MICROCOMPUTER BASED DATA ACQUISITION
FOR A TRACTOR-MOUNTED PENETROMETER

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CHAPTER I

INTRODUCTION

High soil strength and high bulk density have been shown to be the most significant soil physical properties that reduce crop yields. Thus a fast accurate method of determining whether a problem exists in a particular soil type is needed for tillage research and research involving yield trials. A cone penetrometer measures soil strength and its use has been shown to exhibit relatively fast and reproducible tests in the field. Cone index is an index of soil strength which is defined as the force, per unit base area of a 30° circular cone, required to force the cone through a small increment of soil and is expressed in kilopascals (kPa).

A study conducted by Carter et al., (1968) showed that cotton yield was significantly reduced by increasing soil strength and bulk density. Yield decreased linearly with increases in bulk density. A 50 percent reduction in yield was found from an increase in bulk density from 1.48 to 1.58 grams per cubic centimeter, corresponding to a change in soil strength at field capacity moisture content from 923 kPa to 2240 kPa. The state of the soil can be measured most quickly by using a cone penetrometer. However, soil strength is affected by a number of parameters including soil moisture and bulk density. Thus one single penetration may not be completely descriptive of soil strength and state.

Taylor and Gardner (1963) found cotton root growth was severely limited when the porosity or air content dropped to 10 percent and cone penetration resistance increased to 2140 kPa. A root tip can develop pressures exceeding 1000 kPa by the root growth mechanism, but nutrient supply, oxygen content, and water limit growth in highly compacted soils.

There are many limitations to be recognized with the use of a cone penetrometer to indicate soil bulk density. Soil bodies can develop ahead of the cone which changes the geometry and therefore resistance to penetration. The shaft of the penetrometer can interact with the soil for very high and low moisture contents, thus increasing the resistance to penetration. Until more is known, penetrometers are useful for comparative measurements on the same soil at the same moisture content with the same rate of penetration. The best time for measurement is at field capacity moisture content.

In the past many recording penetrometers used X-Y plotters. Plotter use was slow and calibration was a problem. Processing data from X-Y plots was a very time-consuming task. To greatly reduce this processing time, a microcomputer was used to record penetrometer lateral position, depth, and cone index on a 20 character printer and on magnetic tape. The soil strength profile was then plotted using the Statistical Analysis System (SAS)[1] procedure GCONTOUR.

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[1]SAS Institute Inc. Box 8000, Cary, North Carolina.

CHAPTER II

OBJECTIVES

1. Develop a system of measuring, recording, and plotting soil strength, as measured by a cone penetrometer, in the form of a contour map of soil strength.

2. Verify the system on a specific soil to examine a soil strength profile, and statistically plot the strength versus depth.

CHAPTER III

LITERATURE REVIEW

The cone penetrometer appears to be the most widely used instrument for determining soil strength in situ, despite the theoretical shortcomings of cone resistance measurements. Anderson (1980) believes cone penetrometers will continue to be widely used for many years. Increased emphasis has been recently received for the importance of soil mechanical properties in tillage research (Reece, 1977; Pidgeon, 1978).

The disadvantages of cone resistance measurements have been widely acknowledged (Mulqueen, 1977) and the empirical nature of the data obtained is one of the major drawbacks. However, useful empirical correlations have often been obtained between cone resistance and crop root growth (Taylor and Ratliff, 1969; Taylor, 1971; Gooderham, 1973; Houben, 1974; Bowen, 1976), vehicle performance and mobility (Wismer and Luth, 1973; Turnage, 1972; Wells and Treesuwan, 1977) and the compactive or loosening effects of wheels or tillage implements (Dumas et al., 1975; Soane et al., 1976; Voorhees et al., 1978; Cassel et al., 1978).

There are many different types of penetrometers ranging from simple, inexpensive hand-held devices (Soane et al., 1971; Howson, 1977) through electronic hand-held penetrometers (Prather et al., 1970) to complex vehicle-mounted systems (Brown and Anderson, 1975; Smith and Dumas, 1978). All these types have disadvantages in field use. Vehicle-mounted types are usually expensive, heavy and limited to taking measurements in bare soil or in small growing crops. When using hand-held devices, one may have problems controlling penetration rate, accuracy of measuring force and depth, recording of raw data and access to recorded data. Anderson et al., (1980) reported few hand-held penetrometers were commercially available and there was a lack of comparative studies of different penetrometers. They developed a new hand-held recording penetrometer and compared it to three existing types; a Farnell hand-held penetrometer (Soane et al., 1971), an electrically-driven constant-velocity recording penetrometer (Brown and Anderson, 1975) and a cassette recording hand-held variable velocity penetrometer described by Spencer et al., (1977). The Farnell penetrometer was probably the most widely used field penetrometer in Britain in 1980, but is described as non-recording since it requires the operator to read dials during penetration.

The Anderson et al., (1980) penetrometer was composed of a force sensing load transducer and a double window optical system for depth measurement. The force sensing transducer was essentially a flexure parallelogram with a strain-gauged center beam which had the advantages of being sturdy and insensitive to side loads while having good resolution for vertical loads, a high spring rate, and a rapid response time. The transducer was a four-arm active element temperature-compensated strain-gauge bridge and the analog signal was amplified and digitized by the combination of a voltage-to-frequency converter and a gated counter. The gate timing was 100 milli-seconds so the readings were effectively averaged over a small range of depth. After counting, the number representing cone resistance (resolution 1% of full scale) was stored in an exclusive location prior to processing.

The maximum force had to be within the limits of the operator to avoid the influence of the operator physical strength and was taken as 500 Newtons. If the limit were exceeded, an audible alarm warned the operator to stop the stroke.

Defining a datum level for depth measurements was a problem, particularly on rough soil surfaces, so a 15 cm diameter base plate rested on the soil surface. Depth was measured to an accuracy of ± 1 mm using a double window optical system. An infrared source and detector unit was mounted on the penetrometer top which passed by accurately placed holes in an angle section metal rod that was attached to the base plate. The metal rod could be inter-changed for different hole spacings for specific operator requirements. The double window arrangement allowed the instrument to distinguish between upward and downward movement, to avoid spurious readings when the cone was withdrawn before reaching full depth.

The penetrometer could be operated in a single stroke mode, without the programmable calculator, and the operator would record each force and depth by a push button after each stroke. With the programmable calculator, data from each stroke could be accumulated. The calculator could then display or print for each depth the mean cone resistance, standard deviation, and the number of strokes recorded at that depth. In stony or hard soils, the number of strokes recorded at each depth would vary and thus the cone resistance at each depth may have had non-normal probability distributions.

Small rechargeable batteries powered the CMOS solid-state electronic components and the low power liquid-crystal display was readable under all ambient lighting conditions.

A 12.83 mm diameter cone was used and calibration was achieved by placing weights, one at a time, and recording the load readings. Slight adjustment for zero was required in the field and sensitivity was sufficiently stable in the field to not require recalibration.

To compare the four penetrometers, two trials were carried out in a 25m x 2m x 0.5m soil tank using two different soil compaction profiles of homogenized loam topsoil. One hundred strokes were made with each penetrometer and each penetration of the four instruments was essentially at the same time. Eight strokes (two for each penetrometer) were made in a straight line across the soil tank starting 25 cm from the edge to eliminate edge effects. This arrangement was then replicated 50 times with intervals of 40 cm between lines of strokes. The positions of the penetrometers in the lines were randomized to minimize errors due to uneven packing and care was taken to avoid footprints on the soil. The means and standard deviations of the 100 readings of each penetrometer were calculated at depth intervals of 3 cm for the recording penetrometers and 6 cm for the non-recording penetrometer.

The results showed the standard error of the means to be small, with individual values in the range 60 to 100 kPa, and the recording penetrometers were superior in detecting abrupt changes in cone resistance. The analysis of variance showed large F ratios for between sites and between depths, as expected, but also there was significant variation between penetrometers. The recording penetrometers all produced similar soil profiles, with a few unexplained discrepancies, but the non-recording penetrometer method smoothed out the abrupt changes in cone resistance. Also measurements on direct drill, deep-plow, and shallow plowed soil indicated variations in cone resistance existed only in the plow zone, which was 25 cm deep, when using the recording penetrometers. The variations in this 25 cm zone was not picked up by the non-recording penetrometer which stressed the need for accurate penetrometers for meaningful cone resistance profiles.

When the penetrometers were used in high stone content soil, major problems of interpretation resulted. Some profiles departed quite markedly from the general trend. Stones produce a single-sided distribution error since stones always increase the readings. Stone distribution could be related to tillage treatment so there may be little gain in conducting more replications in stony soils to reduce the variations between tillage treatments. Stone friction on the side of the rod, after a stone was pushed aside, would effect further readings. This effect could be eliminated by placing the force transducer at the base of the cone.

Ayers (1980) investigated the effects of moisture and dry density on cone index for soil mixtures of Zircon sand and Fire clay in proportions 100% clay, 75% clay-25% sand, 50% clay-50% sand, 25% clay-75% sand, and 100% sand. Results showed the moisture content for maximum cone index to be lower than the moisture content for maximum dry density. For the 50% clay-50% sand mixture a maximum cone index of 3300 kPa occurred at 5% moisture (dry basis) for a compactive effort of 12 blows of a 4.3 kg drop hammer from a height of 30.5 cm. The maximum dry density occurred at 10% moisture when the cone index was only 1200 kPa.

For a given compactive effort, Ayers (1980) found an increase in the percentage of clay increases the moisture content at which the maximum cone index occurred. Also for a given soil type, an increase in compactive effort produced an increase in the maximum cone index. With increasing moisture content, a logarithmic decline in cone index was observed. For all soil types, except for 100% sand, cone index increased with increasing dry density. At low moisture contents (2.6 - 6.7%) the cone index seemed to increase exponentially with dry density giving a large increase in cone index for a small increase in dry density. At higher moisture contents, the relationship was more nearly linear and at high moisture contents (11.8%) the rate of increase of cone index with dry density decreased considerably. Thus at higher moisture contents, cone index was less dependent on dry density.

Ayers (1980) developed the following prediction equation model to represent the cone index - density - moisture content relationship.

$$CI = (C1 \times DD^{C4})/[C2 + (MC - C3)^2]$$

where:

CI = cone index, kPa

DD = dry density, gm/cc

MC = moisture content, % dry weight

C1, C2, C3, C4 = constants to be estimated depending on soil type. The values Ayers found are shown in Table I.

TABLE I

CONE INDEX MODEL CONSTANTS
FOR EACH SOIL TYPE

Soil Type	C1	C2	C3	C4	R-Square
100% clay	4540.9	31.94	9.21	6.37	0.985
75% clay-25% sand	928.1	20.22	7.41	6.60	0.983
50% clay-50% sand	82.39	9.47	4.77	7.50	0.978
25% clay-75% sand	1.10	2.19	3.29	9.34	0.982
100% sand	1.58	17.72	5.54	8.92	0.940

These equations predict cone index for an average of the top 15 cm with dry density in the range 1.88-2.35 gm/cc and moisture content in the range 2.6-11.8% (dry basis). For natural soils, new constants would have to be estimated.

Threadgill (1981) studied the effects of controlled traffic on soil strength measured by a cone penetrometer of base area 1.3 sq. cm, cone angle 30 degrees, and operated according to the ASAE Standard S313.1 (ASAE, 1980). Three tillage practices were used over a period of four years (1977-1980) - moldboard plow, in-row subsoil and plant, and slot plant.

A tractor mounted, hydraulically operated, recording soil cone penetrometer was used to collect data from the center bed of each plot. All penetrometer data were collected when soil moisture was as near as possible to field capacity. Profiles of cone index versus depth were obtained to a depth of about 51 cm below the nominal soil surface elevation at 15 cm lateral intervals across the 182 cm wide bed. A single curve was obtained by averaging four replications which was then digitized at two centimeter depth increments. Contour lines of cone index were drawn on the profile using a shading format of the Statistical Analysis System (SAS) (neglecting spurious readings caused by rocks) and then the contour lines were again digitized for plotting (Threadgill, Personal Communication, 1981).

Threadgill (1981) concluded that the residual effectiveness of an initial tillage practice such as in-row subsoiling in a controlled-traffic production system with conventional wheel spacings was evident after moldboard plowing the second year but was eliminated by moldboard plowing a third year with a resulting reestablishment of a compacted layer. The generally accepted criteria of a compacted layer is 2000 kPa cone index or greater which frequently reduces crop yields and values above 1500 kPa frequently reduce root growth (Carter and Tavernetti, 1968; Chancellor, 1977; Taylor and Gardner, 1963; and Smittle and Threadgill, 1977). In contrast, when only a slot plant was used, in-row subsoiling effects were eliminated after the second year and a very severe compacted layer had reestablished by the third year. Compacted layers under the moldboard plowed conditions could have been due to implement traffic or natural cementation, but compact layers under the slot planter appeared to be only attributable to a natural cementation process. This indicated the usefulness of the controlled traffic concept may be limited since benefits of in-row subsoiling may extend for one year under certain tillage systems but may be entirely lost by the second year under other systems. Some soils recompact in one year under very limited traffic conditions. Treadgill (1981) proposed that a tillage rotation such as in-row subsoiling in alternate years would be desirable for certain soils, even when controlled-traffic systems are used, in order to allow the reduced energy benefits of "no-till" planters to be realized.

CHAPTER IV

INSTRUMENTATION SYSTEM

A microcomputer based system was chosen for versatility in programming, low cost, high speed of data manipulation and ease of interfacing with data inputs. The system was based on a ROCKWELL AIM 65 microcomputer which uses a 6502 processor. The AIM 65 was selected for its keyboard, 20 character heat sensitive line printer, input/output tape control, and AIM 65 BASIC (BASIC: Beginner's All-Purpose Symbolic Instruction Code originally developed at Dartmouth College, Hanover, NH) language option. With this microcomputer, collected data could be manipulated, saved on magnetic tape, and routed to the line printer for immediate observation. The tape recorder was a General Electric audio cassette player Model No. 3-5145B. The overall instrumentation system is illustrated in Figure 1 which shows the three input variables - penetrometer force, depth and lateral position; and in addition, it shows signal conditioning circuitry and data acquisition system. The signal condition circuitry is shown in Figure 2 with the power supplies shown in Figure 3.

