25-26	5.5	4.9	5.20	129.8
10	27	✓	26-27	5.1	5.2	5.15	135.0
9	28	✓	27-28	5.0	5.1	5.05	140.0
8	29	✓	28-29	5.1	5.1	5.10	145.1
7	30	✓	29-30	5.1	5.1	5.10	150.2
6	31	✓	30-31	5.1	4.9	5.00	155.2
5	32	✓	31-32	5.1	5.1	5.10	160.3
4	33	✓	32-33	4.9	5.0	4.95	165.3
3	34	✓	33-34	5.2	5.2	5.20	170.5
2	35	✓	34-35	5.1	5.1	5.10	175.6
1	36	✓	35-36	5.1	5.0	5.05	180.6
			36-End	2.4	2.3	2.35	183.0

The installation generally followed the procedures described in the "LTPP Seasonal Monitoring Program: Instrumentation Installation and Data Collection Guidelines" and went very smoothly. Some of the exceptions to the guidelines included:

- Without instruction, the saw operator made a diagonal cut across the interior, leave-side corner of the square cut-out for the instrumentation hole. After replacement of the block, the triangular space formed by this cut was replaced with cold mix asphalt patching material.

- Since the auger did not create a hole large enough for placement of the TDR probes, a metal bar was used to enlarge the sides of the hole. With the sandy soil this procedure worked well and resulted in a "tight" placement of the ends of the TDR sensors into notches carved in the side of the hole.

- The 152mm diameter hole for the observation well and bench mark caved in two times. On the final trail, a 6m deep hole was augured and the hardware inserted immediately after removal of the augur prior to refilling.

Table 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.

Table 5. Installed depths of TDR sensors.

Sensor #	Depth from Pavement Surface (m)	Layer
49B01	0.254	Base
49B02	0.406	Subgrade
49B03	0.559	
49B04	0.711	
49B05	0.864	
49B06	1.016	
49B07	1.168	
49B08	1.321	
49B09	1.626	
49B10	1.930	

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.

Table 6. Installed location of MRC thermistor sensors.

Unit	Channel Number	Depth from Pavement Surface (m)	Remarks
1	1	.005	This unit was installed in the AC layer.
	2	.064	
	3	.122	
2	4	.221	This unit was installed in the base and subgrade.
	5	.300	
	6	.375	
	7	.452	
	8	.526	
	9	.680	
	10	.833	
	11	.985	
	12	1.136	
	13	1.289	
	14	1.441	
	15	1.593	
	16	1.745	
	17	1.898	
	18	2.049	

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 cut-out corner piece of the instrumentation hole was repaired with asphaltic cold patch material. The conduit trench was repaired by placing and compacting a UDOT supplied cold mix asphalt concrete patching material.

Table 7. Location of electrodes of the resistivity probe.

Connector Pin Number	Electrode Number	Depth from Pavement Surface (m)
36	1	0.232
35	2	0.283
34	3	0.333
33	4	0.382
32	5	0.434
31	6	0.485
30	7	0.536
29	8	0.586
28	9	0.638
27	10	0.688
26	11	0.739
25	12	0.790
24	13	0.842
23	14	0.892
22	15	0.943
21	16	0.993
20	17	1.043
19	18	1.095
18	19	1.145
17	20	1.196
16	21	1.247
15	22	1.298
14	23	1.349
13	24	1.397
12	25	1.449
11	26	1.501
10	27	1.553
9	28	1.603
8	29	1.654
7	30	1.705
6	31	1.755
5	32	1.806
4	33	1.856
3	34	1.908
2	35	1.959
1	36	2.009

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)
49B01	0.254	Base[1]	5.46	3.41
49B02	0.406	Subgrade[2]	10.05	6.09
49B03	0.559		12.39	4.72
49B04	0.711		12.72	5.27
49B05	0.864		11.68	5.15
49B06	1.016		12.01	4.87
49B07	1.168		8.04	5.34
49B08	1.321		4.62	5.91
49B09	1.626		2.93	4.15
49B10	1.930		3.75	5.76

[1] Conversion factor = 2.18, determined from laboratory maximum dry density.
[2] Conversion factor = 1.84, determined from laboratory maximum dry density.
[3] Raw data are given in Appendix C

III. Initial Data Collection

The second day activities consisted of initial data collection on the site and checks on functioning of the installed equipment. This work included 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 resistance and resistivity measurements, deflection measurements, and an elevation survey.

Air Temperature, Subsurface Temperature, Precipitation Measurements

The air temperature, pavement and subsurface temperature profile, and rainfall data monitored and stored by the onsite CR10 datalogger overnight were examined. It was found that at the end of installation on the first day, the data logger time was inadvertently set to 6:00 instead of 18:00. The datalogger interpreted this as 6:00 am instead of 6:00 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. Observations of the Onsite data logger in the monitoring mode indicated that measurements from all 18 channels on the thermistor probe were functioning. There was no precipitation that night. The equipment and datalogger appeared to be functioning properly. The battery voltages were checked and found to be acceptable. The overnight Onsite data file is presented in Appendix D. Note that in this data file, the resistance measurement function was active, although it was not connected to the resistivity probe, and produced a series of large negative numbers. This is data type 6, identified by the first number on the line.

Figure D-1 shows the air temperature data collected from 6:00 p.m. (August 5) through 1:00 p.m. (August 6). Figure D-2 shows the hourly average subsurface temperature for the first 5 sensors.

TDR Measurement Data

TDR data were collected using the Mobile data acquisition system. The mobile system contains a CR10 datalogger, a battery pack, two TDR multiplexers, and a resistance multiplexer circuit board. 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. These figures indicate that the multiplexers of the mobile systems and TDR sensors were working.

Resistance Measurement Data

Resistance data were collected in two modes: automated and manual. The Mobile data acquisition system automatically performs two point contact resistance measurements and stores the values in terms of millivolts between adjacent electrodes. In the field the contact resistance measurements with the Mobile system appeared to be correct, since the numbers changed and were within the logical range of correct values, however after further 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 and in Figure D-14 for the 4-point resistivity. Raw data are given in Appendix D.

Deflection Measurement Data

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 491001 was completed on August 5, 1993 and initial data collection was completed on August 6, 1993. The instrumentation installed included time domain reflectometery (TDR) 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 serve as a bench mark, and an on-site datalogger.

The test section is located on northbound U.S. Highway 191 southwest of the town of Bluff in southeastern Utah. The pavement structure on this test section consists of 140mm asphalt concrete over an average of 147mm granular aggregate base. The subgrade is primarily a sand.

The instrumentation was installed on the approach end of the test section at approximately test section station 0-20. This end of the section is in a cut section which is more representative of the average cut depth within the monitoring section. The equipment cabinet was installed partially up the cut slope and out of the lateral drainage ditch.

The instrumentation installation generally followed the procedures described in the "LTPP Seasonal Monitoring Program: Instrumentation Installation and Data Collection Guidelines" and went very smoothly. Some of the exceptions to the guidelines included:

- Without instruction, the saw operator made a diagonal cut across the interior, leave-side corner of the square cut-out for the instrumentation hole. After replacement of the block, the triangular space formed by this cut was replaced with cold mix asphalt patching material.

- Since the auger did not create a hole large enough for placement of the TDR probes, a metal bar was used to enlarge the sides of the hole. With the sandy soil this procedure worked well and resulted in a "tight" placement of the ends of the TDR sensors into notches carved in the side of the hole.

- The 152mm diameter hole for the observation well and bench mark caved in two times. On the final trail, a 6m deep hole was augured and the hardware inserted immediately after removal of the augur prior to refilling.

All equipment and instrumentation installed 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.

It was also found on this site, that in sandy soils, augurs of less size than specified can be used for the instrumentation hole by widening the hole with an appropriate hand tool. When this is done, care should be taken not to contaminate other sensor locations in the hole with the wall scrapings from higher elevations.

For the placement of the piezometer in dry sandy soils, the use of a larger augur size should be considered to minimize the impact of wall collapse. Alternatively, a hollow steam augur could be used and the hardware inserted through the center of the augur so that it remains in place as the auger is removed.

APPENDIX A

Test Section Background Information

Appendix A Includes the Following Supporting Information:

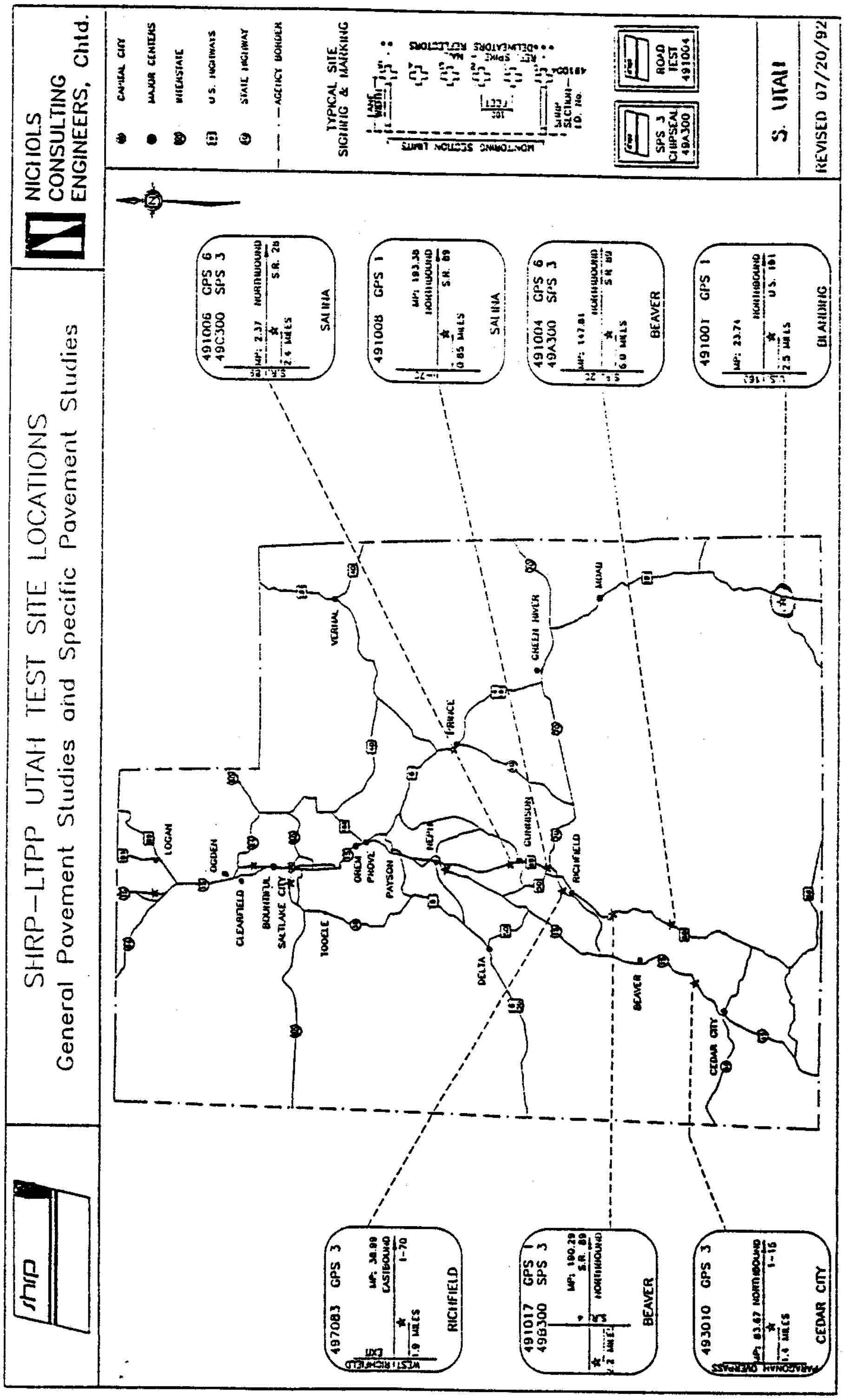


Figure A-1. Location of test site, GPS test section 491001.

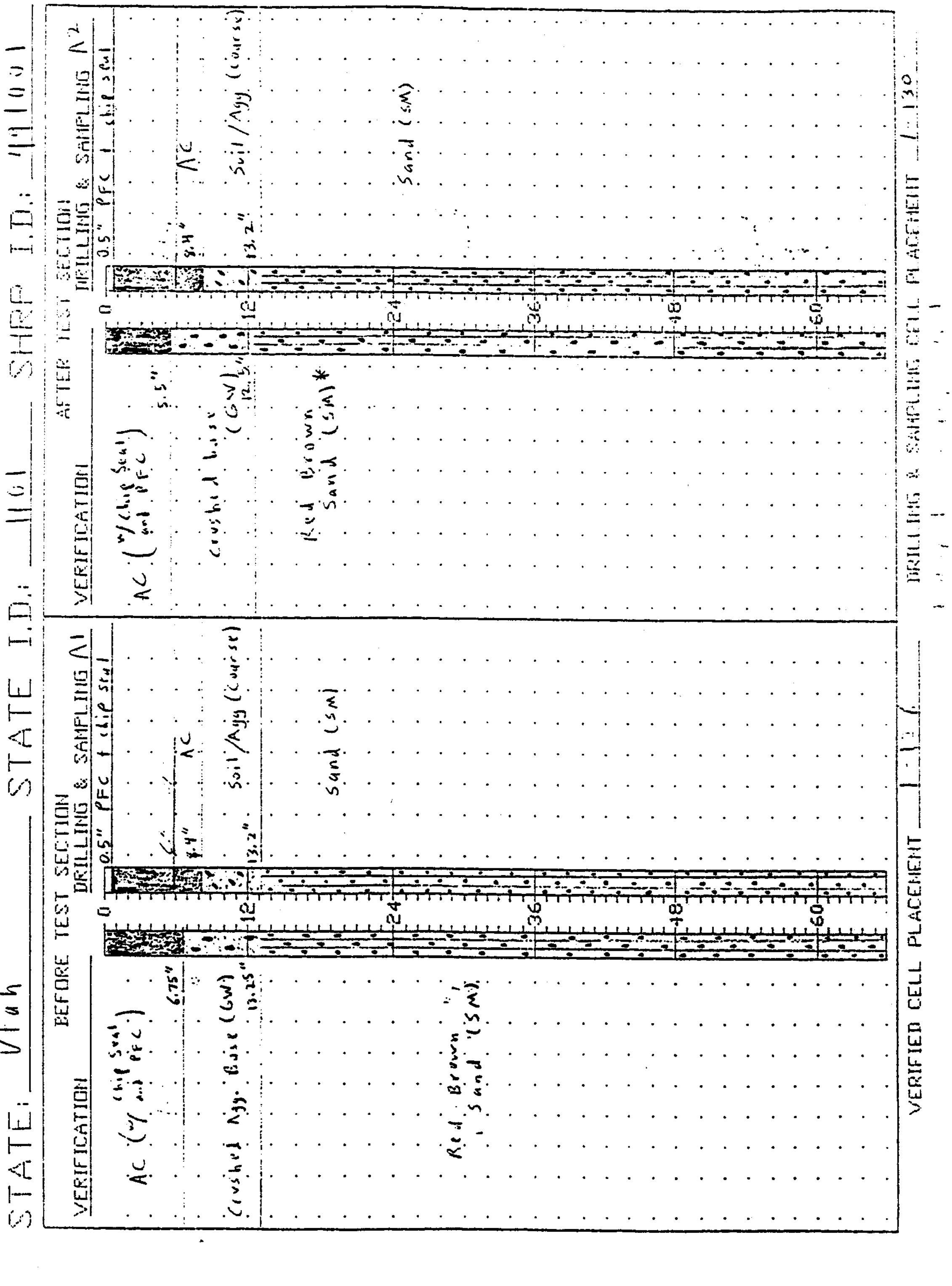


Figure A-2. Profile of test section.

