Design and Development of a Tractor-Mounted, Recording Penetrometer

by

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(ABSTRACT)

As part of a long term study dealing with the effect of continuous use of no-till practice on soil structural characteristics, this study was conducted with the following objectives: (i) to design and develop a tractor-mounted, hydraulically-operated, recording penetrometer, (ii) to collect the initial penetration resistance data from the experimental plots established for the long term study.

A penetrometer assembly was designed and constructed with the capability of collecting penetration resistance across two crop rows. At any point, the penetration resistance data could be collected up to a depth of 60 cm. A simple hydraulic circuitry was developed to control the rate of penetration at 3 cm/s.

A micro-computer based data acquisition system was developed to record the penetration resistance and depth data during each penetration test. This data acquisition system together with a cassette tape recorder could record the data from large number of tests under field conditions. The data stored on the tape could be transferred to a personal computer for data reduction and analysis.

Field tests were conducted to evaluate the system developed and to establish the initial data for the experimental plots established for long term study. Results of these tests indicated that the system functioned satisfactorily and there exists significant difference in penetration resistance from plot to plot and as a function of depth within each plot.

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Table of Contents

List of Illustrations

List of Tables

1.0 INTRODUCTION

The efficient utilization of all farm inputs leads to profitable farming. To feed the ever increasing world population, it is necessary, in many parts of the world to keep all cultivable lands in production and in some instances, to increase the area being cultivated. Conversely, land that was fertile is being rendered unproductive at an alarming rate because of inappropriate cultural practices. This irreversible degradation of soil reduces its productive potential.

In temperate countries, crop cultivation is possible during a portion of the year because of weather conditions. Therefore, farming operations must be synchronized with weather patterns within the cropping season to ensure a successful crop. In addition to weather, soil condition and weed competition also influence crop production. Soil preparation used with conventional planting method generally includes loosening of the top soil as well as incorporating weeds in the soil. In addition to plowing, conventional soil preparation includes other sequential tillage operations such as disking and levelling. The time between these operations may be large depending on the cropping system used. Therefore, conventional methods generally require more time, labor and energy inputs for land preparation. The plowing operation alone uses about 50% of the total energy required for seed bed preparation (Sin et al. 1979, Cannel 1985).

One disadvantage associated with conventional land preparation is that the soil is exposed to varying weather conditions during the period between plowing and crop establishment. During this period, wind and rain can cause considerable soil erosion because of lack of proper cover. For the same reason, moisture retention capacity of the soil is reduced and surface runoff and soil erosion are increased. Crop residue on the soil surface or incorporated close to the surface helps to conserve soil. This type of soil conservation can be achieved with a dead or live mulch on the soil. In most cropping situations, a live mulch is undesirable since it competes with the main crop. A dead mulch can be formed in one of the following two ways:

1. By transporting and spreading the dead plant residues in the field.

2. The vegitative cover crop, which may be weeds or a planted crop, can be killed with herbicides and left on the field.

Creating a mulch using the second procedure is more widely used because it is practical and economical. Plant growth regulators such as paraquat which was developed during World War II, are used widely for this purpose. Since weed control is accomplished by herbicide applications, plowing the soil is not necessary. This observation probably set the stage for the reduced tillage concept. According to Allmaras and Dowdy (1985), the reduced tillage concept was introduced first in 1941. However, a more systematic study of the reduced tillage or no-till farming concept was initiated only in 1951 (Phillips, 1973). Even though many studies during the period 1950 - 1970 showed the potential of the use of the reduced or no-till concept for minimizing soil erosion, the procedure, did not become popular until the1960's (Allmaras and Dowdy,1985).

Even after the no-till conept was proven successful, many farmers have continued to use conventional tillage methods. On the other hand, on large farms, producers have tried to minimize the labor and time required for planting by combining operations into one pass across the field. In some cases, chemical and fertilizer applications and seeding are all done as one operation using heavier tractors. One disadvantage in using heavy machines is that these machines compact the soil and create a hard layer below the plowing depth which is known as the plow pan. This compact layer inhibits the root propagation and water movement within the soil, resulting in reduced crop yields.

The popularity of conservation tillage among the farmers in the southeastern United States in the 1960's is attributed to the following four major factors (Phillips, 1973):

1. delayed corn and soybean planting dates due to wet soil conditions in the spring of the year;
2. labor shortages;
3. the development of no-till planters; and
4. increased availability of dependable chemicals to control competing vegetation.

Energy supply interruptions along with the increased cost of petroleum fuels in the early 1970's encouraged farmers to adopt energy saving methods in their operations. Many farmers found the no-till farming concept more attractive because it eliminated operations associated with seedbed preparation. Because of the advantages stated earlier along with increased yields reported for many crops, more and more farmers around the world are adopting conservation tillage practices each year.

In contrast, a few recent studies have shown that the continuous use of no-till methods can reduce crop yields (Cannel et al., 1979; Frankinet et al., 1979 and Vyn et al., 1979). In most reported cases, the reduction in yield was attributed to soil compaction resulting from the use of heavy equipment year after year. A significant increase in soil compaction has adverse effects on water and nutrient movement within the soil, moisture holding capacity of the soil, root penetration, and thus, on crop yield. Therefore, the changes in the structural characteristics of the soil can negate the advantages attributed to no-till concept.

Even though the no-till concept is widely accepted and used, very little is known about the effect of the continuous use of the no-till procedure on the soil structure. This information is essential to determine the duration which a farmer can use the no-till procedure without loosening the soil and for selecting a tillage system most suitable to accomplish that task. A long range study to assess the effect of the continuous use of the no-till procedure on the soil-air-water matrix is planned by the Departments of Agricultural Engineering and Agronomy at Virginia Tech. During this study several field and laboratory measurements are planned to characterize the structural changes within the soil. One of the field measurements planned is the soil penetration resistance to a standard cone penetrometer.

Most commercially available cone penetrometers are manually operated and lack provision for recording the penetration resistance continuously as a function of depth. Since the collection of data while maintaining the penetration rate at the recommended rate of 3 cm/s is not possible manually, a mechanically operated, recording penetrometer is essential for most field studies.

Therefore, the specific objectives of this study are:

1. To design a tractor-mounted, hydraulically-operated cone penetrometer with a micro computer data logging system.

2. To evaluate the penetrometer by collecting penetration resistance data from 9 test plots which are to be used in a long range study on the effects of continuous use of the no-till procedure on the soil-air-water matrix.

2.0 LITERATURE REVIEW

2.1 Advantages and Disadvantages of No-till Practices

The equation most widely used to predict the soil loss is Universal Soil Loss Equation, expressed as:

$$A = RKLSCP \quad [1]$$

where:

A = total annual soil loss (kg/ha)

R = rain fall factor (erosion index units/year)

k = erodibility of the soil (kg/ha/erosion index)

LS = topographic factor (length and slope factor) (%)

C = vegetative cover and crop management factor (%)

P = erosion control practice factor (%)

The total annual soil loss is directly proportional to P and C, which can be controlled. For example, one thousand pounds straw cover per acre can reduce the value of C by one half. This reduced value is approximately the same as that observed for untilled bare soils (Evans and Kalkanis, 1976). This amount of straw mulch also reduces the P factor to 1% (Roose, 1976). Thus, use of the no-till method is effective in controlling soil erosion since it leaves a mulch on the soil surface and does not disturb the soil. Harrold (1972) showed that soil erosion can be reduced from 242,000 kg/ha under conventional tillage to 330 kg/ha when using no-tillage on sloping land with high intensity rainfall. Thus, the no-till procedure helps to maintain the productivity of farmland and to minimize pollution of public streams while decreasing the energy required for crop production. Other advantages associated with the no-till practice include timely planting because the time normally spent for land preparation is avoided, savings in irrigation water usage, and reduced evaporation loss (Phillips, 1973).

Soil arthropods and earthworms are generally more prevalent with no-till methods compared to conventional tillage practices (House and Parmelee, 1985). These soil fauna are involved in the decomposition of organic matter in the soil. Favorable moisture levels and temperature regimes are listed as possible reasons of the increased earthworm activities (Armon and Lal, 1979). The macropores created by earthworms, as well as by decayed root systems of previous crops, increase the hydraulic conductivity and infiltration rates in the upper layers of the soil. Plowing generally disturbs the continuity of these passages, causing a decrease in hydraulic conductivity of the surface layer (Armon and Lal, 1979; Lal, 1985).

Conservation tillage practices help to increase yield in many cropping situations. Kemper and Derpsch (1979) reported a yield increase of 37% for wheat using no-tillage compared to conventional tillage practices. The increase was attributed to lower soil temperatures, greater moisture availability, higher microbial activity and increased infiltration rates. Sin et al. (1979) also reported increased yields in wheat.

Water stored in the soil using no-till practices is usually about 20 percent or more compared to conventional tillage (Phillips, 1973). This extra moisture helps to reduce plant stress during short drought periods. Thus, use of no-till practices generally results in increased crop yields in years having low rainfall. Therefore, medium textured, well drained to moderately well drained soils are suited for the no-tillage cultural practices (Blevins and Thomas, 1973). No-till practices have also been used successfully with well to excessively drained sandy soils such as loamy sands in Delaware (Mitchell and Teel, 1977), and on sandy loam to sandy clay soils in Georgia (Gallaher, 1977). Using good management practices, no-till winter crops have also been grown in well drained loam soils (Davies et al., 1979).

However, in poorly drained soils, the moisture availability with no-till practices may not be high enough to produce significant increases in yields in years having low rainfall (Triplett et al., 1968; Moschler et al., 1973 and Hummel et al., 1985). In years with plentiful rain, the no-till practice can result in reduced crop yields due to low oxygen concentration and restricted root growth in poorly drained clay soils (Cannel et al., 1979 and Voorhees et al., 1985).

Since the soil is covered with a surface mulch, the amount of thermal energy absorbed by the soil is less in no-till plots when compared to conventionally tilled plots. This condition may result in a soil temperature lower than the optimum temperature for plant growth which affects the growth rate and the crop yield (Moschler et al., 1973; Triplett et al., 1968; and Carter and Rennie, 1985). After the crop canopy is developed, soil temperatures for no-till and conventionally tilled plots are not significantly different. (Carter and Rennie, 1985).

Murdock (1974) reported reduced yields from inadequately drained soils using conservation tillage practices. He cited the following reasons for the reduced yields: (a) poor growth and emergence related to the low soil temperature, (b) loss of nitrogen, (c) disease damage due to the seedling stress, (d) insect damage to the plants during the time of reduced vigor, and (e) poor growth due to low levels of oxygen following rainy periods.

According to Frankinet et al. (1979), the continuous use of no-till practices reduced the yield of the sugar beet by about 20%, barley by 11%, fodder maize by 14%, winter wheat by 1%, and oats by 2%, while increasing horse bean yields by 5%. Vyn et al. (1979) observed a reduction in maize yields by about 11% as compared to conventional tillage over 15 years of experimentation using continuous no-tillage practices. Yield results were related to less favorable aggregate size distribution and increased soil density.

Initially, the general assumption among researchers was that the no-till practice would reduce soil compaction because of reduced traffic (Phillips, 1973). Studies have shown that 75-90 percent of the compaction due to multiple passes by a vehicle is caused on the first pass (Taylor et al., 1982; Trouse, 1966; Soane et al. 1981). However, the soil response to multiple passes depends markedly on the initial soil strength and strength distribution. Soils which are initially loose experience maximum compaction during the first pass, whereas on soils which have higher initial strength, the compaction resulting from the first pass differs little from that of subsequent passes (Soane et al., 1981). Conservation tillage systems frequently combine operations such as fertilizer application, herbicide application, and planting into a single operation, which generally requires heavier and larger equipment and more stabilizing wheels than conventional tillage systems (Voorhees and Lindstrom, 1983). Thus the continuous use of no-till practices with no primary tillage may cause severe compaction in certain soil types. Soil compaction increases soil bulk density and reduces hydraulic conductivity and moisture holding capacity of the soil. In clay soils, soil compaction has been found to result in low dry matter yield of silage corn (Douglas and McKeys, 1983). Tayler et al. (1984) showed that the crop responses to no-till planting in clay soils might depend on the type of clay, weather pattern, residue management and the method of seeding. On the other hand, the variations in yield could be due to variations in plant density. The emergence of seedlings greatly depend on the depth of seed placement. The depth at which the seeds are placed by no-till slot planters may be affected by the presence of stalk on corn fields (Janke and Erbach, 1985).

Taylor et al. (1981) reported an increase in silage corn yields using the no-till system compared to traditional tillage in a Ste. Rosalie clay soil in Canada. The increase was attributed to improved root penetration resulting from improvements in soil structure due to loosening effects of freeze-thaw cycles on compacted soils. Voorhees (1983) reported incomplete amelioration of compacted soils by natural forces during the winter season when soil was covered with mulch. He also reported higher soil bulk density, aggregate density and penetration resistance due to the continuous use of no-till systems. Kay et al. (1985) found that the loosening caused by ice lens formation in the winter was temporary and that soils, upon thawing, reconsolidated to the prefreezing bulk densities. Bauder et al. (1984) found the highest soil strength in a clay loam soil in a no-till treatment compared to other plowing treatments. He rated the soil strength resulting from different tillage treatments as mold boardplow < chisel plow < till planting < no-till planting. Similar results were observed by Lindstrom and Onstad (1984). Hilfiker et al. (1984) found higher penetration resistance and bulk density values for soils in no-till plots in Kewaunee soils, and that the level of compaction was detrimental to corn yield. Soane et al. (1976) and Voorhees (1979) observed that the zone of maximum compactness in a soil profile tends to approach the surface with repeated passes.

2.2 Characterization of Soil Compaction

Different types of measurements are used to characterize the soil condition and to express the degree of soil compaction. Bulk density, hydraulic conductivity and pore size distribution are some examples of such measurements. The soil resistance to the penetration of a penetrometer is also used as an indicator of soil compaction. For a given soil, at constant moisture level, the penetration resistance is directly proportional to the degree of compaction. The standard cone penetrometer was originally developed by the Waterways Experimental Station (WES) of the US Army Corps of Engineers to predict the trafficability of vehicles over a particular terrain. The penetrometer has a cone with an apex angle of 30 degrees and base area of 3.23 cm^2 which is mounted on a 91 cm long graduated shaft of 0.97 cm diameter. A proving ring with a dial gauge is provided between the handle and the rod to indicate the penetration resistance. The proving ring is calibrated so that the reading on the dial gauge represents the soil resistance in pounds per square inch.

The soil properties together with the size, shape and the rate of penetration influence the penetration resistance (Frietag, 1967; Gill, 1967). Therefore, it is important that the results of penetration tests be compared carefully. As a result, a standard for the cone penetrometer was developed by the American Society of Agricultural Engineers (ASAE standard S313.1). According to the standard, a penetration rate of 3 cm/s is recommended for penetration tests.

The ASAE standard S 313.1 is widely used to measure cone index for tillage and traction studies, soil mobility research, soil compaction studies and plant growth studies. The resistance of a given soil to penetration represents the combined influence of both the cohesional and frictional characteristics of the soil. When a frictional component exists, the relation of cone index to the state of the soil depends on the state of compaction as well as other physical properties of the soil (Frietag, 1971). The moisture content of the soil has been found to have a greater effect on cone index (Ayers and Perumpral, 1982).

Commercially available, hand-held penetrometers lack provisions for recording the penetration resistance continuously and for controlling the rate of penetration. The operation of this cone penetrometer generally requires at least two persons since dial gauge readings are to be taken at one-inch depth increments while the penetrometer is pushed into the soil at the prescribed rate. In addition, manually maintaining a constant penetration rate of 3 cm/s during the test is also practically impossible. To overcome these limitations, recording penetrometers have been developed.

A recording, hand-held penetrometer was developed by Scottish Institute of Agricultural Engineering (Anderson et al. 1980). The penetrometer records a limited number of readings per penetration (15) which must be transferred after each penetration test to paper or electronic memory. Carter (1967) developed a simple hand-held recording penetrometer with a calibrated spring and a spring-loaded frame to graph the soil strength on a 7.5 x 12.7 cm card. Hendrick (1969) described a recording penetrometer consisting of a calibrated spring and moving chart paper. Howson (1977) made a recording penetrometer with a calibrated spring and rotating chart paper. Prather et al. (1970) introduced electronics into the hand held recording penetrometer by connecting an X-Y plotter to plot the penetration resistance versus depth of penetration. Woodruff and Lenker (1984) designed a hand-held digital penetrometer with a data logger which could store data from 60 to 70 penetrations of 48 readings each.

All the hand-held penetrometers discussed thus far lack the provision for controling the rate of penetration. Carter (1967) stated that the difference between cone indices resulting from penetration rates of 3.05 to 30.5 cm is negligible. To overcome this drawback Lowery (1984) designed a tripod mounted portable cone penetrometer which could be driven into the soil at a constant rate using an electric motor.

Williford et al. (1972) developed a tractor mounted penetrometer. A hydraulic cylinder was used to push the penetrometer probe into the soil. An X-Y plotter recorded the force-depth relationship during the penetration tests. Smith and Dumas (1978) collected data at given depth intervals in the soil profile using a tractor-mounted recording soil penetrometer. The power to push the probe into the soil was supplied by an electric motor. This unit could measure cone index values in the range of 0-14000 kPa. Threadgill (1982) used an electronic recording, tractor-mounted, hydraulically-operated cone penetrometer to measure soil resistance. This recording penetrometer was modified later by Cromer and Threadgill (1985) using a personal computer with dual disk drives and monitor for field data collection and analysis. The depth vs force relationship displayed on the monitor, helped the operator with the decision to save or reject the data and repeat the test. Recording across 2-m wide sections were possible and lateral movement of the unit was accomplished using an electric gear motor. The electric motor was powered by a portable generator. Wilkerson et al. (1982) developed a microprocessor- based tractor mounted soil cone penetrometer which was hydraulically operated. The micro-processor-based control unit actuated all the mechanisms and automatically recorded the data on a magnetic tape.

3.0 PENETROMETER ASSEMBLY AND DATA ACQUISITION SYSTEM

Development of mechanically operated, recording cone penetrometer involved design and development of a penetrometer assembly which could be mounted on a medium sized farm tractor and developing appropriate data acquisition system for recording the penetration resistance data as a function of depth under field conditions. The design and development of each is discussed in this section.

3.1 Design and Development of Penetrometer Assembly

Since the penetrometer assembly were to be used to assess the soil penetration resistance as an indicator of changes in soil structural characteristics due to continuous use of no-till procedures, the following criteria were selected for its design and development.

1. Penetrometer assembly should have provisions to take penetration resistance data on a vertical section across crop rows (two row wide) at pre determined interval laterally.

2. The penetrometer should have the provision to take readings up to a depth of 60 cm maintaining a standard rate of penetration of 3 cm/s (ASAE standard S313.1).

Based on the criteria listed, it was decided that the total system should be tractor mounted and the tractor hydraulic system should be used to maintain the desired rate of penetration. Accordingly, the penetrometer assembly shown in Figure 1 and Figure 2 were designed and constructed.

The penetrometer assembly consists of the following major components:

- A frame to facilitate lateral movement of the penetrometer,
- A penetrometer carriage, and
- A hydraulic system for controlling the rate of penetration,

3.1.1 Penetrometer assembly

A rectangular frame 3 m long, 0.5m wide was constructed of 5 X 5 cm box beams to permit penetrometer resistance data collection from a vertical soil section across two crop rows with a maximum spacing of 1 m. This rectangular frame was supported by two 3.75 X 3.75 cm angle iron legs in the front and two 2.5 X 2.5 cm angle iron legs in the rear. The 97.5 cm long legs were welded to the frame at the corners. A 5 X 5 cm box beam was located between the front legs, approximately 60 cm below the upper rectangular frame, to mount the connectors for the 3-point linkage. Additional braces as shown in Figure 1, were provided for reinforcement. The entire frame work was mounted on two 75 X 20 X 2.5 cm boards for stability as well as for distributing the load on a larger area.

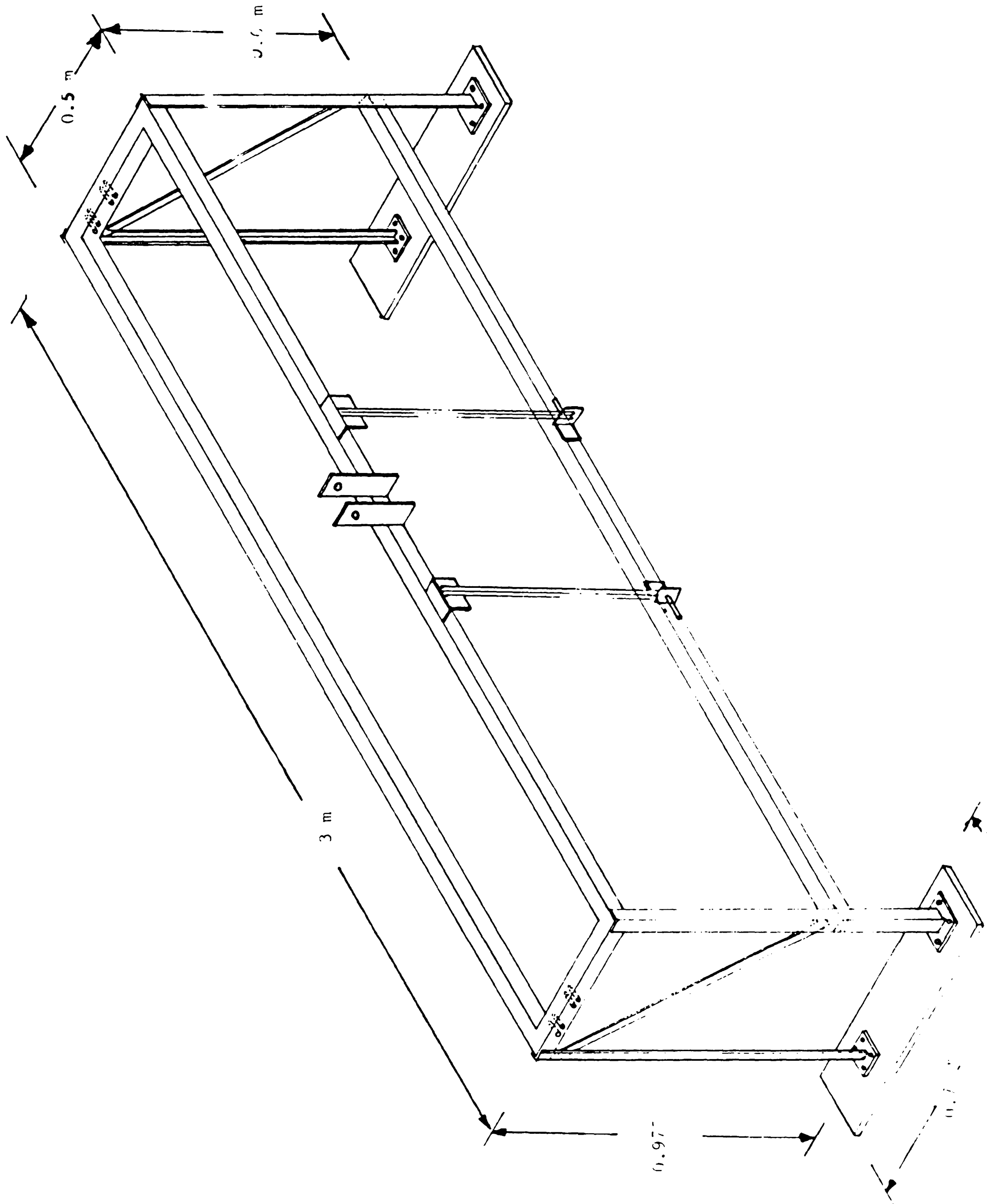

Figure 1. The penetrometer frame.

