Seismic Pavement Analyzer Operations Manual with Technical Specifications

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Abstract

This report describes an instrument for monitoring conditions associated with pavement deterioration that was designed and constructed as part of the Strategic Highway Research Program (SHRP). The conditions measured by the instrument are voids or loss of support under a rigid pavement; moisture infiltrating asphalt concrete (AC) pavement; fine cracking in pavements; delamination of overlays; and aging of asphalt.

These conditions of pavement deterioration are determined by estimating Young's and shear moduli in the pavement, base, and subgrade from the following wave propagation measurements:

1. Impulse echo.
2. Impulse response.
3. Spectral analysis of surface waves.
4. Ultrasonic surface wave.
5. Ultrasonic body wave velocity.

The instrument designed to make these measurements records the pavement response produced by high- and low-frequency pneumatic hammers on five accelerometers and three geophones, over a wide range of distances. Data acquisition, instrument control, and interpretation are computer controlled, with measurements and interpretations reported in both screen and data base formats.

Tests conducted during this research program produced very promising results. The device was simple to use and produced diagnostic results that were repeatable. With minimal hardware modifications, the device can be commercialized. This report includes a user's manual along with the technical specifications for the device.

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Executive Summary

This document contains the user's manual and technical specifications for a new project-level measurement device called the Seismic Pavement Analyzer (SPA). The equipment has been designed and built to meet the needs of the pavement and maintenance engineer. The SPA is an effective tool for identifying and measuring the precursors of pavement distress in early stages.

The following five distress precursors are addressed:

1. Moisture in base layer (flexible pavement)
2. Voids or loss of support under joints (rigid pavement)
3. Overlay delamination
4. Fine cracking
5. Pavement aging.

To effectively diagnose the specific distress precursors identified, an equivalent number of independent pavement parameters are required. These parameters are measured using equipment similar to a falling weight deflectometer, but the computer processing and interpretation algorithms are more sophisticated than those used with the falling weight deflectometer.

The potential savings are tremendous. First, if the precursor of distress is detected and measured, the potential problem can be resolved with preventive maintenance at a fraction of the cost of later rehabilitation. Second, the device will enable the maintenance engineer to distinguish between maintainable sections and those that require rehabilitation. This enables the highway agencies to direct the available maintenance funds toward maintainable projects.

The equipment can be used for two distinct purposes. The first is to perform more detailed analyses of pavement conditions identified in the network-level surveys and to diagnose specific distress precursors to aid in selection of the maintenance treatment. The second is to monitor pavement conditions after a maintenance treatment has been applied to determine its effectiveness.

The operation of the system is quite simple because it is automated. Most of the data reduction is done rapidly in the field, and the results are saved in a data base for further analysis. A graphic representation of the data collected in the field can be produced on demand to enable an engineer to identify the troublesome areas of the pavement as the data is collected. Finally, the software presents the diagnosis of pavement conditions in engineering terms (as opposed to stiffness parameters).

The advantages of the device are several. The Seismic Pavement Analyzer is highly accurate and precise in determining the state of the pavement. It uses methods based on accepted engineering physics principles. The field testing and data reduction methodologies are compatible with the theoretical assumptions. The hardware is relatively inexpensive. The device is expected to be inexpensive to modify because only the software should require updating or replacement.

The Seismic Pavement Analyzer might be used effectively in the future to enhance the results of many Strategic Highway Research Program (SHRP) projects. Because the device yields information that is inherently more accurate than that produced by the falling weight deflectometer, many of the Long-Term Pavement Performance (LTPP) projects can use the equipment for better diagnosis and more effective evaluation.

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1

Introduction

This document describes the operation of the software and hardware of the Seismic Pavement Analyzer (SPA) developed under Project H-104B for the Strategic Highway Research Program (SHRP). Technical specifications for the SPA are included in appendix A.

The device consists of a towed trailer, a computer with special data acquisition hardware and software, and a power supply for the trailer and computer. The operation of the trailer is controlled exclusively through the computer; consequently the user's manual deals primarily with operating the software. Aspects of hardware operation are described in chapter 1 and in appendix A. The following section describes the overall structure of the user interface software.

The overall structure of the SPA is that of an interactive controller program that sets up tables and executes specific functions of the SPA hardware through software control. Figure 1.1 shows a schematic of the main functions. The data communication, analysis functions, data plotting, and data acquisition boxes are stand-alone programs that are initialized by the setup tables. They generally require knowledge only of the setup tables and should not necessarily require interaction with the user. By breaking software functions into separate programs, functions are easily added or modified, system maintenance and testing are simplified, and hardware requirements are minimized.
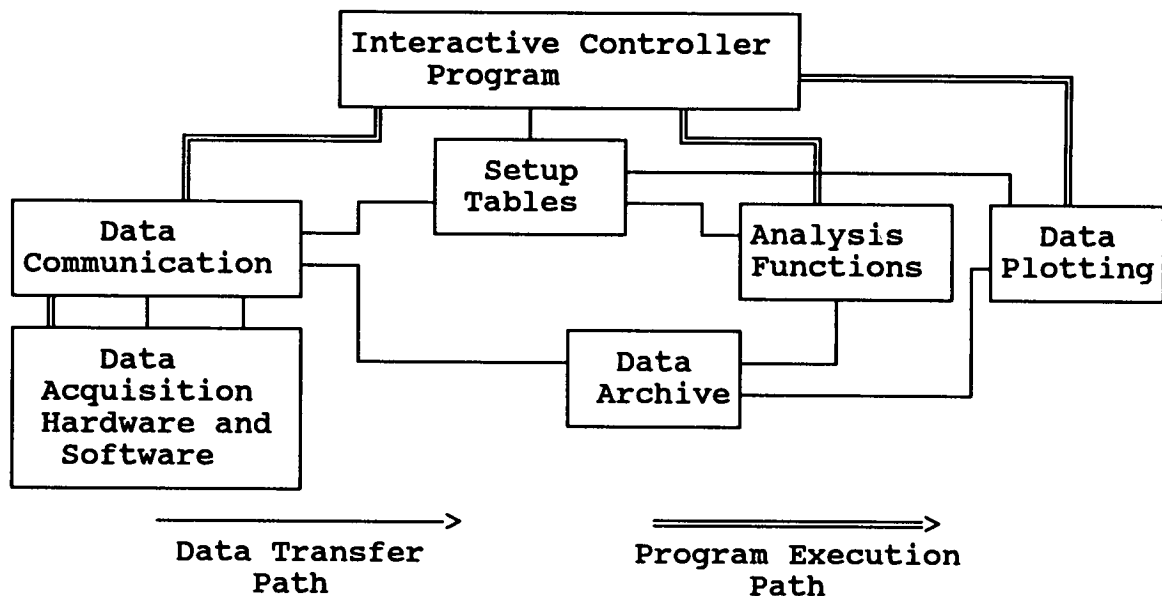
Figure 1.1 - Diagram of general SPA structure. A single main controller program handles user interaction and command execution.

User Interface Appearance

The interactive controller program presents options to the user through a set of three types of screens. These three screens are for menu choices, dialogue interaction, and list selection. Output to the user is in the form of tables and graphs. Graphic display of data is a strong requirement; consequently, a graphic interface is used. The software will support Hercules, color graphics adaptor (CGA), enhanced graphics adaptor (EGA) and video graphics adaptor (VGA) monochrome or color displays.

The menu screen lets the user select one of a set options for immediate action. A sample menu for the main level of the interactive controller program is shown in figure 1.2. The menu is outlined with a double line, while a single-line box indicates the menu option ready to be selected. Selection of one of these options may execute another of the three interactive screen types or some other specific action. A return <RET> key selects the active option; the escape <ESC> key exits the menu without a specific selection; and arrow keys change the active option.

```
+-------------------------------------------------------------+
|                    MAIN MENU OPTIONS                        |
|                          +----------------+                 |
|   Acquisition    Analysis | Table Setup    |   Help    Exit  |
|                          +----------------+                 |
+-------------------------------------------------------------+
```

Figure 1.2 - Main menu options for the controller program. The option to be selected is outlined with a box and is selected by the return <RET> key. The escape <ESC> key exits a menu without choice.

A dialogue screen lets the user interactively edit text fields or choose menu options. A sample dialogue box is shown in figure 1.3. The current edit field is indicated by the arrow (=>) and menu options are highlighted by a single-line box as shown in figure 1.3. The active edit field or menu option is chosen with the arrow keys or <RET> key, and the dialogue is exited and saved with the <ESC> key.

```
+-------------------------------------------------------------+
|              TEMPERATURE CALIBRATION MENU                   |
|  +--------------------+                                     |
|  | Cold Bath Sample   |   Cold Bath Temperature => 1.2      |
|  +--------------------+                                     |
|-------------------------------------------------------------|
|                                                             |
|     Hot Bath Sample      Hot Bath Temperature      97.4     |
|                                                             |
+-------------------------------------------------------------+
```

Figure 1.3 - A sample dialogue menu for selecting program options and editing text fields. The dialogue is exited and saved using the escape <ESC> key.

A list screen lets the user activate a fixed list of options for programs to be executed by the controller program. A short sample list for selecting measurement types is shown in figure 1.4. An arrow (=>) in the left-hand column indicates the item to be changed. This arrow is moved using the arrow keys. Cursor control keys (-> or <-) will toggle the item back and forth between the active and inactive columns. The list is exited and saved using the <ESC> key.

Menu, dialogue, and list-option selections are all saved and the next time the screen is used, previous menu choices are restored. As long as the menu is properly exited, this status is

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saved through all program operations. Thus, frequently used menu options are quickly selected with minimal key strokes.

```
┌─────────────────────────────────────────┐
│         MEASUREMENT OPTIONS              │
│      Inactive          Active            │
├──────────────────────┬──────────────────┤
│                      │  MI              │
│    SASW              │                  │
│    Pulse  Echo       │                  │
│  =>                  │  Comment         │
└──────────────────────┴──────────────────┘
```

Figure 1.4 - Sample list menu for selecting data collection options. The arrow highlights the option that may be toggled between active or inactive using the <RET> key. The list is exited and saved using the <ESC> key.

Software Structure Philosophy

The software controlling the Seismic Pavement Analyzer has been designed to accommodate three main modes of use. These three modes are (1) routine data collection by a technician; (2) setting up options for routine data collection by the project engineer or technician; and (3) diagnostics or general interactive data collection and analysis by the project engineer or researcher.

In routine data collection, the technician needs only to command the computer to collect data. Software then reports selected analysis results to the user's screen, and complete analysis results to the data archive, after successful completion of data collection. If data collection is unsuccessful, the program notifies the user and suggests corrective actions. Options for equipment diagnostics, calibration, and operator comments are also readily available in this mode of operation.

The mode for setting up options and tables is designed so that a wide array of default information may be set up by an experienced operator. The operator has control over the measurements to be made, values to be reported, and diagnostics to be run. The operator also controls the pavement properties and equipment parameters. Some setup tables, such as standard concrete properties, are globally applicable, while others, such as pavement layers and thicknesses, are project specific. Project categories may be set up for specific types of measurements and pavement types to hold these tables and recorded data.

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When the project engineer is interactively collecting and interpreting data, large amounts of detailed information are reported to the screen on a specific measurement. This is defined under the setup and analysis modes, with all results reported to the screen after data collection. This mode effectively provides the project engineer in the office all the information that would be collected by a technician in routine operation.

Hardware Requirements

The Seismic Pavement Analyzer software, exclusive of the data acquisition software, is expected to run on an IBM-PC XT- or AT- equivalent platform with Hercules, color graphics adaptor (CGA), enhanced graphics adaptor (EGA) or video graphics adaptor (VGA) graphics, 2 megabytes of random-access memory (RAM), and two floppy disk drives. A hard disk and math coprocessor will be highly desirable, but not necessary, for speed of operation. Disk storage requirements are determined by the amount of data acquired in the field, as the total floppy disk or hard disk-drive space required to run the user interface, data acquisition, and interpretation software is less than 900 kilobytes. Three serial ports will be necessary for communication with the data acquisition hardware, distance measuring equipment, and other potential additions.

Operation of computationally intensive interpretation functions such as the Spectral Analysis of Surface Waves (SASW) inversion would require an AT or equivalent platform with a math coprocessor.