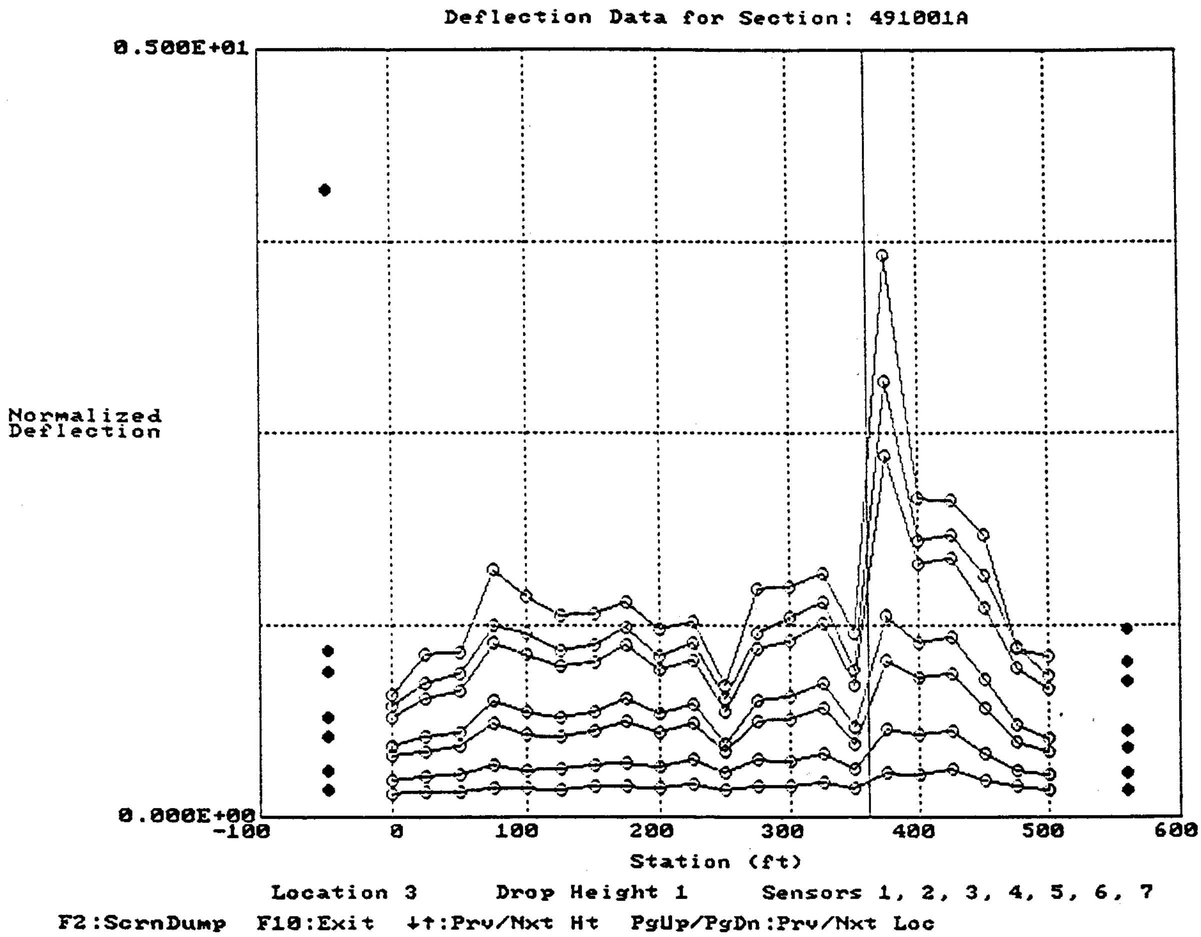


Figure A-3. Normalized deflection profile from FWDCHECK (test date 4/10/89).

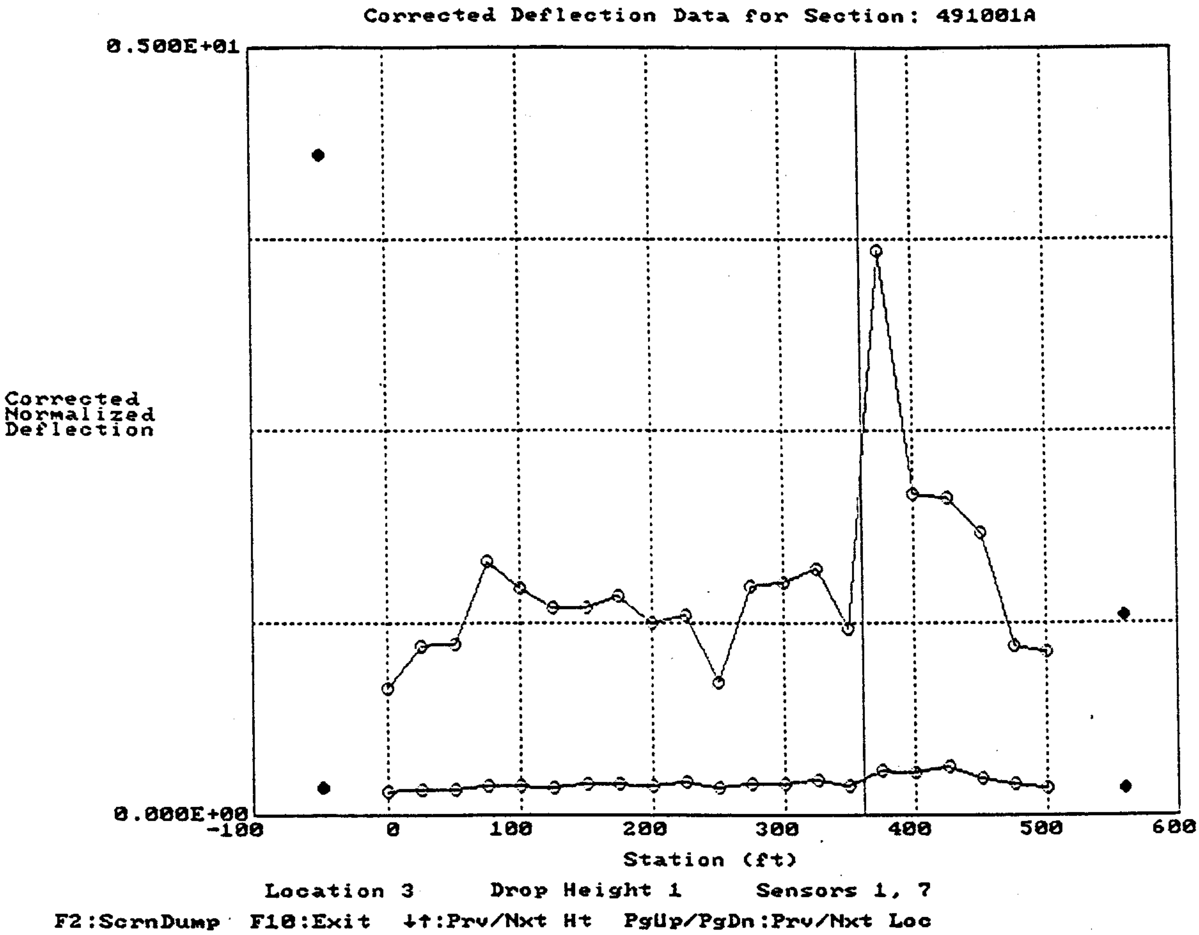


Figure A-4. Corrected normalized deflection profile from FWDCHECK.

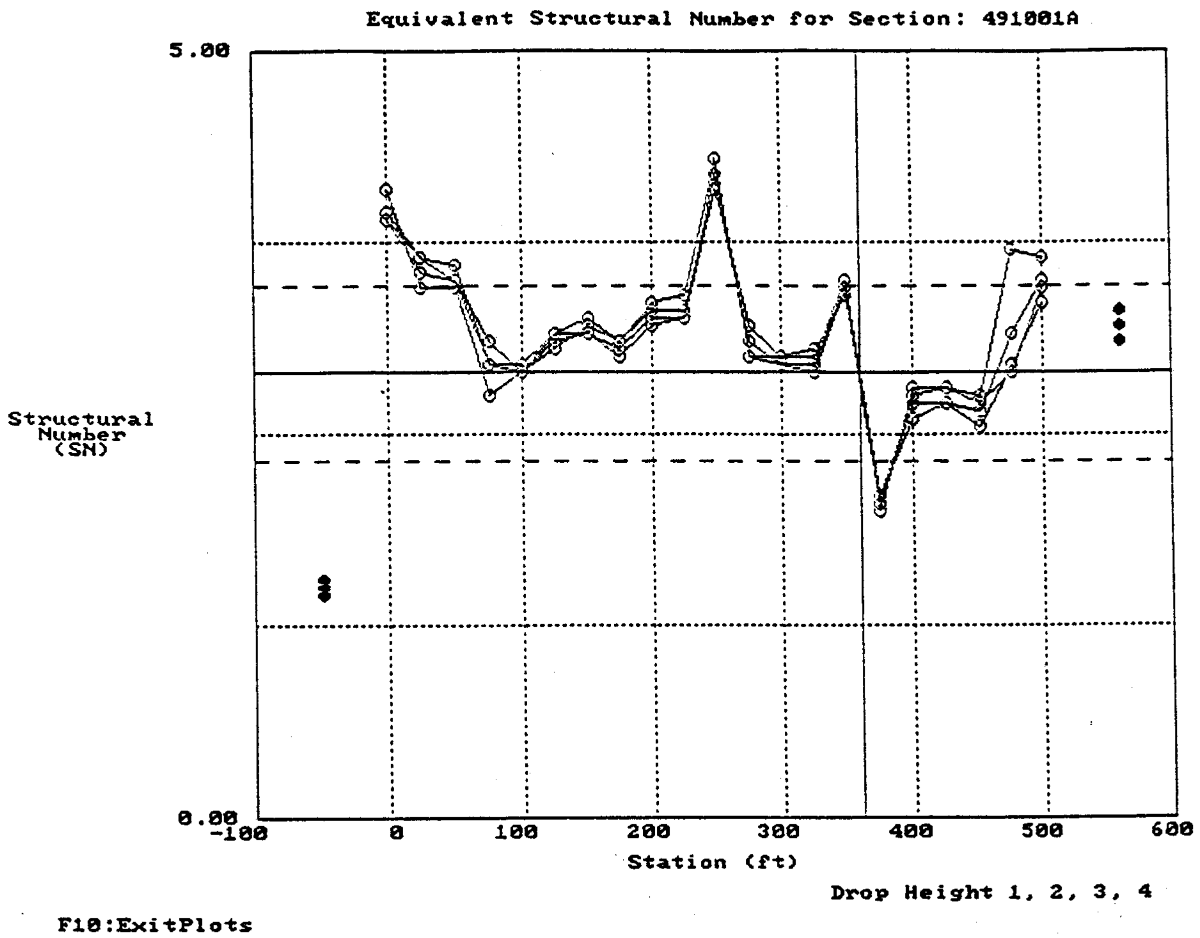


Figure A-5. Structural Number (SN) profile from FWDCHECK.

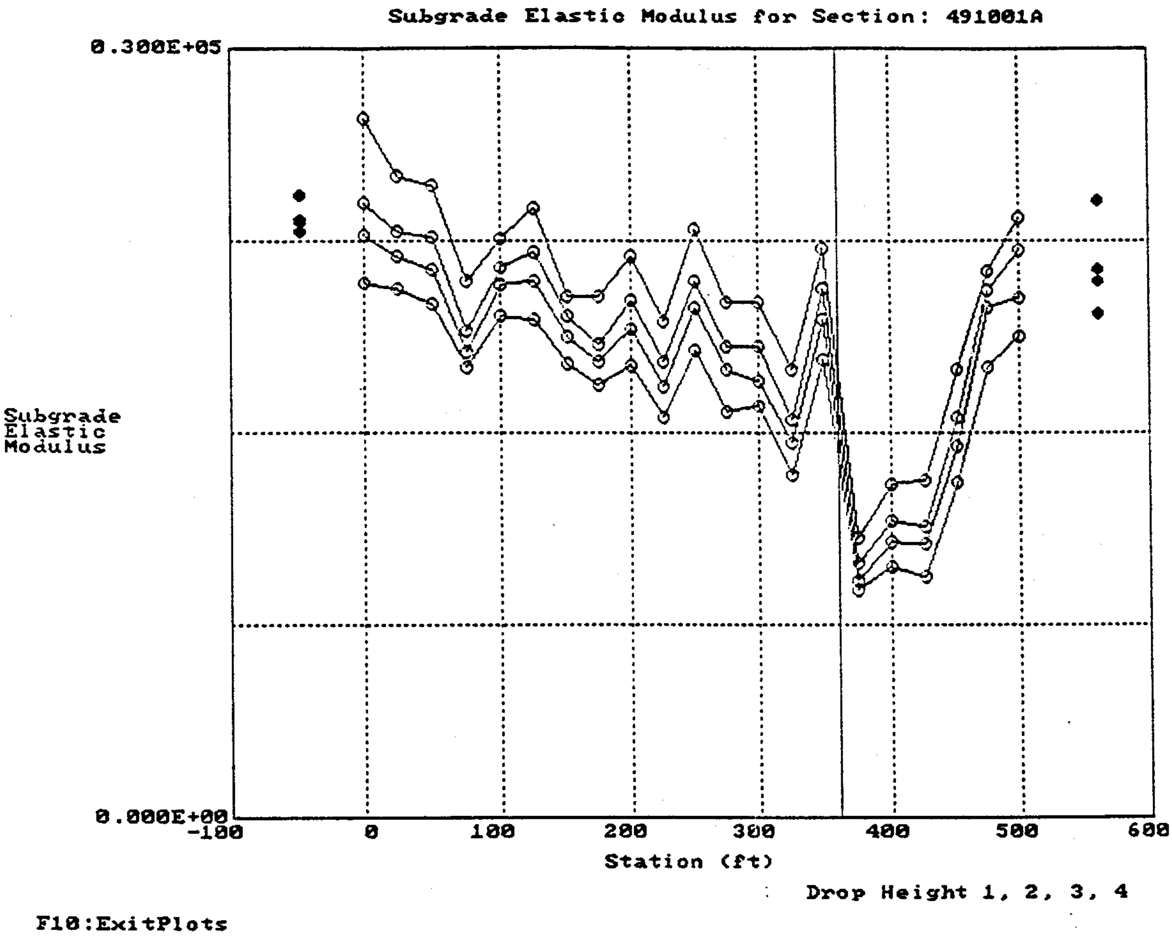


Figure A-6. Subgrade elastic modulus profile from FWDCHECK.

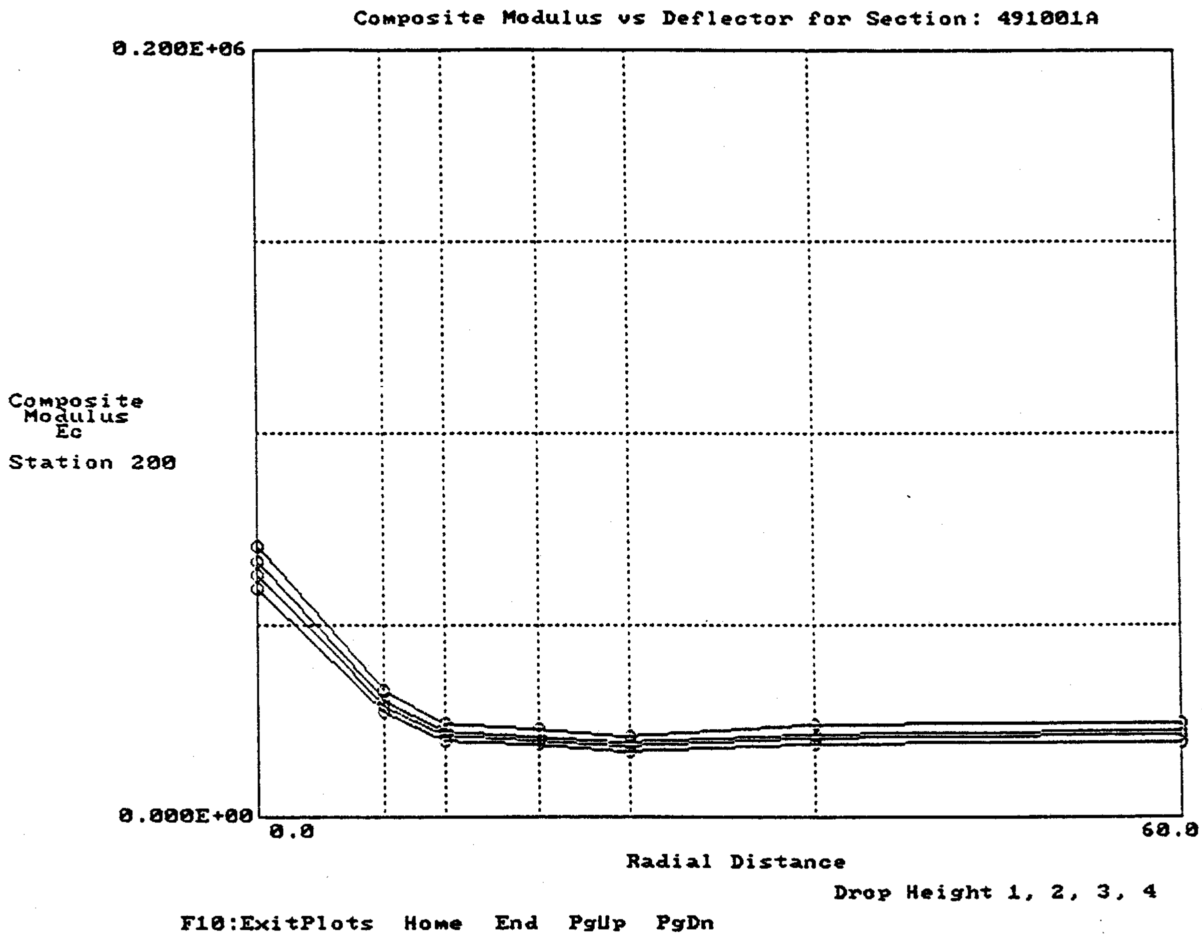


Figure A-7. Composite modulus Ec at station 200 from FWDCHECK.