Figure 1. The penetrometer frame.

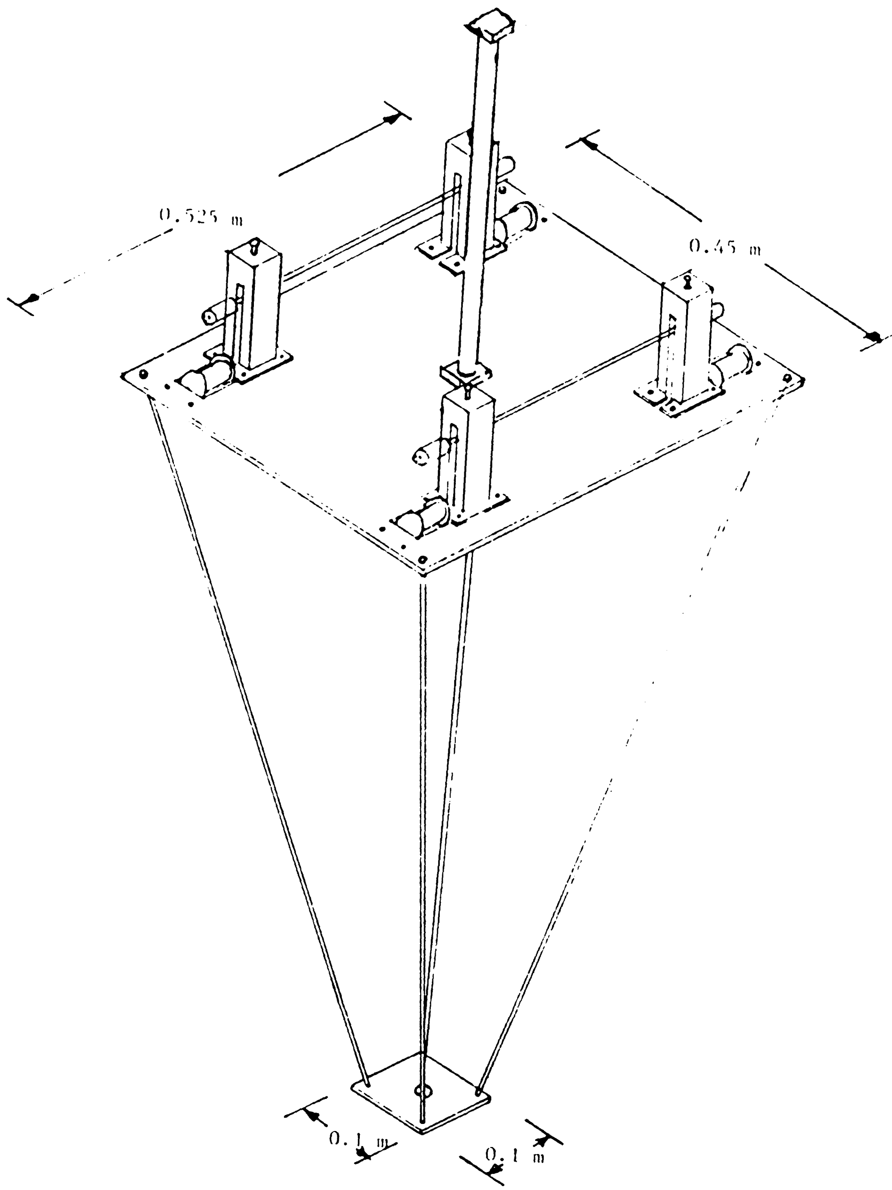

Figure 2. The penetrometer carriage.

The penetrometer carriage (Figure 2) included a rectangular steel plate, hydraulic cylinder, load cell, cone penetrometer, wheels to support and guide during the lateral movement of the penetrometer and a mechanism for depth measurement. The hydraulic cylinder was mounted on a rectangular steel plate 52.5 X 45 X 0.625 cm with the rod extending through a 1.9 cm hole provided at the center of the plate. The load cell and the penetrometer were attached to the cylinder rod. In order to guide the penetrometer into the soil straight, a squire steel plate (10 X 10 X 0.625 cm) with a 1.9 cm hole in the center was located 85 cm below the larger plate described earlier. This plate was attached to the larger plate with the help of 4, 1.3 cm threaded rods. The two plates were located in such a fashion the centers of both holes were on the same vertical line. On each corner of the larger plate, approximately 4.5 cm from the edge, four 20 cm posts constructed of 5 X 5 cm box beam with 2 cm wide slots on two sides were mounted. Two, 1.9 cm diameter shafts with press wheels (5 x 5 cm) at the ends were located inside the two sets of slots so that the axes of the shafts were perpendicular to the largest dimension of the rectangular frame described earlier. The four press wheels riding on the box beam supported the entire penetrometer carriage. The shafts with wheels were spring loaded with four springs located vertically inside each vertical post. The force on these springs pressing on the shaft could be increased by turning the bolt provided on the top plate of the post clockwise and pushing against flat washer located on the top of the springs. In order to prevent rotation of penetrometer carriage and to guide it along the box beams of the rectangular frame, 4 wheels (5 X 7.5 cm) with flanges were mounted directly beneath the press wheels so that the box beams were sandwiched between four sets of wheels. The wheels with flanges were mounted on the rectangular plate and through the slots provided on the plate. The wheels were pressed against the beam.

The lateral movement of the penetrometer carriage on the rectangular frame was facilitated with a hand cranking mechanism. It consisted of a crank, four sprockets and two roller chains. On either side of the rectangular frame, two sets of sprockets were mounted (Figure 3).

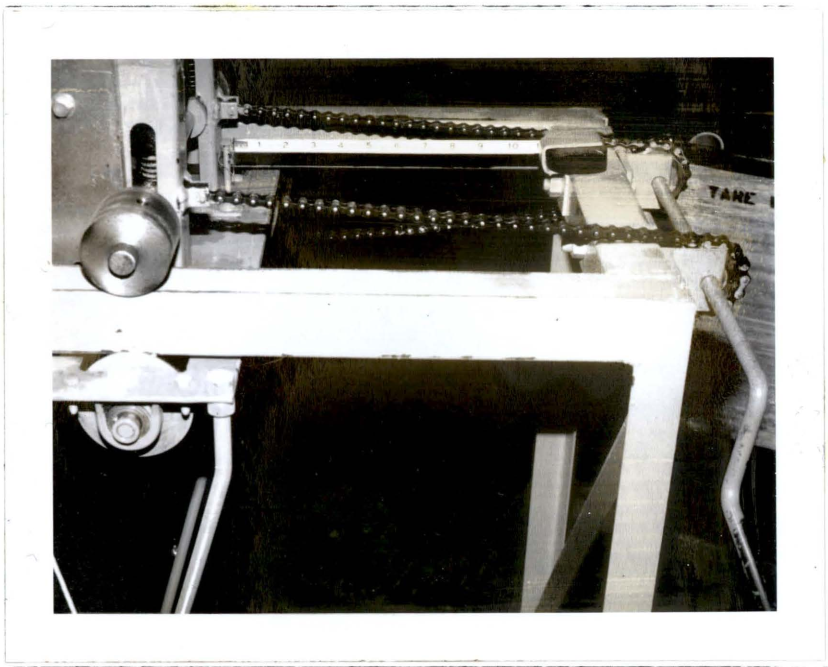

Figure 3. A hand cranking mechanism for lateral displacement of penetrometer carriage.

The sprocket set on the right had a hand crank through them and were the driving sprockets. Two roller chains were looped around all the four sprockets and their ends were attached to the penetrometer carriage. A retractable 3.3 m metal tape was mounted on the same end of the rectangular frame with hand crank. With the tape end attached to the penetrometer carriage it extended as the carriage moved to the left. This simple arrangement helped the placement of the penetrometer assembly at predetermined intervals laterally.

The penetrometer used in the study consisted of a steel shaft 1.9 cm in diameter and 71 cm long with standard cone from a Soil Test cone penetrometer, model CN-973. The penetrometer was threaded into a 2224 N capacity, sheer type load cell (GSE model 5353) mounted on the cylinder rod.

A linear variable resistor was used to sense the penetration depth. The resistor with a pulley attached to its shaft was mounted on a bracket located between the load cell and the cylinder rod. A cable looped around the pulley was stretched between the two steel plates (Figure 4). With this arrangement, during extension stroke, the pulley moved down on the cable changing the resistance of the resistor. The depth measuring technique and the circuit used for the same are discussed in detail in a later section.

3.1.2 Hydraulic system

Since a decision was taken to make use of the tractor hydraulic system for maintaining constant rate of penetration during tests, a simple circuit was added to control the rate of penetration and to limit the maximum force on the penetrometer. The components of the circuit designed for this purpose included a hydraulic cylinder, pressure relief valve, directional control valve and a flow control valve as illustrated in the Figure 5.

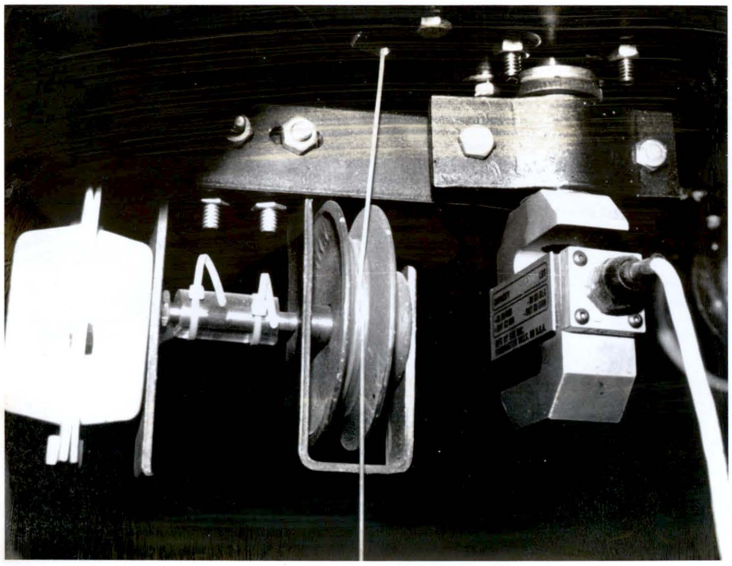

Figure 4. A close up view of the force and the depth transducers.

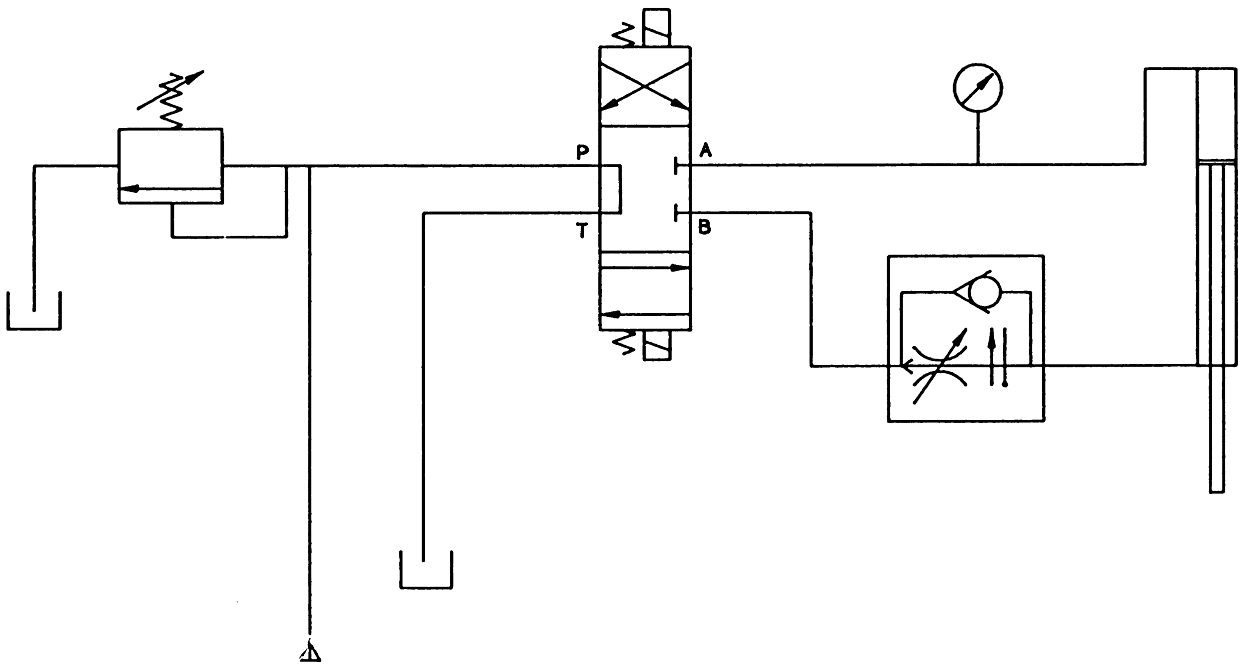

Figure 5. The schematic of the hydraulic system added to control the penetration rate and maximum force on the penetrometer.

A hydraulic cylinder with 3.75 cm bore and 70 cm stroke, was selected to push the penetrometer probe into the soil and obtain penetration resistance up to a minimum depth of 60 cm. The pressure relief valve in Figure 5 was in addition to the relief valve available with the tractor hydraulic system. This was provided to limit the maximum force on the penetrometer. A pressure and temperature compensated flow control valve was located on the rod end of the cylinder to regulate the flow rate out of the cylinder and thereby control the rate of penetration. A solenoid operated three position, tandem center, 4-way directional control valve was used to extend or retract the cylinder. The directional control valve could be activated using the power from the tractor ignition system.

3.2 Design and Development of Data Acquisition System

The collection of penetration resistance data as a function of depth and the ability to store the data from a large number of tests are essential for the field study under consideration. Since manual collection of these data was not practical, the decision was taken to record the data electronically. The design criteria selected for the data acquisition system were:

1. Read and store the penetration resistance at predetermined intervals during each penetration test,
2. Obtain power for the data logger from the tractor electrical system, and
3. The data logger should have the capacity to store the data collected over an 8-hour period.

The schematic of the data acquisition system developed based on the criteria stated, is shown in the Figure 6, and it included the following major components:

1. Force transducer,
2. Linear variable resistor to sense the depth,
3. Amplifier to condition the transducer output,
4. Analog to digital converter,
5. Micro-computer for data collection,
6. Cassette tape recorder for data storage, and
7. DC/DC converters to condition the power input to the system and load cell.

The 5V DC excitation voltage for the strain gage load cell was obtained from the tractor ignition system through a DC/DC converter. A linear, variable resistor as discribed earlier was used to sense the penetration depths (Figure 6). A voltage output corresponding to the penetration depth was obtained due to the resistance change within the variable resistor, resulting from the rotation of the pulley.

The position and force transducers were connected to an analog to digital (A/D) converter (DATEL SDAS-8A). This A/D converter was capable of receiving the differential analog inputs from 8 different channels and digitizing 15 samples per second. The digital output from the A/D converter was directly proportional to the voltage differential between the input lines of the channel. Updating the data was done by the converter from the register 1 to 8 in a sequential manner whether or not the data was sent to the micro computer. Therefore, to maximize the sampling rate, position and force transducers were connected to all of the even and odd numbered channels respectively. The length of the data string sent to the micro-computer could be manipulated through an output formatting procedure described later.

A Radio-Shack TRS 80, model 100 micro-computer was used as the host computer in the data logging system. It was connected to the A/D converter through the RS232 port. To maximize

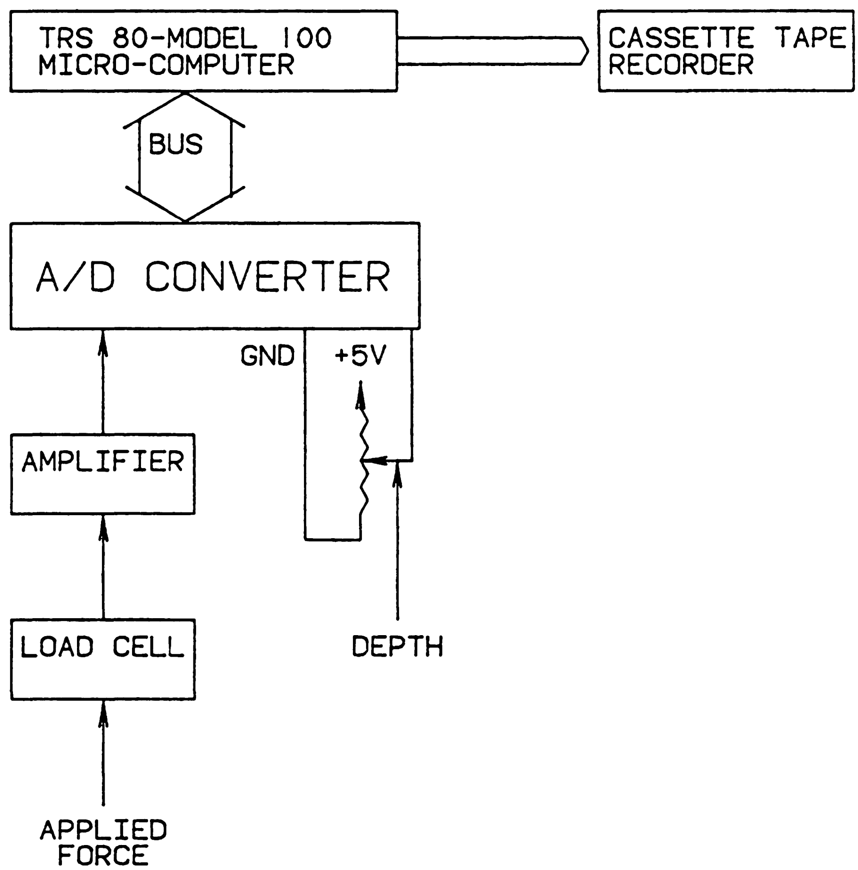

Figure 6. The schematic diagram of the data acquisition system.

the rate of data collection, the baud rate of 9600 was used to communicate between the micro-computer and the A/D converter.

The micro-computer and the tape recorder used a 6V DC supply, provided by the POWER GENERAL model 704 DC/DC converter. The PACKAGED POWER ES12T15 DC/DC converter generated 5V, + 15V and -15V DC supplies to the A/D converter and the amplifier. The 12V DC tractor battery supplied power to the DC/DC converters.

The circuit diagrams of this data logging system are given in appendix A. The circuit boards with the amplifier, DC/DC converters and the A/D converter were housed in an aluminum rack. Thirty two pin connectors and multi-wire ribbon cables were used to make connections between boards. The rack together with the micro-computer and the tape recorder were kept in an aluminum case for transportation and for protection under field conditions. A 37 pin quick coupler was mounted on the case for the external connections between the transducers and the data logger. Another 16 pin quick coupler was fitted to the case to supply power from the tractor battery.

3.2.1 Formatting the A/D converter output

The output from the A/D converter normally contained the echoed command, the time, the displacement and penetration resistance data, the hex sum of the data string and 216 null characters. This output was printed in lines of 20 characters. Storage of this long data string could result in undesirable delay in data collection. Therefore, using the output formatting commands, it was possible to exclude unnecessary informations such as echoed commands, date, null characters and line feed characters from A/D converter output were excluded prior to storage on the tape. The commands and the procedure used for formatting the A/D converter output are given in the User's Manual in appendix B.

The memory capacity of the computer was 32k bytes. It could hold 275 strings of 85 characters without affecting its string manipulating capabilities. A BASIC program IMP.BA, listed in the appendix C, was developed to send the commands to the A/D converter for formatting the output and for collecting the data. The flow chart of this program is given in the Figure 7.

The program had four major sections. The first section was used to record the background information about the plots. The next section formatted the A/D converter output. The third section was for the data collection and had to be initiated by pressing any key on the key pad. When the penetrometer was fully extended or in case of an emergency, such as penetrometer running into a rock, the data collection could be stopped by pressing the function key F1. Otherwise, the computer would collect 275 data strings from the A/D converter before it quits.

The A/D converter updated its memory locations for channels 1 through 8 in a sequential manner at the rate of 15 channels/s. However, even if it was in the middle of an updating cycle, the A/D converter read the memory and sent the data to the host computer if requested. Therefore, it was not clear whether the data recorded for a channel was from an earlier updating cycle or not. Most of the time the output contained both new and old data. Therefore, a decision was made to request data from A/D converter as frequently as possible and get several data strings from A/D converter at various stages in each memory updating cycle. Those strings which contained new data for the first channel indicated the beginning of a new memory updating cycle. Therefore, the string assembled at the end of the previous memory updating cycle were assumed to have updated data for all 8 channels. At the end of each penetration test, the micro computer sorted the complete data strings and transferred them on to the cassette tape. The final section of the program permitted the operator to enter comments pertaining to the test and store on the tape.