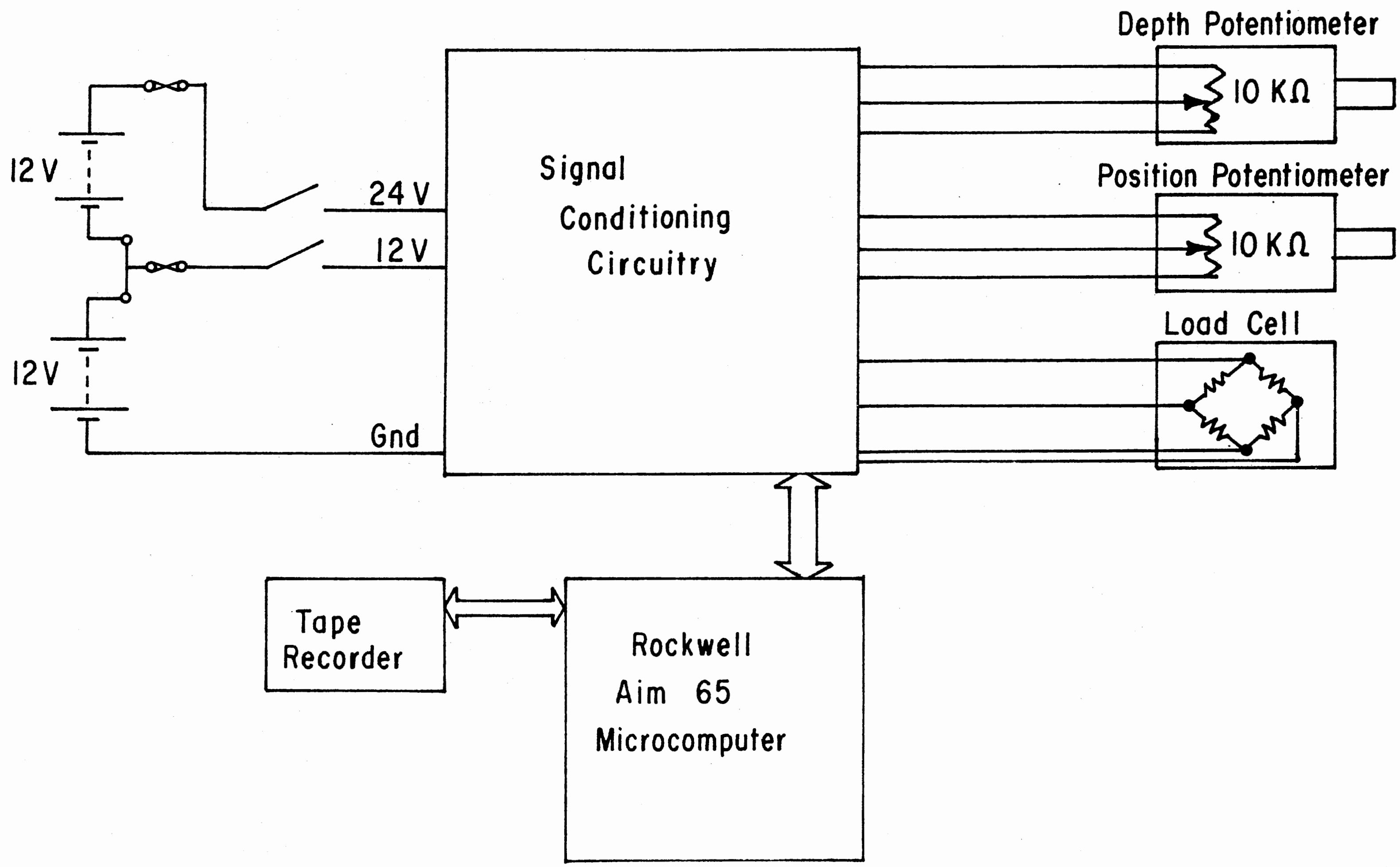


Figure 1. Overall Instrumentation System

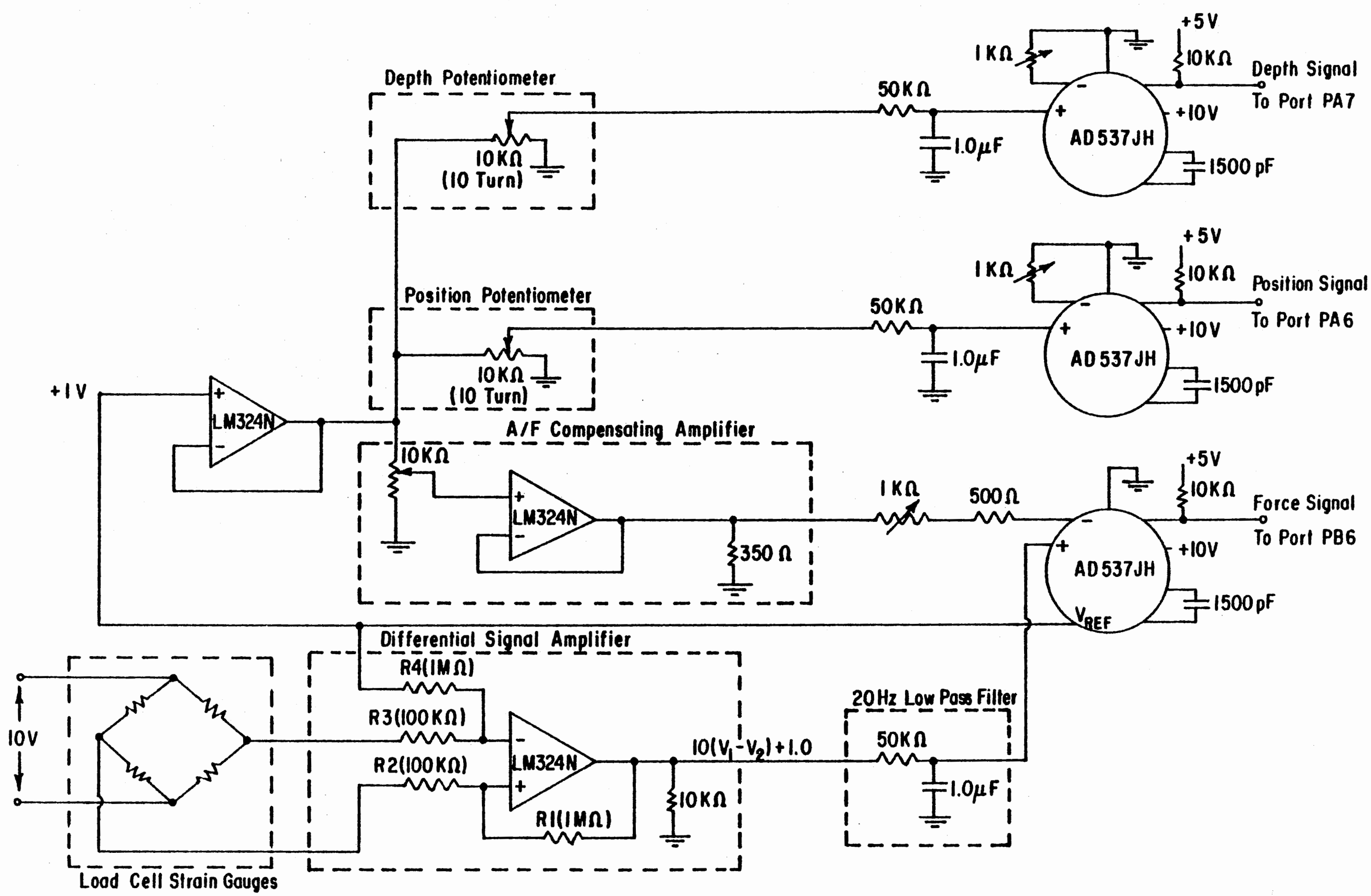
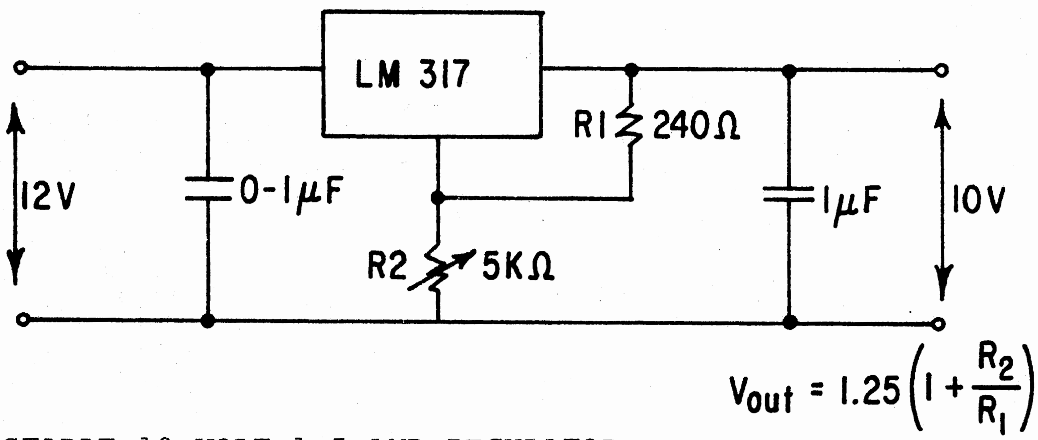
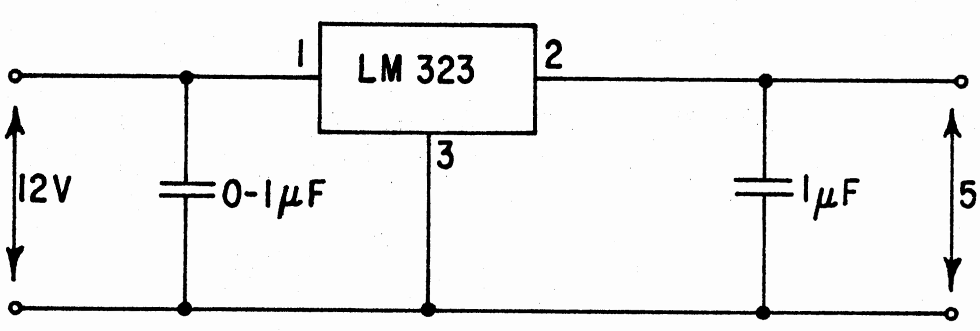


Figure 2. Signal Conditioning Circuitry



ADJUSTABLE 10 VOLT 1.5 AMP REGULATOR



5 VOLT 3 AMP REGULATOR

Figure 3. Power Supplies

Penetrometer Lateral Position Transducer

The penetrometer was forced into the soil using a hydraulic cylinder powered by the tractor hydraulic remote lines and controlled by a flow control valve, pressure reducing valve, and a three position, center detent, direction control valve. The hydraulic cylinder and direction control valve were mounted on a carriage that could be moved along the main frame and locked in position by two friction holding devices. A 10-turn 10K ohm rotary potentiometer was attached to the carriage so that the pulley on the potentiometer shaft was horizontal and close to the main stationary frame. A cord, held in tension by a spring, was attached to the main frame at one end passed around the pulley once and onto the other end of the main frame (Figure 4). In this way, as the carriage was moved across the profile, the potentiometer turned giving an output voltage proportional to the lateral distance along the main frame. The potentiometer input voltage was regulated to 1.0V by a feedback amplifier with a 1.0V reference voltage input (Figure 2).

The potentiometer output voltage was then converted to a 0 to 5 volt square wave signal of frequency controlled by an AD 537 JH voltage-to-frequency converter which had a temperature stable 1500 picofarad polystyrene timing capacitor. The output frequency was then proportional to

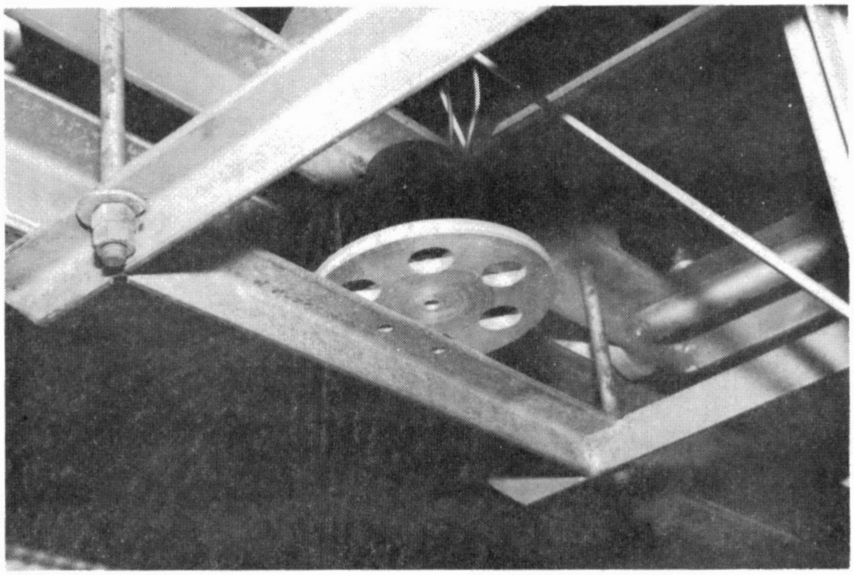


Figure 4. Penetrometer Lateral Position Transducer

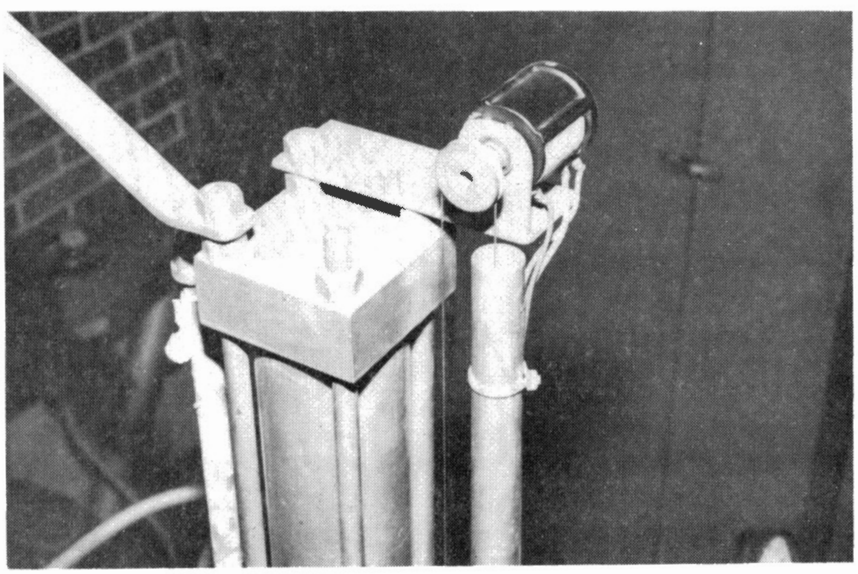


Figure 5. Penetrometer Depth Transducer

the input voltage. This square wave signal was connected to the microcomputer input port PA6 which counted the pulses in a fixed time to give a number proportional to carriage lateral position.

Penetrometer Depth Transducer

A 61 cm stroke hydraulic cylinder forced the penetrometer into the soil. On the end of cylinder rod was a pointer to which a cord was attached. The cord travelled up beside the cylinder body and 1.5 times around a pulley on a 10-turn 10K ohm potentiometer at the top and down to a counter balance weight inside a guide pipe (Figure 5). The voltage applied to the potentiometer was regulated to one volt. The output voltage was proportional to the movement of the cylinder rod. This voltage was similarly converted to a 0 to 5 volt square wave signal by another AD 537 JH voltage-to-frequency converter and connected to the microcomputer input port PA7 (Figure 2). All wires carrying frequency signals were made as short as possible and a 20 Hz low pass filter was placed close on the input to the frequency converter to reduce signal noise from the atmosphere. Shielding was used on signal lines to the tape recorder.