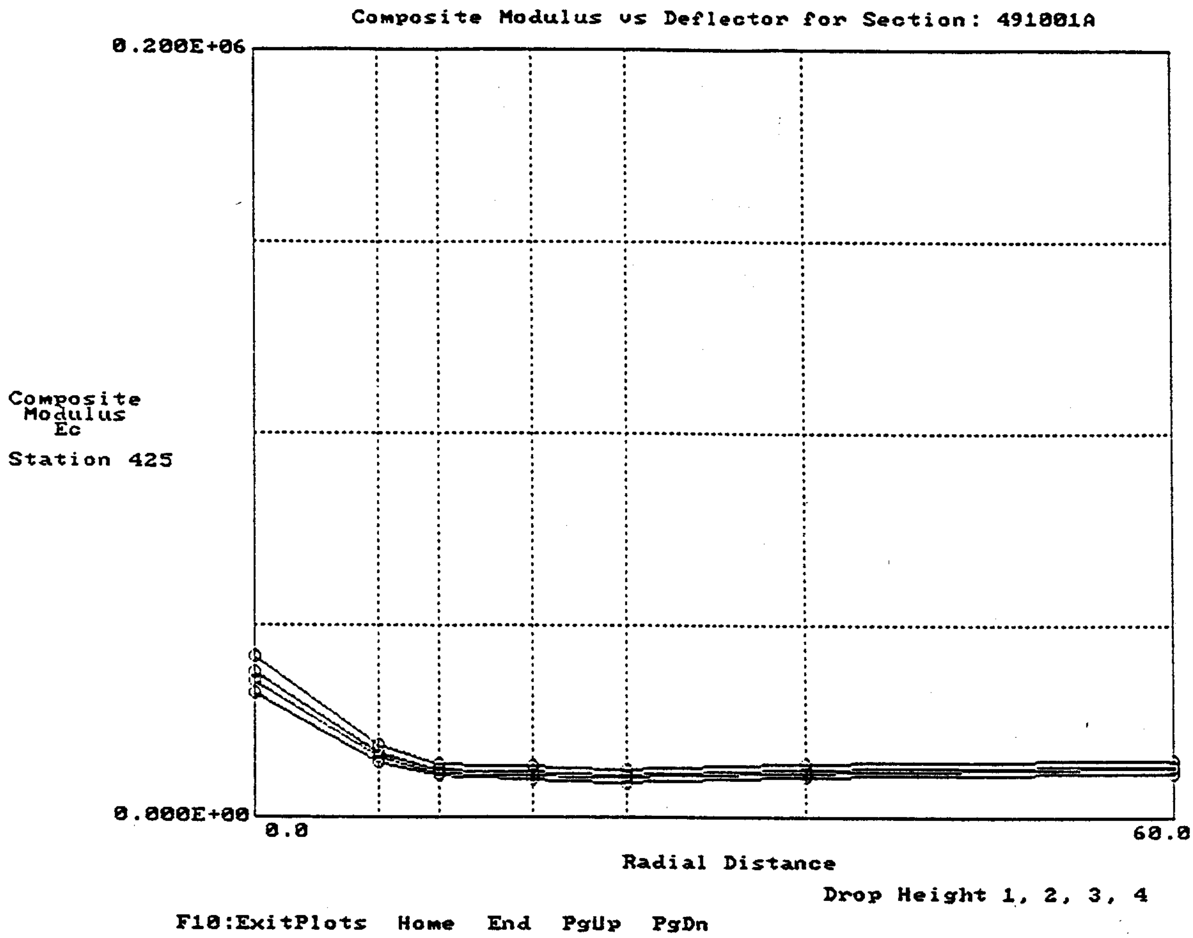


Figure A-8. Composite modulus Ec at station 425 from FWDCHECK.

APPENDIX B

Installed Instrument Information

Appendix B Includes the Following Supporting Information:

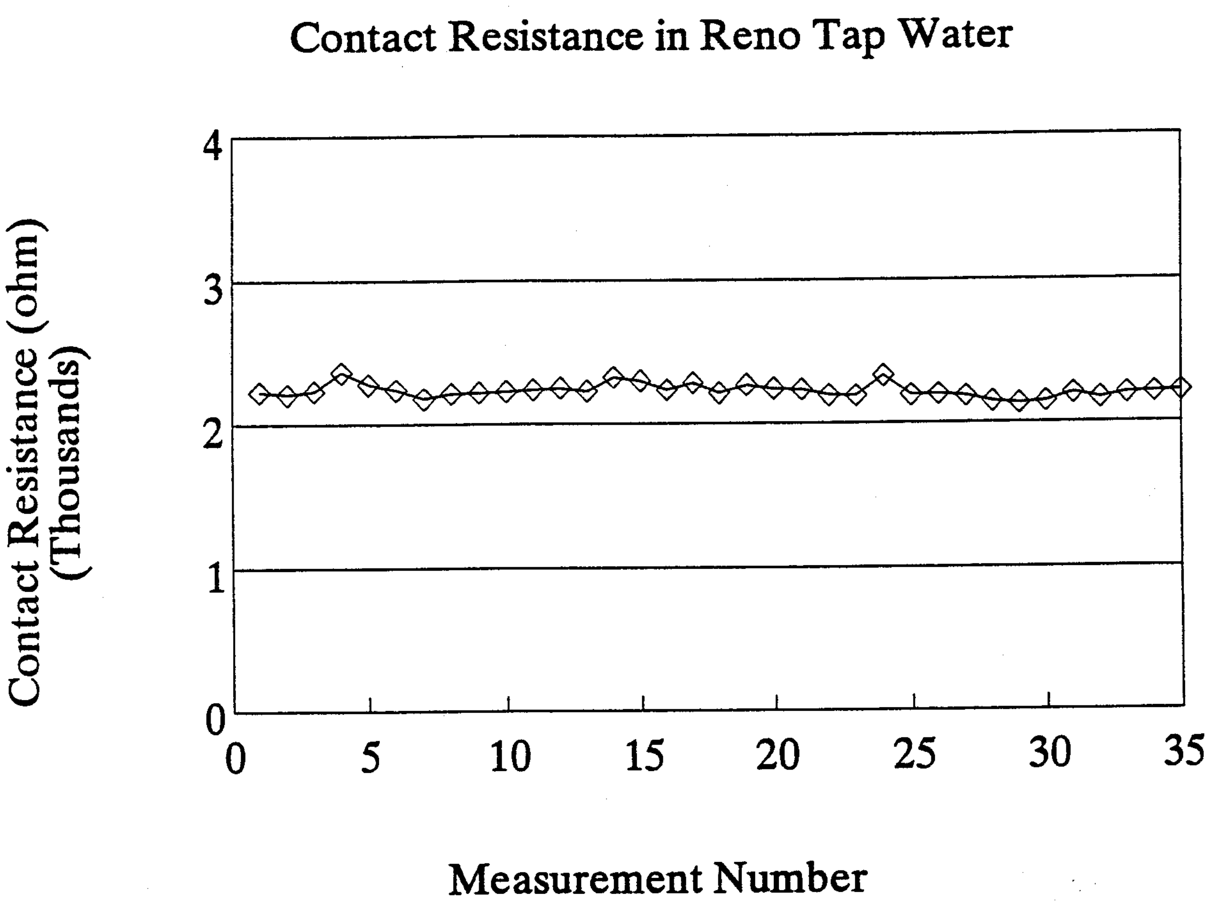


Figure B-1. Contact resistance measured in Reno tap water.

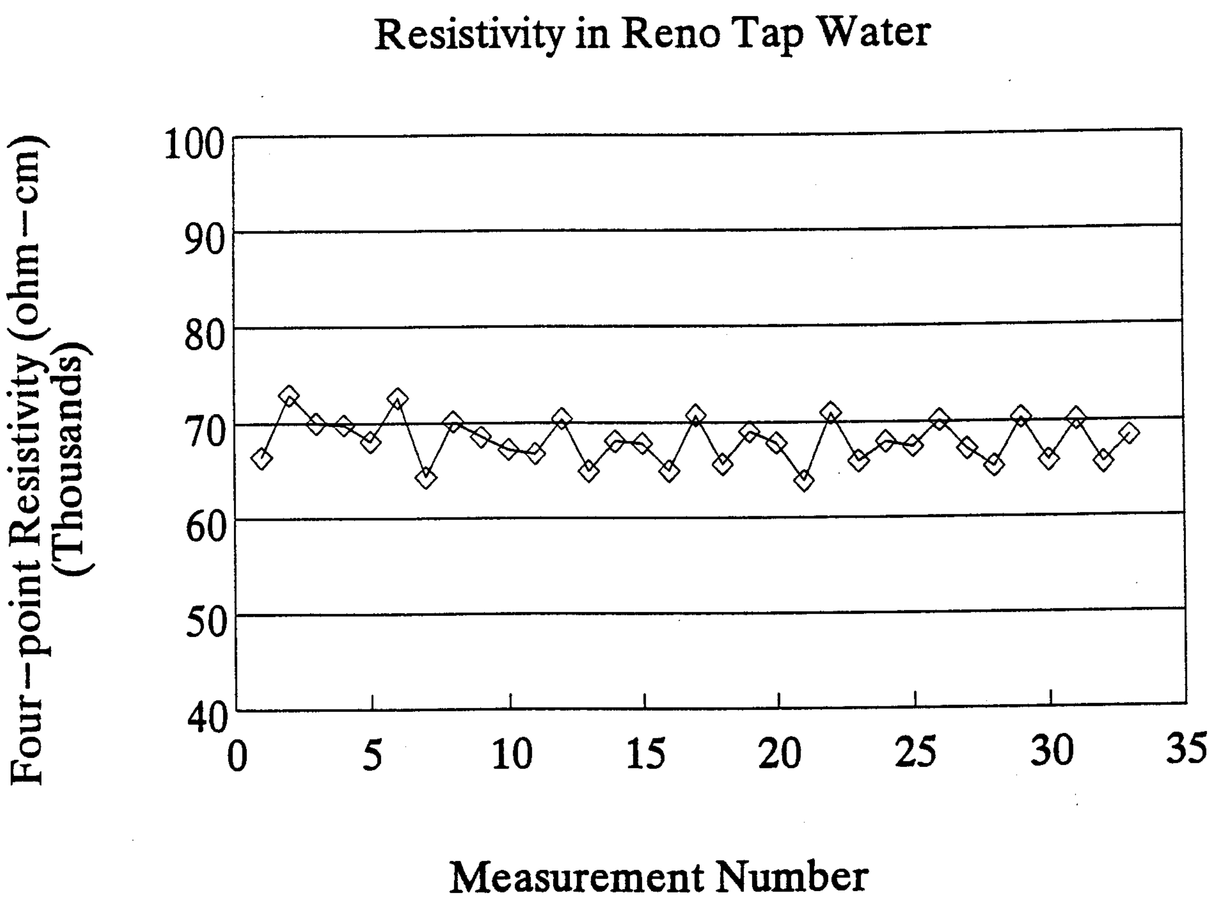
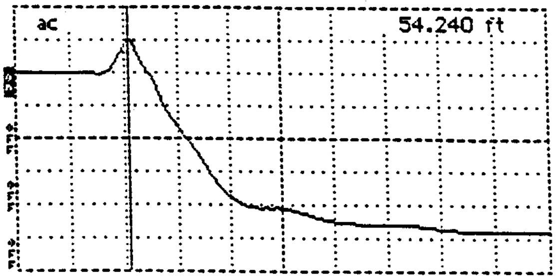


Figure B-2. Four-point resistivity measured in distilled water.

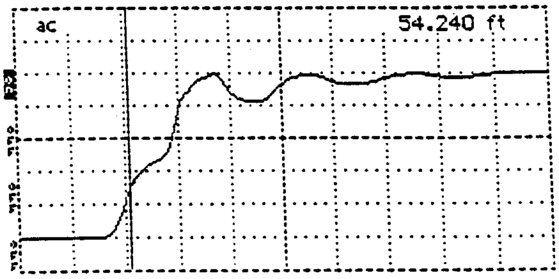
Cursor .... 54.240 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49B10
Notes 74°F
Shorted

Input Trace
Stored Trace
Difference Trace

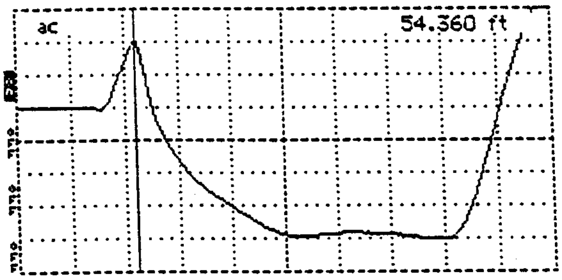
Cursor .... 54.240 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49B10
Notes 74°F
In Air

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

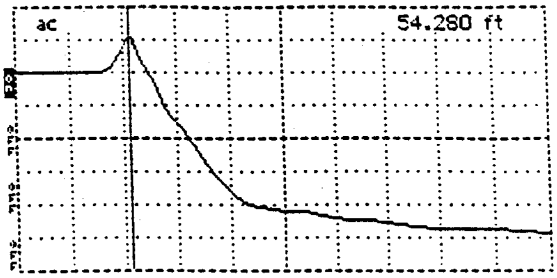


Tektronix 1502B TDR
Date 7/21/93
Cable 49B10
Notes 72°F
In Distilled Water

Input Trace
Stored Trace
Difference Trace

Figure B-3. TDR traces obtained during calibration.

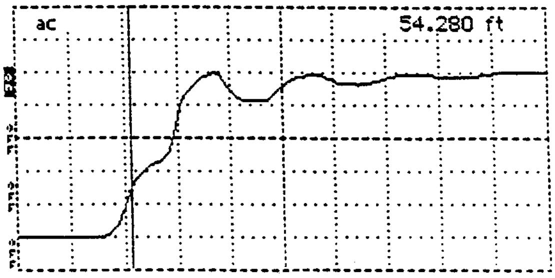
Cursor .... 54.280 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49309
Notes 74°F
Shorted

Input Trace
Stored Trace
Difference Trace

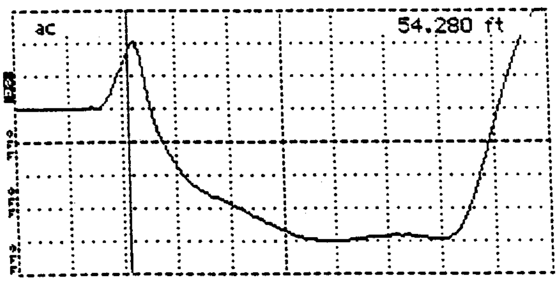
Cursor .... 54.280 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49309
Notes 74°F
In Air

Input Trace
Stored Trace
Difference Trace

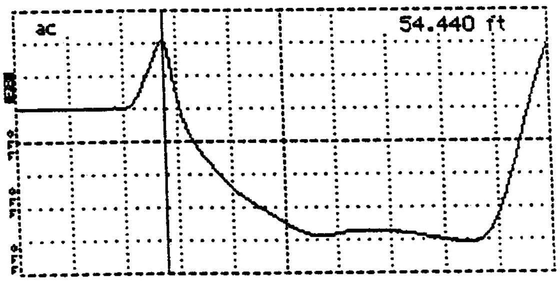
Cursor .... 54.280 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49309
Notes 72°F
Distilled Water

Input Trace
Stored Trace
Difference Trace

Cursor .... 54.440 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac

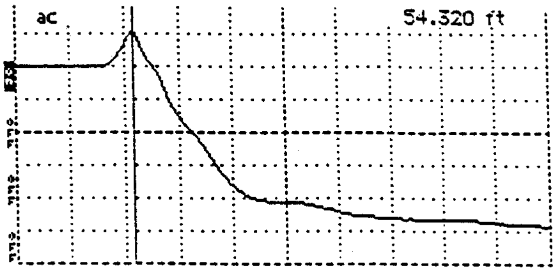


Tektronix 1502B TDR
Date 7/21/93
Cable 49309
Notes 72°F
Distilled water

Input Trace
Stored Trace
Difference Trace

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

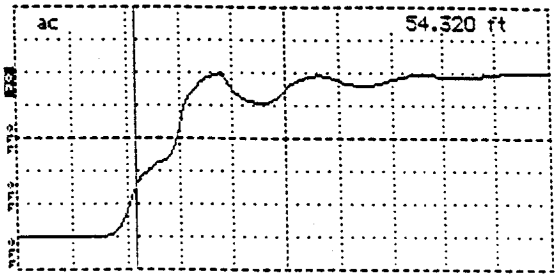
Cursor .... 54.320 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter ...... 1 avg
Power .... ac