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Start-Up and Main Menu Options

Start-up

The Seismic Pavement Analyzer (SPA) is started by turning on the main 12-volt DC and 120-volt AC power switches to the trailer. The air compressor in the trailer will start and operate for several minutes. Power to the data acquisition hardware is then turned on. Once the air compressor in the trailer has shut off, check that operating pressures on the regulator gauges are satisfactory (40 psi source firing, 20 psi source lower, 15 psi transducer hold-down), that air springs on the trailer are inflated (see figure A.1 in appendix A), and that the valve permitting air pressure to raise the source assembly is open.

A power cutoff switch is attached to the tow vehicle parking brake. If the parking brake is not set, the trailer control electronics will not be powered up. This cutoff should help prevent movement of the trailer while the transducers and sources are in the lowered position.

The Seismic Pavement Analyzer software is located in the subdirectory named c:\pavement. Upon starting the computer, the following three disk operating system (DOS) commands in bold type will bring up the software for use.

> DOS> **c:**
> DOS> **cd pavement**
> DOS> **userint**

These commands may be typed by the user or inserted in the "autoexec.bat" file for automatic execution when the computer is turned on. The main menu (figure 1.2) should now appear on your screen. In the event the Seismic Pavement Analyzer software does not start, refer to appendix B for troubleshooting.

As described briefly in the introduction, the Seismic Pavement Analyzer software is designed to be used by three classes of users: the technician performing routine data collection; the engineer or technician setting up the machine for data collection; and the engineer performing interactive data collection or research. The structure of the main menu, shown in figure 2.1, reflects this division of function.

Acquisition

The first menu option (figure 2.1), Acquisition, contains four suboptions necessary for the technician performing routine data collection. The following three suboptions are available under the Acquisition heading and are described in more detail in chapter 2. The Data Collection suboption sends commands for data acquisition and retrieves and archives collected data. The Save Waveforms option saves detailed time and frequency domain data for later extensive analysis. The Diagnostics suboption runs specific hardware tests and reports potential instrument failure. The Calibration suboption pulls up another menu for selection of specific calibration procedures.

```
                       MAIN MENU OPTIONS

 ┌───────────┐
 │Acquisition│  Analysis   Table Setup      Help   Exit
 └───────────┘
 ┌───────────────┐
 │Data Collection│
 │Save Waveforms │
 │Diagnostics    │
 │Calibration    │
 └───────────────┘
```
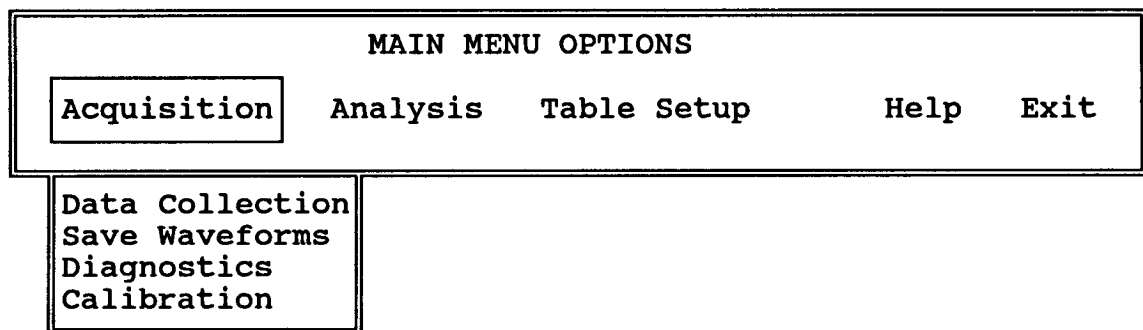
Figure 2.1 - Main menu options and suboptions for the acquisition option.

Analysis

The second menu option, Analysis (figure 2.2), contains the options necessary for analyzing and viewing data collected with the Acquisition option. The experienced engineer may review routinely collected data or may switch back and forth between Analysis and Acquisition functions. The figure's five suboptions are available under the Analysis function and are described in more detail in chapter 3.

```
                           MAIN MENU OPTIONS

      Acquisition    │Analysis│   Table Setup        Help    Exit


             │Select Measurements        │
             │Display Measurements       │
             │SASW Inversion             │
             │Distress Identification    │
             │Help                       │
```
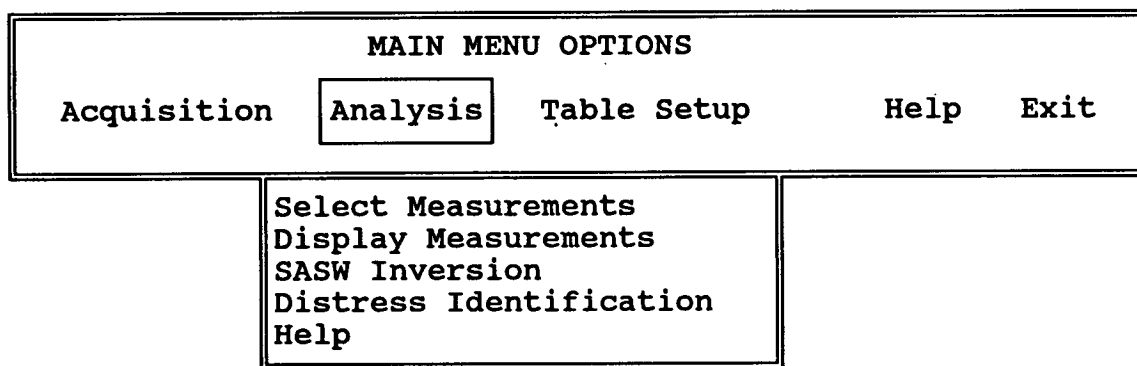
Figure 2.2 - Main menu options and suboptions for the analysis option.

The Select Measurements option brings up a menu that permits selection of specific data sets and data attributes that will be used in other analysis functions. The Display Measurements suboption presents a graphic summary of collected data and analysis results. The SASW Inversion displays a dialogue menu of modifiable options and calculates shear modulus and Young's Modulus profiles from frequency-dependent phase data. The Distress Identification suboption implements identification of the type of pavement distress on the data sets selected in the Select Data Set option in this menu.

Table Setup

The third menu option, Table Setup (figure 2.3), will be used by the experienced engineer or technician to define data collection and analysis defaults. The five suboptions are described in more detail in chapter 4.

The Screen Reporting selection brings up a menu of options on the types of information that are reported to the user's screen, and the Data Base Reporting those that are saved to the

data base, during routine or research data acquisition. The Measurement Options selection allows the user to set up the types of measurements and quality control calculations to be performed during data acquisition. The Setup Tables selection brings up a menu of user-modifiable tables that deal with project definition, concrete and asphalt properties, and the expected pavement structure. The Help suboption gives a brief description of the operation of each of the options in this menu.

```
┌─────────────────────────────────────────────────────────────────┐
│                      MAIN MENU OPTIONS                            │
│                               ┌─────────────────┐                 │
│   Acquisition    Analysis     │ Table Setup     │    Help   Exit  │
│                               └─────────────────┘                 │
└─────────────────────────────────────────────────────────────────┘
                          ┌──────────────────────┐
                          │ Screen Reporting     │
                          │ Data Base Reporting  │
                          │ Measurement Options  │
                          │ Setup Tables         │
                          │ Help                 │
                          └──────────────────────┘
```
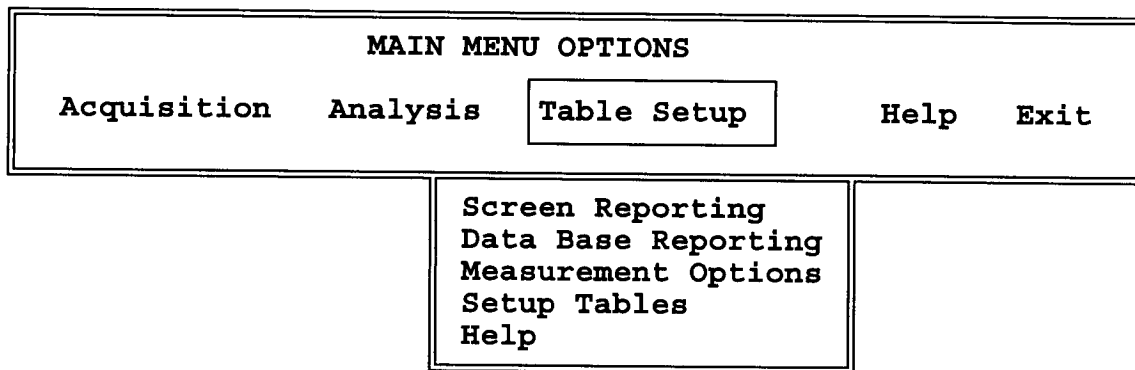
Figure 2.3 - Main menu options and suboptions for the table setup option.

Help

The fourth menu option, Help (figure 2.4), brings to the screen a text window with information similar to that contained in this section. Help options will appear on all appropriate menus and are specific to the context of the software. For instance, while in the Analysis option of the main menu, only information useful for analysis options is available with its help command.

```
┌─────────────────────────────────────────────────────────────────┐
│                      MAIN MENU OPTIONS                            │
│                                                  ┌──────┐         │
│   Acquisition    Analysis    Table Setup         │ Help │  Exit   │
│                                                  └──────┘         │
└─────────────────────────────────────────────────────────────────┘
```
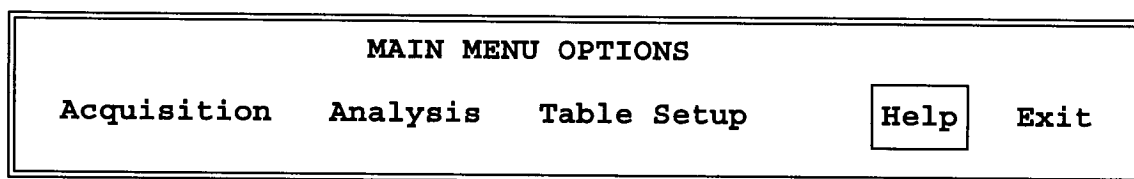
Figure 2.4 - Main menu options with help option selected.

Exit

The fifth menu option, Exit, permits a graceful exit from the Seismic Pavement Analyzer software into the personal computer's (PC's) operating system. The Acquisition option is restored when the software is rerun. Choosing the Exit option is equivalent to using the <ESC> key to exit this menu.

```
┌─────────────────────────────────────────────────────────────┐
│                     MAIN MENU OPTIONS                        │
│                                                    ┌──────┐   │
│   Acquisition    Analysis    Table Setup    Help   │ Exit │   │
│                                                    └──────┘   │
└─────────────────────────────────────────────────────────────┘
```
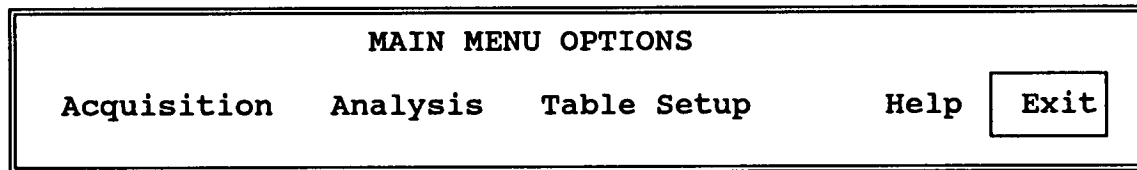
Figure 2.5 - Main menu options with exit option selected.

3

Acquisition

The Acquisition option of the main menu permits the selection of the four functions for data acquisition shown in figure 3.1. These four functions are Data Collection, Save Waveforms, Hardware Diagnostics, and Calibration. Each of these functions is a subheading in this chapter.

```
┌──────────────────────────────────────┐
│         ACQUISITION MENU             │
│  ┌────────────────────────────────┐  │
│  │ Data Collection                │  │
│  └────────────────────────────────┘  │
│    Save Waveforms                    │
│                                      │
│    Hardware Diagnostics              │
│                                      │
│    Calibration                       │
└──────────────────────────────────────┘
```
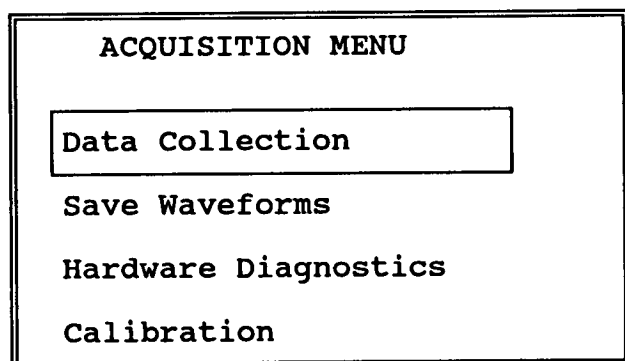
Figure 3.1 - Menu options for controlling the hardware, pneumatics, and data acquisition subsystem. The single-line box highlights the Data Collection option to be selected with the <RET> key.

