14573

DEVELOPMENT OF AN INSTRUMENTATION PLAN FOR THE OHIO SPS TEST PAVEMENT (DEL-23-17.48)

Job No. 14573(0)

FINAL REPORT

FOR

OHIO DEPARTMENT OF TRANSPORTATION, and FEDERAL HIGHWAY ADMINISTRATION

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16. Abstract

A Specific Pavement Studies (SPS) program, formulated under the Strategic Highway Research Program (SHRP), consists of nine experiments, four of which will be included in this DEL-23 project. Since the basic instrumentation plan proposed by SHRP was limited, Ohio Department of Transportation opted to develop a more comprehensive plan for DEL-23. The Ohio Test Road consists of SPS-1, SPS-2, SPS-8, and SPS-9 experiments, all constructed for this project where the climate, soil, and topography are uniform throughout. In this comprehensive instrumentation plan, thirty-three sections are to be instrumented. LTPP guidelines require four instrumented sections in each of the SPS-1 and SPS-2 experiments for the study of seasonal factors and dynamic response. DEL-23 includes an additional nine instrumented sections for the SPS-1 experiment, twelve sections for the SPS-2 experiment, and two sections each in the SPS-8 and SPS-9 experiments to study structural response parameters. A total of eighteen sections will be instrumented for the study of seasonal factors, ten more sections than required by SHRP.

This report provides a detailed description of types of sensors, installation methodology, calibration procedures and wiring schematics for instrumentation of pavements for the Ohio SHRP SPS Test Road to measure environmental factors and structural response. Environmental or climatic parameters include temperature, base and subbase moisture, and frost depth. Structural response parameters entail strain, deflection, pressure, and joint opening.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL STATEMENT

The AASHTO Road Test, conducted in the late 1950s and early 1960s, is the basis for the current design procedures for highway pavements. New experimental techniques have emerged since this highway design test. Electronic sensors, material testing methods, and automated data acquisition systems have recently been developed which provide researchers with additional capabilities to monitor pavement under live and nondestructive dynamic loading. Furthermore, previous test results do not reflect regional experience and are not based on mechanistic design.

A national impetus within the transportation industry is to improve the performance of flexible and rigid pavements. Attention has been focused on mechanistic design. The Strategic Highway Research Program (SHRP) initiated a series of Specific Pavement Studies (SPS) to evaluate several key performance parameters of highway pavements.

As part of the national effort, the Ohio Department of Transportation (ODOT) is planning construction of a test pavement on U.S. 23 in Delaware County. Four SPS experiments will be included, viz., SPS-1, SPS-2, SPS-8, and SPS-9. To conduct a more comprehensive highway test program, ODOT will contract with six universities in the state of Ohio to instrument 33 of the 38 test sections contained within these experiments.

In mechanistic design, pavement design is based on mechanical properties of the materials utilized in the pavement system. To formulate, calibrate, and verify this type of design, full-scale instrumentation must be implemented to monitor performance of pavement sections. The verification of mechanistic designs for several different pavement depths and materials is necessary. Measurements of multiple response parameters, such as strain, deflection, and pressure are essential. Climatic parameters including temperature, base and subbase moisture, and frost depth also affect pavement performance and must also be included in the analysis.

The purpose of this investigation is to document environmental and load response instrumentation for pavement systems as part of the Long Term Pavement Performance (LTPP) study, administered by the LTPP Division of the Federal Highway Administration. This report consists of finalized plans for instrumenting U.S. 23. A discussion of instrumentation, types of sensors, installation procedures, and locations of instrumentation is included.

1.2 OUTLINE

The objective of the current study is to design a detailed instrumentation plan for the SPS test pavement on U.S.23 in Delaware County. The report is structured in the following format to present this comprehensive plan effectively.

Chapter 2 constitutes comprehensive instrumentation diagrams to identify the types and location of sensors specified at each of the thirty-three pavement sections. The second part of this chapter outlines installation procedures for each sensor in a step-by-step manner. The last part of Chapter 2 is concerned with calibration procedures to be implemented for these sensors.

Chapter 3 is devoted to aspects of data acquisition for the DEL-23 project. Characteristics of the required data acquisition systems are outlined. Details are included for a plan to evaluate the test pavement sections both for seasonal parameters and structural response, using nondestructive test (NDT) methods and controlled vehicles. A wiring diagram is also provided to show the arrangement of pins in connectors and the location of pull-boxes where sensor wires can be connected to the data acquisition units.

Chapter 4 is focused on the work-time schedule for the DEL-23 project. The role of each participating university during the field instrumentation phase is identified.

CHAPTER 2

INSTRUMENTATION

2.1 OVERVIEW

The Specific Pavement Studies (SPS), formulated under the Strategic Highway Research Program (SHRP), consist of nine experiments, four of which will be included in the DEL-23 project. Since the basic instrumentation plan proposed by SHRP was limited, ODOT opted to develop a more comprehensive plan for DEL-23. This plan includes all instrumentation proposed under the LTPP program, with additional sensors to monitor other important pavement parameters. Objectives will encompass a long term study of structural factors, maintenance effectiveness, rehabilitation, and environmental factors on the mechanistic response of various pavement sections. Of particular interest will be the interaction of load response to environmental parameters. The Ohio Test Road consists of SPS-1, SPS-2, SPS-8, and SPS-9 experiments, all constructed on one project where the climate, soil and topography are uniform throughout.

SPS-1 (Strategic Study of Structural Factors for Flexible Pavements): Variables of the SPS-1 study include asphaltic concrete thickness, base type and thickness, and the presence or absence of drainage.

SPS-2 (Strategic Study of Structural Factors for Rigid Pavement): Variables of the SPS-2 study include portland cement concrete thickness, base type and thickness, concrete strength, pavement width, and the presence or absence of drainage.

SPS-8 (Study of Environmental Effects in the Absence of Heavy Traffic-Asphalt and Concrete): This project includes two instrumented sections, one of asphaltic concrete, and the other of portland cement concrete. These sections are located on a low volume, light weight traffic ramp to southbound

U.S. 23 where truck traffic is expected to be limited.

SPS-9 (Asphalt Program Field Verification Studies): This program consists of one asphalt concrete section for SHRP constructed with the new SHRP specifications and one supplemental state section constructed with current ODOT specifications. SPS-9 sections also include instrumentation to monitor structural response and seasonal factors. These sections are referred to as SPS-9 (SHRP Mix) and SPS-9 (ODOT Mix).

LTPP guidelines require four instrumented sections in each of the SPS-1 and SPS-2 experiments for the study of seasonal factors and dynamic response. DEL-23 includes an additional nine instrumented sections for the SPS-1 experiment, twelve sections for the SPS-2 experiment, and two sections each in the SPS-8 and SPS-9 experiments to study structural response parameters. A total of eighteen sections will be instrumented for the study of seasonal factors, ten more sections than required by SHRP.

The 33 instrumentation sections for dynamic response, and the 18 instrumentation sections for seasonal factors all exceed requirements of the LTPP pavement instrumentation program. Figure 2.1 shows an overview of the instrumentation sections. Tables 2.1 and 2.2 explain the characteristics of each section. Specific pavement base types used in the test sections include the following:
Dense Graded Aggregate Base (DGAB), Asphalt Treated Base (ATB), Permeable Asphalt Treated Base (PATB), Permeable Cement Treated Base (PCTB), Lean Concrete Base (LCB).

SHRP requires that the J2, J4, J8 and J10 sections be instrumented for the SPS-1 experiment, and the J1, J5, J8 and J12 sections be instrumented for the SPS-2 experiments. To further enhance the value of the DEL-23 project, ODOT decided to instrument a number of other sections.

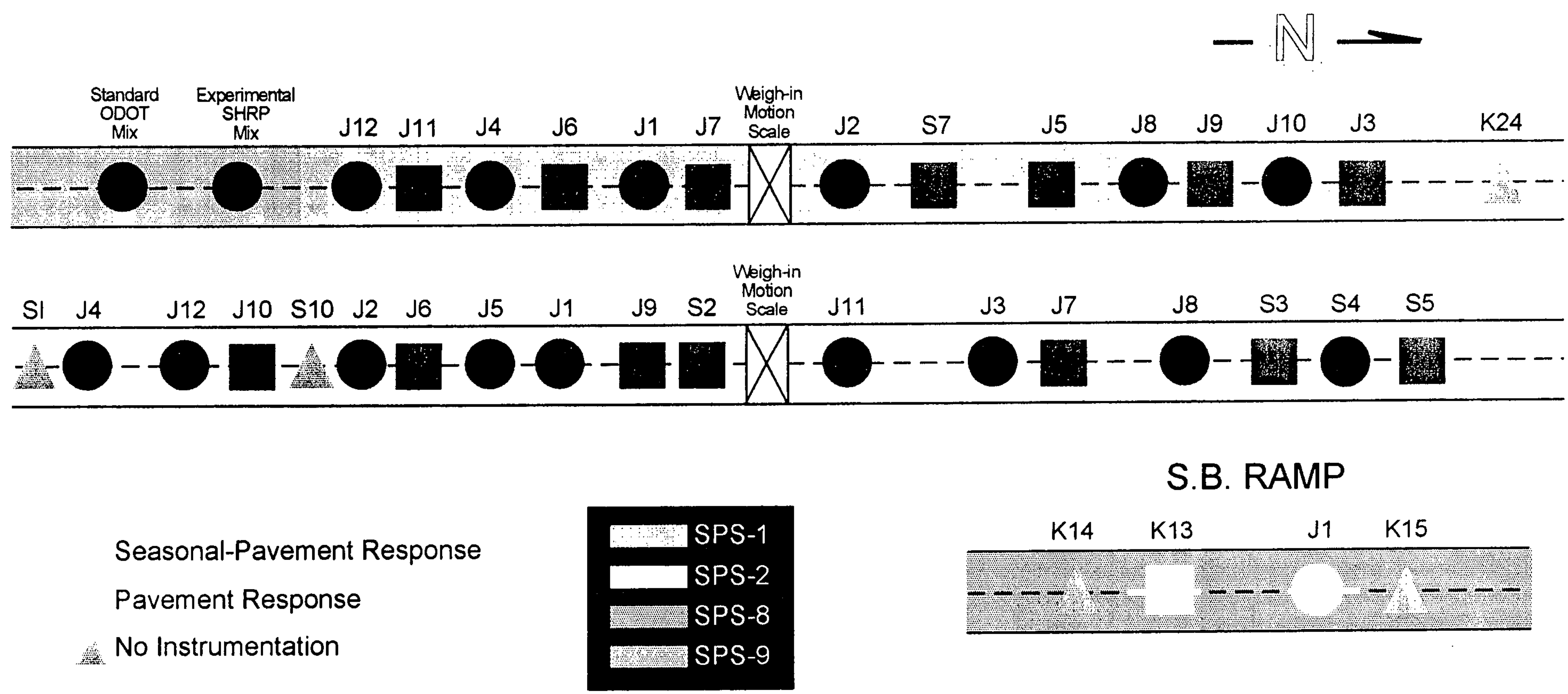


Figure 2.1 SHRP Test Pavement, DEL-23

Table 2.1: AC Sections Characteristics

ASPHALT CONCRETE STUDIES			
SPS-1			
Section	**AC Thickness** (in)	**Base Type and Thickness**	**Drain**
J1	7	8" DGAB	NO
J2	4	12" DGAB	NO
J3	4	8" ATB	NO
J4	7	12" ATB	NO
J5	4	4"ATB/ 4"DGAB	NO
J6	7	8" ATB/ 4"DGAB	NO
J7	4	4" PATB/ 4" DGAB	YES
J8	7	4" PATB/ 8"DGAB	YES
J9	7	4" PATB/ 12" DGAB	YES
J10	7	4" ATB/ 4" PATB	YES
J11	4	8" ATB/ 4" PATB	YES
J12	4	12" ATB/ 4" PATB	YES
S7	7	8" DGAB	NO
K24	7	12" ATB/ 4" PCTB/ 6" DGAB	YES
SPS-8			
K13	4	8" DGAB	NO
K14	7	12" DGAB	NO
SPS-9			
SHRP	4	12" ATB/ 4" PATB/ 6" DGAB	YES
ODOT	4	12" ATB/ 4" PATB/ 6" DGAB	YES

Table 2.2: PCC Sections Characteristics

PORTLAND CEMENT CONCRETE STUDIES					
SPS -2					
Section	**Lane Width (ft)**	**PCC Layer**		**Base Type and Thickness**	**Drain**
		Strength (PSI)	**Thickness (in.)**		
J1	12	550	8	6" DGAB	NO
J2	14	900	8	6" DGAB	NO
J3	14	550	11	6" DGAB	NO
J4	12	900	11	6" DGAB	NO
J5	12	550	8	6" LCB	NO
J6	14	900	8	6" LCB	NO
J7	14	550	11	6" LCB	NO
J8	12	900	11	6" LCB	NO
J9	12	550	8	4" PATB/ 4" DGAB	YES
J10	14	900	8	4" PATB/ 4" DGAB	YES
J11	14	550	11	4" PATB/ 4" DGAB	YES
J12	12	900	11	4" PATB/ 4" DGAB	YES
S1	12	900	11	6" DGAB	YES
S2	14	ODOT	11	4" PCTB/ 4" DGAB	YES
S3	12	ODOT	11	4" PCTB/ 4" DGAB	YES
S4	14	ODOT	11	6" DGAB	YES
S5	12	ODOT	11	6" DGAB	YES
S10	12	ODOT	11	4" PATB/ 4" DGAB	YES
SPS-8					
J1	12	550	8	6" DGAB	NO
K15	12	550	11	6" DGAB	NO

2.2 INSTRUMENTATION

2.2.1 Introduction

The selection of sensors, installation procedures, and location of instrumentation are based on previous field studies conducted in the United States and Canada. Two workshops held in Columbus, Ohio, in 1993 brought together experts in instrumentation from the FHWA, universities, several state Departments of Transportation, and the U.S. Army Corps of Engineers. During these workshops, experiences obtained from Mn/Road, North Carolina Test Pavement, I-80 in Iowa, Denver Airport, U.S.33 and S.R.2 in Ohio, and the Alberta Research Council were shared and discussed. These discussions provided information and background for planning the DEL-23 project.

Mathematical modeling such as finite element, boundary element, and finite difference are essential to any mechanistic design procedure for pavement systems. There are several mathematical models in present use to predict the behavior of rigid and flexible pavements, and to model joint and loading conditions. Any mathematical model and design procedure must be completely verified before it is widely applied. It is unrealistic to verify these models with only one parameter such as deflection. Thus, measured parameters to be applied to model verification are:

- Pressure between layers.
- Deflection of layers.
- Temperature distribution.
- Frost depth.
- Strain in pavement.
- Joint opening.

Mathematical model predictions are heavily influenced by input parameters such as material characteristics. Since these properties vary with temperature, moisture, and stress path, field results must be supplemented with comprehensive material testing in the laboratory. Failure criteria for various materials must also be determined.

Sensors for structural response were selected based on their cost, accuracy, sensitivity, longevity and successful performance in S.R.2 (Instrumentation of a Rigid Pavement System), and U.S.33 (A Demonstration project on Instrumentation of a Flexible Pavement) projects in Ohio. Also, these instruments are selected based on FHWA recommendations and past experience with pavement instrumentation. Sensors for environmental factors were selected in consultation with FHWA personnel charged with coordinating the LTPP program for SHRP. FHWA has modified existing environmental sensors and successfully utilized them in other LTPP sites around the country.

The main parameters that will be monitored can be divided into two groups; response parameters, and seasonal parameters. Table 2.3 lists the type of sensors that will be used in monitoring each parameter.

Table 2.3: List of Sensors for Response/Seasonal Parameters

Category	Parameter Monitored	Sensor To Be Used
Response Parameters	Strain (AC Sections)	Dynatest Past-II AC
	Strain (PCC Sections)	Dynatest Past-II PCC TML KM-100B TML PMR-60 Carlson A-8
	Deflection	Schaevitz GPD 121-500 DC-LVDT
	Pressure	Geokon Model 3500 Pressure Cell
Seasonal Parameters	Base/Subbase Temperature	MRC Thermistor Probes
	Pavement Temperature	MRC Thermistor Probes
	Volumetric Water Content	TDR Probes
	Frost Depth	CRREL Resistivity Probes

2.2.2 Seasonal Parameter Sensors

Instrumentation for monitoring seasonal parameters are identical for SPS-1, SPS-2, SPS-8, and SPS-9 sections. Instrumentation details have been developed as part of the LTPP Seasonal Monitoring Program (SMP). Seasonal monitoring will provide a fundamental understanding of the magnitude and impact of seasonal variations in pavement load response along with properties due to separate and combined effects of temperature and moisture variation within the pavement. As part of the DEL-23 study, pavement structural response due to seasonal variations will be monitored.

An automatic weather station supplied by SHRP will be installed to collect data related to air temperature, precipitation (rain and snow), wind speed and direction, relative humidity, and incoming solar radiation. Each pavement section will be instrumented to identify temperature, moisture, frost depth, and ground water table elevation. The following instruments will be used:

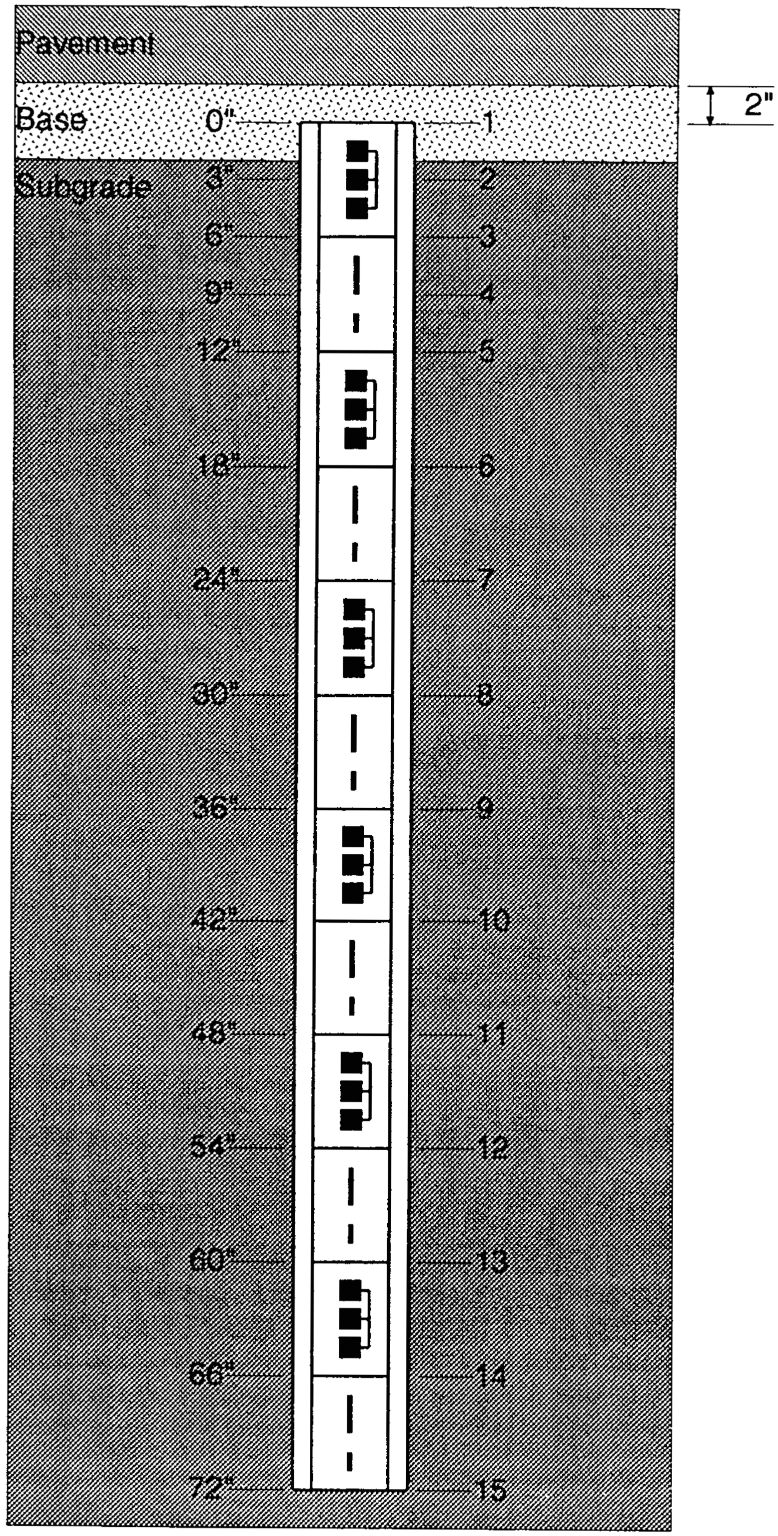


Figure 2.2 - Typical MRC Thermistor Probe Assembly.

- Time-domain reflectometry (TDR) probes will be used to collect volumetric water content. Ten TDR probes will be used per pavement section, spaced depth-wise at 150 or 300 mm (6 or 12 in.) through the mid-depth of the granular base layer and the subgrade.

- MRC thermistor probes (one assembly per section) will be used to measure temperature variation in each section. Depending on layer thickness, 3 or 4 thermistors will be used in the surface layer and a string of 15 thermistors will be used in base and subgrade layers. Each MRC probe will be encased in a 1.8 m (6 ft) long PVC rod. Figure 2.2 shows details of an MRC thermistor probe in the base and subgrade. The surface probe will contain three or four sensors, so that measurements can be made at approximately 1.0 inch depth, mid depth, and 1.0 inch above the bottom of the layer. Individual probes will be acquired to accommodate thickness variation in the pavements. These probes will also have hooks at each end to aid in placement.

- CRREL resistivity probes (one assembly per section) will be used to measure the frost depth in each section. The probe consists of 36 metal (rings) wire electrodes, spaced 51 mm (2 in.) apart, and mounted on a solid PVC rod. Figure 2.3 shows details of a resistivity probe.
In addition, piezometer water table observations will be made.

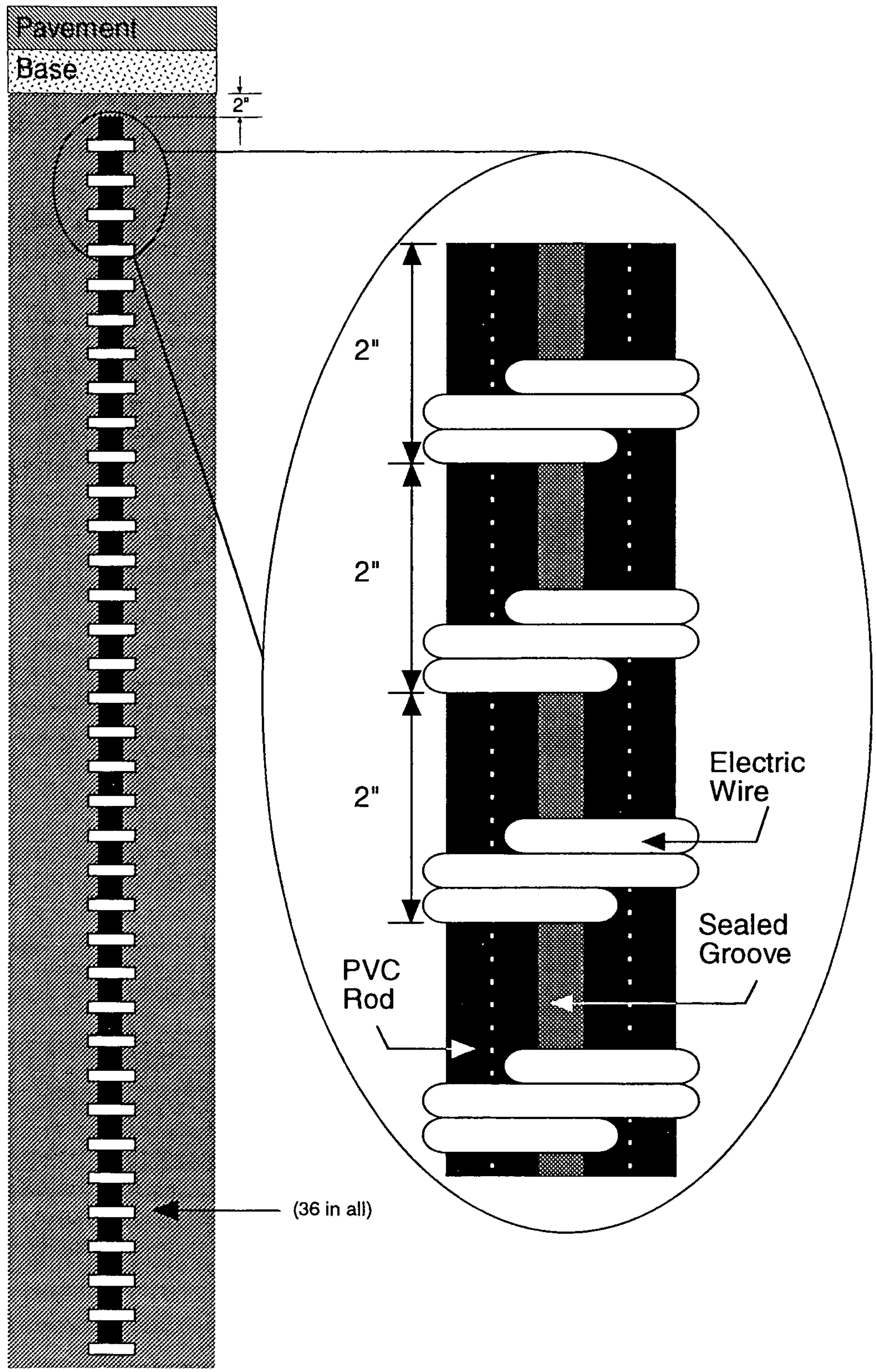


Figure 2.3 Typical CRREL Resistivity Probe Assembly

2.2.3 Structural Response Sensors

Instrumentation used to monitor structural response in AC and PCC sections include Linear Variable Differential Transformers (LVDT), pressure cells, and strain gauges.

2.2.3.1 AC Sections

- Vertical pavement displacement will be measured with Schaevitz GPD 121-500DC Linear Variable Differential Transformers (LVDT). This LVDT is hermetically sealed and spring loaded. Other special features added for this project include stainless steel bushings and rings, hard chrome plunger and core assembly, a high force stainless steel spring, and three foot long, radial, moisture proof cable attachment. Custom housing units and cable lengths will be specifically fabricated for these LVDTs. LVDTs will be installed in each AC pavement section.

- Vertical pressure will be measured using *Geokon* Model 3500 earth pressure cells. These cells consist of two circular stainless steel plates which are welded together around their periphery and spaced apart by a narrow cavity filled with antifreeze solution. A length of high-pressure stainless steel tubing connects the cavity to a pressure transducer. The pressure transducer converts the pressure on the cell into an electrical signal, which is transmitted by a six wire conductor shielded cable. Two pressure cells will be used in each AC section.

- AC strains will be measured using *Dynatest* PAST II-AC strain gauges. The PAST II-AC strain gauge is an "H" shaped precision transducer, specifically manufactured for strain measurements in AC. These strain gauges will be installed in longitudinal and transverse directions. Gauges oriented longitudinally will be placed at the bottom of the Asphalt Treated Base (ATB) layer and at the bottom of each AC layer. Transversely oriented gauges will be placed at the bottom of each AC layer. Gauges located under the center-line will only be placed at the bottom of the first AC layer. A maximum of 24 gauges will be installed per section.

2.2.3.2 PCC Sections

- Vertical pavement displacement will be measured with Schaevitz 121-500 DC Linear Variable Differential Transformers (LVDT).

- Vertical pressure will be measured using *Geokon* Model 3500 earth pressure cell. Two pressure cells will be used at each PCC section.

- PCC strains will be measured using four types of strain gauges.

  a. Dynatest PAST II-PCC, which is similar to the PAST II-AC strain gauges , will be used to measure strain at the top and bottom of the PCC slab along the wheel path.
  b. TML KM-100B is a 350Ω, full bridge embedment gauge specifically designed to measure concrete strain. The transducer is temperature-compensated. These gauges will be placed on the top and bottom of the PCC slab at the centerline.
  c. TML PMR-60 is a 120Ω three-axes rosette, quarter bridge embedment strain gauge specifically designed for the measurement of interior strains in concrete. The gauge and lead wires are hermetically sealed in an epoxy strip. The gauge is coated with a coarse grit to ensure bonding with concrete. Two gauges will be placed at the corner of the PCC slab, one each at the top and bottom.
  d. Carlson A-8 strain meters will be used to measure strains resulting from thermal variations. Carlson gauges are elastic wire strain meters containing two coils of highly elastic steel wire, one of which increases in length and electrical resistance when strain

occurs, while the other decreases. Since the total resistance is independent of strain (one coil increases the same amount the other decreases), the total resistance is a measure of temperature. These gauges will be placed in the middle of the PCC layer at the center-line of the slab.

2.3 INSTALLATION PROCEDURE

The general installation procedure for the sensors follows. These instructions are adapted from FHWA guidelines(1) and have been slightly modified to improve the survivability and performance of sensors under the conditions of the DEL-23 project. Table 2.4 details section numbering and location of each section. These will assist in identifying each section on the project site. Furthermore, Appendix A includes a detailed plan of each section, showing wire conduits and secondary and primary manholes in which cable and data acquisition will be located. Table 2.5 is the legend for all figures.

Installation procedures need to be followed with no deviation unless necessitated by on -site problems or variation of construction procedure by the contractor, and approved by the project supervisors and coordinator.

2.3.1 Seasonal Parameter Instrumentation

Installation procedures will follow guidelines set by the Federal Highway Administration. Seasonal instrumentations are similar for AC or PCC sections, and are adopted based on protocols set by the LTPP program. Figures 2.4 through 2.10 and Figures 2.11 through 2.17 show instrumentation details for AC and PCC sections, respectively. Instrumentation procedures are as follows:

1. The TDR probes, thermistor sensors, and resistivity probes will be placed in one hole. The hole will be drilled in the base, before the placement of the asphalt/portland concrete layers. The 12 inch diameter hole will be located in the outer wheel path (0.6 to 0.9 m or 2 to 3 ft from the outer edge of the lane) at least 1.2 m (4 ft) away from joints to avoid surface moisture infiltration. Figure 2.18 shows a typical layout of the seasonal instrumentation hole location. The hole will extend approximately 2.1 m (7 ft) beneath the bottom of the bound pavement layers.

2. The thermistor and resistivity probes will be placed approximately 51 mm (2 in) below the bottom of the lowest stabilized layer in order to minimize the likelihood of damage to the sensors from traffic loads. The ten TDR probes will be placed at the following depths (in reverse order of installation):

    a. If the top granular base/subbase layer is greater than 12 inches, the first TDR probe (from top to bottom) will be placed 6 inches below the bottom of the lowest stabilized layer.

    b. Otherwise, the probe will be placed at mid-depth of the top granular base/subbase layer. This probe may require installation upside down so that the top of the circuit board does not touch the bottom of the bound layers.

    c. The next seven TDR probes will be placed at 6 inch intervals. The bottom two TDR probes will be placed at 12 inch intervals.

3. The temperature probe, with wire wrapped around it, will be buried vertically with the hook pointing upwards. Wires leading from the installed sensors will be placed in a 2.0 inch diameter conduit and buried in a trench leading to the equipment cabinet. Trench and conduit will be provided by the contractor.

4. After the concrete layers are placed (asphalt or portland), a 2 inch core will be drilled to access the probe.

5. The probe will then be pulled to the surface with the attached hook and epoxied in a groove cut into the core. Any voids created in the base will be filled at this time with the base material. Then the core, with the probe attached, will be epoxied back into the pavement.

Table 2.4: Instrumented Sections Numbering and Location.