Tektronix 1502B TDR
Date [illegible]
Cable [illegible]
Notes 74°F
Saturated

Input Trace
Stored Trace
Difference Trace

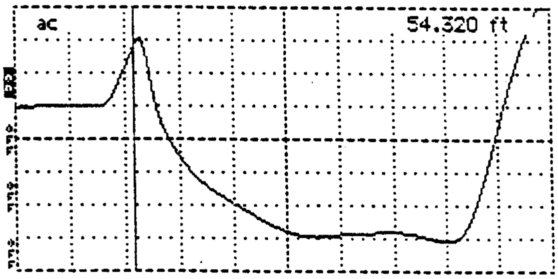
Cursor .... 54.320 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter ...... 1 avg
Power .... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49808
Notes 74°F
In Air

Input Trace
Stored Trace
Difference Trace

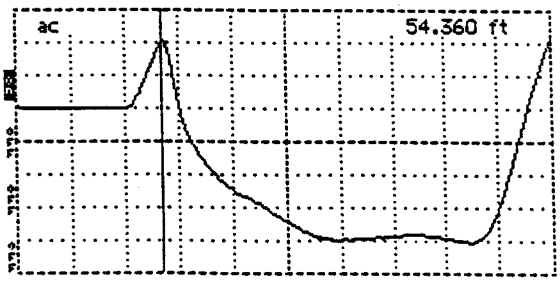
Cursor .... 54.320 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
VP 0.99
Noise Filter ...... 1 avg
Power .... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49808
Notes 72°F
In Distilled water

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

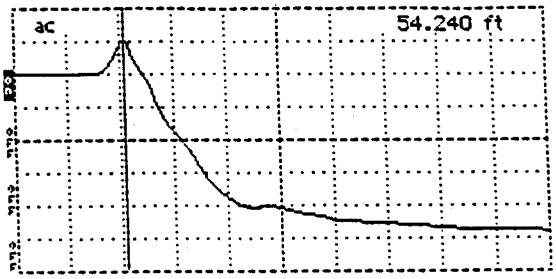


Tektronix 1502B TDR
Date 7/21/93
Cable 49808
Notes 72°F
In Distilled water

Input Trace
Stored Trace
Difference Trace

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

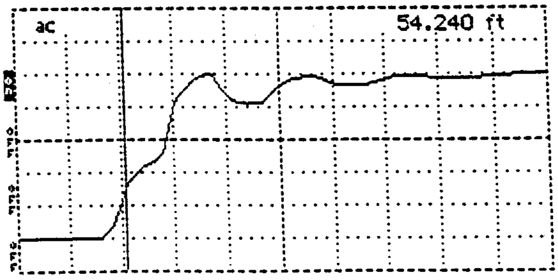
Cursor .... 54.240 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power.......... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49B07
Notes 74°F
shorted

Input Trace
Stored Trace
Difference Trace

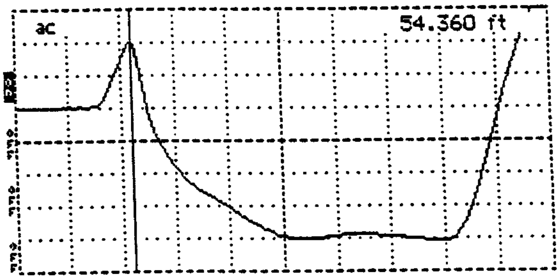
Cursor .... 54.240 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power.......... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49B07
Notes 74°F
In Air

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

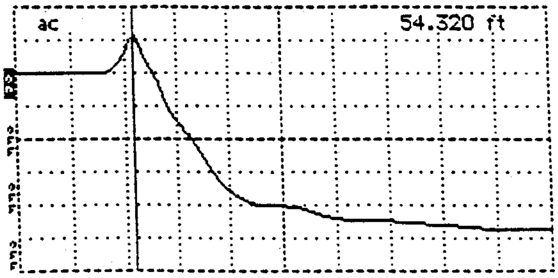


Tektronix 1502B TDR
Date 7/21/93
Cable 49B07
Notes 72°F
In Distilled Water

Input Trace
Stored Trace
Difference Trace

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

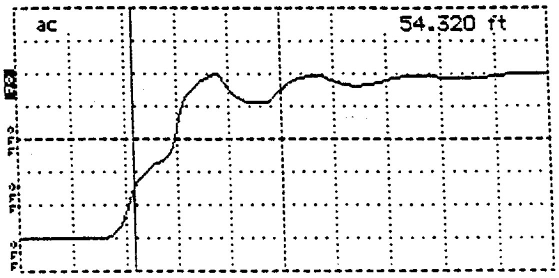
Cursor .... 54.320 ft
Distance/Div..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date [illegible]
Cable [illegible]
Notes 74°F
Shorted

Input Trace
Stored Trace
Difference Trace

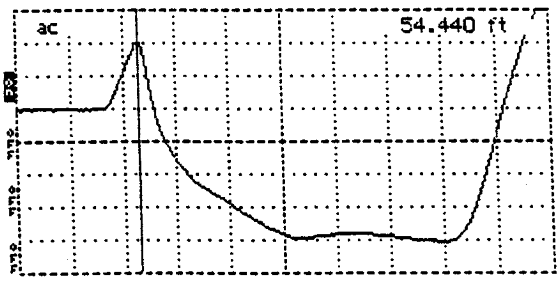
Cursor .... 54.320 ft
Distance/Div..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49806
Notes 74°F
In Air

Input Trace
Stored Trace
Difference Trace

Cursor .... 54.440 ft
Distance/Div..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac

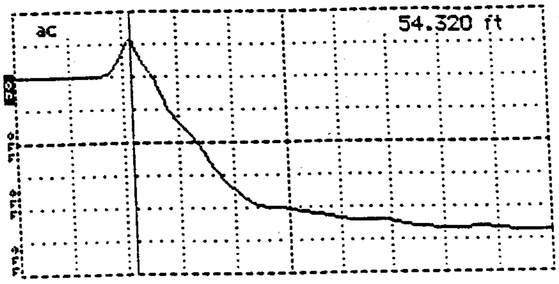


Tektronix 1502B TDR
Date 7/21/93
Cable 49806
Notes 72°F
In Distilled Water

Input Trace
Stored Trace
Difference Trace

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

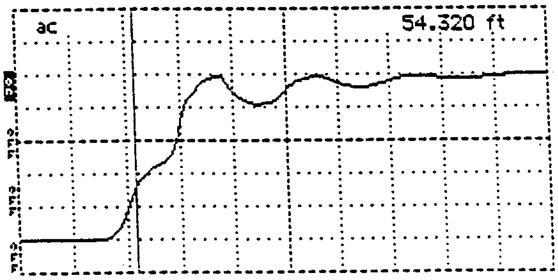
Cursor .... 54.320 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power .... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49305
Notes 74°F
shorted

Input Trace
Stored Trace
Difference Trace

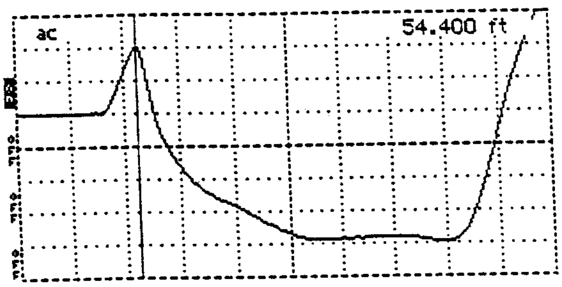
Cursor .... 54.320 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power .... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49305
Notes 74°F
In Air

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

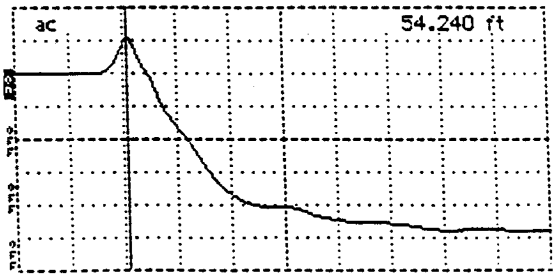


Tektronix 1502B TDR
Date 7/21/93
Cable 49305
Notes 73°F
In Distilled Water

Input Trace
Stored Trace
Difference Trace

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

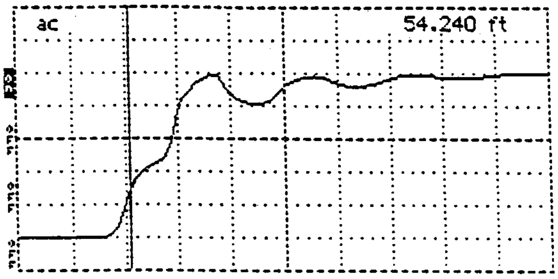
Cursor .... 54.240 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 40 304
Notes 74°F
shorted

Input Trace
Stored Trace
Difference Trace

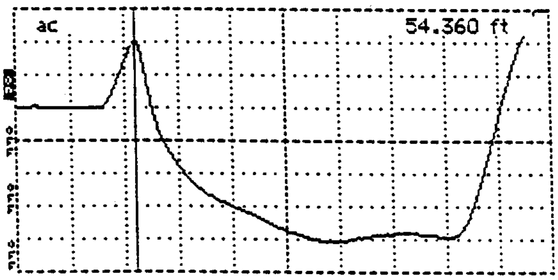
Cursor .... 54.240 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
Vp 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 40304
Notes 74°F
In Air

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 7/21/93
Cable 40 304
Notes 72°F
In Distilled
water

Input Trace
Stored Trace
Difference Trace

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

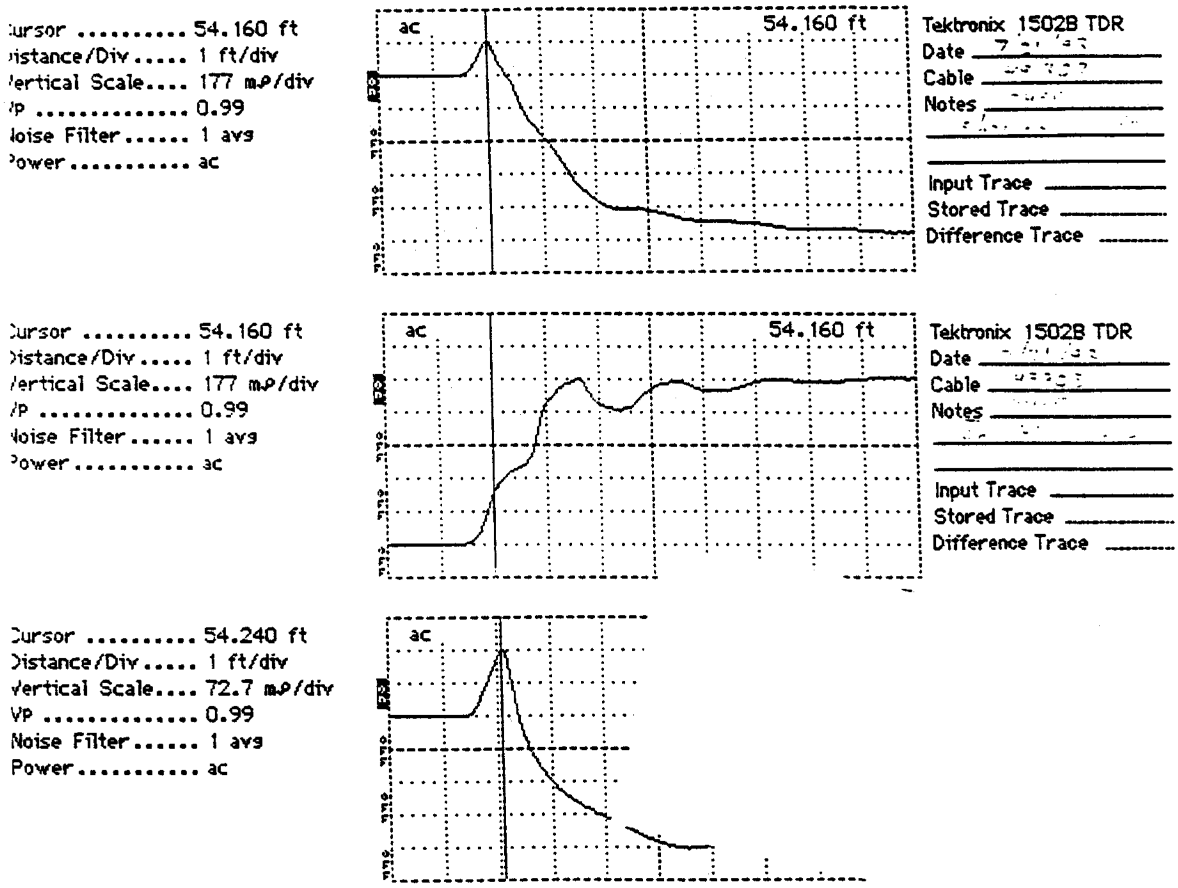
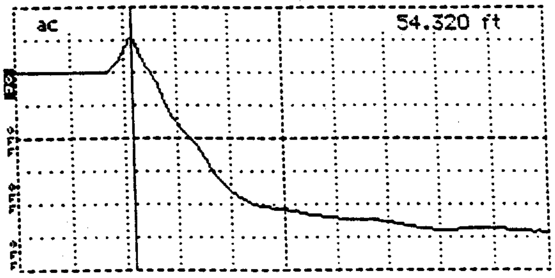


Figure B-3. TDR traces obtained during calibration (cont.).

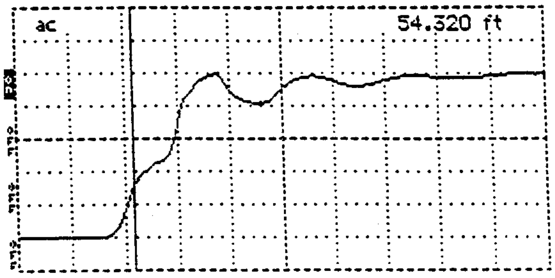
Cursor .... 54.320 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49 B02
Notes 74°F
Shorted

Input Trace
Stored Trace
Difference Trace

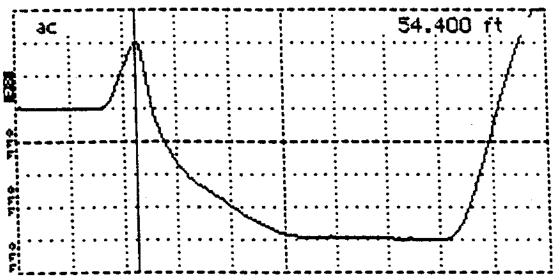
Cursor .... 54.320 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 177 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac



Tektronix 1502B TDR
Date 7/21/93
Cable 49 B02
Notes 74°F
In Air

Input Trace
Stored Trace
Difference Trace

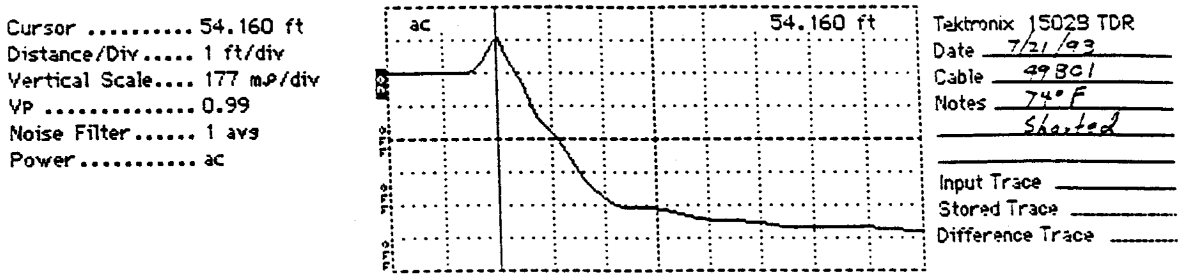
Cursor .... 54.400 ft
Distance/Div ..... 1 ft/div
Vertical Scale.... 72.7 mρ/div
VP 0.99
Noise Filter...... 1 avg
Power........... ac

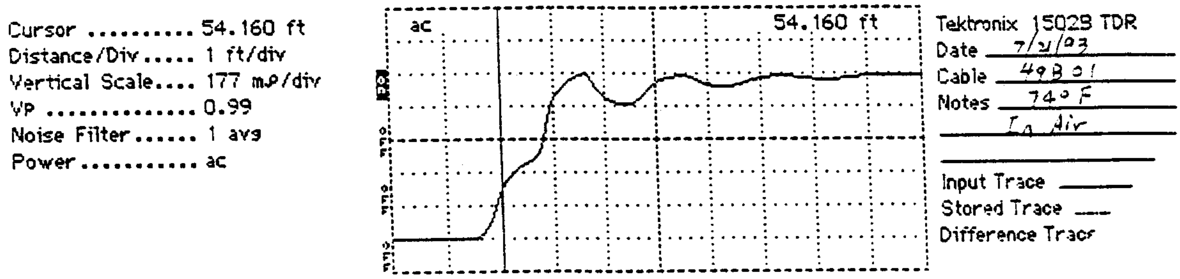


Tektronix 1502B TDR
Date 7/21/93
Cable 49 B02
Notes 72°F
In Distilled Water

Input Tr
Stored Tr
Difference

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





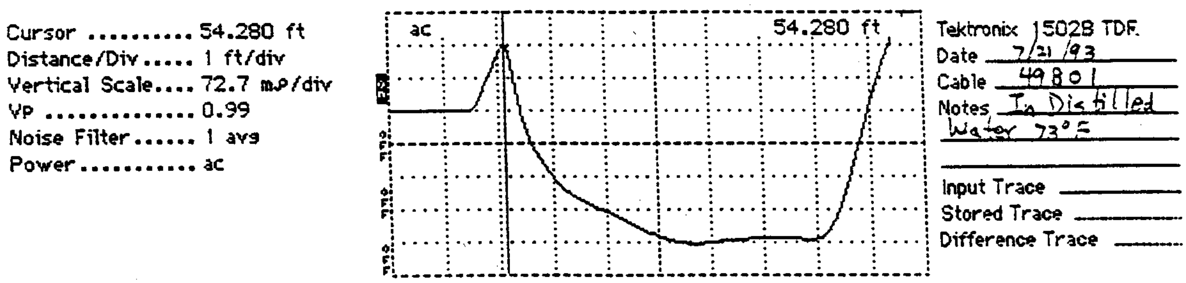


Figure B-3. TDR traces obtained during calibration (cont.).