Data Acquisition

Choice of the Data Acquisition option will initiate hardware data collection and reporting back to the user's screen and data base.

Actions that occur with selection of this option depend on whether or not the transducer mechanism is already lowered. The mechanism may have been lowered through software or may have been left lowered by a software malfunction during acquisition. If the transducer mechanism has not been explicitly lowered, it will be lowered and retracted immediately following completion of the measurements. If the mechanism has been previously lowered, it will be raised after data collection is completed. If a malfunction occurs, the mechanism may remain lowered. Release of the tow-vehicle parking brake will cut power to the trailer control electronics and raise the transducer- and source-mounting mechanisms.

Save Waveforms

The Save Waveforms option performs a data compression and archiving operation. It compresses and moves the time-domain waveforms, intermediate interpretations, and frequency domain data into a file associated with the unique data tag. This option may be selected only when the machine is run in the Local Acquisition mode (see chapter 5, Acquisition Mode, figure 5.11). These data may be used for later detailed interpretations, for comparison with core samples, or for detailed diagnosis of equipment operation. Restraint should be exercised in using this option, as up to 400 kilobytes of data are saved to disk with each operation.

Hardware Diagnostics

Selection of the Hardware Diagnostics option will replace accelerometers and geophones with hardware calibration signals and error-testing software. This function has been designed, built, and tested, but is not yet routinely available.

Calibration

Selection of the Calibration option will bring up another menu (figure 3.2) from which specific calibration procedures may be selected. Time intervals for calibration have not yet been determined, as no changes in calibration have been observed to date.

The Distance calibration sequence will be incorporated in purchased hardware from a commercial vendor of vehicle-mounted distance meters.

```
+---------------------------------------+
| | |
| |  CALIBRATION MENU  | |
| | |
| |  +-----------------------+  | |
| |  | Distance              |  | |
| |  +-----------------------+  | |
| | |
| |  Velocity          | |
| | |
| |  Temperature       | |
| | |
+---------------------------------------+
```
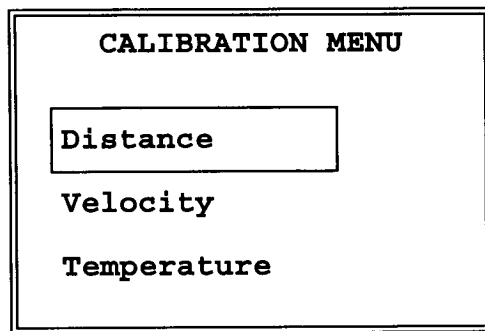
Figure 3.2 - Menu for selection of specific calibration options. The single-line box highlights the selected option.

The Velocity calibration requires a standard slab of known compressional velocity. The Seismic Pavement Analyzer is lowered onto the standard slab and the Velocity option is selected. The menu shown in figure 3.3 is brought up listing source-detector spacings in dialogue entries for verification and also requesting the velocity of the standard slab in a dialogue entry.

The Temperature calibration sequence requires that both the pavement and air thermocouples be placed sequentially in an ice bath and hot water bath with water temperatures measured with a thermometer. Selection of the Temperature option will bring up the dialogue box shown in figure 3.4. With the thermocouples in the Cold Bath Sample, the user selects that menu entry, hits the <RET> key, and a digital, uncalibrated temperature reading is taken after the temperature has stabilized. The user then moves the cursor to the Thermometer Reading entry to the right and enters the reference thermometer reading. The user then places the thermocouples in the hot water and selects Hot Bath Sample, waits for a stable digital temperature reading, and enters the reference thermometer reading. Following

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calculation of new calibration constants, deviations of the old temperature calibration are recorded in the data base. The user may calibrate the system in either English units or metric (International System of Units or SI) units.

```
┌─────────────────────────────────────────────┐
│ ╔═════════════════════════════════════════╗ │
│ ║        VELOCITY CALIBRATION MENU         ║ │
│ ║                                          ║ │
│ ║    Spacing of source to detector (m)     ║ │
│ ║                                          ║ │
│ ║         A1        0.0762                 ║ │
│ ║         A2        0.1524                 ║ │
│ ║         A3   =>   0.3048                 ║ │
│ ║         A4        0.6096                 ║ │
│ ║         A5        1.2192                 ║ │
│ ║                                          ║ │
│ ║    Standard Slab Velocity 4913.          ║ │
│ ║                                          ║ │
│ ║         Calibrate Velocity               ║ │
│ ║                                          ║ │
│ ║       Help            Exit               ║ │
│ ╚═════════════════════════════════════════╝ │
└─────────────────────────────────────────────┘
```

Figure 3.3 - Velocity calibration menu. Source-detector spacings are alterable in dialogue entries. The calibration velocity is entered in a dialogue entry, and the calibration procedure is selected by a menu entry.

```
┌───────────────────────────────────────────────────────────┐
│ ╔═══════════════════════════════════════════════════════╗ │
│ ║            TEMPERATURE CALIBRATION MENU                ║ │
│ ║ ┌───────────────────┐                                 ║ │
│ ║ │ Cold Bath Sample  │  Cold Bath Temperature => 1.2   ║ │
│ ║ └───────────────────┘                                 ║ │
│ ║                                                       ║ │
│ ║   Hot Bath Sample      Hot Bath Temperature    97.4   ║ │
│ ║                                                       ║ │
│ ║   Help                 Exit                           ║ │
│ ╚═══════════════════════════════════════════════════════╝ │
└───────────────────────────────────────────────────────────┘
```

Figure 3.4 - Menu entries for temperature calibration. Cold Bath Sample and Hot Bath Sample are menu entries that initiate a digitized temperature recording. Upon taking the digital sample, the user records the reference thermometer reading in the dialogue entry.

4

Analysis

The Analysis option of the main menu (figure 2.2) permits selection of four suboptions shown in figure 4.1. These four functions are Select Measurements, Display Measurements, Spectral Analysis of Surface Waves (SASW) Inversion, and Distress Identification. Each of these options is a separate section in this chapter.

```
┌─────────────────────────────────────┐
│ ╔═══════════════════════════════════╗│
│ ║         ANALYSIS MENU             ║│
│ ║                                   ║│
│ ║  ┌──────────────────────────┐     ║│
│ ║  │ Select Measurements      │     ║│
│ ║  └──────────────────────────┘     ║│
│ ║                                   ║│
│ ║   Display Measurements            ║│
│ ║                                   ║│
│ ║   SASW Inversion                  ║│
│ ║                                   ║│
│ ║   Distress Identification         ║│
│ ║                                   ║│
│ ║   Help                            ║│
│ ╚═══════════════════════════════════╝│
└─────────────────────────────────────┘
```
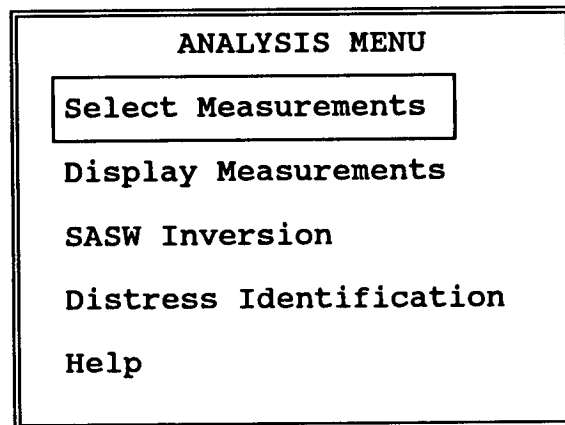
Figure 4.1 - Menu options for controlling analysis and data-plotting software.

Analysis functions are likely to be used in two modes. In the first, the project engineer or technician will review and analyze a series of measurements routinely collected on a particular project. In the second, the project engineer is likely to be making a detailed set of

analyses and judgments interactively with measurements, occasionally referring back to previous measurements of a similar type. Consequently, analysis functions are controlled by the context of other program operations. For instance, if data collection has just occurred, Display Measurements, SASW Inversion, and Distress Identification functions all operate on the most recently collected measurement. Review or analysis of previously collected data sets is accessed through the Select Measurements option. The program remains in that mode until new data collection occurs.

Select Measurements

Selection of the Select Measurements entry brings up a list menu of previously collected and unarchived data in the currently active project directory (figure 4.2). See chapter 5 about the Project Directory selection option for instructions on how to select this option. Specific measurements may be toggled between active (for analysis) and inactive (to be ignored). Measurements are identified by a unique number (called a "tag"), time, and distance. The measurements that are shown in this list menu can come from two sources. Data that have been recently collected and not yet loaded into the data base manager will be displayed in this list. In addition, if data are retrieved from the data base manager into the appropriate project directory, it will be available for display or analysis through this list.

DEMONSTRATION DATA	
Inactive	Active
Tag 1 Tag 3 => Tag 4	Tag 3

Figure 4.2 - List menu for selecting data sets to be reviewed, plotted, or analyzed.

Display Measurements

Selection of the "Display Measurements" option brings up an experimental graph summarizing the modulus and thickness measurements made by the Seismic Pavement Analyzer (SPA). Figure 4.3 shows a sample of this summary display. The graph is a schematic pavement cross-section divided into four layers. The top layer is asphalt concrete

(AC) properties, underlain by a portland cement concrete (PCC) layer, underlain by a base layer, with the bottom layer representing the subgrade. The width of the left-hand box is proportional to a normalized shear modulus, and the width of the right-hand box in the paving layers is proportional to Young's Modulus. The box height is proportional to the normalized thickness and separation between paving layers, and the base is proportional to the impact echo amplitude height and to damping in the mechanical impedance test. Default properties used for normalization are selected in the Pavement Properties and Pavement Structure options of Table Setup (chapter 6). If the Select Data Set Measurements option has not been activated since the last data acquisition step, the most recently collected measurements will be reported to the screen.
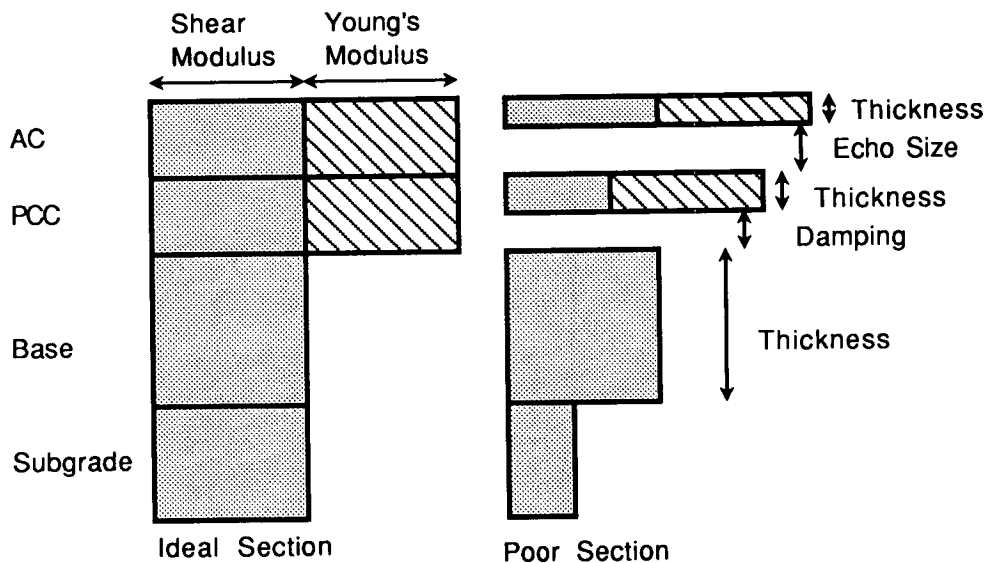

Figure 4.3 - **Sample schematic pavement cross-section description. Boxes represent paving layers; height is proportional to thickness; and widths are proportional to shear modulus and Young's Modulus estimates in the layer.**

Commercial spreadsheets can provide the user with many other types of graphs of measurements from the SPA. The SPA data base records may simply be loaded into the

spreadsheet for display, computations, or statistical analysis. This data base file resides in the project directory specified in Setup Tables (Directory Selection) with the name "moduli.txt."