The soil surface depth from the top was recorded by stopping at the soil surface to press the "soil surface light" button on the signal conditioning box (Figures 6 and 7). The soil surface was considered the point when

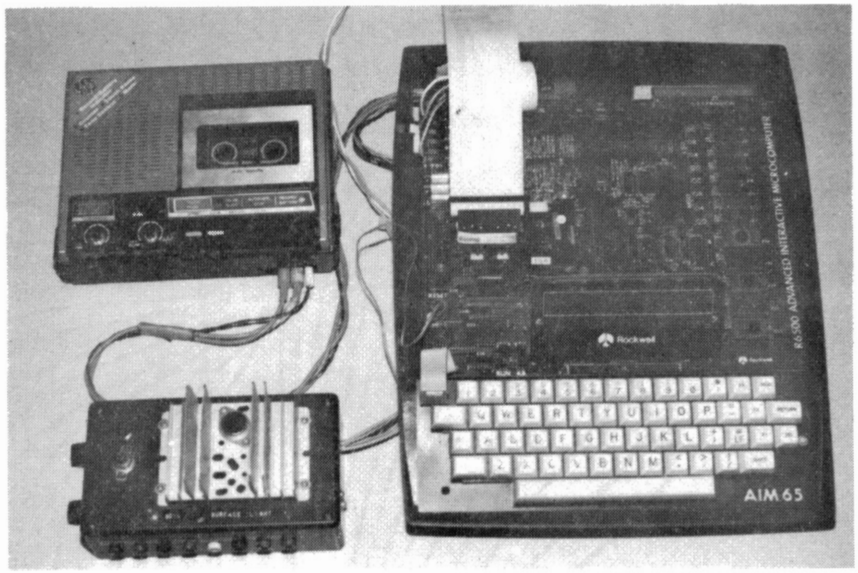


Figure 6. Uncovered AIM 65 Microcomputer with Tape Recorder and Signal Conditioning Box

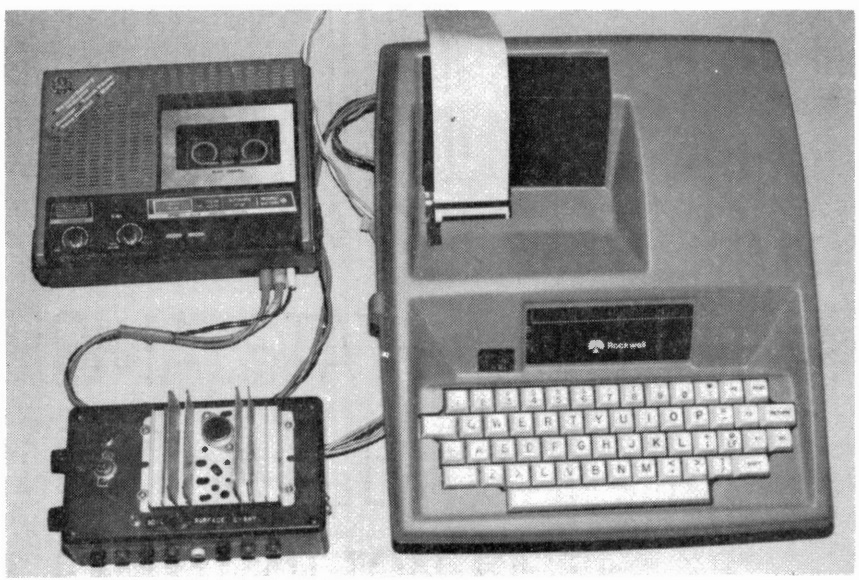


Figure 7. AIM 65 Microcomputer with Tape Recorder and Signal Conditioning Box

the cone base was flush with the soil surface. This button placed a pulse on the microcomputer port PA4 (Figure 8) which recorded the depth. A resistor was placed in parallel with the light bulb to keep PA4 grounded while not in use in case the bulb in the socket did not contact properly.

Penetrometer Force Transducer

The force on the penetrometer (Figure 9) was measured using a four arm temperature compensated strain gauge bridge load cell (BLH ELECTRONICS, INC. TYPE U3G1) (Figure 10 and Appendix D). The maximum load was 2224 Newtons with a 50% peak safe overload of 3337 Newtons. The hydraulic cylinder oil pressure was regulated to 716 kPa (read on a calibrated pressure gauge) so as to not allow the force to be greater than 2224 Newtons on the penetrometer. If this force were not enough, as with hard, dry, soil a smaller penetrometer could be used.

The voltage to the load cell was regulated to 10V by an LM317 voltage regulator. Amplifying the load cell output differential voltage posed a slight problem since an instrumentation amplifier requires a negative as well as a positive power supply. Also without a negative power supply an operational amplifier will not be accurate at less than 0.3 V output. A gain of 10 was chosen to keep the

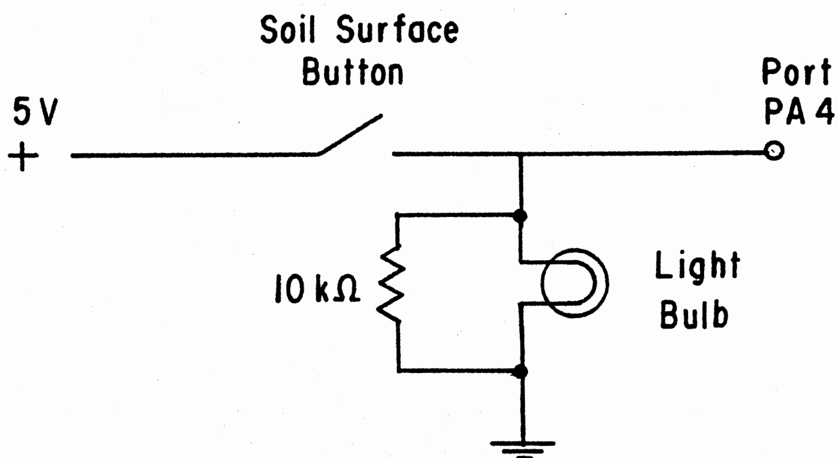


Figure 8. Soil Surface Circuitry

Figure 9. Cone Penetrometer

Figure 10. Penetrometer Load Cell

input impedance high so as not to affect the strain gauge bridge. The output voltage then ranged from 0.0-0.5V which is in the non-linear range of the operational amplifier. To overcome this, a differential amplifier was used and a one volt input added at a gain of one so the output range was 1.0-1.5 volts (Figure 2). This gave a linear output response since the parallel resistance of R1 and R2 was the same as the parallel resistance of R3 and R4.

To compensate for this additional one volt input, the negative input to the voltage-to-frequency converter was raised to one volt by a direct feedback operational amplifier thus giving a differential voltage range of 0-0.5V at the frequency converter. The compensating operational amplifier was loaded heavily to allow enough current to pass for the V to F converter as the output frequency depends on the current flowing between the positive and negative inputs which has a maximum of 1mA.

A 20 Hz low pass filter was added close to the V to F converter to reduce noise in the positive input line.

The Microcomputer

The Rockwell R6500 Advanced Interactive Microcomputer AIM 65 is a complete general purpose microcomputer having advanced hardware and software which can serve as a low cost central processor or controller/monitor. The AIM 65 has two modules -- the master module and the keyboard module -- connected by a plug-in ribbon cable. The master module has a 120 line per minute, 20 column dot matrix thermal printer, a 20 character 16-segment alphanumeric LED display, and microcomputer components.

The Central Processing Unit (CPU) is the R6502 8-bit microprocessor which operates at 1MHz giving a minimum instruction execution time of two microseconds. The R6502 can address 4K bytes of Random Access Memory (RAM) and 20K bytes of Read Only Memory (ROM) on the Master module plus an additional 40K bytes of user provided external RAM, ROM or I/O. Other R6500 devices on the AIM 65 include the R6522 Versatile Interface Adapter (VIA), the R6532 RAM-Input/Output Timer (RIOT), the R2332 ROM, and the R2114 Read/Write RAM.

The keyboard has 70 functions (26 alphabetic, 10 numeric, 22 special, 9 control and 3 user-defined used by the AIM 65.

A ROM-resident 8K monitor controls AIM 65 operations which simplifies use of the CPU, memory, and I/O devices. The monitor translates functional commands into machine code with makes development faster. The AIM 65 Monitor includes commands to:

a. Enter R6502 instructions in mnemonic form for direct translation to object code.

b. Disassemble R6502 instructions from object code to mnemonic form

c. Execute user written programs with debugging aids such as instruction trace, register trace, and breakpoints.

d. Display and alter memory and registers.

e. Transfer object code to and from one or two audio cassette recorders or a teletype.

f. Allow user defined functions to interface with user provided peripherals.

An Editor allows entry, editing, and listing of R6502 source instructions, data, and general text. The Editor has commands to:

a. Transfer text, enter programs or data into memory, or transfer source code to and from one of two audio cassette recorders or a teletypewriter.

b. Locate and change character strings.

c. Move the text line pointer.

d. List selectable lines on output devices.

The Master Module has three ROM sockets for optional AIM programs. A R6502 Assembler, resident in a 4K R2332 ROM was installed for converting R6502 source instructions into object code using symbolic labels and operands. This two-pass assembler checks for errors in mnemonics but is slow when source code is read from a cassette recorder. The remaining ROM sockets were used for the optional AIM 65 8K BASIC Interpreter. The AIM 65 can be interfaced to external equipment through the application connector and the user dedicated R6522 VIA which has 16 bi-directional input/output lines, four control lines, and two timers. Using remote control lines the user can input source code from one cassette recorder and output object code to another cassette recorder when using the AIM 65 assembler.

Programming the Microcomputer

The main program was written in AIM 65 BASIC language with machine language subroutines. The machine language subroutines were written in source code and assembled, using the AIM 65 Assembler, to machine language. In this way the subroutines could be relocated in memory easily. The BASIC program and machine language subroutines were "burned" into an Erasable Programmable Read Only Memory (EPROM) 4K 2532 chip using a DRAM PLUS[2] Board. This chip was thus placed in the AIM 65 Assembler socket (at hex D000), since it was then spare, and could be addressed by keyboard key "5" which causes a jump to D000. The BASIC variables had to be located in RAM however so a program was used (called BASIC DRIVER) at D000 to tell BASIC where the variables were located. The complete memory map is shown in Figure 11.

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[2]Sold by The Computerist, 34 Chelmsford St., Chelmsford, MA.

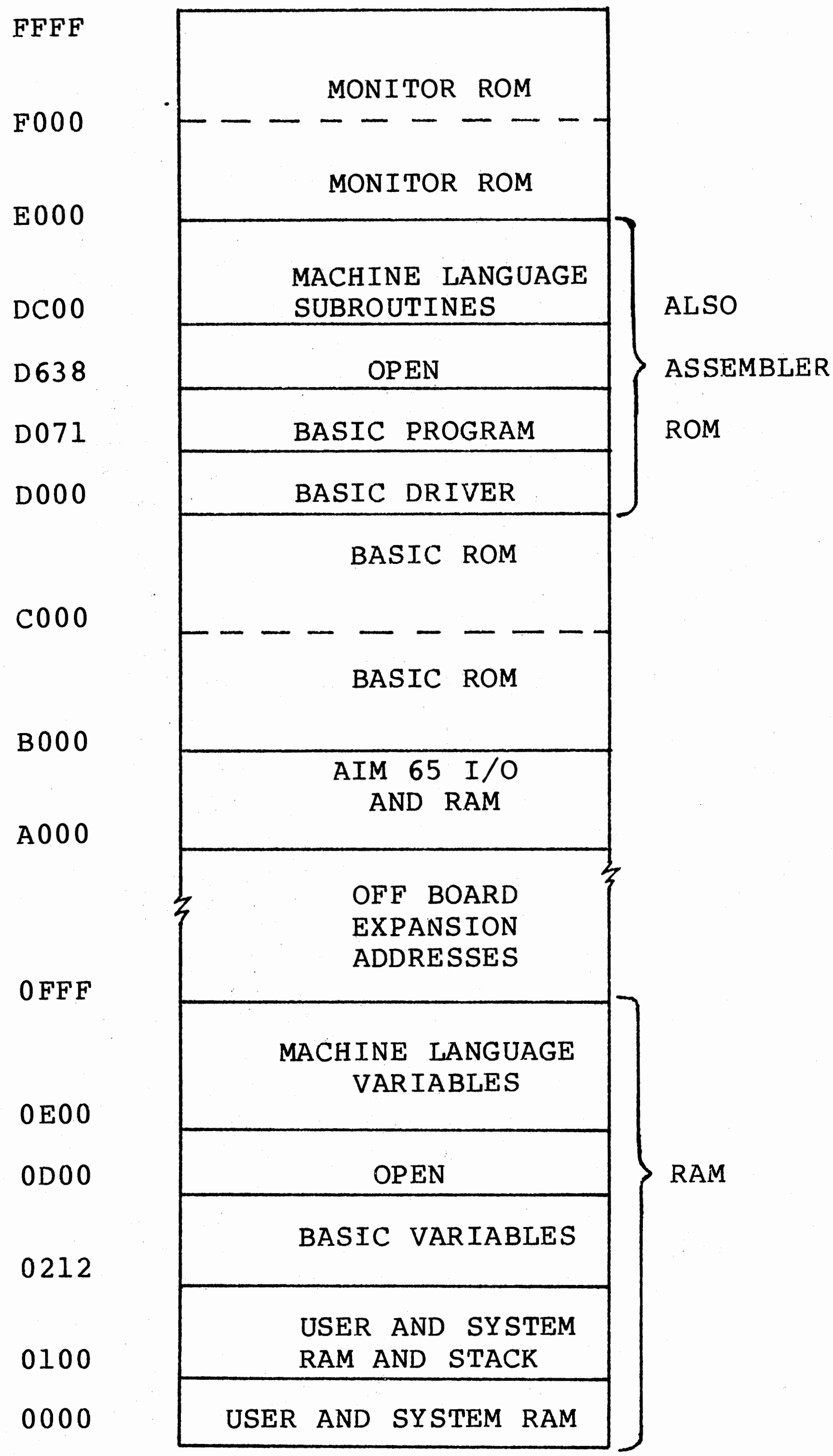

Figure 11. AIM 65 Complete Memory Map

CHAPTER V

CALIBRATION PROCEDURES

Lateral Position Calibration

To avoid having to calibrate the lateral position of the penetrometer carriage in the field, it was calibrated in the laboratory. It was found to not vary by more than five percent of the full scale in the field.