APPENDIX C

Supporting Instrumentation Installation Information

Appendix C Includes the Following Supporting Information:

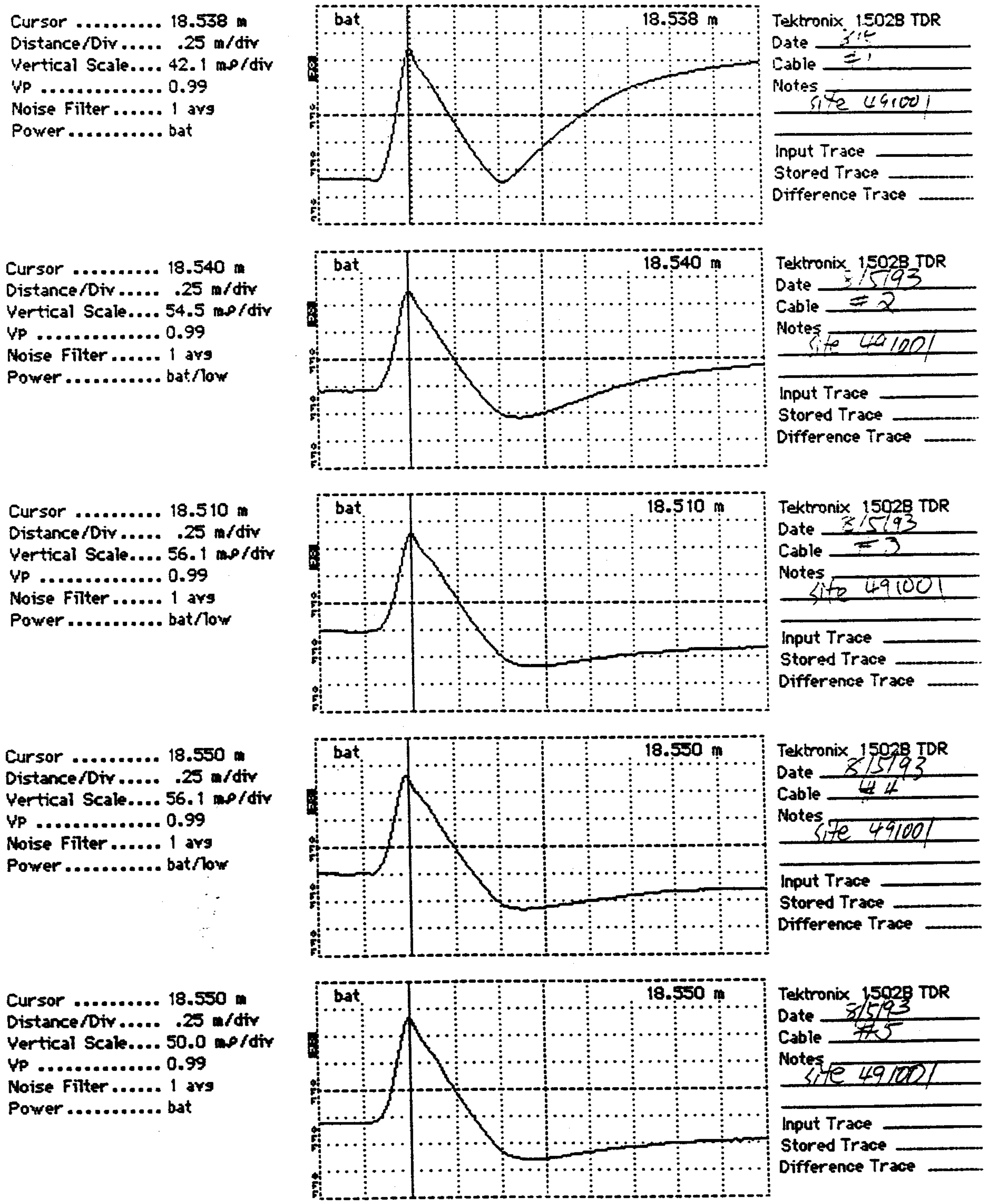
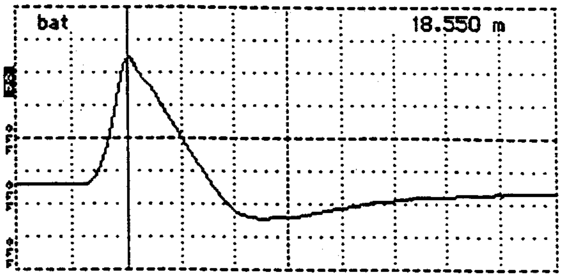


Figure C-1. TDR traces measured during installation.

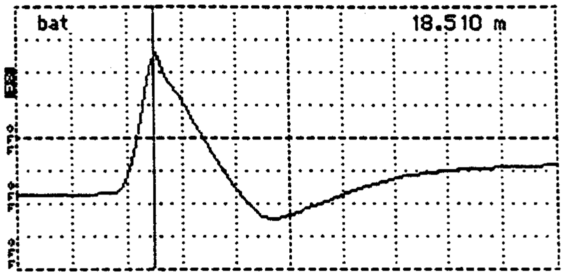
Cursor .... 18.550 m
Distance/Div ..... .25 m/div
Vertical Scale.... 53.0 mρ/div
Vp 0.99
Noise Filter ...... 1 avg
Power .... bat



Tektronix 1502B TDR
Date 8/5/93
Cable #6
Notes
Site 491001

Input Trace
Stored Trace
Difference Trace

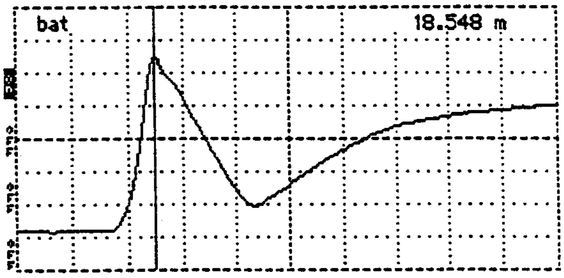
Cursor .... 18.510 m
Distance/Div ..... .25 m/div
Vertical Scale.... 45.9 mρ/div
Vp 0.99
Noise Filter ...... 1 avg
Power .... bat



Tektronix 1502B TDR
Date 8/5/93
Cable #7
Notes
Site 491001

Input Trace
Stored Trace
Difference Trace

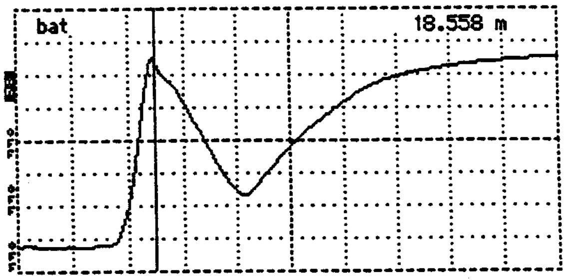
Cursor .... 18.548 m
Distance/Div ..... .25 m/div
Vertical Scale.... 39.7 mρ/div
Vp 0.99
Noise Filter ...... 1 avg
Power .... bat



Tektronix 1502B TDR
Date 8/5/93
Cable #8
Notes
Site 491001

Input Trace
Stored Trace
Difference Trace

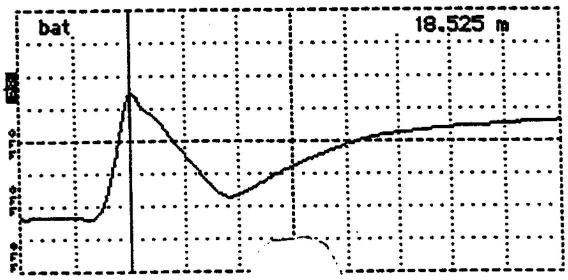
Cursor .... 18.558 m
Distance/Div ..... .25 m/div
Vertical Scale.... 37.5 mρ/div
Vp 0.99
Noise Filter ...... 1 avg
Power .... bat



Tektronix 1502B TDR
Date 8/5/93
Cable #9
Notes
Site 491001

Input Trace
Stored Trace
Difference Trace

Cursor .... 18.525 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 8/5/93
Cable #10
Notes
Site 491001

Input Trace
Stored Trace
Difference Trace

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

LTPP Seasonal Monitoring Study Moisture Contents (%)	* State Code [49] * Test Section Number [1001]

Personnel : Jason M. Dietz
Date : 8/5/93
Start Time : 12:30 PM
Finish Time : 2:00 PM
Surface Type : Asphalt Concrete
Weather Conditions : Clear 32.2°C
Unusual Conditions : None

TDR Probe #	Moisture Content (%)
10	5.76
9	4.15
8	5.91
7	5.34
6	4.87
5	5.15
4	5.27
3	4.72
2	6.09
1	3.41

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 from the onsite datalogger during initial data collection, August 5 - August 6, 1993

```
4,217,600,33.69,0
5,217,600,45.44,42.67,40,37.05,35.52
6,217,601,-351.7,-795,-1219,-1606,-1894,-2065,-2156,-2200,-2222,-2233,-2238,-2239,-2241,-2241,-2242,-2241,-2242,-2242,-2243,-2242,-2243,-2242,-2243,-2241,-2242,-2242,-2241,-2241,-2241,-2242,-2242,-2243,-2244,-2243,-2
4,217,700,33.26,0
5,217,700,43.54,42.22,40.25,37.46,35.91
4,217,800,31.78,0
5,217,800,40.14,40.67,39.92,37.8,36.32
4,217,900,29.94,0
5,217,900,36.98,38.56,38.96,37.84,36.6
4,217,1000,28.48,0
5,217,1000,34.79,36.71,37.79,37.56,36.71
4,217,1100,26.7,0
5,217,1100,33.12,35.22,36.67,37.09,36.64
4,217,1200,24.51,0
5,217,1200,31.84,34,35.66,36.54,36.44
6,217,1201,139,-439.6,-1003,-1550,-2020,-2309,-2449,-2512,-2537,-2547,-2552,-2553,-2554,-2555,-2555,-2554,-2553,-2553,-2550,-2549,-2549,-2549,-2550,-2549,-2549,-2549,-2547,-2548,-2550,-2549,-2549,-2548,-2549,-2548,-2
4,217,1300,22.43,0
5,217,1300,30.72,32.95,34.75,35.94,36.14
4,217,1400,21.66,0
5,217,1400,29.93,32.16,33.97,35.35,35.81
4,217,1500,20.36,0
5,217,1500,29.27,31.53,33.33,34.8,35.44
4,217,1600,19.23,0
5,217,1600,28.36,30.76,32.68,34.29,35.08
4,217,1700,17.64,0
5,217,1700,27.52,29.97,32.02,33.77,34.7
4,217,1800,16.11,0
5,217,1800,26.77,29.25,31.35,33.25,34.31
6,217,1801,-515.4,-1124,-1716,-2189,-2456,-2576,-2626,-2647,-2653,-2657,-2658,-2659,-2659,-2658,-2659,-2658,-2658,-2657,-2657,-2657,-2657,-2657,-2658,-2657,-2655,-2655,-2654,-2655,-2656,-2657,-2657,-2656,-2655,-2655,-2
4,217,1900,16.2,0
5,217,1900,26.16,28.59,30.73,32.73,33.92
4,217,2000,17.92,0
5,217,2000,26.52,28.28,30.22,32.23,33.52
4,218,900,20.66,0
5,218,900,28.39,28.97,30.12,31.76,33.07
4,218,1000,23.95,0
5,218,1000,30.23,29.82,30.38,31.61,32.84
4,218,1100,27.12,0
5,218,1100,35.04,32.29,31.32,31.6,32.61
4,218,1200,29.55,0
5,218,1200,36.8,34.86,32.98,32.01,32.58
6,218,1201,-275.8,-769,-1245,-1690,-2019,-2207,-2300,-2343,-2363,-2373,-2375,-2377,-2377,-2377,-2377,-2377,-2379,-2378,-2377,-2376,-2376,-2375,-2375,-2375,-2375,-2373,-2375,-2375,-2375,-2375,-2375,-2373,-2373,-2374,-2
4,218,1300,31.37,0
5,218,1300,39.97,36.15,34.02,32.7,32.79
```

Note: The time 600 was 1800 on Julian day 217.

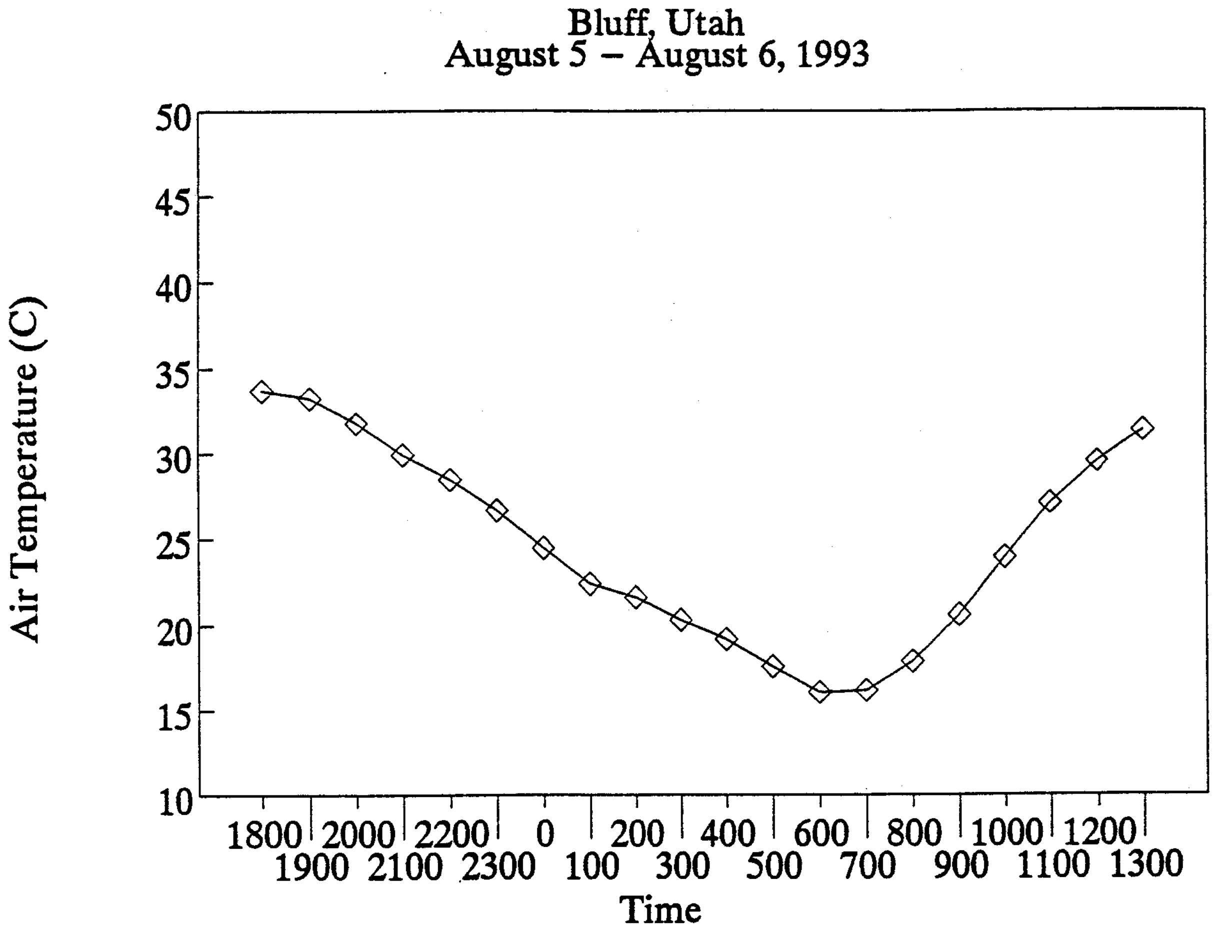


Figure D-1. Measured air temperature during initial data collection.