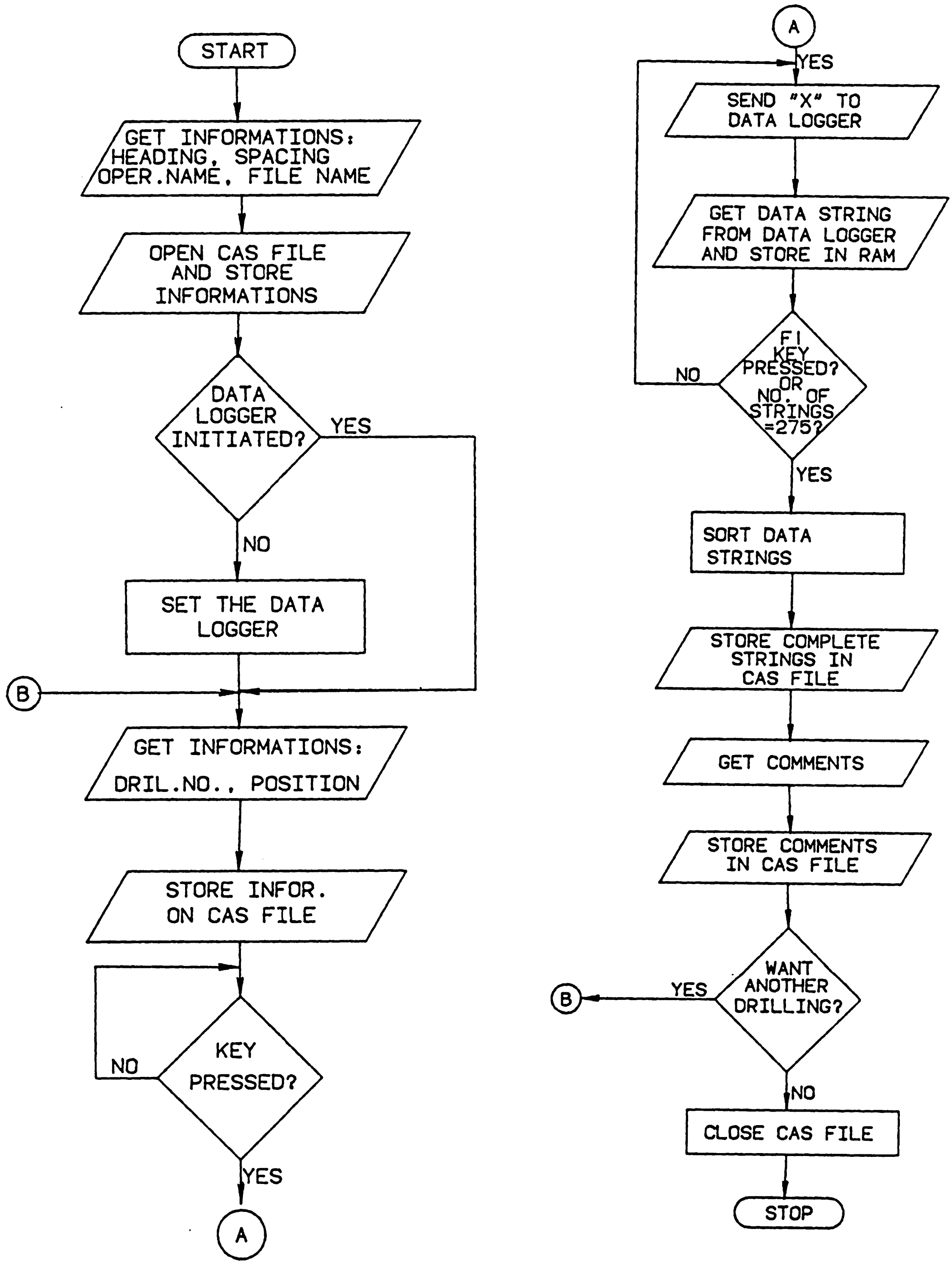

Figure 7. The flow chart for the BASIC program IMP.BA.

3.2.2 Calibration

The load cell was calibrated by applying loads in the range of 0 to 1780 N (0 - 400 lbs) and recording the A/D converter output. The relationship between the load and the voltage output was found to be linear and the regression line fitted to the data has an r^2 value of 0.9999. The gain of the amplifier used for amplifying the load cell output was set such that the following equation could be used to express the penetration resistance in kPa.

$$PR = 1103.2 \times Y \qquad [2]$$

where:

PR = penetration resistance (kPa).

Y = A/D converter output (V).

Data collected during calibration tests indicated that the A/D converter requires 45 minutes warm up time for its output to stabilize. After this initial warm up period, the maximum change in the output was within $\pm\ 0.002V$ or $\pm\ 2.2kPa(\ \pm\ 0.32lbs)$.

The depth sensor was also calibrated by recording the A/D converter output corresponding to different displacements of the hydraulic cylinder rod. A linear regression model was fitted to the data to obtain the following equation with a r^2 value of 0.9999.

$$D = (15.02 \times X - 29.48) \times 2.54 \qquad [3]$$

where:

D = penetrometer depth (cm).

X = A/D converter output (V).

4.0 FIELD DATA COLLECTION AND ANALYSIS

Field tests using the penetrometer assembly were conducted with the following objectives: (a) to evaluate the total system developed and (b) to obtain the initial penetration resistance data within experimental plots established for a long-term study dealing with the effect of continuous use of conservation tillage on soil structure. Test plots for the long-term study were located on the Agronomy Farm of the Virginia Polytechnic Institute and State University. A 40m X 20m area was plowed and disked. The total area was divided into nine test plots with a 4m wide buffer strip between each set of 3 test plots as shown in the Figure 8. The soil within the test plots included sandy loam on the surface with fine clay below the surface layer.

4.1 Data Collection

The following procedure was employed for collecting the penetration resistance data in the field. The tractor with the penetrometer assembly was backed into the experimental plots to prevent soil compaction. The penetrometer assembly was placed at a predetermined location so that the frame was perpendicular to the larger dimension of the test plot. The data logger was connected appropriately and was allowed to warm up for a period of about 45 minutes. Using the hand crank

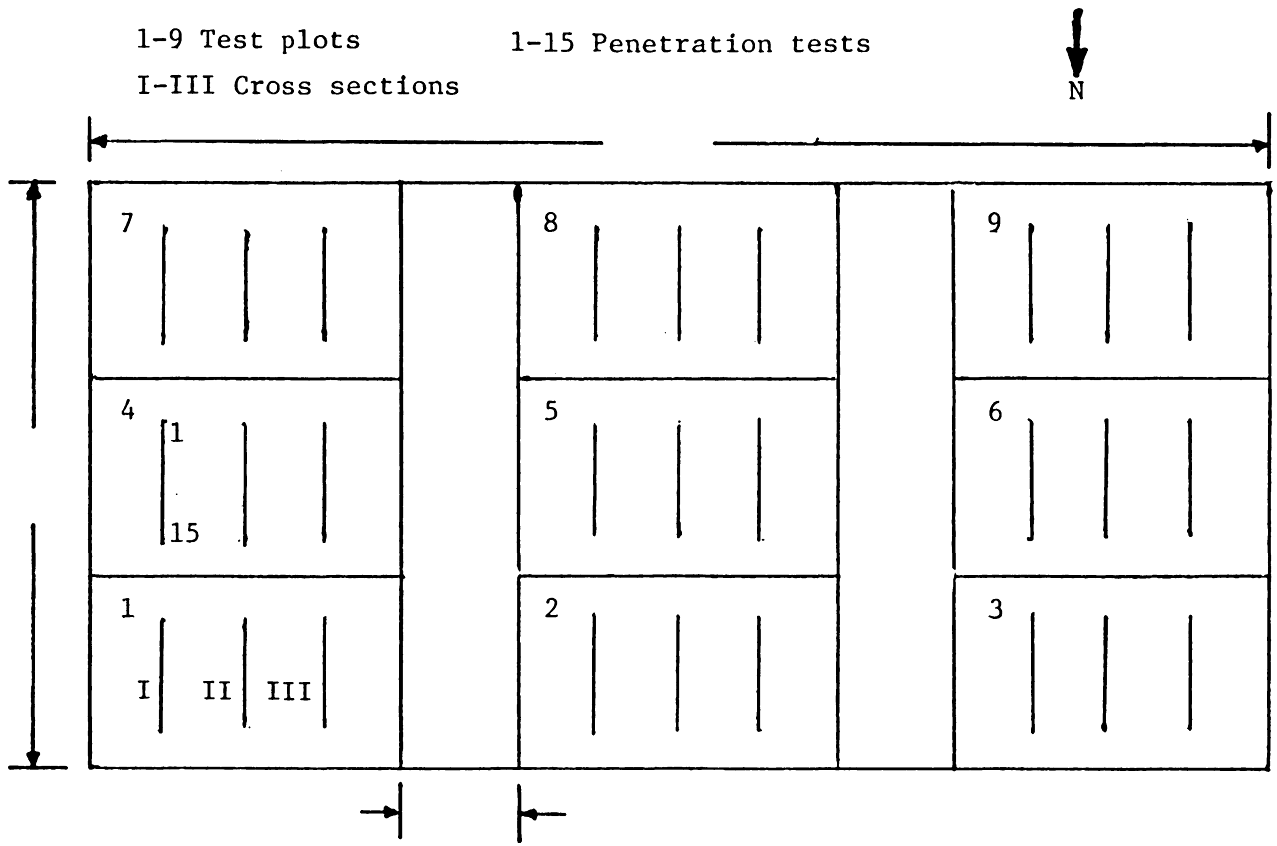

Figure 8. Field layout of the experimental plots.

the penetrometer carriage was brought to the rightmost position when facing the rear end of the tractor. The program IMP.BA was then executed. Comments were entered. The penetrometer probe was raised by activating the directional control valve. The data collection was initiated by pressing any key on the computer key pad. The directional control valve was reactivated to the opposite side simultaneously to extend the cylinder and push the penetrometer probe into the soil. At the end of the stroke, the function key F1 was pressed to stop the data collection and the penetrometer was raised. If the data collection needed to be stopped in between, it could be done by pressing F1 key. At the end of the first penetration test, the data collected was sorted and transferred on to the cassette tape. The penetrometer carriage was then moved 15 cm to the left with the help of hand crank mechanism. The same procedure was continued until the data from a total of 15 penetration tests were collected at one location. Similar readings were taken at two more locations, to give a total of three sets of readings within each test plot.

Since penetration resistance depends heavily on soil moisture level, core samples were extracted to determine the moisture level. Four soil samples were extracted at 7.5 cm depth intervals using a push type sampler. Two more soil samples were taken at 15 cm intervals below the previous sampling depth using a soil auger. The soil samples were placed in Zip-loc polyethylene bags and sealed to avoid moisture loss. In the laboratory, the samples were oven dried in aluminum cans at 150°C for 24 hours after recording the initial weight. Dry samples were weighed again and percent soil moisture levels were determined on the dry basis.

The data files stored on cassette tapes were transferred to an IBM PC to store on floppy diskettes by executing the program TRANS.BA (appendix D) stored in TRS 80 model 100 computer and the program TRANS.BAS (appendix E) stored in IBM PC, for further data reduction and analysis.

Using the program REDUCE.BAS (appendix F) the data strings were reduced. The penetration resistance and the depth values were calculated using equations 2 and 3. During each penetration test, the data collection was initiated prior to the cone coming in contact with the soil. Therefore, the penetration resistance readings recorded until the cone came in contact with the soil included the weight of the penetrometer. The cone head position with the cylinder in fully retracted position was considered as the reference point for the depth measurement. After activating the cylinder, when the penetration resistance was equivalent to a compressive pressure of 10.3 kPa (1.5 psi), it was considered that the penetrometer was in contact with the soil. It was further assumed that an additional 2.5 cm (1 in.) displacement brought the cone head in flush with the soil surface. Based on these assumptions, the depth and penetration resistance data were corrected and for each penetration test, the depth and the penetration resistance data from the soil surface were stored in an output file.

As described earlier, within each test plot, 15 penetration tests were conducted at three different locations. Data collected from each penetration test included large number of penetration resistance readings with 0-60 cm range. From these readings, the average penetration resistance for each 7.5 cm layer was completed. This was done by each of the 15 penetration tests at one location. Using the same procedure two more sets of penetration resistance data were obtained for the other two locations within the same plot. Comparing these three sets of values, the median penetration resistance was selected. A program (MEDIAN.BAS) developed to compute the average and for selecting the median is listed in appendix G.

A program CONPTS.BAS (appendix H) was used to plot the contours of penetration resistance and to identify contour levels with different symbols. For convenience, the contours are plotted at 344.75 kPa (50 psi) increments. In the event that the difference in penetration resistance between two layers was more than 344.75 kPa, the exact level of the contour was calculated using linear interpolation method.

The averages of mean penetration resistance and the moisture contents were calculated for each layer in each experimental plot. These averages are plotted as a function of depth for each test plot.

4.2 Statistical Analysis

A statistical analysis was performed on the average penetration resistance and moisture content data of each layer from all 9 test plots to determine whether or not the data collected were significantly different from one plot to the other. Either the t-test or Tukey's studentized range test could be used for this purpose. However, Tukey's studentized range test was selected for the statistical analysis because it could control the type I error rate for the entire experiment.

The average penetration resistance for each 7.5 cm layer of soil within each test plot was computed by taking the average of the median values obtained for a particular plot as described earlier. In otherwords, it represented the average of 15 median values obtained. This procedure was followed to obtain the average penetration resistance for other 7.5 cm layers up to a depth of 60 cm within all 9 plots.

For each layer, the average penetration resistance values within the 9 test plots were arranged in descending order. The average penetration resistance values were compared statistically for significant differences. This procedure was repeated for other layers. Similar analysis was performed on the moisture content data.

5.0 RESULTS AND DISCUSSION

Field tests were conducted to meet the following objectives; (a) to evaluate the performance of the penetrometer assembly and data acquisition system under field conditions and (b) to collect initial, penetration resistance and moisture data from 9 test plots established for a long-term study evaluating the effect of the continuous use of conservation tillage practices on soil structure.

5.1 Penetrometer Assembly and Data Acquisition System Performance.

The total system performed satisfactorily in the field. However, the maximum penetration force which could be applied was limited to the total weight of the penetrometer assembly, 113 kg (250 lbs). This load corresponded to a penetration resistance of 3447.5 kPa (500 psi). The load capacity could be increased up to about 1780 N (400 lbs) by adding additional weight to the penetrometer frame and by raising the setting on the pressure relief valve shown in the circuit. Any additional increase in the load capacity will require redesign of the penetrometer shaft.

Since the penetrometer assembly requires only a low flow input, it will not work satisfactorily when it is operated with tractors with hydraulic systems having high volume capacity. Erratic cylinder extension and inability to shift the solenoid valve were some of the problems observed. Provisions for regulating the volume output is available on most tractors. If this provision is not available, use of a flow control valve or a flow divider should be considered to bleed off the excess flow to the reservoir.

A pressure and temperature compensated flow control valve helped to control the penetration precisely at the desired rate of 3 cm/s. At this rate, the data logger was able to record penetration resistance data at every 0.75 - 1.25 cm of cone displacements. The data collection did not occur at a constant cone displacement because the time delay between two memory upgrading cycles is greater than the time delay between the upgrading of two successive memory locations within a cycle. In each cycle upgrading was done at a rate of 15 channels per second. This rate could be doubled by altering the A/D converter circuit.

When the computer collected 275 data strings, the time taken for each penetration test was considerable. At those instances, each penetration test required about 10 minutes to collect, sort and transfer the data strings on to the cassette tape. The time required per test could be reduced if a micro-computer with a larger memory is used or by replacing the cassette recorder with a disk drive.

The recording time of the computer cassette tapes commonly available is limited to a maximum period of about 20 minutes. These cassettes do not have enough capacity to store data from a single test location which includes 15 penetration tests. Therefore, the use of 60 minutes or larger cassette tapes should be considered depending on the number of tests per cross section. To avoid loss of data, it is necessary that the blank leads found at the end of each cassette tape is wound on the empty spool. The process of transferring the files from the cassette to diskette, periodically experienced some difficulty. Occasionally the process was terminated before reaching the end of the file. When this happened, the tape was reversed for approximately 10 cm, created a new file and the remaining data was transfered to the diskette under the new file name. Later, the two files were merged after excluding the duplications.

5.2 Contours of Penetration Resistance.

The contours of penetration resistance were developed for each test plot using the median penetration resistance data and are presented in Figure 9 through Figure 17. These figures show an increase in the penetration resistance up to a depth of about 35 cm below the soil surface. A reduction in the resistance was observed at depths greater than 35 cm. In most cases, around the 35 cm depth, the contours of different resistance were closer to each other indicating the presence of a hard pan or a compacted layer. This is more clearly visible in figures 8, 10, 11, 12 and 14. In figures 9, 14 and 16 the contours above 2400 kPa, did not extend to the entire width. This may be the result of deep plowing done previously or the natural structure of the soil. At depths greater than 25 cm, in certain cases the contours looped around rather than extending over the entire width of the test plot. This may be due to discontinuity within the soil due to the presence of clods created during plowing and harrowing or pockets of soil having different characteristics. During a few penetration tests, the penetrometer could not extend to the full 60 cm depth, due to the presence of hard layers or rocks. In such situations, the test had to be aborted. Consequently, penetration resistance readings for some cells were not available. However, the missing data did not pose any difficulty in developing the contours because the median penetration resistance values were obtained from data collected at three different locations within each plot and were used in plotting the contours.

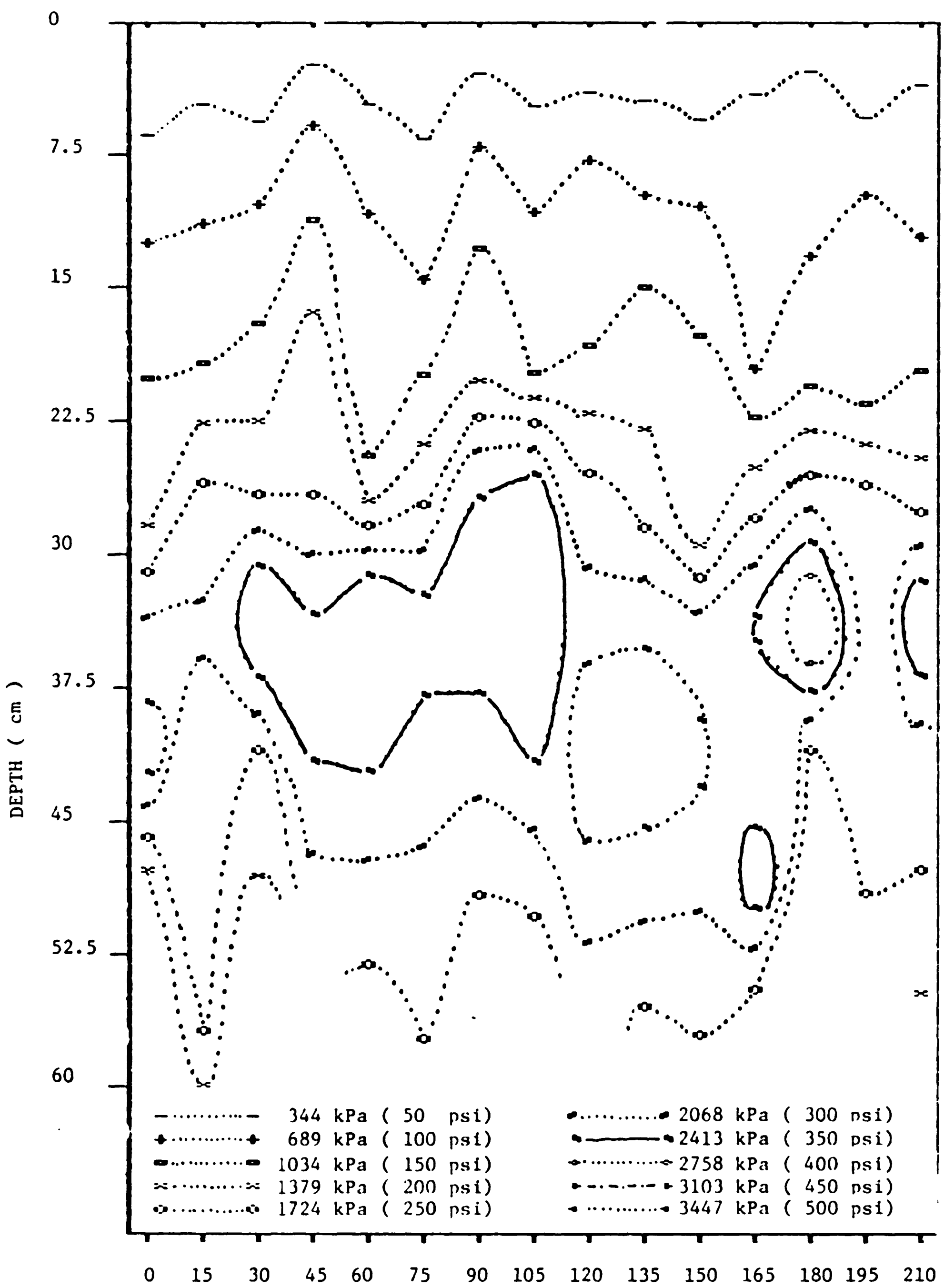

Figure 9. Penetration resistance for test plot 1.

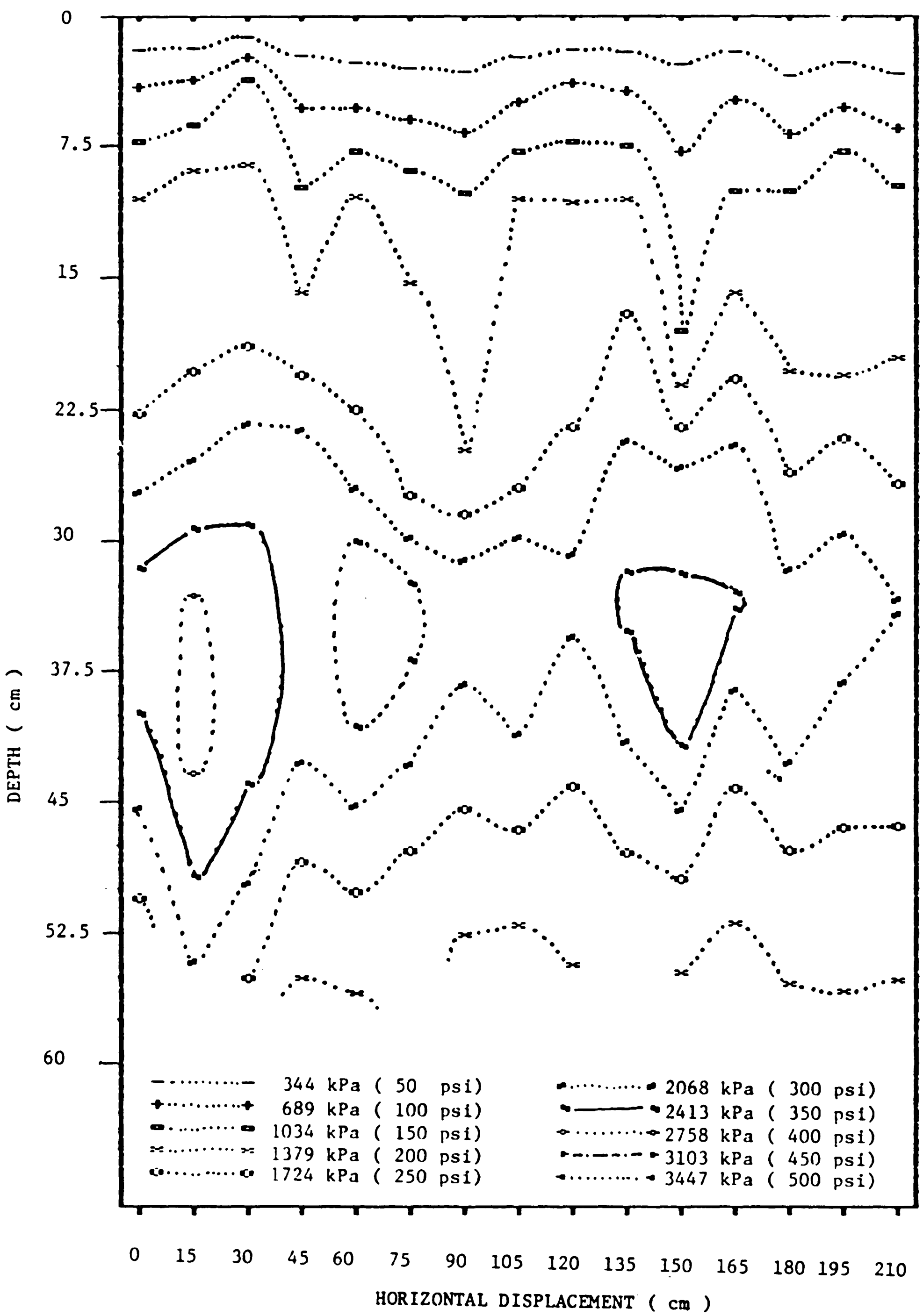

Figure 10. Penetration resistance for test plot 2.

