

Design and Construction of a Tractor Mounted Penetrometer

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ABSTRACT

Evaluation tests were conducted to determine the data compatibility of a newly designed penetrometer as compared with data obtained from a hand-operated penetrometer before and after subsoiling the field for soil compactness. There was no significant differences ($P>0.05$) between the data obtained from the two penetrometers in the field under no subsoiling condition. Similar results were obtained for the two penetrometers when the field was subsoiled ($P>0.05$). Newly designed penetrometer performance was found to be reliable and the system worked without any malfunctions.

Key Words: Penetrometer; Photodiodes; Loadcell; Soil resistance

INTRODUCTION

Use of penetrometers as a device to sense penetration resistance of soils have been considered by researchers in the past forty years. One of the problems in measuring compaction and other soil characteristics is a quick and accurate method of making the measurement. The two major objections to the use of most soil penetrometers are the laborious process of manually pushing the cone into the soil media and recording individual reading obtained at specified intervals. Another problem encountered with the manually operated penetrometers is the difficulty to maintain a constant penetration rate when the cone is pushed into the soil. Various types of penetrometer and the effect of different factors on penetration resistance were studied by previous researchers.

Carter (1967) and Prather *et al.* (1970) have developed recording penetrometers which plot depth-resistance curve as the probe is forced into the soil, but the force must be applied manually. Williford *et al.* (1972) developed a tractor-mounted penetrometer in which a hydraulic cylinder is used to force the penetrometer into the soil. An x-y plotter records the penetration data consisting of force-depth relationship at any point across three 1m rows. For their design, two men are needed to collect data.

Microcomputer-based cone penetrometers have been developed for recording penetration resistance. Phillips and Perumpral (1983) modified a conventional cone penetrometer to provide an electrical signal corresponding to the penetration resistance by placing strain gauges on the proving ring. The designed system required two operators for conducting test and recording data.

As the instrument became more popular, many versions of hand or machine operated static cone penetrometers of different capacity have been developed (Schmertmann, 1975). Woodruff and Lenker (1984)

designed a manually operated recording type penetrometer which can record the penetration resistance data with depth increments of 12mm to a depth of 100cm on an electronic data logger. The data logger can store data from 60 to 70 penetration tests each with 48 readings.

Wilkerson *et al.* (1982) developed a more elaborated test unit for soil strength measurements. It consisted of a tractor-mounted hydraulically-operated cone penetrometer designed to operate to a depth of 61cm over a 4-row width. A microprocessor-based control unit is used to activate all moving mechanisms and automatically record the data on a magnetic tape.

Radcliffe *et al.* (1985) investigated the effect of two tillage systems on soil compaction by measuring the cone index using a tractor mounted penetrometer. Their instrument recorded cone index in each 2.5cm increment to a depth of 40cm. They found that cone index was higher in the no-till field as compared in the tilled field. They concluded that tilling eliminated the compacted depth zone (10-30cm).

Ohmiya (1998) developed a technique for soil strength assessment. He introduced a penetrometer for three dimensional cone resistance mapping. The penetrometer is able to measure the penetration resistance in three directions. Brye *et al.* (2005) studied the effect of shallow-cut land leveling and cropping on penetration resistance with a penetrometer before and after land leveling. The penetration resistance (Cone Index, CI) was measured at 0.05m intervals to 0.35m depth at each grid (0.36 ha). They found that land leveling increased the CI ($P<0.05$) at all depth. Also, land leveling resulted in a 0.1m shallower hard pan which effectively reduced the soil volume for subsequent crop root growth by 50%.

The objective of this study was to develop a tractor mounted penetrometer operated by one individual and also to do a quick, easy, and economical task in order to obtain force-depth curve in different soil media.

MATERIALS AND METHODS

The soil penetrometer system designed consists of three major components as follows:

- 1 - Force transducer and housing
- 2 - Depth measuring sensor and housing
- 3 - Recording unit.