With the carriage to the far left on the main frame, a program (DeJong, 1980) was run to count pulses on the frequency wave output from the signal conditioning circuitry in the same time the normal program counted pulses (one second) and continuously output the count to the LED display. The carriage was then moved to the extreme right a distance of 3300 mm. The frequency of the output signal was adjusted (by a variable resistor) so that the difference in counts from one end of the main frame to the other was 6600 counts which gave one pulse for each 0.5 mm. The BASIC program then subtracted the initial left hand count (611) from each position along the main frame and divided the result by two to give the position in millimeters starting at zero from the left.

Depth Calibration

The depth was also calibrated in the laboratory in a similar manner to the lateral position except pulses were counted for one-tenth of a second. With the hydraulic cylinder fully raised the number of pulses was recorded and then with the cylinder fully lowered. The difference was adjusted to give 600 pulses which corresponded to a depth of 600 mm. There was little electrical drift during several months of operation so the depth did not require recalibrating.

Load Cell Calibration

The load cell on the hydraulic cylinder was positioned over a 320 kg balance scale. A hydraulic lift jack was then placed on the scale to force up on the load cell. The main frame did not lift and oil could not escape the hydraulic cylinder. The 4.08 kg jack weight was subtracted from the scale readings. At 2224 Newtons force (maximum continuous for load cell) the output frequency was set to 10,000 Hertz. The results of the calibration is shown in Table II.

The BASIC program thus converted the one tenth second pulse count to kPa by dividing by the area of the cone base. The conversion constant is shown below:

TABLE II

LOAD CELL CALIBRATION

Load (kg)	Force (N)	Output (mV)	Pulses (1/10) sec.
0	0	1.16	32
41.3	405	6.57	168
86.6	850	12.52	370
132.0	1295	18.46	570
177.3	1740	24.43	774
222.7	2184	30.39	980
268.0	2629	36.22	1180
313.4	3074	41.91	1376

R-square = 0.99957

$$\text{Cone area} = \pi D^2/4$$
$$= 0.7854\ D^2\ (\text{mm}^2)$$

where: D = diameter of cone base (mm)

The initial force was subtracted from subsequent measurements to give zero pressure before the penetrometer entered the soil.

The load cell calibration was checked in the field by forcing the penetrometer onto a rigid board which stopped the penetrometer, allowing the oil pressure relief valve to hold the pressure constant, and the depth potentiometer was turned by hand to simulate the penetrometer entering the soil. With the oil pressure relief set at 716 kPa the force on the cylinder was 2224 Newtons. With a cone diameter of 20.16 mm this gave a cone index of 6970 kPa. The oil pressure gauge was calibrated with a dead weight tester (type - Hanson Chemical Equipment Co., Beloit, Wisconsin, USA) with the results shown in Table III.

The load cell calibration was found to not vary more than four percent of full scale when used in the field (Figure 12). Penetration speed was set at the ASAE standard of 1829 mm per minute using an oil flow control valve (Figure 13).

TABLE III

PRESSURE GAUGE CALIBRATION

Dead Weight Tester (kPa)	Gauge Reading (kPa)
0	0
345	358
689	689
1030	1020
1380	1360
1720	1700
2070	2050
2410	2390
2760	2740
2410	2400
2070	2050
1720	1710
1380	1360
1030	1030
689	689
345	351
0	0

Figure 12. Penetrometer Operation in Field

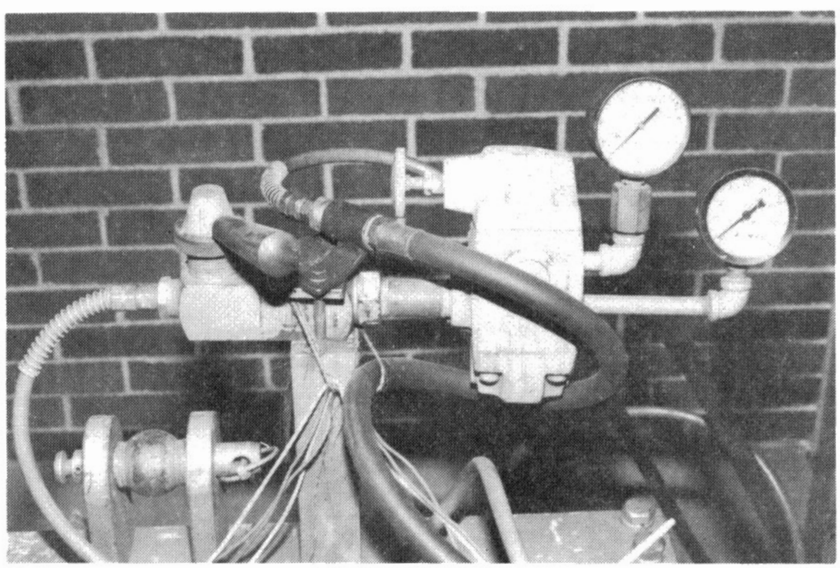

Figure 13. Oil Flow Control and Pressure Reducing Valve

CHAPTER VI

PROGRAM SOFTWARE

The AIM 65 BASIC and disassembled machine language subroutines are listed in Appendix A and are stored in an erasable programmable read only memory (EPROM) chip located at hexadecimal D000. The BASIC program was entered by the 5 key on the AIM 65 keyboard which executed a jump to D000. The location and date was then entered on the keyboard followed by a "return." The penetrometer cone diameter was required in millimeters and if changed during a test, the BASIC program had to be restarted. At the end of each penetration a question was asked for another test. If the answer was no, the program stored a block of zeros on the magnetic tape to identify the end of the profile. The hydraulic cylinder fully raised position was chosen as a reference depth, so the cylinder had to be raised fully before each penetration.

The penetrometer depth and force were recorded by starting both R6522 timers simultaneously. Timer T1 counted the pulses from the depth signal and timer T2 was loaded with hexadecimal FFFF and decremented by one for each pulse from the force signal. At the end of one-tenth of a second time period an interrupt occurred and timer T1 was read and timer T2 was read, and exclusive-ored (EOR) with FFFF, giving the number of pulses in the time period. The interrupt program decided whether to record the depth and force or return and restart the timers (Figure 14).

The initial depth was saved in a temporary location for a reference which was increased by an increment corresponding to a depth increase of 20 mm each time a sample was taken. A sample was taken only when successive depth readings exceeded the comparing depth thus giving depth and force readings each 20 mm of depth.

The soil surface was recorded by stopping at the surface to press the "soil surface" button which put a momentary high pulse on port PA4. This port was being read in each time period but only stored in memory when PA4 was high. If a mistake were made of not pressing the button before reaching the full depth, the penetrometer could be raised to the surface and the button pressed again to record the depth. A check was made of the last depth memory location which if not zero at a depth of 600 mm the machine language subroutine returned to the BASIC program.

When the BASIC program read the data memory, it automatically converted hexadecimal numbers to decimal. However since memory data was stored in high byte-low byte manner the high byte had to be multiplied by 256 and added to the low byte to give the correct decimal number. Depth

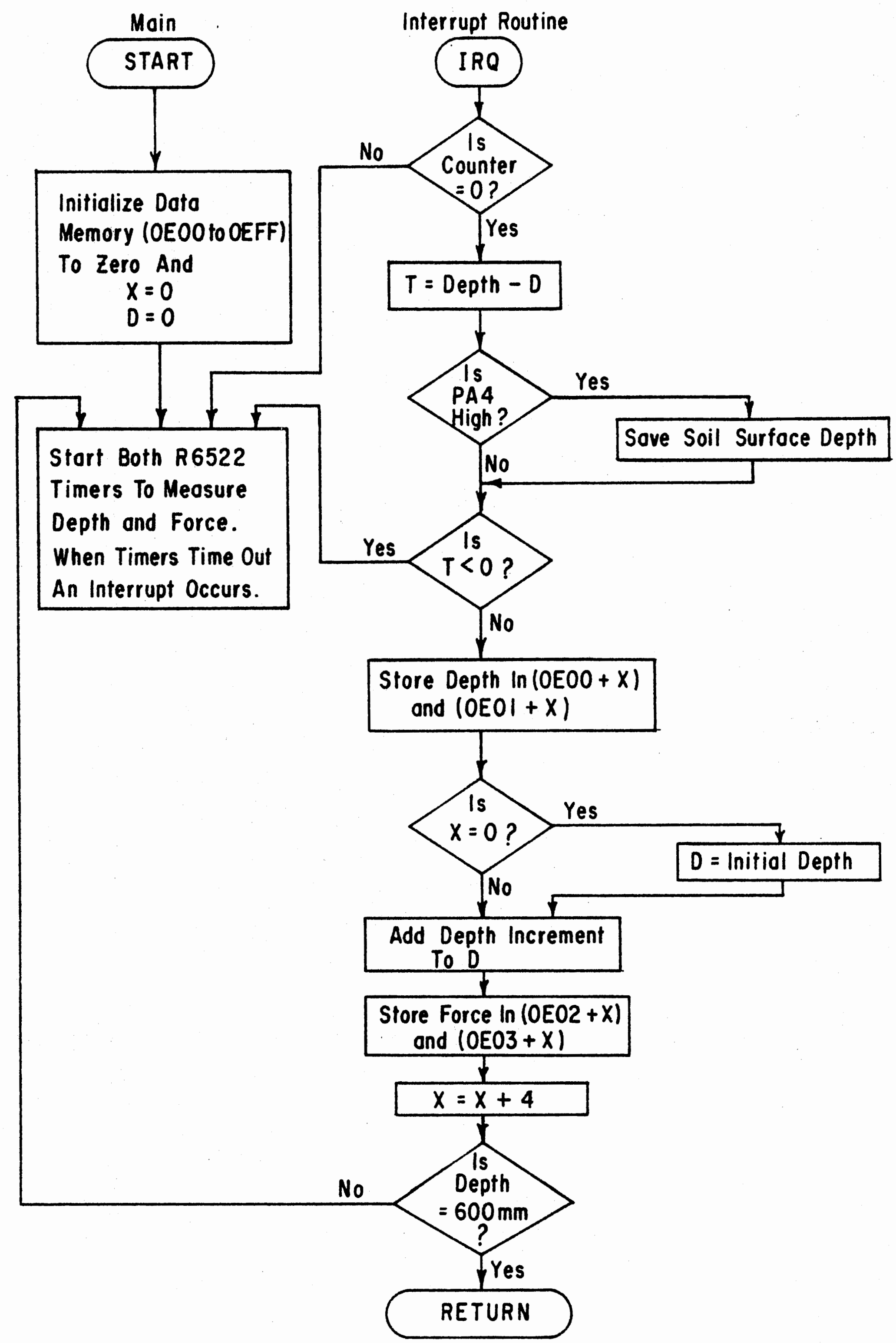

Figure 14. Data Recording Subroutine Flowchart

and cone index were then printed on the AIM 65 thermal printer and the hexadecimal data array was stored on magnetic tape by remote control of the tape recorder. If another penetration were required with the same cone penetrometer size, the BASIC program allowed this decision. If no more data were required, the program stored an array of zeros on the magnetic tape to indicate the end of a profile.

A flowchart of the data recording and processing system is shown in Figure 15. The hexadecimal data on magnetic tape was converted to decimal and transferred to a magnetic tape file on a Tektronix 4052 computer by the program in Appendix B using an RS-232 connector cable interfaced to the Tektronix. The data arrays were then input to a Statistical Analysis System (SAS) data set via a 1200 baud telephone modem. A SAS data set was first initialized for input of data then control was passed to the Tektronix by the "Return to Basic" key. A Tektronix BASIC (called Graphic System BASIC which has two levels: basic BASIC which is the vocabulary used in all applications; and extended BASIC for the graphic system capabilities) program (Appendix C) was then run which output the data arrays via the modem to the SAS data set.

A SAS program using procedure GCONTOUR was used to plot a profile of soil strength contour lines. The values of the contour lines may be manually written on the plot as this procedure provides a legend.

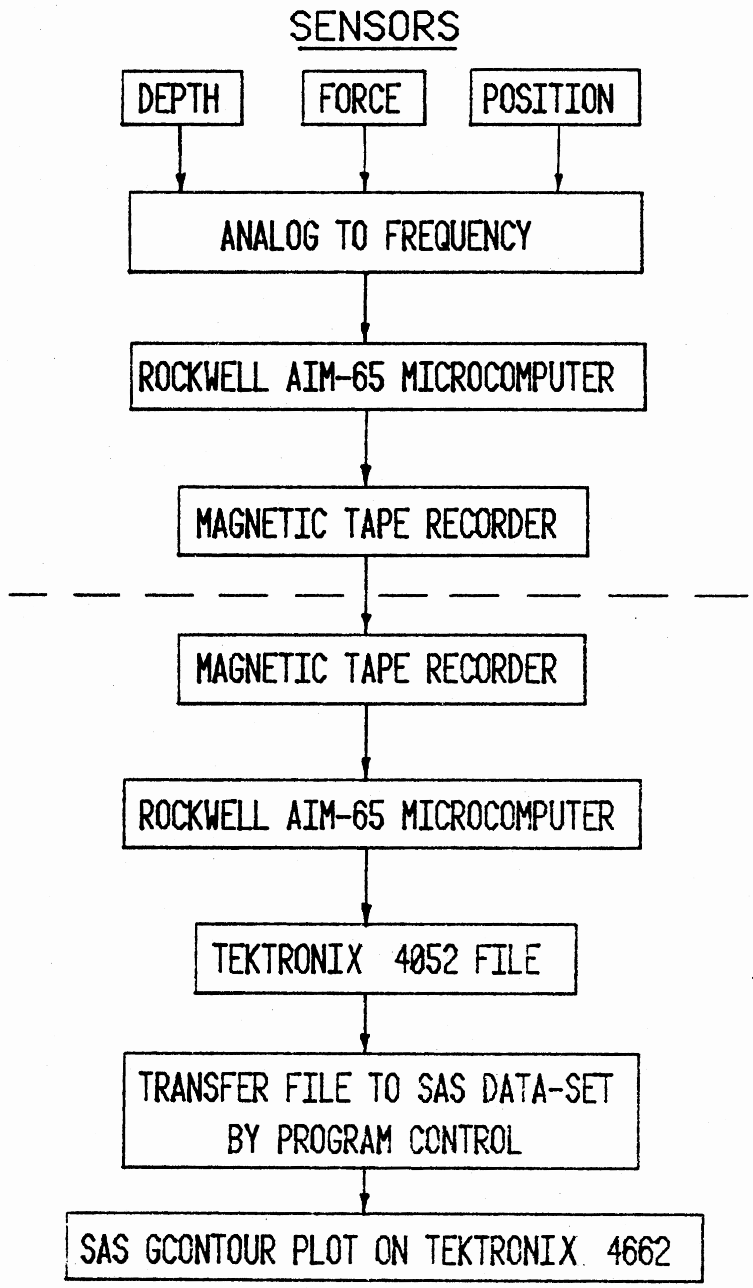

Figure 15. Data Recording and Processing Flowchart

CHAPTER VII

RESULTS AND DISCUSSION

The penetrometer was tested in a Tabler silt loam at Blackwell, Oklahoma. The results of two profiles are shown as examples of the output (Figures 16 & 17). Different colored pens could be used if desired for contour lines. The average cone index was also plotted with 95 percent confidence limits (Figure 18). A slight hard pan was shown at a depth of 240 mm. The confidence limits were wider close to the soil surface which could be expected due to previous tire tracks or uneven tillage.