Instrumentation Section	SHRP Designation	Location (station)
J4 (SPS2)	390204	285+55 to 285+80
ODOT Mix (SPS9)	390901	286+58 to 286+92
J12 (SPS2)	390212	301+65 to 301+90
J10 (SPS2)	390210	302+75 to 303+00
SHRP Mix (SPS9)	390904	301+83 to 302+17
J2 (SPS2)	390202	324+55 to 324+80
J6 (SPS2)	390206	325+40 to 325+65
J12 (SPS1)	390112	326+08 to 326+42
J11 (SPS1)	390111	327+08 to 327+42
J5 (SPS2)	390205	341+45 to 341+70
J1 (SPS2)	390201	342+25 to 342+50
J4 (SPS1)	390104	341+43 to 341+77
J6 (SPS1)	390106	342+23 to 342+57
J9 (SPS2)	390209	355+80 to 356+05
S2 (SPS2)	390261	356+55 to 356+80
J1 (SPS1)	390101	355+43 to 355+77
J7 (SPS1)	390107	356+33 to 356+67
J11 (SPS2)	390211	373+95 to 374+20
J2 (SPS1)	390102	375+43 to 375+77
S7 (SPS1)	390160	376+23 to 376+57
J3 (SPS2)	390203	388+95 to 389+20
J7 (SPS2)	390207	390+05 to 390+30
J5 (SPS1)	390205	392+93 to 393+27
J8 (SPS1)	390108	393+45 to 393+79
J8 (SPS2)	390208	403+45 to 403+70

Instrumentation Section	**SHRP Designation**	**Location (station)**
S3 (SPS2)	390262	404+35 to 404+60
J9 (SPS1)	390109	406+71to 407+05
J10 (SPS1)	390110	407+45 to 407+79
S4 (SPS2)	390263	421+06 to 421+31
S5 (SPS2)	390264	421+91 to 422+16
J3 (SPS1)	390103	420+98 to 421+32
K13 (SPS8)	390803	20+40 to 20+65
J1 (SPS8)	390809	20+02 to 20 +36

Table 2.5: Legend for Instrumentation Figures

Seasonal Parameter Instrumentation

- Resistivity Probes Figure 2.3
- FHWA TDR Probes
- Thermistor Probes Figure 2.2
- Surface Temperature Probe

Structural Response Instrumentation

- ODOT KM-100B GAGE
- ODOT DYNATEST GAGE
- SHRP DYNATEST GAGE
- ODOT CARLSON A-8 GAGE
- SHRP LVDT
- ODOT LVDT
- ODOT PRESSURE CELL
- SHRP PRESSURE CELL
- ODOT ROSSETTES PMR-60