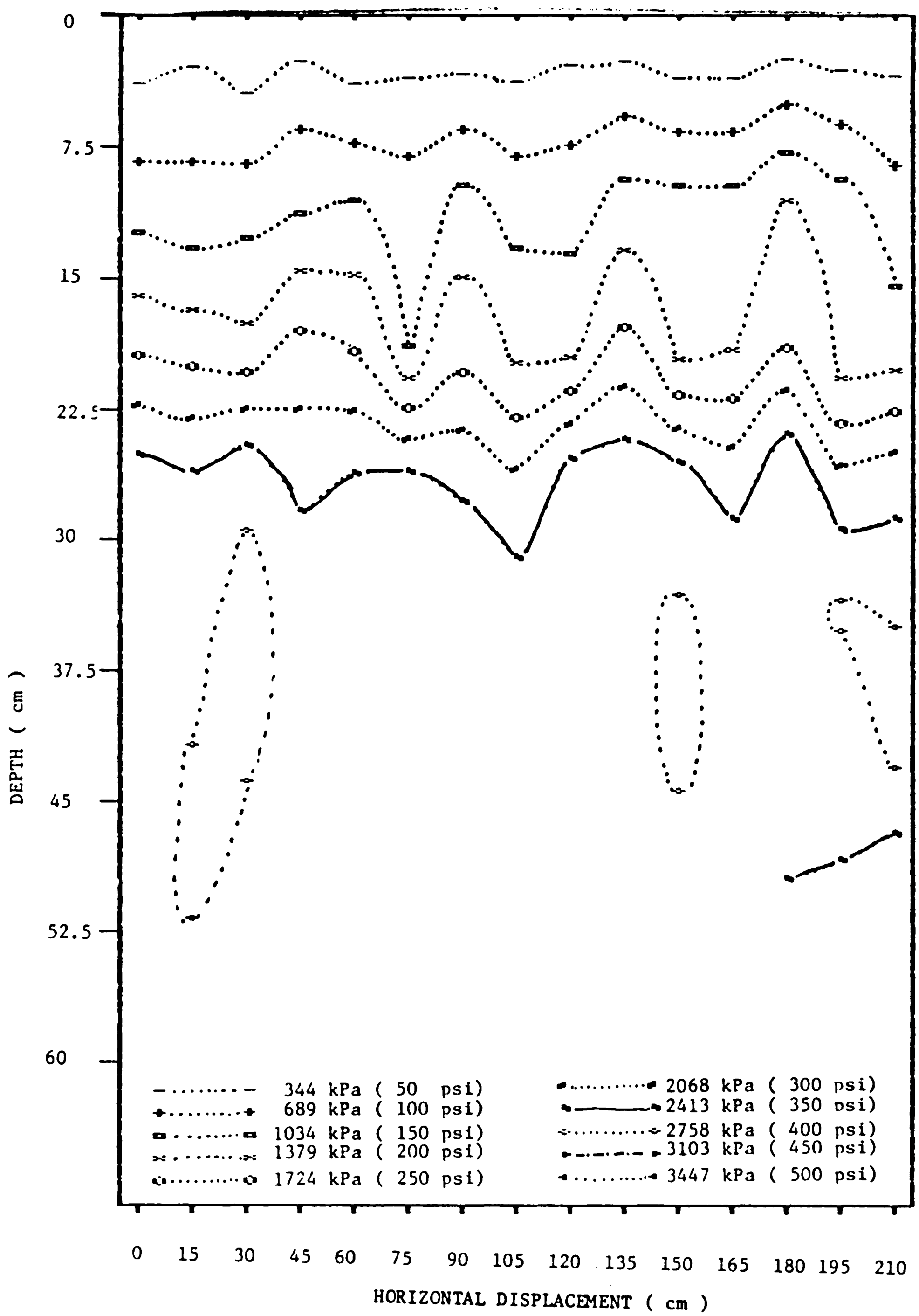

Figure 11. Penetration resistance for test plot 3.

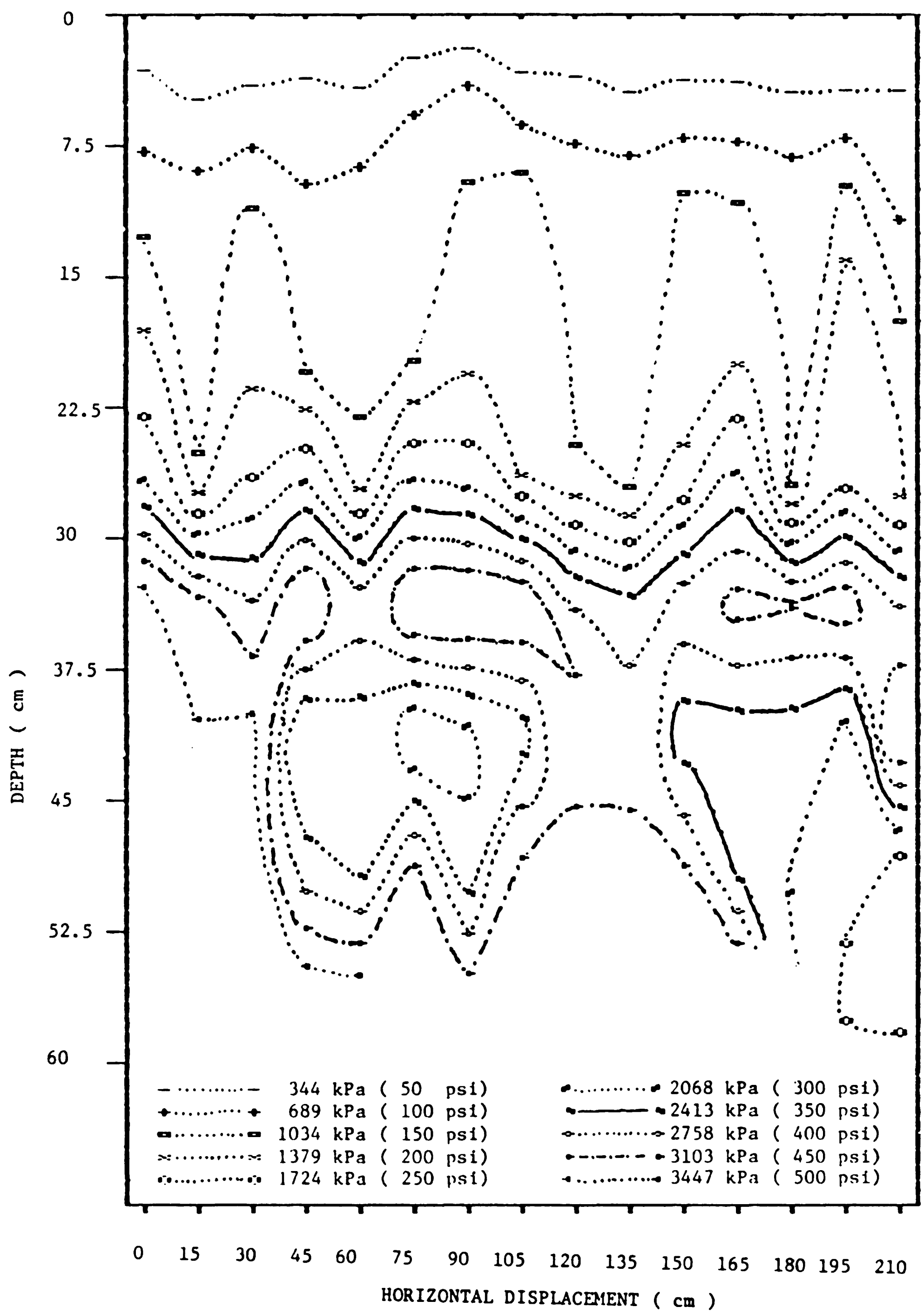

Figure 12. Penetration resistance for test plot 4.

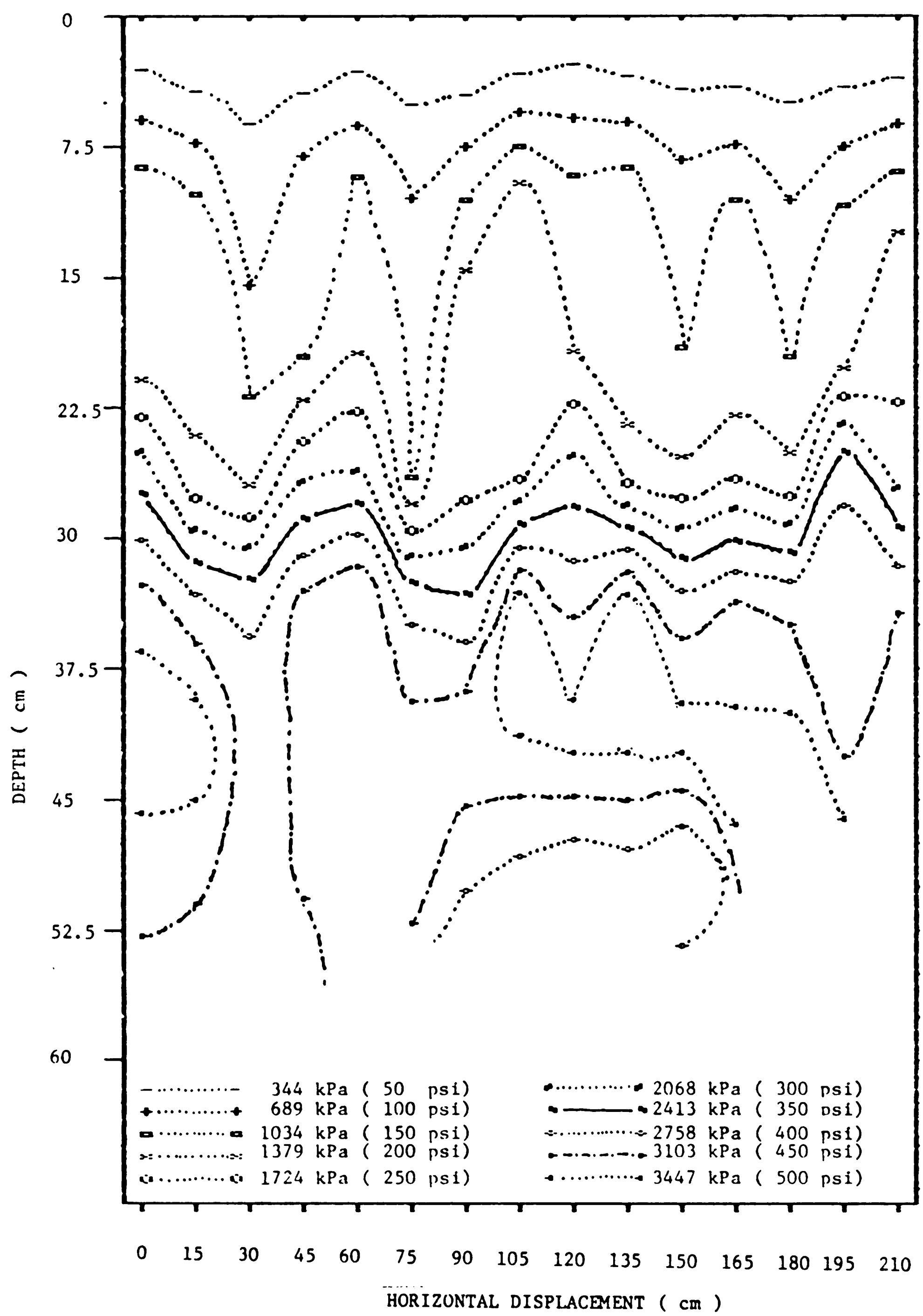

Figure 13. Penetration resistance for test plot 5.

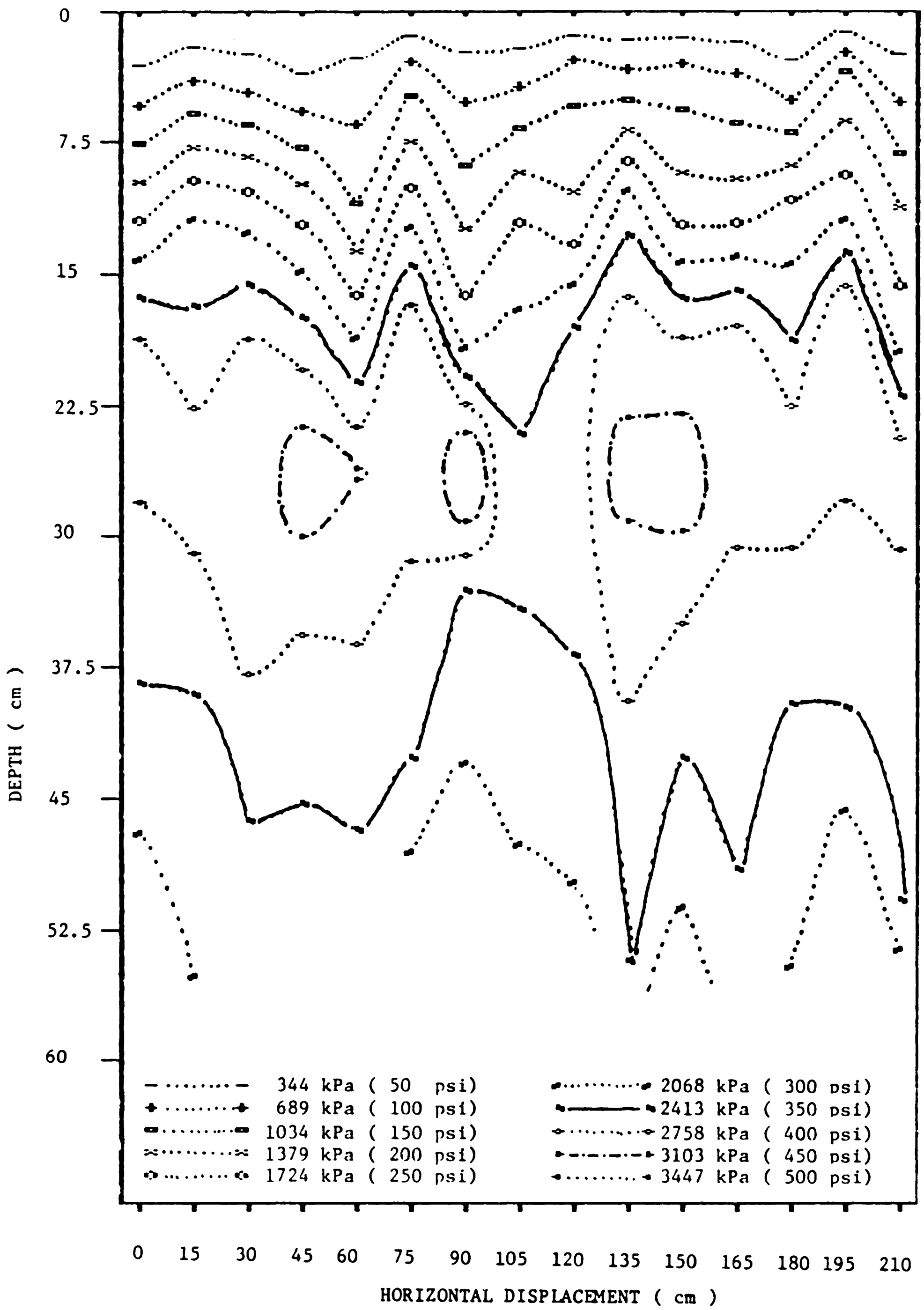

Figure 14. Penetration resistance for test plot 6.

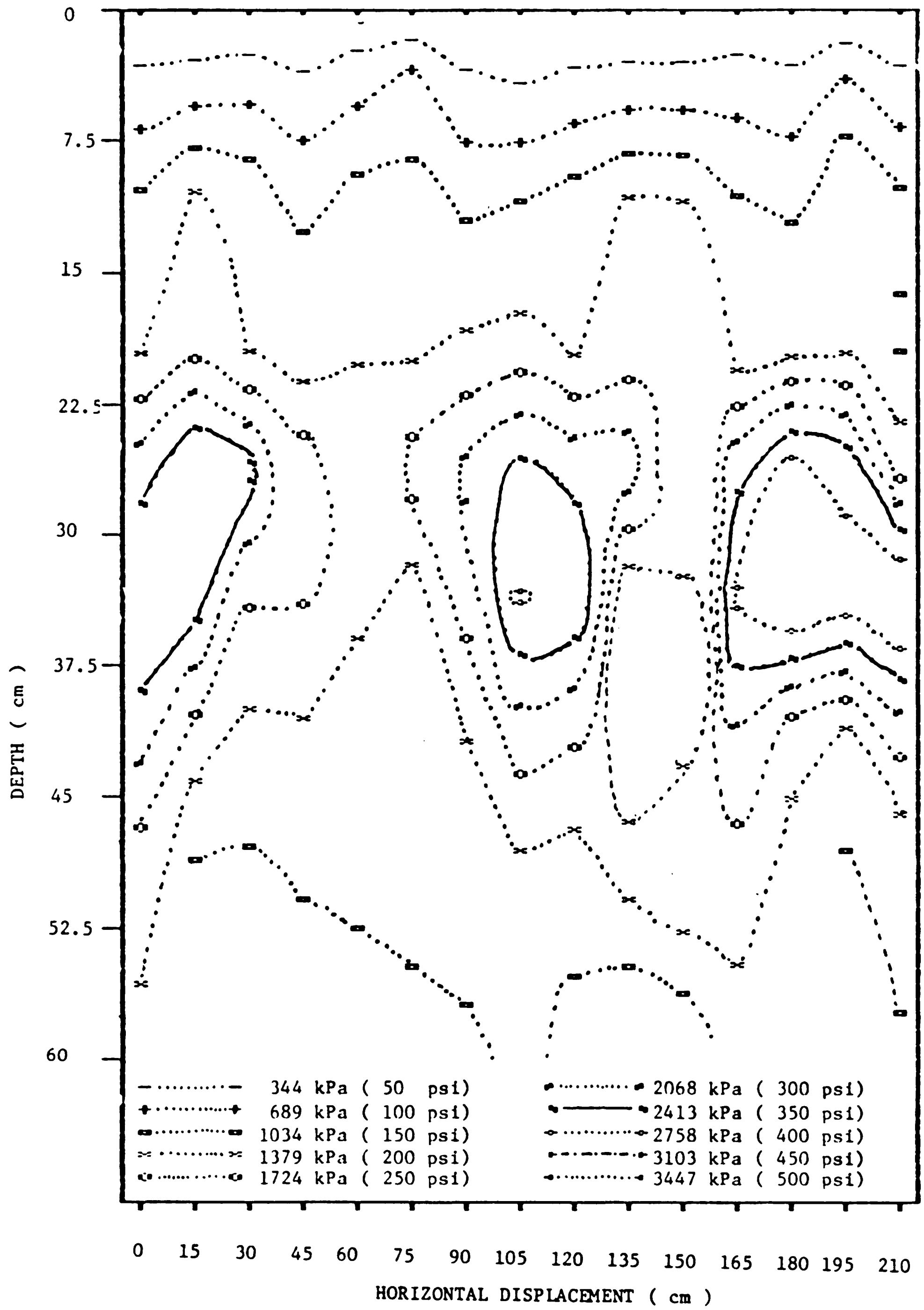

Figure 15. Penetration resistance for test plot 7.

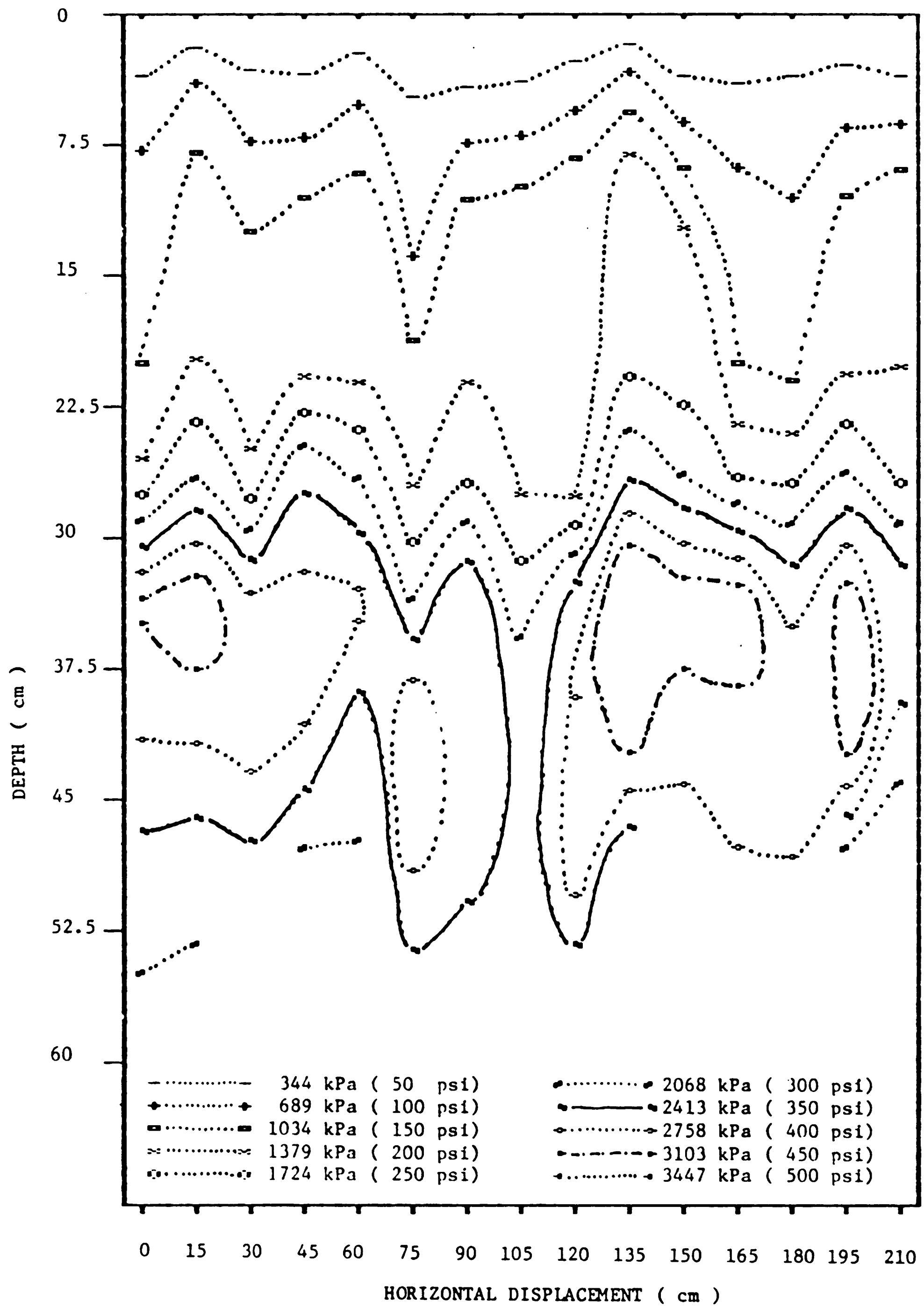

Figure 16. Penetration resistance for test plot 8.