The entire penetrometer assembly is mounted on a frame that attached to the three point linkages of a Universal tractor (Model, U651) as shown in Fig. 1. A fourth arm was provided to support the frame vertically during the data collection. Two 5x5cm adjustable hollow tubes with triangle base welded to the sides of supporting frame for the unit standing on floor when it is not mounted on the tractor. A hydraulic cylinder with 6.3cm in diameter and a 100cm in stroke is mounted at the center of the frame. The load cell constructed with four strain gauges used in a wheatstone bridge circuit and its housing is attached to the end of cylinder rod. A cone penetrometer as described in the ASAE standard S313.2 (ASAE, 1998) with driving shaft length of 70cm, diameter of 1.3cm and cone angle of 30 degree was built and mounted beneath the load cell unit. The hydraulic components are powered by the tractor hydraulic system. Flow control assembly with pressure compensated and flow regulator valves were used to obtain a desired constant speed of penetration (Fig. 2). Several methods can be used to obtain the depth signals. A linear variable differential transformer or a multi-turn potentiometer can be used to acquire an electrical signal proportional to the depth of penetration.

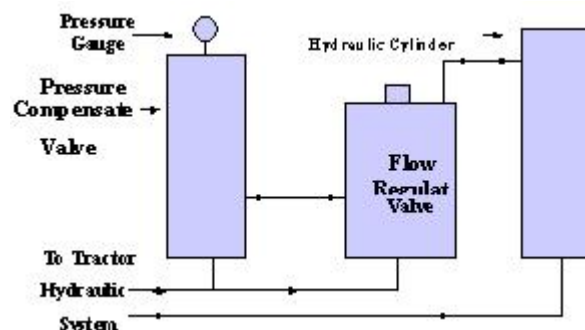
In this study, for depth transducer mechanism, a different method was employed by using two pairs of photodiode sensors, a 2mm thick plate (800mm x 30mm) folded along the length forming a L-shaped plate, a base block and a guiding block machined as shown in Fig. 3. On one side of the L-shaped plate forty holes (4mm in diameter) were drilled equally with 15mm intervals. On the other side of plate, two notches (60cm apart) were made to limit the ranges. The penetrometer shaft and L-shaped plate were fitted into the machined guiding block so that the guiding block could move easily over the length of L-shaped plate. The photodiode sensors were mounted on guiding block so that the L-shaped plate can pass through the detectors (photodiode sensors) and interrupt the ultra-red rays passing from transmitter to detectors. Vertical forces on the penetrometer are then transmitted to the force transducer, but side forces were absorbed by the base block and supporting frame (Fig. 3, left).

An electronic circuitry (A/D converter, signal conditioning & appropriate amplifiers) with a regulated 12V power supply are the instrumentation used to receive the transducers' signals. The instrumentation is powered from the tractor battery. Force and depth signals are generated by appropriate transducers installed on the penetrometer unit and sent to the circuit assembly (electronic unit) mounted on the side of force transducer housing (Fig. 3, right). The

Fig. 1. View of the tractor mounted penetrometer



Fig. 2. Block diagram of penetrometer hydraulic system



appropriate output signals are then sent to x-y recorder to obtain force–depth curve. Before using the penetrometer unit, calibration tests were conducted for load cell assembly. A 50kN Tensile-Compression test machine (AMSLER, Germany) was used for this purpose. The average forces applied on the load cell from different tests were plotted against the voltage changes of strain gauges bridge measured with digital multimeter and regression analysis results revealed a very good linear correlation with R-Square of 0.9988.

The overall performance of the completed penetrometer was evaluated by the field tests for three general basic characteristics; (a) accuracy and repeatability, (b) stability with respect to time and temperature, and (c) compatibility of the penetrometer data with data of another available type of penetrometer.