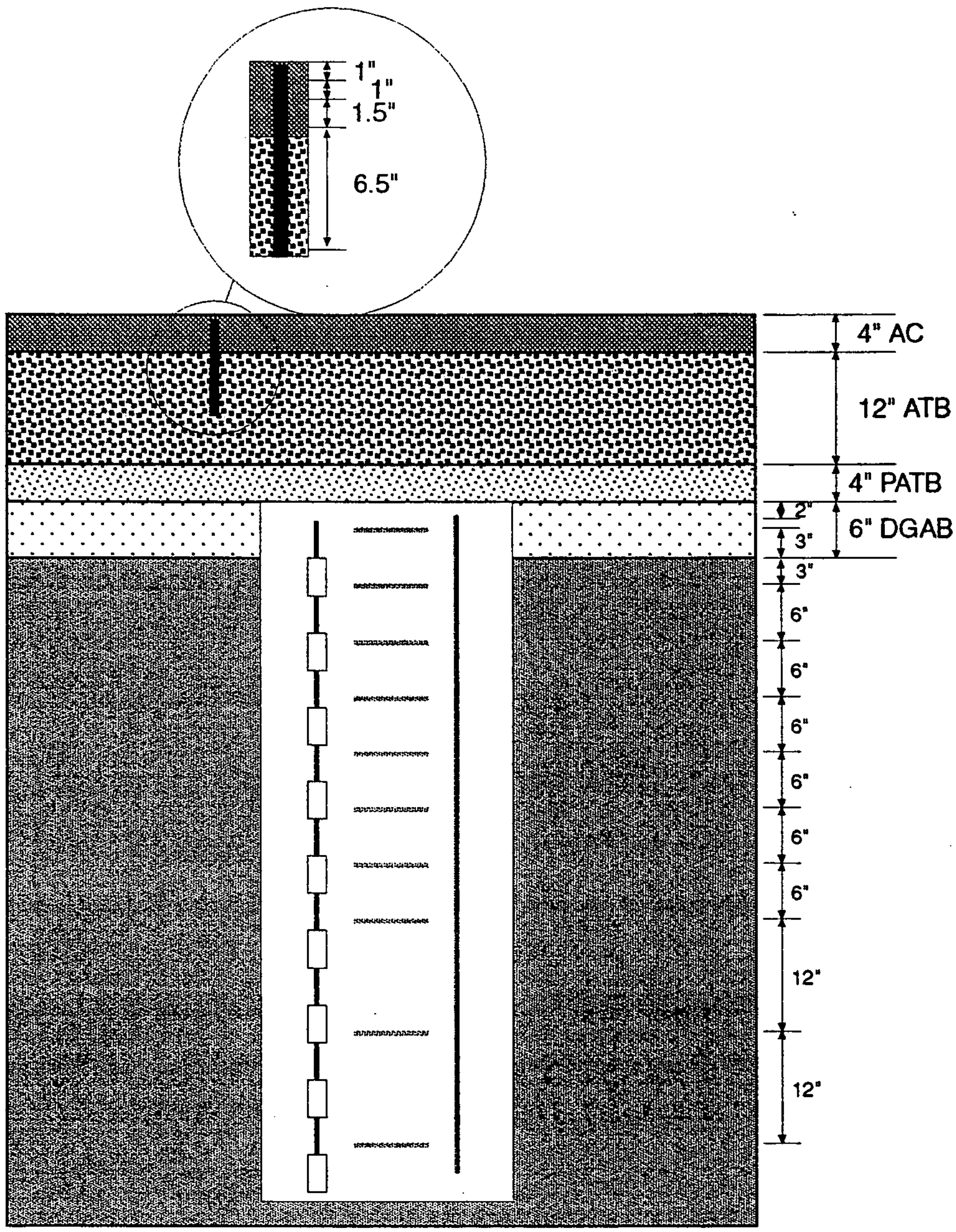


Figure 2.4 Typical SPS9 Seasonal Instrumentation

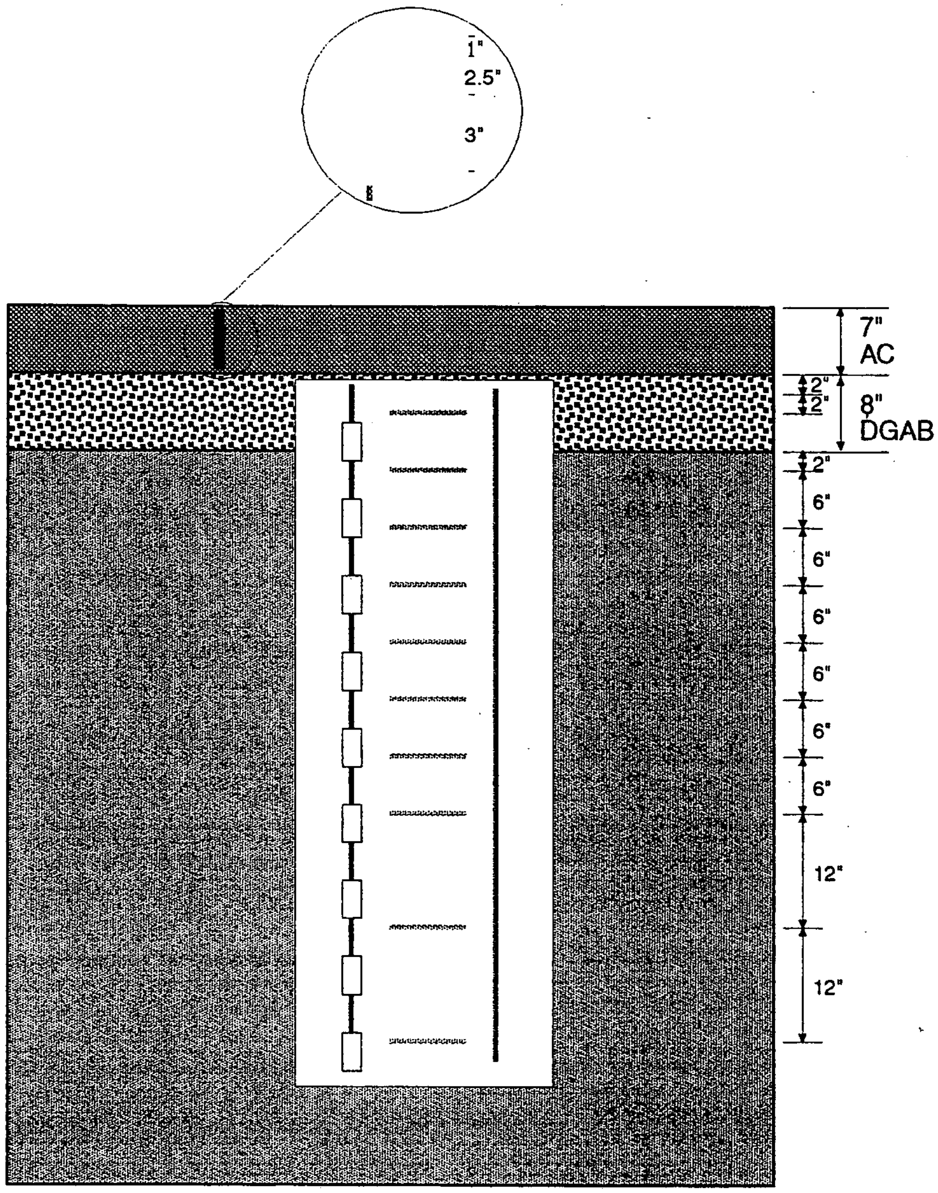


Figure 2.5 Section J1 (SPS1) Seasonal Instrumentation

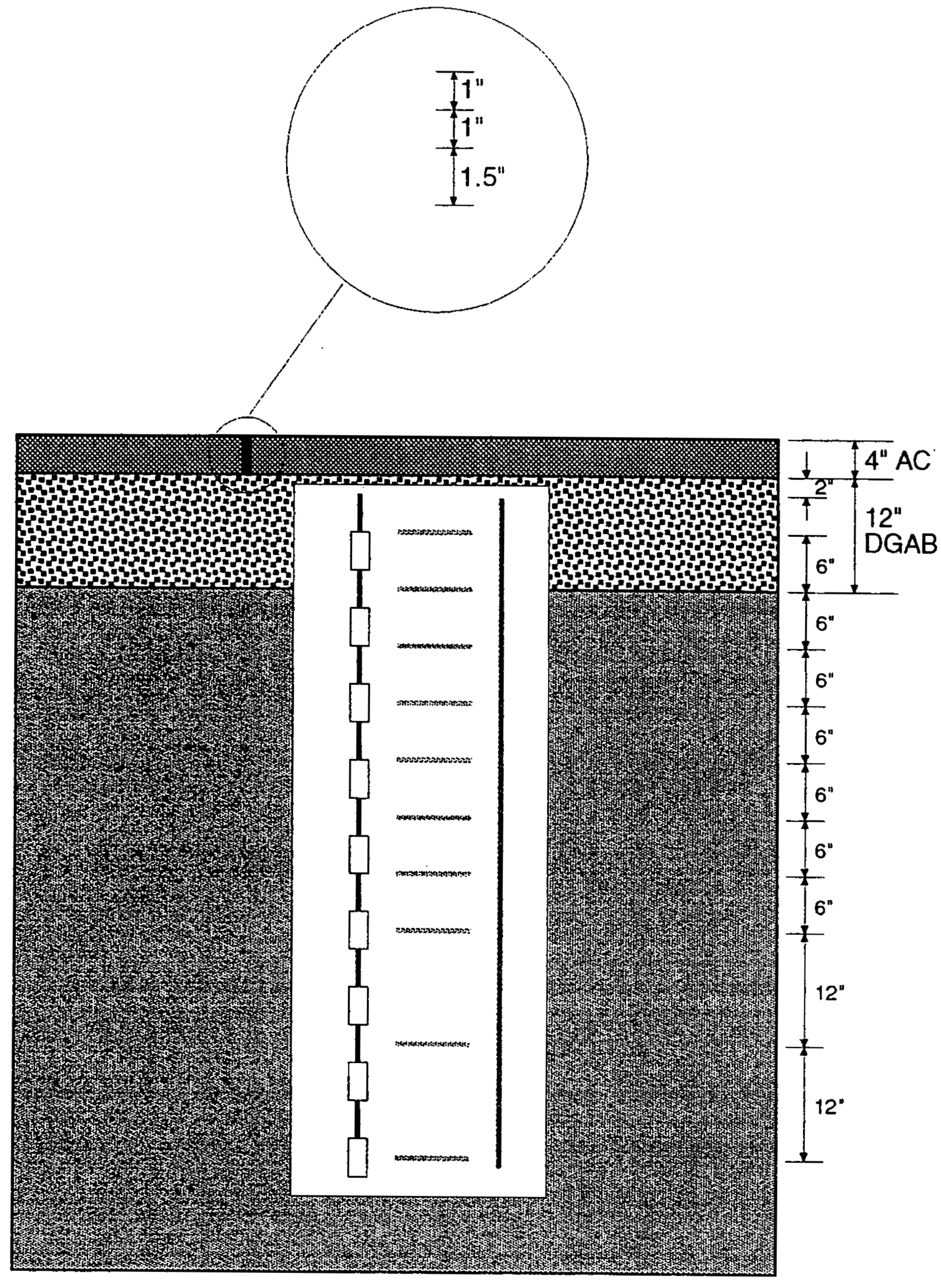


Figure 2.6 Section J2 (SPS1) Seasonal Instrumentation

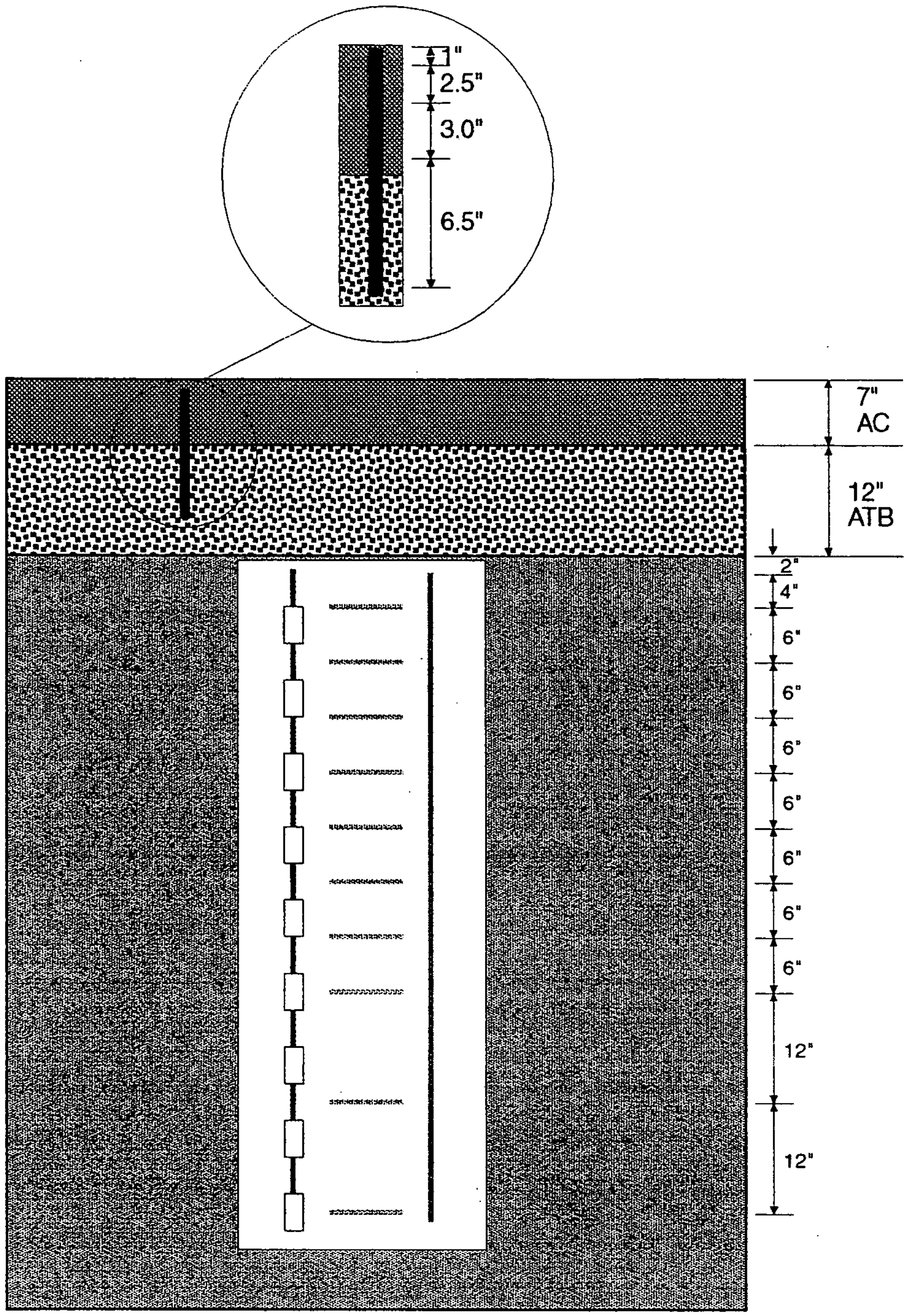


Figure 2.7 Section J4 (SPS1) Seasonal Instrumentation

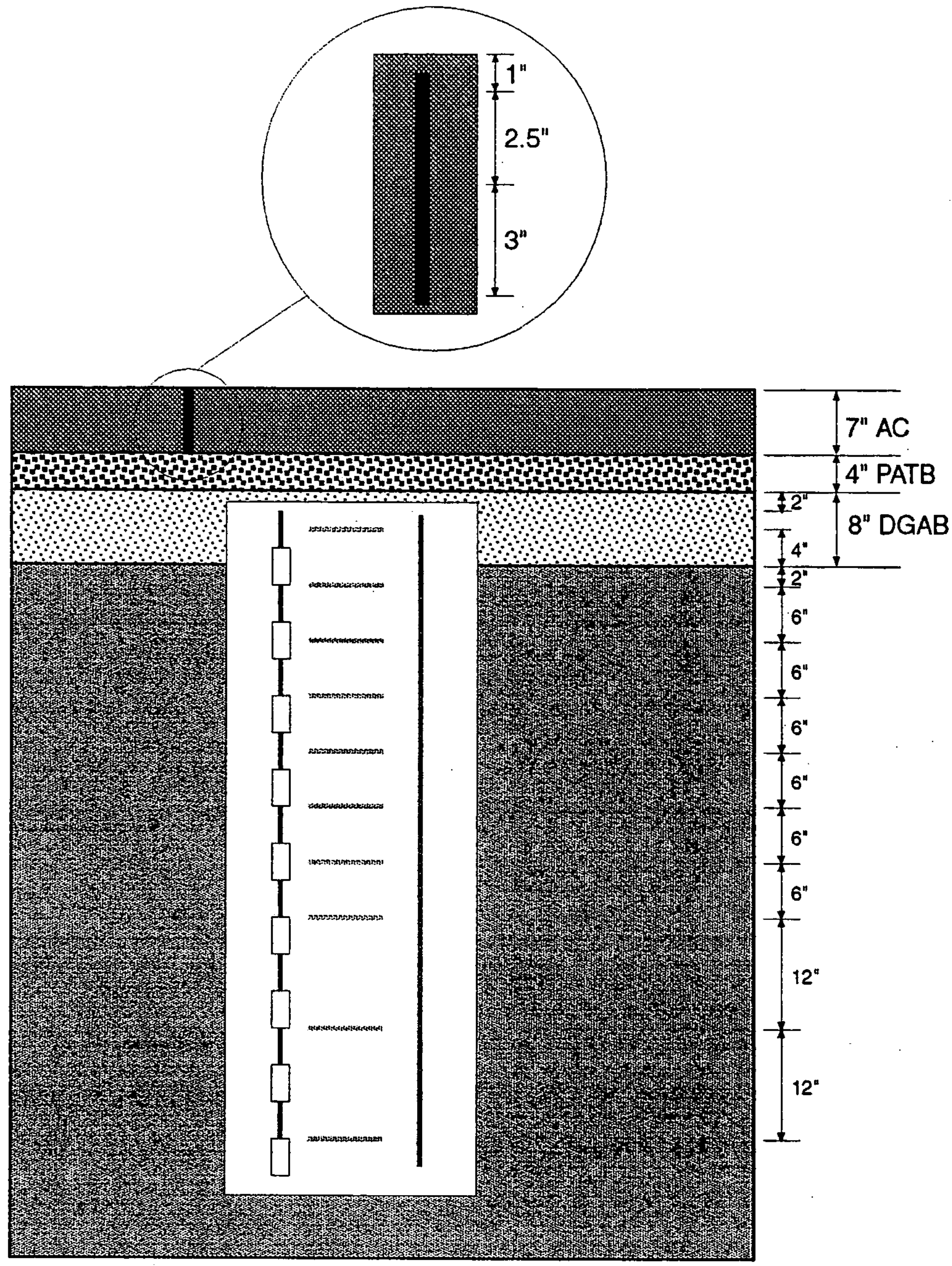


Figure 2.8 Section J8 (SPS1) Seasonal Instrumentation

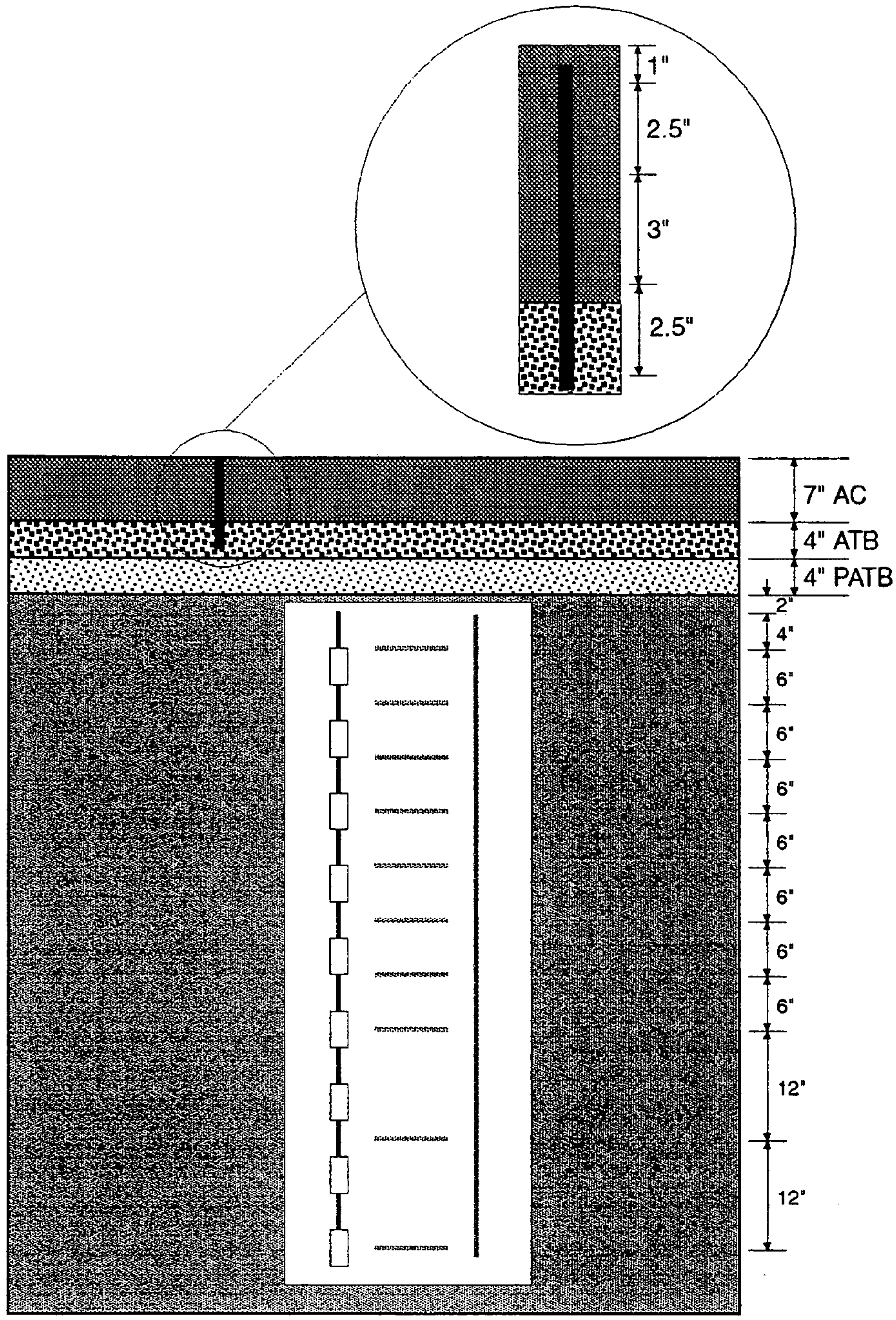


Figure 2.9 Section J10 (SPS1) Seasonal Instrumentation

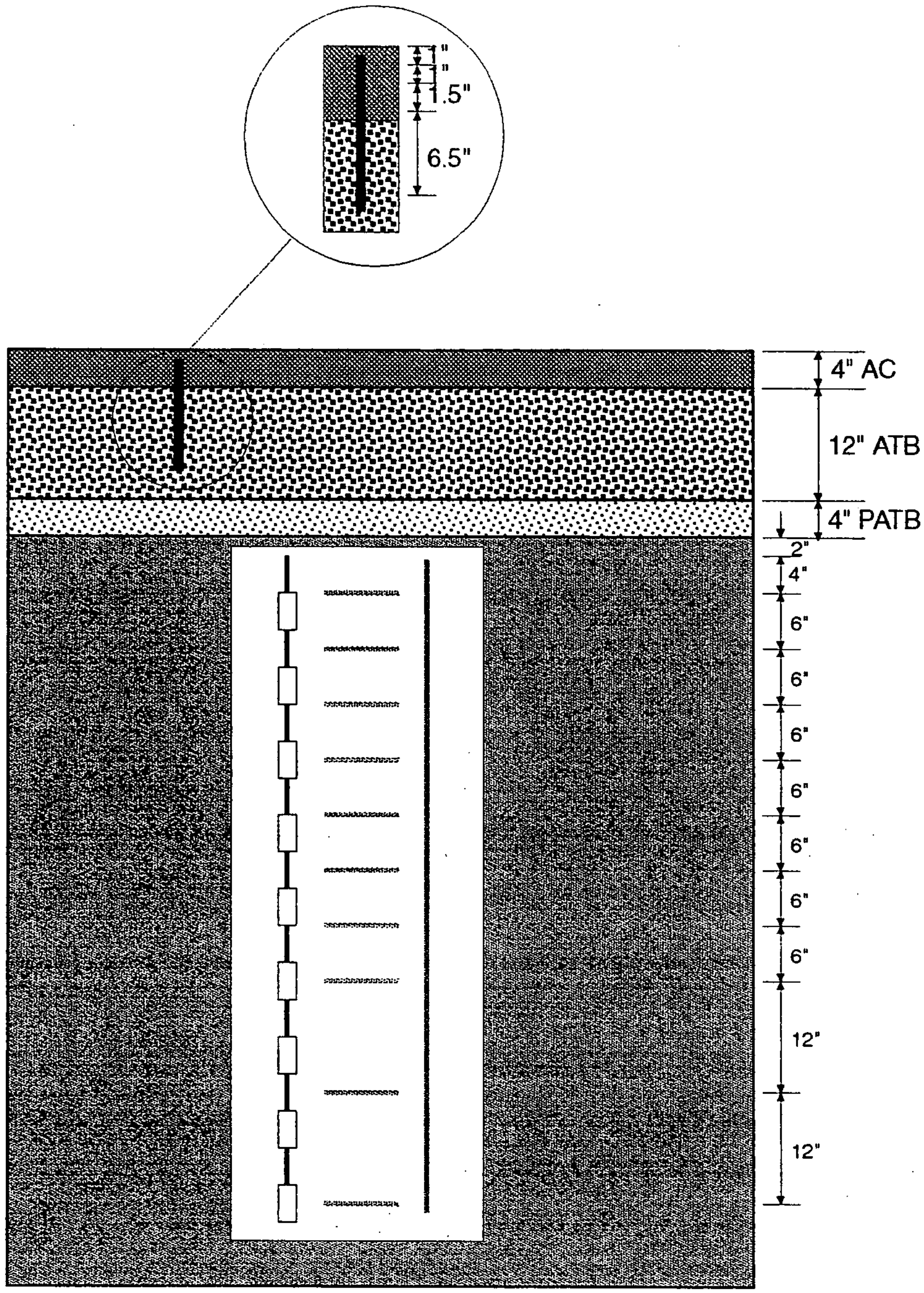


Figure 2.10 Section J12 (SPS1) Seasonal Instrumentation

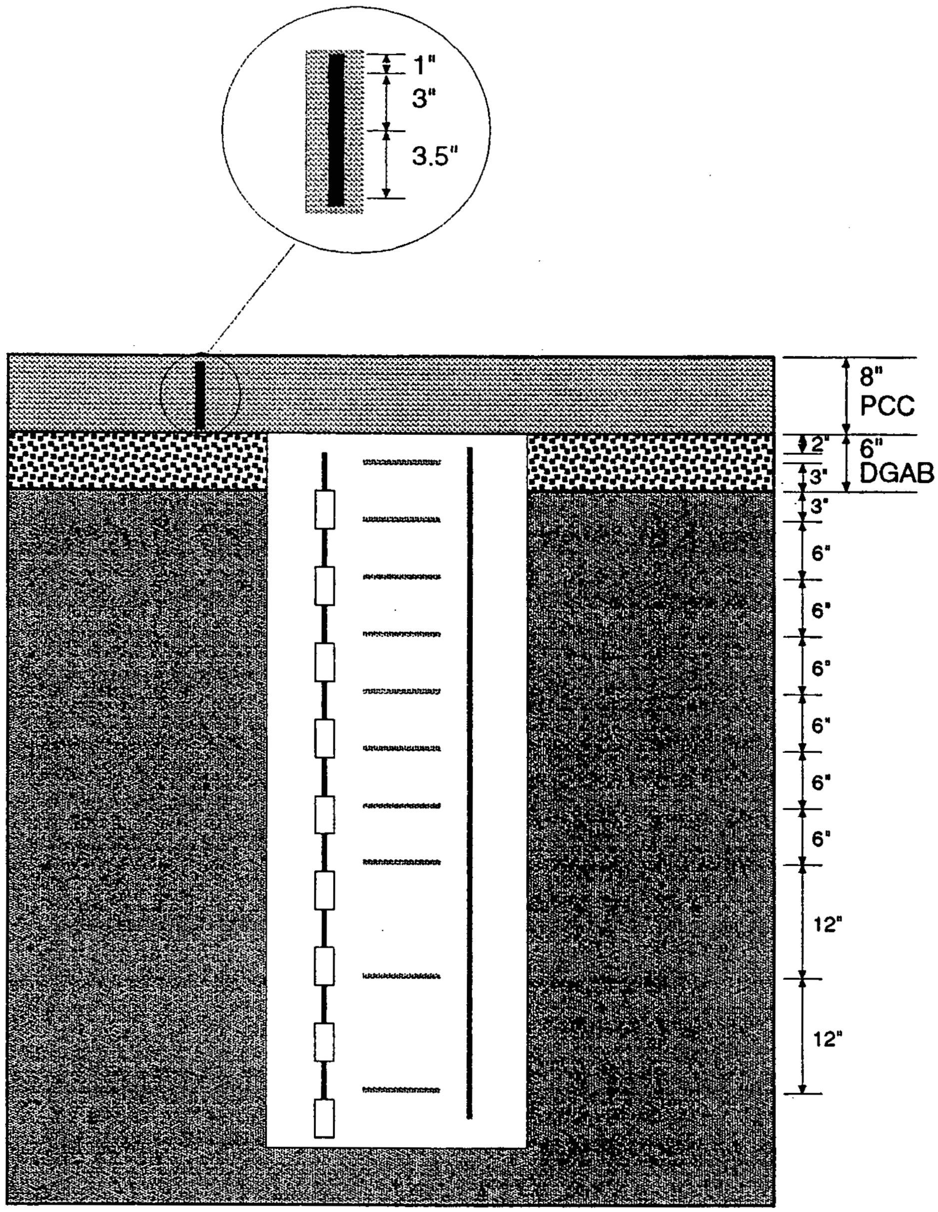


Figure 2.11 Sections J1 and J2 (SPS2) Seasonal Instrumentation

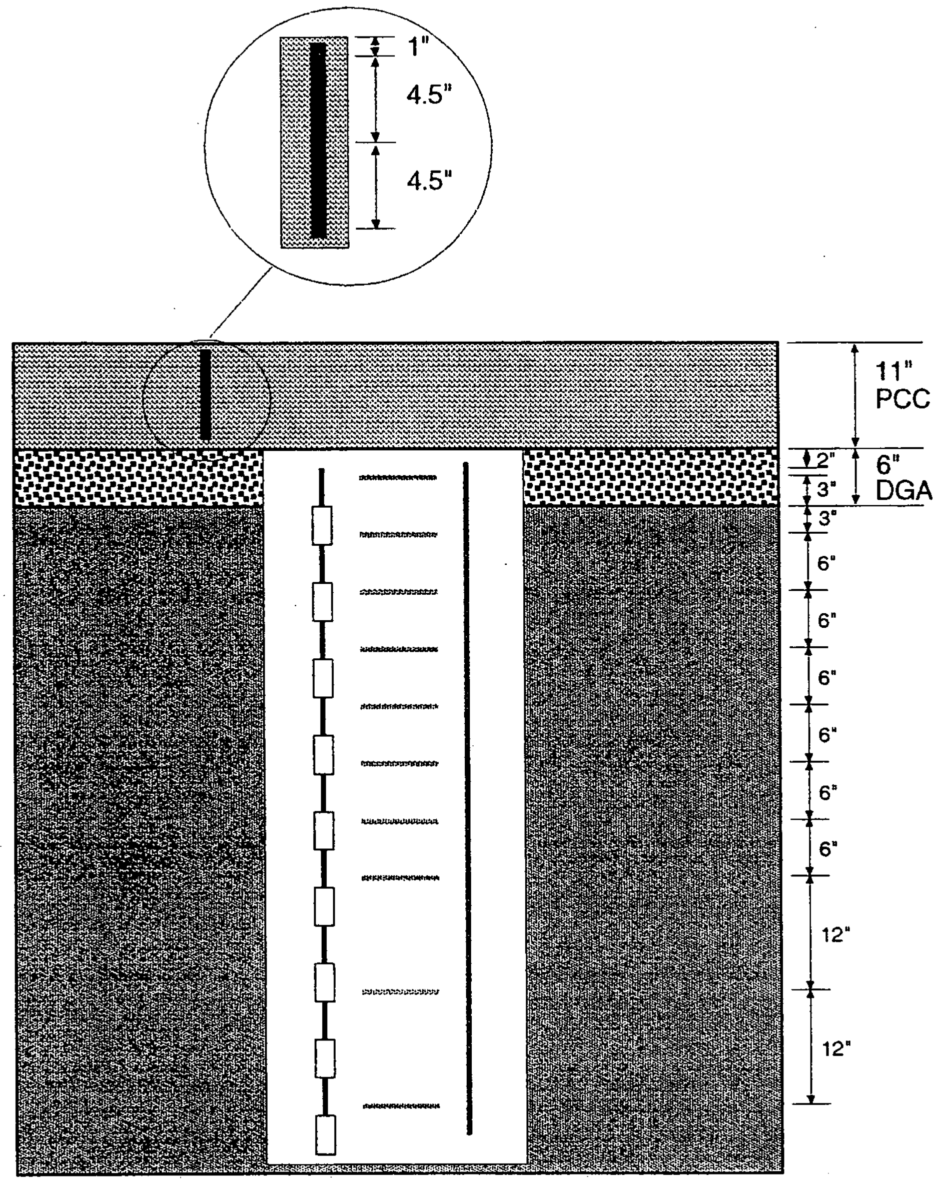


Figure 2.12 Section J3 and J4 (SPS2) Seasonal Instrumentation

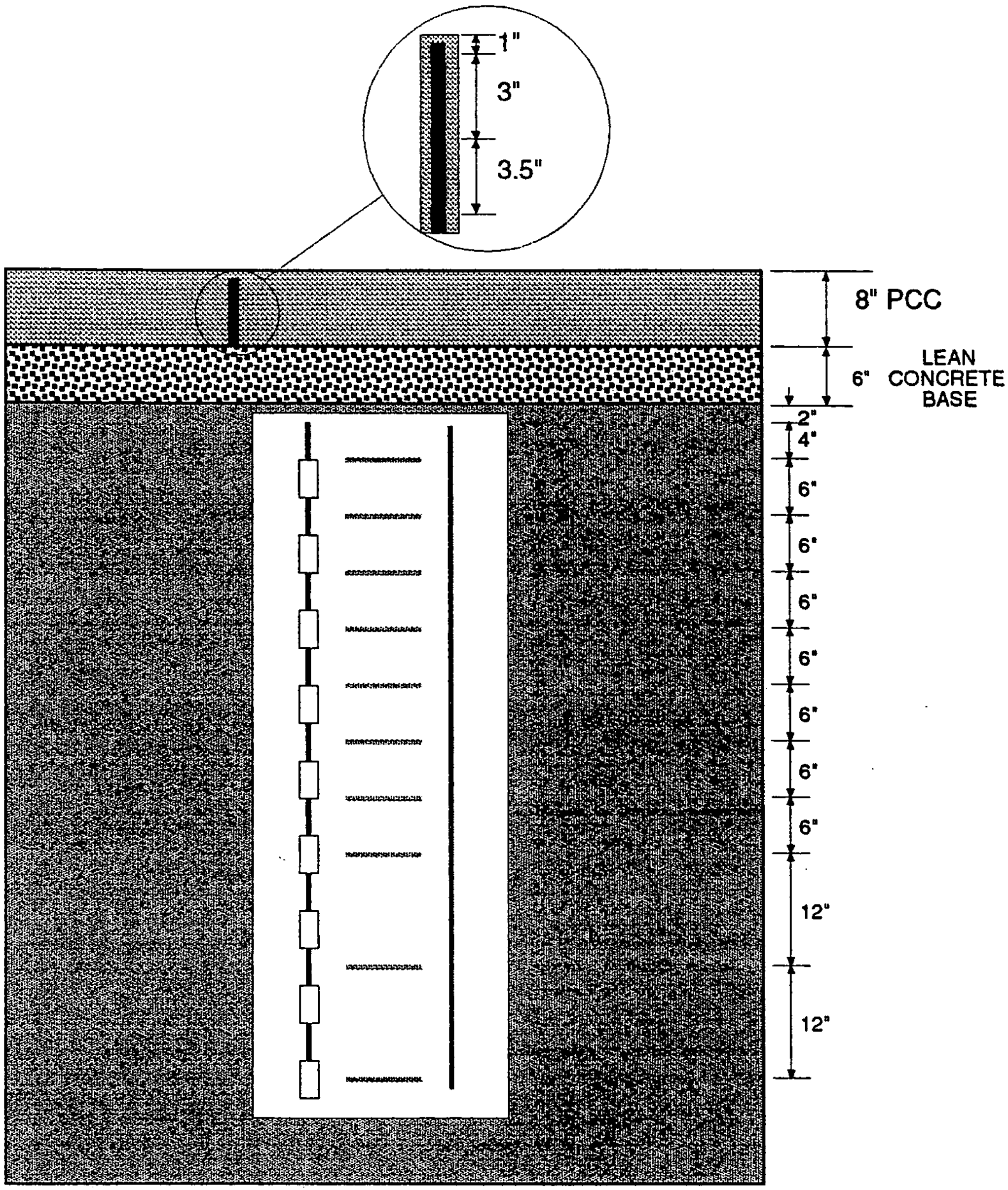


Figure 2.13 Section J5 (SPS2) Seasonal Instrumentation

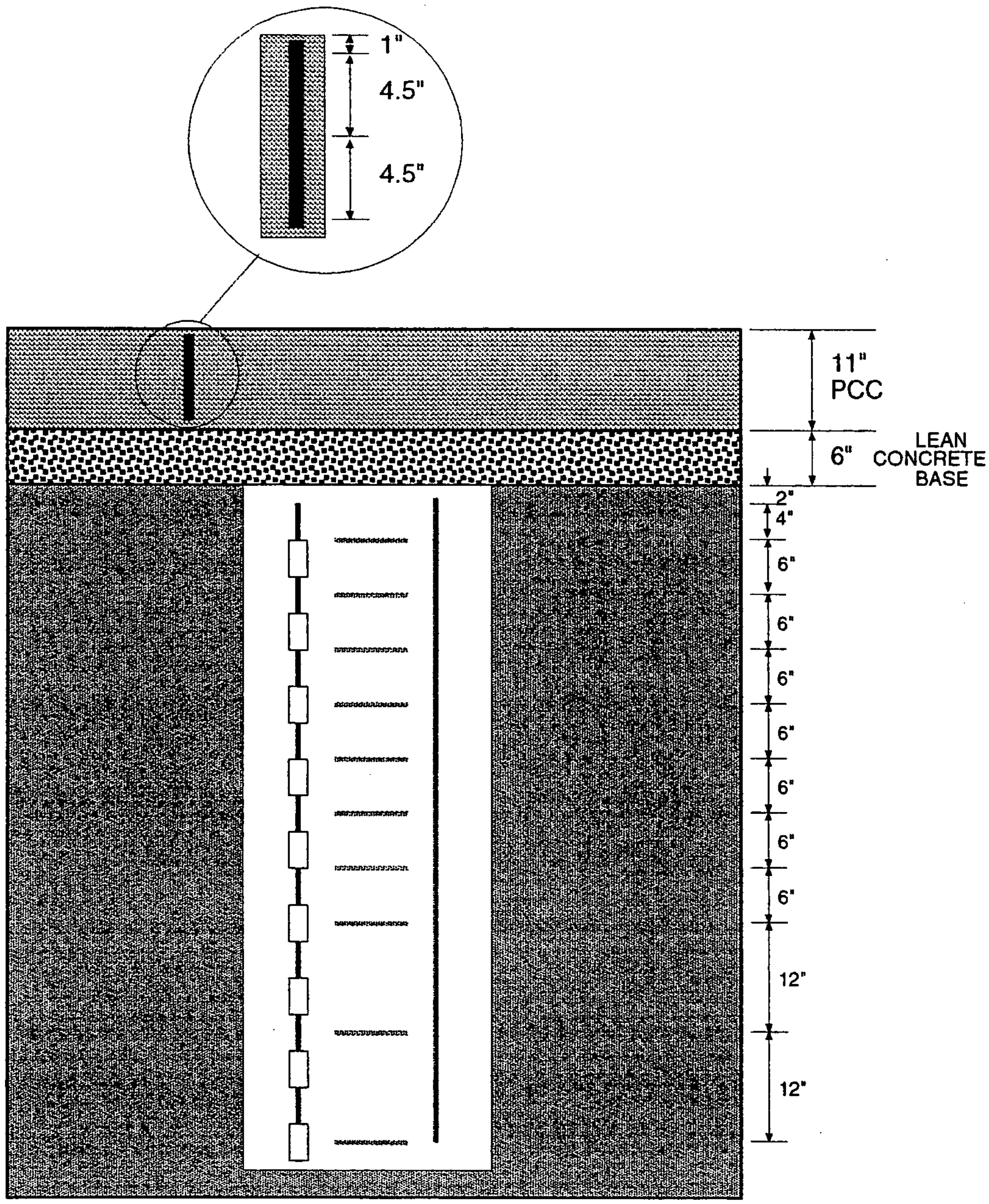


Figure 2.14 Section J8 (SPS2) Seasonal Instrumentation

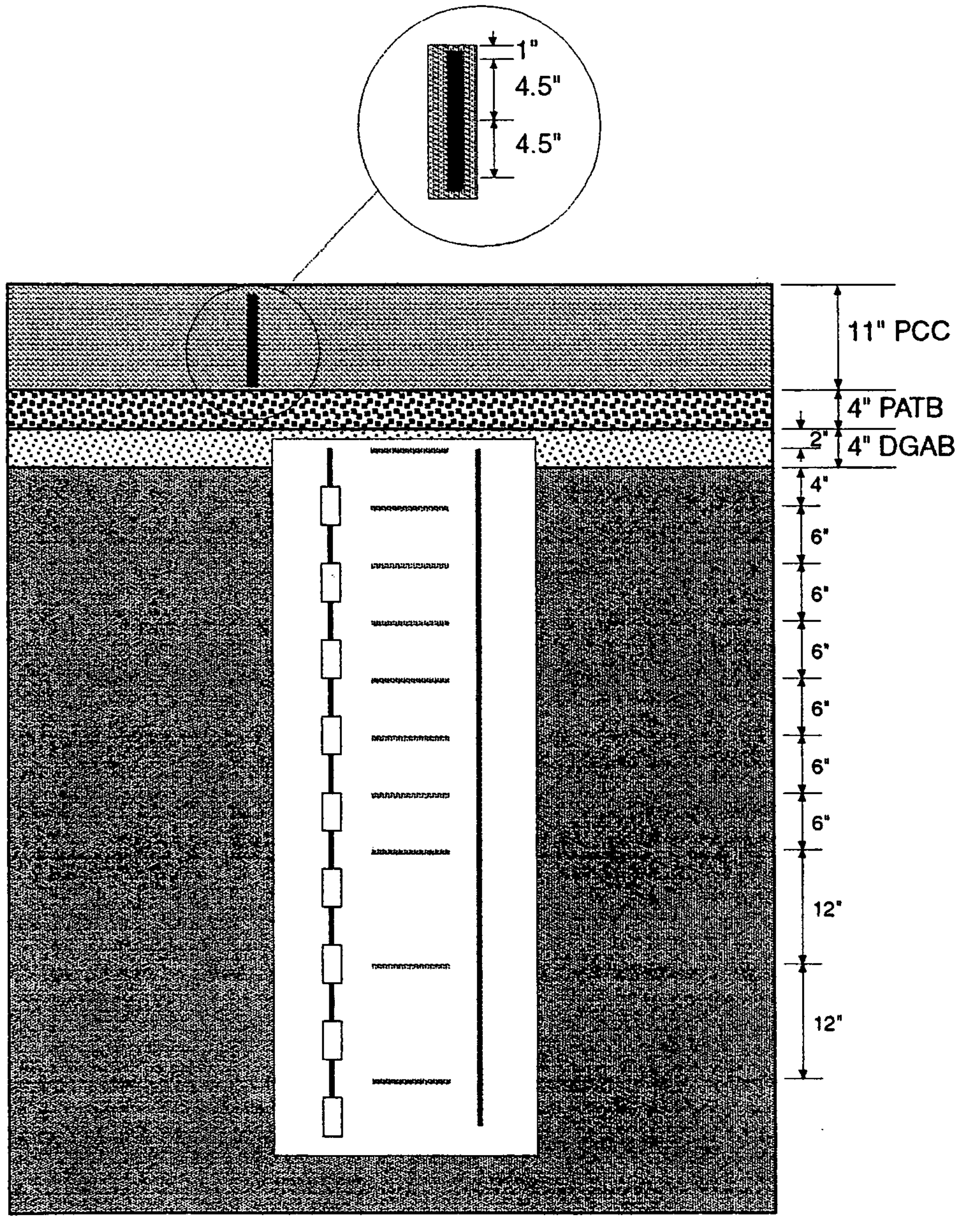


Figure 2.15 Sections J11 and J12 (SPS2) Seasonal Instrumentation

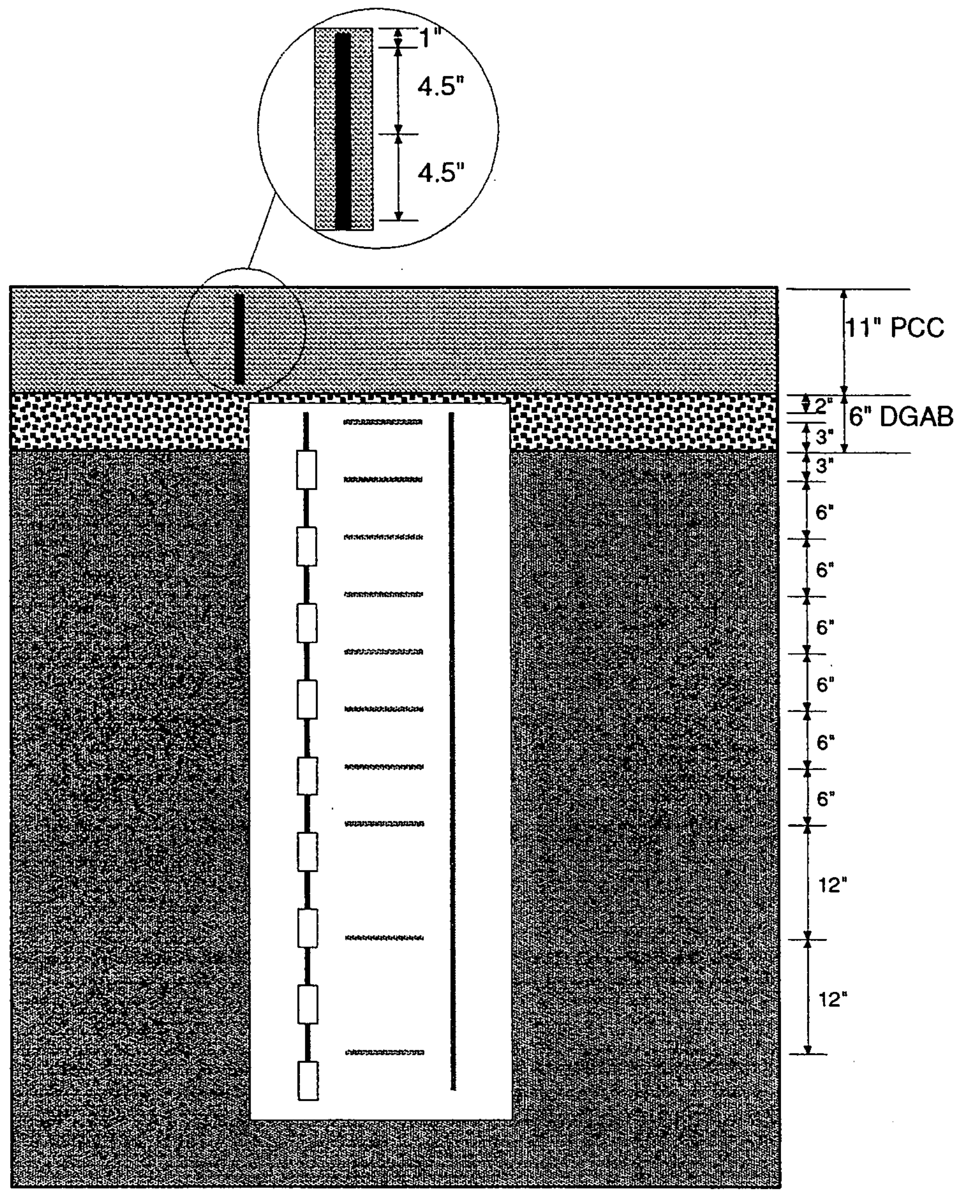


Figure 2.16 Section S4 (SPS2) Seasonal Instrumentation

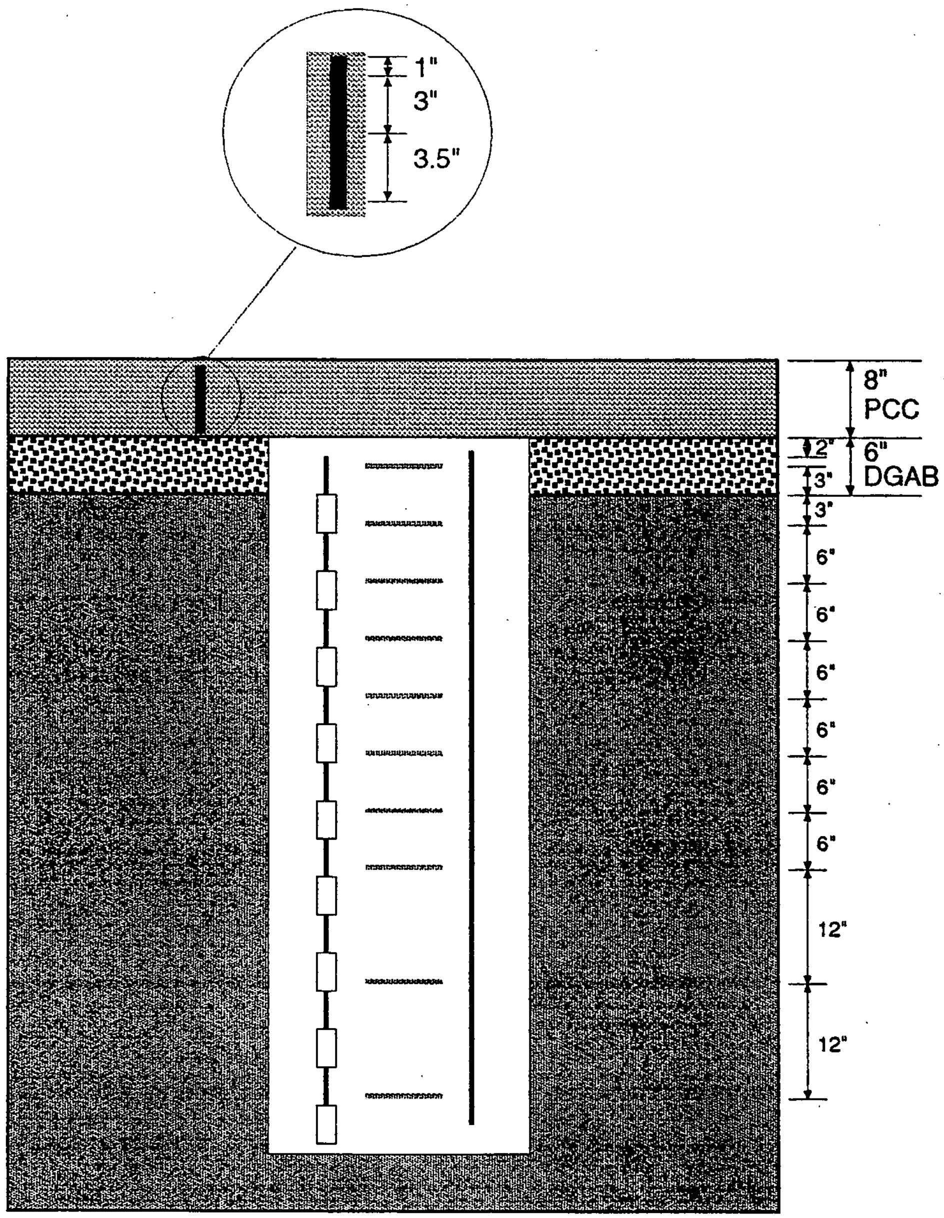


Figure 2.17 Section J1 (SPS8) Seasonal Instrumentation

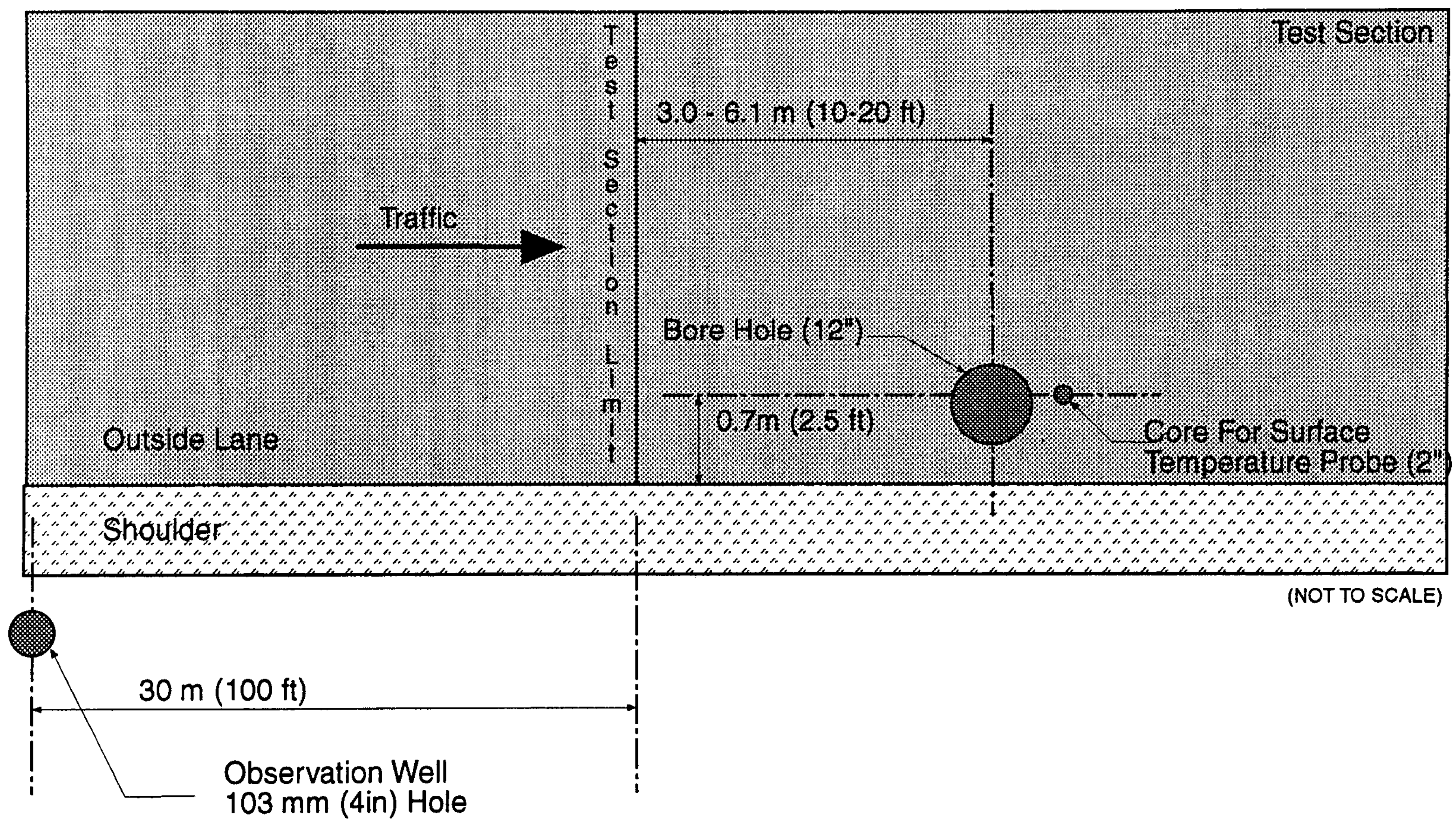


Figure 2.18 Typical Layout of Seasonal Instrumentation Hole for AC & PCC Sections.

2.3.2 Structural Response Instrumentation

The following guidelines are based on successful instrumentation procedures developed in previous research projects for the structural response of pavement. These procedures were modified to meet requirements of the DEL-23 project.

To precisely position instrumentation in each section, a coordinate system must be established. This coordinate system, in conjunction with a Total Station, available at the site, will make it possible to pinpoint the location of each sensor accurately and easily. A local benchmark will be placed at each section by the contractor. This benchmark will provide a permanent reference point. In addition, four reference pins will be placed in each section by the researchers to aid in instrumentation placement and location. The reference pins will be inserted to a depth of about two feet (one foot below subgrade) to be below grading depth. These pins will be located behind any guard rail if convenient. After allowing for berm width, pins 1 and 2 will be located at the beginning of each section approximately two feet off the berm. Pins 3 and 4 will be located by measuring the appropriate distances off the centerline or by correctly laying in diagonals. Pins one and two will be referenced from the bench mark. Lines drawn through the pins create a coordinate system by which the gauges can be located. Along with the coordinate identification, the elevation of each gauge will be determined. The top and bottom of each slab will be used as the reference for the vertical location of the sensors.

2.3.2.1 AC Sections

Structural response sensor location for each typical AC section is shown in Figures 2.19 through 2.24. The installation procedure for each sensor used (LVDT, pressure cell, and strain gauge) follows. LVDTs will be placed after the paving is completed. Pressure cells will be installed as each specified layer is finished. Strain gauges will be inserted as each layer is placed.

LVDT installation will be subdivided into two parts; Deep Reference and Shallow Reference. The Deep Reference procedure will only apply to LVDTs whose reference point is 12 feet below the last base layer. The Shallow Reference procedure will apply to all other LVDT installations.

Deep Reference Linear Variable Differential Transformers

1. LVDT holders and reference rods will be fabricated. Figure 2.25 illustrates a typical LVDT holder. Reference rods for the deep reference LVDTs will be approximately 12 ft long. The top of the reference rods will be finished and painted to provide a smooth, non-corrosive surface for the LVDT armature to contact.
2. When work on the subgrade is completed, a trench extending to within 0.5 inches of the proposed location of the LVDT will be excavated.
3. A two foot length of 2 inch diameter PVC pipe will be placed in the trench adjacent to the LVDT position. LVDT wire will be placed through the PVC pipe. Three feet of excess wire will be placed in the PVC pipe. The PVC pipe is used to protect the wire while coring. The trench will be backfilled.
4. Measurements will be taken to locate the exact location of the PVC pipe.
5. After paving, a 3.0 inch diameter hole will be cored to the bottom of the AC layer.
6. After removal of the core, a hole will be drilled to an approximate depth of 11 feet. The bottom of the hole will be compacted using a special compaction rod. Depth of the hole will then be checked. If a depth of 11 ft was not achieved, the drill rig will be redeployed.
7. Buried LVDT wires will be located and pulled out.
8. A two inch diameter PVC pipe will be placed in the hole to safeguard the hole from caving in.

9. The reference rod will be placed in the hole and plumbed. The reference rod is then driven one foot using a sledge hammer and special rod-guard.

10. The bottom of the hole will be filled with three feet of grouting material .

11. The space around the PVC pipe will be filled with backfill material and clean sand if necessary. A PVC spacer will be placed around the reference rod to maintain the alignment with the rod.

12. The top of the hole will be cleaned using wire brushes in order for the epoxy to set properly.

13. LVDT housing unit will be set in place, and epoxied in the hole using cold mix epoxy.

14. After the epoxy is set, the LVDT will be placed in the housing unit. LVDT wires will be soldered and protected using heat-shrink tubing, and the operation of the LVDT will be checked. At this time the LVDT will be set as close to the null point as possible with the supplied mounting nuts.

15. Brass caps will then be installed on the LVDT holders to ensure a smooth surface for traffic.

Shallow Reference Linear Variable Differential Transformers

1. LVDT holders and reference rods will be fabricated. Figure 2.26(a) and (b) illustrate typical LVDT holders. Reference rod lengths for the shallow reference LVDTs will depend on the location of the specific LVDT. Specific rods will be fabricated. The top of the reference rods will be finished and painted to provide a smooth, non-corrosive surface for the LVDT armature to contact.
2. When work on the subgrade is completed, a trench extending to within 0.5 inches of the proposed location of the LVDT will be excavated.
3. Two feet length of 2 inch diameter PVC pipe will be placed in the trench adjacent to the LVDT position. LVDT wire will be placed in the trench and through the PVC pipe. Three feet of excess wire will be placed in the PVC pipe. The PVC pipe is used to protect the wire while coring. The trench will be backfilled.
4. A reference plate will be placed at a specific depth under each LVDT location.
5. Measurements will be taken to locate the position of the reference plate.
6. After paving, 3.0 inch diameter holes will be cored to the bottom of the AC layer.
7. After removal of the core, a drill rig will drill through the core hole until the reference plate is reached.
8. Buried LVDT wires will be located and pulled out.
9. Two inch diameter PVC pipe will be placed in the hole to safeguard the hole from any falling debris.
10. The reference rod will be placed in the hole and plumbed. The reference rod will be attached to the reference plate and grouted in place.
11. The space around the PVC pipe will be filled with backfill material and clean sand if necessary.

A PVC spacer will be placed around the reference rod to maintain alignment with the rod.

12. The top of the hole will be cleaned using wire brushes in order for the epoxy to set properly.

13. LVDT housing unit will be set in place, and epoxied in the hole using cold mix epoxy.

14. After the epoxy is set, the LVDT will be placed in the housing unit. LVDT wire will be soldered and protected using heat-shrink tubing, and the operation of the LVDT checked. At this time the LVDT will be set as close to the null point as possible with the supplied mounting nuts.

15. Brass caps will be placed on the LVDT holders to ensure a smooth surface for traffic.

Pressure Cells

1. When the subbase layer is completed, 1 foot by 1.5 feet rectangular holes will be excavated, approximately 2 inches deep, in the subbase layer for placing the pressure cells at specified locations. A trench will be also be made extending from each pressure cell installation location to bury the pressure cell cable. The trench will be approximately 2 inches deep and will be backfilled after laying the cable.
2. The excavated hole will be filled with a 2 inch thick, compacted, moist concrete sand layer to form an uniform bedding for the pressure cell. Then, the pressure cell will be placed over the sand layer with its sensitive surface facing up, even with the surface of the subbase layer.
3. The pressure cell cable will be extended along the trench, and the trench will be backfilled with the subbase material. The sensitive surface of the cell will be covered entirely with a 2 inch thick layer of subbase material.
4. Readings from the pressure cell will be checked to ensure its functionality.
5. After installation, the location of the pressure cell will be verified. Any deviation from the instrumentation plan will be recorded.

Strain Gauges

1. Before paving commences on each specified layer, gauge locations will be marked and labeled. Orange spray paint will be used.
2. Gauges will be oriented such that the wire from each gauge will be pushed toward the instrument by the paver, rather than being pulled away. Extra wire will be available to allow for tension relief.
3. The functionality of each gauge will be checked.
4. Before the paver reaches the gauge, an amount of hot asphalt will be obtained from delivery trucks.
5. This asphalt will be sifted using a 0.25 inch wire mesh sieve to remove large aggregates.
6. A thin layer of sifted asphalt will be placed at the location of each sensor. The sensor will be placed over the asphalt. More asphalt will be placed over each sensor and sensor wires extending to the edge of the pavement. This layer of fine aggregate will help bond the instruments in place, and safeguard the sensors from displacement by the paver.
7. The asphalt on top of each gauge will be compacted using a specially fabricated steel roller.
8. Each gauge will be re-examined for resistance.
9. The paver will then continue with the paving process.
10. Gauges will be monitored continuously as paving progresses.
11. A small amount of asphalt will be heaped in front of the transverse gauges so the roller does not damage or move them. As the roller passes by, it will "jump" over these gauges.
12. Vibrators are to be turned off when rollers pass over the sensors.

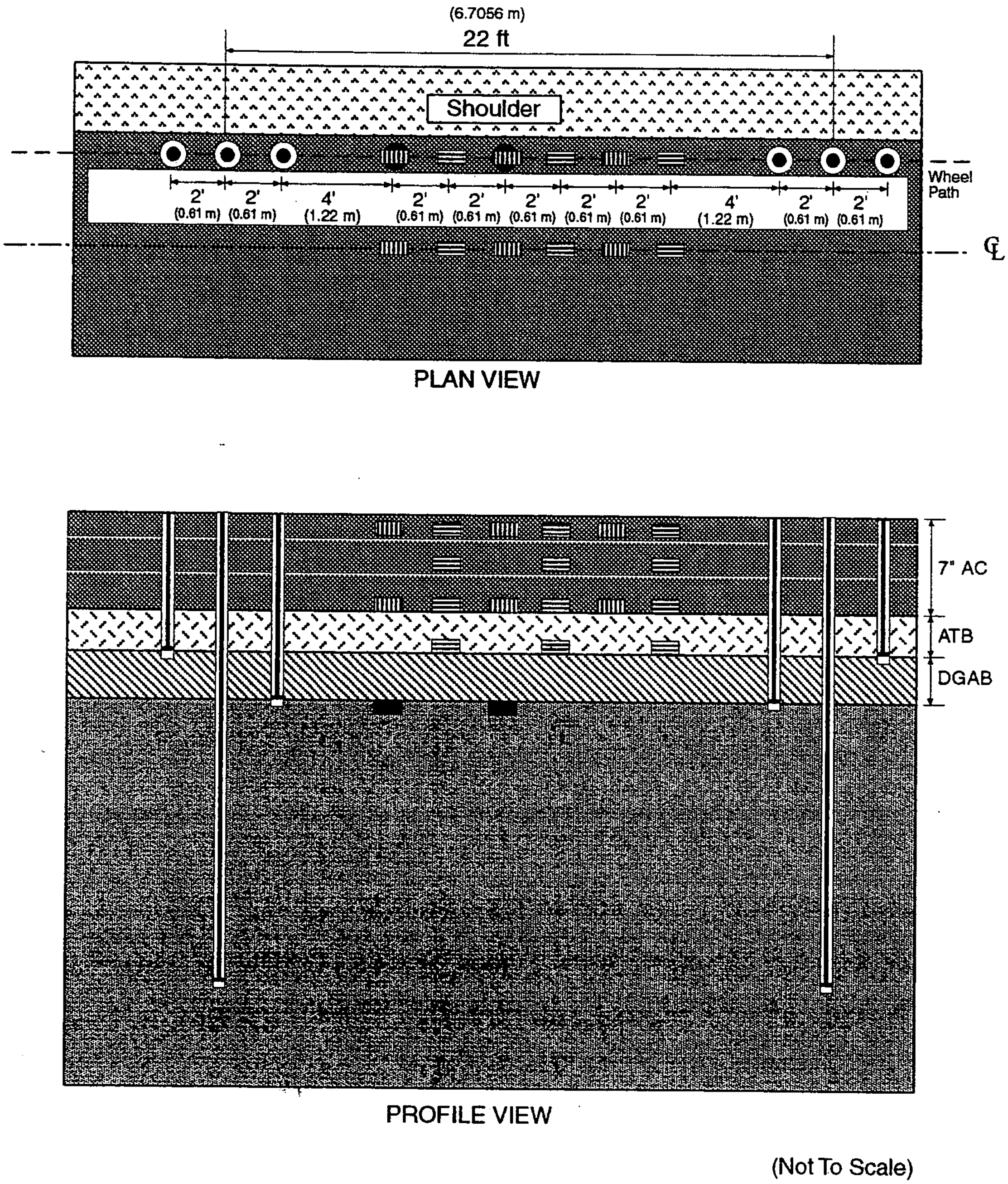


Figure 2.19(a) Structural Response Instrumentation. Typical AC Section (Two Base Layers, Three AC Lifts).

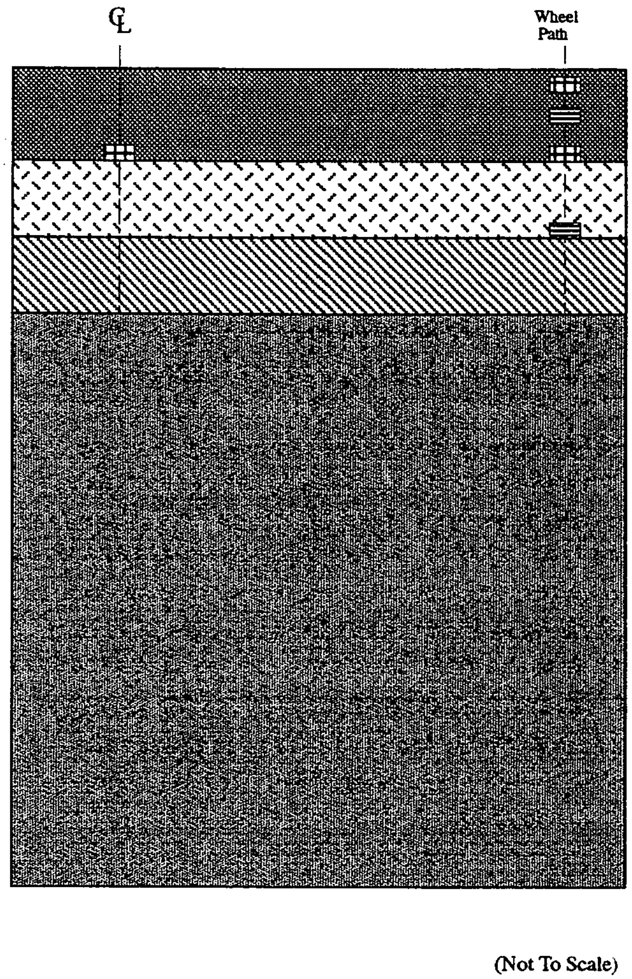


Figure 2.19 (b) Lateral Profile, Structural Response Instrumentation. Typical AC Section (Two Base Layers, Two AC Lifts).