SASW Inversion

Selection of the SASW Inversion option converts the dispersion curves for active selections from the Select Measurements option into shear velocity and Young's Modulus estimates for the pavement layers. The menu shown in figure 4.4 is brought up to verify and set up parameters used in the inversion. The expected pavement properties are retrieved from the master tables. Setup of the master tables is described in chapter 5 under the topics dealing with setting up the pavement structure and the tables of pavement properties.

```
                    SASW  INVERSION  SETUP

          Expected  Pavement  Properties
                  Thickness    Density   Young's    Poisson's
                                         Modulus     Ratio
     Pavement          6          150      6.0        0.16
     Base       => 15             130      1.2        0.25
     Subgrade        -            110      0.3        0.35

            | Invert |            Help           Exit
```

Figure 4.4 - Menu options for setting up the SASW Inversion for shear
velocity and Young's Modulus profile with depth.

Results of the inversion are revised estimates of shear moduli and thicknesses for the pavement, base, and subgrade layers. These estimates are inserted into the data base records for access by other analysis or display functions.

Distress Identification

Selection of the Distress Identification option brings up a dialogue menu that summarizes a comparison of measured and expected pavement properties for the most recently collected

data, prior to attempting an interpretation (figure 4.5). These measured and expected values are editable as dialogue items, and a menu item to predict distress type will run the interpretation software. A typical output consists of the unique data tag followed by diagnostic information for that data measurement (figure 4.6).

```
                DISTRESS IDENTIFICATION MENU
                       Measured Value    Expected Value
Pavement YM (P)             4.4              6.0
         PR (P)             0.22             0.15
         PR (USW)           0.30             0.15
         Thickness          6.0              6.0

Base     YM (SASW)          1.0              1.2
         YM (MI)            1.3              1.2
         PR                 0.3              0.3
         Thickness          16               16

Subgrade YM (SASW)          0.34             0.2
         YM (MI)            0.43             0.2
         PR                 0.35             0.35

Delamination Depth          6.0              6.0
Resonance Amplitude         0.5              0.2
MI Damping                  0.83             0.70

  Identify Distress                          Help
```

Figure 4.5 - Menu options for setting up the distress identification interpretation module. The abbreviations in parentheses define the source of the estimate.

```
   Tag 143
        Weak Subgrade
        Possible Cracked Concrete Layer
        Possible Void Under the Concrete Layer
```

Figure 4.6 - Sample diagnosis for a measurement.

5

Table Setup

The Table Setup option of the main menu (figure 2.3) permits selection of the four suboptions shown in figure 5.1. These four functions are Screen Reporting, Data Base Reporting, Measurement Options, and Setup Tables. Each of these options is a separate section in this chapter.

```
┌─────────────────────────────────────┐
│          SETUP TABLE MENU           │
│  ┌───────────────────────────────┐  │
│  │ Screen Reporting              │  │
│  └───────────────────────────────┘  │
│    Data Base Reporting              │
│    Measurement Options              │
│    Setup Tables                     │
│    Help                             │
└─────────────────────────────────────┘
```
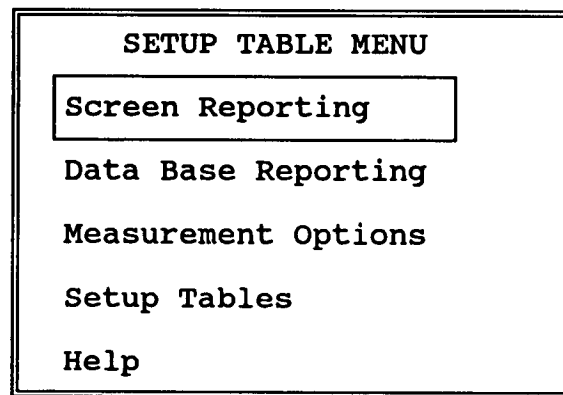
Figure 5.1 - Menu options for setting up default data collection, display, and reporting selections.

The Table Setup option generally includes all types of analyses and calculations that may be performed routinely. In the current version, the Analysis options SASW Inversion and

Distress Identification are not included. They will be added as routine functions when they can be run without user intervention.

The structure of these options has been designed so that the computer screen shows technicians performing routine data collection the quantity and level of information required to perform the job successfully at their training level. The project engineer reviewing data after collection requires a different quantity and level of information from the data base. Provision is also made in these options for the Seismic Pavement Analyzer (SPA) to be repaired or to perform in a suspect state of repair. Extensive diagnostics are also available.

Screen Reporting

Upon selection of the Screen Reporting menu item, a menu is brought to the screen (figure 5.2) that breaks the Report category into three options: Diagnostic Level, Plot Display, and Parameter Display. A list of options for diagnostic reporting is given in figure 5.3.
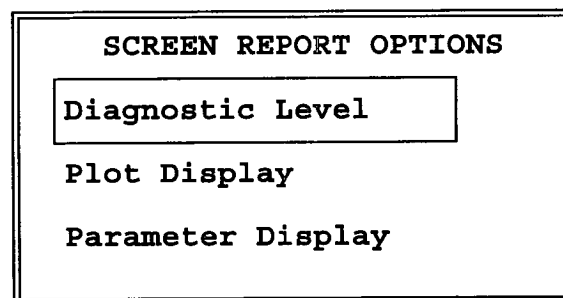
```
┌──────────────────────────────────────┐
│    SCREEN REPORT OPTIONS              │
│  ┌──────────────────────────┐        │
│  │ Diagnostic Level         │        │
│  └──────────────────────────┘        │
│    Plot Display                       │
│                                       │
│    Parameter Display                  │
│                                       │
└──────────────────────────────────────┘
```

Figure 5.2 - Menu options permitting selection of specific types of screen reports.

Different levels of condition messages are available under the Diagnostic Level option. Under Suggest Repairs, serious malfunctions that prevent collection of good measurements are reported. Message Malfunction Warning reports instrument conditions that might lead to degradation of data quality but that do not necessarily require immediate attention. Full Status Report lists all negative status conditions in the hardware which are useful in repair or field checking before initiating a project.

The Plot Display and Parameter Display options currently perform no function, having been tentatively superseded by the Display Measurements function. These functions can be

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performed by loading data sets in a spreadsheet. The options have not been removed from the software in the event these two functions are not adequate.

```
┌──────────────────────────────┐
│     DIAGNOSTIC LEVELS        │
│  ┌────────────────────────┐  │
│  │ None                   │  │
│  └────────────────────────┘  │
│     Suggest Repairs          │
│                              │
│     Malfunction Warning      │
│                              │
│     Full Status Report       │
└──────────────────────────────┘
```

Figure 5.3 - List of options for diagnostics to be displayed to the user during data collection and instrument testing, available under either data base or screen reporting options. The currently active option is highlighted by the box when it is accessed.

Data Base Reporting

Selection of the Data Base Reporting option (figure 5.1) will bring up a menu shown in figure 5.4. Data base and record formats are not standard among prospective users, so records and tables are formatted for compatibility with several commercial personal computer (PC) data base packages.

```
┌──────────────────────────────┐
│    DATA BASE REPORTING        │
│  ┌────────────────────────┐   │
│  │ Diagnostic Level       │   │
│  └────────────────────────┘   │
│    Parameter Archive          │
│                               │
│    Standard Formats           │
└──────────────────────────────┘
```

Figure 5.4 - Menu selections to set up data base entries documenting test conditions, results, and diagnostics.

The Diagnostic Level is identical to that under the Screen Display option (figure 5.3). Typically, diagnostics at the malfunction level are routinely saved. By default, all data are currently archived in Borland's Paradox data base. As additional needs or data bases are accommodated, the Parameter Archive and Standard Formats options will be extended.

Measurement Options

On selection of Measurement Options, a list of possible measurements to be reported from the Seismic Pavement Analyzer is given (figure 5.5). Items may be toggled between the Inactive and Active modes using the return <RET> key. Quality Control (QC) estimates on geophone, accelerometer, and load-cell responses are included here, rather than under diagnostic indicators. These are time-consuming, but provide a higher level of quality control in the data base for critical or research applications.

The list of measurement options is not displayed in its entirety on the screen at one time, as it is too long for some screens. The lists will scroll up- and down- through use of the up and down arrow cursor controls, as well as the "PgUp" and "PgDn" keys.

```
                    MEASUREMENT SELECTION
            Inactive                        Active

   =>                              Low-frequency SASW
        Mechanical Impedance
        High-frequency SASW
        Compressional Velocity
        Ultrasonic Surface Wave
        Pulse Echo
        Temperature
        Position
                                  Operator Comment
        Geophone QC
        Accelerometer QC
        Load-Cell QC
```

Figure 5.5 - List of options for measurements to be collected.

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Setup Tables

The Setup Tables option allows definition of the analysis and collection environment of the SPA. The units and dimensions of measurements are implicitly defined in the tables that can be modified in this section. All tables are currently defined in International System of Units (SI). If some other system of units is desirable, the source-receiver geometry, pavement properties, pavement structure, and calibration tables must be changed to reflect consistent units. The units are defined in tables; the software expects no explicit units.

On selection of the Setup Tables option, the menu shown in figure 5.6 appears on the screen giving a list of the tables to be edited.
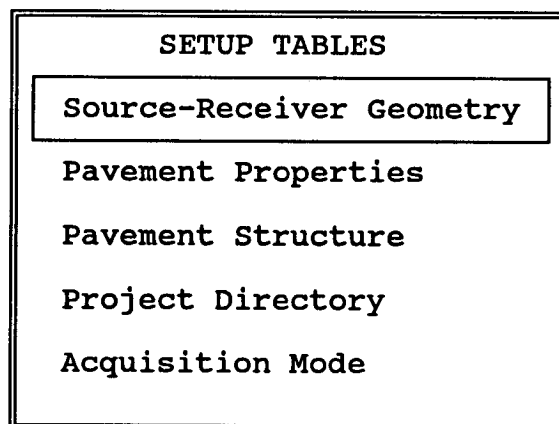
```
+-----------------------------------------+
|            SETUP  TABLES                |
|  +-----------------------------------+  |
|  |   Source-Receiver  Geometry       |  |
|  +-----------------------------------+  |
|     Pavement  Properties                |
|                                         |
|     Pavement  Structure                 |
|                                         |
|     Project  Directory                  |
|                                         |
|     Acquisition  Mode                   |
|                                         |
+-----------------------------------------+
```

Figure 5.6 - Menu options to select specific setup tables and options.

Upon selection of the Source-Receiver Geometry option, the spacing table (figure 5.7) specific to the current working directory is loaded into the DOS system editor. If changes are made, these spacings are moved to the working table for data acquisition. Units of these spacings are implicitly assumed to match those used for modulus values.

The spacing table abbreviations L2 and L1 represent the low-frequency and high-frequency load cells respectively. G1-G3 and A1-A5 are the representations of consecutive geophones and accelerometers. The entry L1A3\0.3048 then implies that the distance between the high-frequency load cell and accelerometer number 3 is 0.3048 meters.

Selection of the Pavement Properties option will execute the system editor on the file of globally applicable pavement properties.

```
        L2L1\0.0635
        L2G1\0.1397
        L2G2\0.9842
        L2G3\2.1780
        L1A1\0.0762
        L1A2\0.1524
        L1A3\0.3048
        L1A4\0.6096
        L1A5\1.2192
```

Figure 5.7 - Source-receiver geometry table for modifying spacings.

Selection of the Pavement Structure option will bring up the dialogue menu of figure 5.8. Thicknesses for each layer may be specified, as well as the type of material that is expected.

```
            PAVEMENT STRUCTURE

    Overlay   Thickness => 50
              Material      AC-Spec1

    Pavement  Thickness     150
              Material      PCC-Spec2

    Base      Thickness     300
              Material      CS-Spec3

    Subgrade  Material      Peat
```
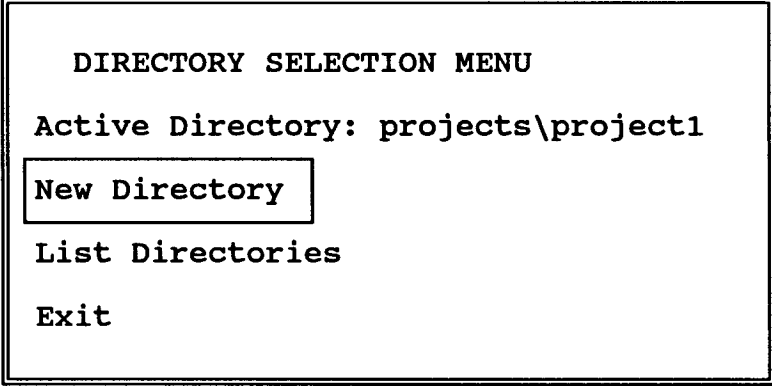
Figure 5.8 - Dialogue entries to specify pavement structure. Materials specified should be standard descriptions accessible through table lookup.