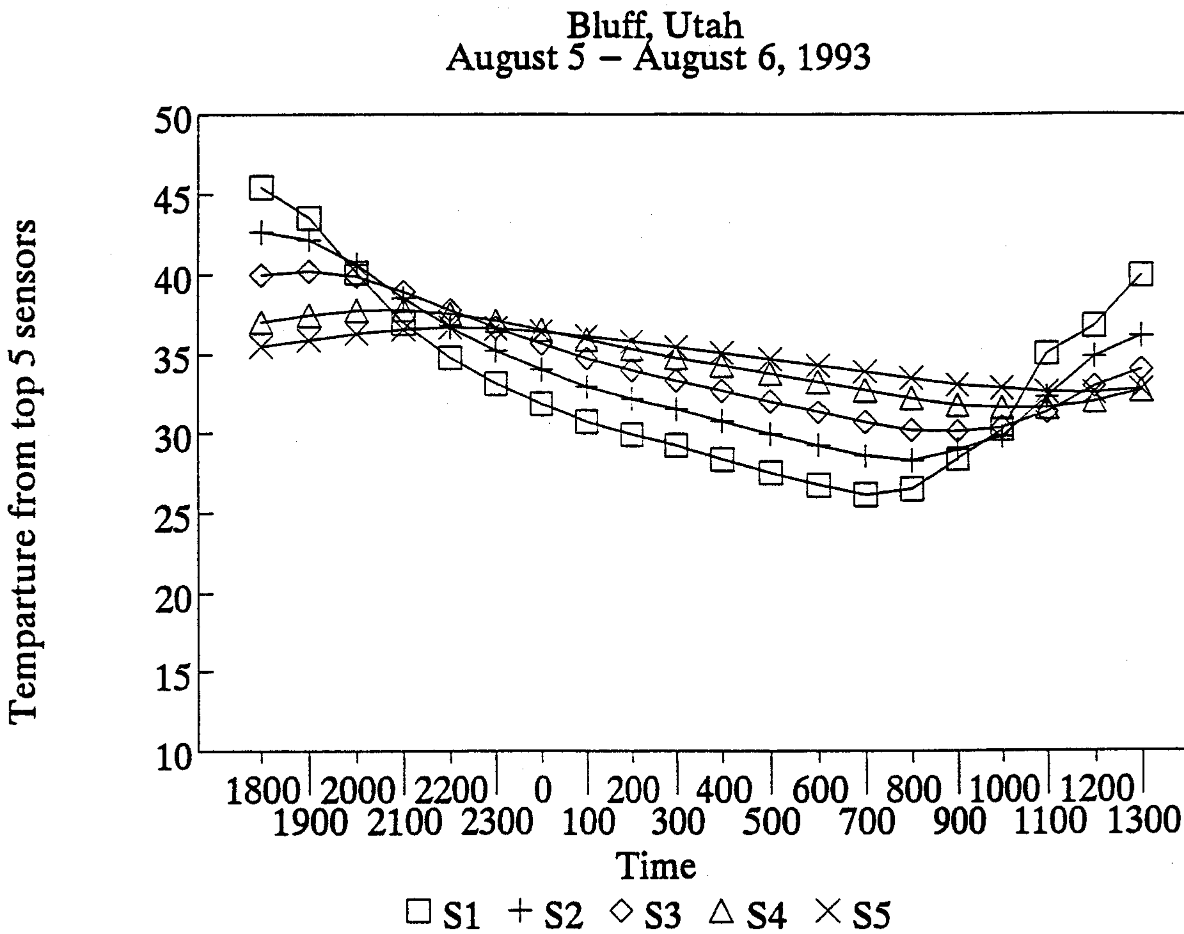


Figure D-2. Measured hourly average subsurface temperature for the first 5 sensors during initial data collection.

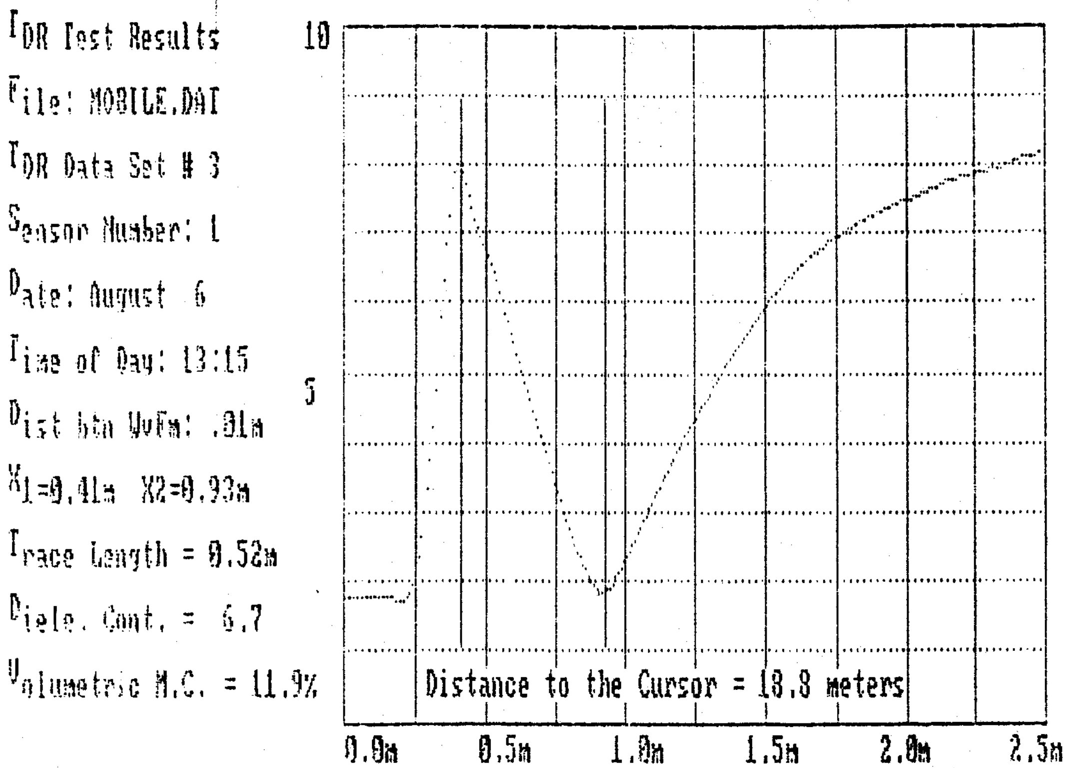


Figure D-3. Trace from TDR sensor 1.

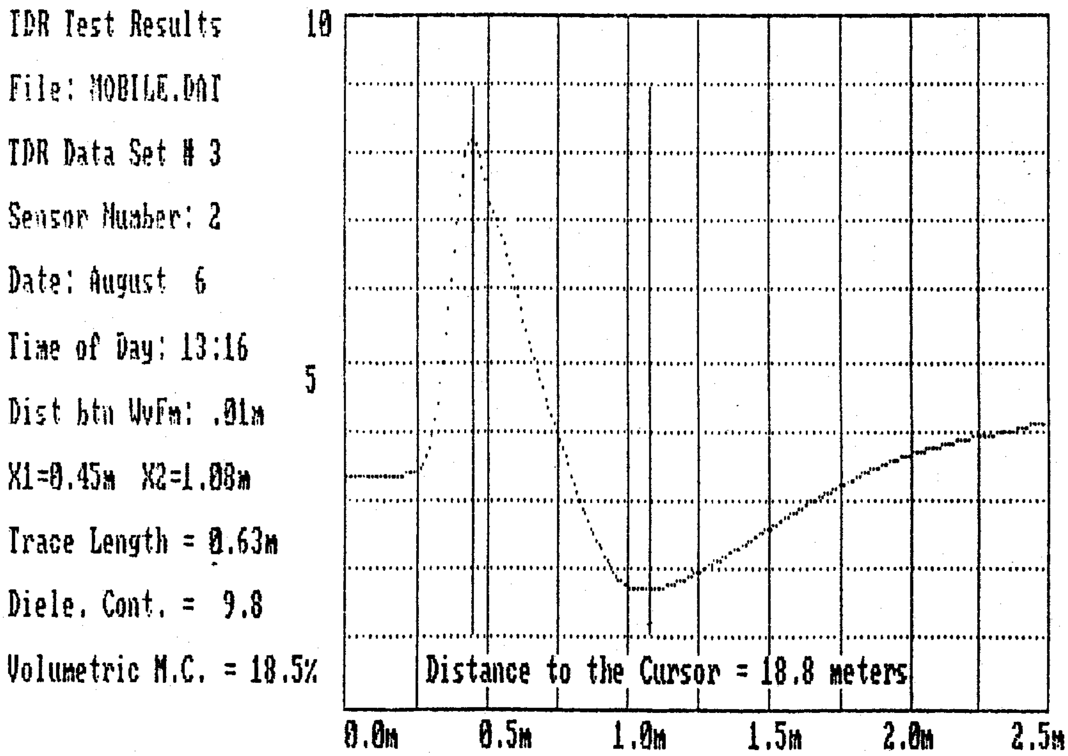


Figure D-4. Trace from TDR sensor 2.

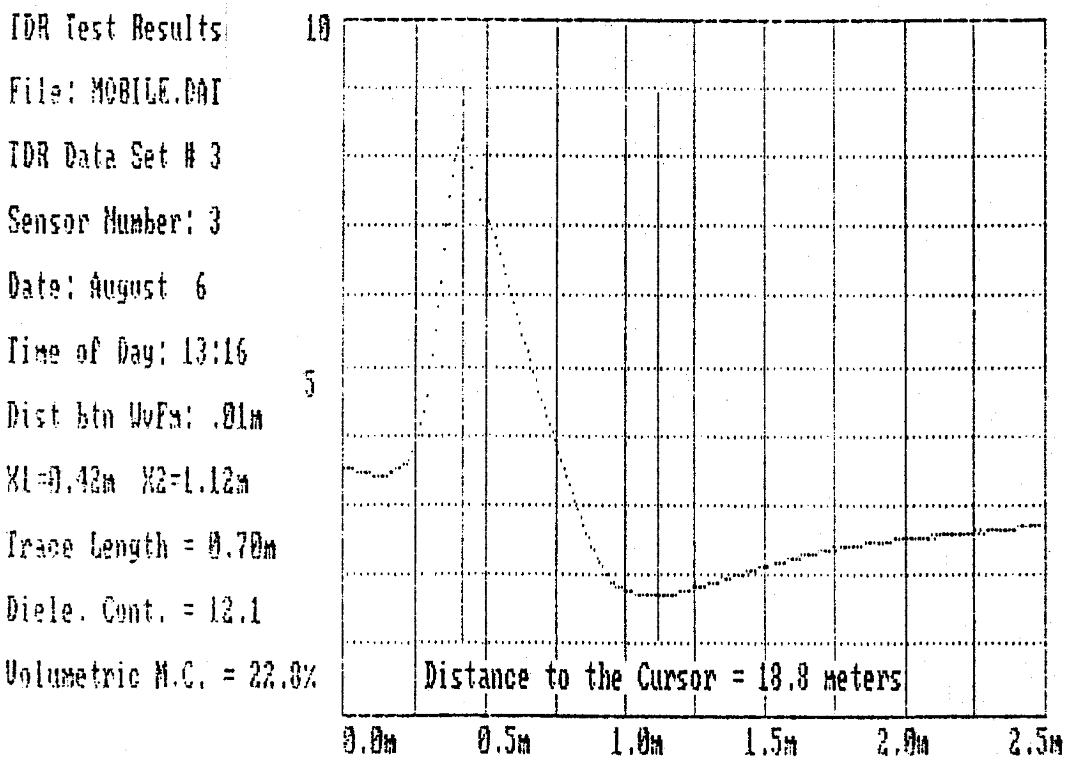


Figure D-5. Trace from TDR sensor 3.

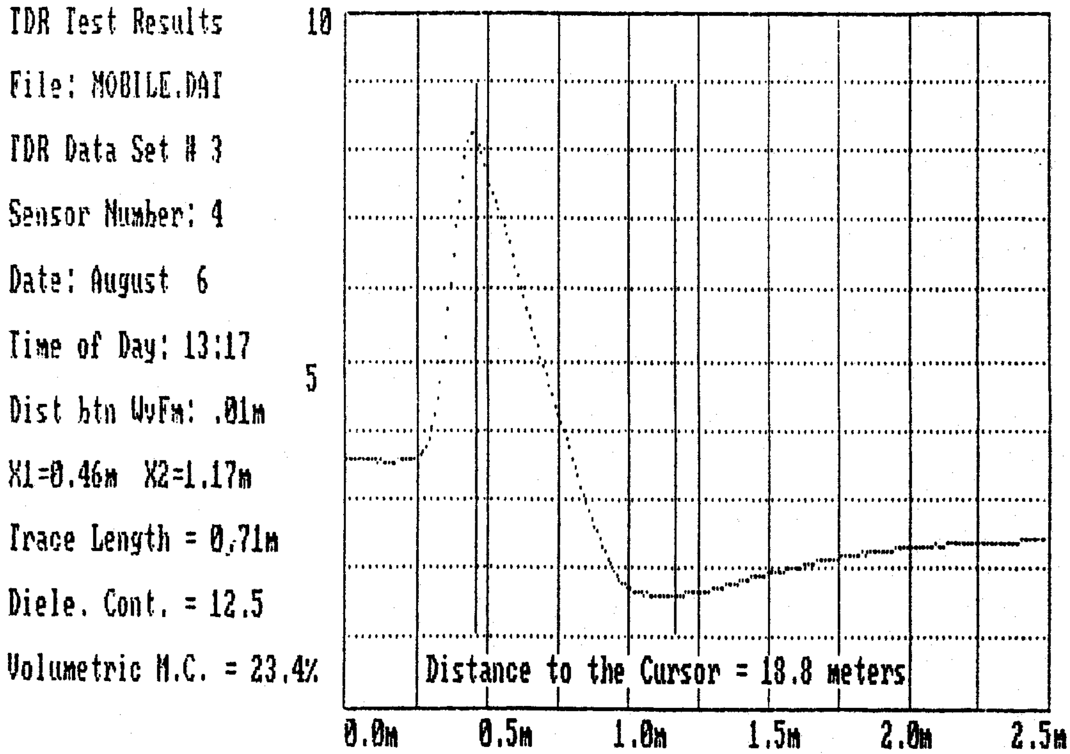


Figure D-6. Trace from TDR sensor 4.