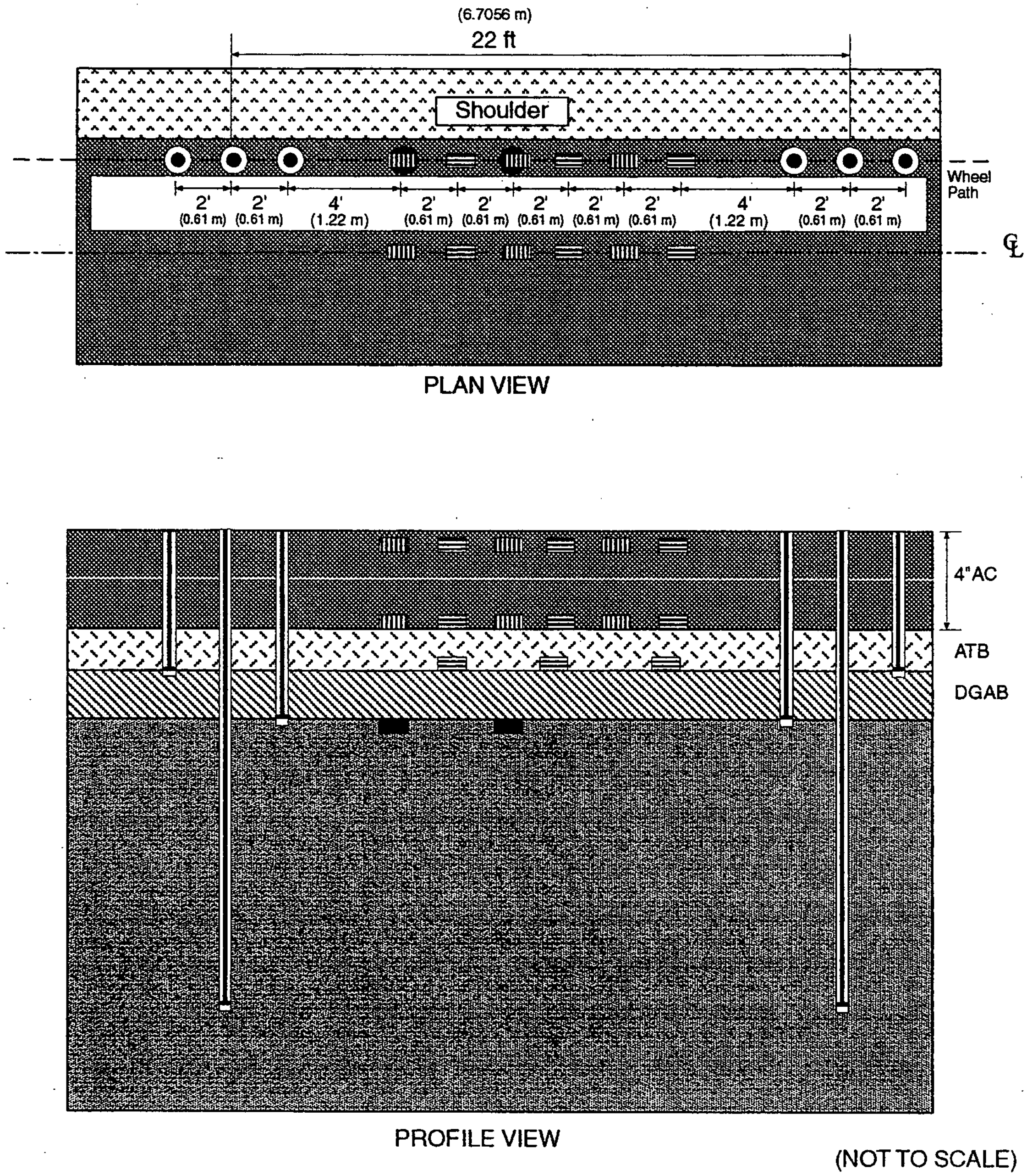


Figure 2.20(a) Structural Response Instrumentation.Typical AC Section (Two Base Layers, Two AC Lifts).

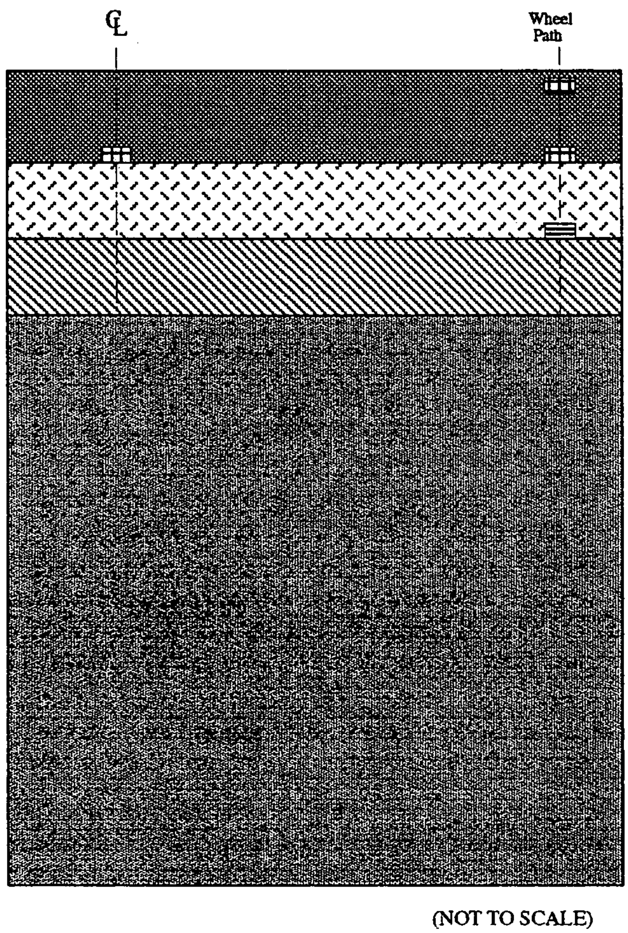


Figure 2.20(b) Lateral Profile, Structural Response Instrumentation . Typical AC Section (Two Base Layers, Two AC Lifts).

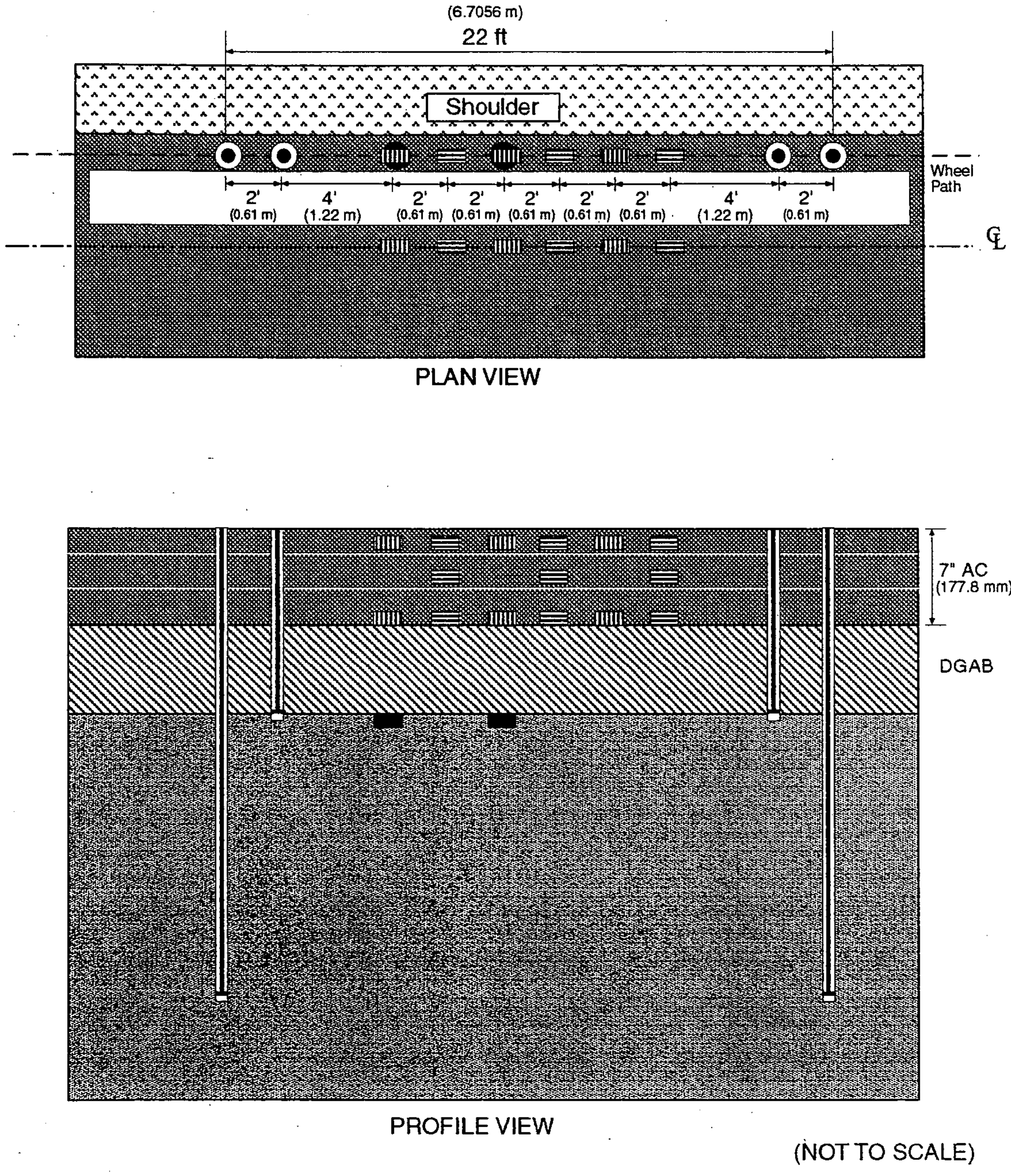


Figure 2.21(a) Structural Response Instrumentation. Typical AC Section (One Base Layer, Three AC Lifts).

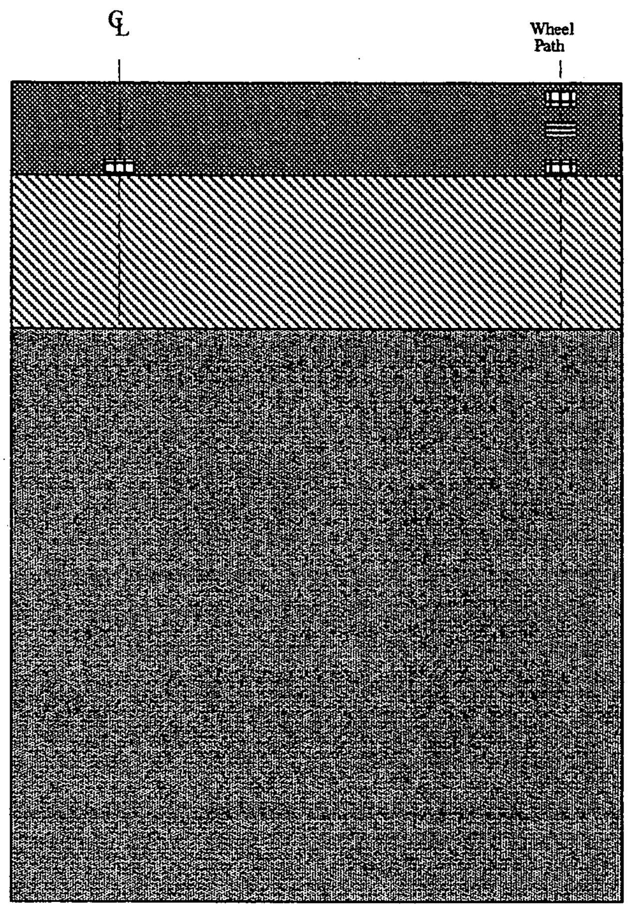


Figure 2.21(b) Lateral Profile, Structural Response Parameters. Typical AC Section (One Base Layer, Three AC Lifts

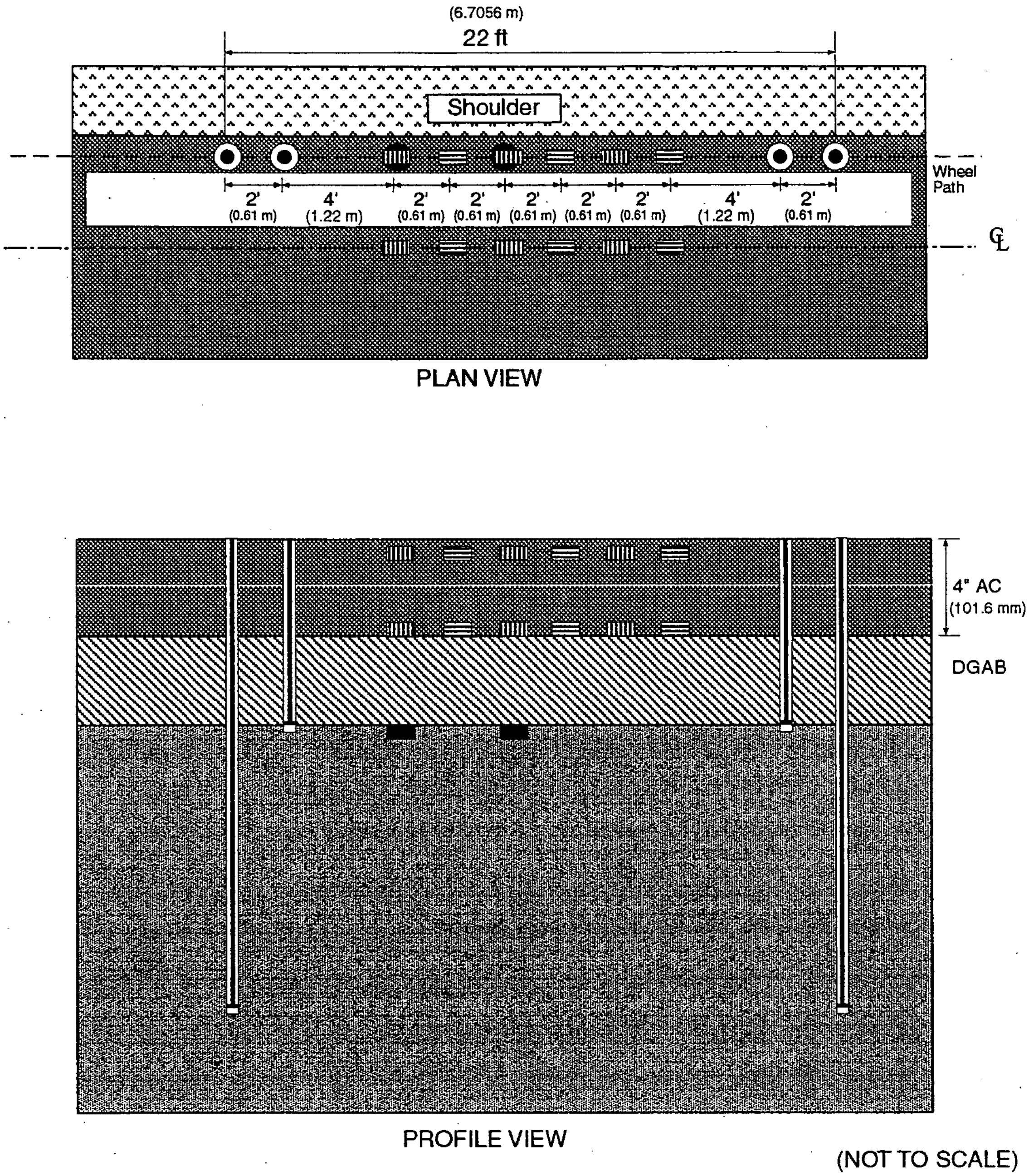


Figure 2.22(a) Structural Response Instrumentation.Typical AC Section (One Base Layer, Two AC Lifts)

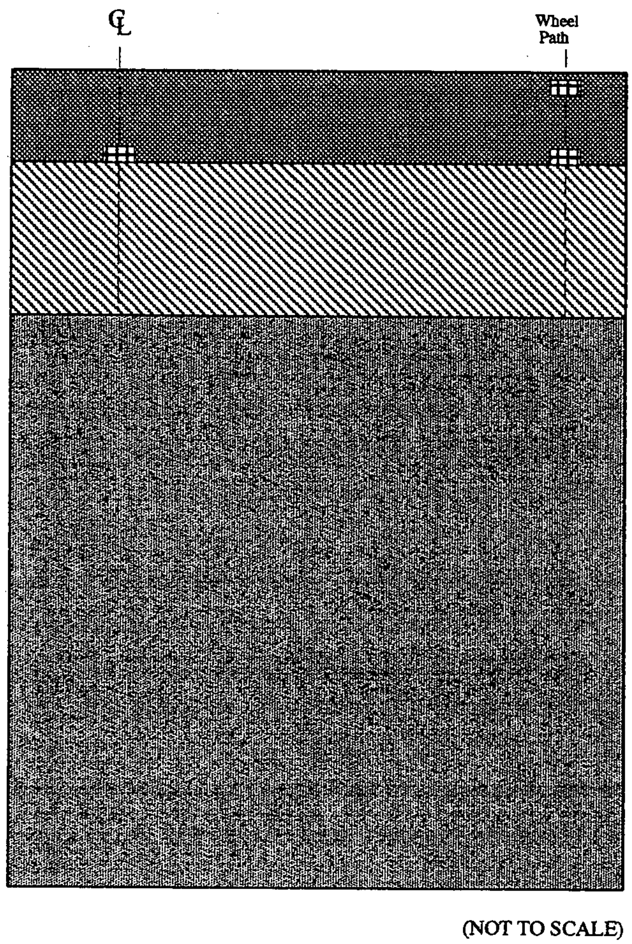
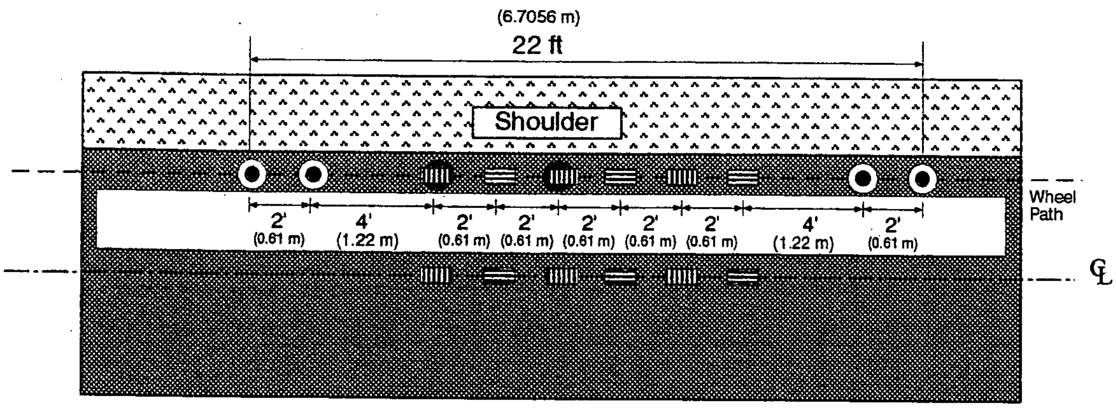
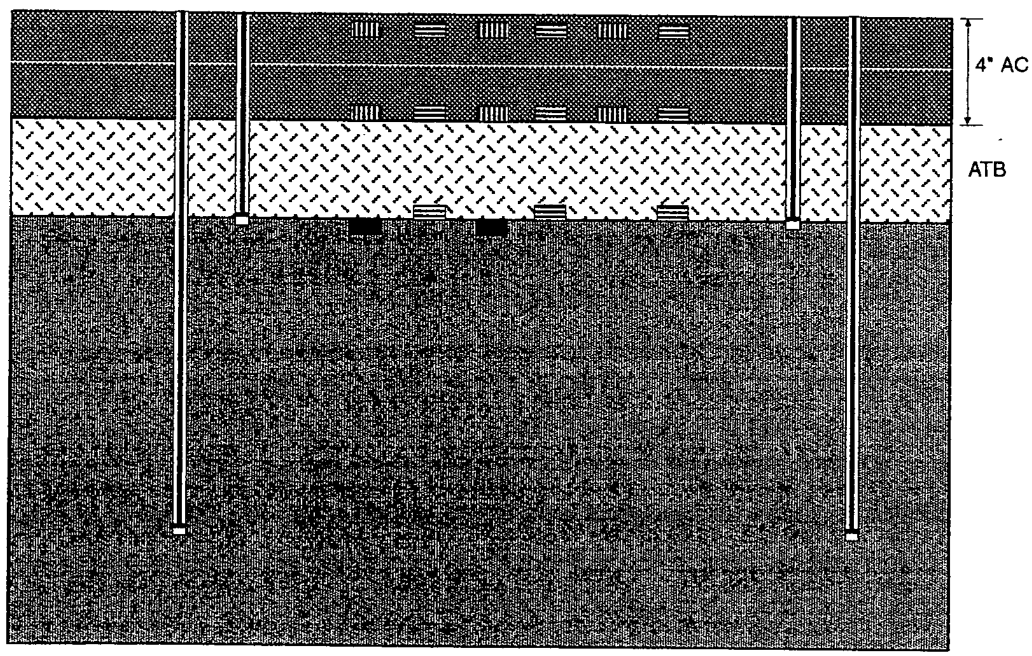


Figure 2.22(b) Lateral Profile, Structural Response Instrumentation.Typical AC Section (One Base Layer, Two AC Lifts).



PLAN VIEW



PROFILE VIEW

(NOT TO SCALE)

Figure 2.23(a) Structural Response Instrumentation. Typical AC Section (One Base Layer, Two AC Lifts).

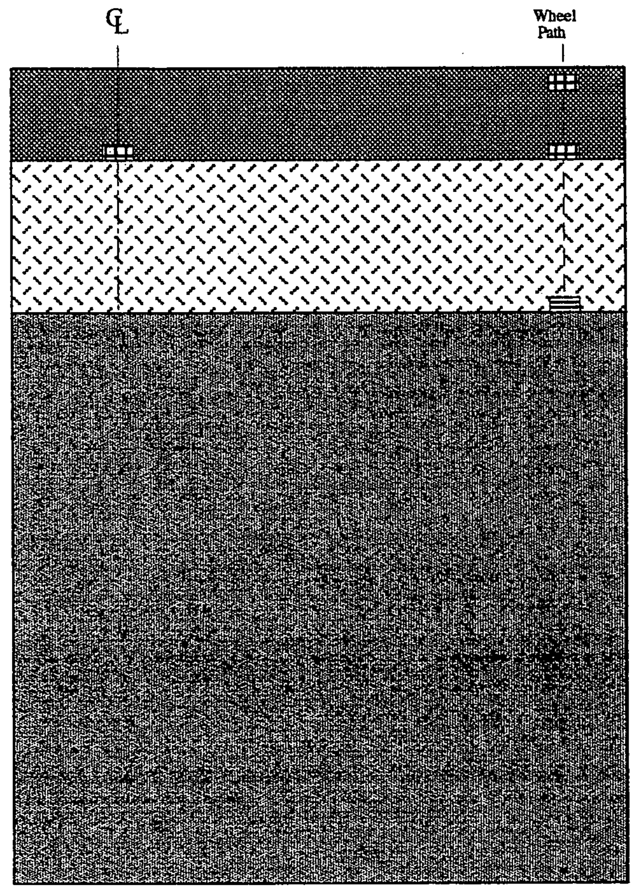


Figure 2.23(b) Lateral Profile, Structural Response Instrumentation. Typical AC Section (One Base Layer. Two AC Lifts).

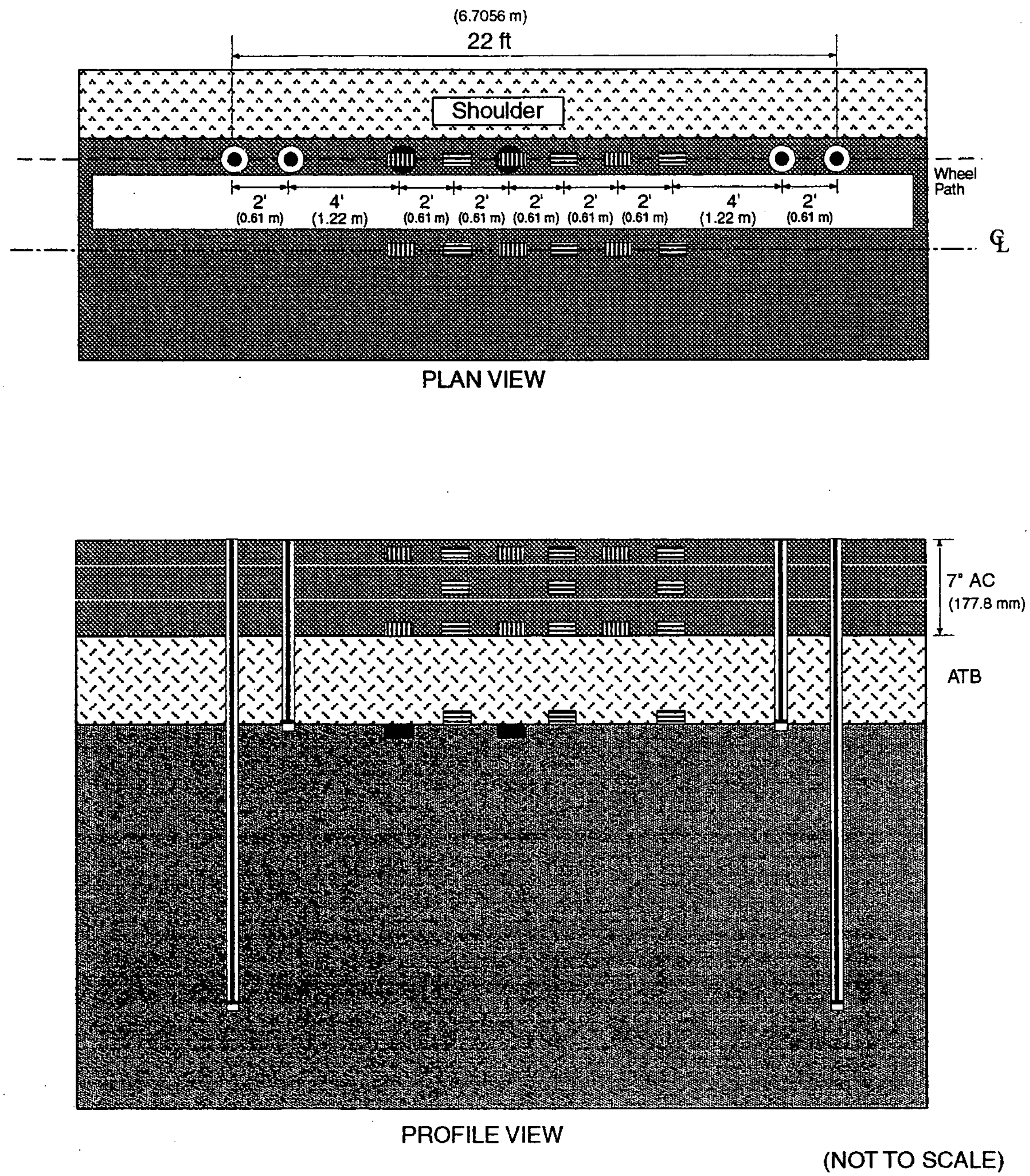


Figure 2.24(a) Structural Response Instrumentation. Typical AC Section (One Base Layer, Three AC Lifts)

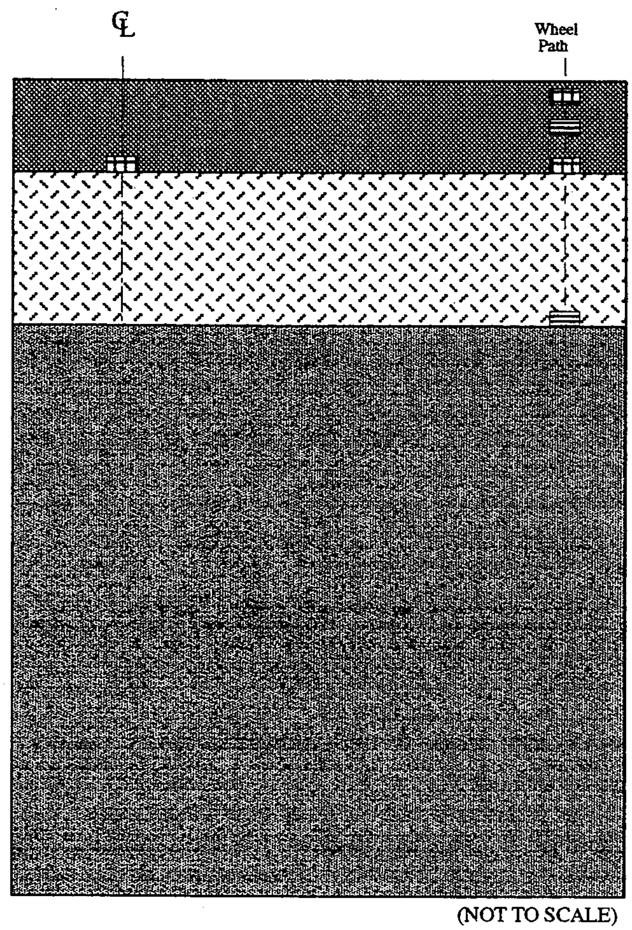


Figure 2.24(b) Lateral Profile, Structural Response Instrumentation. Typical AC Section (One Base Layer, Three AC Lifts).