Materials specified in this dialogue should have a set of properties associated with the name in the pavement properties table.

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Project Directory

Under the operating directory of the SPA, a directory named "projects\"is reserved for newly created or previously existing project subdirectories. Project directories may be created and accessed that are not under this reserved directory, but some aspects of routine operation will not be visible to the user.

Selection of the Project Directory option brings up a dialogue menu showing the currently active directory, with options for change (figure 5.9). The Active Directory entry is a dialogue entry that indicates the project directory that is currently active and permits creation of a new name, or selection of an unreserved project directory. An old project directory may be typed in, or a new directory name may be entered and the New Directory menu item selected as shown in figure 5.9.

```
┌─────────────────────────────────────────┐
│                                         │
│     DIRECTORY SELECTION MENU            │
│                                         │
│   Active Directory: projects\project1   │
│   ┌───────────────────┐                 │
│   │ New Directory     │                 │
│   └───────────────────┘                 │
│   List Directories                      │
│                                         │
│   Exit                                  │
│                                         │
└─────────────────────────────────────────┘
```

Figure 5.9 - The Directory Selection Menu displays the currently active directory, permits creation of a new directory name entered in the field, or lets you select an active directory from a list.

The List Directories menu option will bring up a list menu of currently available directories with the currently active directory in the Active zone (figure 5.10). An existing directory may be moved to the Active zone to select it as the current operating directory. If multiple directories are selected to be active, the software will complain until only one directory is selected. Only project directories in the "projects\" subdirectory are shown in this list.

```
+==================================================+
|              PROJECT DIRECTORY                   |
|        Inactive          Active                  |
|--------------------------------------------------|
|       Project1         |                         |
|       Project2         |                         |
|  =>                    |  RWParkway              |
+==================================================+
```

Figure 5.10 - Project directory selection list. Selection of the New option will create a new directory.

Acquisition Mode

Selection of the Acquisition Mode option brings up a menu allowing you to select between two options (figure 5.11).

```
+==================================================+
|              ACQUISITION MODE                    |
|                                                  |
|       Remote Acquisition                         |
|      +-------------------------+                 |
|      | Local Acquisition       |                 |
|      +-------------------------+                 |
+==================================================+
```

Figure 5.11 - Menu to permit selection of whether acquisition is made using two computers connected by modem (Remote) or by one computer (Local).

Selection of the Remote Acquisition option (figure 5.11) assumes that the user interface software resides on a different computer than the data acquisition software and that the two are connected through a cable or through modems and a phone line. Selection of the Local Acquisition option assumes that the data acquisition software and user interface are on the same computer.

6

Menu and Interpretation Templates

This section describes the structure of the user-accessible files that define the functions and actions of the user interface software. This section is of use to those who need to translate the user interface into a different language, to modify the menus, or to change the result of choosing a specific menu option.

Three types of interactions have been defined between the user and the interface software: selection of an item from a menu, entry or modification of values in a dialogue, and activation of multiple entries from a list of items. Each of the screen displays for these interactions is controlled by a specific file, named with a specific three-letter disk operating system (DOS) file type, with a special structure. Information about the menu, dialogue, or list location are held in "*.tmp" file name. For dialogues and lists, the "*.tmp" file contains a file name for the values in "*.val" file names and for lists in "*.lst" file names. These files are contained in the "template\" subdirectory under the main directory for the Seismic Pavement Analyzer (SPA).

Each template file, regardless of the type of interaction, contains several common attributes. The first portion defines the location of the screen window, the window attributes, and the title for the window. This portion is followed by a file name that points to some subsequent menu or data file, depending on the type of interaction. Subsequent entries are menu or dialogue entries followed by a character string returned to the calling program. In most cases, this character string is expected to point to the subsequent menu file for that option. The three following sections discuss the different types of interactions and file formats in more detail.

```
5 5  90 20      -1    -1    -1    -1              Line 1
40 10 MAIN MENU OPTIONS                           Line 2
NOFILE                                            Line 3
10 70 0 Acquisition                               Line 4
..\menus\template\acq.tmp                         Line 5
30 70 0 Analysis                                  Line 6
..\menus\template\anal.tmp                        Line 7
50 70 0 Table Setup                               Line 8
..\menus\template\setup.tmp                       Line 9
75 70 0 Help                                      Line 10
..\menus\help\main.txt                            Line 11
90 70 0 Exit                                      Line 12
                                                  Line 13
```

Figure 6.1 - Sample menu template for the main controller menu with line numbering on the right.

Menus

A sample of a menu template that creates the main controller menu (figure 1.2) is shown in figure 6.1. A description of the significance of each entry follows.

Line 1   Entry 1: Left edge of menu in percent of screen size.
          Entry 2: Top edge of menu in percent of screen size.
          Entry 3: Right edge of menu in percent of screen size.
          Entry 4: Bottom edge of menu in percent of screen size.
          Entry 5: Foreground color (-1 default).
          Entry 6: Background color (-1 default).
          Entry 7: Text color (-1 default).
          Entry 8: Line width (-1 default).

Line 2   Entry 1: Lower left title position X, percent of menu size.
          Entry 2: Lower left title position Y, percent of menu size.
          Entry 3: Title text string.

Line 3   Entry 1: File name allowed but is not used in menus.

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Line 4 Entry 1: Menu text position X, percent of menu size.
     Entry 2: Menu text position Y, percent of menu size.
     Entry 3: (-1) nonmenu text string.
          (0) menu text string.
          ($>$0) X dialogue position, percent of menu size.
     Entry 4: Menu text string for Acquisition option.

Line 5 Entry 1: Text string returned to software upon selecting this menu option, file
        name for the Acquisition template file.

Line 6,7 Menu item and template file for Analysis.

Line 8,9 Menu item and template file for Table Setup.

Line 10,11 Menu item and help file for Help option.

Line 12,13 Menu item for Exit with no text returned.

Dialogues

A sample of a dialogue template for the temperature calibration menu is shown in figure 6.2. The structure and significance of the first two lines are the same as for the menu template of figure 6.1. Line 3 contains the file name of default and modified values for the dialogue items. A sample of this file is shown in figure 6.3.

```
10 30  90 70    -1   -1   -1   -1        Line 1
40 10 TEMPERATURE CALIBRATION MENU       Line 2
temp.val                                 Line 3
60 30 95 Cold Bath Temperature           Line 4
CBT                                      Line 5
60 70 95 Hot Bath Temperature            Line 6
HBT                                      Line 7
20 30 0 Cold Bath Sample                 Line 8
Some message to data acquisition         Line 9
20 70 0 Hot Bath Sample                  Line 10
Another message to data acquisition      Line 11
```

Figure 6.2 - Dialogue template for the temperature calibration menu.

Line 1,2   As defined for figure 6.1.
Line 3   Entry 1: File containing dialogue values.
Lines 4-7   Dialogue entries as defined for figure 6.1.
Lines 8-11   Menu entries as defined for figure 6.1.

```
2                                         Line 1
Cold Bath Temperature                     Line 2
3.4                                       Line 3
Hot Bath Temperature                      Line 4
98.4                                      Line 5
```

Figure 6.3 - Value file for the temperature calibration menu.

The value file contains two types of entries for dialogues. The first line contains the default (or last chosen) option. The next time this dialogue file is accessed, the previously used menu option is the first available. Lines 2 and 3 contain the dialogue entry label and value. The label is not specifically used in the menu. Rather, it is written so that the value file is readable and not context specific when programs read parameters from the file.

Lists

A sample list template for selecting measurement options is shown in figure 6.4 for the menu shown in figure 1.4. Lines 1 and 2 define the menu window and title as in figures 6.1 and 6.2. Line 3 points to the list of options to be displayed, as pictured in the shortened list of figure 6.5.

An entry of "1" in the first column of the list of figure 6.5 indicates an active item, and an entry of "0" indicates an inactive item.

```
30 12 70 92                               Line 1
20 5 MEASUREMENT OPTIONS                  Line 2
..\menus\template\flist.lst               Line 3
```

Figure 6.4 - Template for the measurement list selection.

```
1 MI              Line 1
0 SASW            Line 2
0 Pulse Echo      Line 3
1 Comment
```

Figure 6.5 - Shortened example of list menu entries. A "1" in the first entry indicates an active item; "0" indicates an inactive item.

Messages

A sample message template for giving information to the user is shown in figure 6.6. Lines 1 and 2 are identical to other menu templates in giving the screen location and attributes, as well as the subject of the message. Line 3 contains a file name that is not currently used but may contain text information. Line 4 gives the location of the text within the box defined in line 1.

The common use of the message template is to supply error messages returned from the data acquisition software.

```
    40   55   95   95               Line 1
    10   20   ERROR MESSAGE         Line 2
    NOFILE                          Line 3
    20   40                         Line 4
```

Figure 6.6 - Sample message template used primarily for error reporting.

7

Directory Structure

This chapter presents the disk operating system (DOS) directory structure for software and data for the Seismic Pavement Analyzer (SPA). This structure is presented to help the user locate files of specific types and to help manage backups of modified files. There are three significant subdirectories the user is likely to work with: the templates, the tables, and the projects subdirectories (figure 7.1).

The templates subdirectory contains all the files that describe the menu types, locations, and interactions for the user interface software. These structures are discussed in chapter 6. In addition, the template\help directory contains text files for the help options for the user interface. Should the user find the help files inadequate or in the wrong language, these files can be modified using the DOS text editor.

The tables subdirectory contains project-specific tables that determine data acquisition parameters, globally significant information such as design properties of specific types of concrete, and temporary storage files. The project-specific and globally specific tables use a "*.tbl" suffix. Many of the files in this subdirectory are copied from a projects directory when the project directory is selected under Table Setup. Other tables are created or modified every time data acquisition occurs. Should these files be accidentally erased, it is best to restore them from a backup of the directory.

The projects subdirectory contains any project information created by the user. All data storage and project-specific modifications to tables are contained in this area. Within project

subdirectories, data base tables built from data acquisition are contained in "*.txt" file suffixes; project-specific tables are contained in "*.tbl" suffixes; and data files resulting from the Save Waveforms command are contained in "*.zip" suffixes.
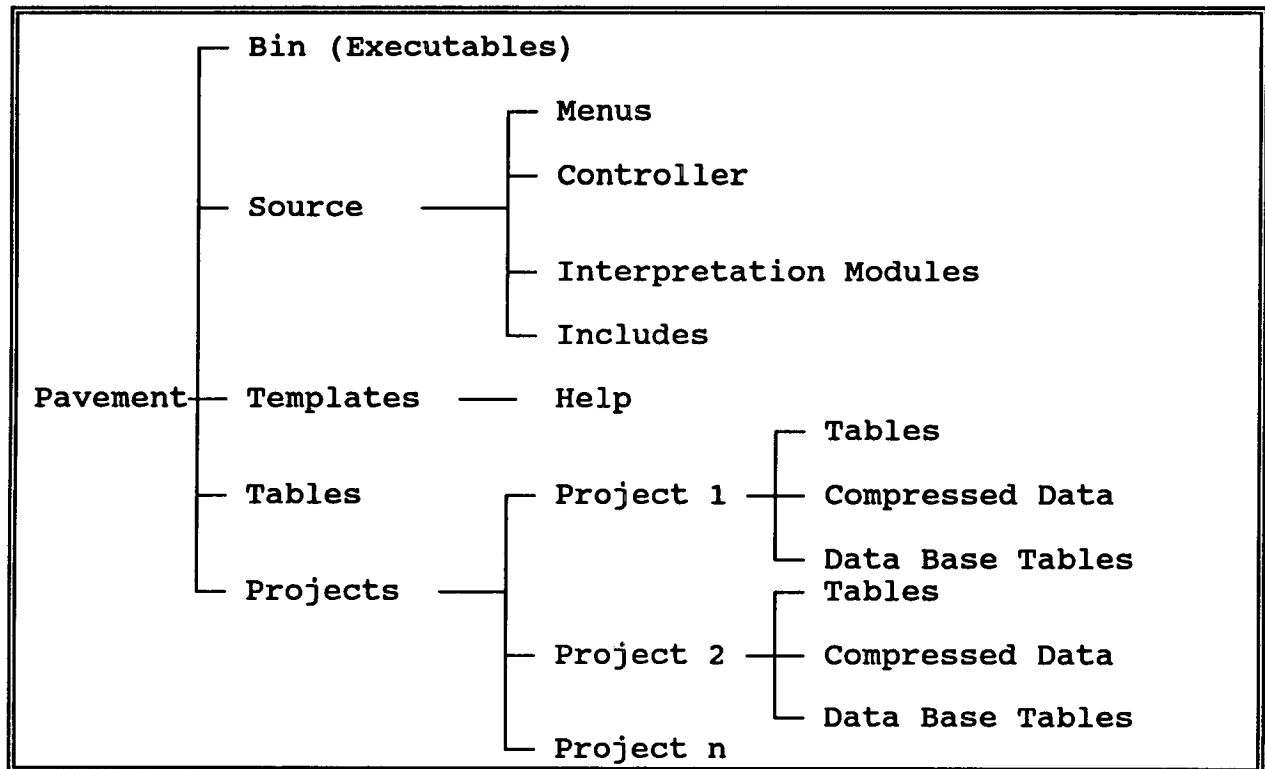
Figure 7.1 - DOS directory structure for software and data base for the SPA.