Prior to experiments, three 1m x 30m sampling grid spaced evenly at 0.5m apart were established in the study area. In each grid, before and after subsoiling (using a 3–

shank subsoiler adjusted at a depth of 50cm) soil penetration resistance measurements were made with both hand-operated (Boush, SP-1000) and the tractor-mounted penetrometers. Six locations along the 30m grid with spaces of 5m were selected for data collection by two penetrometers separately. The hand-operated penetrometer was set to record data every 1cm from a depth of zero to 50cm. The tractor mounted penetrometer collect data in a continuous manner. Both penetrometers had a 30 degree cone angle with a base diameter of 1.3cm (132.7mm² cone base area). By dividing the force recorded by area of cone, the soil penetration resistance is obtained.

RESULTS AND DISCUSSION

The system's reliability tests were conducted by comparing the recording outputs for a number of tests with the same input applied each time. An error of less than $\pm 1\%$ of full scale was reported for 20 preliminary test runs. Similarly, the short term total accuracy was determined by comparing the output of the force and depth axes with the known inputs. For the given inputs, the maximum output error of either axis was found to be less than $\pm 1\%$ of full-scale reading. Stability of the system was determined by measuring the change in the output over a period of time and temperature ranges. The drift over a 6-hr period at a constant temperature was less than $\pm 0.3\%$ and for a $\pm 5^\circ\text{C}$ temperature change an $\pm 0.8\%$ error was recorded on full scale. These results were in the acceptable ranges and corroborate the earlier reports by Prather *et al.* (1970).

The method used to determine the data compatibility of the penetrometer was to compare it with data obtained from a hand-operated penetrometer. Averaged penetration resistance measurements for three grids and six locations (18 averaged data points) by both penetrometers were plotted for comparison at 6cm depth intervals from zero to 48cm before and after subsoiling (Fig. 4). These findings are in agreement with those of Williford *et al.* (1972) whom reported that data of these types are used to isolate production practices that produce zones of compacted soil and prevent proper root development.

Subsoiling significantly affected the mean soil resistance near the hardpan (30cm depth) which support the field observations (Fig. 4). Soil resistance plotted for hand-operated and tractor-mounted penetrometers before subsoiling (Hand-Penet_Ntill & Tractor-Penet_Ntill) are nearly the same. This is also true for the data plotted after subsoiling (Hand-Penet-Till compared to Tractor-Penet_Till). This conclusion is in agreement with the reports of Prather *et al.* (1970), Williford *et al.* (1972) and Byre *et al.* (2005). In general, a significant difference exists in the soil resistance data (cone index) for no-till and tilled field. Subsoiling almost eliminated the hardpan developed in the depth of 10 to 35cm (Fig. 4). This conclusion was also reported by the work done by Radcliffe *et al.* (1985) that tilling eliminates the compaction in the 10-25cm depth zone.

Fig. 3. Force and depth transducer's assembly(left) and electronic unit (right)

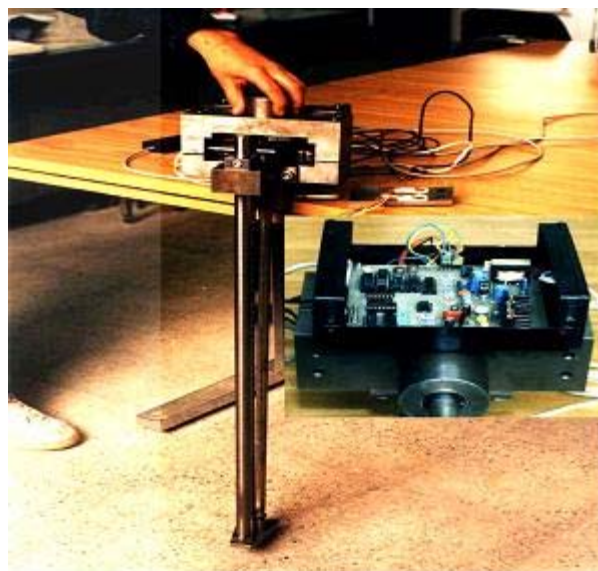
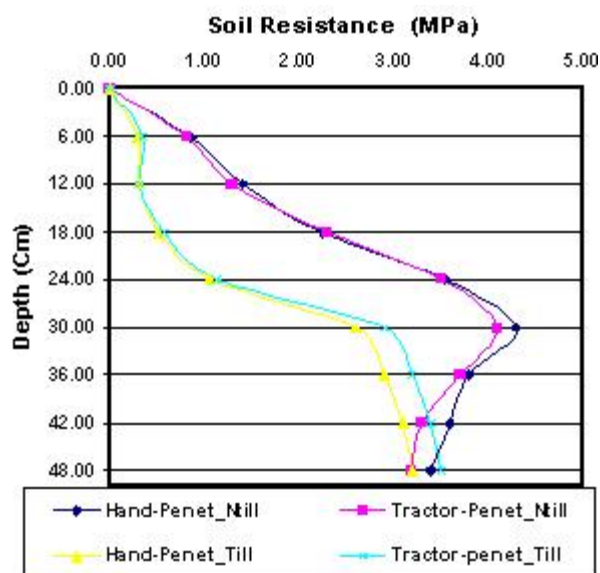