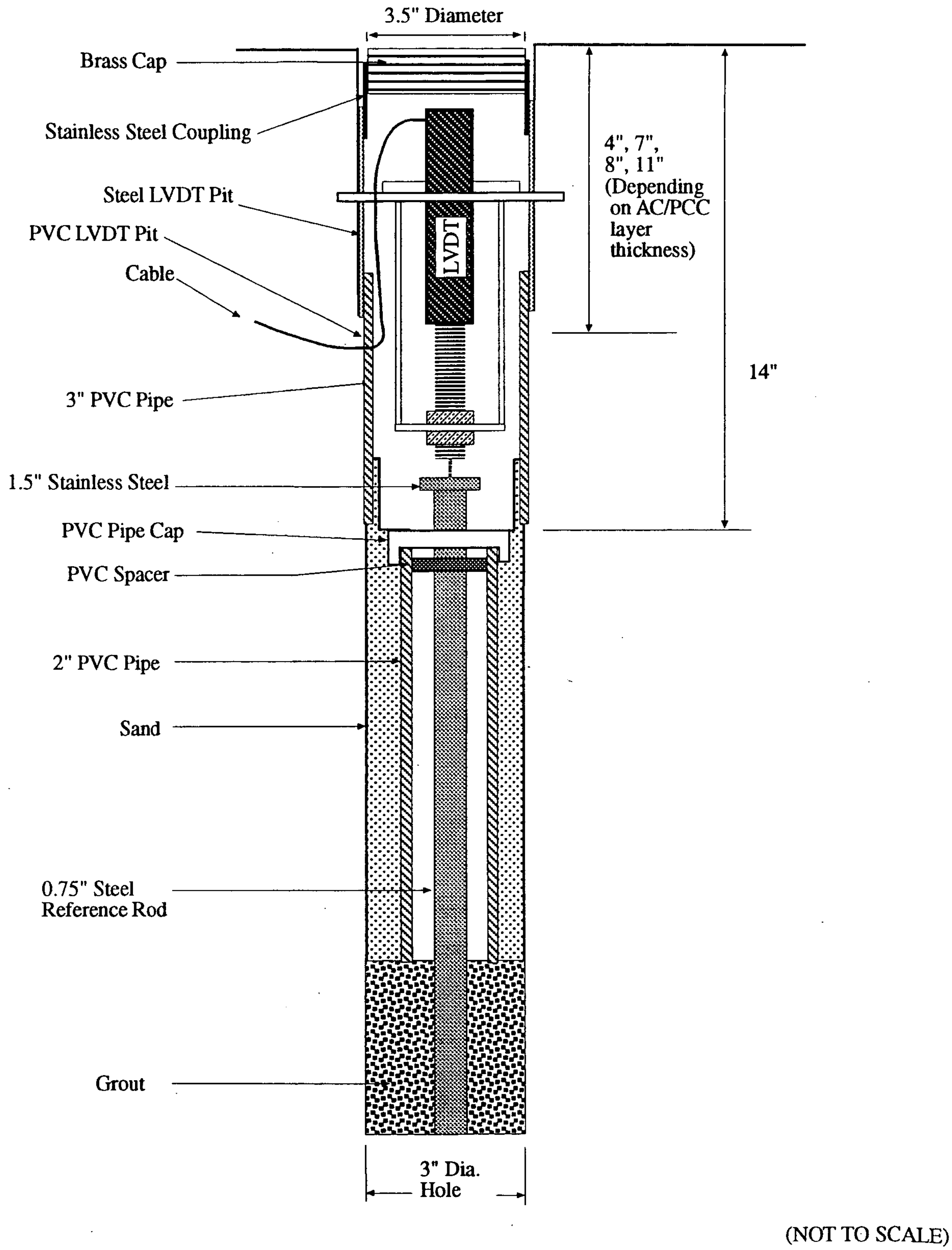


Figure 2.25 Deep Reference Single Layer Deflectometer Profile

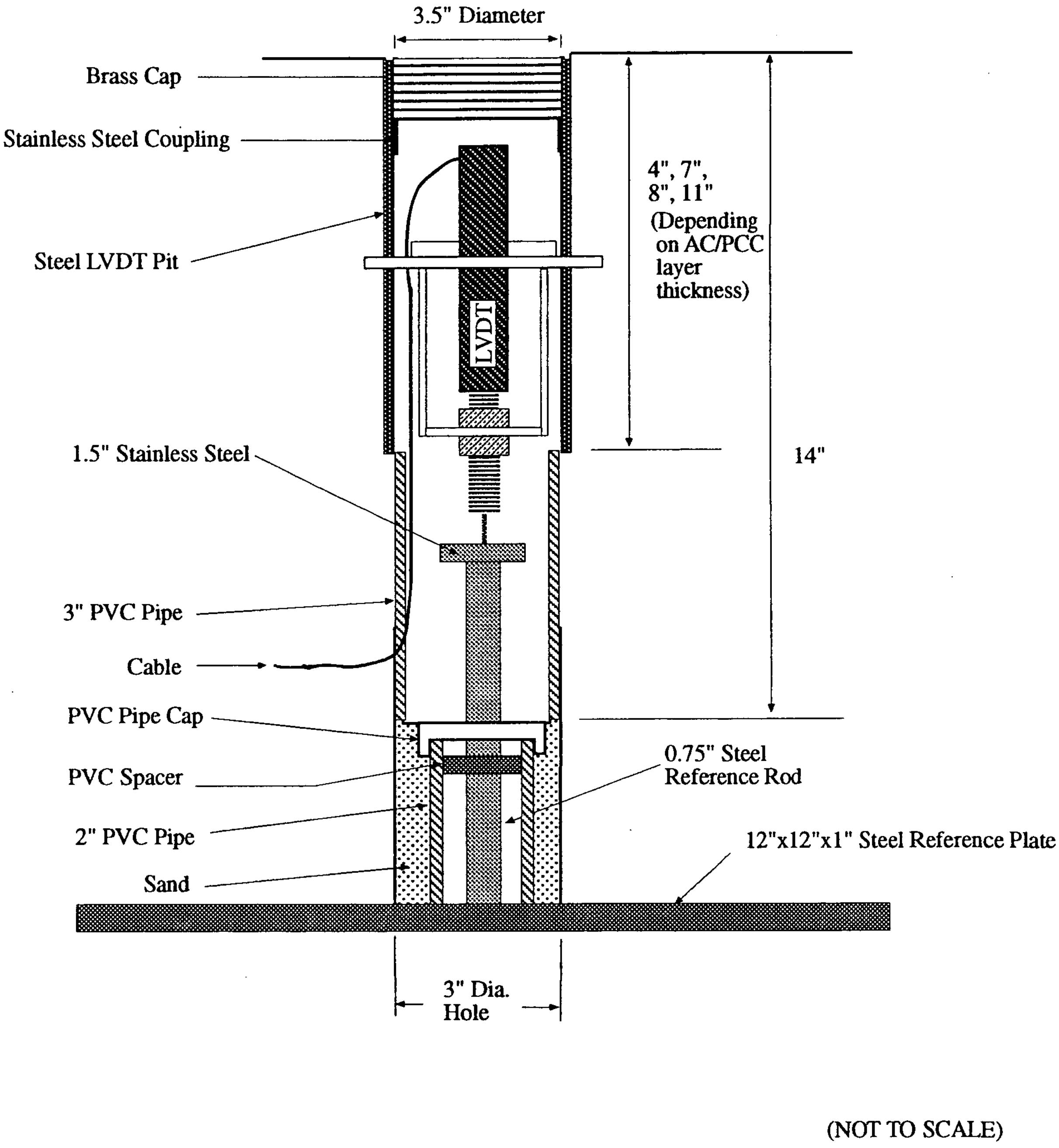


Figure 2.26(a) Shallow Reference Single Layer Deflectometer Profile

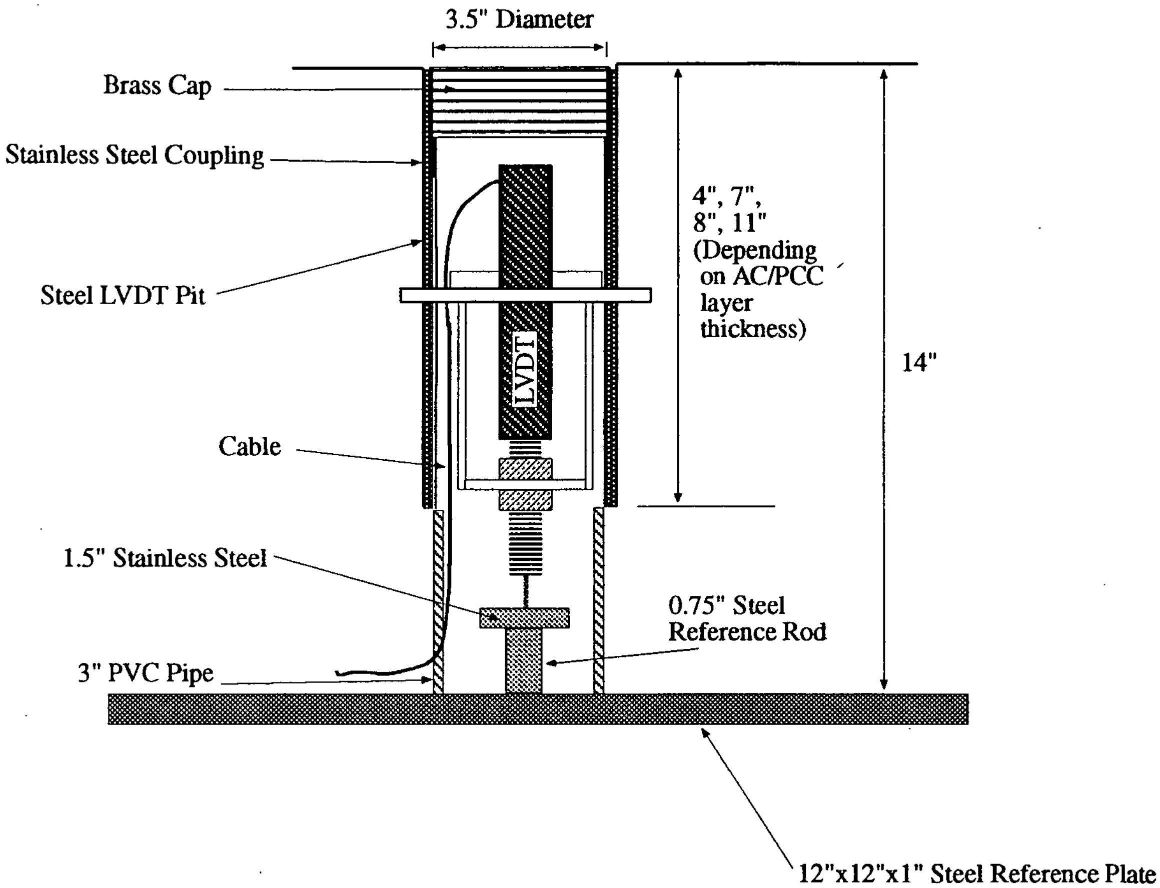


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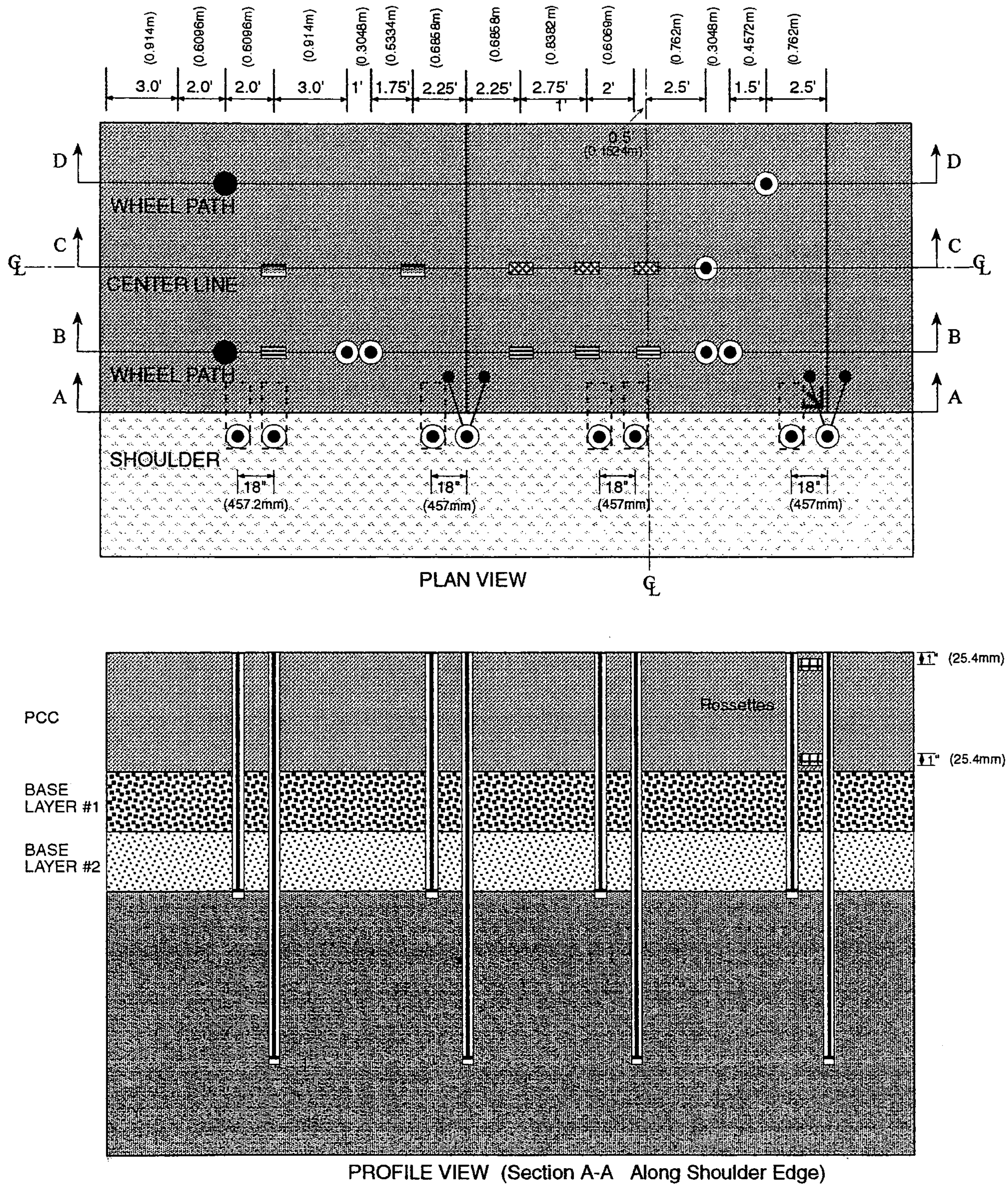
Figure 2.26(b) Shallow Reference Single Layer Deflectometer Profile

2.3.2.2 PCC Sections

Structural response sensor location for typical PCC sections is shown in Figures 2.31 and 2.32. In PCC, in contrast to AC sections, LVDTs will be installed prior to the placement of the concrete. LVDT placement procedure will be divided into three categories; Deep Reference LVDTs, Shallow Reference LVDTs, and Slab Edge LVDTs. Deep reference LVDT procedure will apply to all LVDTs whose reference point is 11 ft deep. All other interior LVDTs will be installed following the shallow reference procedure. LVDTs installed at the edge of slabs will follow the third specified procedure.

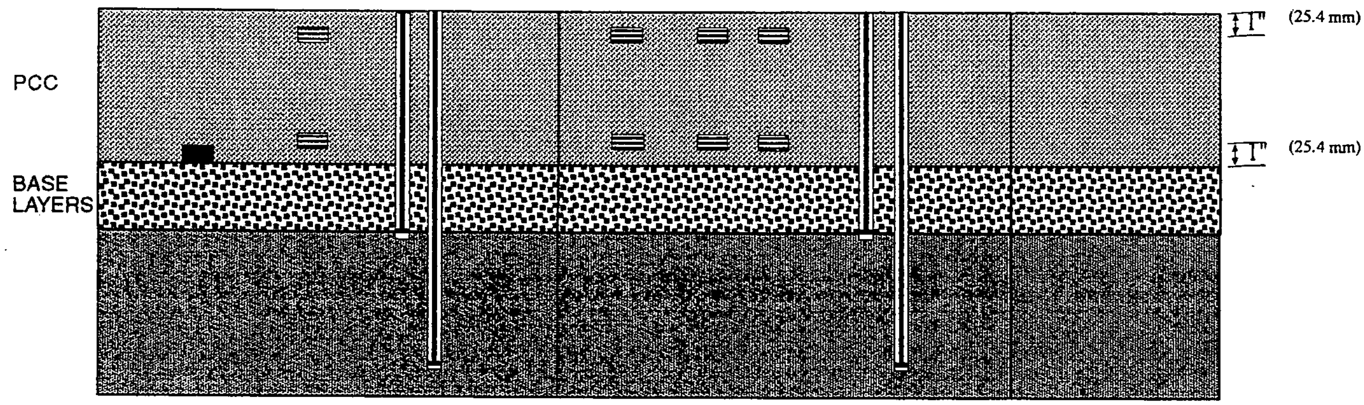
<u>Wire Layout</u>

1. All wires will be taken from the sensor location to the center of section at the pavement edge.
2. A trench will be dug to accommodate sensor wires.
3. Wires from each sensor will be placed in the trench.
4. Excess wire length will be provided for each sensor to relieve stress.
5. Trenches will be filled with base material.

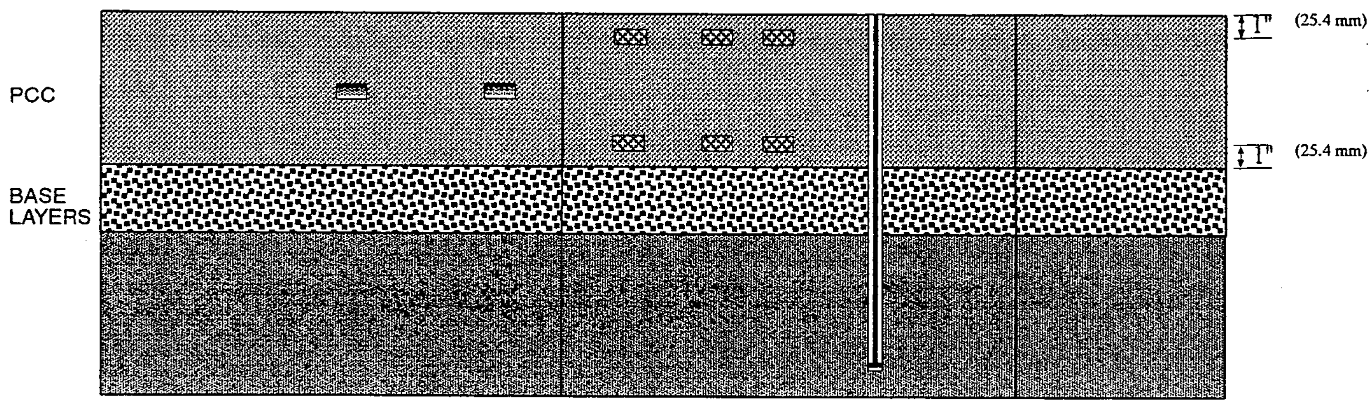


(NOT TO SCALE)

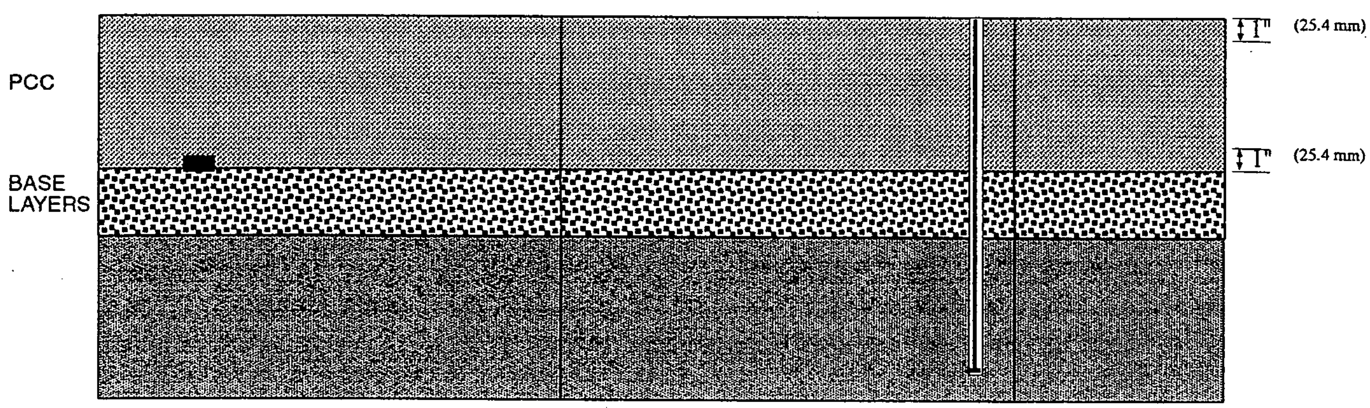
Figure 2.27(a) Structural Response Instrumentation.Typical PCC Section.



Section BB (Inner Wheel Path)



Section CC (Center Line)



Section DD (Outer Wheel Path)

(NOT TO SCALE)

Figure2.27(b) Profile Views For Structural Response Instrumentation.Typical PCC Section

Deep Reference Linear Variable Differential Transformers

1. LVDT holders and reference rods will be fabricated. Figure 2.25 illustrates a typical LVDT holder. Reference rods for the deep reference LVDTs will be approximately 12 ft long. The top of the reference rods will be finished and painted to provide a smooth, non-corrosive surface for the LVDT armature to contact.
2. When work on the base is completed, a drill rig will auger three inch diameter holes at the LVDT locations. Each hole will extend to a depth of approximately 11 ft. The bottom of the hole will be compacted using a special compaction rod. Depth of the hole will then be checked. If a depth of 11 feet is not achieved, the drill rig will need to be redeployed.
3. A 2 inch diameter PVC pipe will be placed in the hole to safeguard the hole from any falling debris.
4. The 12 ft rod will then be placed in the hole and plumbed. The reference rod will be driven one foot using a sledge hammer and special rod-guard.
5. The bottom of the hole will be filled with three feet of grouting material.
6. The space around the PVC pipe will then be filled with backfill material and clean sand if necessary. A PVC spacer will be placed around the reference rod to maintain alignment with the rod.
7. The LVDT housing units will be placed over the reference rods. The housing units will extend approximately one-half inch below the finished slab elevation.
8. Position of the LVDTs will be checked and recorded.
9. LVDT wire will enter through the bottom of the housing unit. Two to three feet of excess wire will be left in the housing unit.
10. Specially designed pour mounts (used to maintain reference rod and holder alignment) will be

placed in the holders.

11. Flush brass caps will be placed on top of the housing units and covered with wall putty to prevent concrete from bonding.

12. Ahead of the paver, concrete will be placed over and around the LVDT housing units and vibrated.

13. Clearance will be maintained between the paving train vibrators and the housing units. Vibrators are to be be moved to avoid contact with any of the housing units.

14. After the concrete cures, concrete above the caps will be removed. Flush caps and pour mounts will be discarded.

15. At this time LVDT wires will be soldered and protected using heat-shrink tubing, and the operation of the LVDT will be checked. The LVDT will be placed in the housing unit, and set as close to the null point as possible with the mounting nuts.

16. Brass caps will be placed on the LVDT holders to ensure a smooth surface for traffic.

Shallow Reference Linear Variable Differential Transformers

1. LVDT holders and reference rods will be fabricated. Figure 2.26 (a) and (b) illustrate a typical LVDT holder. Reference rod length for the shallow reference LVDTs will depend on the location of the specific LVDT. Specific length rods will be fabricated. The top of the reference rods will be finished and painted to provide a smooth, non-corrosive surface for the LVDT armature to contact.
2. When work on specific subbase layers is completed, reference plates will be buried in the LVDT location.
3. After work on the base is completed, a drill rig will auger three inch diameter holes at the LVDT locations. Each hole will extend to the reference plate.
4. A 2 inch diameter PVC pipe will be placed in the hole to safeguard the hole from any falling debris.
5. The reference rod will be placed in the hole and plumbed. The reference rod will be attached to the plate and grouted in place.
6. The space around the PVC pipe will be filled with backfill material and clean sand if necessary. A PVC spacer will be placed around the reference rod to maintain the alignment with the rod.
7. The LVDT housing units will be placed over the reference rods. The housing units will be approximately one half inch below the finished slab elevation.
8. Position of the LVDTs will be checked and recorded.
9. LVDT wire will enter through the bottom of the housing unit. Two to three feet of excess wire will be left in the housing unit.
10. Specially designed pour mounts (used to maintain reference rod and holder alignment) will be placed in the holders.

11. Flush brass caps will be placed on top of the housing units and covered with wall putty to prevent concrete from bonding.

12. Ahead of the paver, concrete will be placed over the LVDT housing units and vibrated.

13. Clearance will be maintained between the paving unit's vibrators and the housing units. Vibrators will be moved to avoid contact with any of the housing units.

14. After the concrete cures, the concrete above the caps will be removed and the flush cap and pour mounts discarded.

15. At this time LVDT wire will be soldered and protected using heat-shrink tubing, and the operation of the LVDT will be checked. The LVDT will be placed in the housing unit, and set as close to the null point as possible with the mounting nuts.

16. Brass caps will be placed on the LVDT holders to ensure a smooth surface for traffic.

Slab Edge Linear Variable Differential Transformers

The reference rod for measuring vertical displacement of the edge slab will be installed in the shoulder. LVDTs at the joint will be housed inside a small steel box. Detailed drawings are shown in Figures 2.28 (a), (b), and (c) and Figures 2.29 (a), (b), and (c). Installation procedures for these LVDTs are identical to procedures presented for LVDTs installed at interior slab locations. The cover of the box will be attached with screws. The top of the screws will be epoxied to prevent screws from loosening from traffic vibration. Boxes located at the joints will also house proximeter probes or LVDTs positioned in the horizontal direction to monitor joint opening.

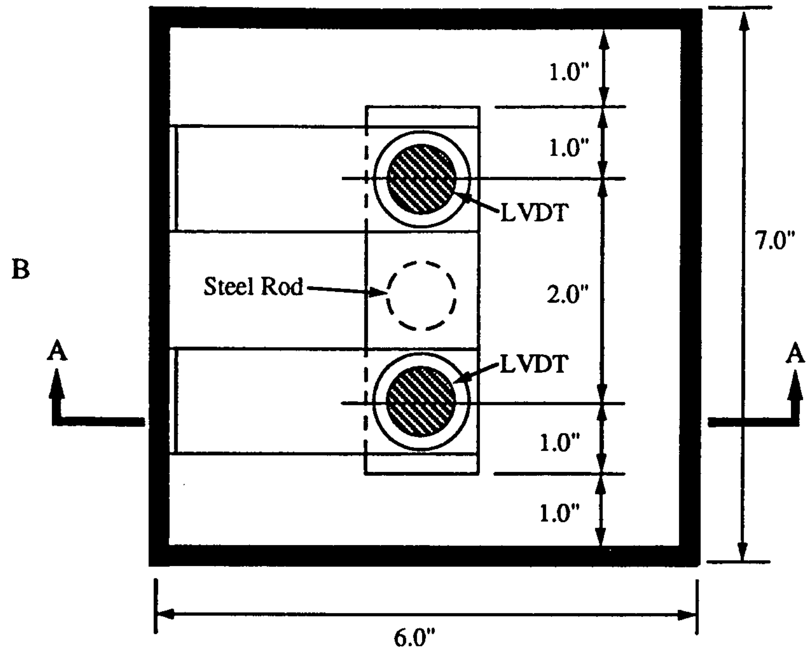


Figure 2.28 (a) Slab Edge Joint Single Layer Deflectometer (Plan View)

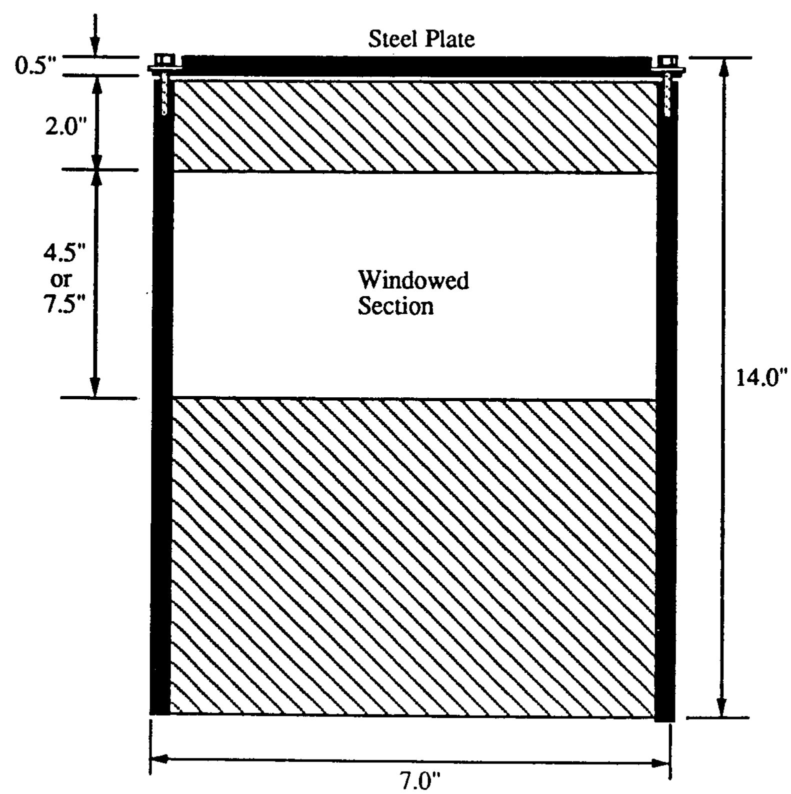


Figure 2.28 (b) Intrumentation Box for Slab Edge Joint Single Layer Deflectometer (Side View B)

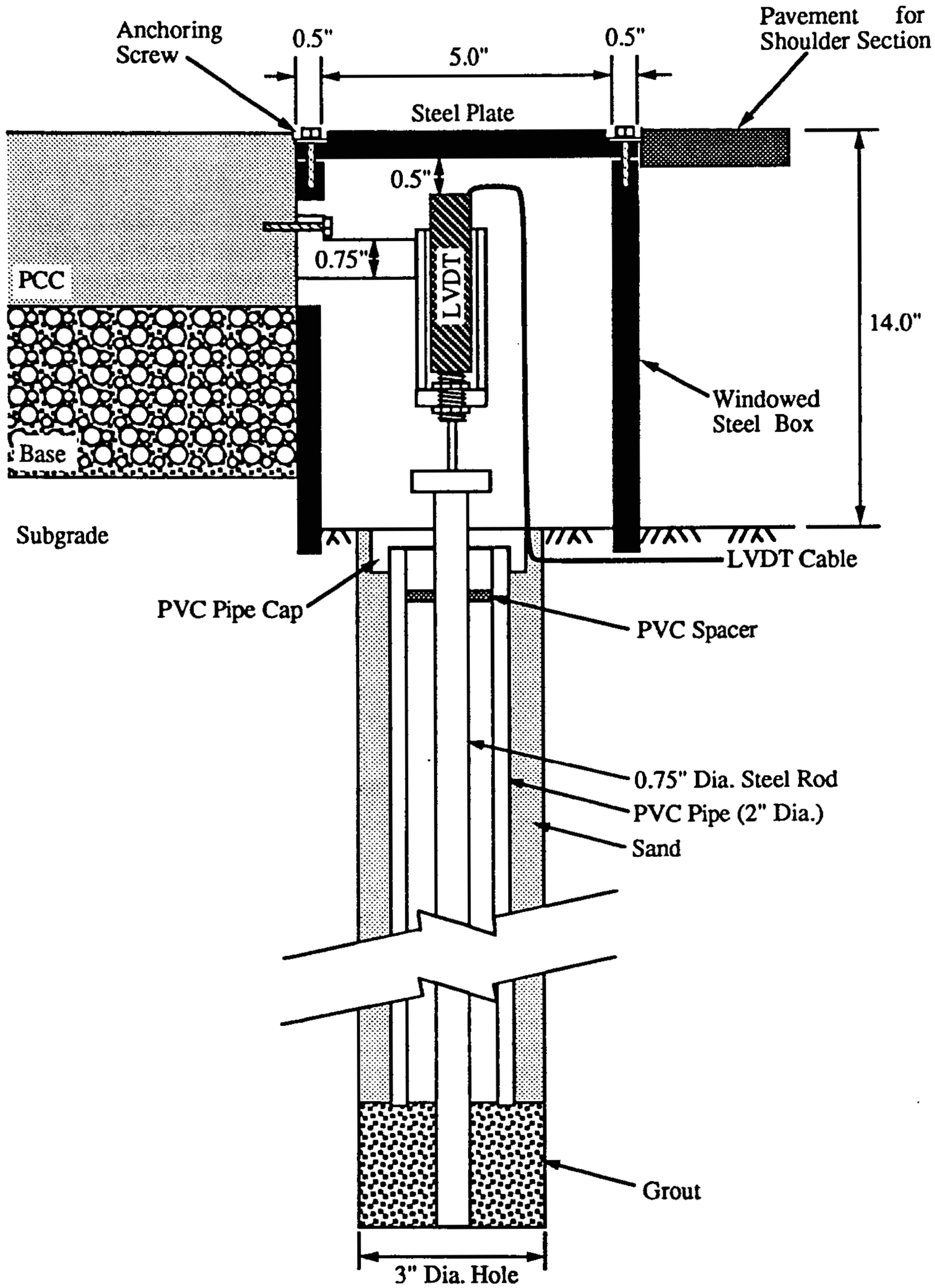


Figure 2.28 (c) Slab Edge Joint Single Layer Deflectometer (Profile A-A)

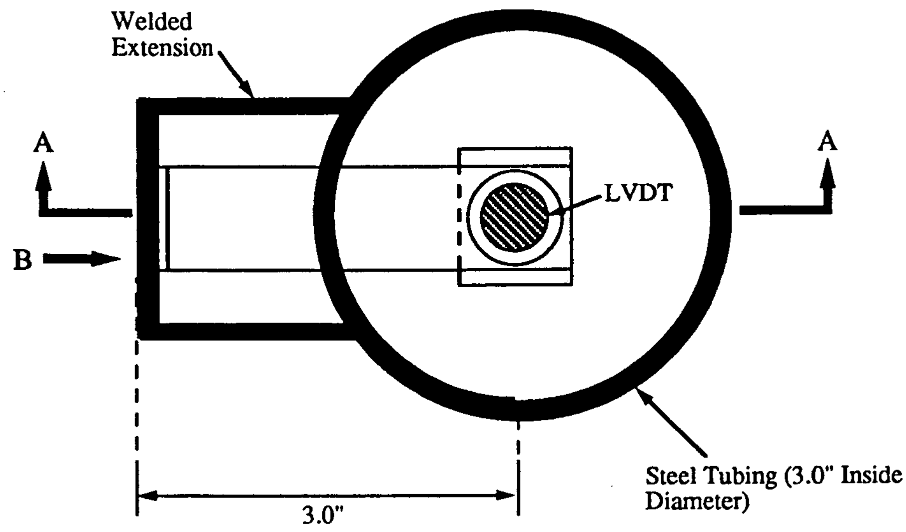


Figure 2.29 (a) Slab Edge Single Layer Deflectometer (Plan View)

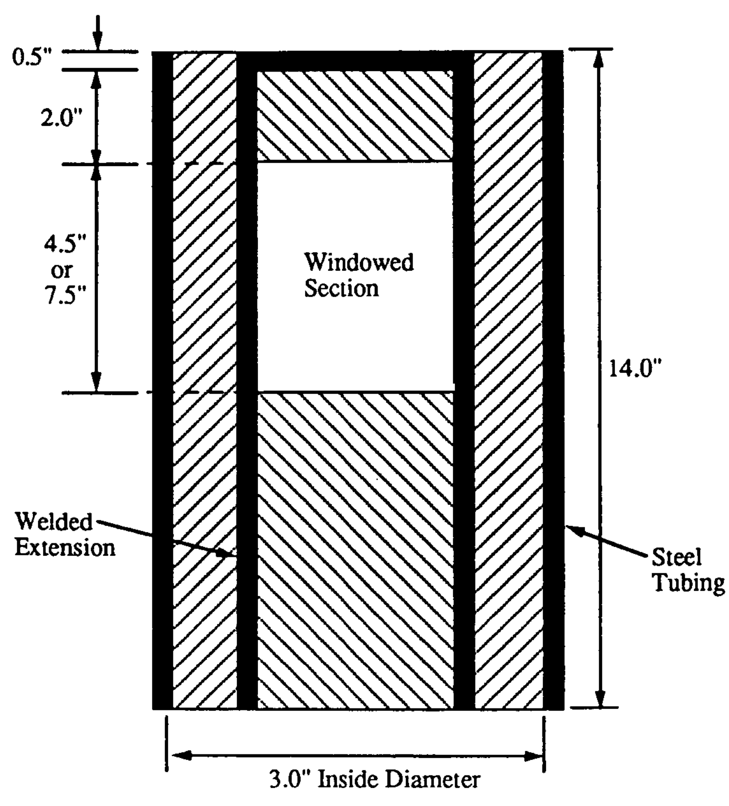


Figure 2.29 (b) Instrumentation Box for Slab Edge Single Layer Deflectometer (Side View B)

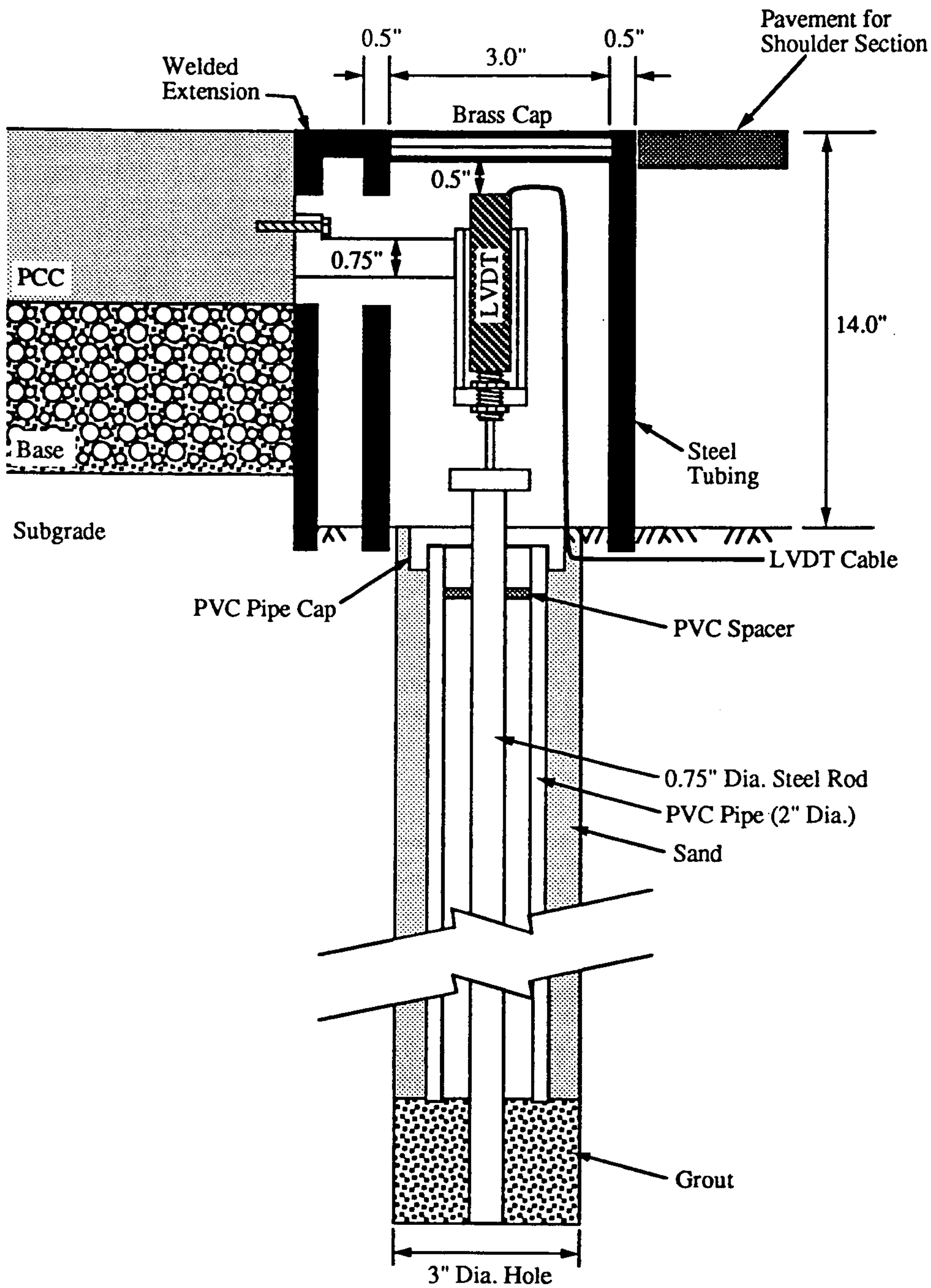


Figure 2.29 (c) Slab Edge Single Layer Deflectometer (Profile A-A)

Pressure Cells

1. To prepare for field installation, each pressure cell will be precast in concrete with the sensitive cell surface exposed and projecting approximately 1/8 inch above the concrete. Dimensions of the concrete block will be 12 inches wide, 24 inches long, and 2 inches thick. The concrete casting prevents shifting of the pressure cell and minimizes disturbances of the bedding sand layer during paving operations.
2. The pressure cell will be calibrated as described later.
3. After the subbase layer has been constructed, a 13x25x3 inch deep rectangular hole will be excavated into the subbase and filled with a 2 inch thick, compacted, moist concrete sand bedding. The sand layer is provided here to prevent the "bridging" phenomena.
4. The precast pressure cell will be placed over the sand with its sensitive cell surface facing down.
5. The readings from the pressure cell will be checked, as well as the location and the serial number of the pressure cell. Cable from the pressure cell will be laid in the wire trench.
6. Prior to the paving process, concrete will be placed over the block for added protection.