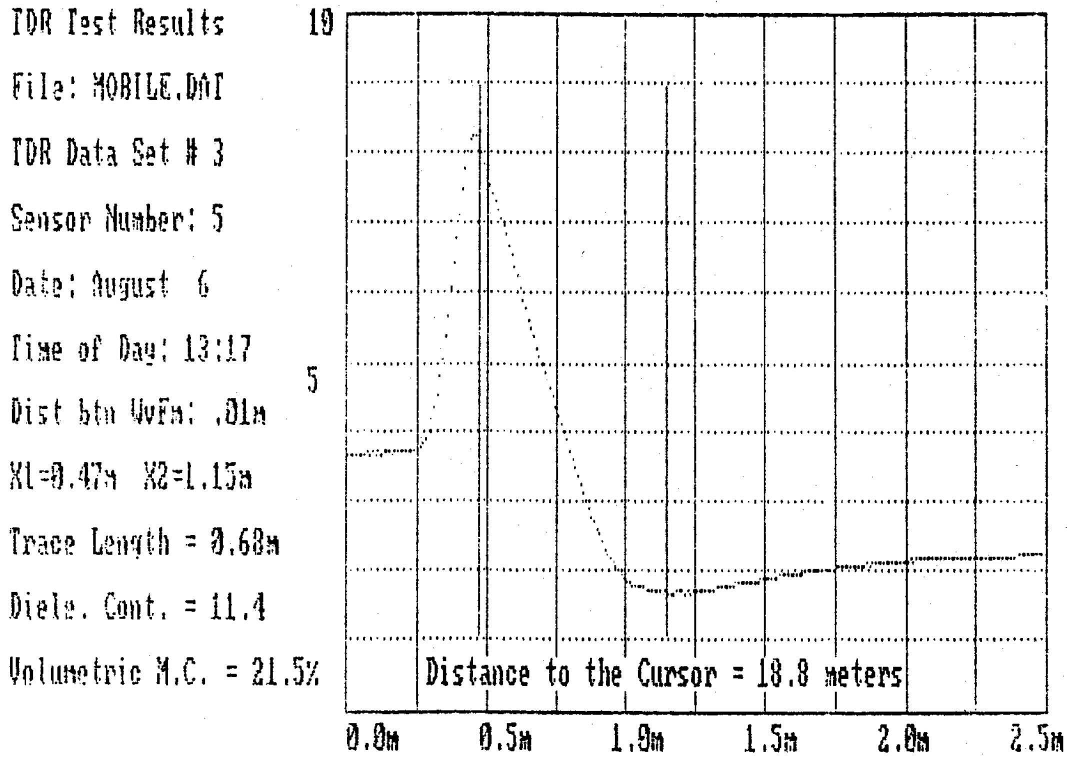


Figure D-7. Trace from TDR sensor 5.

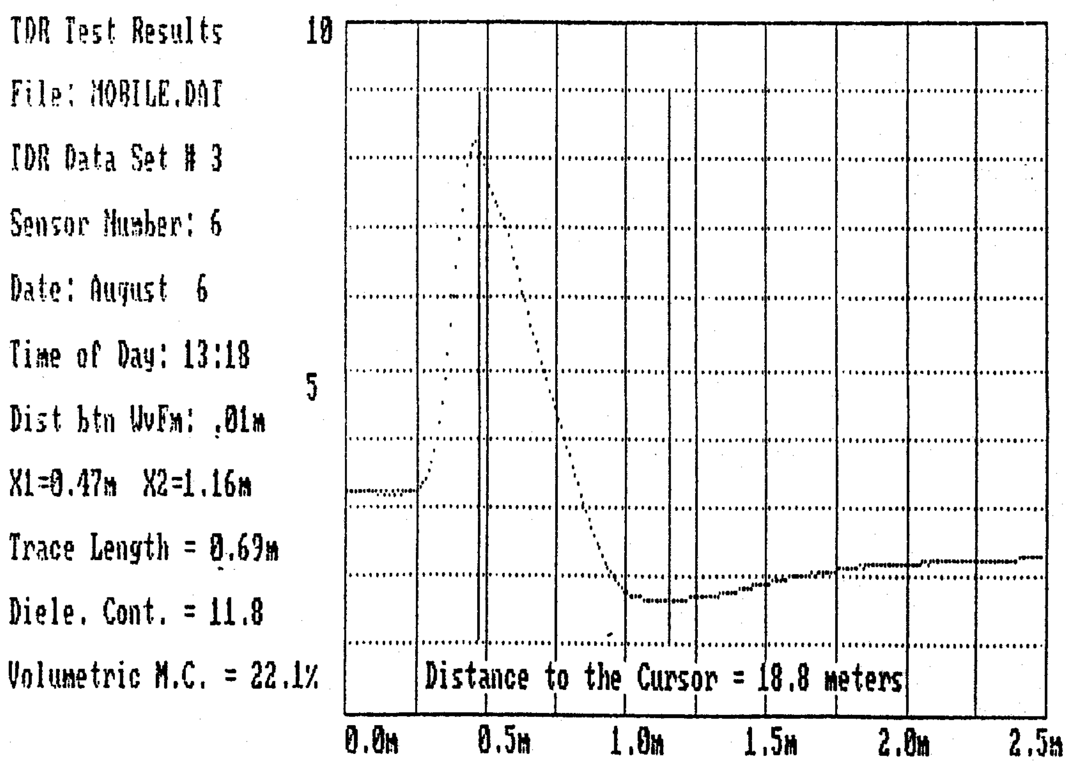


Figure D-8. Trace from TDR sensor 6.

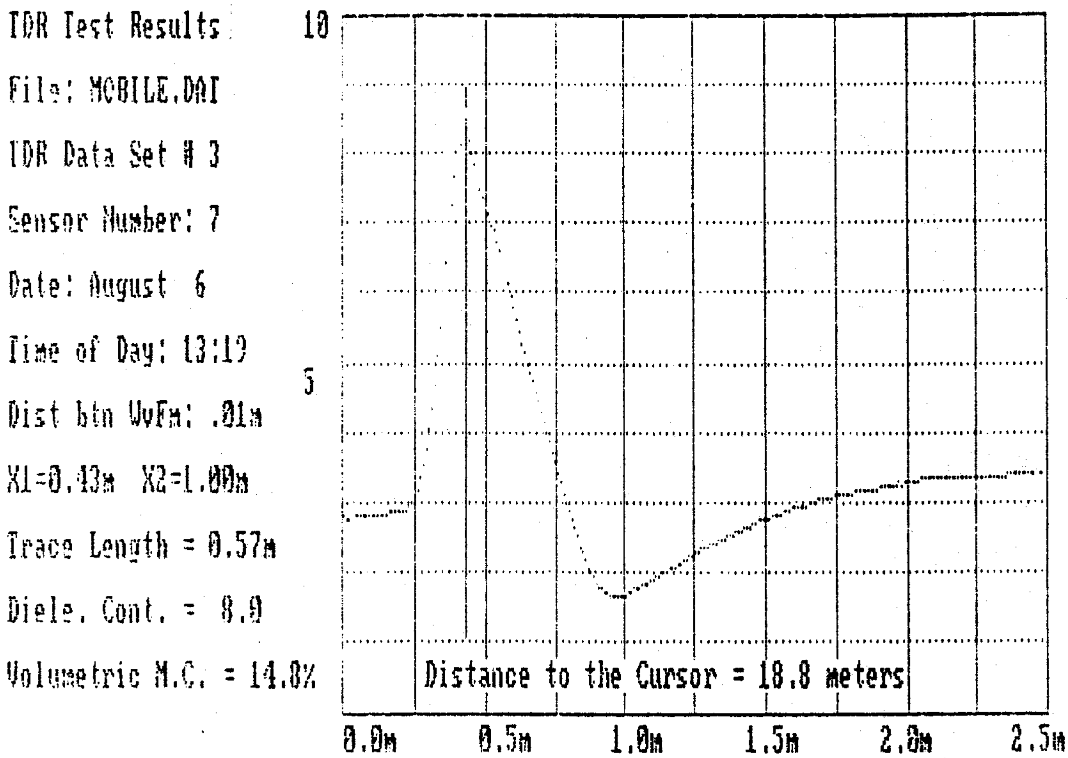


Figure D-9. Trace from TDR sensor 7.

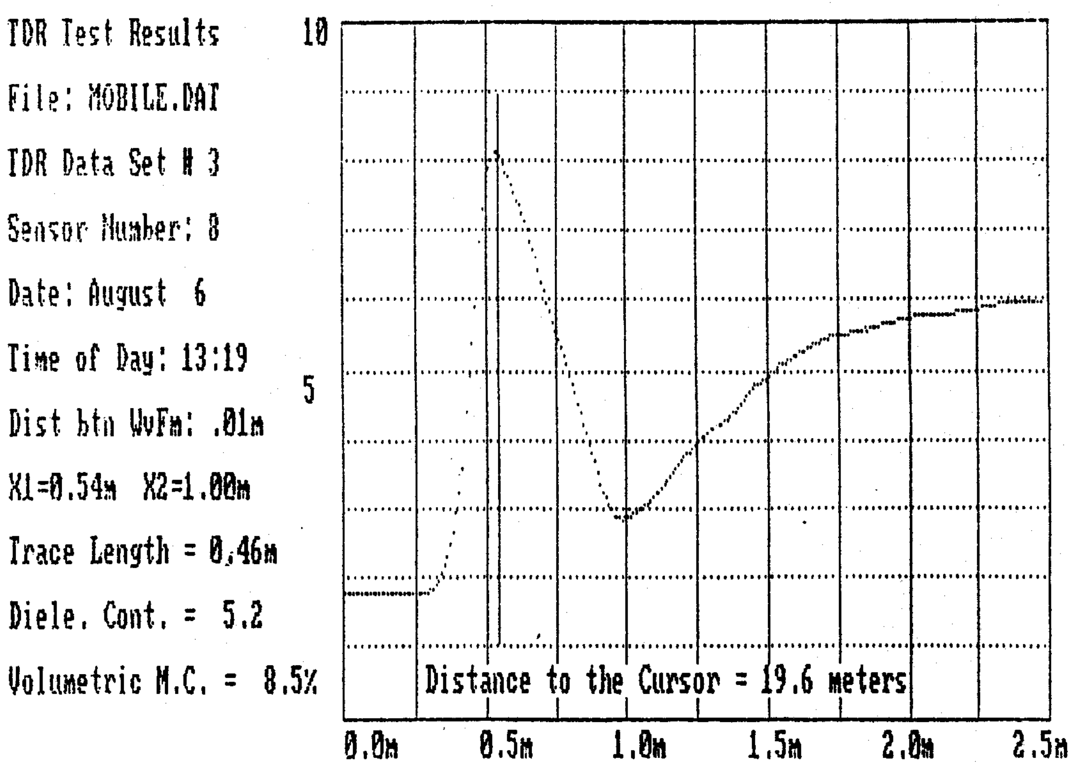


Figure D-10. Trace from TDR sensor 8.

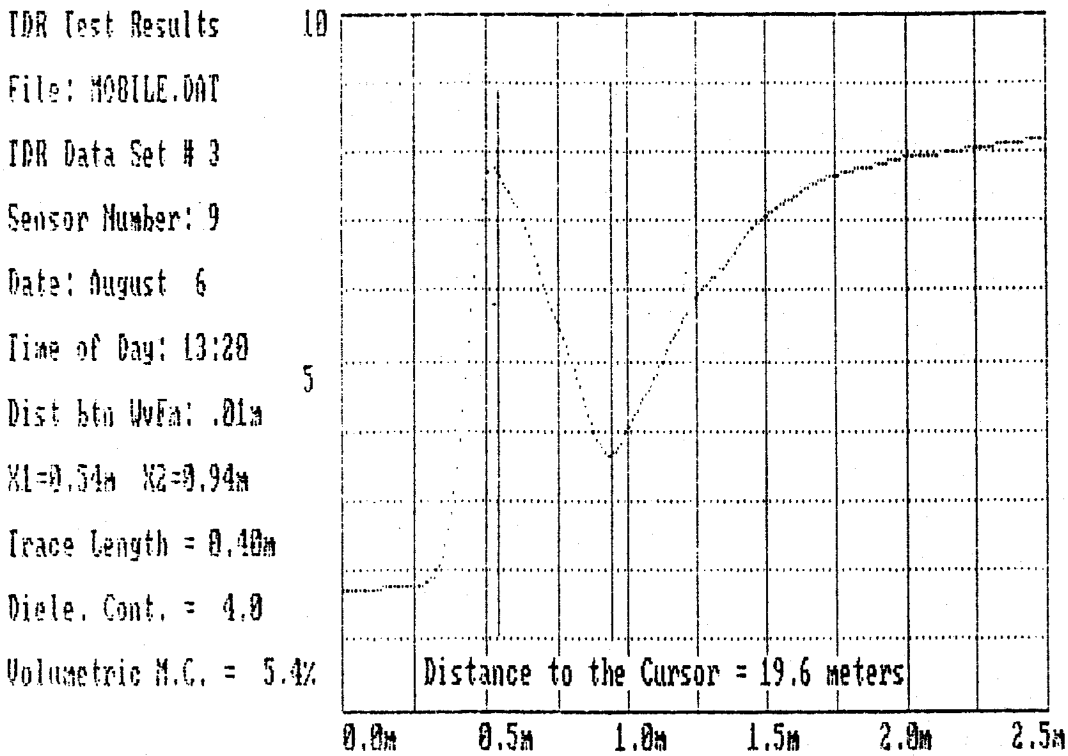


Figure D-11. Trace from TDR sensor 9.

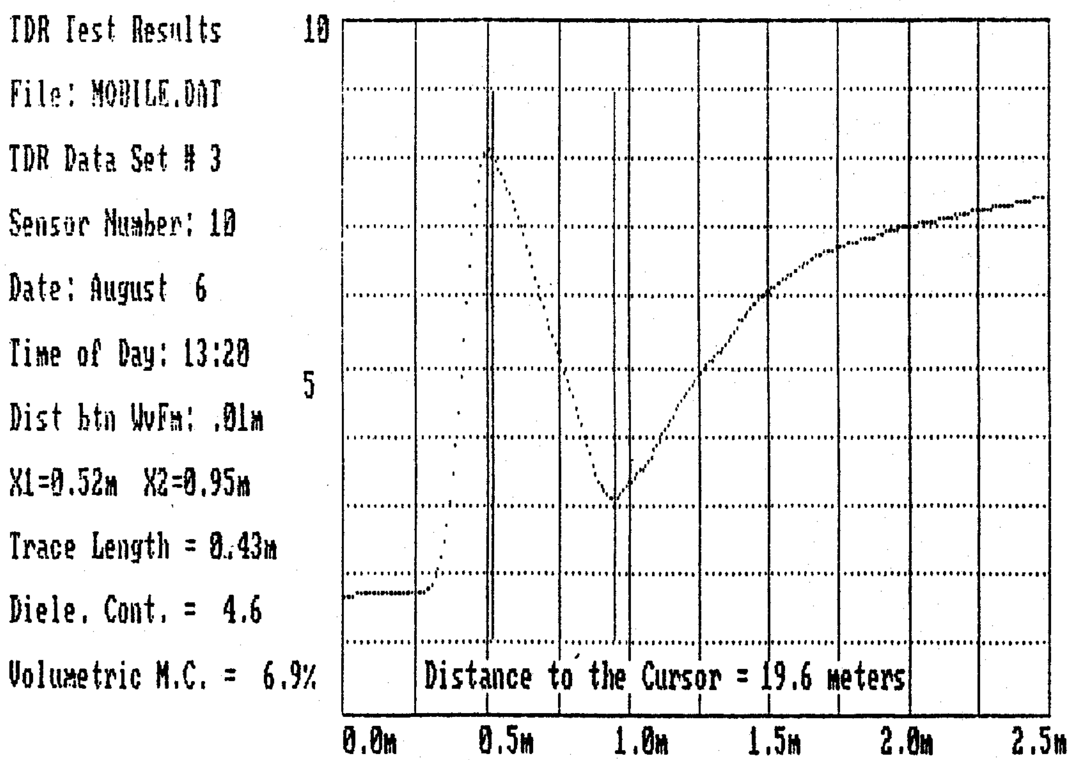


Figure D-12. Trace from TDR sensor 10.