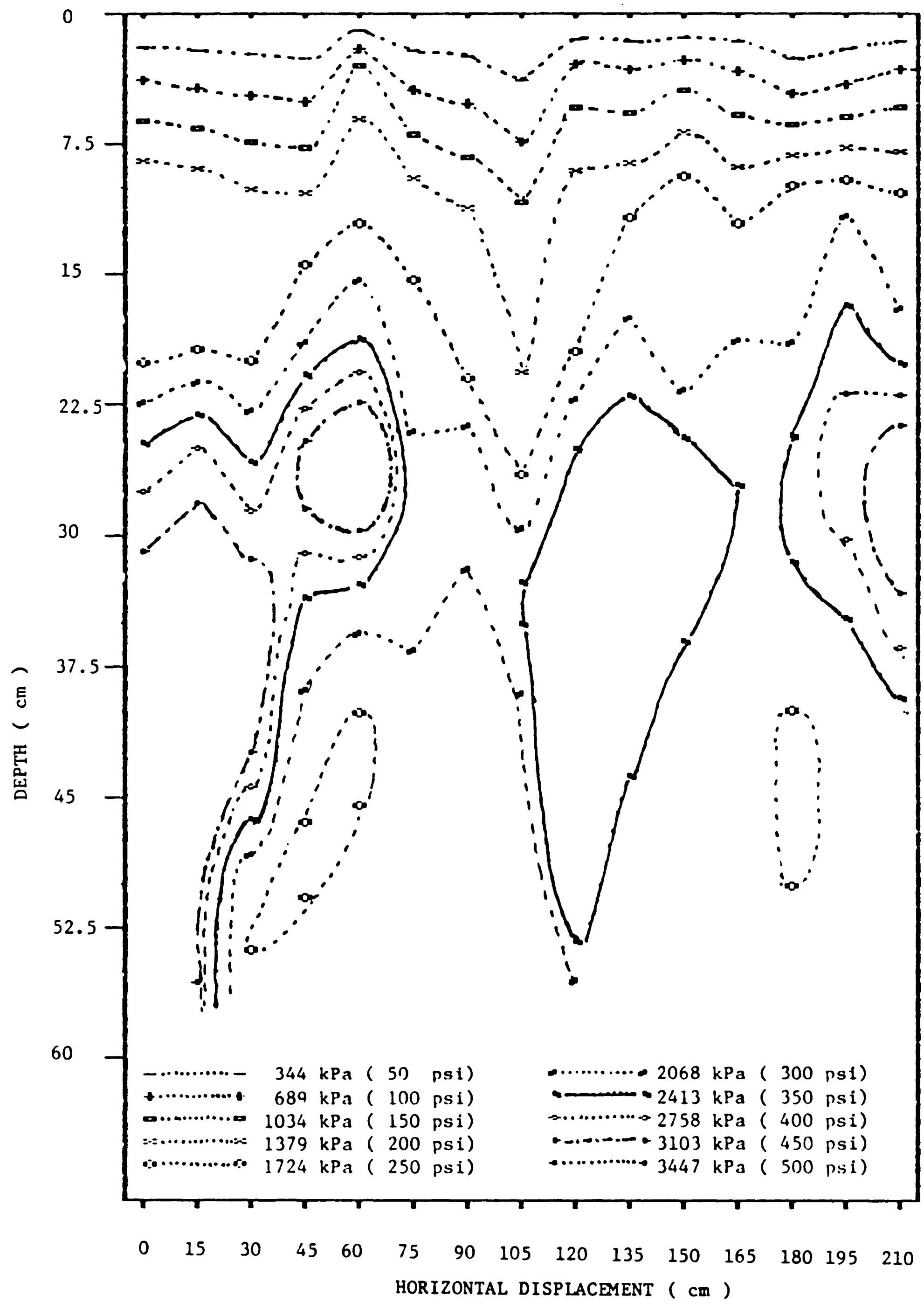

Figure 17. Penetration resistance for test plot 9.

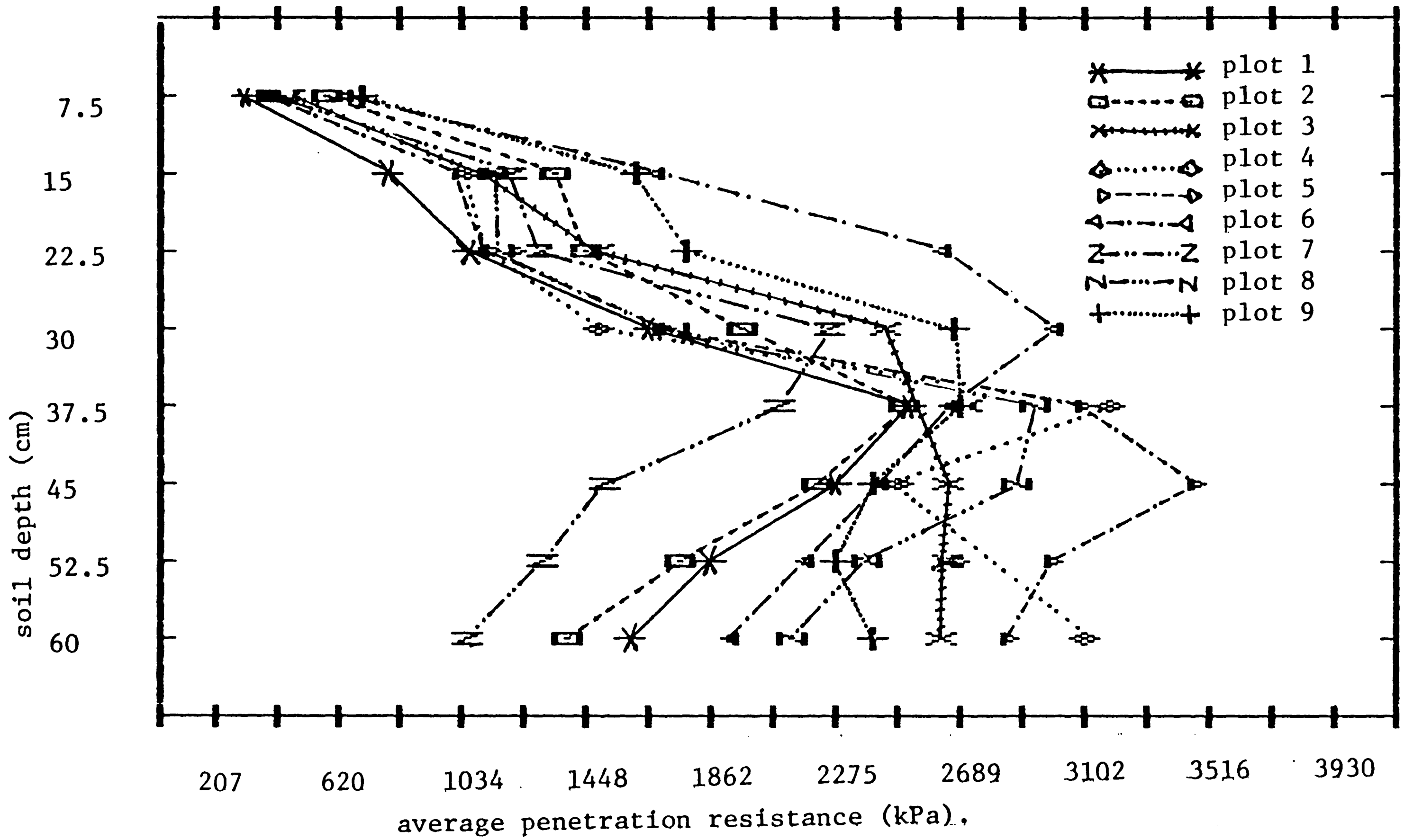

Figure 17. Average soil pressure vs depth intervals from plot 1 to plot 9.

The penetration test results are summarized in table 1. The solid lines drawn between the plot numbers indicate the groups of plots with nonsignificant difference in average penetration resistance. However, there were no data available in plot 4 for depths greater than 33 cm, for test 1. Therefore, the Tukey's studentized range test results show different groups of plots with nonsignificant differences in penetration resistance starting from the same plot in the descending order.

According to these results, plots 6 and 9 had the highest penetration resistance in the first four layers. This could have been due to the texture of top soil which appeared to be coarse in these two plots. But, plots 4 and 5 clearly showed the existence of soil compaction below 30 cm deep. The looping contours found in plot 7 could have resulted in a low average value for penetration resistance below the 30 cm depth. However, the grouping of plots by penetration resistance varied at different depth intervals. This could have been due to natural soil structure.

The mean penetrometer resistance for each layer of each test plot was calculated as a function of the depth in Figure 18. There was a general trend for the penetration resistance to increase with depth to 30 cm as shown by the plotted curves. The high resistance at this depth could be attributed to the natural compaction of the soil and the presence of a plow pan. Below the plow pan, the soil compaction due to vehicular traffic is minimal. The compaction pressure is absorbed by this hard layer. Since the moisture content stabilized below 30 cm, the reduction in penetration resistance was likely due to less compaction at these depths.

Table 1. Tukey's test results on penetration data by layers.

plot numbers with averages in descending order

Layer 1 (0 - 7.5 cm)

9	6	2	7	8	3	4	5	1
A	A	A						
			C	C	C	C	C	C
		B	B	B	B			

Layer 2 (7.5 - 15 cm)

9	6	2	7	8	5	3	4	1
A	A							
		B	B	B	B	B		
							D	D
			C	C	C	C	C	

Layer 3 (15 - 22.5 cm)

6	9	3	2	7	5	8	4	1
A	B	C	C	C	C	C		
				D	D	D	D	D

Layer 4 (22.5 - 30 cm)

6	9	3	7	2	5	8	1	4
A	A							
		C	C					
				E	E	E	E	
	B	B						
			D	D				
					F	F	F	F

Layer 5 (30 - 37.5 cm)

4	5	8	3	9	6	1	2	7
A	A	A	A					
	B	B	B	B	B			
		C	C	C	C	C	C	
			D	D	D	D	D	D

Layer 6 (37.5 - 45 cm)

5	8	3	4	6	9	2	1	7
A	B	B	B	B				C
	D	D	D	D	D	D	D	
		E	E	E	E	E	E	
			F	F	F	F	F	

Layer 7 (45 - 52.5 cm)

5	3	4	8	6	9	1	2	7
A	B	B	B	B	B			C
	D	D	D	D	D	D		
			E	E	E	E	E	
				F	F	F		
						G	G	

Layer 8 (52.5 - 60 cm)

4	5	3	9	8	6	1	2	7
A	A	A	B		C	C	C	
D	D	D	D	D		E	E	E
		F	F	F	F		G	G

5.3 Moisture Content

The results of the Tukey's studentized range test on moisture data is summarized in table2. According to these results, the average moisture contents between the plots were not significantly different for all the layers except for layers 2 and 3. The surface layer within plots 1 and 2 were low in moisture as compared to the second layer due to surface evaporation.

The moisture content as a function of depth for each test plot is shown in the Figure 19. In general the moisture content was found to increase as a function of depth, up to the third layer and then decrease. But, the change in moisture content below the 30 cm depth was minimal.

The penetration resistance in a given soil is greatly influenced by the moisture content. To avoid the variability based on the moisture level, some researchers have suggested taking penetrometer data at field capacity moisture content. But, the moisture content at field capacity will likely change with changes in the total volume of micropores. Therefore, the field capacity moisture content might not eliminate the effect of moisture content on penetration resistance data. Also, bringing the test site to field capacity under field condition may not be practical. Overhead irrigation might possibly be used to bring the soil moisture content to field capacity level. But, this method of irrigation is expensive, time consuming and may not be feasible.It would also be difficult to move the testing equipment on the test plots if the soil were at maximum soil moisture content. Another possibility would be to relate the penetration resistance and moisture level to density. This will require developing a three dimensional relationship among penetration resistance, moisture level, and density for the soil under consideration using the procedure discribed by Ayers and Perumpral (1983). Additional work is needed to evaluate the potential use of this procedure.

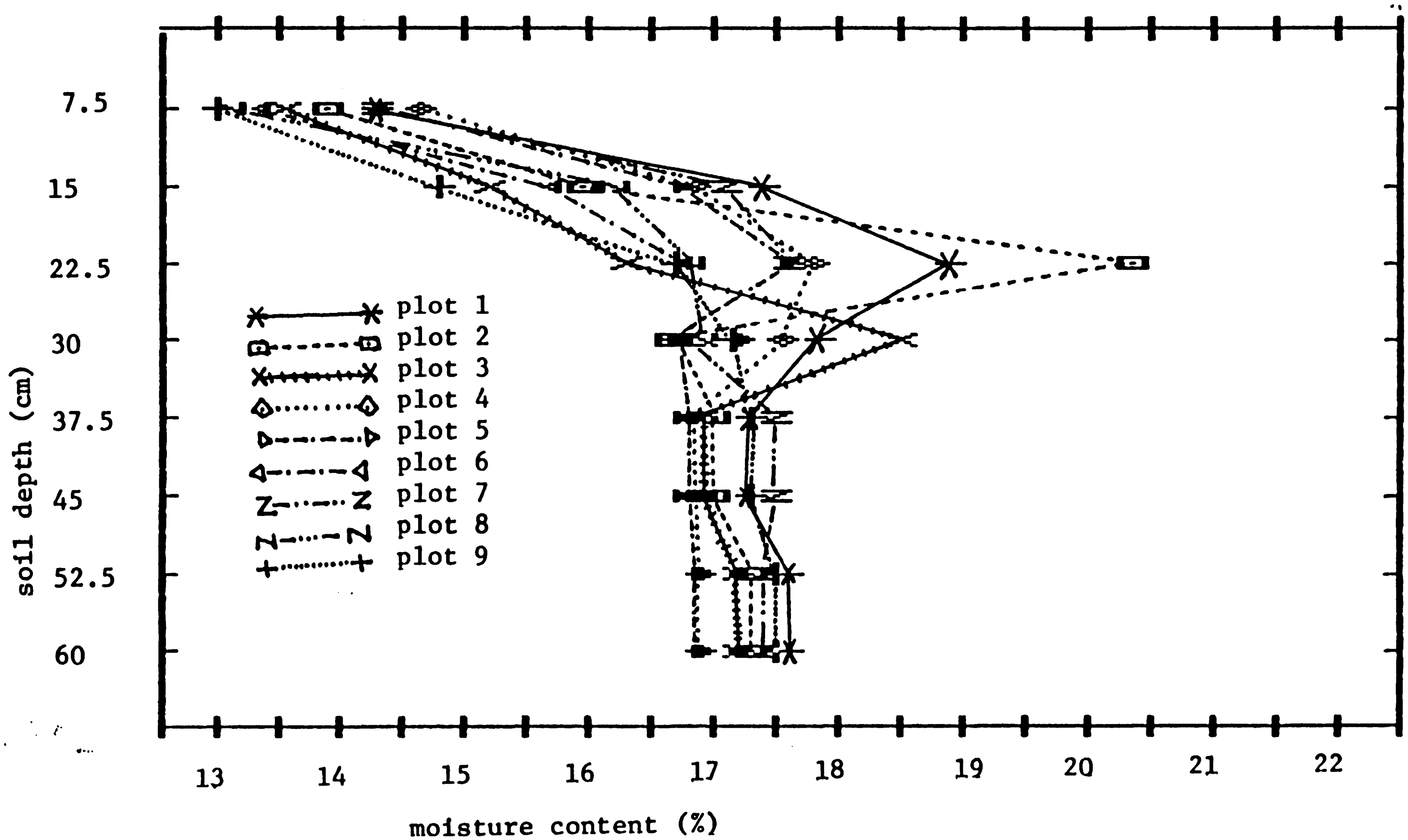

Figure 19. Average moisture content vs depth interval from plot 1 to plot 9.

Table 2. Tukey's studentized test results on moisture data by layers.

plot numbers with averages in descending order

Layer 1 (0 - 7.5 cm)

4	1	5	7	2	3	6	8	9
A	A	A	A	A	A	A	A	A

Layer 2 (7.5 - 15 cm)

5	1	7	4	8	2	6	3	9
A	A	A	A	A	A	A	A	
	B	B	B	B	B	B	B	B

Layer 3 (15 - 22.5 cm)

2	1	4	7	5	8	6	9	3
A	A							
		C	C	C	C	C	C	C
	B	B	B	B				

Layer 4 (22.5 - 30 cm)

3	1	4	5	9	8	7	6	2
A	A	A	A	A	A	A	A	A

Layer 5 (30 - 37.5 cm)

7	9	1	6	2	8	4	3	5
A	A	A	A	A	A	A	A	A

Layer 6 (37.5 - 45 cm)

7	9	1	6	2	8	4	3	5
A	A	A	A	A	A	A	A	A

Layer 7 (45 - 52.5 cm)

1	9	7	2	8	6	3	4	5
A	A	A	A	A	A	A	A	A

Layer 8 (52.5 - 60 cm)

1	9	7	2	8	6	3	4	5
A	A	A	A	A	A	A	A	A

6.0 SUMMARY AND CONCLUSION

A tractor mounted, hydraulically driven, recording type penetrometer was designed and developed to collect the soil penetration resistance data. The system developed can collect data from a vertical cross section of 2.6 m wide and 0.6 m deep. Using the tractor hydraulic system and an additional hydraulic control system, the rate of penetration and maximum force on the penetrometer were maintained at 3 cm/s and 1.1 kN respectively. A hydraulic circutry added to control the rate of penetration and maximum load included a pressure relief valve, a directional control valve, and a temperature and pressure compensated flow control valve.

A micro-computer based data acquisition system was developed to record the penetration resistance and depth data at 0.75-1.25 cm intervals. The data acquisition system included a linear amplifier, an analog/digital (A/D) converter, a micro-computer, and a cassette tape recorder. A linear variable resistor was used as the depth sensor. A shear type load cell was used to sense the penetration resistance. The load cell output was amplified before sending it to the A/D converter. The micro-computer communicated with the A/D converter through a RS232 port and collected up to 275 data strings of depth and resistance data for each penetration test. This data was sorted by the computer and were recorded on cassette tape for future analysis.

The penetrometer assembly worked satisfactorily. But the maximum penetration resistance which could be recorded was limited by the weight of the assembly. Therefore, for higher resistance applications, a tractor which can push the assembly downward by the 3 point linkage or additional weights on the frame may be necessary. In those instances when the micro-computer collected 275 data strings, it required about 10 minutes to complete each penetration test. This time requirement could be reduced by replacing the cassette tape recorder with a disk drive. Test time could also be reduced by using a computer with a larger memory.

The field tests were conducted to meet the following objectives: (a) to evaluate the total system developed and (b) to obtain the initial penetration resistance data within the experimental plots established for the long-term study dealing with the effect of continuous use of conservation tillage on soil structure. In addition to the penetration resistance, the average moisture level within each 7.5 cm layer of soil was also determined up to a depth of 60 cm.

The contours of penetration resistance were plotted for each test plot. The penetrometer resistance and moisture content data from nine plots were compared using the Tukey's studentized range test on a layer by layer basis. There was no significant difference in moisture level between layers except in layers 2 and 3. However, significant differences in penetration resistance were found among different layers within a plot and among the test plots.

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APPENDIX A. CIRCUIT DIAGRAMS OF THE DATA LOGGER

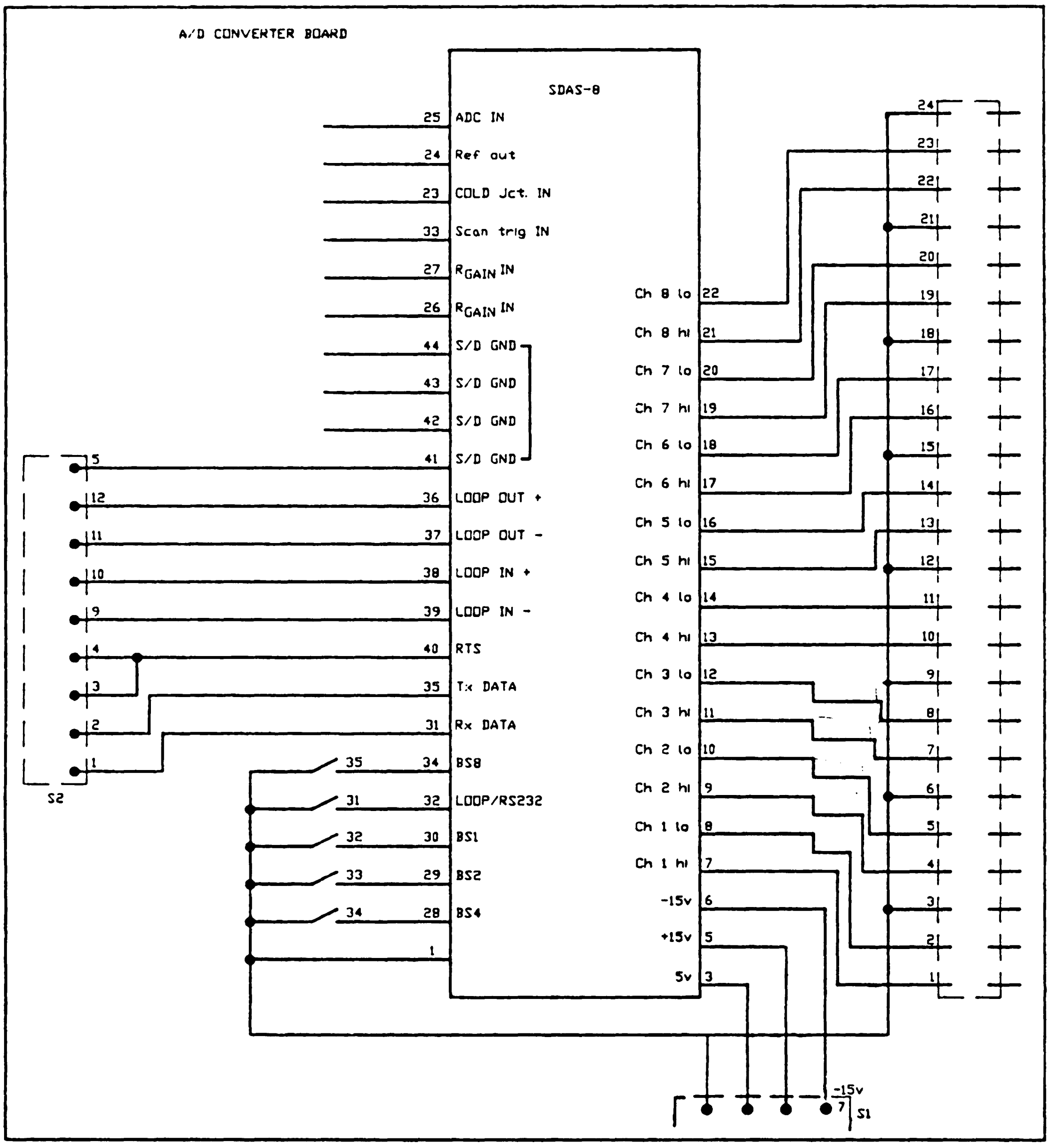

Figure 20. The SDAS-8 analog/digital converter.