Strain Gauges

1. Enclosures measuring 12x6x7.5 or 10.5 in. high (depending upon pavement thickness) will be fabricated from 22-gauge sheet metal. Since there is no mesh in the concrete to hold the boxes, boxes will be stabilized with anchor pins. When the boxes are pulled, to prevent disturbing the gauge locations, all gauges will be attached to chairs. Figure 2.30 shows a typical strain gauge enclosure.
2. Once the base material is in place, the chairs and enclosures will be positioned at the appropriate locations.
3. Within each enclosure, the strain gauges will be held by plastic ties to chairs.
4. Ahead of the paving train, concrete free of large aggregate will be carefully placed inside each enclosure and vibrated. This will ensure a uniform concrete mixture around gauges. During vibration of the concrete in the immediate vicinity of the gauges, care must be taken that the gauge is not displaced, rotated, or damaged.
5. After the finishing paver passes, the enclosure will be carefully removed. The concrete in the vicinity of the gauges will be vibrated to eliminate any discontinuities.
6. Gauge operation will be checked during paving operation to ensure that the sensors are not damaged.

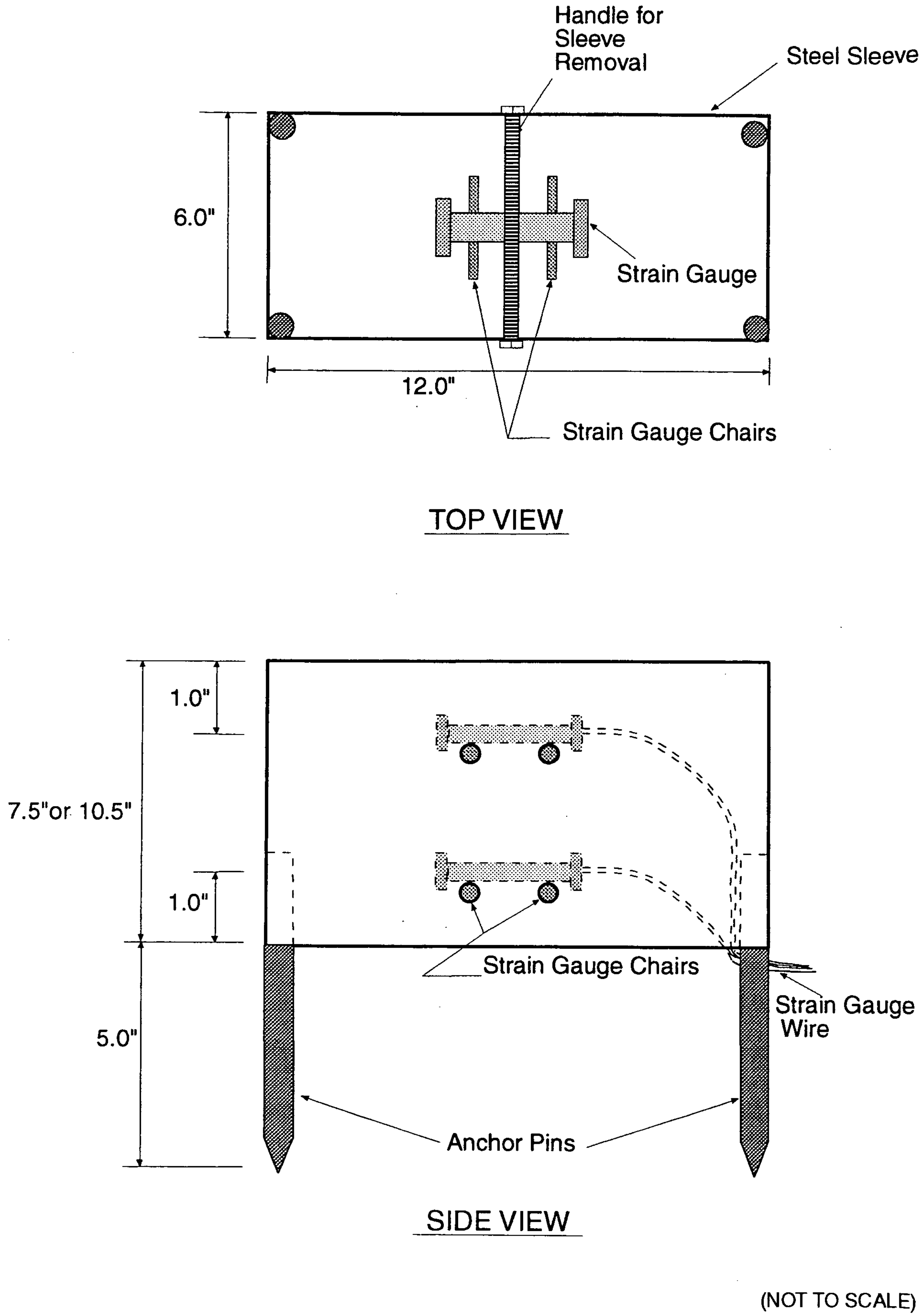


Figure 2.30 Typical Strain Gauge Sleeve

2.4 CALIBRATION PROCEDURE

All sensors will be identified, checked and calibrated, if appropriate, at time of arrival in the lab. Strain gauges will be checked for continuity and resistance. Resistance values for each gauge will be noted. All gauges will be connected to data acquisition systems and the response checked.

2.4.1 Minimum Quality Assurance (QA) Plan

Field measurement accuracy depends on the quality of the calibration factors established for the sensors. Therefore, a minimum level of QA plan must be implemented into the standard calibration procedures. At least two calibration tests must be performed for each pressure cell and LVDT. If two calibration tests are made, relative percent difference (RPD) is the quality indicator, as calculated from:

$$RPD(\%) = \frac{(C_1 - C_2) * 200}{C_1 + C_2}$$

where C_1 = larger of the two observed calibration factors; and C_2 = smaller of the two observed calibration factors. If three or more calibration tests are repeated, relative standard deviation (RSD) is the quality indicator, as calculated by:

$$RSD(\%) = \frac{100}{\bar{C}} * \sqrt{\sum_{i=1}^{n} \frac{(C_i - \bar{C})^2}{n-1}}$$

where $\bar{C}$ = mean of the observed calibration factors; n = total number of calibration tests; C_i = calibration factor from the *i* th calibration test. For pressure cells, the acceptable limit of RPD and RSD values is 2%. For LVDTs, the acceptable limit is 0.5% for both RPD and RSD. If these criteria are not satisfied, appropriate action must be taken to resolve the problem.

2.4.2 Pressure Cells

Pressure cells must be calibrated in the laboratory under carefully simulated field installation conditions. Each pressure cell at the subbase/base interface for the AC sections will be underlain by a 2 inch layer of dense concrete sand and overlain by soil from the site. For the PCC sections, pressure cells will be precast in a concrete block and placed against a 2 inch thick concrete sand bedding. Therefore, items required for the pressure cell calibration procedure are:

- Precision loading system, equipped with a load cell (such as MTS).
- A steel container (inside dimensions: 14" Wx26" Lx4"H).
- Concrete sand (slightly moist, free from gravel).
- Soil obtained from the site.
- Semi-rigid elastic ring (made from 2" thick polyethylene sheet).
- Circular loading plate (9" diameter, rigid).
- Data acquisition system.

The diameter of the elastic ring should be slightly larger than that of the cell and the height of the ring must be a little less than 2 inches. The elastic ring is utilized to control the loaded area during the test. Figures 2.31 (a) and 2.31 (b) illustrate a typical calibration test set-up for the pressure cells for AC and PCC sections, respectively. The steps involved in each calibration test will be:

1. The steel container is placed on the precision loading system platform. If the container is unstable, use of a 12" x 12" x 1"thick steel plate under the container is recommended for additional support.
2. For pressure cells to be used in the AC sections, a 2" thick concrete sand layer is placed with tamping inside the container (Proceed to step 3). For pressure cells to be used in the PCC sections, place the concrete block inside the steel container so the sensitive, exposed cell surface

faces up (Proceed to step 4).

3. A pressure cell is positioned along the centerline of the container over the sand bedding. If the cell has only one sensitive surface, the cell positioning is made so the sensitive face is facing up.

4. The elastic ring is set around the sensitive disk surface of the cell, and the site material is placed inside the ring for the pressure cells for AC sections. For PCC sections pressure cells, a 2" thick concrete sand cover is made by compacting the sand inside the ring.

5. The circular loading plate is placed on top of the elastic ring.

6. A load of 100 lbs. is applied and then removed to condition the cell set-up.

7. Excitation voltage, gain, and filter are set properly and recorded on a data sheet. The cell and the load cell are connected to the data acquisition system. Serial number of the pressure cell is also noted.

8. Initial output readings from the pressure cell and load cell are saved.

9. Load is increased incrementally to 80% of the load capacity of the pressure cell, and outputs from the two sensors are recorded after a few minutes of loading under each loading increment.

10. Load is removed completely from the pressure cell.

11. A plot is made from the data, which correlates the pressure over the cell to the output voltage from the pressure cell.

12. A linear regression analysis is made to obtain a linear slope and the correlation coefficient.

13. All data and plots are maintained on file for future auditing.

The above steps assume that the loading system, such as MTS, is already equipped with an accurate load cell. If there is a doubt about the reliability of the load cell, a separate calibration test should be performed on the load cell, using a proving ring. At least two calibration tests are required for each pressure cell.

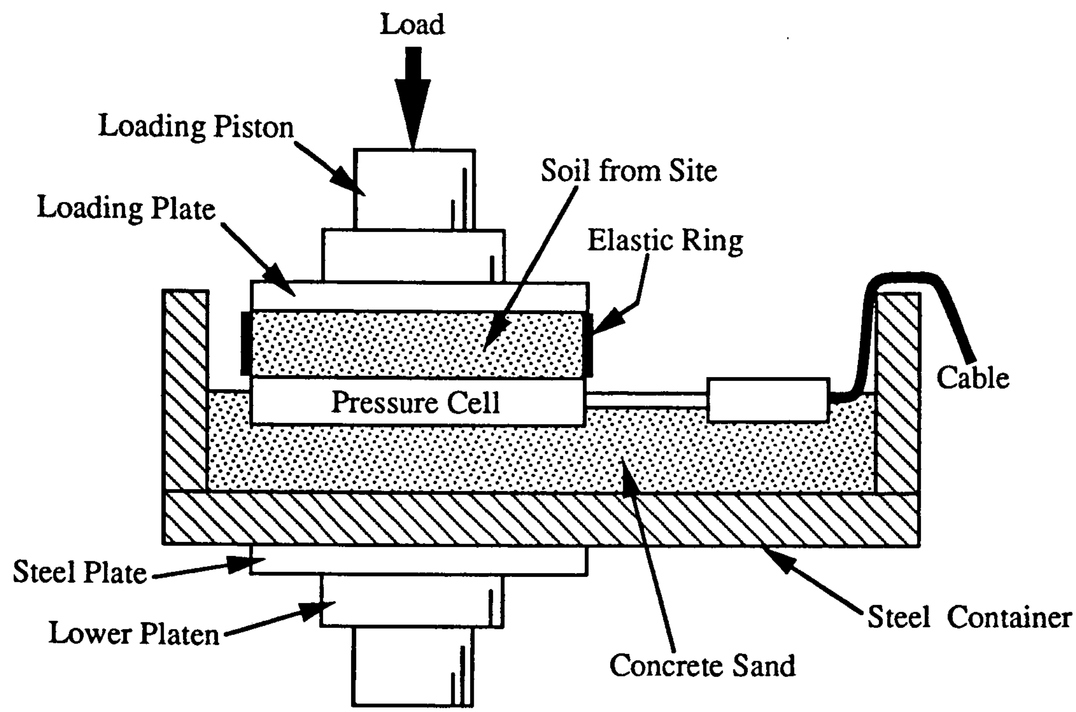


Figure 2.31 (a) Typical Set-Up for Laboratory Calibration of AC Section Pressure Cells

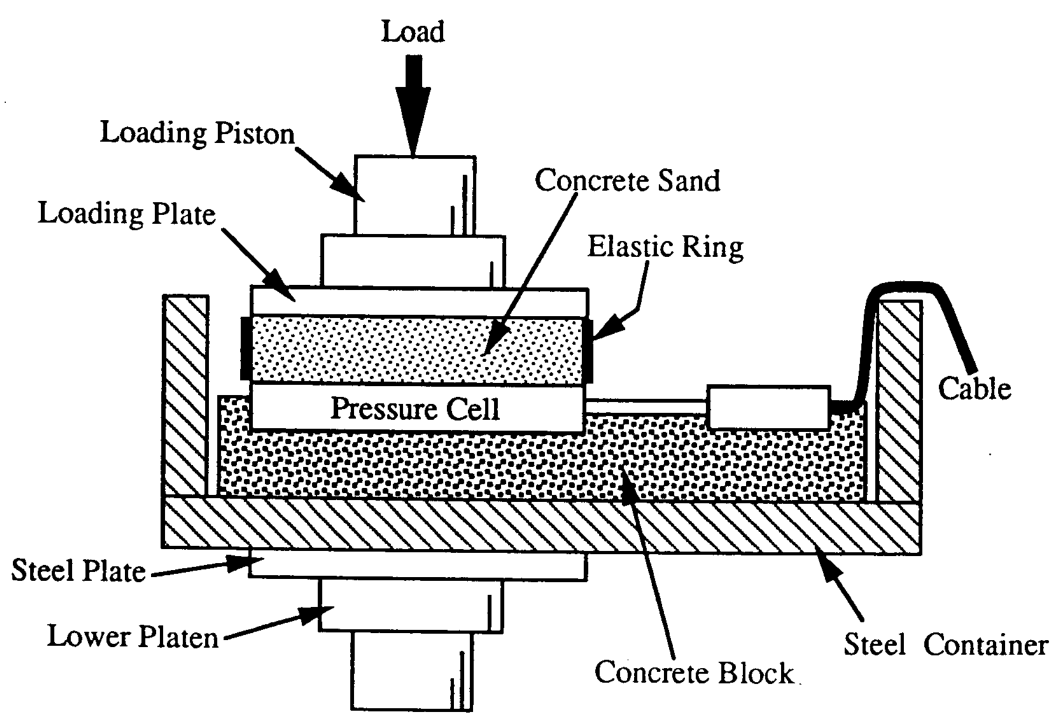


Figure 2.31 (b) Typical Set-Up for Laboratory Calibration of PCC Section Pressure Cells

2.4.3 Linear Variable Displacement Transformers

To calibrate each LVDT, items required are an LVDT calibration stand (equipped with a precision micrometer), and data acquisition system. Before field installation, the LVDTs will be checked for continuous response. The following calibration procedure will be repeated at least twice for each LVDT, and relative percent difference of the results must be within ± 1.0%.

1. The LVDT is installed on the calibration stand.
2. The LVDT is connected to the power supply/data acquisition system. Allow 10 to 15 minutes warm up time for the electronics to stabilize.
3. The LVDT core is set at null. The output voltage and micrometer readings are recorded.
4. The LVDT core is *compressed* in small increments. Both the micrometer and the LVDT output voltage readings are recorded for each increment. This process is repeated until reaching half of the full scale range.
5. The LVDT core is repositioned to null. The output voltage and micrometer reading should be back to the value recorded in Step 4.
6. The LVDT core is *extended* in small increments. Both the micrometer and the LVDT output voltage readings are recorded for each increment. This process is repeated until reaching half of the full scale range.
7. A plot is made from the data which correlates the LVDT core displacement to the output voltage from the LVDT.
8. A linear regression analysis is made to obtain a linear slope and the correlation coefficient.
9. All data and plots are maintained on file for future auditing.

CHAPTER 3

DATA ACQUISITION SYSTEMS

3.1 SEASONAL PARAMETERS DATA ACQUISITION SYSTEM

LTPP guidelines specify Campbell Scientific's CR10 data acquisition system to monitor seasonal sensors. The CR10 system will be used with four AM416 multiplexers to read full bridge strain gauges , LVDTs, and thermistors. A portable CR10 system will be developed and will contain one Tektronix 1502B TDR cable tester to read the TDR soil moisture probes, and a CRREL multiplexer to monitor the CRREL resistivity probes.

Since it is important to study the effect of seasonal variation on the structural performance of pavement systems, data collection on the DEL-23 pavement will be initiated immediately after the completion of construction. These data will include soil moisture from 18 sections collected every week for the first two months. In addition to soil moisture, weather station data and temperature profile in the pavement will be collected at the same time. The seasonal monitoring program will closely follow guidelines of the LTPP Seasonal Monitoring Program.

3.2 STRUCTURAL RESPONSE PARAMETERS

Nine Optim Electronics Corporation *MEGADAC* 5108AC systems will be used to collect data for structural dynamic response. Each unit will be connected to one 0116AC unit to provide space for the placement of data acquisition electronic boards. The system will be capable of monitoring eighty channels of strain gauges, LVDTs, and pressure cells. The 5108AC unit has the ability of collecting 250,000 samples per second and has a maximum gain of 10,000. Each 5108AC unit will also have 16MB RAM of storage. The 5108AC unit contains RS-232, RS-422, RS-485, and IEEE/488 interfaces. The Megadac systems will be used with IBM compatible 486 DX33 PCs using the IEEE/488 interface card and cable since this card is among the fastest and most reliable computer interfaces. The computer will provide an environment for the Test Control Software (TCS). TCS is a DOS based program used to control, collect, and analyze data from the 5108AC units. This software package will be customized for data collection on the DEL-23 project. In addition, software packages for 3-D plotting and digital filtering will be provided.

Data acquisition will include AD 808FB-1 cards, which were specially manufactured for the DEL-23 project. The AD 808FB-1 will be used to monitor and record data from strain gauges, and strain gauge based pressure cells. This card provides bridge completion, excitation, and remote sensing capabilities to ensure and maintain accuracy of the prescribed voltage applied to the gauge. CB100 cards will be used to supply ±15V excitation for LVDTs and pressure cells, and AD 808D-1 cards will be used to read the LVDT signals. Data acquisition cards will interface with the sensors via Screw Terminal Blocks (STBs). The STBs will be placed in a junction box with DB37 connectors for sensors and DB9/DB37 connectors linking to data acquisition cards. Complete wiring diagrams for sensors in PCC and AC sections are shown in Section 3.3. Data acquisition will be triggered with an infrared triggering system used to detect the approach of moving control vehicles or the initiation of an FWD load pulse.

3.2.1 Testing Procedure

Non-Destructive Tests will be conducted on all sections at least four times per year (once for every season). SHRP will collect data during the Spring and Mid-Summer. ODOT will run Non-Destructive Tests during the Spring, Mid-Summer, Fall, and Winter. Research teams will record dynamic response and seasonal data at this time. Approximately two weeks will be required per test. Driving lanes will be closed for the entire length of the SPS experiment during these tests. Tests will be conducted using ODOT Dynaflect and Falling Weight Deflectometer (FWD) vehicles. Load will be applied to instrumentation located on the wheel-path. Three weight drops at each location will be required to establish good data repeatability.

In addition, ODOT will use specially modified dump trucks (Single and Tandem axle trucks). These trucks will contain assisted guidance systems that will help the driver maintain the proper lateral position with respect to a precisely placed highway edge line (with an accuracy of $\pm$1 inch). Lateral position will be recorded for data analysis. The system incorporates automatic image processing and control algorithms in addition to gyro-assisted driver control mechanisms. Individual wheel weights will be measured prior to each test. Truck tests will be performed at various speeds.

Data will be used to establish correlations between axle type, load, speed, temperature and moisture variation on pavement response. Based on discussions with SHRP, DEL-23 researchers, and various experts around the country will develop detailed processing procedures for data obtained on this test pavement.

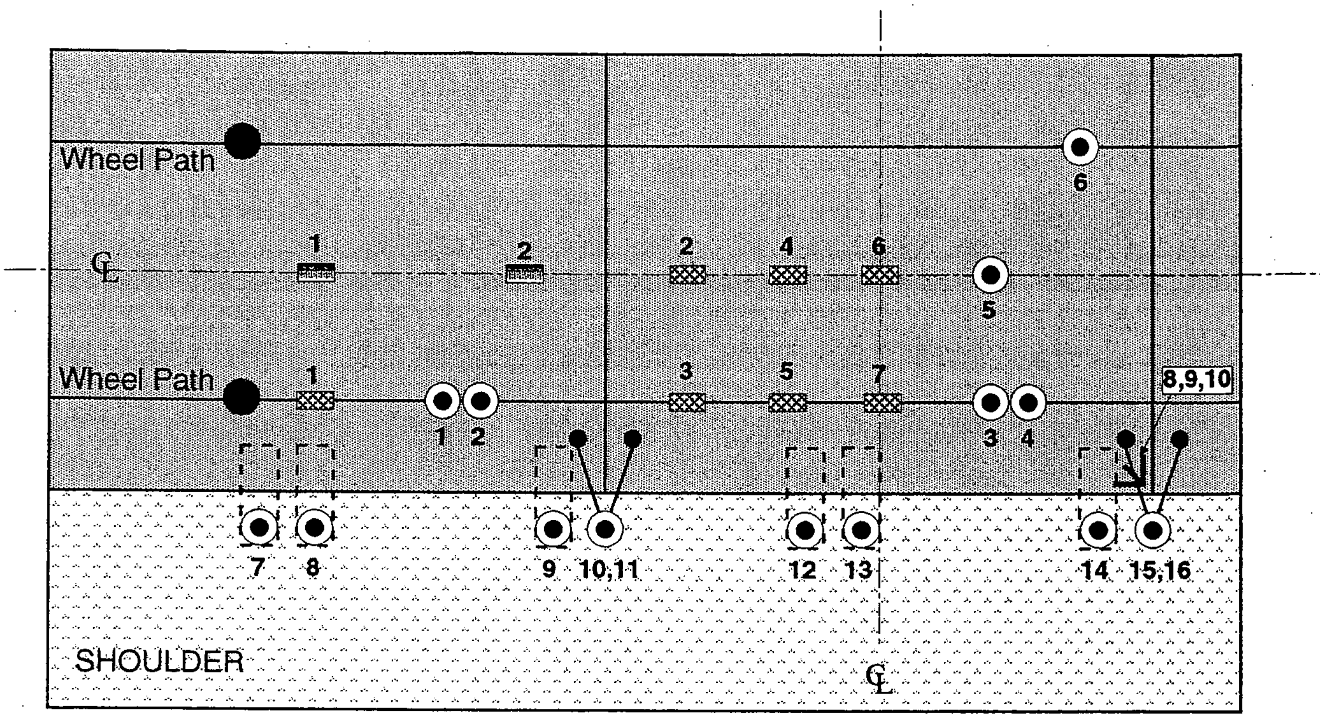
3.3 WIRING DIAGRAMS

All gauges and pressure cells will be connected using a six wire system: two wires for excitation, two wires for recording the signal, and two wires for monitoring the excitation voltage at the sensor bridge completion location. This provides accurate remote sensing capabilities. Because of the lead wire length up to 45 ft., and the need for accurate readings, the remote sensing wires will allow the 5108AC to adjust the excitation voltage to a predetermined value at the sensor. LVDTs will be connected using a four lead wire system.

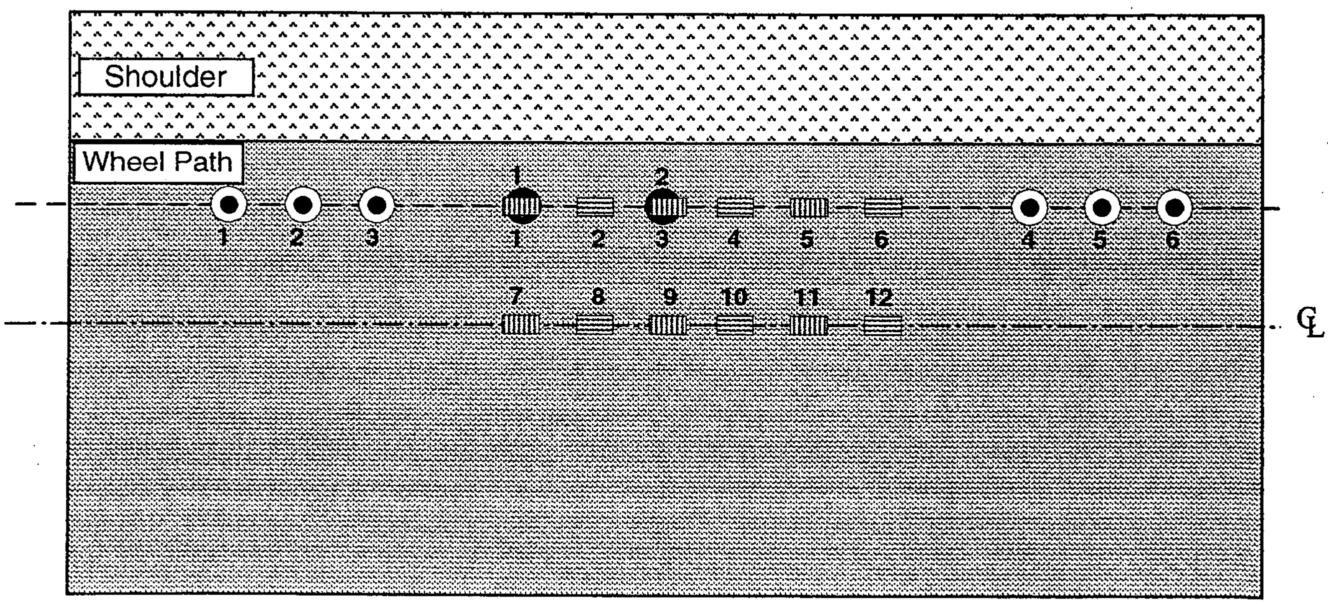
Xtra-Guard 3, Suprashield, 300 Volts-AWm, 150 Volts-CL2 multipair conductor cable will be used to. *Alpha35123* will be used to extend full-bridge, rosette, and LVDT wires to the first manhole. *Alpha35129/19* will be used to connect the STBs to the MEGADAC system. Some of the wire specifications are listed:

- Conductor: Stranded tin coated copper.
- Insulation: Color Coded, 80° C premium Polyvinylchloride.
- 22 AWG UL Style 1061, CSA, AWM SR-PVC. Insulation thickness 0.25 mm.
- Suprashield: Aluminum/polyester/aluminum foil with drain wire plus overall braid of tinned copper.
- Nylon rip cord for ease of jacket stripping.

Figure 3.1 shows the location of sensors in the PCC and AC sections. These locations were used to calculate the lead wire length required for each sensor. Tables 3.1 through 3.9 show wire lengths for each section (For section numbering refer to Table 2.4).



Typical PCC Section



Typical AC Section

(NOT TO SCALE)

Figure 3.1 Sensor Location Numbering Layout for PCC and AC Sections

Table 3.1: Rigid Pavement Instrumentation Section J4, Wire Length to First Pull Box.

Location	LVDT (ft)	Strain Gages (ft)	Pressure Cells (ft)
1	28.5	31.5	38
2	27	29.25	31
3	28.5	25.75	-
4	27.5	32	-
5	20.5	28.5	-
6	19	34.5	-
7	25	31	-
8	26.5	34	-
9	37	-	-
10	33.5	-	-
11	34.5	-	-
12	43	-	-
13	32.5	-	-
14	34	-	-

Table 3.2: Rigid Pavement Instrumentation Sections J2, J3, J6, J7, J8, J9, J10, J11, J12, S2 and S3 Wire Length to First Pull Box.

Location	LVDT (ft)	Strain Gages (ft)	Pressure Cells (ft)
1	29.5	32.5	39
2	28	30.25	32
3	29.5	26.75	-
4	28.5	33	-
5	21.5	29.5	-
6	20	35.5	-
7	26	32	-
8	27.5	35	-
9	38	-	-
10	34.5	-	-
11	35.5	-	-
12	44	-	-
13	33.5	-	-
14	35	-	-

Table 3.3: Rigid Pavement Instrumentation Sections J1, and J5 Wire Length to First Pull Box

Location	LVDT (ft)	Strain Gages (ft)	Pressure Cells (ft)
1	27.5	30.5	37
2	26	28.25	30
3	27.5	24.75	-
4	26.5	31	-
5	19.5	27.5	-
6	18	33.5	-
7	24	30	-
8	25.5	33	-
9	36	-	-
10	32.5	-	-
11	33.5	-	-
12	42	-	-
13	31.5	-	-
14	33	-	-

Table 3.4: Rigid Pavement Instrumentation Sections S4, and S5 Wire Length to First Pull Box.

Location	LVDT (ft)	Strain Gages (ft)	Pressure Cells (ft)
1	24.5	27.5	34
2	23	25.25	27
3	24.5	21.75	-
4	23.5	28	-
5	16.5	24.5	-
6	15	30.5	-
7	21	27	-
8	22.5	30	-
9	33	-	-
10	29.5	-	-
11	30.5	-	-
12	39	-	-
13	28.5	-	-
14	30	-	-

Table 3.5: Rigid Pavement Instrumentation Section J1(SPS-8) Wire Length to First Pull Box

Location	LVDT (ft)	Strain Gages (ft)	Pressure Cells (ft)
1	35.5	38.5	45
2	34	36.25	38
3	35.5	32.75	-
4	34.5	39	-
5	27.5	35.5	-
6	26	41.5	-
7	32	38	-
8	33.5	41	-
9	44	-	-
10	40.5	-	-
11	41.5	-	-
12	50	-	-
13	39.5	-	-
14	41	-	-

Table 3.6: Flexible Pavement Instrumentation Section ODOT Mix SPS9, Wire Length to First Pull Box.

Location	LVDT (ft)	Strain Gages (ft)	Pressure Cells (ft)
1	33.5	25.5	24.5
2	31.5	23.5	21.5
3	29.5	21.5	-
4	29.5	21.5	-
5	31.5	23.5	-
6	33.5	25.5	-
7	-	31.5	-
8	-	29.5	-
9	-	27.5	-
10	-	27.5	-
11	-	29.5	-
12	-	31.5	-

Table 3.7: Flexible Pavement Instrumentation Sections SHRP Mix SPS9, J1, J2, J5, J6, J7, J8, J9, J10, J11, J12, and S7 Wire Length to First Pull Box.

Location	LVDT (ft)	Strain Gages (ft)	Pressure Cells (ft)
1	34	26	25
2	32	24	22
3	30	22	-
4	30	22	-
5	32	24	-
6	34	26	-
7	-	32	-
8	-	30	-
9	-	28	-
10	-	28	-
11	-	30	-
12	-	32	-

Table 3.8: Flexible Pavement Instrumentation Section J3, Wire Length to First Pull Box.

Location	LVDT (ft)	Strain Gages (ft)	Pressure Cells (ft)
1	31	23	22
2	29	21	19
3	27	19	-
4	27	19	-
5	29	21	-
6	31	23	-
7	-	29	-
8	-	27	-
9	-	25	-
10	-	25	-
11	-	27	-
12	-	29	-

Table 3.9: Flexible Pavement Instrumentation Section K13(SPS8), Wire Length to First Pull Box.