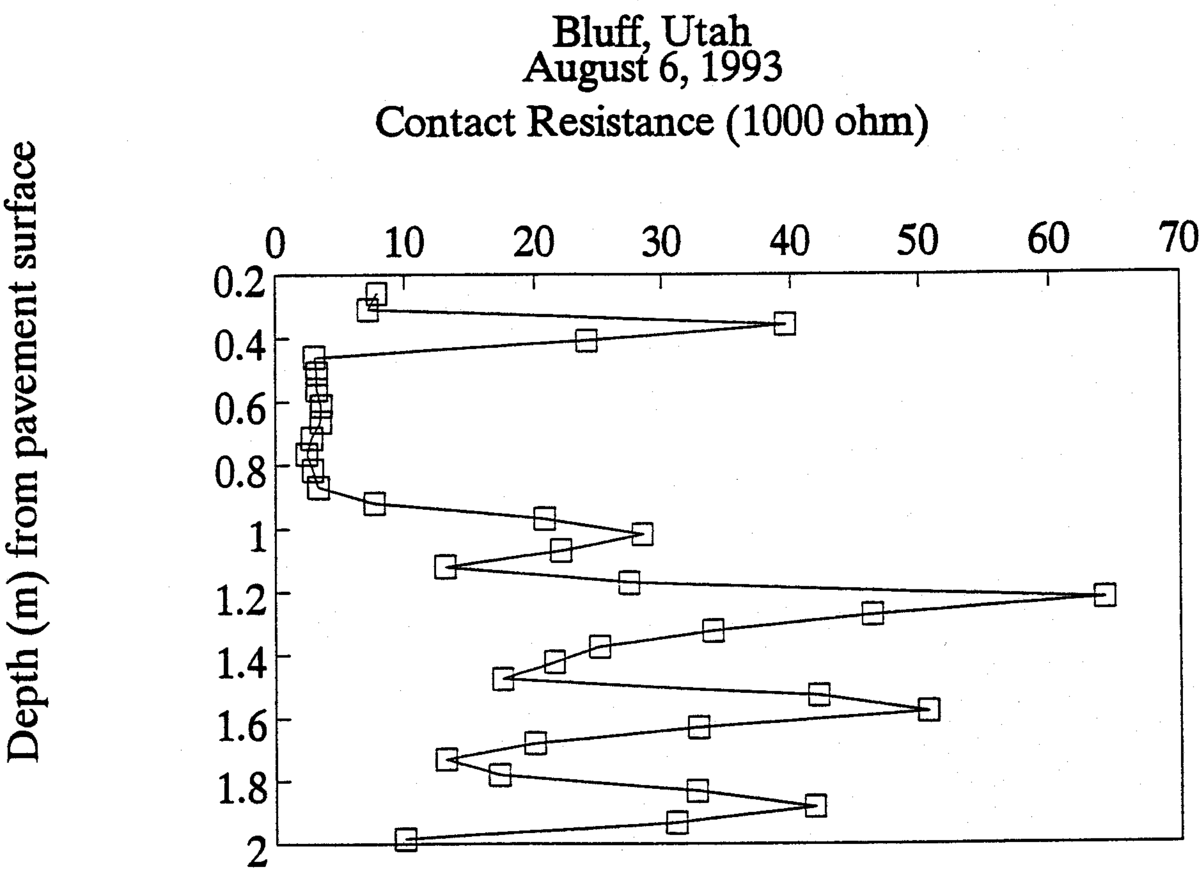


Figure D-13. Manually collected contact resistance.

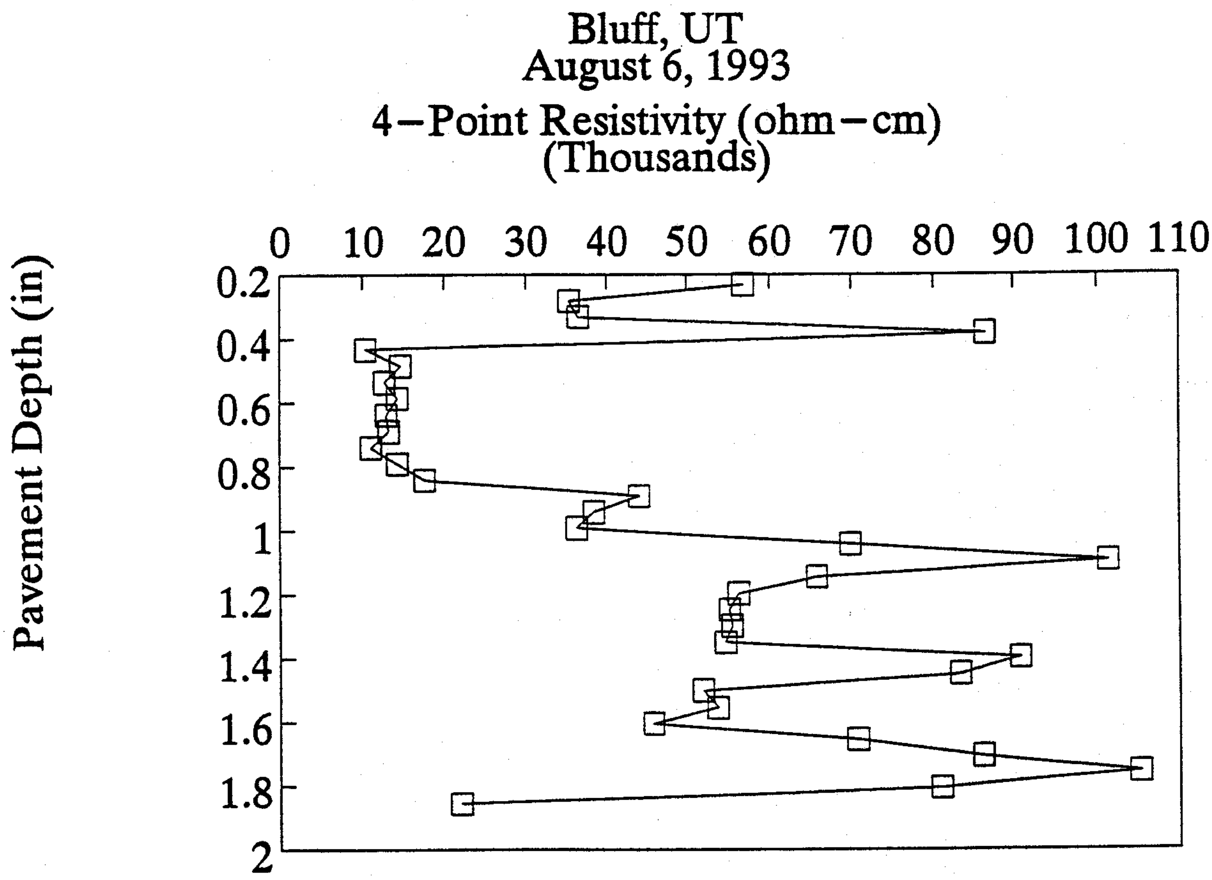


Figure D-14. Manually collected 4-point resistivity.

Table D-2 Contact Resistance Measurement Data Sheet

SEASONAL INSTRUMENTATION DATA COLLECTION SHEET

Resistant Measurements

Site No: 491001

Sheet ____ of ____

Collected by: JH

Time Collected: 1:40pm

Date: 8/6/93

Weather Conditions: Hot

FWD Run? Y

Connections	Voltage		Current		Comments
I_1, V_1	Range Setting	Reading	Range Setting	Reading	
1, 2	20V	4.64	2m	.500	
2, 3		4.63		.645	
3, 4		8.87		.224	
4, 5		8.91		.370	
5, 6		3.53		1.174	
6, 7		3.58		1.112	
7, 8		3.52		1.104	
8, 9		3.54		1.005	
9, 10		3.60		1.036	
10, 11		3.57		1.200	
11, 12		3.25		1.337	
12, 13		3.28		1.135	
13, 14		3.65		1.116	
14, 15		3.74		.489	
15, 16		6.76		.326	
16, 17		6.79		.239	
17, 18		6.08		.276	
18, 19		6.09		.464	
19, 20		7.85		.287	
20, 21		7.89		.123	
21, 22		7.32		.158	
22, 23		7.33		.216	
23, 24		6.70		.268	
24, 25		6.71		.312	
25, 26		6.35		.362	
26, 27		6.40		.152	
27, 28		7.44		.147	
28, 29		7.44		.227	
29, 30		6.09		.305	
30, 31		6.10		.464	
31, 32		7.00		.405	
32, 33		7.08		.217	
33, 34		7.23		.173	
34, 35		7.29		.235	
35, 36		4.06		.407	

Replaced with "new" battery about 1.24V/[illegible]

Table D-3 Four Point Resistivity Measurement Data Sheet

SEASONAL INSTRUMENTATION DATA COLLECTION SHEET

Resistivity Measurements

Site No: 491001

Sheet ____ of ____

Collected by: HZ

Time Collected: 2:00 pm

Date: 8/6/93

Weather Conditions: Hot

FWD Run? Y

Read No.	Connections				Voltage		Current		Comments
	I_1	V_1	V_2	I_2	Range Set	Reading	Range Set	Reading	
1	1	2	3	4	200m	47.0	200μ	51.9	
2	2	3	4	5		102.0		188.7	
3	3	4	5	6		100.8		170.3	
4	4	5	6	7		106.0		797	
5	5	6	7	8	122.4	~~47.6~~	2m	.745	
6	6	7	8	9		134.9		.601	
7	7	8	9	10		145.0		.700	
8	8	9	10	11		143.7		.657	
9	9	10	11	12		131.6		.628	
10	10	11	12	13		130.6		.638	
11	11	12	13	14		138.7		.781	
12	12	13	14	15		105.6		.482	
13	13	14	15	16		114.6		.403	
14	14	15	16	17		140.9		.204	
15	15	16	17	18		125.2		.241	
16	16*	17/15	18/2	19/1		112.2		.191	
17	17	18	19	20		93.6		.088	
18	18	19	20	21		157.3		.098	
19	19	20	21	22		149.7		.146	
20	20	21	22	23		79.8		.091	
21	21	22	23	24		98.1		.109	
22	22	23	24	25		114.0		.138	
23	23	24	25	26		139.5		.157	
24	24	25	26	27		113.9		.082	
25	25	26	27	28		148.2		.113	
26	26	27	28	29		104.3		.132	
27	27	28	29	30		108.7		.128	
28	28	29	30	31		119.5		.165	
29	29	30	31	32		131.0		.120	
30	30	31	32	33		163.3		.118	
31	31	32	33	34	2V	.205		.128	
32	32	33	34	35		.168		.130	
33	33	34	35	36		.108		.313	

* Alternate reading configuration for Idaho section (163023).

Replaced with "new" battery about 1.24 v/each

Table D-4 Surface Elevation Measurement Data Sheet

LTPP Seasonal Monitoring Study Surface Elevation Measurements	* State Code [49] * Test Section Number [1001]

Surveyed : Jason M. Dietz
Date : 8/6/93
Start Time : 10:30 PM
Finish Time : 12:00 PM
Surface Type : Asphalt Concrete
Weather Conditions : Clear 32.2°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	1.339	1.348	1.380	1.391	1.423
0+25	3+25	1.321	1.328	1.357	1.366	1.394
0+50	3+50	1.293	1.300	1.327	1.335	1.360
0+75	3+75	1.275	1.278	1.303	1.307	1.332
1+00	4+00	BM	1.258	1.281	1.286	1.304
1+25	4+25	1.234	1.237	1.266	1.273	1.291
1+50	4+50	1.210	1.217	1.243	1.248	1.268
1+75	4+75	1.176	1.183	1.207	1.216	1.238
2+00	5+00	1.154	1.157	1.182	1.190	1.213

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

→ Eastbound Direction. US 163 West of Bluff, UT

0+00 1+00 5+00

o

(Bench Mark)
Observation Well
@ 2.61 m from OLE

APPENDIX E

Photographs

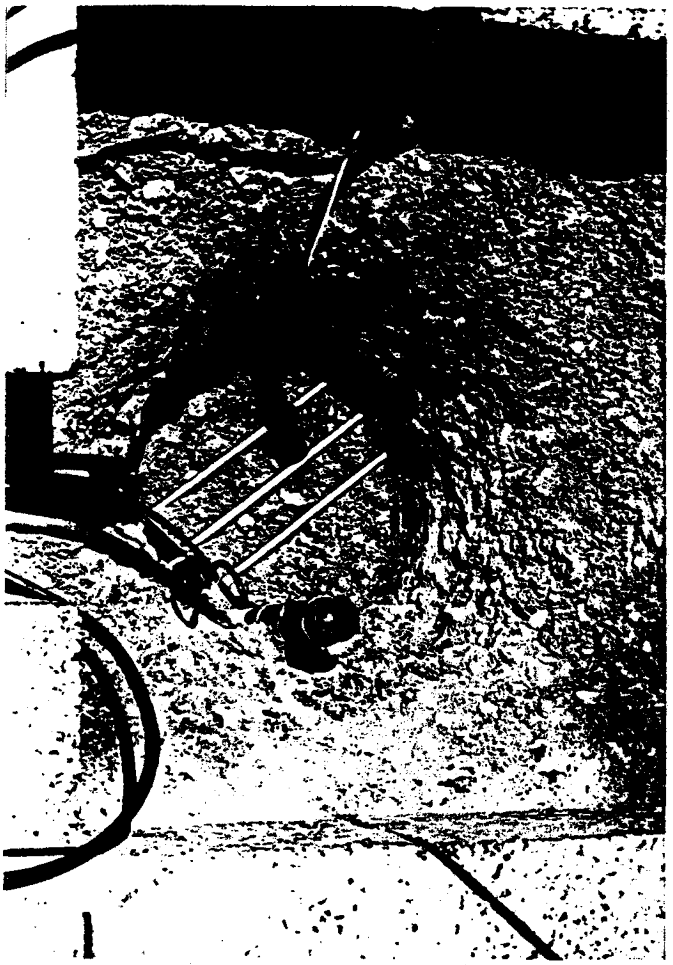


Figure E-1. Position of in-pavement instrumentation.

Figure E-2. Repair of the instrumentation hole.

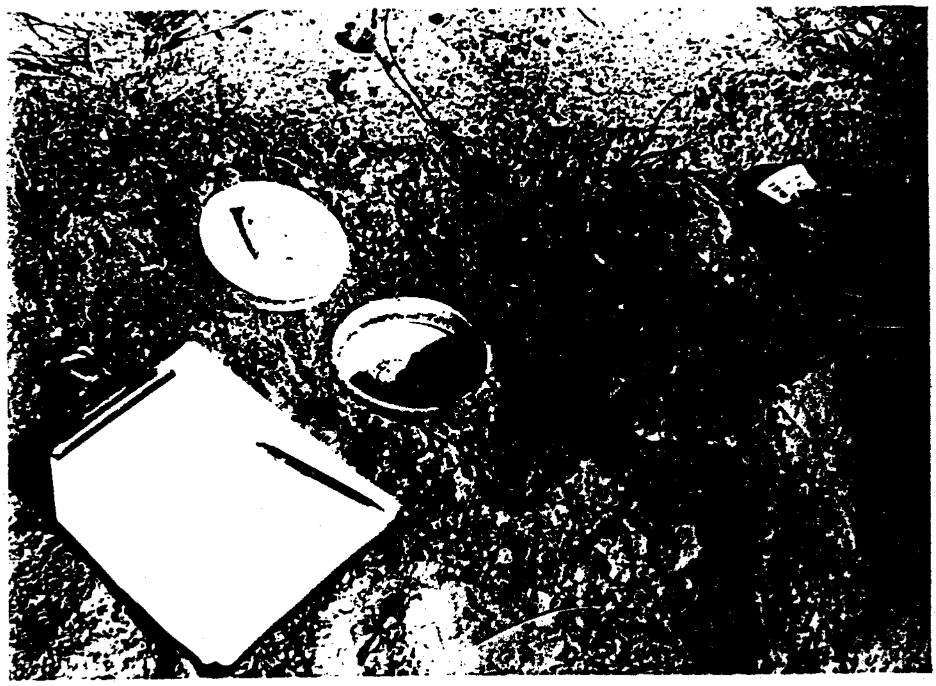


Figure E-3. Completed piezometer/bench mark.

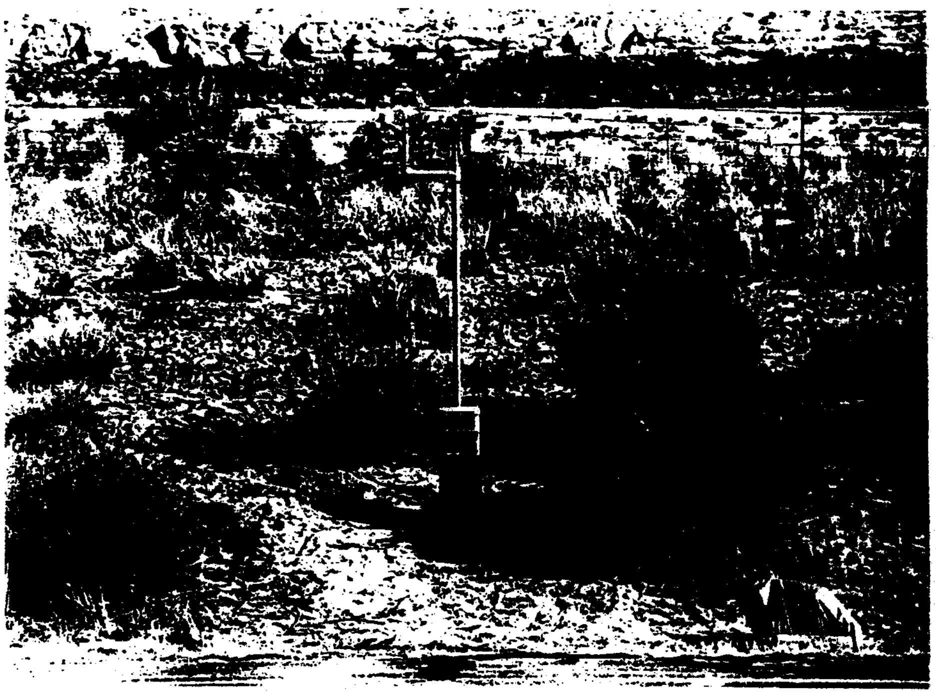


Figure E-4. Placement of equipment cabinet and climatic sensors.