Appendix A

System Design

Transducers, Sources, and Mounting

The major mechanical components of the Seismic Pavement Analyzer (SPA) are schematically depicted in figure A.1. These include the transducer mounting member (B), individual transducer holders (D), two pneumatic hammers (G, H) that are raised and lowered to the pavement surface, pneumatic cylinders to individually raise and lower the transducers (C), and a pressurized air supply contained in the large box (E) at the tail of the trailer. A schematic of the air control system housed in this box is shown in figure A.2. The air control system includes a compressor, air tank, regulators, and solenoid valves. These are mounted on a light trailer for towing behind a car or truck.

The major electrical components of the Seismic Pavement Analyzer are schematically shown in figure A.3. These include power supplies, a computer for data acquisition and analysis, signal conditioning electronics, and control electronics. Subsections of this chapter describe the individual elements of each of these three systems in greater detail.

Transducer Mounting

The transducer-mounting member of the Seismic Pavement Analyzer is a 2-in. by 6-in. U-channel that is about 6-ft. long (figure A.1, item B). Individual geophone and accelerometer air cylinders (figure A.1, item C) are bolted to this U-channel, transducers
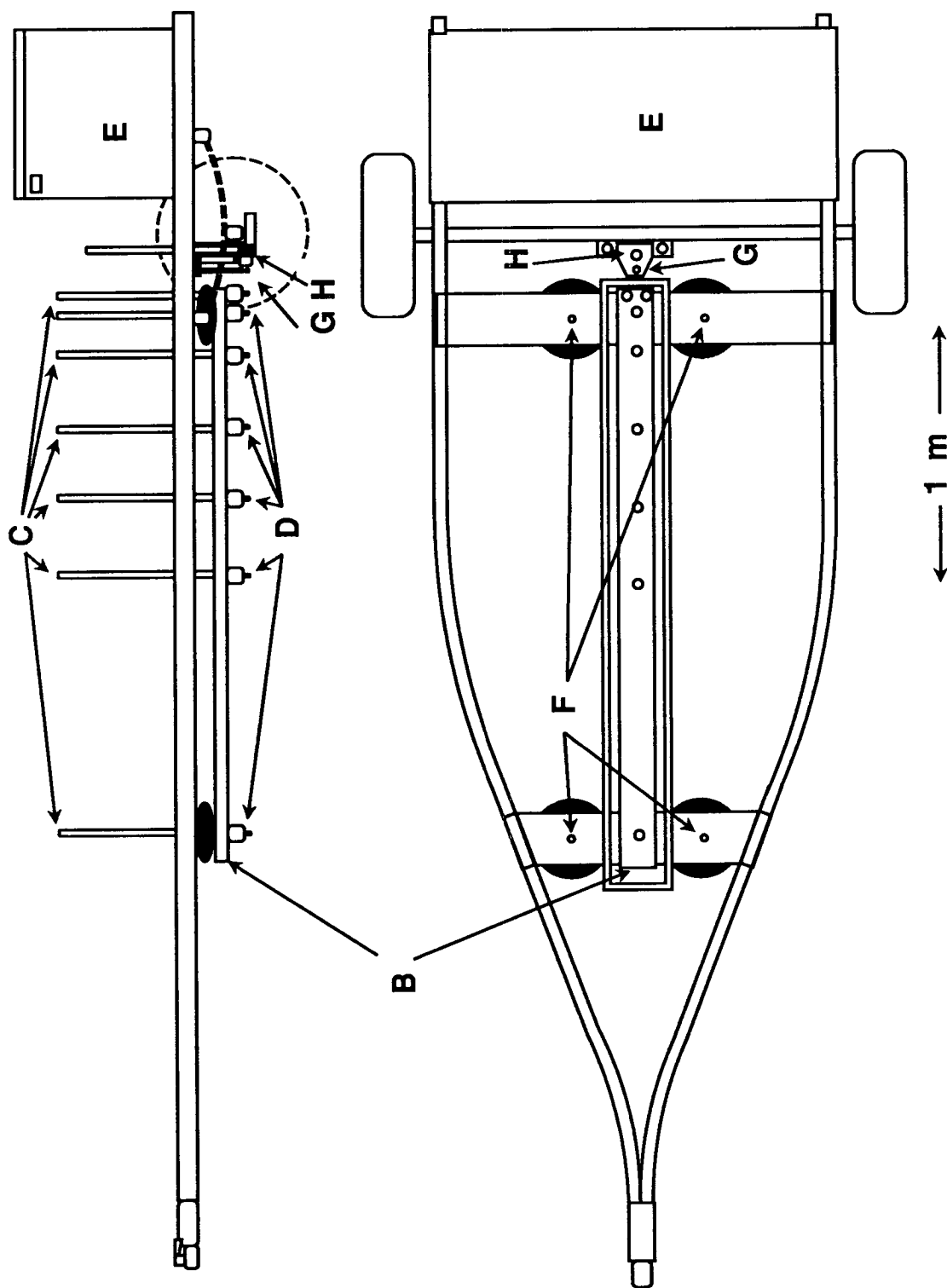
Figure A.1 - Major mechanical components of the Seismic Pavement Analyzer.

← 1 m →
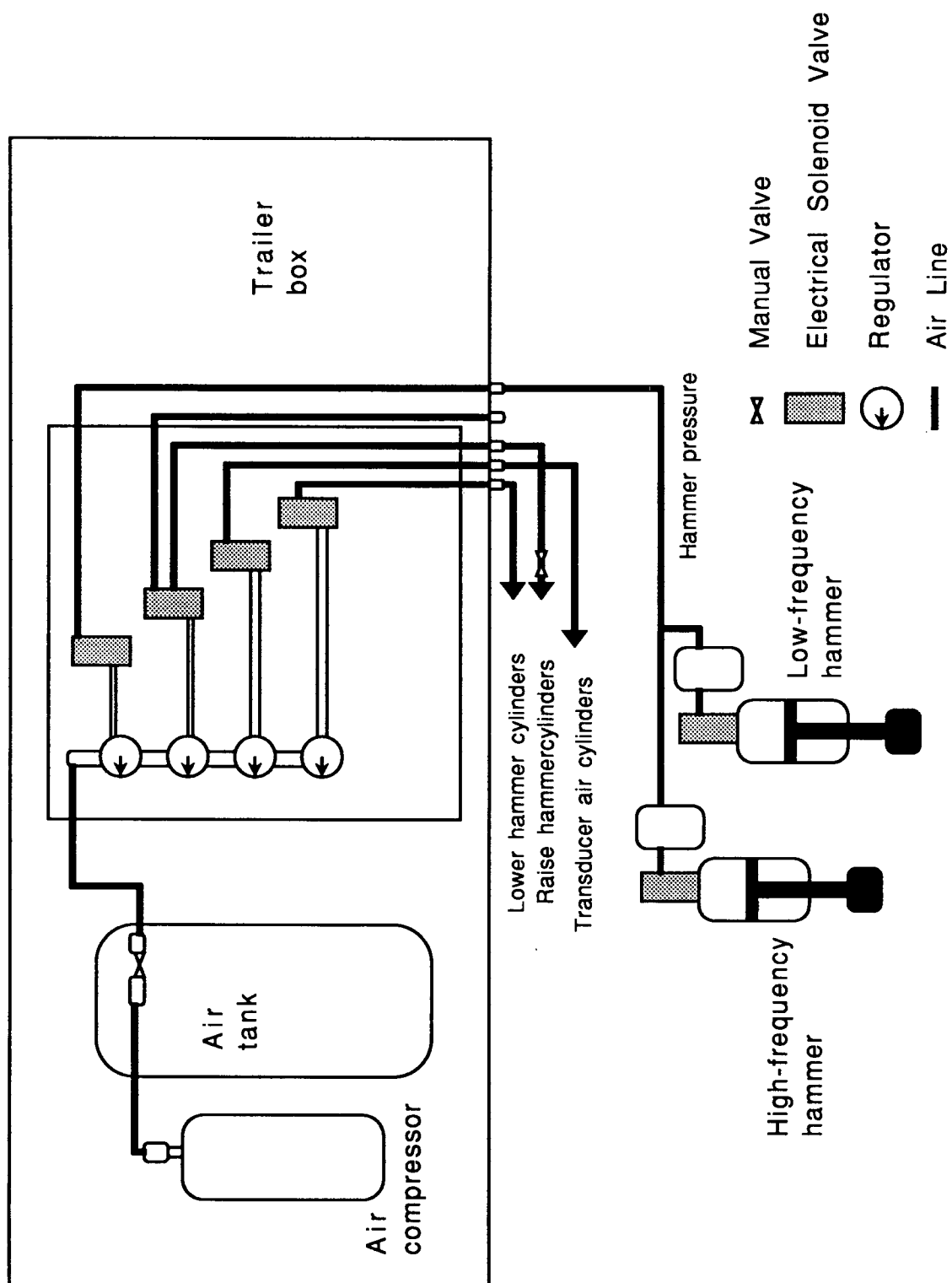
Figure A.2 - Schematic of air control system.