Location	LVDT (ft)	Strain Gages (ft)	Pressure Cells (ft)
1	26	18	17
2	24	16	14
3	22	14	-
4	22	14	-
5	24	16	-
6	26	18	-
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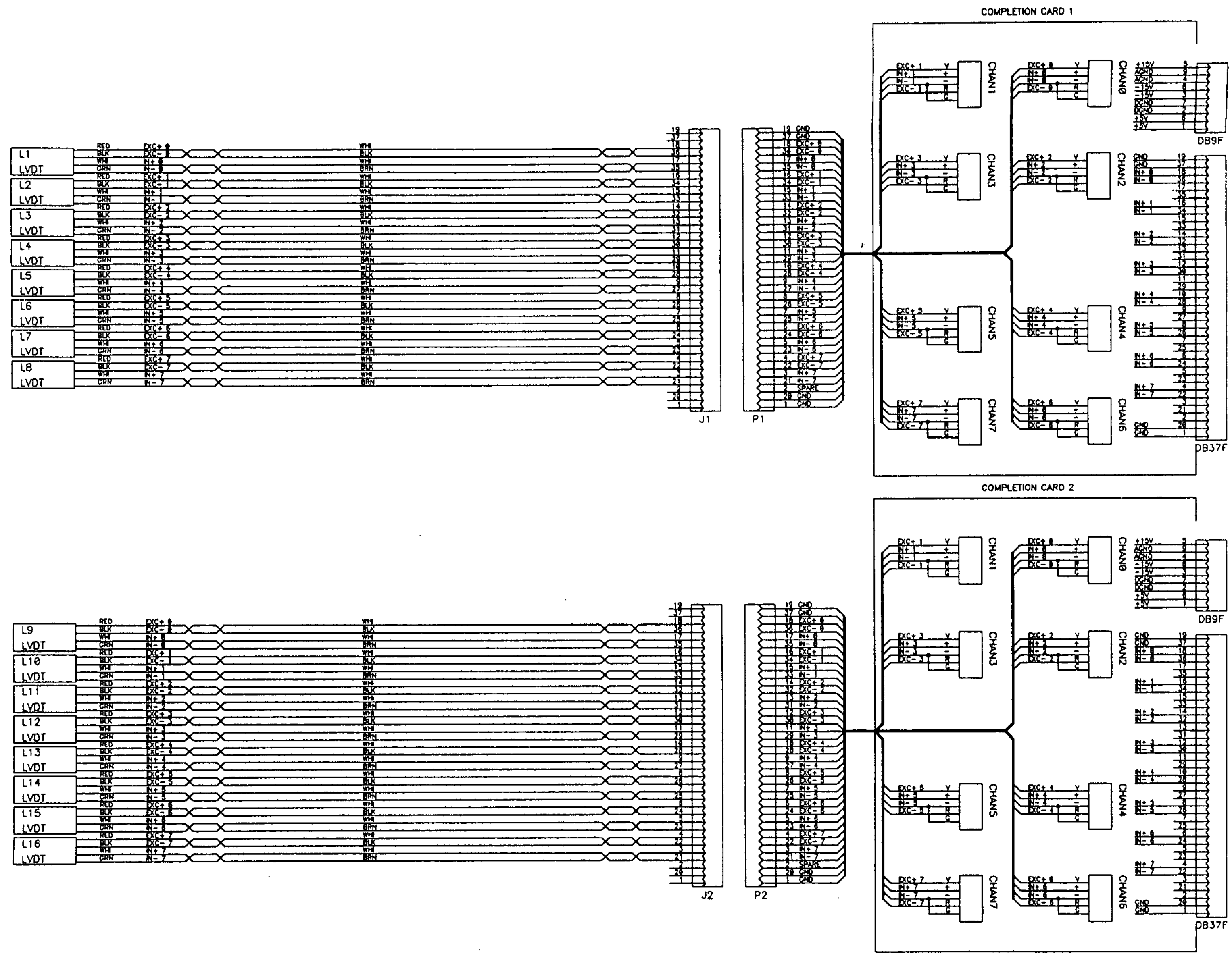
9	-	20	-
10	-	20	-
11	-	22	-
12	-	24	-



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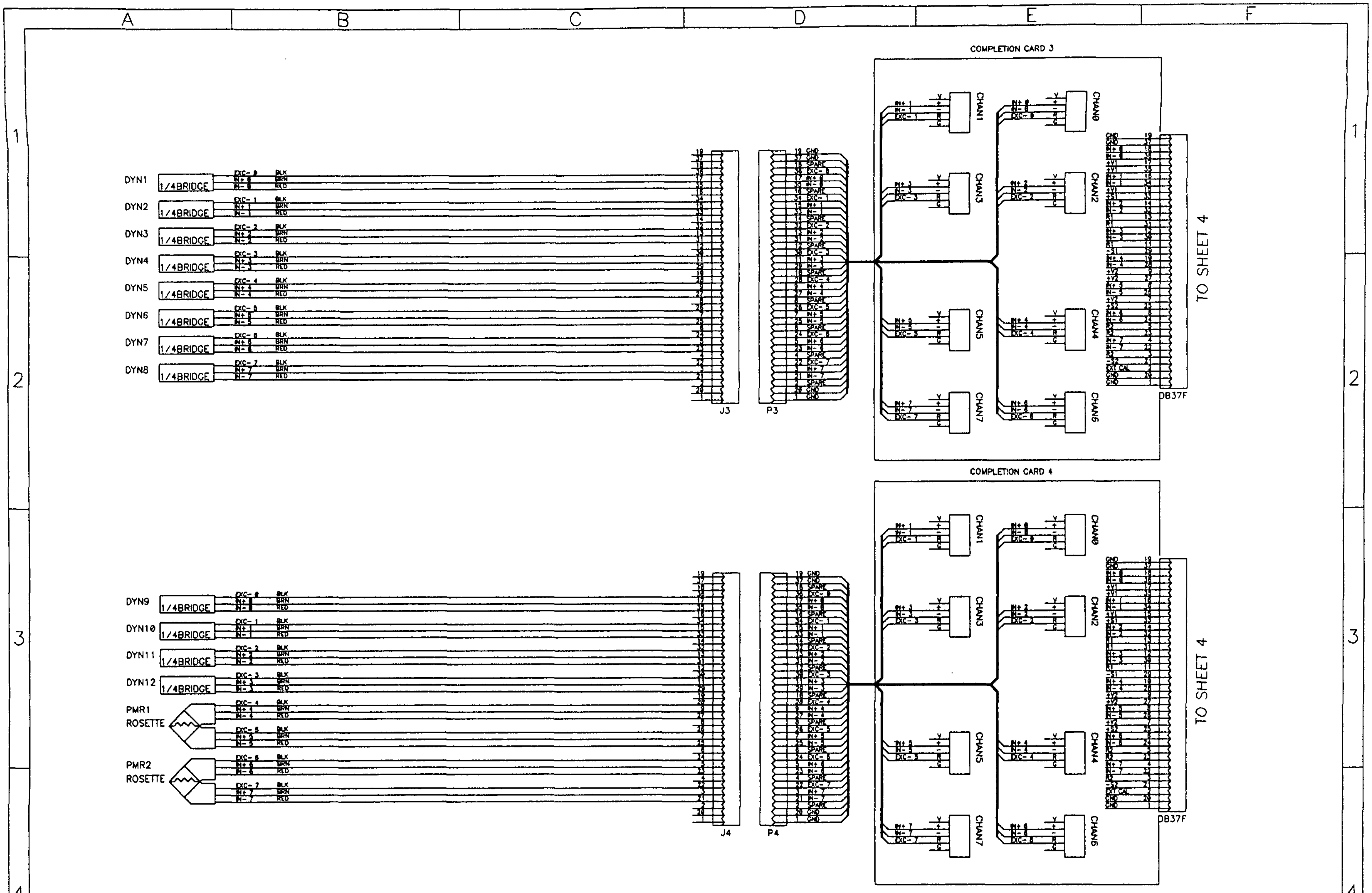

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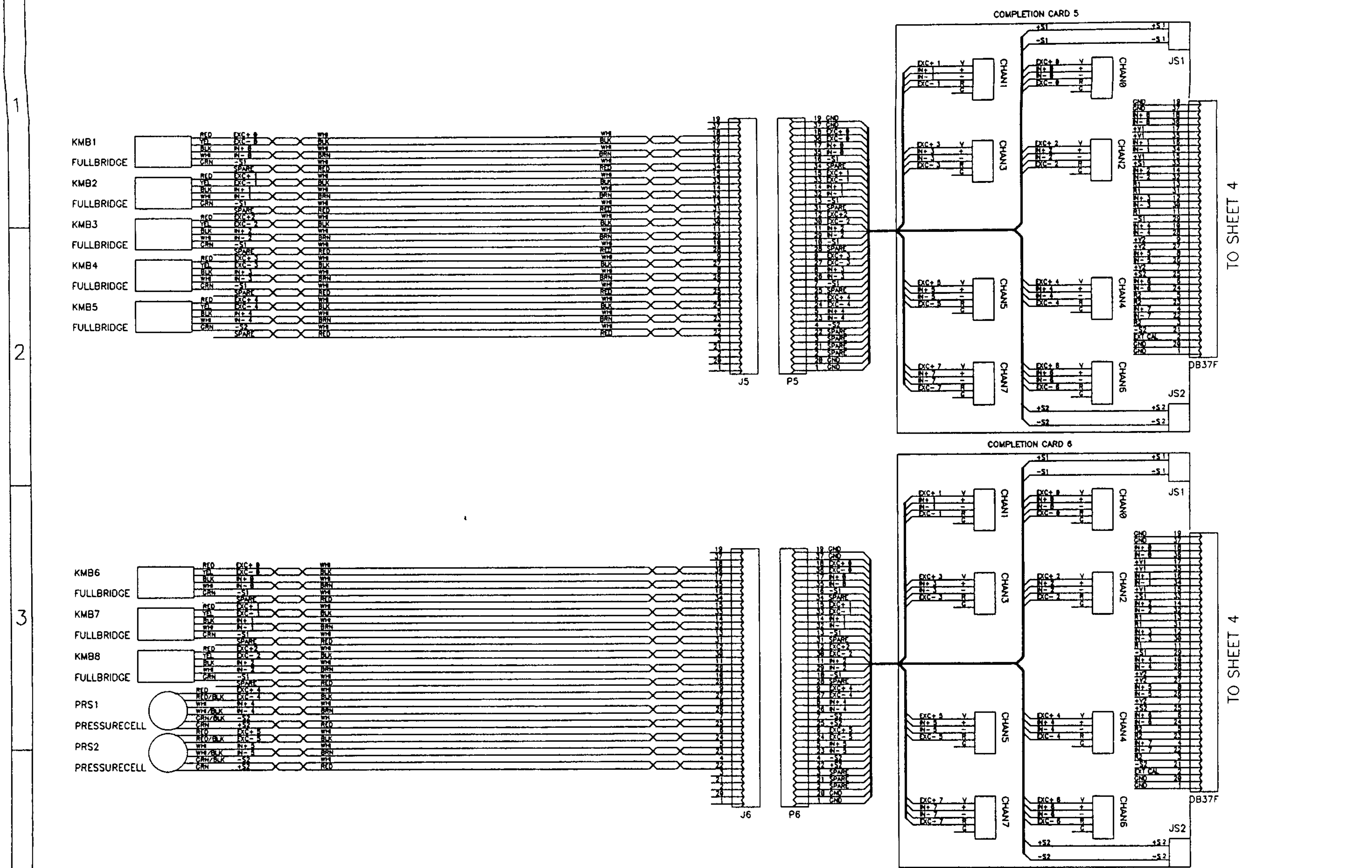

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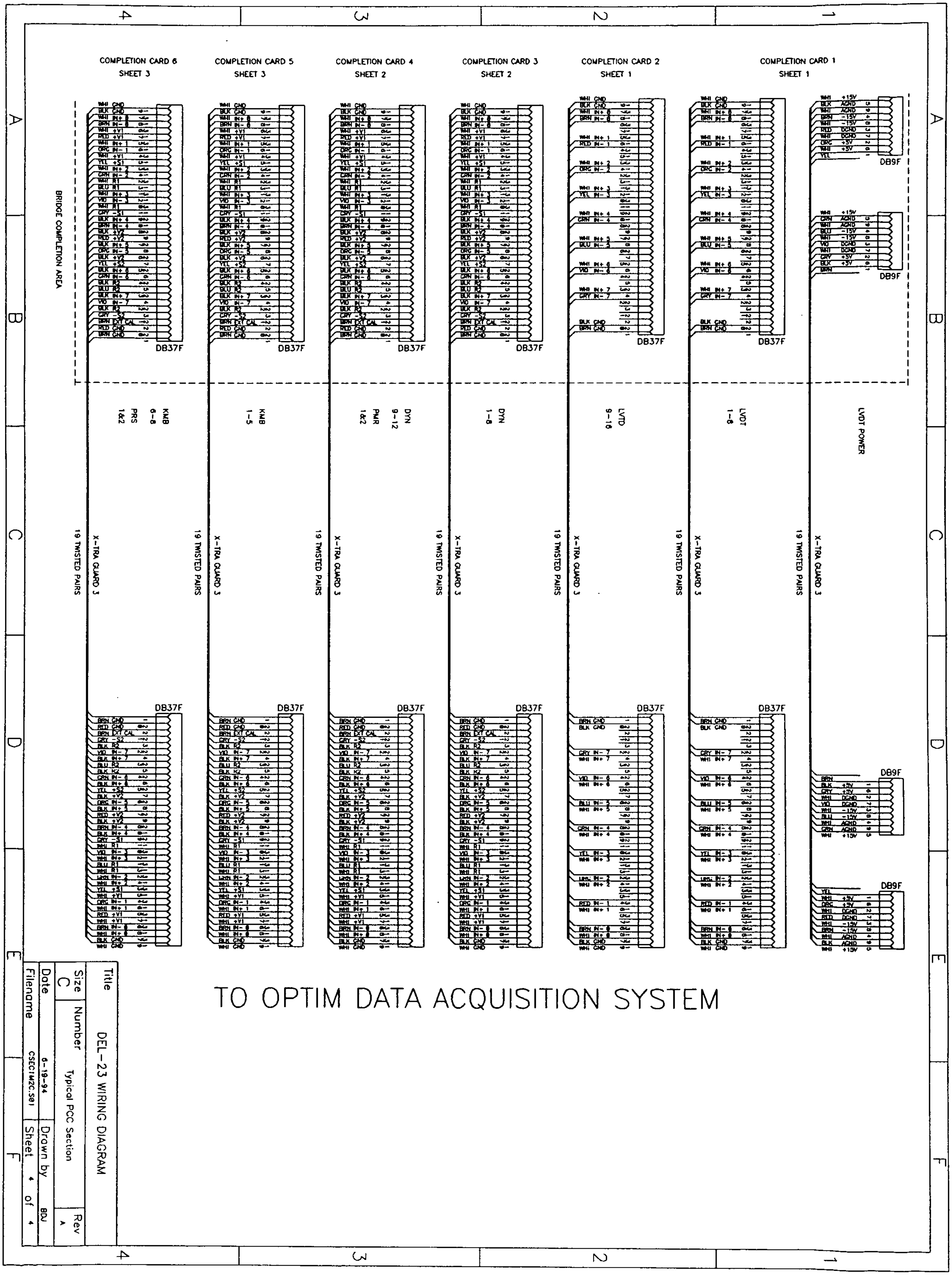

COMPLETION CARD 6
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COMPLETION CARD 4
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SHEET 1
COMPLETION CARD 1
SHEET 1
BRIDGE COMPLETION AREA
DB37F
DB9F
KMB 6-8
PRS 1&2
KMB 1-5
DYN 9-12
PWR 1&2
DYN 1-8
LVTD 9-16
LVDT 1-8
LVDT POWER
19 TWISTED PAIRS
X-TRA GUARD 3
TO OPTIM DATA ACQUISITION SYSTEM
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Rev A
Date 6-19-94
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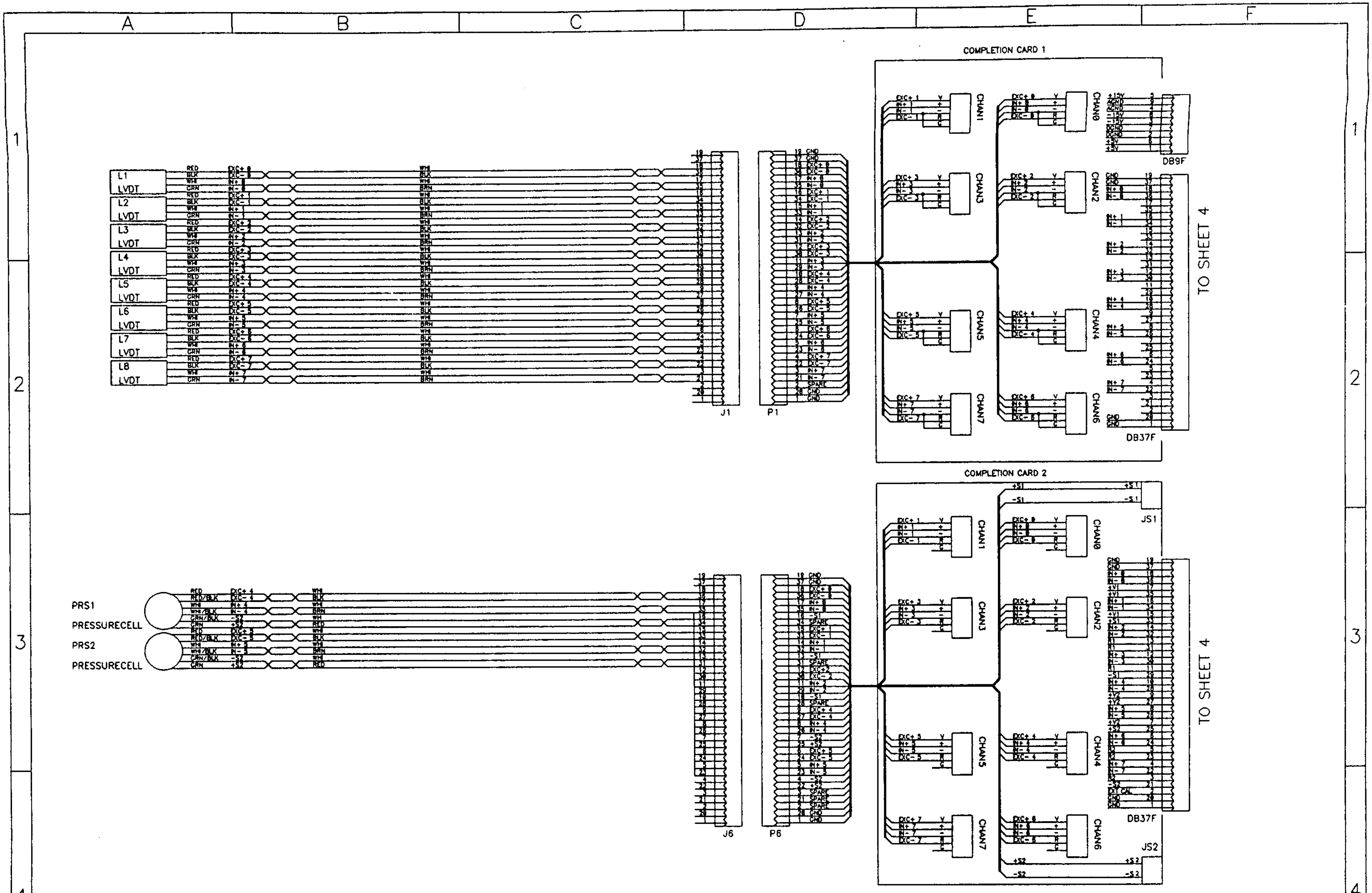
Sheet 4 of 4



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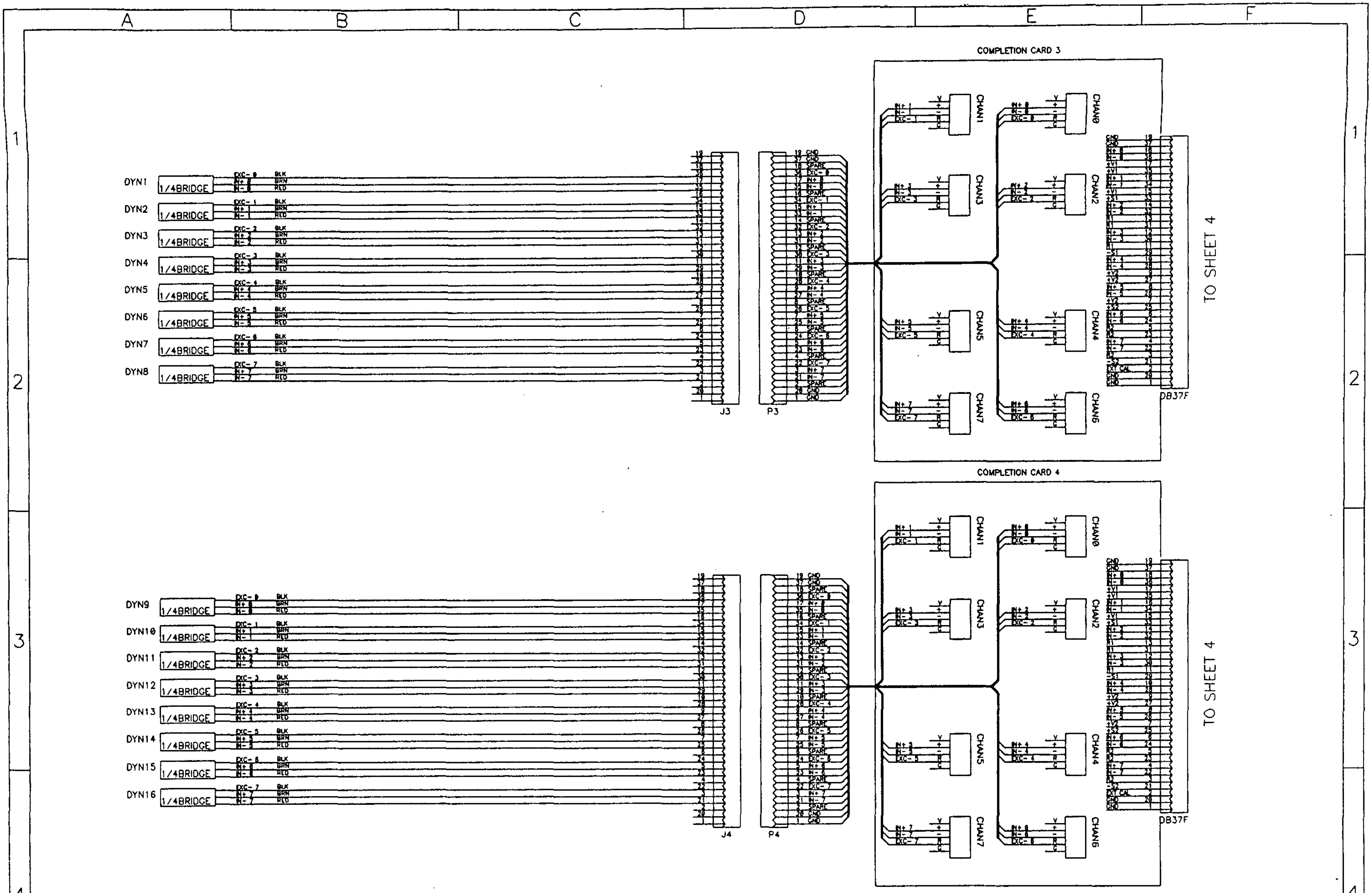

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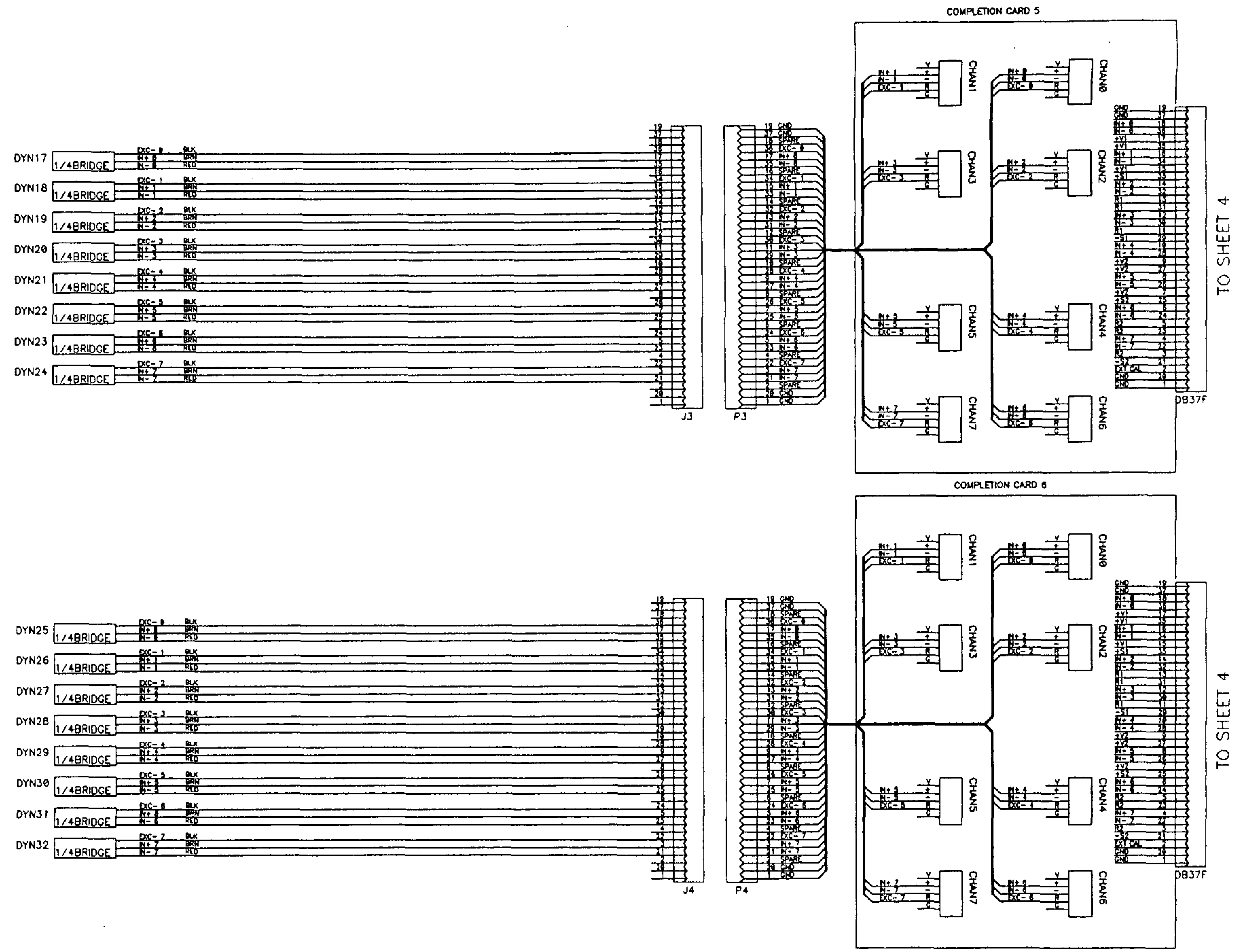

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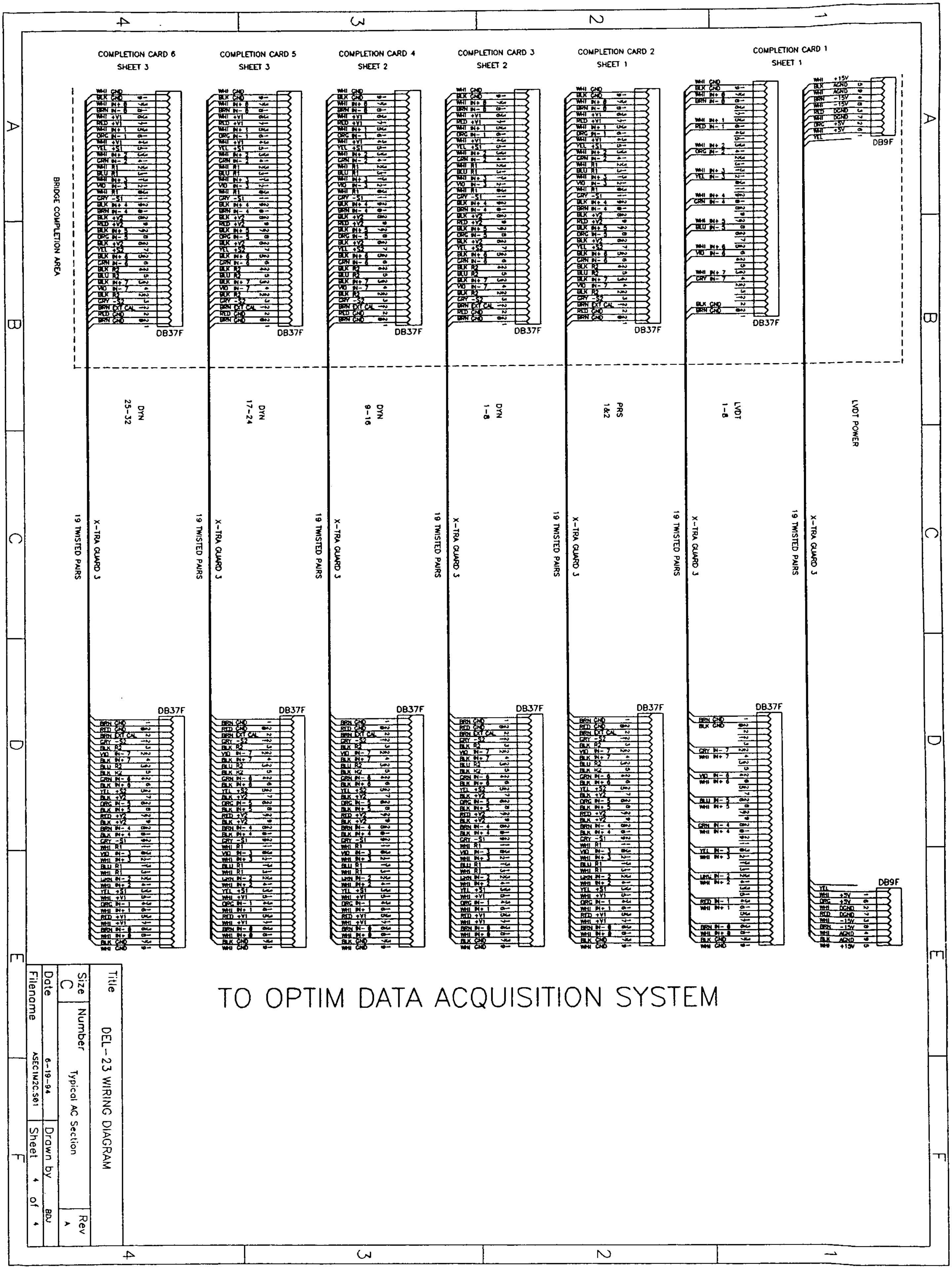

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COMPLETION CARD 4
SHEET 2
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COMPLETION CARD 2
SHEET 1
COMPLETION CARD 1
SHEET 1
BRIDGE COMPLETION AREA
DB37F
DB9F
DYN 25-32
DYN 17-24
DYN 9-16
DYN 1-8
PRS 1&2
LVDT 1-8
LVDT POWER
X-TRA GUARD 3
19 TWISTED PAIRS
TO OPTIM DATA ACQUISITION SYSTEM
Title DEL-23 WIRING DIAGRAM
Size C
Number Typical AC Section
Rev A
Date 6-19-94
Drawn by BDJ
Filename ASEC1N2C.S01
Sheet 4 of 4

CHAPTER 4

WORK TIME SCHEDULE

The specific task initiation date and time schedule for instrumentation are contingent on the Contractors' work progress. The following approximate time periods are required to accomplish each task. It is essential that the Contractors keep the research coordinator informed on the progress of the work.

4.1 SEASONAL INSTRUMENTATION

Seasonal instrumentation will be installed in two phases:

- Phase I. After the completion of the base and subbase (Spring, 1995), an independent Contractor will drill eighteen (18) bore holes at specified locations; each hole will be 305mm in diameter (12 in.) and 2.1m deep (7 ft.). Seasonal instrumentation (MRC Thermistor, TDR, and CRREL Resistivity probes)will be placed in each of these holes, and the holes will be backfilled by the university team. Since the location of the holes will be in the driving lane, the general Contractor and subcontractors will be able to proceed with their scheduled work with minimal disruption. Approximately one week will be required for the completion of this work. Once this work has been accomplished, there should be no disruption of the base or subbase in these areas, to avoid damaging sensor wires located close to the surface.
- Phase II. Upon completion of the paving process (AC or PCC), ODOT or an independent Contractor will core 18 holes, 51 mm (2 in.) diameter in the top layer. Thermistor probes will be epoxied to the cores, and then the cores will be reinserted and sealed. Approximately four days will be required to finish this phase. These holes will be located above the instrumentation which was installed in Phase I

4.2 STRUCTURAL RESPONSE INSTRUMENTATION

University researchers will insert LVDT reference plates and pressure cells at specific lifts as the base and subbase are completed. This will be accomplished by embedding these devices by hand into the top of the appropriate layers. Installation will be completed quickly and with no inconvenience to the Contractor. The summary of installation schedule of the remaining sensors for PCC and AC are presented below.

4.2.1 PCC Sections

Two days prior to placement of the portland cement concrete pavement sections, strain gauges, LVDT pits, and wires will be laid out in designated areas by researchers. Lead wires will be laid on the subbase and extended to conduits along the edge of the pavement. Extreme care should be taken to avoid damaging sensors and wires prior to paving. Once the instrumentation is installed, vehicles will not be allowed on the lane where instrumentation was installed.

As the paving machine approaches each sensor array, the research team will hand pack green concrete around the sensors to insulate them from excessive force and prevent movement as the paver passes. Students riding on the back of the paving machine will pull gauge housing units placed around the sensors. The minor disturbance left in the pavement surface by this operation can easily be smoothed during finishing. This procedure has been successfully used in the past with no disruption of the contractor's time schedule.

4.2.2 AC Sections

- One day prior to placement of designated asphalt concrete pavement lifts, research personnel will mark and place strain gauges on the pavement. Lead wires will run on the existing surface to conduits at the edge of the pavement. Construction traffic must avoid these sensors and wires while they are exposed.
- Ten minutes before the arrival of the paver to the area where sensors are to be installed, researchers will obtain hot asphalt from the paver or trucks. This asphalt will be sieved and placed over the Strain gauges. The paver will continue unhindered. To avoid damage from excessive heat, the paver should not stop over the sensors.
- After completion of paving, ODOT or an independent contractor will core 76 mm (3in.) diameter holes in the asphalt and drill to reference plates which were installed during construction of the base and subbase. Research personnel will complete the installation of LVDT pits in these holes. This work will require approximately three weeks and will be performed independent of Contractor and should not affect his schedule.

4.3 DISTRIBUTION OF RESPONSIBILITIES AMONG PARTICIPATING UNIVERSITIES

To provide consistent data, each group is required to install sensors following procedures in this report. The instrumentation installation schedule will be arranged with the contractor and coordinated with the project director and ODOT. However, the schedule is contingent on the progress of the contractor's work. Researchers should be prepared to execute their responsibilities as site conditions warrant.

4.3.1 Instrumentation for Seasonal Factors

The following sensors will be instrumented as part of the seasonal parameters studies:

- Time-domain reflectometry (TDR) probes will be used to collect volumetric water content.
- MRC thermistor probes (one assembly per section) will be used to measure the temperature variation in each section.
- CRREL resistivity probes (one assembly per section) will be used to measure the frost depth in each section.

As agreed among the research participants, each university team will instrument particular test sections as indicated in Table 4.1

Table 4.1: Distribution of Effort for Seasonal Parameters

Pavement Study	University of Toledo	Case Western Reserve University	Ohio State University	Ohio University	ODOT
SPS-1	J4, J12, J1	J2	J8	J10	-
SPS-2	J4, J12	J3, J2, J5	J1, J11, S4	J8	-
SPS-9	-	ODOT MIX	SHRP MIX	-	-
SPS-8	-	-	-	-	J1
Other	-	*	-	-	-

* Coordinate Weather Station Activities

4.3.2 Instrumentation for Structural Response of Pavement

University of Cincinnati and Ohio University will install the following sensors for structural performance parameters

- Schaevitz GPD 121-500 DC-LVDT's.
- Dynatest Past II-AC strain gauges.
- Dynatest PAST II-PCC strain gauges.
- TML KM-100B , full bridge embedment gauge.
- TML PMR-60 three-axes rosettes.
- Carlson A-8 strain meters .

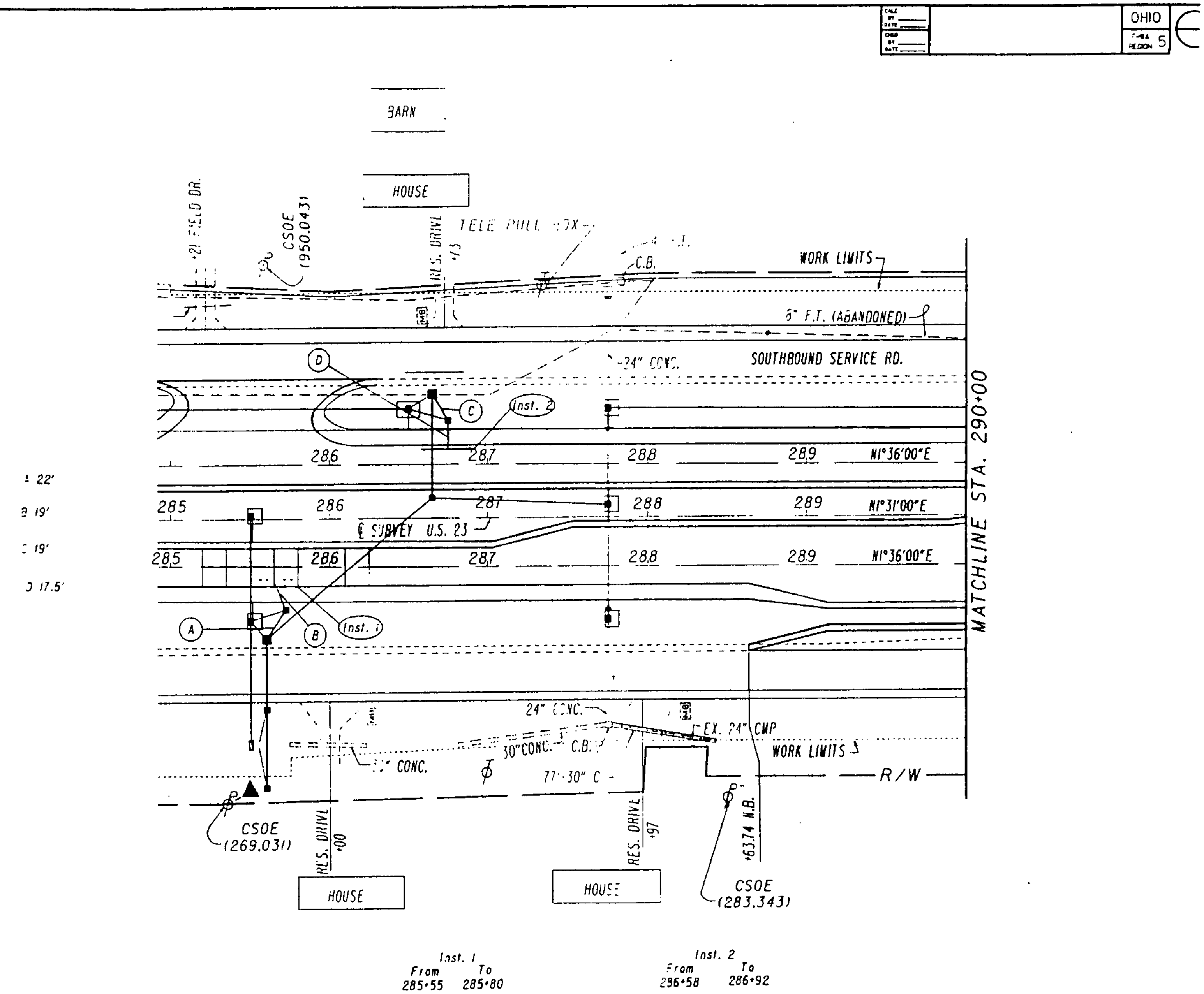
University of Akron will be responsible for the instrumentation of Geokon 3500 pressure cells.