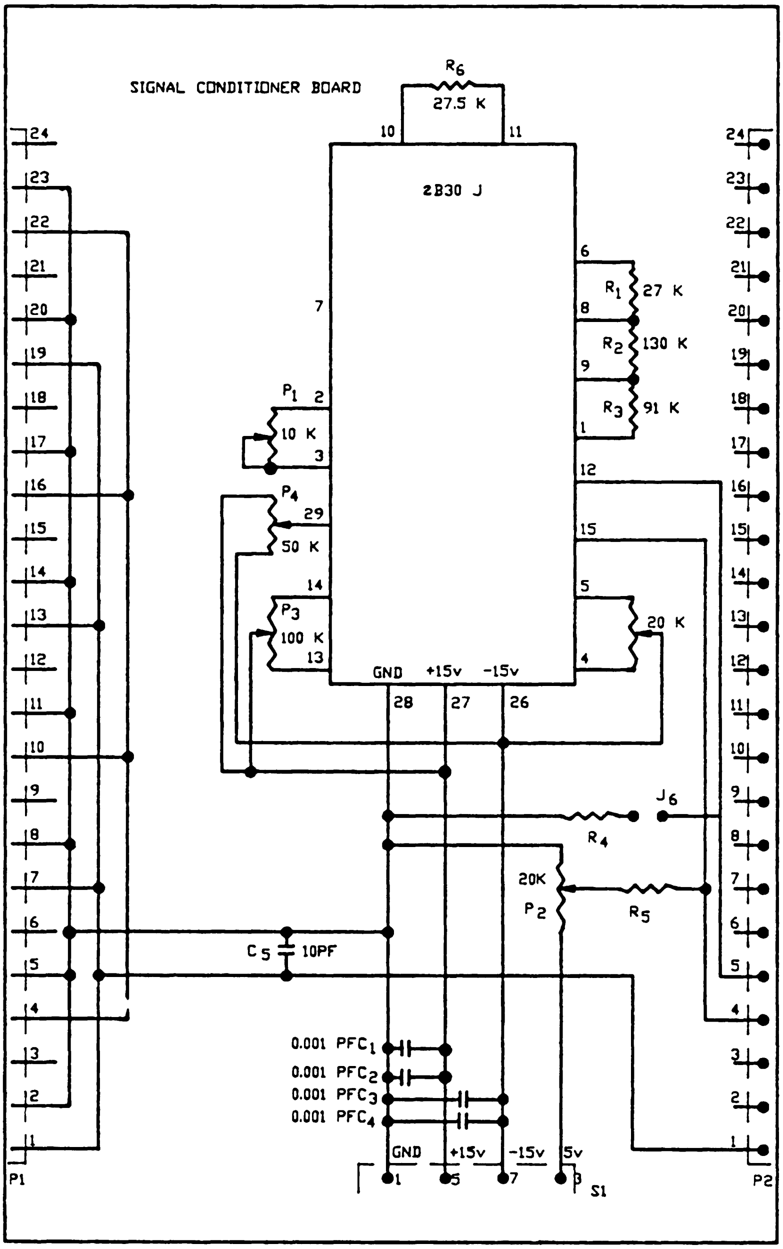

Figure 21. The amplifier.

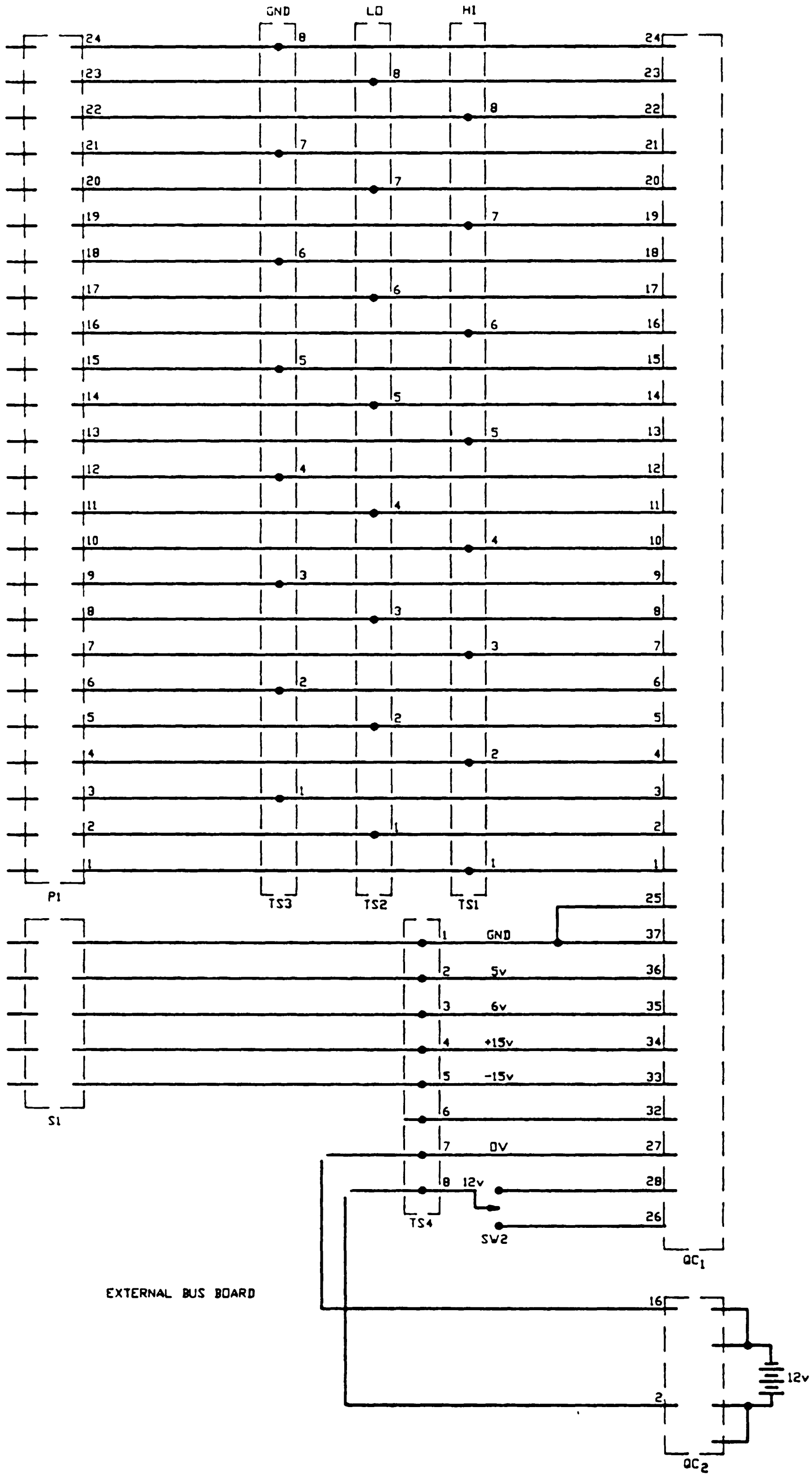

Figure 22. The external bus.

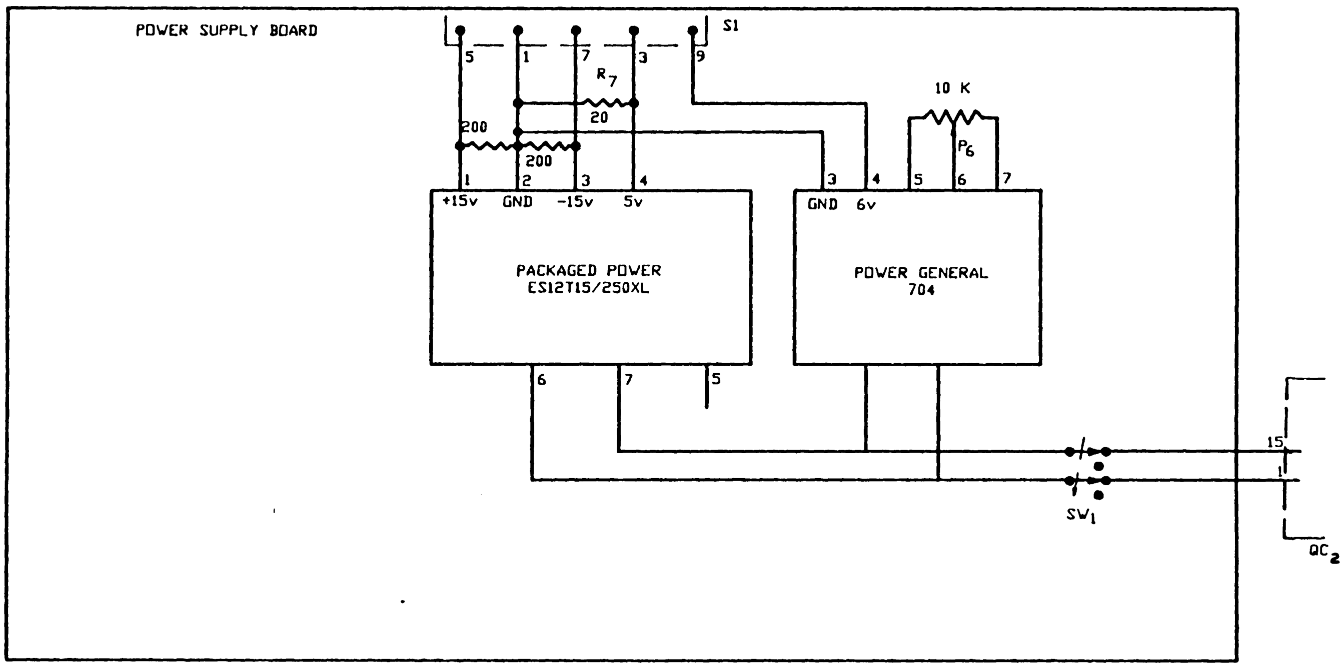

Figure 23. Power supply.

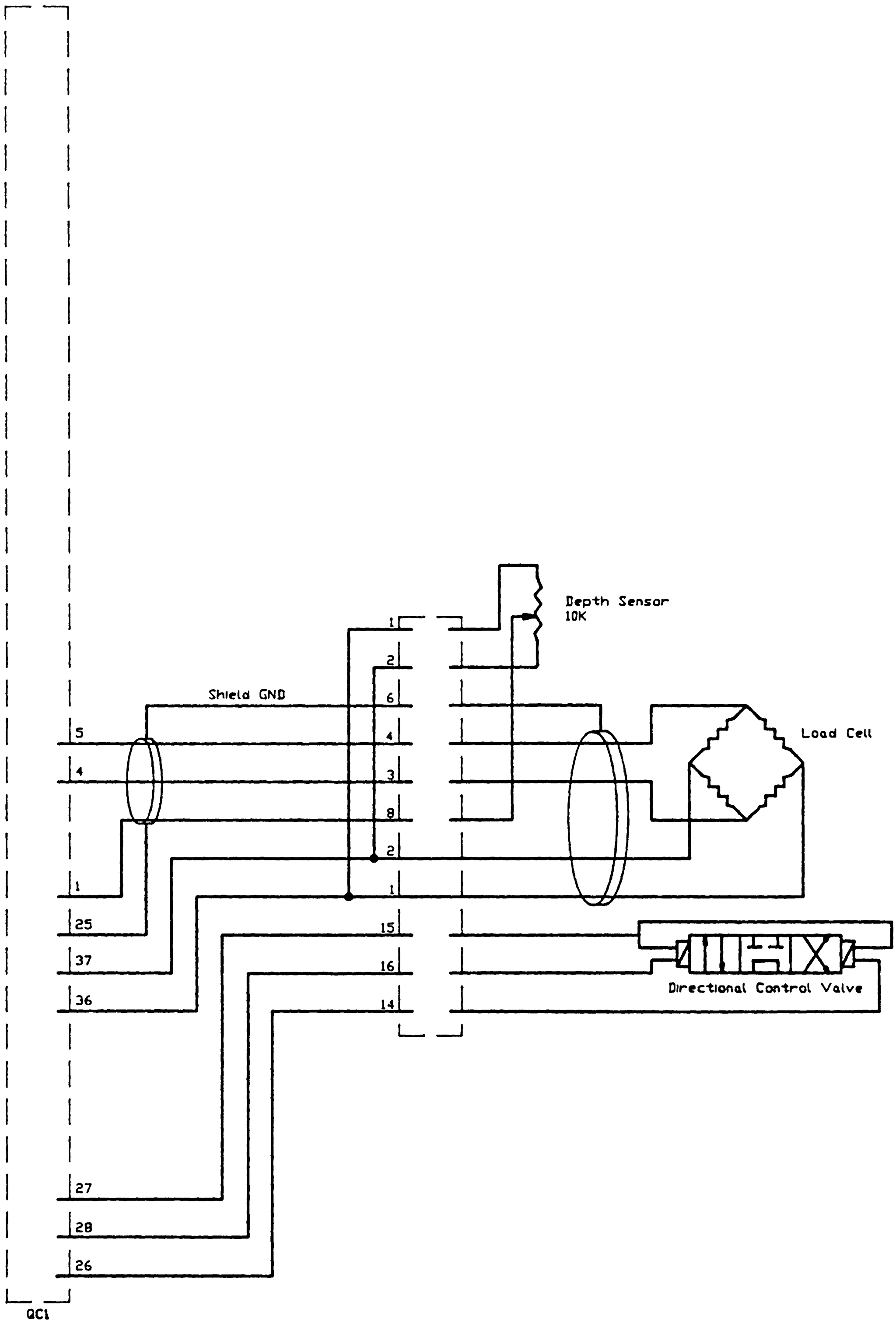

Figure 24. The load cell and the depth sensor.

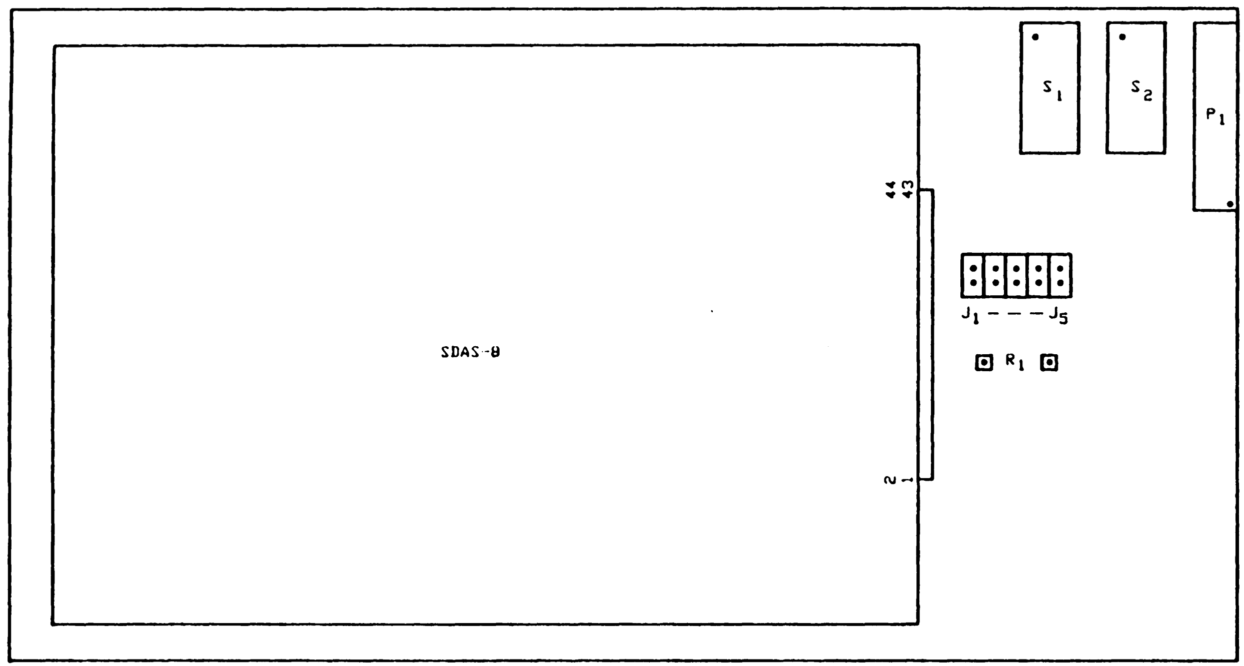

Figure 25. Layout of components on A/D converter board.

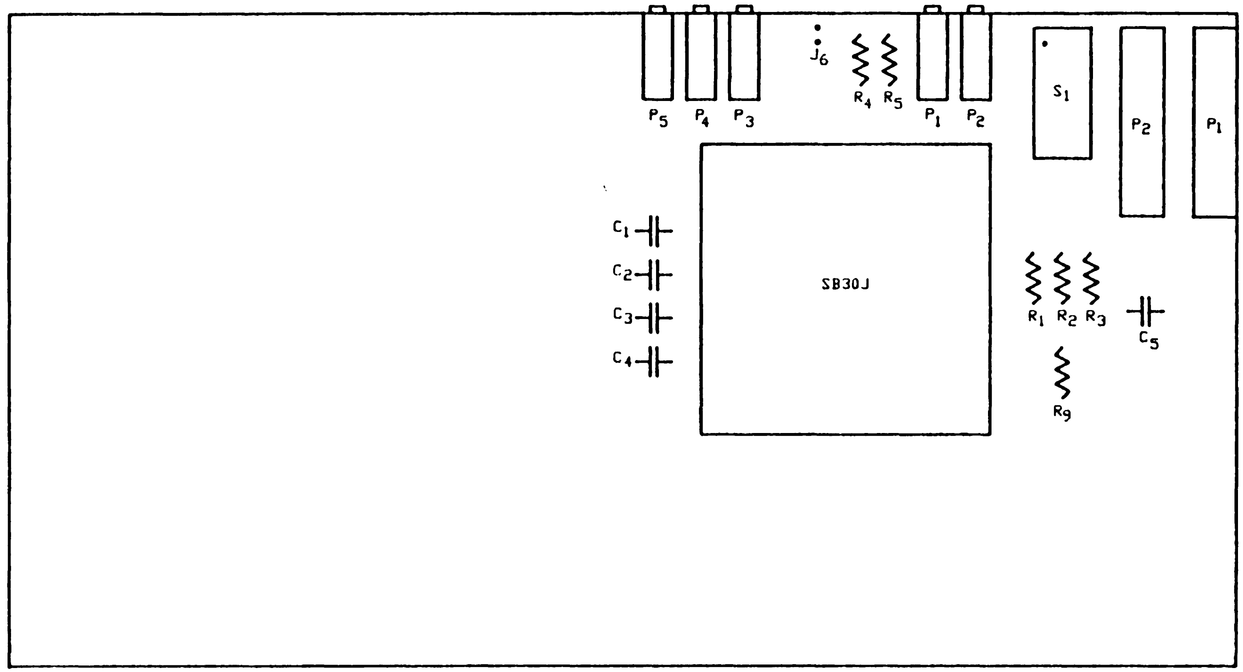

Figure 26. Layout of components on the amplifier board.

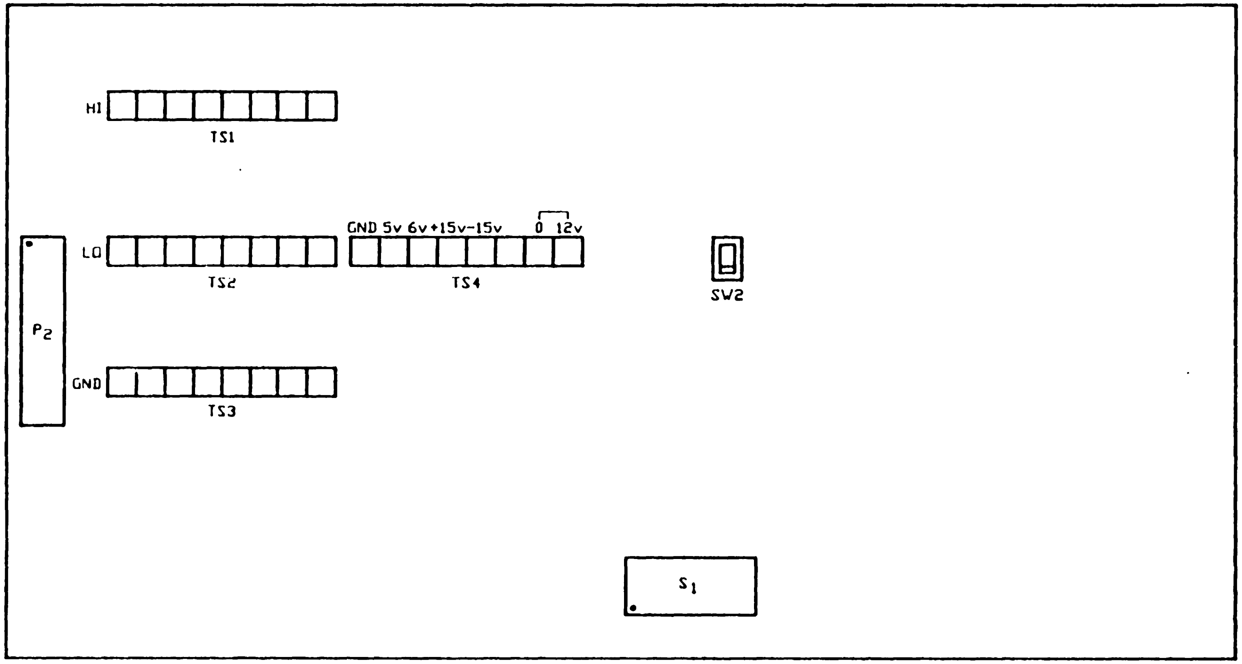

Figure 27. Layout of the components on the external bus board.