Trailer box

Air tank

Air compressor

Lower hammer cylinders
Raise hammer cylinders
Transducer air cylinders

Hammer pressure

High-frequency hammer

Low-frequency hammer

Manual Valve

Electrical Solenoid Valve

Regulator

Air Line

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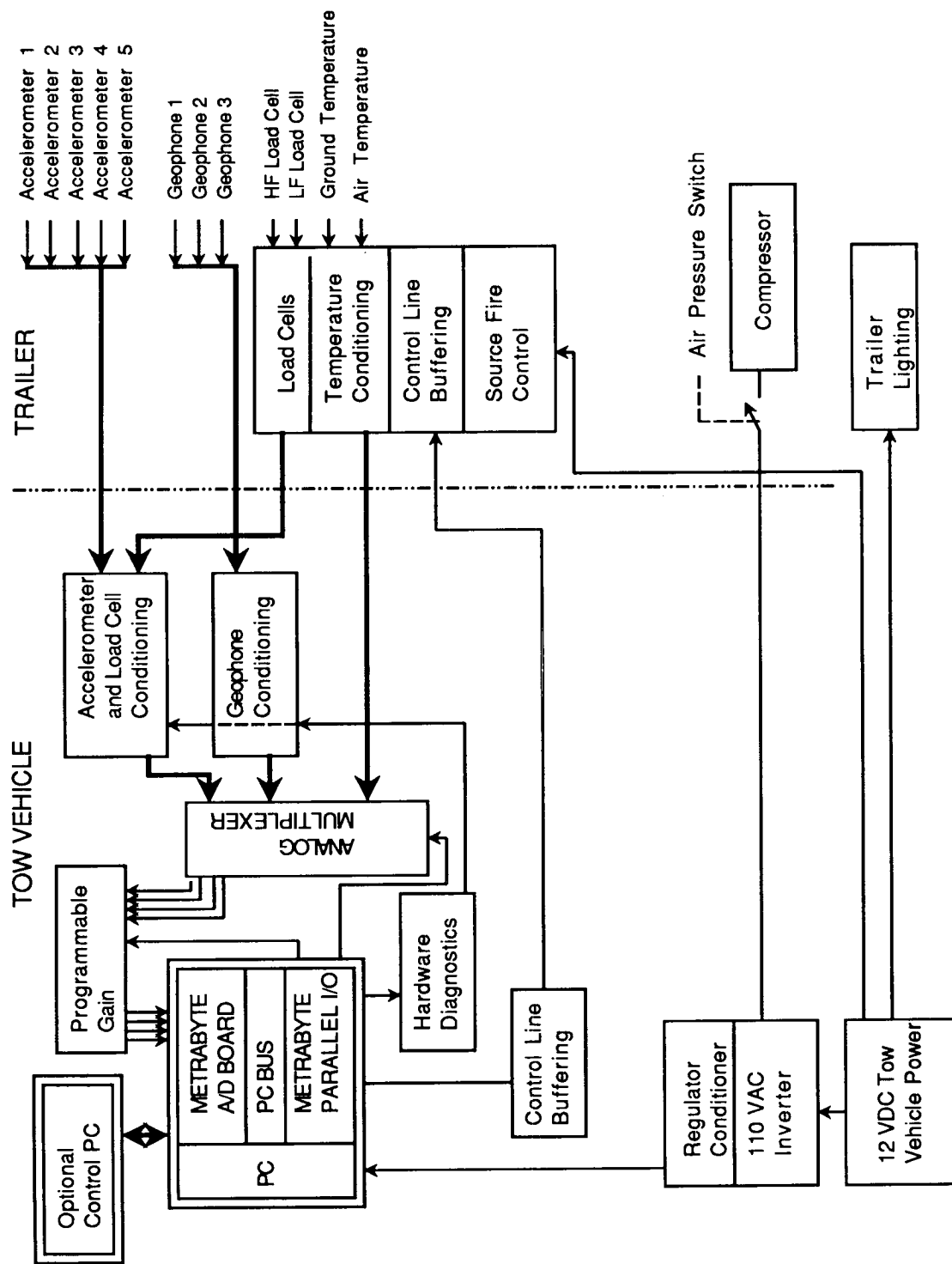
Figure A.3 - Schematic of major electronic components.

(figure A.1, item D) are mounted to the air cylinders, and electrical cables are routed underneath the U-channel.

The transducer-mounting member is mounted to the trailer through four manually controlled air springs (figure A.1, item F) that provide vibration isolation with some height and level adjustment to accommodate different tow-vehicle heights. The weight of each transducer is counterbalanced by a spring in its air cylinder. The air cylinders have a useful throw of 16 in. and, fully retracted, the transducers have a clearance of about 5 in. for high-speed travel. This clearance, in retrospect, has proven the durability of the raise/lower mechanism through numerous bendings and straightenings. The next version of the trailer will incorporate skid protection for the transducers with additional clearance.

Positive air pressure is required to lower transducers so that in the event of electrical or pneumatic failure, the transducers rise so that the trailer may be safely towed for repair. The individually mounted air cylinders accommodate a wide range of pavement or pothole topography with a uniform force coupling the transducer to the pavement.

Geophone and Accelerometer Mounting

Geophones and accelerometers are mounted in 2-in.-diameter polyvinyl chloride (PVC) tubes (figure. A.4) that provide a nonresonant protection and centering support. The geophones and accelerometers are isolated from the air cylinders with rubber vibration isolators. Thin rubber feet are used on the transducers to provide a relatively uniform, damped coupling with various pavement surfaces.

The geophone and accelerometer holders are screwed onto the control air cylinder and tightened with lock nuts. Vibration isolation tests indicate that greater than 70-decibel signal reduction is achieved between the transducers and the frame.

Source Mounting

The high- and low-frequency pneumatic hammers (figure A.1, items G and H, respectively) are mounted to a movable frame that is attached through air cylinders to the trailer axle. Air pressure lowers the source frame to the pavement surface to ensure uniform source height from sample to sample. The sources are raised by springs and air pressure to ensure adequate clearance during travel. The sources are isolated from the transducer-mounting member by
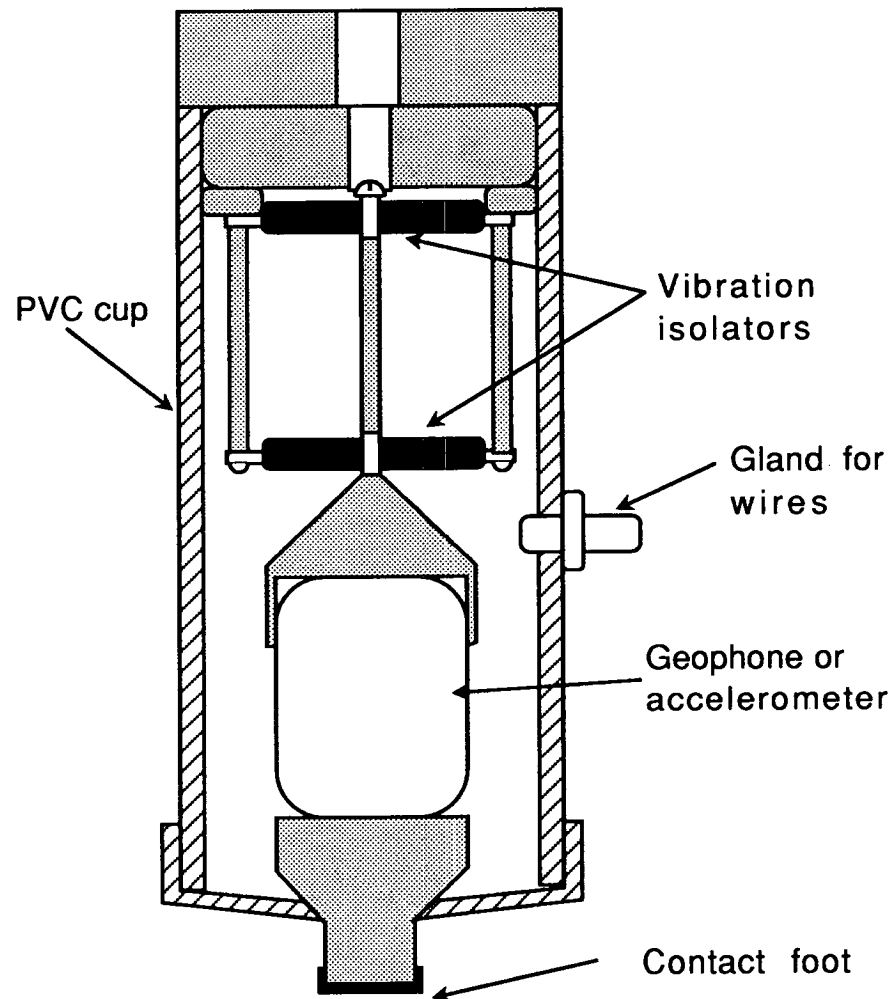
Figure A.4 - Schematic of geophone and accelerometer mounting.

both the lowering air cylinders and the transducer-mounting-member air springs. The mounting permits adjustment of the stroke of the hammer that may be required to control hammer force in extreme variations of pavement conditions. Load cells are included in the high- and low-frequency hammer heads to measure the applied force of the hammer hits. The load cells measure force in both extension and compression.

Pneumatic Control

Air pressure is used in the Seismic Pavement Analyzer to raise and lower the transducers and sources and to impact the low- and high-frequency hammers. A 120-volt compressor is used to charge an air tank that provides air power during operation. The air compressor is controlled by a pressure switch that turns on at 40 psi and turns off at 60 psi. Individual circuit pressures are usually run at about 40 psi for the source firing, 20 psi for raising and lowering the hammer assembly, and 15 psi for holding down the transducer.

The general schematic design of the pneumatic control system is shown in figure A.2. The following three subsections describe the design considerations for the raising/lowering mechanism, the physical pneumatic hammers, and the feedback control of hammer characteristics.

Raising/Lowering Mechanism

The lowering of the transducers and sources is accomplished through air cylinders. A cylinder-mounted spring counterbalances the transducer weight and part of the source weight so that active pressure is required only to lower the mechanisms. The transducer and source-lowering cylinders are tied to electrically controlled solenoid valves that are software controlled by the computer. These valves connect the cylinders either to outside air or to pressurized air when not activated.

Pressure to the lowering mechanisms is provided by mechanical regulators and requires adjustment only after major modifications or repairs.

Sources

Each pneumatic hammer consists of an accumulator chamber, a computer-controlled firing solenoid, and a spring-return air cylinder (figure A.2). Air from the supply tank fills the accumulators through a common regulator. Upon receiving a signal from the computer, the solenoid turns on for several tenths of a millisecond and allows the air from the accumulator into the hammer cylinder. When the solenoid turns off, the cylinder is connected to outside air pressure, the spring retracts the hammer, and the accumulator refills.

The solenoid valve is mounted directly on the cylinder. The accumulator is mounted as close to the valve as physically possible to minimize time delays and pressure losses associated with propagation of air-pressure transients.

The accumulator provides a high volume (several cylinder volumes) of pressurized air that may be moved quickly into the cylinder to provide rapid hammer acceleration. This action isolates the hammer movement from regulator flow restrictions caused by distance from the air supply.

The cycle time for the hammer stroke and preparation for the next stroke is controlled by pneumatic line size, accumulator volume, and regulator flow rate. Using conventional 1/4-inch connections and pneumatic lines, cycle times are less than one second and are longer than the data acquisition/processing phase.

Source Feedback Control

Two factors are important in controlling the hammer hit: the force of the impact and the duration of the impact. The ideal situation is to have the shortest impact time at a controlled force level. Impact times and force levels are influenced by external conditions such as pavement or asphalt stiffness, surface condition, and temperature.

Two controls are available over the hammer behavior. The first is the duration of the solenoid opening that determines both applied force and pulse duration. The second is the initial height of the hammer above the pavement, which is manually adjusted.

A computer feedback loop is used to control the hammer hit characteristics. The digitized load-cell signal is compared with an expected load-cell signal. When the digitized load-cell signal quality falls outside the desirable limits, the computer will adjust the solenoid opening

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duration and repeat the hit to either increase force, decrease force, or eliminate hammer bounce. If these adjustments are not adequate, then the operator is advised by the computer of the degraded signal quality and repairs suggested.

Electronic Components

This section on the electronics of the Seismic Pavement Analyzer gives a general description of the circuits that are not purchased as systems from other vendors and must be custom built. The circuits are built on printed circuit cards mounted inside the personal computer (PC).

A general schematic of the total electronic system, including interface with the computer, is shown in figure A.3. Transducer signals collected on the trailer are indicated in the upper right. The first level of boxes to the left of the transducer signals are electronics located on the trailer and include load-cell routing, temperature conditioning, source control buffers, and compressor switching. Analog signals are run through conditioning stages, located in the tow-vehicle computer, and then go into the analog multiplexer, which routes a computer-selected subset of 4 of the 12 signals through to the programmable gain stage and into the analog-to-digital (A/D) board. The distance measurement is input to the computer through a serial port from a commercially available distance-measuring device. The hardware diagnostics circuit injects a known signal into the signal-conditioning circuits so that overall circuit functions may be tested and compared with ideal responses. The complete electronic package is run from a conditioned inverter connected to the 12-volt system of the tow vehicle.

Subsequent sections of this chapter will deal with the signal-conditioning functions (including temperature, accelerometer, load-cell, and geophone conditioning), multiplexer and gain control circuits, distance measuring, and internal diagnostic circuits.

Signal Conditioning

Signal conditioning circuits include geophone conditioning, accelerometer and load-cell conditioning, and temperature corrections. These circuits are differentiated based on the level of signal the transducer produces, the output impedance of the transducer, and the type of circuit required for conditioning.

A channel of the geophone signal conditioning uses two operational amplifiers (U4B, U5A, upper half, figure A.5). This amplifier gain may be adjusted by changing a resister to account for different geophones that may be used in the system. The circuit converts the moderate geophone impedance to a low-impedance output signal that will not influence the analog multiplexer, includes output offset adjustment to maximize digitized dynamic range, and includes a low-pass filter to minimize high-frequency interference and aliasing.

A sample of the accelerometer and load-cell signal-conditioning circuits (lower half, figure A.5) uses two operational amplifiers (U3, U4A) for conditioning, a transistor array (U1) for a constant current source, and a comparator chip (U2) to monitor the accelerometer connections. The amplifier gain is also adjustable to account for different accelerometer sensitivities that might be used in the system. It also converts the high accelerometer and load-cell impedances to a low-impedance signal that will not influence the analog multiplexer. The circuit includes output offset adjustment similar to the geophone circuit and a low-pass filter to reduce high-frequency interference and aliasing in digitization. The accelerometer-monitoring circuit warns the operator when the accelerometer supply voltage falls above or below reasonable limits by turning on an LED (D1), corresponding to an open circuit or short circuit on the cable, respectively.