An example of the AIM 65 printer output, taken in a sand in the laboratory, is shown in Figure 19 which shows the date and location of a three hole profile. At Chickasha, Oklahoma a different tractor was used, and a problem arose of the computer memory being randomly altered. This could have been caused by noise from the tractor alternator or from the frame of the penetrometer. When a filter was placed on the power supply and a ground rod was used on the penetrometer carriage frame the problem was solved. Whether the ground rod was necessary was unclear since occasionally the ground rod was not used and

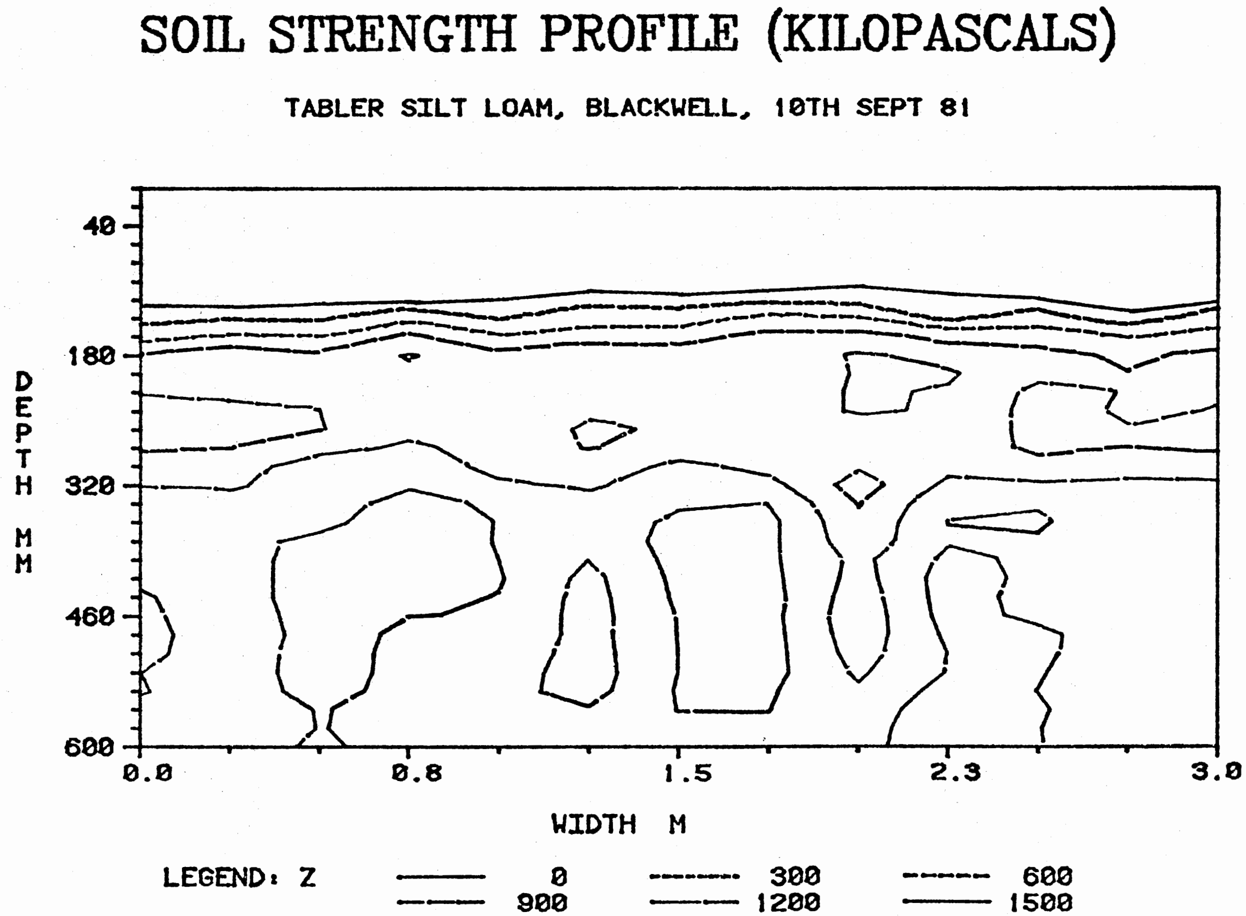

Figure 16. Soil Strength Profile

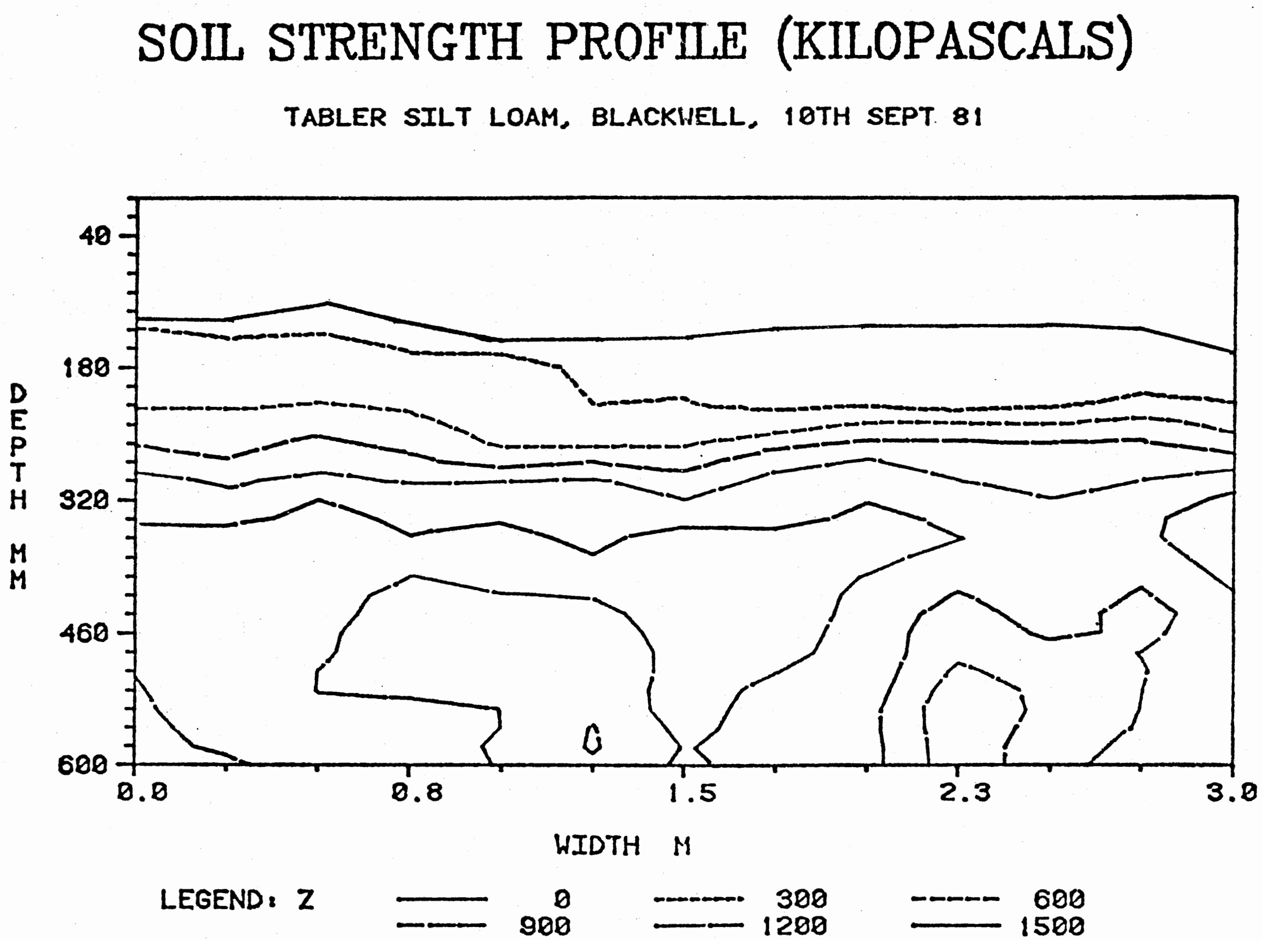

Figure 17. Soil Strength Profile

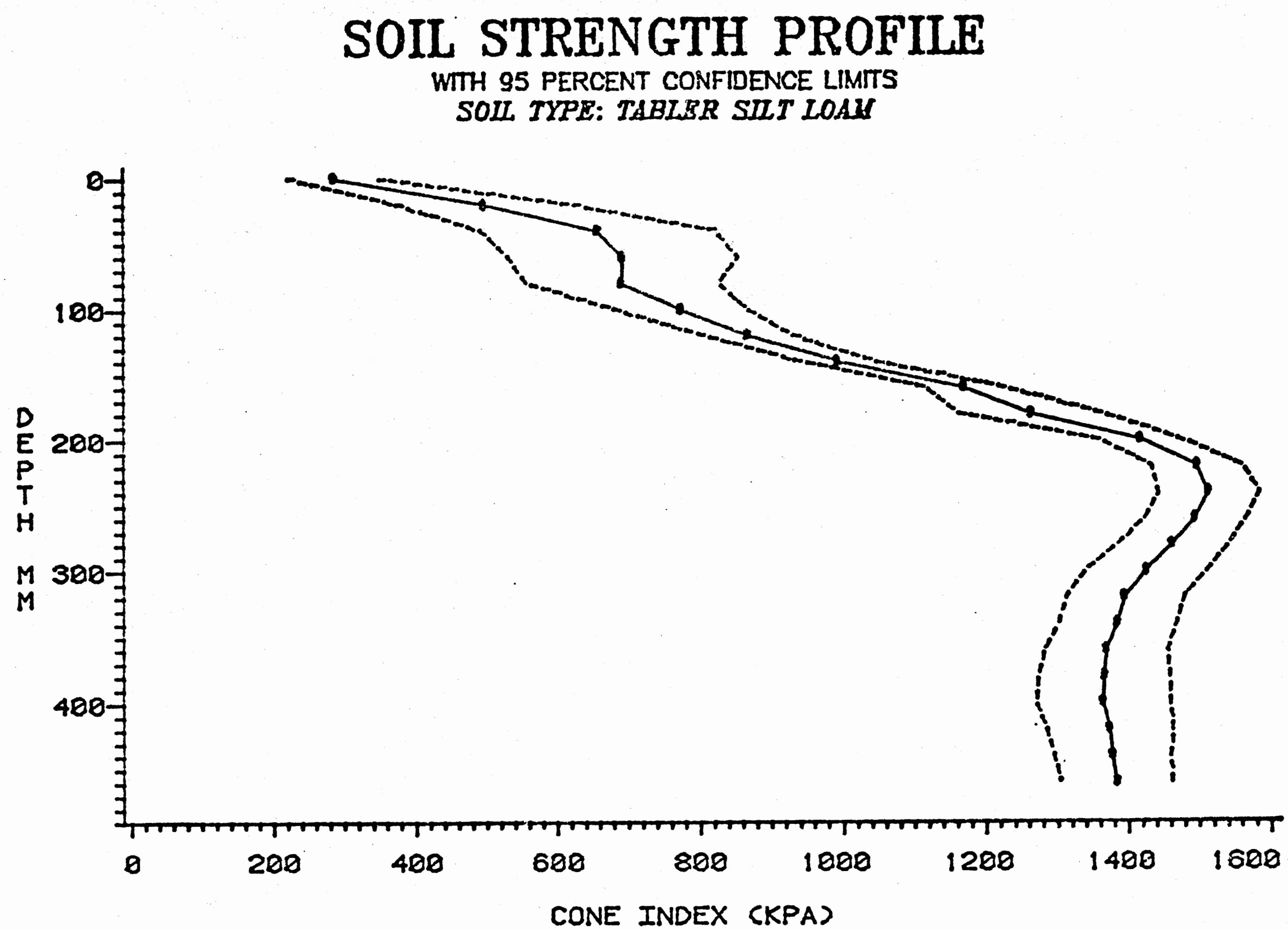

Figure 18. Average Cone Index with Depth at Blackwell, 10th Sept. 81

```
ROCKWELL AIM 65

<N>
THIS PROGRAM READS
AND DISPLAYS PROBE
DEPTH (MM) AND CONE
INDEX (KPA) AT THE
END OF EACH STROKE

START PENETRATION
WITH CYLINDER FULLY
RAISED, AND STOP
AT THE SOIL SURFACE
TO PRESS THE SOIL
SURFACE BUTTON
THEN CONTINUE TO THE
CYLINDER FULL EXTENT

LOCATION?
? SOIL LAB.
DATE?
? 2-23-1982


CONE DIAMETER (MM)?
? 20.16
CONE DIA = 20.16 MM

POSITION OF CARRIAGE
FROM LEFT =  412 MM

START PENETRATION
SOIL SURFACE
DEPTH= 239 MM

DEPTH     CONE INDEX
 MM          KPA
 0  0
 20  0
 40  0
 60  0
 80  0
 100  0
 120  0
 140  0
 160  0
 180  0
 200  0
 220  27
 240  118
 260  226
 280  397
 300  640
 320  856
 340  1149
 360  1193
 380  1665
 400  1929
 420  2257
 440  2508
 460  2731
 480  3009
 500  3274
 520  3616
 540  3897
 560  4130
 580  4500
 600  4661
```

```
ANOTHER TEST? Y OR N
? Y
RAISE CYLINDER FULLY


READY?  ENTER Y
? Y

POSITION OF CARRIAGE
FROM LEFT =  581.5 M
M

START PENETRATION
SOIL SURFACE
DEPTH= 254 MM

DEPTH     CONE INDEX
 MM          KPA
 0  0
 20  0
 40  0
 60  0
 80  0
 100  0
 120  0
 140  0
 160  0
 180  0
 200  0
 220  0
 240  34
 260  132
 280  278
 300  466
 320  703
 340  975
 360  1233
 380  1546
 400  1832
 420  2111
 440  2410
 460  2721
 480  3002
 500  3281
 520  3602
 540  3922
 560  4201
 580  4424
 600  4479
```

```
ANOTHER TEST? Y OR N
? Y
RAISE CYLINDER FULLY


READY?  ENTER Y
? Y

POSITION OF CARRIAGE
FROM LEFT =  748.5 M
M

START PENETRATION
SOIL SURFACE
DEPTH= 245 MM

DEPTH     CONE INDEX
 MM          KPA
 0  0
 20  0
 40  0
 60  0
 80  0
 100  0
 120  0
 140  0
 160  0
 180  0
 200  0
 220  41
 240  118
 260  264
 280  431
 300  634
 320  850
 340  1121
 360  1358
 380  1623
 400  1922
 420  2215
 440  2473
 460  2786
 480  3100
 500  3441
 520  3818
 540  4305
 560  4932
 580  5469
 600  5901


ANOTHER TEST? Y OR N
? N

FINISHED
```

Figure 19. AIM 65 Printer Output

everything functioned normally. The cord turning the depth potentiometer gave some slippage which had to be checked so as not to exceed the limit of potentiometer before the penetrometer was fully in the soil. A link chain and sprocket drive, instead of a cord drive, on the depth potentiometer would have solved this problem.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

A Rockwell AIM 65 microcomputer was used to record and display lateral position, depth, and cone index of a tractor mounted hydraulically operated cone penetrometer. Analog data inputs were converted to a square wave signal of frequency proportional to the input and interfaced to the microcomputer which counted the square wave pulses in a time period. The microcomputer was programmed in BASIC with machine language subroutines to count pulses. The program was "burned" into an erasable programmable read only memory (EPROM) chip so the program could be accessed simply by turning on the microcomputer and pressing key N. The depth and cone index was stored on magnetic tape as well as printed on the 20 character AIM 65 thermal printer. Data on magnetic tape was transferred to a Statistical Analysis System (SAS) data set via a Tektronix 4052 computer. A SAS contour plot of soil strength was used to display the soil strength profile.