REFERENCES

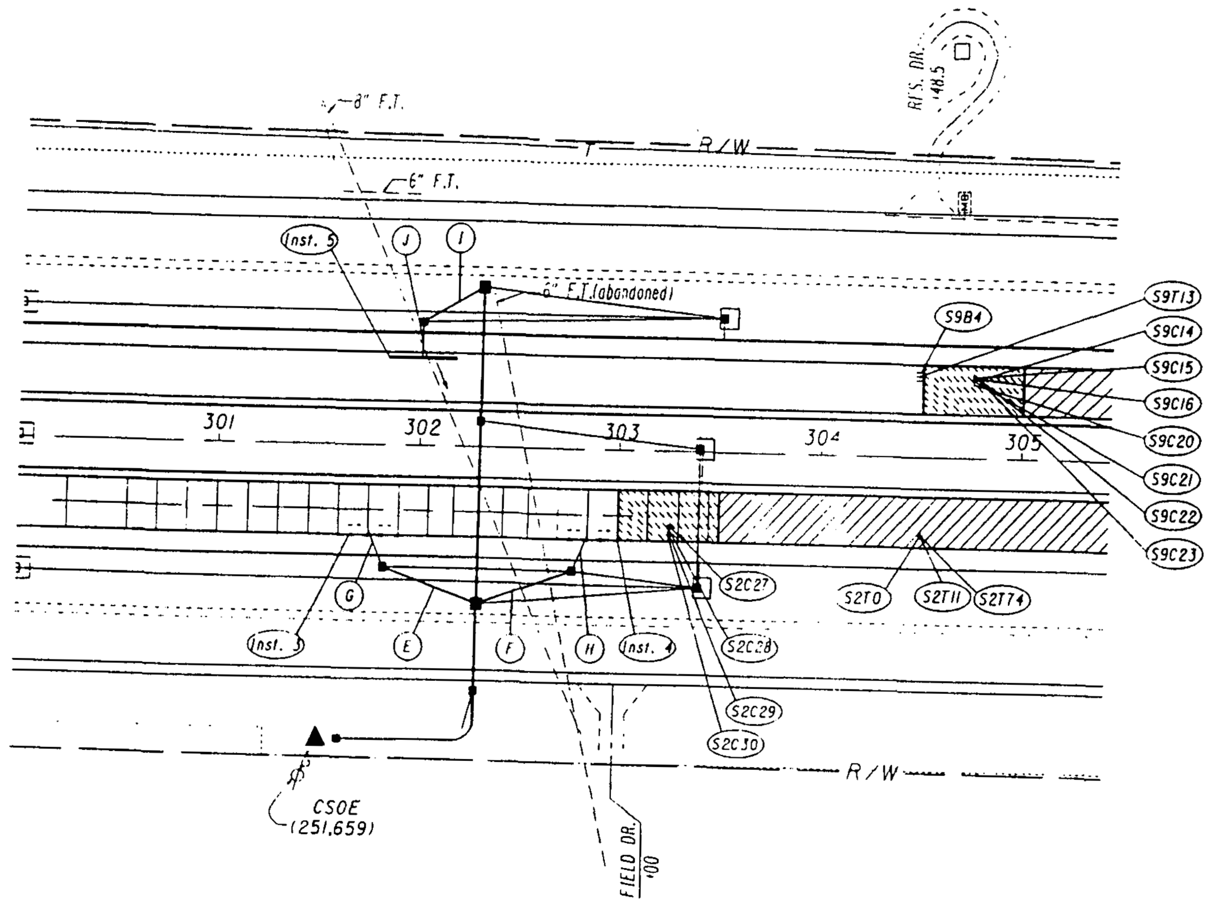
1. Pavement Instrumentation Program for SPS-1 and SPS-2 Experiments. Instrumentation Details. Prepared for the Federal Highway Administration, LTPP Division-HNR-40. Prepared by PCS/LAW Engineering. August 1993, Revised November 1993.

2. Pavement Instrumentation Program for SPS-1 and SPS-2 Experiments. Instrumentation Needs. Prepared for the Federal Highway Administration, LTPP Division-HNR-40. Prepared by PCS/LAW Engineering. March 1993, Revised November 1993.

Layout of Cable Conduits


OHIO
REGION 5
BARN
HOUSE
HOUSE
HOUSE
+21 FIELD DR.
CSOE (950.043)
RES. DRIVE +13
WORK LIMITS
C.B.
6" F.T. (ABANDONED)
-24" CONC.
SOUTHBOUND SERVICE RD.
Inst. 2
Inst. 1
286
287
288
289
N1°36'00"E
285
N1°31'00"E
℄ SURVEY U.S. 23
MATCHLINE STA. 290+00
24" CONC.
EX. 24" CMP
30"CONC.
WORK LIMITS
R/W
CSOE (269,031)
RES. DRIVE +00
RES. DRIVE +97
+63.74 N.B.
CSOE (283.343)
Inst. 1
From 285+55
To 285+80
Inst. 2
From 286+58
To 286+92

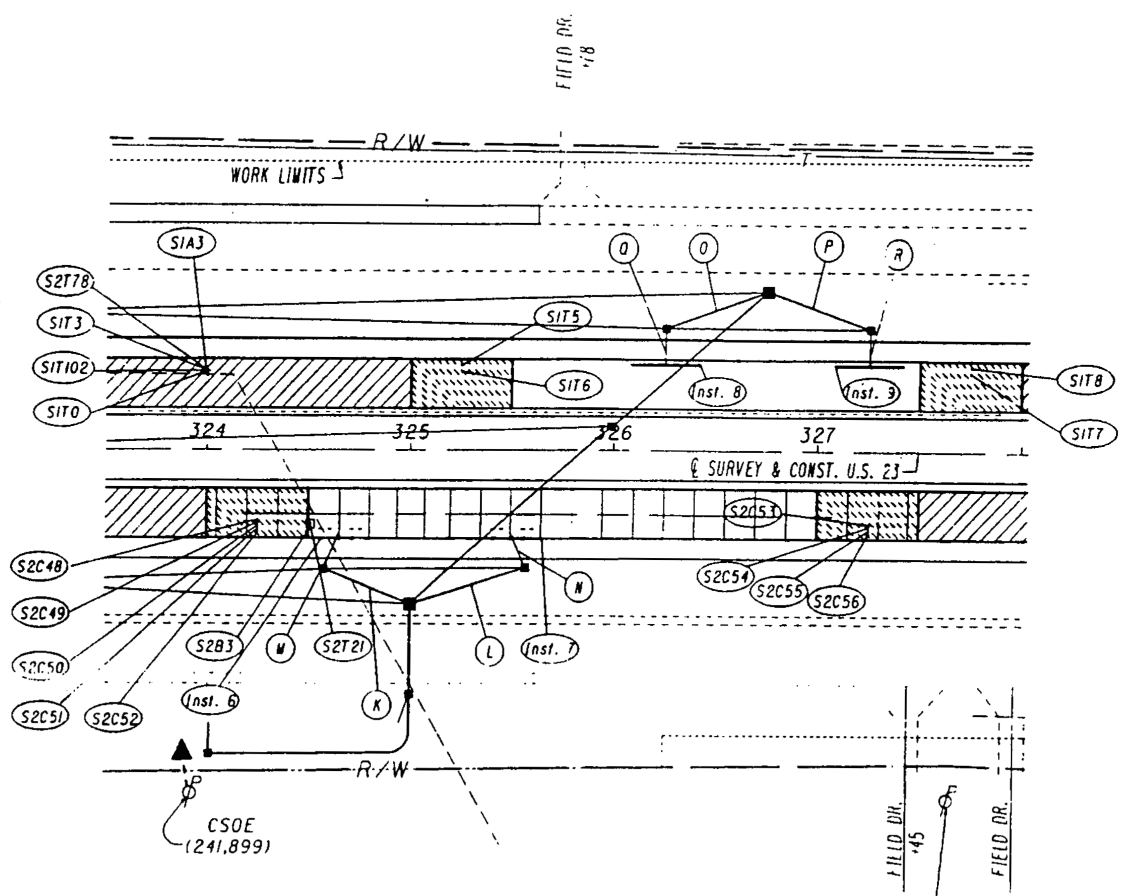
OHIO	
FHWA REGION	5



E	50'
F	50'
G	20'
H	20'
I	35'
J	18'

	Inst. 3		Inst. 4		Inst. 5
From	To	From	To	From	To
301+65	301+90	302+75	303+00	301+83	302+17

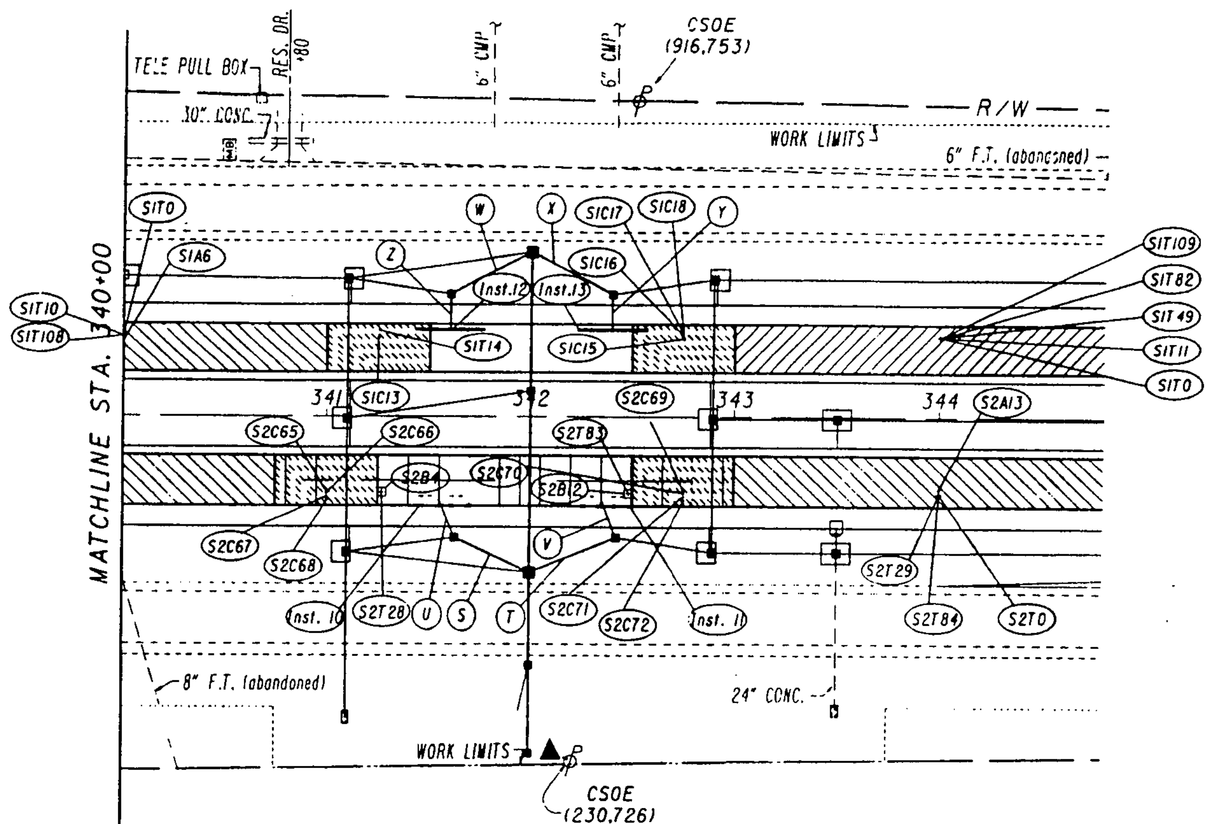
OHIO
FHWA REGION 5



K 45'
L 59'
M 20'
N 20'
O 53'
P 53'
Q 18'
R 18'

	Inst. 6		Inst. 7		Inst. 8		Inst. 9
From	To	From	To	From	To	From	To
324+55	324+80	325+40	325+65	326+08	326+42	327+08	327+42

OHIO | FHWA REGION 5

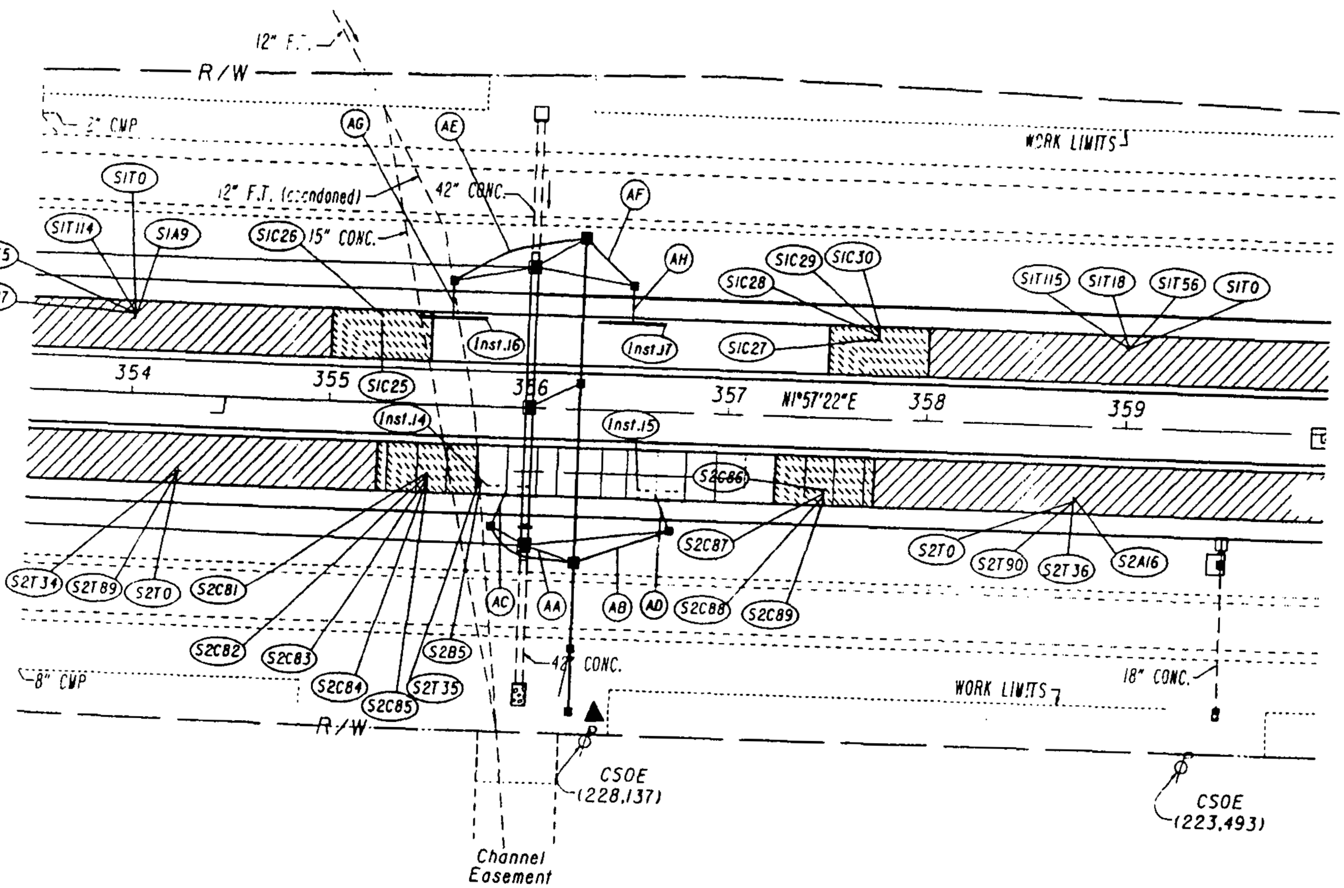


S 40'
T 45'
U 18'
V 18'
W 44'
X 44'
Y 18'
Z 18'

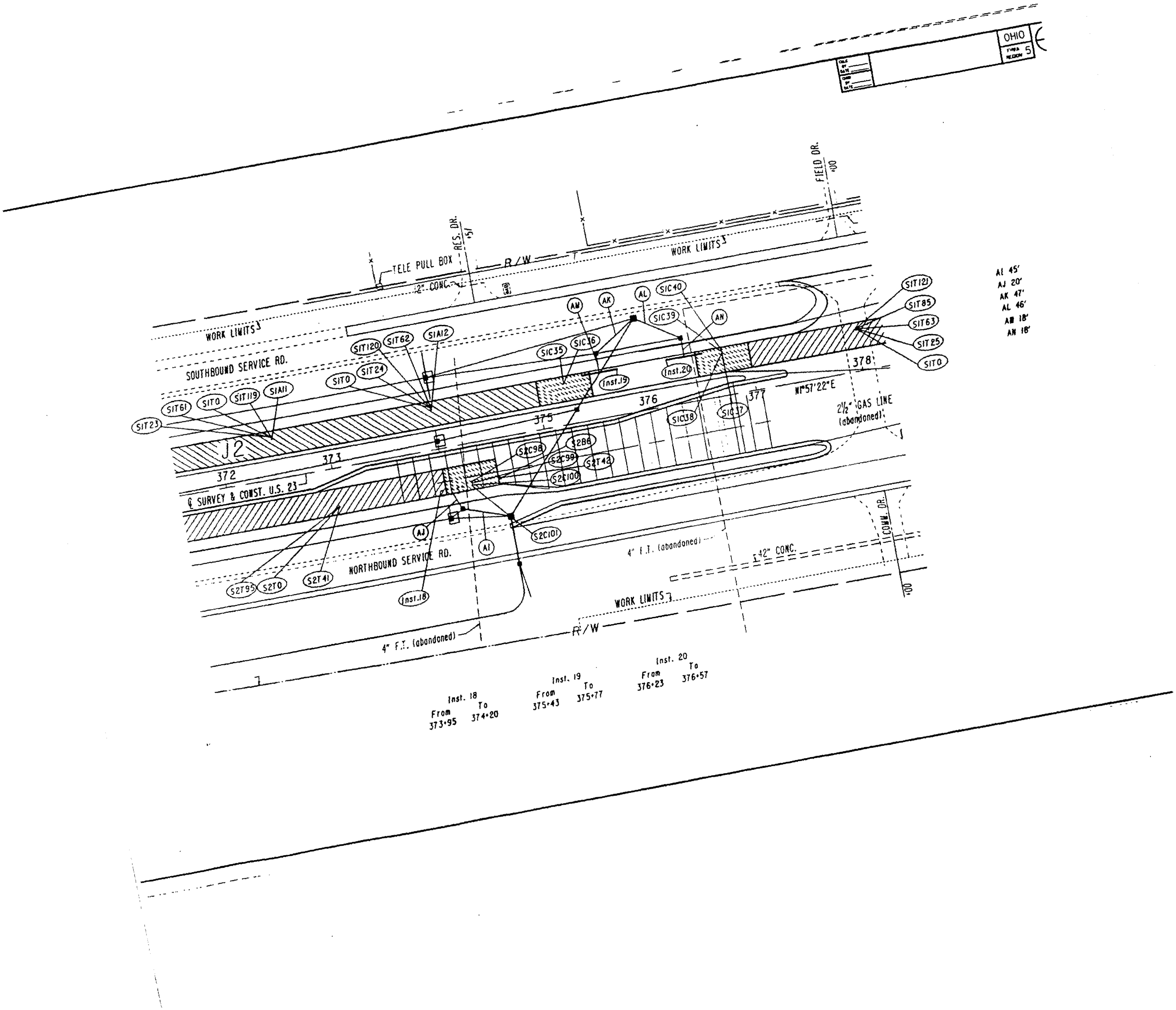
Inst. 10		Inst. 11		Inst. 12		Inst. 13	
From	To	From	To	From	To	From	To
341+45	341+70	342+25	342+50	341+43	341+77	342+23	342+57

OHIO
FHWA REGION 5

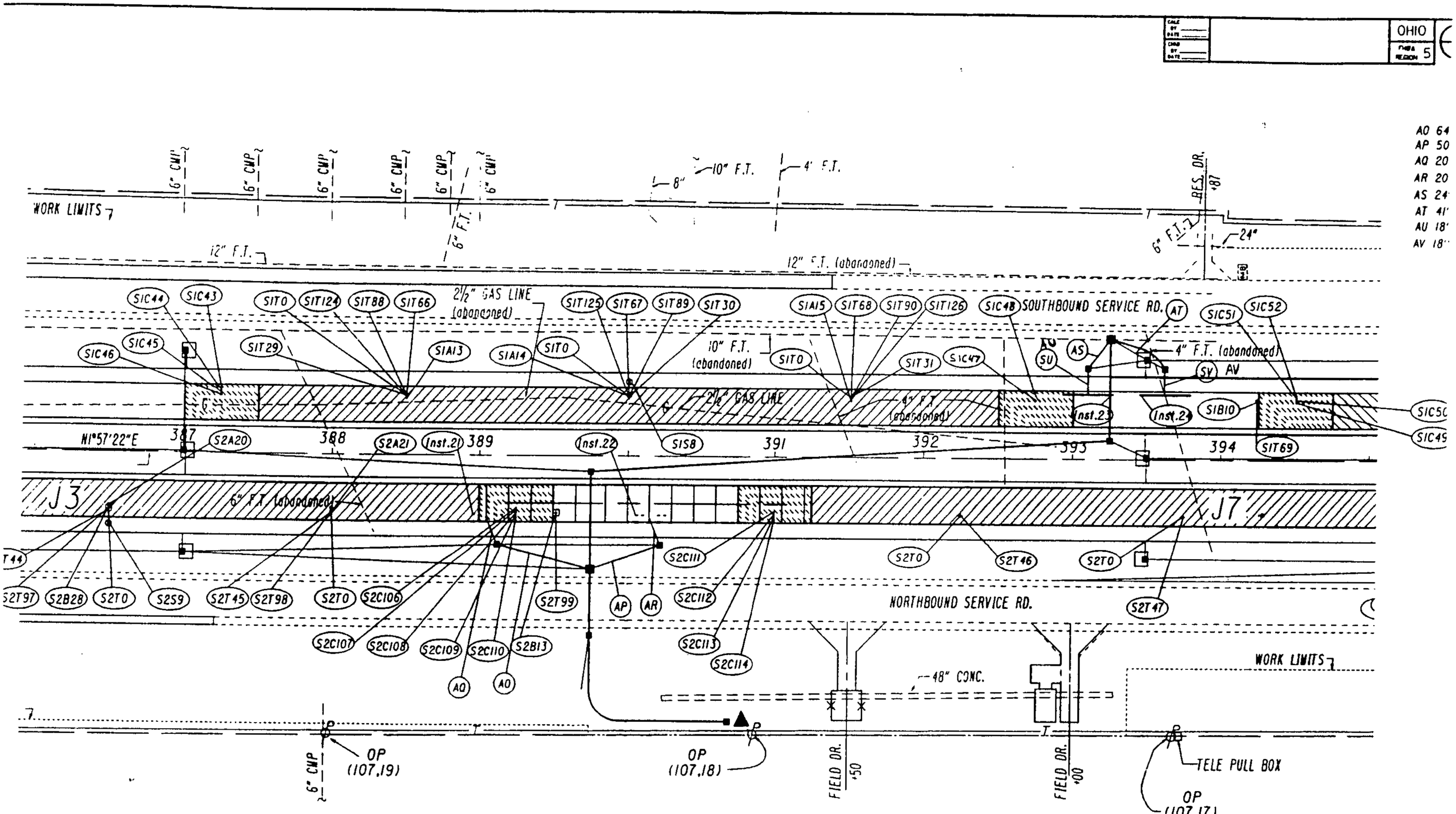
AA 50'
AB 50'
AC 20'
AD 20'
AE 70'
AF 33'
AG 18'
AH 18'



Inst. 14		Inst. 15		Inst. 16		Inst. 17	
From	To	From	To	From	To	From	To
355+80	356+05	356+55	356+80	355+43	355+77	356+33	356+67

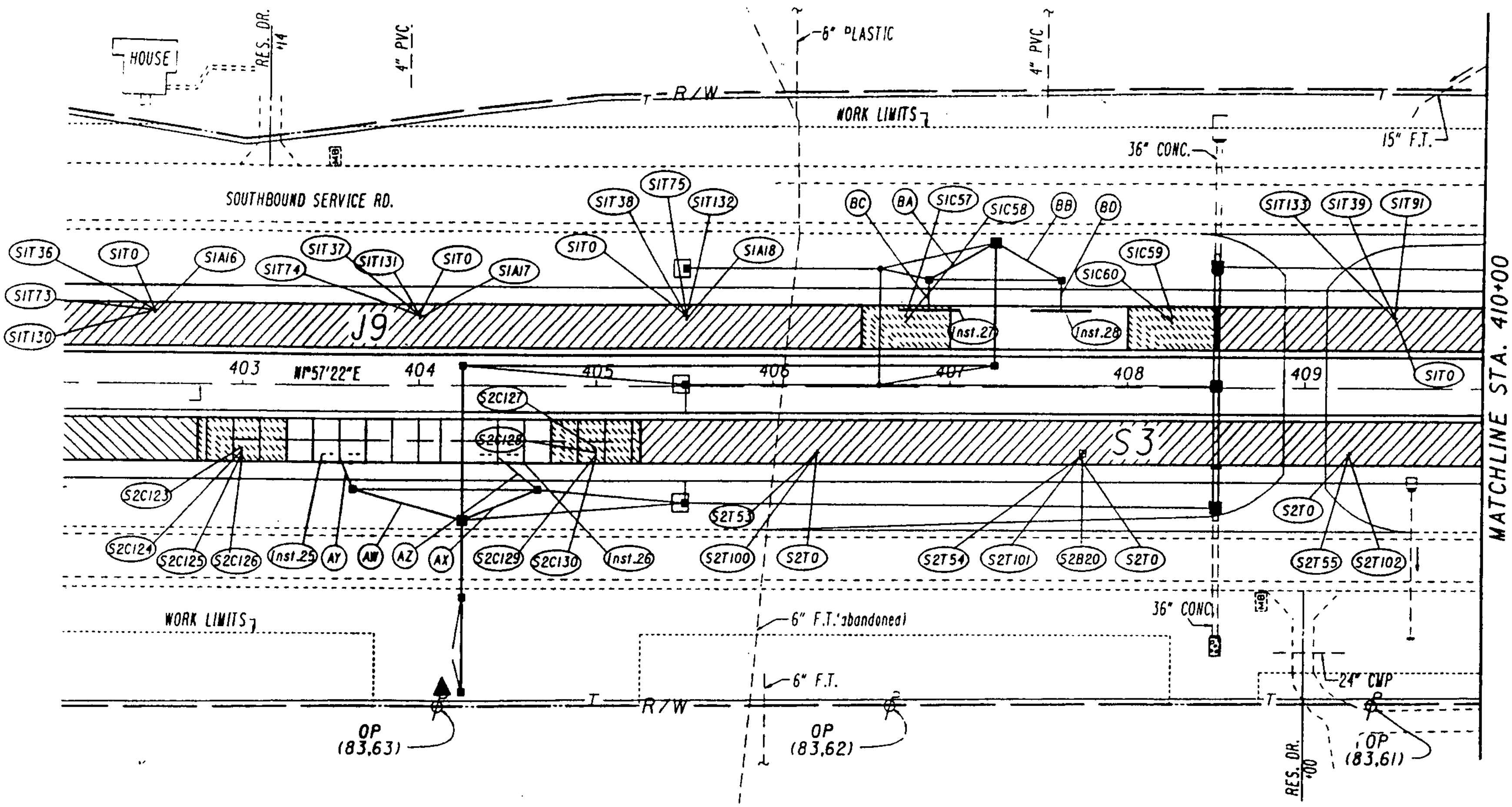


OHIO
FHWA REGION 5
FIELD DR.
RES. DR.
TELE PULL BOX
R/W
WORK LIMITS
2" CONC.
SOUTHBOUND SERVICE RD.
J2
372
373
375
376
377
378
SURVEY & CONST. U.S. 23
NORTHBOUND SERVICE RD.
N1°57'22"E
2½" GAS LINE (abandoned)
COMM. DR.
12" CONC.
4" F.T. (abandoned)
S1T121
S1T85
S1T63
S1T25
S1T0
S1C40
S1C39
S1C38
S1C37
S1C36
S1C35
S1A12
S1T62
S1T120
S1T24
S1A11
S1T119
S1T61
S1T23
S2C98
S2C99
S2C100
S2C101
S2T42
S2T41
S2T95
S2T0
AI
AJ
AK
AL
AM
AN
Inst.18
Inst.19
Inst.20
Inst. 18 From 373+95 To 374+20
Inst. 19 From 375+43 To 375+77
Inst. 20 From 376+23 To 376+57
AI 45'
AJ 20'
AK 47'
AL 46'
AM 18'
AN 18'



Inst. 21		Inst. 22		Inst. 23		Inst. 24	
From	To	From	To	From	To	From	To
388+95	389+20	390+05	390+30	392+93	393+27	393+45	393+79

OHIO
FHWA REGION 5



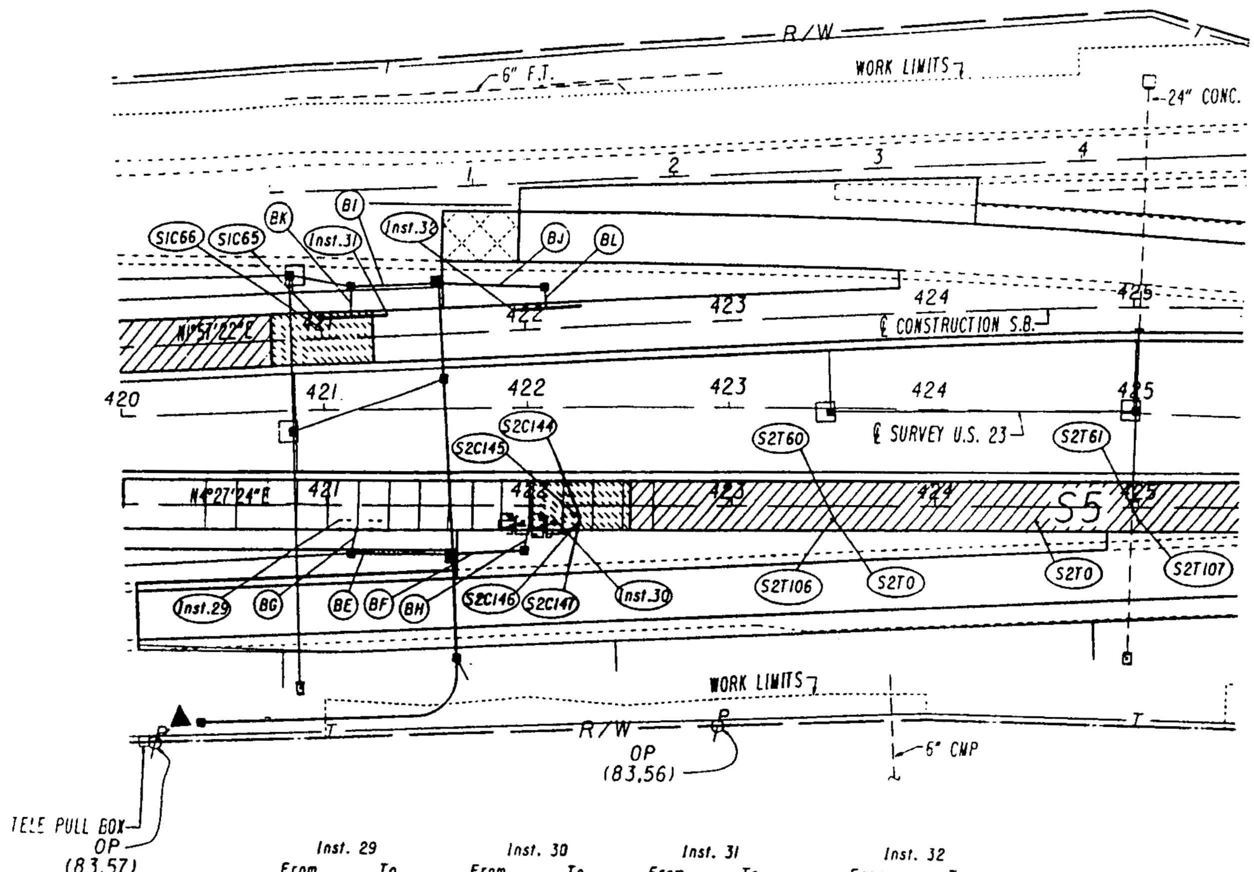
AW 64'
AX 46'
AY 20'
AZ 20'
BA 42'
BB 42'
BC 18'
BD 18'

Inst. 25		Inst. 26		Inst. 27		Inst. 28	
From	To	From	To	From	To	From	To
403+45	403+70	404+35	404+60	406+71	407+05	407+45	407+79

OHIO

FHWA REGION 5

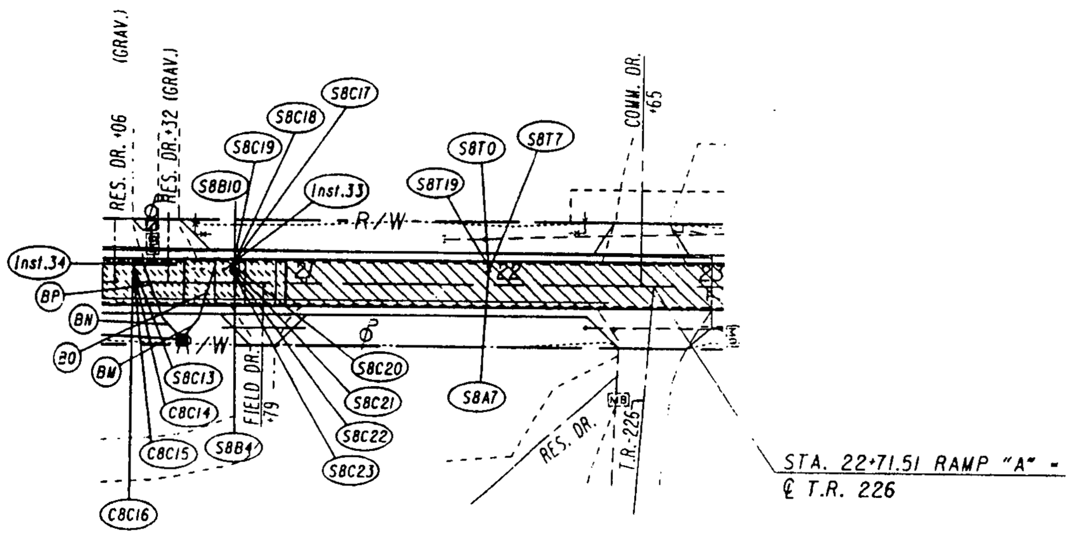
BE 50'
BF 35'
BG 15'
BH 15'
BI 42'
BJ 53'
BK 15'
BL 10'



Inst. 29		Inst. 30		Inst. 31		Inst. 32	
From	To	From	To	From	To	From	To
421+06	421+31	421+91	422+16	420+98	421+32	421+94	422+28

OHIO	F-WA REGION 5

BM 13'
BN 14'
BO 26'
BP 27'



Inst. 33
From 20+40 To 20+65

Inst. 34
From 20+02 To 20+36