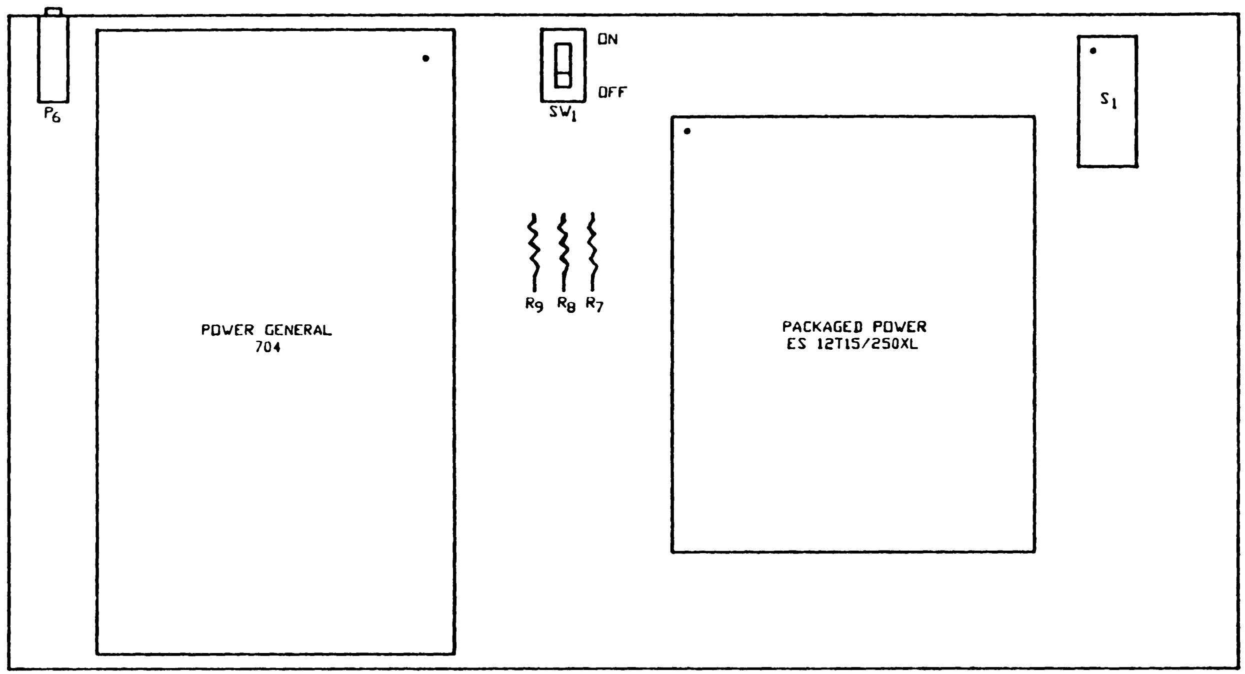

Figure 28. Layout of the components on the DC/DC converter board.

APPENDIX B. OPERATING INSTRUCTIONS

The operating procedures for the penetrometer and the data logger are described in the following sections.

B.1 Power Connections to Data Logger

- Power connections should be made by containing the 16 pin quick coupler mounted on the aluminum case of the data logger to the tractor battery. The red wire of the power cable should be connected to the positive terminal of the battery, while the black wire is connected to the tractor chassis.

- The 37 pin quick coupler on the twisted cable is connected to the connector on the aluminum case. The other end of this cable should be connected to a 16 pin quick coupler provided on the penetrometer carriage.

- Connect the 6V DC power jacks provided to the computer and the cassette recorder.

- Connect the cassette recorder to the computer using the interfacing cable provided.

- Then, switch on the power by flipping up the switch mounted on the DC/DC power converter board and let the system to warm up for about 45 minutes.

B.2 Hydraulic Connections

- Then, connect the quick couplers on the pressure relief valve and the directional control valve to the pressure and return outlets of tractor hydraulic system, respectively.
- Position the three position, double throw switch located on the external bus board at the middle.
- Start the tractor.
- Lock the control lever of the tractor hydraulic system in such a position when the double throw switch is flipped down, the penetrometer moves down.

Then, position the penetrometer assembly over the cross section marked in the field. Position the penetrometer probe over the first drilling point, using the hand cranking mechanism.

Raise the penetrometer to the uppermost position by flipping the double throw switch upward.

B.3 Operating the data logger

- Set the cassette recorder and run the program IMP.BA on the computer.
- Answer each question asked by the computer by entering a single line.

B.4 Formatting A/D Converter Output

Whenever the power is turned on, the A/D converter sets itself to the power up status which sends unnecessary characters such as time, echo of the commands, line feed characters and null characters, with the data string. These additional characters delay the data collection. The rate of data collection can be improved by cancelling the unnecessary characters and by formatting the output data string using the commands listed below:

1. Pnnn - nnn is the no. of characters printed per line before printing a line feed character. This value could vary from 20 to 132. (P132 was used.)

2. N255 -used to print a line feed character at the end of transmission of data string.

3. Nxxx - xxx is the no. of nulls printed at the end of data string. (N0 was used.)

4. BN - used to cancel the running header.

5. Q - used to cancel the echo of the characters received by the A/D converter.

6. M;x,y - when used each scan will contain data from channel x to channel y. (The default setting M;1,8 was used)

7. X - used to request to send data

While formatting the A/D converter output, the computer emits a sound and displays the command it sends to the A/D converter.

B.5 Data Collection

After completing the steps listed above, the data may be collected through the following steps:

1. When the computer is ready to receive data, press any key on the computer key pad and activate the directional control valve simultaneously to extend the cylinder.

2. In case of an emergency stop data collection by pressing the function key F1 and retract the cylinder. Then the computer will sort the data for complete data strings and transfer them on to the cassette tape.

3. Even if the cassette tape does not have enough space, the computer sends the data to the recorder. In such events it is possible to record data on another tape by answering the questions asked at the end of transferring data.

4. When the computer is ready for comments, enter the desired comments in one line.

5. If the data collection from another drilling is to be done, press the key "y", move the carriage to the next position, using the retractable tape as a guide.

6. Repeat the steps listed in this section.

APPENDIX C. DATA ACQUISITION PROGRAM IMP.BA

```
5 '*******************************************************
6 '* Program name: IMP.BA
10 '* This program is written by D. N. Jayatissa to be used
11 '* in the Radio Shack TRS 80 model 100 computer of the
15 '* data acquisition system developed for the tractor
16 '* mounted, hydraulically operated pentrometer assembly.
20 '* It records  on the cassette tapes, the background
21 '* informations about the plot. Then it sets the A/D
22 '* converter if not done previously.
25 '*******************************************************
30 '
40 clear 25000, himem
50 maxfiles = 5
60 on error goto 4000
70 dim ss$(275)
80 key(1) on
125 on key gosub 5000
150 open"com:88N1E" for output as 2 ' RS232 port at 9600
   baud rate
175 sound 400,30
200 cls: print" ": print"set the cassette recorder for
   data storage and press any key"
225 a$ = inkey$ : if a$ = "" then 225
230 cls
240 print" "
250 input "enter the heading for field identification"; id$
```

```
260 cls
275 print" " : input "enter your name"; na$
300 cls
325 print" " : input " what is the horizontal spacing"; hs
400 cls
425 print" " : input "enter other informations if any"; in$
450 if in$="" then in$ = "no"
625 print#4," date : " date$
650 print#4," data collected by: " na$
700 print#4," horizontal spacing: " hs
725 print#4," other info: " in$
750 motor off
775 cls
800 print" "
850 input"did you initiate the data logger (y/n)"; c$
900 if (c$="y" or c$="Y") then 1500
1000 x$ = chr$(27) : gosub 3000
1100 x$ = "N0" : gosub 3000
1200 x$ = "Q" : gosub 3000
1300 x$ = "BN" : gosub 3000
1400 x$ = "P132" : gosub 3000
1500 open "com:88N1E" for input as 1 : sound 400,30
1510 dr$ = " drilling no.: "
1550 input" do you want to make another drilling (y/n)";a$
1560 if (a$="y" or a$="Y") then 1580 else close : end
1580 cls : print"": input"what is the drilling number";dr
```

```
1590 cls :print"": input"enter other informations (position)";k$

1600 cls

1650 print" " : print "press any key to start scanning"

1700 a$ = inkey$ : if a$ = "" then 1700

1750 sound 2000,45 : cls

1800 print" " : print" " : print"          scanning"

1850 print" " : print"     press F1 to stop"

1900 key(1) on : kk = 0 : on key gosub 8000

2000 st$ = time$ ' starting time

2100 kk = kk + 1 : print#2, "X" ' request to send data

2200 ss$(kk) = input$(89,1) : goto 2100 ' A/D output

2225 et$ = time$ : cls  ' end time

2250 print" started at : " st$ : print" ended at : " et$

2300 sound 2000,30 : print" # data points : " kk : print" "

2325 print"    wait"

2350 '    starts sorting data strings

2375 jj = 1: d1 = val(mid$(ss$(1),5,5))

2400 for i=2 to kk: d2=val(mid$(ss$(i),5,5)): if d1=d2 then next
    i else ss$(jj)=left$(ss$(i-1),85): d1=d2: jj=jj+1: next i

2425 ' if the memory location for the channel 1 is upgraded,
    assume the previous data string to be complete.

2450 ss$(jj) = left$(ss$(kk),85)

2500 motor on

2510 print#4," treatment:  " id$

2525 print#4, dr$ dr

2550 print#4," position: " k$
```

```
2575 print#4," starting time : " st$

2600 print#4," end time : " et$

2625 ' store data strings on tape

2650 for i = 1 to jj : print#4, ss$(i) : next i

2675 motor off

2700 input" do you want to save data on another casssette";a$

2710 if (a$="n" or a$="N") then 2825

2720 cls : close 4 : print" "

2730 input " what is the name of the file to record data?
    (------.do)";fn$ : cn$ = "cas:" + fn$

2740 print" set the casstee recorder and press any key"

2750 a$=inkey$ : if a$="" then 2750

2760 open cn$ for output as 4

2780 goto 2510

2800 cls : print" " : input" enter comments"; co$

2825 motor on : print#4," comments : " co$

2850 print#4,"_________________"

2875 motor off

2900 ' clear the memory space for next repetition

2950 for i = 1 to kk : ss$ = "" : next i : goto 1550

3000 sound 400,25 : print#2,x$ : print x$

3100 for i=1 to 100: for j=1 to 10: next j: next i ' time delay

3200 return

4000 if err=9 then print " 275 data points received" :kk=275 :
    resume 2225

5000 print" interrupt " : goto 2225
```

APPENDIX D. PROGRAM TRANS.BA FOR TRS80 MODEL 100

```
1 REM ****************************************************
2 REM * This program is written by D. N. Jayatissa for
3 REM * Radio Shack TRS 80 Model 100 micro computer
4 REM * to be used with the program TRANS.BAS in IBM PC
5 REM * for transfer document files stored in RAM or
6 REM * cassette tapes from model 100 to IBM PC.
7 REM * The files would be saved in IBM PC drive B in the
8 REM * same file name with the extension .DAT .
9 REM ****************************************************
10 REM
15 CLEAR 3000,HIMEM
20 MAXFILES=3: YY=0
30 OPEN "COM:47N1D" FOR OUTPUT AS 1
40 OPEN "COM:47N1D" FOR INPUT AS 2
45 CLS: PRINT" "
50 INPUT" ENTER THE NAME OF FILE TO UPLOAD"; S$
55 CLS: PRINT" "
60 INPUT" WHERE IS IT STORED (RAM/CAS)"; PL$
100 FN$=PL$ + ":" + S$ + ".DO"
110 OPEN FN$ FOR INPUT AS 3
120 MOTOR OFF
125 CLS: PRINT" "
130 PRINT" RUN 'TRANS.BAS' IN DRIVE 'A' OF IBM PC AND LOAD"
132 PRINT" DISK IN DRIVE 'B' TO STORE THE FILE TRANSFERED "
140 PRINT" PRESS ANY KEY WHEN IBM PC IS READY"
150 A$= INKEY$ : IF A$="" THEN 150 ELSE CLS
```

```
155 PRINT" READY TO TRANSFER DATA "
160 A$=INPUT$(1,2) : AA=ASC(A$): IF AA=0 THEN 160
165 IF (AA=255 OR AA=04 OR AA= 127) THEN 170 ELSE 160
170 CLS: PRINT" " : PRINT" TRANSFERRING DATA !!!"
171 IF( A$=CHR$(4) OR A$=CHR$(13) OR A$=CHR$(255)) THEN
   172 ELSE 174
172 SS$=S$ : GOSUB 200: PRINT#1,SS$
173 MOTOR ON: INPUT#3,S$: MOTOR OFF : IF (S$="" OR S$=" ")
   THEN 173 ELSE 175
174 PRINT#1,SS$ : GOTO 160
175 IF EOF(3) THEN YY=0 : GOTO 400
180 GOTO 160
200 AC=0
205 FOR I=1 TO LEN(SS$)
210 CS$=MID$(SS$,I,1)
215 BB=ASC(CS$)
220 AC=AC+BB
225 NEXT I
230 SC$=RIGHT$(STR$(AC),2)
240 SS$=SS$+SC$
250 RETURN
300 PRINT#1,SS$: SOUND 4000,50
305 PRINT" DATA TRANSFER IS COMPLETE": PRINT" "
310 INPUT" DO YOU WANT TO TRANSFER ANOTHER FILE (Y/N)";T$
320 IF T$="Y" OR T$="y" THEN RUN ELSE CLOSE: END
400 A$=  INPUT$(1,2) : AA=ASC(A$): IF AA=0 THEN 400
```

```
410 IF (AA=255 OR AA=04 OR AA=127) THEN 415 ELSE 400
415 IF((A$=CHR$(04) OR A$=CHR$(13)) AND (YY<3)) THEN YY=YY+1
420 IF(A$=CHR$(04) OR A$=CHR$(13)) THEN SS$=S$: GOSUB 200 :
   PRINT#1,SS$: GOTO 425 ELSE PRINT#1,SS$: GOTO 425
425 IF YY=1 THEN S$="ENDENDSTOP" : GOTO 400
430 IF YY>2 THEN 300 ELSE 400
```

APPENDIX E. PROGRAM TRANS.BAS FOR IBM PC

```
1 REM *****************************************************
2 REM * This program is written by D. NIMAL JAYATISSA, for
    * IBM PC, to be used with the program TRANS.BA in
3 REM * TRS80 Model 100 to transfer document files stored
4 REM * in the RAM/CAS.
    * The files transfered would be saved in drive 'b'
5 REM * with the same file name with the extension '.dat'.
6 REM *****************************************************
7 REM
10 CLEAR ,32000,25000
20 MAXFILES=3
30  ON COM(1) GOSUB 90: X=0 : CLS
40 OPEN"COM1:600,N,7,1,DS,CS,CD,RS" AS#1
50 PRINT"Run TRANS.BA in Model 100 and press any key"
60 A$= INKEY$ : IF A$="" THEN 60 ELSE PRINT" ready to receive"
65 B$=CHR$(4)
67 KK=0
70 PRINT#1,B$;
80 COM(1) ON : FOR I=1 TO 1000: NEXT I : KK=KK+1 :
  IF KK=1000 THEN SOUND 4000,30 :
  PRINT"transmission error" : GOTO 67 ELSE 80
90 INPUT#1,SS$ :COM(1) OFF: GOSUB 300  :
  IF B$=CHR$(127) THEN GOTO 67 else cls:
  print" Receiving data !!! Do Not Disturb !!!!!"
100 IF SS$="ENDENDSTOP" GOTO 400
110 IF X< >0 THEN PRINT#3,SS$ :SS$="": GOTO 65
```

```
120 FF$="b:"+SS$+".dat"
130 OPEN FF$ FOR OUTPUT AS 3
140 PRINT FF$ "  file is open"
150 X=10 : GOTO 65
300 CS$=RIGHT$(SS$,2) : ACS=0
305 SS$=LEFT$(SS$,LEN(SS$)-2)
310 FOR I=1 TO LEN(SS$)
312 S$=MID$(SS$,I,1)
314 ACS=ACS+ASC(S$)
316 NEXT I
320 CSS$=RIGHT$(STR$(ACS),2)
330 IF CS$ < > CSS$ THEN B$=CHR$(127) ELSE B$=CHR$(4)
335 CS$="": CSS$=""
340 RETURN
400 PRINT"Data transfer is complete."
410 INPUT"Do you want to transfer another file (y/n)";T$
440 IF T$="y" OR T$="Y" THEN RUN ELSE CLOSE: end
```

APPENDIX F. PROGRAM REDUCE.BAS

```
1 rem*****************************************************
    * This program is written by D. N. Jayatissa for
    * IBM PC, to reduce the A/D converter output strings.
2 rem* using the calibration equations.
    * It can reduce data strings from 10 files at a time.
3 rem*****************************************************
4 rem
5 rem F: pressure
6 rem Y: depth
7 rem F=data from even numbered channels * 160 (psi)
8 rem Y=data from odd numbered channels*15.0204-29 (inch)
9 rem
10 CLEAR,,32768!
12 DIM NI$(10),NO$(10),Y(4),Y$(4),F(4),F$(4)
15 PRINT" HIT ANY KEY TO START"
16 C$=INKEY$ : IF C$="" THEN 16
31 FOR LL=1 TO 10
32 PRINT" count =",LL
33 PRINT" enter blank when finished"
34 INPUT"enter the name of input file (*:******)";NI$(LL)
35 INPUT"enter the name of output file (*:******)";NO$(LL)
36 IF NI$(LL)="" THEN LL=LL-1: GOTO 39
37 NEXT LL
39 FOR MM=1 TO LL
40 PRINT NI$ (MM) " TO " NO$ (MM)
50 X=-6
```

```
80 OPEN NI$ (MM) FOR INPUT AS #1
90 OPEN NO$ (MM) FOR OUTPUT AS #2
100 NO=0
110 GOSUB 250
115 rem 10.34 KPa (1.5 psi) increase in pressure indicates
      that the cone head touches the surface.
120 IF NO=0 THEN FF=F (1): X=X+6: NO=NO+1: F(0)=FF
130 FOR I=1 TO L: IF ((FF-F (I))>1.5 AND (FF-F(I-1))>1.5)
   THEN 140 ELSE NEXT I: F(0)=F(L): Y(0)=Y(L) : GOTO 110
145 rem When the cone head goes 2.5 cm (1 in)into the soil,
      base of the cone head flushes with the soil surface.
140 IF NO=1 THEN PRINT#2,"0.0      0.0": NO=NO+1
150 FOR K=I TO L: IF (Y (K)-XX)>1 THEN I=K:
   PRINT"dril@ " X,"surface = "Y(K),"f = "FF-F(K) :
   GOTO 170 ELSE NEXT K : GOSUB 250 : I=1: GOTO 150
160 GOSUB 250 : I=1
170 FOR K=I TO L: IF (Y (K)-XX)>1 THEN PRINT#2,
   USING " ###.## #####.##";Y (K);F (K)-FF : NEXT K
180 GOTO 160
250 IF EOF(1) THEN 500 ELSE INPUT#1,SS$
260 S$=LEFT$(SS$,2): IF S$< >"01" THEN 100
300 LN=LEN (SS$) : L=CINT(LN/20)
310 FOR I=1 TO L
340 P1=(I-1)*20+4 : P2=(I-1)*20+14
350 Y$ (I)=MID$(SS$,P1,6) : F$ (I)=MID$(SS$,P2,6)
360 Y (I)=VAL(Y$ (I))*15.0204-29
```

```
370 F(I) = VAL(F$(I))* 160
380 NEXT I
390 RETURN
500 CLOSE
510 NEXT MM
```

APPENDIX G. PROGRAM MEDIAN.BAS

```
1 REM ****************************************************
    * This program is written by D. N. Jayatissa for
    * IBM PC, to be used in data analysis of penetration
2 REM * test results reduced by the program REDUCE.BAS.
    * It calculates the average pressure values for each
    * drilling at specified depth interval from three
3 REM * profiles in each plot. Then it find the median
    * pressure for each depth and drilling combination
    * and prints into a file with the average depth which
4 REM * corresponds to the depth interval.
    ****************************************************
5 REM
6 SCREEN 0,1
10 CLEAR,,20000
12 DIM NN(10,15),FA(10,15),REL(3,10,15),NI$(3),R(10,15): CLS
15 FILES
18 FOR II=1 TO 3
19 COLOR II,0
20 PRINT "count = ",II
22 INPUT" enter the name of the input file (_:______.dat)";NI$(II)
25 NEXT II
28 COLOR 5,10
29 PRINT" "
30 INPUT" enter the name of the output file (_:______.dat)";NO$
31 COLOR 4,10 :PRINT""
32 INPUT" What is the spacing between drillings";SP
```

```
33 COLOR 4,11:PRINT""
34 INPUT" What is the depth of layers for averaging";DP
35 WIDTH "lpt1:",132
38 LPRINT CHR$(15);
40 DP$ = " The av. pressures in "+STR$(DP)
41 LPRINT" ": LPRINT DP$;
42 LPRINT"in. depth intervals from the files:"
43 CLS: SCREEN 0,0,0
45 MM = 1
50 CLOSE
55 OPEN NI$(MM) FOR INPUT AS 1
60 FOR I=1 TO 10
65 FOR J=1 TO 15
70 NN(I,J) = 0 : FA(I,J) = 0 : REL(MM,I,J) = 0 : R(I,J) = 0
75 NEXT J
80 NEXT I
90 J=0
100 GOSUB 1000
110 X1=X: Y1=Y
160 GOSUB 1000
165 X2=X-X1 : Y2=Y
170 IF X2<0 THEN 160
180 XX=X2
190 F=-Y2
200 I=CINT((XX+(DP/2))/DP)
210 NN(I,J)=NN(I,J)+1
```

```
220 FA(I,J) = FA(I,J) + F
230 GOTO 160
1000 IF EOF(1) THEN 2000 ELSE INPUT#1,A,B : IF A = 0! AND B = 0!
   THEN J = J + 1 : GOTO 100
1010 X = A : Y = B
1020 RETURN
2000 LPRINT NI$(MM)
2005 LPRINT"    1    2    3    4    5    6";
2006 LPRINT"    7    8    9    10    11    12";
2007 LPRINT"    13    14    15"
2010 FOR I = 1 TO 10
2020 FOR J = 1 TO 15
2030 IF NN(I,J) = 0 THEN 2050
2040 REL(MM,I,J) = FA(I,J)/NN(I,J)
2045 R(I,J)  =  FA(I,J)/NN(I,J)
2050 NEXT J
2053 LPRINT USING"##  ";I;
2055 LPRINT USING"####.## ";R(I,1),R(I,2),R(I,3),R(I,4);
2056 LPRINT USING"####.## ";R(I,5),R(I,6),R(I,7),R(I,8);
2057 LPRINT USING"####.## ";R(I,9),R(I,10),R(I,11),R(I,12);
2058 LPRINT USING"####.## ";R(I,13),R(I,14),R(I,15)
2060 NEXT I
2070 PRINT NI$(MM) "  is done!"
2075 PRINT "press 'y' to continue"
2080 A$ = INKEY$ : IF A$  = "" THEN 2080
2090 IF(A$ = "y" OR A$ = "Y")THEN 2095 ELSE 2075
```

```
2095 MM = MM + 1 : IF MM > 3 THEN 2100 ELSE 50
2100 LPRINT" ": LPRINT" The median of pressure values for ";
2125 LPRINT"the representative profile"
2150 LPRINT" ": LPRINT"Layer  Drillings 1 -> 15 ":
   LPRINT" !  ------> " : LPRINT" V"
2175 LPRINT"    1     2     3     4     5     6";
2180 LPRINT"    7     8     9     10    11    12";
2185 LPRINT"    13    14    15"
2200 REM  Find median pressure for the representative matrix
2210 FOR I=1 TO 10
2215 FOR J=1 TO 15
2220 IF REL(1,I,J) = > REL(2,I,J) THEN HIGH= REL(1,I,J) :
   LOW= REL(2,I,J) ELSE HIGH =REL(2,I,J) : LOW = REL(1,I,J)
2225 IF (REL(3,I,J)> HIGH ) THEN MEDIAN=HIGH
2230 IF (REL(3,I,J)< HIGH AND REL(3,I,J)>LOW) THEN
   MEDIAN=REL(3,I,J)
2235 IF (REL(3,I,J)< LOW ) THEN MEDIAN=LOW
2240 IF (REL(1,I,J)=0 AND REL(2,I,J)=0) THEN MEDIAN= REL(3,I,J)
2245 IF (REL(2,I,J)=0 AND REL(3,I,J)=0) THEN MEDIAN= REL(1,I,J)
2250 IF (REL(3,I,J)=0 AND REL(1,I,J)=0) THEN MEDIAN= REL(2,I,J)
2260 R(I,J)=MEDIAN
2265 REM        Print the median pressure values
2270 NEXT J
2275 LPRINT USING"##  ";I;
2280 LPRINT USING"####.## ";R(I,1),R(I,2),R(I,3),R(I,4);
2282 LPRINT USING"####.## ";R(I,5),R(I,6),R(I,7),R(I,8);
```

```
2284 LPRINT USING"####.## ";R(I,9),R(I,10),R(I,11),R(I,12);
2286 LPRINT USING"####.## ";R(I,13),R(I,14),R(I,15)
2290 NEXT I
2300 OPEN NO$ FOR OUTPUT AS 2
2310 FOR J=1 TO 15
2320 PRINT#2,"0.0      0.0" : PRINT#2,"0.00001    0.0"
2330 PRINT#2,"0.0001 0.0"
2340 LL=DP/2
2350 FOR I=1 TO 10
2360 IF R(I,J)=0 THEN 2370 ELSE PRINT#2,LL,R(I,J)
2370 LL=LL+DP
2380 NEXT I
2390 NEXT J
2400 CLOSE
2500 PRINT"Do you want to analyse data from another plot?";
2501 print"(y/n)"
2505 LPRINT CHR$(12)
2510 A$=INKEY$
2520 IF A$="" THEN 2510
2530 IF A$="Y" OR A$="y" THEN RUN ELSE END
```