Fig. 4. Soil resistance plots for two penetrometers in different soil conditions



The proof of above findings was supported by statistical analysis (T-test) that was conducted for comparison of data obtained by the two penetrometers for soil resistance (Table I). The result showed no significant difference ($P > 0.05$) between the variance of two variables. Since the two data samples have equal variances, the T-test analysis assuming equal variance was conducted (Table II). The presence of no differences ($P > 0.05$) between the data obtained from the field tests under no subsoiling condition, led to conclude that the soil resistance measurements for

both hand-operated and tractor-mounted penetrometers are similar (Fig. 4).

As indicated in this, the variances between the two variables can be assumed equal (Table III). Likewise, the result of T-test analysis conducted for equal variances shows no significant differences ($P>0.05$) between the data for soil resistance measurement from two different penetrometers (Table IV). It can be concluded from these findings that performance of the tractor-mounted penetrometer is highly correlated with the hand-operated penetrometer which is in conformity to the work done by Williford *et al.* (1972). It can be discussed from this study and previous related works that, higher soil resistance data is an indication of soil compaction increase and therefore a reduction in crop yield due to lack of root growth is

expected. For the field that are left without subsoiling for years, and since the soil compaction is not visible, the farmers have to be appraised of compaction zones of their field before the crops are sown.

During the tests conducted, no mechanical or electrical problem was experienced. Using mechanical penetrometer, one man can operate and collect data without leaving the tractor seat. The man-hours required for collection of field data in the form of continuous curve rather than discrete points is 12.5%. Williford *et al.* (1972) reported that their tractor mounted penetrometer with two men can obtained data in 25% of time required with hand penetrometer, which is general conformity to these findings.

CONCLUSION

The penetrometer unit designed and tested in this study has been proven good and can be used for performance evaluation of soil strength, trafficability predictions, and soil compaction. However, further improvement in the system is possible by using a portable datalogger with on-line printing facility. Furthermore, comparison for compatibility of data of this penetrometer with data of other mounted type penetrometers with constant rate of penetration is suggested.

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(Received 01 April 2005; Accepted 20 July 2005)

Table I. F-test for equality of variance: No – Tilled

	Hand-Penet_Ntill	Tractor-Penet_Ntill
Mean	2.57	2.47
Variance	2.29	2.09
Observations	9	
Df	8	
F	1.09	
Prob.	0.45	-

Table II. T-test assuming equal variance : No –Tilled

	Hand-Penet_Ntill	Tractor-Penet_Ntill
Mean	2.57	2.47
Variance	2.29	2.09
Observations	9	
df	16	
T	2.58	
Prob.	0.44	

Table III. F-test for equality of variance : Tilled

	Hand-Penet_Till	Tractor-Penet_Till
Mean	1.55	1.71
Variance	1.86	2.25
Observations	9	
df	8	
F	0.82	
Prob.	0.40	-

Table IV. T-test assuming equal variance : Tilled

	Hand-Penet_Till	Tractor-Penet_Till
Mean	1.55	1.71
Variance	1.86	2.25
Observations	9	
df	16	
t	-0.23	
Prob.	0.41	