The temperature measurement circuit consists of two thermocouples and cold-junction compensation. This circuit serves as a reference potential and a very high-input impedance amplifier so that the analog multiplexer does not load the measurement. This signal conditioning is performed by an Analog Devices AD564 chip, with no external components required.

Multiplexer and Gain Control

As the A/D converter used in the Seismic Pavement Analyzer handles only four channels, it is necessary to route subsets of the 12 input signals under computer control. The analog multiplexer takes a two-bit control signal (permitting selection of up to four banks) and routes one bank of 4 input signals to the A/D. The multiplexer is basically an electronically controlled set of switches that are controlled by the parallel input-output (I/O) board in the computer.

Since the high-frequency load cell and one accelerometer are used in multiple measurements, these signals are wired to be chosen in two banks. The temperature measurements occupy their own bank. The low-frequency measurements occupy one bank.
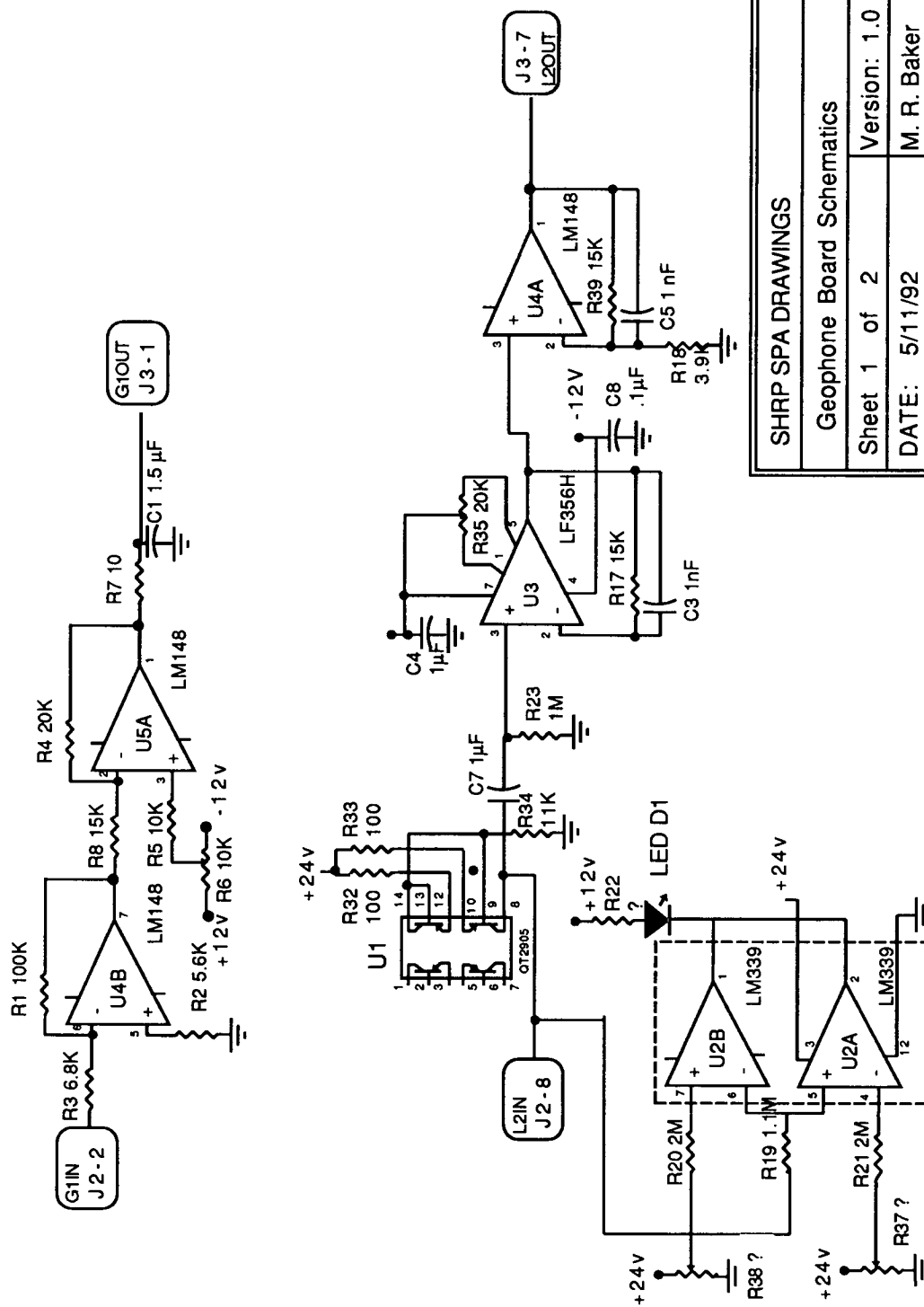
Figure A.5 - Schematic of sensor amplifiers.

Signal strengths from the transducers may vary widely with pavement conditions so computer-controlled programmable gain is included between the multiplexer and the A/D board. In order to take advantage of the full precision of the A/D board, the gain is recursively adjusted using trial hammer hits and previous signal strengths to give an optimum signal-to-noise ratio.

Distance

Distance measurement is accomplished by counting revolutions of a transmission-mounted encoder. The data acquisition computer queries the distance-measuring device over an RS-232 serial port.

Several vendors provide this type of equipment, and calibration of the distance should be performed to their specifications. This gives the driver a single, calibrated, readable control for repositioning.

Internal Diagnostics

To assist in interchannel calibration and troubleshooting malfunctions, the capability to inject a known signal into the input of the signal-conditioning circuitry is included. This function tests the signal conditioning, analog multiplexer, programmable gain, and A/D boards for proper functioning. Implicitly, this also tests for failure of a transducer.

The data acquisition software has the option to switch signal-conditioning inputs to a computer-controlled pulse generator if there is a need to test circuit operation. The resulting digitized waveform may be compared with ideal responses for each channel to help diagnose failures by eliminating all other possible sources of failure.

Computer Specifications

The data acquisition software of the Seismic Pavement Analyzer (SPA) requires either and i386 or i486 class of IBM-PC AT, or equivalent, computer with a floating-point processor and 4 megabytes of RAM, five expansion slots and two serial ports. If the data acquisition software is run on the same machine as data acquisition, a Hercules, color graphics adaptor

(CGA), enhanced graphics adaptor (EGA) or video graphics adaptor (VGA) graphics monitor and keyboard are required.

The user interface software of the Seismic Pavement Analyzer (SPA) runs on an IBM-PC XT- or AT-equivalent computer with Hercules, CGA, or EGA/VGA graphics, 640 Kb ram, two 720 Kb floppy disk drives, with three serial ports. An AT with a hard disk and a floating-point chip would be highly desirable, but not necessary, to increase speed of operation in analysis-intensive operations.

Appendix B

Troubleshooting

Software Error Messages

Software error messages returned to the screen or to the data base are coded together with a four-digit number indicating the source of the error message, followed by a one- to three-digit code indicating the type of error or warning. The warning or error message is accompanied by a number that indicates the importance of the condition: numbers less than 200 are severe failures requiring immediate attention; numbers from 200-399 indicate that parts of the machine are functioning while others are not; numbers from 400-599 are warnings indicating that a condition exists that might compromise data quality; and numbers greater than 600 are conditions that do not compromise data quality but should be corrected when the machine returns home.

The following table contains a list of these error messages. Their source in the software is indicated by the location code.

1001 ()   Parallel I/O board initialization failed; () returned from the
           I/O board; if () nonzero, replace board or check that
           hardware board address set to 0x03b0 [driver.c]

1002 ()	Analog/Digital board initialization failed; () returned from the A/D board; if () nonzero, replace board, or check that hardware board address set to 0x???, [Ctrl F2] should interrogate software driver [driver.c]
1003 ()	External communications initialization failed; () returned [driver.c]
1005 201	A test option from tables/dc.cmd is not coherent [testopt.c]
1005 604	The distance-measuring device is not responding to a query [nxtcmnd.c]
1006 4	Unrecognized type of source-receiver spacing in tables\dc.cmd [dtable.c]
1007 5	A digitization parameter is not valid in tables\dc.cmd [digopt.c]
1008 10	Table initialization; undeclared transducer spacing [updtbl.c]
1008 11	Table initialization; unreasonable transducer spacing [updtbl.c]
1008 ()	Table initialization; initialization of frequency domain arrays failed [set_spectra_indices.c]
1008 602	Table initialization; pavement structure is not initialized [updtbl.c]
1009 12	Error in setting multiplexer channel; hardware error, replace mux or I/O board [collect_data.c]
1009 14	Error in setting preamp value; hardware error, replace mux or I/O board [collect_data.c]
1009 15	Error in defining preamp value in setup table [collect_data.c]
1009 19	Error in defining multiplexer channel in setup table [collect_data.c]
1009 22	Cannot initialize source firing as transducers are not lowered [collect_data.c]
1009 31	Out of stack memory [colldat.c]
1010 ()	Undefined error [analdata.c]
1010 31	Out of memory for arrays [analdat.c]

1011 0	Table initialization; initialization of time domain arrays failed [updtbl.c]	

1012 7   No such transducer name exists [banksel.c]

1013 5   A desired measurement option does not exist [testopt.c]

1014 5   A command from tables\dc.cmd is not coherent [measopt.c]

1016 405   No time domain signal on accelerometer 1, check or replace transducer, cable, amplifier [pickarr.c]
1016 406   No time domain signal on accelerometer 2, check or replace transducer, cable, amplifier [pickarr.c]
1016 407   No time domain signal on accelerometer 3, check or replace transducer, cable, amplifier [pickarr.c]
1016 408   No time domain signal on accelerometer 4, check or replace transducer, cable, amplifier [pickarr.c]
1016 409   No time domain signal on accelerometer 5, check or replace transducer, cable, amplifier [pickarr.c]
1016 410   High signal offset on accelerometer 1, rezero [pickarr.c]
1016 411   High signal offset on accelerometer 2, rezero [pickarr.c]
1016 412   High signal offset on accelerometer 3, rezero [pickarr.c]
1016 413   High signal offset on accelerometer 4, rezero [pickarr.c]
1016 414   High signal offset on accelerometer 5, rezero [pickarr.c]

1018 23   Invalid name for data array stored in high memory [stksig.c]
1018 24   Unable to read data from a high memory array, check installation of high extended memory drivers [stksig.c]
1018 25   Unable to write data to a high memory array, check installation of high extended memory drivers [stksig.c]

1019   No specific error [analdat.c]

1020 401   A parameter estimate does not exist when it should have been defined from an external table [res_est.c]

1021 402   Damping higher than the maximum default limit [impulse.c]
1021 403   Damping lower than the minimum default limit [impulse.c]

1022 402	Shear modulus of the subgrade is higher than the maximum default limit [impulse.c]	
1022 403	Shear modulus of the subgrade is lower than the minimum default limit [impulse.c]	
1023 404	Inadequate number of data points for phase interpretation [analdat.c]	
1024 402	Air temperature above maximum limit [analdat.c]	
1024 403	Air temperature below minimum limit [analdat.c]	
1025 402	Ground temperature above maximum limit [analdat.c]	
1025 403	Ground temperature below minimum limit [analdat.c]	
1026 402	Pavement shear modulus is above maximum limit [ultrsonc.c]	
1026 403	Pavement shear modulus is below minimum limit [ultrsonc.c]	
1027	No specific error [analdat.c] LF	
1027 31	Out of stack memory HF data [stksasw.c]	
1028	No specific error [analdat.c] HF	
1028 31	Out of stack memory LF data [stksasw.c]	
1029 413	No SASW phase data available [analdat.c]	
1030 402	Echo size or pavement thickness above maximum limits [findpeak.c]	
1030 403	Echo size or pavement thickness below minimum limits [findpeak.c]	
1030 602	No paving layer type is defined for thickness calculation [findpeak.c]	
1031 27	High-frequency source malfunction [revfire.c]	
1031 28	Low-frequency source malfunction [revfire.c]	
1032 30	Late or nonexistent trigger on data; reset A/D [digsig.c]	
1033 31	Out of stack memory; cannot continue [intsasw.c]	

1034   No specific error [setxpct.c]

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