APPENDIX H. PROGRAM CONPTS.BAS

```
1 REM    *************************************************
     * This program is written by D. N. Jayatissa for
     * IBM PC, to be used with the output data from
2 rem  * the program MEDIAN.BAS.
     * This program plots different symbols to show
3 rem  * the points through which different pressure
     * contours at 345 KPa (50 psi) intervals pass.
     * The maximum width of the profile is 213 cm
4 rem  * (84 inches).
     *************************************************
5 rem
6 CLEAR ,,20000
10 P=196
15 SCREEN 0,0 : COLOR 14,9
20 CLS
25 CLOSE
30 PRINT"" : INPUT" Enter the name of the input file
  (_:______.dat)";NI$
35 PRINT"" : INPUT" Enter the total number of drillings";ND
40 SP= 180/ND
45 OPEN NI$ FOR INPUT AS 1
50 CLS : SOUND 4000,25 : PRINT "" : COLOR 4,7
60 PRINT"After printing the screen, press 'y'to plot" :
  PRINT"another data set": COLOR 1,7 : PRINT "" :
  PRINT"Any other key will TERMINATE the program !!!!"
70 COLOR 7,4 : PRINT"" : PRINT"PRESS ANY KEY TO CONTINUE"
```

```
80 A$=INKEY$ : IF A$="" THEN 80

90 SCREEN 2 : KEY OFF: GOSUB 4000

100 GOSUB 1000

110 X1=X: Y1=Y : DD=X : FF=Y1: IF X1<0 THEN X1=.1

120 DR$="BM  1 , "+STR$(P) : DRAW DR$

130  DRAW "bl1 r2"

140 DR$="BM  630, "+STR$(P) : DRAW DR$

150  DRAW "bl1 r4"

160 GOSUB 1000

170 X2=X : Y2=Y

180 XX=X2

190 F=Y2 :D=XX

195 FLAG=0

198 IF F<FF THEN 480

200 IF  (FF<=50 AND F>=50) OR (FF>=50 AND F<=50) THEN KK=50:
    DS$=A1$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
    ELSE 3000

220 IF  (FF<=100 AND F>=100) OR (FF>=100 AND F<=100) THEN KK=100:
    DS$=A2$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
    ELSE 3000

240 IF  (FF<=150 AND F>=150) OR (FF>=150 AND F<=150) THEN KK=150:
    DS$=A3$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
    ELSE 3000

260 IF  (FF<=200 AND F>=200) OR (FF>=200 AND F<=200) THEN KK=200:
    DS$=A4$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
```

```
    ELSE 3000
280 IF  (FF< =250 AND F> =250) OR (FF> =250 AND F< =250) THEN KK=250:
    GOSUB 1500: GOSUB 1900 : IF FLAG=1 THEN 195 ELSE 3000
300 IF  (FF< =300 AND F> =300) OR (FF> =300 AND F< =300) THEN KK=300:
    GOSUB 1500: GOSUB 1800 : IF FLAG=1 THEN 195 ELSE 3000
320 IF  (FF< =350 AND F> =350) OR (FF> =350 AND F< =350) THEN KK=350:
    GOSUB 1500: GOSUB 1700 : IF FLAG=1 THEN 195 ELSE 3000
340 IF  (FF< =400 AND F> =400) OR (FF> =400 AND F< =400) THEN KK=400:
    DS$=A8$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
    ELSE 3000
360 IF  (FF< =450 AND F> =450) OR (FF> =450 AND F< =450) THEN KK=450:
    DS$=A9$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
    ELSE 3000
380 IF  (FF< =500 AND F> =500) OR (FF> =500 AND F< =500) THEN KK=500:
    DS$=A0$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
    ELSE 3000
400 IF  (FF< =550 AND F> =550) OR (FF> =550 AND F< =550) THEN KK=550:
    DS$=B1$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
    ELSE 3000
420 IF  (FF< =600 AND F> =600) OR (FF> =600 AND F< =600) THEN KK=600:
    DS$=B2$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
    ELSE 3000
460 GOTO 3000
480 IF  (FF< =600 AND F> =600) OR (FF> =600 AND F< =600) THEN KK=600:
    DS$=B2$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
```

```
ELSE 3000
500 IF (FF< =550 AND F> =550) OR (FF> =550 AND F< =550) THEN KK=550:
DS$=B1$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
ELSE 3000
520 IF (FF< =500 AND F> =500) OR (FF> =500 AND F< =500) THEN KK=500:
DS$=A0$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
ELSE 3000
540 IF (FF< =450 AND F> =450) OR (FF> =450 AND F< =450) THEN KK=450:
DS$=A9$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
ELSE 3000
560 IF (FF< =400 AND F> =400) OR (FF> =400 AND F< =400) THEN KK=400:
DS$=A8$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
ELSE 3000
580 IF (FF< =350 AND F> =350) OR (FF> =350 AND F< =350) THEN KK=350:
GOSUB 1500: GOSUB 1700 : IF FLAG=1 THEN 195 ELSE 3000
600 IF (FF< =300 AND F> =300) OR (FF> =300 AND F< =300) THEN KK=300:
GOSUB 1500: GOSUB 1800 : IF FLAG=1 THEN 195 ELSE 3000
620 IF (FF< =250 AND F> =250) OR (FF> =250 AND F< =250) THEN KK=250:
GOSUB 1500: GOSUB 1900 : IF FLAG=1 THEN 195 ELSE 3000
640 IF (FF< =200 AND F> =200) OR (FF> =200 AND F< =200) THEN KK=200:
DS$=A4$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
ELSE 3000
660 IF (FF< =150 AND F> =150) OR (FF> =150 AND F< =150) THEN KK=150:
DS$=A3$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
ELSE 3000
680 IF (FF< =100 AND F> =100) OR (FF> =100 AND F< =100) THEN KK=100:
```

```
   DS$=A2$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
   ELSE 3000
700 IF  (FF< =50 AND F> =50) OR (FF> =50 AND F< =50) THEN KK=50:
   DS$=A1$ : GOSUB 1500: GOSUB 2000 : IF FLAG=1 THEN 195
   ELSE 3000
720 GOTO 3000
1000 IF EOF(1) THEN 5000 ELSE INPUT#1,A,B : IF A=0! AND B=0!
   THEN P=P-SP : PS$=STR$(P): GOTO 100
1010 X=A :Y=B
1020 RETURN
1400 REM  interpolate to find the point to plot the symbol.
1500 DF=ABS(F-FF): IF DF=0 THEN 160
1510 DX=ABS(D-DD)
1515 DK=ABS(KK-FF)
1520 YY=DD+DX/DF*DK
1530 YY=YY*23
1540 YY=CINT(YY)
1550 YS$=STR$(YY)
1560 DR$="BM "+YS$+","+PS$
1570 DRAW DR$
1580 IF FF> =KK+50 OR FF< =KK-50 OR F> =KK+50 OR F< =KK-50 THEN
   FLAG=1: GOTO 1590 ELSE  RETURN
1590 IF F<FF THEN FF=FF-50 : DD=DD+DX/DF*50 : RETURN
1600 IF F>FF THEN FF=FF+50 : DD=DD+DX/DF*50 : RETURN
1700 CIRCLE (YY,P),2,,-1.5,-3! ' LEFT upper quadrant   350 psi
1710 RETURN
```

```
1800 CIRCLE (YY,P),2,,-3!,-4.5 ' RIGHT upper quadrant  300 psi
1810 RETURN
1900 CIRCLE (YY,P),2   ' CIRCLE                  250 psi
1910 RETURN
2000 DRAW DS$
2010 RETURN
3000 DD=D : FF=F
3010 GOTO 160
4000 A1$="Nu1 d1"           ' - SIGN              50 psi
4010 A2$="NU1 ND1 NL2 R2"    ' + SIGN             100 psi
4030 A3$="BL1 U1 R2 D2 L2 U1"   ' BOX SIGN        150 psi
4040 A4$="Ne1 NF1 NG1 H1"   ' X SIGN              200 psi
4080 A8$="BL1 E1 F1 G1 H1"  ' DIAMOND             400 psi
4090 A9$="BU1 F1 L2 E1"' UP TRIANGLE              450 psi
4100 A0$="BD1 E1 L2 F1"  ' DOWN TRIANGLE           500 psi
4110 B1$="BL1 BD1 U2 F2 U2"  ' N SIGN             550 psi
4120 B2$="BL1 BU1 R2 G2 R2"  ' Z SIGN             600 psi
4200 RETURN
5000 P=10 : PS$= STR$(P)
5010 GOSUB 6000
5200 P=190 : PS$=STR$(P)
5210 GOSUB 6000
5300 REM draw the box around the plot.
5400 LINE (0,12)-(629,188),,B
5500 AA$=INKEY$
5510 IF AA$="" THEN 5500
```

```
5520 IF (AA$="y" OR AA$="Y") THEN 5530 ELSE END
5530 LPRINT CHR$(12) ' move printer paper to next page
5540 RUN
5550 REM draw the tic marks to show 1 inch depth intervals
6000 FOR I=0 TO 29
6020 XY=I*23
6030 XY$=STR$(XY)
6040 DS$="BM "+XY$+","+PS$
6050 DRAW DS$
6060 DRAW"nu2 d2" : NEXT I
6065 RETURN
```

APPENDIX I. THE MEDIAN PENETRATION RESISTANCE FOR THE TEST PLOTS

Table 3. Median penetration resistance from plot 1 (psi).

Layer	Penetration Test Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	27.40	43.09	29.99	79.96	42.51	35.59	62.84	41.92	46.66	43.76	32.13	48.08	67.64	31.32	52.90
2	90.05	98.79	110.41	150.14	103.01	72.57	145.92	103.81	145.57	114.01	107.82	87.29	94.99	116.96	94.41
3	148.24	143.03	161.34	222.63	78.78	134.86	165.52	116.22	150.28	186.39	156.48	86.08	113.28	87.12	140.56
4	158.15	254.50	239.05	244.83	173.08	232.01	347.47	374.48	262.84	210.53	116.35	220.37	264.48	254.66	217.46
5	302.73	307.93	428.05	355.04	442.69	377.45	381.69	436.62	323.91	340.76	313.15	354.94	469.62	298.95	404.37
6	379.84	279.43	244.20	354.16	359.92	327.93	322.61	354.95	248.93	385.71	362.84	321.67	242.53	287.23	270.96
7	169.98	265.33	195.11	281.22	283.59	287.51	252.65	257.09	328.59	320.19	309.58	373.54	243.68	251.40	246.61
8	162.38	259.11	176.98	279.41	225.28	253.19	197.87	222.20	260.37	241.95	256.13	212.01	212.22	214.18	187.63

Table 4. Median penetration resistance from plot 2 (psi).

Layer	Penetration Test Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	94.88	100.19	154.30	82.48	70.17	62.18	57.54	76.86	98.20	89.61	67.51	89.46	53.92	69.84	55.55
2	210.32	245.06	225.75	164.62	216.79	188.67	164.12	211.89	206.80	211.82	126.55	160.55	167.42	218.41	173.53
3	207.57	233.90	248.35	222.49	214.46	209.50	160.44	232.16	196.40	260.63	152.25	224.24	186.41	174.72	194.72
4	288.21	308.22	333.18	340.82	286.09	227.70	209.37	237.81	281.18	313.80	306.93	321.21	251.26	278.76	246.39
5	375.13	408.48	376.71	349.06	411.14	374.65	346.13	365.08	311.40	362.61	363.24	353.00	318.33	325.91	301.81
6	345.15	417.20	374.01	313.90	345.62	317.87	271.74	299.38	265.99	303.40	358.70	272.62	315.69	282.34	277.60
7	264.60	355.59	309.65	247.97	262.52	240.32	233.26	230.32	223.81	243.57	256.48	215.77	240.51	236.08	237.24
8	203.85	278.99	239.05	191.71	197.56	201.30	169.01	162.64	191.73	201.55	186.35	178.78	195.28	198.10	194.12

Table 5. Median penetration resistance from plot 3 (psi).

Layer	Penetration Test Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	48.55	64.92	41.49	71.32	47.14	52.62	56.00	49.11	66.42	71.47	51.63	52.14	74.94	60.35	53.93
2	133.05	121.58	134.87	149.84	160.59	135.73	174.12	137.48	135.36	176.23	177.25	176.95	213.29	180.49	125.59
3	239.78	229.63	213.13	262.86	244.18	149.32	226.98	183.91	182.68	261.20	179.04	195.76	247.02	162.96	169.44
4	369.61	352.82	388.21	336.38	351.46	355.00	338.85	303.59	374.20	381.47	367.18	328.02	396.80	308.79	327.05
5	372.10	383.83	415.75	385.19	398.51	391.78	392.56	374.98	389.31	387.50	402.78	393.81	375.11	404.04	395.46
6	361.88	398.05	408.83	341.77	381.44	369.17	401.62	351.01	385.51	372.55	416.16	399.83	358.36	383.96	422.55
7	362.36	425.59	382.72	373.78	378.92	357.17	373.02	396.83	437.39	359.96	377.01	375.14	352.96	348.08	325.81
8	348.86	361.92	388.38	344.45	411.42	383.31	351.29	419.51	415.81	338.82	394.14	393.70	322.77	309.32	324.73

Table 6. Median penetration resistance from plot 4 (psi).

Layer	Penetration Test Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	56.76	35.34	43.80	50.06	44.90	76.02	96.52	54.79	51.72	41.12	48.85	48.39	40.08	39.73	46.35
2	136.51	128.83	152.26	113.50	128.15	163.25	165.32	189.48	152.32	142.70	165.90	156.33	142.24	177.22	95.74
3	206.11	140.81	176.63	111.74	128.57	129.31	177.70	188.10	125.81	130.35	191.08	179.75	117.93	238.61	161.34
4	283.74	151.74	243.20	281.21	165.84	284.16	271.70	192.81	156.47	122.88	202.30	298.56	119.14	218.24	154.01
5	529.82	465.51	403.69	511.71	433.89	512.70	509.97	500.13	395.12	362.87	436.25	468.66	453.94	481.83	398.15
6	--	504.53	519.08	289.05	316.06	246.91	284.45	329.35	495.30	441.73	319.81	323.58	324.78	281.68	507.37
7	--	458.25	--	366.66	333.66	450.04	316.30	459.19	411.41	456.04	450.75	328.44	312.52	272.51	226.32
8	--	536.56	--	541.61	532.63	--	480.99	512.58	403.38	448.30	--	536.89	251.74	234.61	203.82

Table 7. Median penetration resistance from plot 5 (psi).

Layer	Penetration Test Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	60.17	39.32	43.61	40.51	57.07	37.53	36.56	56.02	66.67	54.61	43.67	44.12	39.27	45.10	52.57
2	195.39	167.03	63.11	143.91	182.95	107.60	161.80	242.63	182.46	197.95	138.32	160.48	106.25	155.22	195.56
3	148.47	178.10	129.40	132.21	192.09	138.86	248.42	246.21	191.38	157.12	148.08	150.17	142.41	154.92	225.02
4	326.83	208.73	179.69	286.44	300.67	142.84	221.61	236.70	316.25	225.27	207.55	239.64	210.42	384.91	279.66
5	470.09	413.56	387.54	465.70	509.77	385.80	358.70	522.54	441.23	521.34	421.49	450.34	437.40	444.79	446.75
6	552.34	531.31	435.40	461.50	463.37	472.14	494.40	500.00	521.41	517.77	525.66	513.11	512.99	432.92	491.55
7	465.14	469.19	399.20	467.98	487.33	480.92	411.93	393.24	370.82	382.44	346.57	494.12	520.68	536.29	355.76
8	437.31	404.18	437.29	395.46	518.25	411.70	349.92	375.36	356.71	320.92	434.33	457.22	--	--	251.29

Table 8. Median penetration resistance from plot 6 (psi).

Layer	Penetration Test Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	59.72	91.99	75.76	52.88	67.91	127.95	78.71	87.63	132.27	112.12	124.30	106.10	65.42	159.61	74.74
2	233.67	292.77	275.37	231.57	153.09	272.61	184.63	242.14	209.31	326.55	226.81	227.72	263.83	279.88	201.83
3	401.43	368.72	401.36	373.36	300.15	446.02	282.97	317.22	364.17	435.64	404.79	420.95	349.77	483.11	284.63
4	410.45	430.28	428.15	489.34	453.03	447.17	521.03	362.77	373.63	460.28	484.78	411.40	451.30	407.53	438.56
5	367.11	382.20	424.79	409.54	409.81	378.28	334.16	353.04	354.59	433.75	409.33	391.96	364.12	373.91	375.04
6	339.71	337.42	380.03	372.52	380.16	363.34	312.36	306.78	343.36	389.14	355.52	370.08	346.16	344.68	398.69
7	288.12	342.20	335.60	331.34	339.41	294.02	260.51	298.91	305.78	375.88	326.60	352.65	317.42	269.67	386.58
8	245.44	293.50	306.70	333.96	327.01	252.00	208.31	285.84	269.30	341.20	248.11	305.01	295.27	205.28	255.74

Table 9. Median penetration resistance from plot 7 (psi).

Layer	Penetration Test Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	56.65	63.90	72.94	52.08	78.34	107.37	54.16	42.55	54.82	60.54	61.77	72.26	57.42	96.45	56.77
2	162.62	216.90	192.37	147.48	171.63	174.02	143.00	154.36	177.34	208.85	204.24	156.68	148.12	210.96	165.72
3	183.60	222.72	182.78	160.22	189.88	185.18	203.60	210.60	181.22	212.44	196.53	158.25	164.27	177.37	141.84
4	328.30	407.41	359.50	283.04	243.00	272.14	310.46	361.96	336.14	333.55	249.72	337.07	424.74	383.91	235.15
5	407.81	374.81	254.42	252.17	210.03	173.63	270.36	402.85	388.78	153.01	188.80	406.61	453.73	429.63	475.99
6	325.59	231.60	188.61	194.67	176.73	148.24	202.17	278.18	259.19	138.46	178.40	295.21	223.95	194.96	271.95
7	222.70	147.94	144.81	155.05	162.59	168.88	172.87	192.13	180.07	227.61	257.19	230.88	177.86	145.29	158.58
8	198.08	127.83	133.79	137.33	137.57	145.10	152.57	150.83	145.37	128.48	149.44	190.73	153.07	134.94	154.12

Table 10. Median penetration resistance from plot 8 (psi).

sk Layer	Penetration Test Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	51.93	96.59	58.16	53.86	81.47	46.39	42.93	46.85	68.00	109.72	52.13	46.66	52.46	64.55	52.77
2	140.47	193.34	147.35	159.76	176.19	72.03	159.23	172.26	204.10	266.05	198.84	125.51	104.84	160.27	192.57
3	138.25	185.02	163.31	150.19	157.76	150.07	183.72	175.81	174.62	219.16	207.21	132.80	113.44	165.47	191.40
4	207.89	290.47	207.77	335.32	293.91	188.56	236.63	183.86	158.96	336.39	294.74	240.55	237.45	299.63	236.36
5	458.47	494.08	416.98	420.82	412.00	303.16	402.90	282.45	383.38	540.79	489.30	482.87	393.01	477.78	395.81
6	402.44	405.46	426.69	398.33	322.55	468.59	390.03	348.26	406.48	473.21	411.20	431.29	432.74	483.53	336.56
7	331.67	320.00	333.28	286.59	294.95	403.55	361.87	322.70	427.57	299.76	381.52	395.23	397.45	273.05	242.22
8	293.54	287.52	313.99	292.45	289.56	321.71	319.10	307.51	301.85	--	377.61	307.95	357.43	227.46	263.87

Table 11. Median penetration resistance from plot 9 (psi).

Layer	Penetration Test Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	97.61	88.13	80.19	73.07	182.43	86.12	74.92	47.94	126.31	114.52	135.82	111.93	71.89	90.38	114.85
2	258.46	251.66	222.13	218.13	238.74	236.05	201.19	154.91	230.62	245.99	289.69	243.92	288.92	294.99	268.08
3	220.21	233.46	228.53	292.12	348.43	261.93	210.84	185.24	237.54	309.77	245.02	299.01	297.63	368.59	309.01
4	380.90	432.32	356.55	494.65	555.98	314.77	343.47	245.07	369.71	401.58	383.73	344.87	367.77	445.07	520.93
5	493.71	502.41	495.11	345.99	320.51	314.21	286.26	367.10	387.15	393.92	383.95	388.12	342.57	360.66	444.97
6	479.42	492.35	478.21	279.01	237.88	277.09	240.87	274.03	393.68	354.96	272.64	371.96	230.77	281.29	318.49
7	430.91	473.37	289.16	236.89	259.68	275.11	225.62	276.34	446.28	340.14	322.80	370.16	239.35	342.16	260.49
8	494.78	502.15	231.58	285.87	414.23	350.35	214.21	269.29	288.48	352.09	344.63	395.56	299.25	338.38	243.25

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