The system was tested in the field and after solving power supply and grounding problems the system was found to work well.

For further research in soil strength, as measured by cone index, the penetrometer system may benefit from a device to quickly measure the two other main parameters, soil moisture and bulk density, to more completely describe the soil physical conditions. Placing strain gauges at the base of the cone would avoid shaft dragging forces. It may be possible to develop a soil moisture and bulk density instrument incorporated in the penetrometer shaft or perhaps used in the hole left by the penetrometer.

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APPENDIXES

APPENDIX A

BASIC AND MACHINE LANGUAGE

PROGRAMS

```
1 REM *************** PENETROMETER BASIC PROGRAM *********
2 DIMH(130),D(34),F(34),L$(20),T$(20)
3 PRINT" "
4 PRINT"THIS PROGRAM READS"
6 PRINT"AND DISPLAYS PROBE"
8 PRINT"DEPTH (MM) AND CONE"
10 PRINT"INDEX (KPA) AT THE"
12 PRINT"END OF EACH STROKE"
14 PRINT" "
15 PRINT"START PENETRATION"
16 PRINT"WITH CYLINDER FULLY"
17 PRINT"RAISED, AND STOP"
18 PRINT"AT THE SOIL SURFACE"
19 PRINT"TO PRESS THE SOIL"
20 PRINT"SURFACE BUTTON:"
21 PRINT"THEN CONTINUE TO THE"
22 PRINT"CYLINDER FULL EXTENT"
23 REM ****** INPUT LOCATION, DATE, & CONE DIAMETER ******
24 PRINT" "
25 PRINT"LOCATION?"
26 INPUT L$
27 PRINT"DATE?"
28 INPUT T$
30 PRINT" "
32 PRINT" "
35 PRINT"CONE DIAMETER (MM)?"
38 INPUT C1
40 PRINT"CONE DIA.=";C1;"MM"
42 REM A = AREA OF CONE BASE
45 A=C1*C1*0.7854
47 REM **************************************************
48 REM ****** CARRIAGE POSITION SUBROUTINE ***************
50 POKE4,64
52 POKE5,221
60 I=1
70 X=USR(I)
80 P4=611
90 P1=PEEK(4093)
100 P2=PEEK(4094)
110 P3=(P1*256+P2-P4)/2
118 PRINT" "
120 PRINT"POSITION OF CARRIAGE"
122 PRINT"FROM LEFT = ";P3;"MM"
180 REM **************************************************
190 REM ************* FORCE AND DEPTH SUBROUTINE *********
199 PRINT" "
200 PRINT"START PENETRATION"
203 POKE4,0
205 POKE5,220
210 X=USR(I)
220 REM GET HEX ARRAY AT 0E00 TO 0E7C
260 FOR I=1 TO 124
270 H(I)=PEEK(3583+I)
272 NEXT I
275 J=0
280 REM GET INITIAL FORCE AND DEPTH IN DECIMAL
281 D1=H(1)*256+H(2)
282 F1=H(3)*256+H(4)
283 REM SOIL SURFACE DEPTH AT 0FF0
284 E=PEEK(4080)
```

```
285 G=PEEK(4081)
286 B=G*256+E
287 PRINT"SOIL SURFACE"
288 PRINT"DEPTH=";B;"MM"
290 PRINT" "
291 PRINT"DEPTH","CONE INDEX"
292 PRINT" MM","   KPA"
293 FOR I=1 TO 124 STEP 4
295 J=J+1
298 REM SUBTRACT INITIAL FORCE & DEPTH & ROUND
300 D(J)=10*INT((H(I)*256+H(I+1)-D1)/10)
310 F(J)=H(I+2)*256+H(I+3)-F1
312 REM CONVERT FORCE TO PRESSURE IN KPA
315 F(J)=INT(F(J)*2224/A)
316 REM NEGLECT SMALL FORCES ( < 2 SIGNAL PULSES )
317 IF F(J)<15 THEN F(J)=0
320 PRINT D(J);F(J)
330 NEXT I
340 PRINT" "
341 PRINT" "
342 PRINT" "
344 REM **************************************************
345 REM *****************HEX DATA TO TAPE RECORDER *******
350 POKE4,0
352 POKE5,223
360 X=USR(I)
362 REM **************************************************
363 REM RETURN FOR NEXT TEST IF REQUIRED
365 PRINT"ANOTHER TEST? Y OR N"
370 INPUT Q$
380 IF ASC(Q$)=78 THEN 400
385 PRINT"RAISE CYLINDER FULLY"
386 PRINT" "
387 PRINT" "
390 PRINT"READY?  ENTER Y"
392 INPUT R$
395 GO TO 50
398 REM **************************************************
399 REM   ************* FILL 0E00 WITH ZEROS *************
400 POKE4,160
401 POKE5,223
410 X=USR(I)
415 REM ********* OUTPUT ZEROS TO TAPE RECORDER **********
420 POKE4,0
421 POKE5,223
430 X=USR(I)
440 PRINT"FINISHED"
450 PRINT" "
460 PRINT" "
470 PRINT" "
480 END
```

PASS 1

PASS 2

```
                   BASIC DRIVER PROGRAM

0000                  ;THIS PROGRAM INITIALIZES BASIC POINTERS TO THE
0000                  ;START AND END OF THE RAM WORK AREA
0000                  ;AND TO THE FIRST INSTRUCTION IN EPROM
0000                  ;THEN IT STARTS THE BASIC PROGRAM
0000                  ;REMEMBER THAT THERE MUST BE A 00 AT THE START OF
0000                  ;THE BASIC PROGRAM. THE POINTER AT 73,74 POINTS
0000                  ;TO THE FIRST BYTE AFTER THE 00

0000                  ;CHANGE THE NEXT THREE SYMBOLS FOR YOUR APPLICATION

0000                  PGMST  =$D071          ;BASIC PROGRAM START ADDRESS + 1
0000                  RAMBOT =$212
0000                  RAMTOP =$0CFF

0000                  ;THIS NORMALLY STARTS AT $D000 FOR THE ASSEMBLER SOCKET

0000                         *=$D000

D000   A9 E1          START  LDA #$E1        ;INITIALIZE BASIC POINTERS
D002   85 82                 STA $82         ;CURRENT LINE NUMBER HIGH
D004   A2 FE                 LDX #$FE
D006   9A                    TXS             ;INITIALIZE THE STACK
D007   D8                    CLD
D008   A9 4C                 LDA #$4C        ;OP CODE FOR JUMP
D00A   85 00                 STA $00         ;NEW LINE JUMP
D00C   85 03                 STA $03         ;USR JUMP
D00E   85 9C                 STA $9C         ;FUNCTION JUMP
D010   85 BB                 STA $BB         ;ERROR JUMP
D012   A2 87                 LDX #$87
D014   A9 BF                 LDA #$BF
D016   86 BC                 STX $BC         ;ERROR ADDRESS
D018   85 BD                 STA $BD
D01A   86 04                 STX $04         ;USR ADDRESS
D01C   85 05                 STA $05
D01E   A9 14                 LDA #$14        ;SETUP FOR 20 COLUMN WIDTH
D020   85 12                 STA $12
D022   A9 0A                 LDA #$0A        ;SETUP FOR 10 COLUMN INPUT WIDTH
D024   85 13                 STA $13

D026   A2 1C                 LDX #$1C        ;LOAD INITIALIZATION CONSTANTS
D028   BD 85 CE       L1     LDA $CE85,X     ;OUT OF BASIC ROM
D02B   95 BE                 STA $BE,X
D02D   CA                    DEX
D02E   D0 F8                 BNE L1

D030   A9 03                 LDA #3
D032   85 9B                 STA $9B         ;WORK AREA
D034   A9 00                 LDA #0
D036   85 01                 STA $01         ;NEW LINE ADDRESS HIGH
D038   85 B0                 STA $B0         ;ACC #1 OVERFLOW WORD
D03A   48                    PHA
D03B   85 60                 STA $60         ;STRING PTR HIGH
D03D   85 10                 STA $10         ;INPUT FLAG
```

```
D03F    A9 41              LDA #$41
D041    85 5E              STA $5E           :STRING STACK POINTER
D043    A9 B9              LDA #$B9
D045    85 02              STA $02           :NEW LINE ADDRESS HIGH

D047    A2 71              LDX #<PGMST       :BASIC PROG START ADR
D049    A9 D0              LDA #>PGMST       :CHG WHEN RELOCATED
D04B    86 73              STX $73           :START OF BASIC PROGRAM
D04D    85 74              STA $74
D04F    A2 12              LDX #<RAMBOT      :BASIC VARIABLE START ADD
D051    A9 02              LDA #>RAMBOT
D053    86 75              STX $75           :START OF VARIABLES
D055    85 76              STA $76
D057    A2 FF              LDX #<RAMTOP      :BASIC VARIABLE END ADDR
D059    A9 0C              LDA #>RAMTOP
D05B    86 7F              STX $7F           :END OF MEMORY
D05D    85 80              STA $80

D05F    20 7C B4           JSR $B47C         :CALL RUN
D062    4C C8 B5           JMP $B5C8         :JUMP TO FIRST STATEMENT

D065                       .END
        ERRORS= 0000
```

```
PASS 1

PASS 2

------------------------------------------------------------------------------
                  PENETROMETER PROGRAM FOR SOIL STRENGTH PROFILE

0000              ;BY GLEN RIETHMULLER
------------------------------------------------------------------------------

0000              INTERL =$A404         ;INTERRUPT VECTOR LOW
0000              INTERH =$A405         ;INTERRUPT VECTOR HIGH
0000              TAPGAP =$A409         ;TAPE GAP
0000              PORTA  =$A001         ;PORT A, PAD
0000              INFLAG =$A404         ;INTERRUPT FLAG
0000              T1LH   =$A005         ;T1 LATCH HIGH
0000              T1LL   =$A006         ;T1 LATCH LOW
0000              T2LL   =$A008         ;T2 LATCH LOW
0000              T2LH   =$A009         ;T2 LATCH HIGH
0000              ACR    =$A00B         ;AUXILIARY CONTROL REGISTER (ACR
0000              IER    =$A00E         ;INTERRUPT ENABLE REGISTER (IER)

0000                     *=$0FF0
0FF0              SURLO  *=*+1          ;SOIL SURFACE LOW
0FF1              SURHI  *=*+5          ;SOIL SURFACE HIGH BYTE
0FF6              DINCHI *=*+1          ;DEPTH INCREMENT HIGH BYTE
0FF7              DINCLO *=*+1          ;DEPTH INCREMENT LOW
0FF8              DCOMPH *=*+1          ;DEPTH COMPARSION HIGH
0FF9              DCOMPL *=*+4          ;DEPTH COMPARSION LOW
0FFD              DEPTHH *=*+1          ;DEPTH MEMORY HIGH
0FFE              DEPTHL *=*+1          ;DEPTH MEMORY LOW
0FFF              COUNT  *=*+1          ;FREQUENCY COUNTER INTERVAL

1000                     *=$0E00
0E00              DHIGH  *=*+1          ;FORCE AND DEPTH
0E01              DLOW   *=*+1          ;STORED ON PAGE 0E00
0E02              FORCEH *=*+1
0E03              FORCEL *=*+1

0E04                     *=$0E7B
0E7B              DEND   *=*+1          ;END OF DATA ON
0E7C              FEND   *=*+1          ;PAGE 0E00


0E7D              DRB    =$A800         ;DATA REGISTER B
0E7D              TAPOUT =$A435         ;OUT FLG (TAPE 1 OR 2)
0E7D              OUTFLG =$A413         ;OUTPUT DEVICE
0E7D              TAOSET =$F21D         ;SET TAPE FOR OUTPUT
0E7D              FILE   =$A42E         ;NAME OF DATA FILE ON TAPE
0E7D              DUMPTA =$E56F         ;OPENS FILE FOR OUTPUT BY BLOCK
0E7D              TOBYTE =$F18B         ;OUTPUT ACC. TO TAPE BUFFER
0E7D              DU12   =$E511         ;TAPE OUTPUT BUFFER

0E7D                     *=$DC00
```

```
---------------------------------------------------------------------------
                     PENETROMETER SUBROUTINE FOR FINDING SOIL SURFACE
---------------------------------------------------------------------------

DC00   08          BEGIN  PHP                ;SAVE P REGISTER
DC01   A2 FF              LDX #$FF
DC02   A9 00       UP     LDA #$00           ;INITIALIZE PAGE
DC05   9D 00 0E           STA DHIGH,X        ;0E00 TO ZERO
DC08   E0 00              CPX #$00
DC0A   F0 04              BEQ INITAL         ;JUMP TO INITAL
DC0C   CA                 DEX                ;WHEN FINISHED
DC0D   4C 02 DC           JMP UP

DC10   A9 00       INITAL LDA #$00           ;INITIALIZE
DC12   8D F0 0F           STA SURLO          ;SOIL SURFACE
DC15   8D F1 0F           STA SURHI          ;MEMORIES
DC18   8D F8 0F           STA DCOMPH         ;ZERO DEPTH COMPARSION
DC1B   8D F9 0F           STA DCOMPL         ;VECTORS

DC1E   8D F6 0F           STA DINCHI         ;DEPTH INCREMENT
DC21   A9 14              LDA #$14           ;HIGH AND LOW
DC23   8D F7 0F           STA DINCLO         ;INCREMENT BY 20
DC26   A9 30              LDA #$30           ;SET TAPE GAP TO
DC28   8D 09 A4           STA TAPGAP         ;HEX 30
DC2B   4C 31 DC           JMP START

---------------------------------------------------------------------------
                     FORCE AND DEPTH SUBROUTINE

DC2E   4C 07 DD    OUT    JMP PULL           ;TAKE IRQ VECTORS OFF STACK

DC31   78          START  SEI                ;DISABLE INTERRUPTS
DC32   A9 88              LDA #<IRQ          ;LOW BYTE OF INTERRUPT
DC34   8D 04 A4           STA INTERL         ;VECTOR
DC37   A9 DC              LDA #>IRQ          ;HIGH BYTE OF INTERRUPT
DC39   8D 05 A4           STA INTERH         ;VECTOR

DC3C   A9 60              LDA #$60           ;ACR TO FREE RUNNING MODE
DC3E   8D 0B A0           STA ACR
DC41   A9 C0              LDA #$C0           ;IER TO ENABLE INTERRUPTS
DC43   8D 0E A0           STA IER
DC46   A2 00              LDX #$00           ;INITIALIZE X REGISTER

DC48   A9 02       RETURN LDA #$02           ;ONE TENTH SECOND
DC4A   8D FF 0F           STA COUNT          ;INTERVAL COUNTER
DC4D   A9 71              LDA #$71           ;SET TIMER T1 FOR
DC4F   8D 06 A0           STA T1LL           ;50,000 CYCLES
DC52   A9 FF              LDA #$FF           ;INITIALIZE TIMER T2 LATCH-LOW
DC54   8D 08 A0           STA T2LL
DC57   A9 03              LDA #$03
DC59   8D 05 A0           STA T1LH           ;START TIMER T1
DC5C   A9 FF              LDA #$FF           ;T2 DECREMENTS FROM FFFF ON PORT
DC5E   8D 09 A0           STA T2LH           ;START TIMER T2
DC61   A9 00              LDA #$00           ;INITIALIZE DEPTH
DC63   8D FD 0F           STA DEPTHH         ;MEMORIES TO USE UP TIME
DC66   8D FE 0F           STA DEPTHL

DC69   58                 CLI                ;CLEAR INTERRUPT
DC6A   2C 01 A0    WAIT   BIT PORTA          ;IS BIT 7 HIGH?
DC6D   10 FB              BPL WAIT           ;NO. GO TO WAIT
DC6F   2C 01 A0    LOAF   BIT PORTA          ;YES. WAIT FOR IT TO GO LOW
```

```
DC72    30 FB                   BMI LOAF

DC74    18                      CLC                 :CLEAR CARRY FLAG
DC75    AD FE 0F                LDA DEPTHL
DC78    69 01                   ADC #$01            :INCREMENT DEPTH BY 1
DC7A    8D FE 0F                STA DEPTHL          :FOR EACH PULSE ON PA7
DC7D    AD FD 0F                LDA DEPTHH
DC80    69 00                   ADC #$00
DC82    8D FD 0F                STA DEPTHH

DC85    4C 6A DC                JMP WAIT            :WAIT TILL T1 TIMES OUT


DC88    48              IRQ     PHA                 :SAVE ACCUMULATOR
DC89    CE FF 0F                DEC COUNT
DC8C    F0 A0                   BEQ OUT             :HAS ONE TENTH SEC. PASSED?
DC8E    AD 04 A4                LDA INFLAG          :CLEAR 6522 INTERRUPT FLAG
DC91    68                      PLA                 :RESTORE ACCUMULATOR
DC92    40                      RTI                 :RETURN TO COUNT PULSES AGAIN
-------------------------------------------------------------------------------
                        SAVING FORCE AND DEPTH ROUTINE

DC93    AD 01 A0        STORE   LDA PORTA           :READ PORT A
DC96    29 10                   AND #$10            :IS PA4=1?
DC98    F0 0C                   BEQ HERE            :NO. THEN BRANCH TO HERE
DC9A    AD FE 0F                LDA DEPTHL          :GET SOIL DEPTH LOW
DC9D    8D F0 0F                STA SURLO           :SAVE SOIL SURFACE DEPTH
DCA0    AD FD 0F                LDA DEPTHH          :GET SOIL DEPTH HIGH
DCA3    8D F1 0F                STA SURHI           :SAVE SOIL SURFACE HIGH

DCA6    38              HERE    SEC
DCA7    AD FE 0F                LDA DEPTHL          :HAS DEPTH ADVANCED
DCAA    ED F9 0F                SBC DCOMPL          :BY THE DEPTH INCREMENT?
DCAD    AD FD 0F                LDA DEPTHH
DCB0    ED F8 0F                SBC DCOMPH
DCB3    90 93                   BCC RETURN          :NO. THEN CHECK DEPTH AGAIN
DCB5    AD FE 0F                LDA DEPTHL          :YES. THEN RECORD DEPTH AND FORCE
DCB8    9D 01 0E                STA DLOW,X          :SAVE DEPTH ON PAGE 0E00
DCBB    AD FD 0F                LDA DEPTHH          :WHICH IS INCREMENTED BY X
DCBE    9D 00 0E                STA DHIGH,X

DCC1    8A                      TXA                 :IS X=ZERO?
DCC2    D0 0C                   BNE THERE           :NO. BRANCH TO THERE
DCC4    AD 01 0E                LDA DLOW            :YES. ADD THE DEPTH TO THE
DCC7    8D F9 0F                STA DCOMPL          :COMPARING DEPTH
DCCA    AD 00 0E                LDA DHIGH
DCCD    8D F8 0F                STA DCOMPH

DCD0    18              THERE   CLC                 :INCREMENT THE DEPTH
DCD1    AD F9 0F                LDA DCOMPL          :VALUE (DCOMP) BY (DINC)
DCD4    6D F7 0F                ADC DINCLO          :WHICH IS THEN USED
DCD7    8D F9 0F                STA DCOMPL          :TO COMPARE THE ACTUAL WITH
DCDA    AD F8 0F                LDA DCOMPH
DCDD    6D F6 0F                ADC DINCHI
DCE0    8D F8 0F                STA DCOMPH
DCE3    AD 08 A0                LDA T2LL            :READ TIMER T2L-L
DCE6    49 FF                   EOR #$FF            :FIND NO. OF DECREMENTS
DCE8    9D 03 0E                STA FORCEL,Y        :SAVE LOW FORCE BYTE
DCEB    AD 09 A0                LDA T2LH            :READ TIMER T2L-H
DCEE    49 FF                   EOR #$FF            :FIND NO. OF DECREMENTS
```

```
DCF0    9D 02 0E             STA FORCEH,X     :SAVE HIGH FORCE BYTE

DCF3    E8                   INX              :INCREMENT THE X REGISTER
DCF4    E8                   INX              :FOR THE NEXT
DCF5    E8                   INX              :FORCE AND DEPTH RECORD
DCF6    E8                   INX

DCF7    AD 7B 0E             LDA DEND         :HAS THE PROBE
DCFA    D0 08                BNE DOWN         :COMPLETED ITS STROKE
DCFC    AD 7C 0E             LDA FEND
DCFF    D0 03                BNE DOWN         :YES. RETURN TO BASIC PROGRAM
DD01    4C 48 DC             JMP RETURN       :NO. GET NEXT DEPTH AND FORCE

DD04    4C 0E DD    DOWN     JMP BASIC

DD07    68          PULL     PLA              :THREE IRQ VECTORS
DD08    68                   PLA              :FROM THE STACK SO THE
DD09    68                   PLA              :BASIC VECTORS ARE LEFT
DD0A    68                   PLA              :RESTORE P REGIETER
DD0B    4C 93 DC             JMP STORE        :RETURN TO STORE DATA

DD0E    A9 40       BASIC    LDA #$40         :DISABLE TIMER T1
DD10    8D 0E A0             STA IER
DD13    28                   PLP
DD14    60                   RTS              :RETURN TO BASIC PROGRAM

DD15                         *=$DD40
```

```
--------------------------------------------------------------------------------
                          CARRIAGE POSITION SUBROUTINE

--------------------------------------------------------------------------------

DD40   08                 PHP            ;SAVE P REGISTER
DD41   78                 SEI            ;DISABLE INTERRUPTS
DD42   A9 8C              LDA #<IRQ2     ;GET THE BYTES OF IRQ2
DD44   8D 04 A4           STA INTERL     ;AND STORE THESE IRQ
DD47   A9 DD              LDA #>IRQ2     ;INTERRUPT VECTORS
DD49   8D 05 A4           STA INTERH
DD4C   A9 60              LDA #$60       ;ACR TO FREE RUNNING
DD4E   8D 0B A0           STA ACR        ;MODE
DD51   A9 C0              LDA #$C0       ;ENABLE INTERRUPTS
DD53   8D 0E A0           STA IER

DD56   A9 71              LDA #$71       ;SET T1 FOR 50,033 CYCLES
DD58   8D 06 A0           STA T1LL
DD5B   A9 14              LDA #$14       ;ONE SECOND INTERVAL
DD5D   8D FF 0F           STA COUNT      ;COUNTER FOR PULSES
DD60   A9 C3              LDA #$C3
DD62   8D 05 A0           STA T1LH       ;START TIMER T1
DD65   A9 00              LDA #$00
DD67   8D FE 0F           STA DEPTHL     ;INITIALIZE DEPTH MEMORIES
DD6A   8D FD 0F           STA DEPTHH     ;TO USE UP TIME
DD6D   58                 CLI            ;CLEAR INTERRUPT FLAG

DD6E   2C 01 A0    STAY   BIT PORTA      ;WAIT FOR PB6 TO
DD71   50 FB              BVC STAY       ;GO HIGH
DD73   2C 01 A0    STOP   BIT PORTA      ;WAIT FOR IT TO GO LOW
DD76   70 FB              BVS STOP

DD78   18                 CLC            ;CLEAR CARRY FLAG
DD79   AD FE 0F           LDA DEPTHL     ;INCREMENT CARRIAGE POSITION
DD7C   69 01              ADC #$01       ;COUNTER (DEPTHL AND DEPTHH)
DD7E   8D FE 0F           STA DEPTHL     ;FOR EACH PULSE
DD81   AD FD 0F           LDA DEPTHH     ;ON PA6
DD84   69 00              ADC #$00
DD86   8D FD 0F           STA DEPTHH
DD89   4C 6E DD           JMP STAY       ;GO AND WAIT FOR NEXT PULSE


DD8C   48          IRQ2   PHA            ;SAVE P REGISTER
DD8D   CE FF 0F           DEC COUNT      ;DECREMENT COUNTER
DD90   F0 05              BEQ POINT      ;BRANCH IF TIME OUT
DD92   AD 04 A4           LDA INFLAG     ;CLEAR 6522 INTERRUPT FLAG
DD95   68                 PLA
DD96   40                 RTI            ;RETURN FROM INTERRUPT

DD97   68          POINT  PLA            ;REMOVE ACC. AND IRQ VECTORS
DD98   68                 PLA            ;FROM THE STACK
DD99   68                 PLA
DD9A   68                 PLA
DD9B   28                 PLP            ;RESTORE P REGISTER
DD9C   A9 40              LDA #$40       ;DISABLE T1. A ZERO
DD9E   8D 0E A0           STA IER        ;IN IER7 CLEARS 1 BITS
DDA1   60                 RTS            ;RETURN TO BASIC PROGRAM

DDA2                      *=$DF00
```

```
--------------------------------------------------------------------------------
                         DUMPING TO TAPE SUBROUTINE

--------------------------------------------------------------------------------

 DF00    A9 40                  LDA #$40
 DF02    8D 0E A0               STA IER           ;DISABLE INTERRUPTS
 DF05    A9 BC                  LDA #$BC
 DF07    8D 00 A8               STA DRB           ;CONTROLS TAPE
 DF0A    A9 00                  LDA #$00
 DF0C    8D 35 A4               STA TAPOUT
 DF0F    A9 54                  LDA #$54          ;ASCII CODE FOR "T"
 DF11    8D 13 A4               STA OUTFLG
 DF14    20 1D F2               JSR TAOSET        ;SETS UP AUDIO TAPE OUTPUT
 DF17    A9 47                  LDA #$47          ;ASCII FOR "G"
 DF19    A2 04                  LDX #$04

 DF1B    9D 2E A4      LOOP1    STA FILE,X        ;FILE NAME GGGGG
 DF1E    CA                     DEX
 DF1F    10 FA                  BPL LOOP1         ;FIVE G'S
 DF21    20 6F E5               JSR DUMPTA        ;OPENS FILE FOR OUTPUT
 DF24    A2 00                  LDX #$00

 DF26    BD 00 0E      LOOP2    LDA DHIGH,X       ;LOAD HEX DATA FROM
 DF29    20 8B F1               JSR TOBYTE        ;PAGE 0E00
 DF2C    E8                     INX               ;TOBYTE DUMPS ACCUMULATOR ON TAP
 DF2D    E0 80                  CPX #$80          ;HAS ALL DATA BEEN STORED?
 DF2F    D0 F5                  BNE LOOP2         ;NO. GO BACK THEN
 DF31    AD F1 0F               LDA SURHI         ;YES. OUTPUT SOIL SURFACE
 DF34    20 8B F1               JSR TOBYTE        ;HIGH AND LOW BYTES TO TAPE
 DF37    AD F0 0F               LDA SURLO
 DF3A    20 8B F1               JSR TOBYTE

 DF3D    AD FD 0F               LDA DEPTHH        ;HIGH BYTE OF CARRIAGE POSITION
 DF40    20 8B F1               JSR TOBYTE        ;TO TAPE
 DF43    AD FE 0F               LDA DEPTHL        ;LOW BYTE OF CARRIAGE POSITION
 DF46    20 8B F1               JSR TOBYTE        ;TO TAPE

 DF49    20 11 E5               JSR DU12          ;FILLS REST OF BLOCKS WITH ZERO

 DF4C    A9 AC                  LDA #$AC          ;STOPS TAPE RECORDER
 DF4E    8D 00 A8               STA DRB
 DF51    60                     RTS               ;RETURN TO BASIC

 DF52                           *=$DFA0

--------------------------------------------------------------------------------
                         BLOCK OF ZEROS TO TAPE RECORDER AT END OF TEST

--------------------------------------------------------------------------------

 DFA0    A2 FF                  LDX #$FF
 DFA2    A9 00         BACK     LDA #$00
 DFA4    9D 00 0E               STA DHIGH,X       ;PAGE 0E00 TO ZEROS
 DFA7    E0 00                  CPX #$00
 DFA9    F0 04                  BEQ LOW
 DFAB    CA                     DEX
 DFAC    4C A2 DF               JMP BACK
 DFAF    60            LOW      RTS
 DFB0                           .END
         ERRORS= 0000
```

APPENDIX B

AIM 65 TO TEKTRONIX DATA

TRANSFER PROGRAM

```
100 REM*********************************************************
110 REM THIS PROGRAM TRANSFERS A PROGRAM TO AN AIM 65 VIA PORT 40
120 REM AND THEN "TELLS" THE AIM TO EXECUTE THIS PROGRAM. THE
130 REM AIM 65 THEN TURNS ON A CASSETTE TAPE DECK AND READS A BLOCK
140 REM OF DATA, WHEN THE BLOCK IS TRANSFERED, THE TEKTRONICS "TELLS"
150 REM THE AIM TO SEND THE DATA.
190 REM *******************************************************
191 REM     SET UP LINE PRINTER
192 PRINT @41,11:1
193 REM
210 REM *******************************************************
220 REM     T1 COUNTS HOW MANY TIMES THROUGH
230 REM *******************************************************
240 T1=0
410 REM ***************************************************
420 REM   FILE 2 HAS THE MACHINE ASSEMBLY LANGUAGE PROGRAM
430 REM ***************************************************
440 FIND 2
450 REM *******************************************************
460 REM CHR(127) IS RUBOUT. THIS SEQUENCE SETS BAUD RATE
470 REM ******************************************************
500 CALL "RATE",1200,2,2
550 PRINT " "
600 PRINT "          HIT 'RESET' ON AIM AND THEN 'RETURN' ON TEKTRONICS"
800 INPUT W$
900 W$=CHR(127)
1000 PRINT @40:W$
1010 REM *******************************************************
1020 REM THE FOLLOWING SECTION SETS UP THE AIM FOR INPUT AT 0200
1030 REM *******************************************************
1040 REM
1100 CALL "WAIT",0.5
1200 PRINT @40:"*"
1300 CALL "WAIT",0.2
1400 READ @33:W$
1500 FOR I=1 TO LEN(W$)
1600 B$=SEG(W$,I,1)
1700 PRINT @40:B$
1800 CALL "WAIT",0.2
1900 NEXT I
2000 K$=CHR(13)
2100 PRINT @40:K$
2200 CALL "WAIT",0.5
2300 PRINT @40:"I"
2400 CALL "WAIT",0.5
2410 REM ********************************************************
2420 REM     NOW READ A LINE AT A TIME FROM THE TEKTRONICS TAPE AND
2430 REM   TRANSFER IT TO THE AIM 65. KEEP IN MIND A SINGLE INSTRUCTION
2440 REM   LIKE, SEC, DOES NOT NEED A CARRIAGE RETURN(K$).
2450 REM ********************************************************
2500 READ @33:W$
2600 ON EOF (0) THEN 3700
2700 FOR I=1 TO LEN(W$)
2800 B$=SEG(W$,I,1)
2900 IF I=4 THEN 3100
3000 PRINT @40:B$
3100 CALL "WAIT",0.2
3200 NEXT I
3300 K$=CHR(13)
3400 IF LEN(W$)=3 THEN 2400
3500 PRINT @40:K$
3600 GO TO 2400
3700 M$=CHR(27)
```

```
3800 PRINT @40:M$
3900 PRINT "__                          DOWNLOADING COMPLETE"
3920 REM
3930 REM ***********************************************************
3940 REM       NOW TELL THE AIM TO EXECUTE THE PROGRAM JUST TRANSFERED
3950 REM *************************************************************
3960 REM
3965 DIM D1(33,14),F(33,14)
3969 K=0
3970 FOR N=1 TO 13
4000 CALL "WAIT",0.3
4100 PRINT @40:"*"
4200 CALL "WAIT",0.4
4300 FOR I=1 TO 4
4400 K$="0200"
4500 M$=SEG(K$,I,1)
4600 PRINT @40:M$
4700 CALL "WAIT",0.2
4800 NEXT I
4900 K$=CHR(13)
5000 PRINT @40:K$
5100 CALL "WAIT",0.4
5200 PRINT @40:"G"
5300 CALL "WAIT",0.4
5400 IF T1>0 THEN 5800
5500 PRINT "__           REWIND THE TAPE AND DEPRESS THE PLAY BUTTON."
5600 PRINT "_______                          HIT 'RETURN' TO CONTINUE."
5610 REM
5620 REM ************************************************************
5630 REM  WAIT FOR SIGNAL FROM AIM INDICATING BLOCK HAS BEEN LOADED
5640 REM ************************************************************
5700 INPUT J$
5800 PRINT @40:K$
5900 I$=CHR(10)
6000 P$=CHR(127)
6100 I$=I$&P$
6200 INPUT @40:Y$
6300 IF Y$=I$ THEN 6500
6400 GO TO 6200
6500 REM
6510 REM ********************************************************
6520 REM  USE THE 'M' COMMAND ON THE AIM TO TRANSFER CONTENTS OF
6530 REM MEMORY. AFTER PRINTING ONE 'M', THEN PRINT SPACES(S$).
6540 REM D$ IS THE CHARACTER STRING THAT HOLDS THE CHARACTER
6550 REM SENT UPON A 'M' COMMAND. H$ AND Q$ ARE SEGMENTS OF THIS
6560 REM CHARACTER STRING WHICH CONTAIN THE HEX DATA. SINCE THE STRING
6570 REM SENT BY THE AIM IMMEDIATELY AFTER THE 'M' COMMAND IS UNIQUE,
6580 REM SPECIAL PROVISION HAS BEEN MADE.
6620 REM **************************************************************
6630 REM
6640 REM
6650 REM
6700 REM
6900 T1=T1+1
7100 S$=CHR(32)
7300 CALL "WAIT",0.4
7400 PRINT @40:"M"
7500 CALL "WAIT",0.2
7600 PRINT @40:"O"
7700 CALL "WAIT",0.2
7800 M$=CHR(13)
7900 PRINT @40:M$
8000 INPUT @40:D$
```

```
8300 H$=SEG(D$,7,2)
8400 Q$=SEG(D$,4,2)
8500 H$=Q$&H$
8600 GOSUB 34600
8700 D1(1,N)=D
8800 H$=SEG(D$,13,2)
8900 Q$=SEG(D$,10,2)
9000 H$=Q$&H$
9100 GOSUB 34600
9200 F(1,N)=D
9300 REM******FINISH DEPTH AND FORCE ********************************
9400 FOR J=2 TO 32
9500 CALL "wait",0.3
9600 PRINT @40:S$
9700 INPUT @40:D$
9800 H$=SEG(D$,14,2)
9900 Q$=SEG(D$,11,2)
10000 H$=Q$&H$
10100 GOSUB 34600
10200 D1(J,N)=D
10300 H$=SEG(D$,20,2)
10400 Q$=SEG(D$,17,2)
10500 H$=Q$&H$
10600 GOSUB 34600
10700 F(J,N)=D
10800 NEXT J
10810 REM**********GET SURFACE DEPTH AND POSITION IN PROFILE *********
10900 CALL "WAIT",0.3
10910 PRINT @40:S$
10920 INPUT @40:D$
10930 H$=SEG(D$,14,2)
10940 Q$=SEG(D$,11,2)
10945 H$=H$&Q$
10950 GOSUB 34600
10960 D1(33,N)=D
10970 H$=SEG(D$,20,2)
10980 Q$=SEG(D$,17,2)
10990 H$=H$&Q$
11000 GOSUB 34600
11010 F(33,N)=D
30900 CALL "RATE",1200,2,2
30910 NEXT N
30982 K=K+1
30983 IF K>1 THEN 30988
30985 FIND 6
30988 DIM B(33,14)
30990 M=0
31000 FOR J=1 TO 33
31010 FOR I=1 TO 13
31020 B(J,1)=M
31040 B(J,I+1)=(F(J,I)-F(1,I))*6.967
31050 NEXT I
31060 M=M+20
31070 NEXT J
31080 PRINT @33:B
31082 IF K=2 THEN 31090
31085 GO TO 3970
31090 STOP
34000 REM ***************************************************
34100 REM SUBROUTINE TWO CONVERT CHARACTER STRING WHICH REPRESENTS
34200 REM  A 4 DIGIT HEX NUMBER(H$) TO A VARIABLE CALLED D.
34300 REM  NOTE LEN(H$) CANNOT > 4 ; D CANNOT > 65535
34400 REM *****************************************************
```

```
34500 REM********************* HEX (H$) TO DECIMAL (D) ***************
34600 C$=""
34700 IF LEN(H$)>4 THEN 36800
34800 D=0
34900 D=0
35000 FOR I=4 TO 1 STEP -1
35100 I$=SEG(H$,I,1)
35200 C$=C$&I$
35300 NEXT I
35400 FOR I=1 TO 4
35500 B$=SEG(C$,I,1)
35600 X=ASC(B$)
35700 IF X=>48 AND X<=57 THEN 36300
35800 IF X=>65 AND X<=70 THEN 36100
35900 PRINT "ERROR-ENCOUNTERED ILLEGAL HEXIDECIMAL DIGIT"
36000 RETURN
36100 X=X-55
36200 GO TO 36400
36300 X=X-48
36400 M=X*16^(I-1)
36500 D=D+M
36600 NEXT I
36700 RETURN
36800 PRINT "ERROR-EXCEEDED NUMERICAL LIMIT"
36900 RETURN
```

FILE 2 CONTENTS

```
0200
LDA #BC
STA A800
LDA #00
STA A434
LDA #54
STA A412
JSR EDEA
LDA #47
STA A42E
STA A42F
STA A430
STA A431
STA A432
JSR E32F
LDX #00
JSR ED3B
STA 00,X
INX
CPX #8C
BNE 0228
JSR E8FE
LDA #AC
STA A800
JMP E192
```

APPENDIX C

TEKTRONIX TO SAS DATA TRANSFER PROGRAM

```
90 REM ***** THIS PROGRAM SENDS DATA FROM A FILE TO A SAS DATA SET****
92 REM
95 REM GET THE FILE
100 FIND 5
110 DIM C(33,14)
120 DIM B(33,14)
130 INPUT @33:B
140 INPUT @33:C
150 FOR I=1 TO 31
160 FOR J=1 TO 14
170 CALL "WAIT",2.5
180 PRINT @40:B(I,J)
190 NEXT J
200 NEXT I
210 FOR I=1 TO 31
220 CALL "WAIT",2
230 PRINT @40:C(I,1)
240 FOR J=14 TO 2 STEP -1
250 CALL "WAIT",2.5
260 PRINT @40:C(I,J)
270 NEXT J
280 NEXT I
290 REM
300 REM ***** SAVE THE DATA-SET ******
310 REM
320 A$=CHR(13)
320 S$=CHR(83)
340 CALL "WAIT",2
350 PRINT @40:A$
360 CALL "WAIT",1
370 PRINT @40:S$
380 PRINT @40:A$
390 CALL "WAIT",9
400 END
```

APPENDIX D

LOAD CELL SPECIFICATIONS

SPECIFICATIONS

	PRECISION T3P1, C3P1	GENERAL PURPOSE U3G1
PERFORMANCE		
Rated Output (R.O.)—millivolts per volt	3	3
Calibration Accuracy—% R.O.	0.10	0.25
Nonlinearity—% R.O.	0.05	0.10
Hysteresis—% R.O.	0.02	0.02
Repeatability—% R.O.	0.02	0.02
Creep—% R.O.	0.03	0.03
ELECTRICAL		
Excitation, recommended	12 volts, AC or DC	12 volts, AC or DC
maximum	20 volts, AC or DC	20 volts, AC or DC
Zero balance—% R.O.	±1%	±1%
Terminal resistance, input—ohms	350 ± 3.5	350 ± 3.5
output—ohms	350 ± 5.0	350 ± 5.0
Electrical connection	10 ft. cable	10 ft. cable
Number of bridges	one	one
Insulation resistance—bridge to ground	5000 megohms	5000 megohms
shield to ground	2000 megohms	2000 megohms
TEMPERATURE		
Temperature range, compensated	+15°F to +115°F	+15°F to +175°F
safe	−30°F to +175°F	−30°F to +175°F
Temperature effect on rated output	0.0008% load/°F	0.005% load/°F
Temperature effect on zero balance	0.0015% R.O./°F	0.0025% R.O./°F
ADVERSE LOAD RATING		
Safe overload—% rated capacity	150	150
Ultimate overload—% rated capacity	300	300
Maximum side load without damage—% rated capacity	10	10
Maximum bending moment without damage—% in inch-pounds	25	25
Maximum torque load without damage—% rated capacity in inch-pounds	10	10
DOUBLE-BRIDGE SPECIFICATIONS	**T3P2B, C3P2B**	**U3G2**
Same as for above types except:		
Electrical connection	Bendix connectors	10 ft cables
Number of bridges	two	two

This model ordered
received 9/5/72

CATALOG NUMBERS AND MECHANICAL DATA

Capacity Lbs.	U3G1 Cat. No.	T3P1 Cat. No.	C3P1 Cat. No.	U3G2 Cat. No.	T3P2B Cat. No.	C3P2B Cat. No.	Wt. Lbs.	Deflec. In.	Nat. Freq. CPS	Eff. Wt. Lbs.
500	206159	206166	206173	207797	206306	206313	6	.007	1250	.45
1,000	206160	206167	206174	207798	206307	206314	6	.006	1800	.50
2,000	206161	206168	206175	207799	206308	206315	6	.005	2600	.56
3,000	206162	206169	206176	207800	206309	206316	6	.005	2600	.56
5,000	206194	202201	206208	207803	206362	206369	10	.007	2200	1.50
10,000	206195	206202	206209	207804	206363	206370	10	.005	3400	1.70

BENDIX PC02C-12-10P

input—B K −
D H +
Output—E J +
A F −
C, G No Connection

NOTE: Mating half and dust cap supplied with above electrical connectors.

ELECTRICAL TERMINATION		
CABLE COLOR CODE		
INPUT	OUTPUT	SHIELD
Black (−)	Red (−)	Yellow
Green (+)	White (+)	

NOTE

1. SYMMETRICAL CIRCUIT. The input circuit resistance is split such that the resistance between either input lead and either output lead is within 1.75 ohms at 77°F.
2. For Tension or Compression types (T or C), Calibration Accuracy applies in direction of standardization only.

VITA

Glen Philip Riethmuller

Candidate for the Degree of

Master of Science

Thesis: MICROCOMPUTER BASED DATA ACQUISITION FOR A TRACTOR-MOUNTED PENETROMETER

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Toowoomba, Queensland, Australia, February 7, 1958, the son of Mr. and Mrs. Percy R. Riethmuller.

Education: Matriculated from Harristown State High School, Toowoomba, in December, 1974; received Bachelor of Engineering (Agricultural) degree from the Darling Downs Institute of Advanced Education, Toowoomba, in May, 1979; enrolled in Master's program in August, 1980 at Oklahoma State University; completed requirements for the Master of Science degree at Oklahoma State University in May, 1982.

Professional Experience: Student Member of The American Society of Agricultural Engineers; graduate research assistant, Oklahoma State University. Agricultural Engineering Department, 1980-1982. Member of the Honor Society for Agricultural Engineering, Alpha Epsilon (in United States). Student Member of the Institution of Engineers Australia. Member of the Agricultural Engineering Society of Australia.