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Hydraulically-operated Cone Penetrometer With Computer-based Data Acquisition System for Quick Measurements of Cone Index

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ABSTRACT. A tractor-mounted hydraulically-operated Cone Penetrometer with a computer-based data acquisition system was developed for quick measurements of cone index. The penetrometer, being driven by the tractor hydraulic system was capable of exerting a large force to overcome the soil resistance, using the weight of the tractor, at any penetration rate. A computer-based data acquisition system was developed to collect depth and penetration resistance data at 1 cm depth intervals. The data acquisition program written in Quick BASIC language was capable of providing an instant picture of the penetration resistance along the depth and storing the data in floppy diskettes for future analysis. These data together with moisture content readings could be used conveniently by researchers to predict soil bulk density in soil compaction studies.

INTRODUCTION

Bulk density of a soil can be determined through direct and indirect procedures. The direct methods (*eg.* soil core methods and excavation methods), are usually more accurate. They provide opportunities to inspect the samples. The requirement of local corrections to give meaningful results and the inability to observe the soil samples at depths where data is collected are disadvantages of the indirect methods (*eg.* radiation methods and cone index models). The core procedure is associated with many practical problems when subsurface soil samples are taken from very hard or loose soils. The gamma-ray densitometers perform well in clay and sandy soils, but poorly in loamy soils due to the presence of large amounts of stones and pyrite which affect attenuation properties of the soil (Gameda *et al.*, 1987).

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The potential health hazards also have limited the use of gamma-ray densitometers in measuring soil bulk density.

The "cone index", stated at a particular depth or averaged over a depth range, is defined as soil resistance to a penetrating cone divided by its base area. The devices used to determine the cone index are called "Cone Penetrometers" and the widespread use of them in soil compaction studies can be attributed to the following:

1. they are quick, easy, and economical to use,

2. test data can be analyzed easily,

3. they can be used to investigate sandy soils where undisturbed sampling is difficult, and

4. possibility to collect data from the deeper layers.

The soil properties, together with the size and shape of the cone and the rate of penetration, influence the penetration resistance (Gill and Vanden Berg 1968). Therefore, the American Society of Agricultural Engineers (ASAE) developed a standard for cone penetrometers (ASAE Standard S313.2) that recommends a rate of penetration of 3 cm/s (ASAE, 1988). This ASAE Standard is widely used to measure the cone index for tillage and traction tests, soil mobility research, soil compaction studies and plant growth investigations.

During penetration tests, readings are taken at every 2.5cm penetration of the cone. Usually, 2-3 persons are required to conduct the test and record data manually. This technique often leads to erroneous results, because of the fluctuations in the penetration rate and difficulty in observing the penetration resistance data quickly. To overcome these shortcomings, many recording penetrometers with appropriate mechanisms have been developed for maintaining a constant rate of penetration.

Williford *et al.*, (1972) developed a tractor-mounted penetrometer using a hydraulic cylinder. Smith and Dumas (1978) developed a tractor-mounted recording penetrometer powered by an electric motor. Wilkerson *et al.*, (1982) developed a tractor-mounted, hydraulically-operated cone penetrometer controlled by a microprocessor that recorded data on a magnetic tape. Threadgill (1982) used an electronically-recording, tractor-mounted, hydraulically-operated cone penetrometer. Jayatissa (1990) developed a tractor-mounted, hydraulically-operated, recording penetrometer. In this study, a microcomputer recorded the depth and penetration resistance data on a cassette tape. Sirois and Stokes (1988) used a hydraulically-operated cone penetrometer mounted on a four-wheel-drive, all-terrain vehicle. The system was capable of storing penetration force data over depths of 0 to 35.5cm for up to 100 penetrations.

There are no continuous recording penetrometers available in Sri Lanka for compaction studies. The imported data acquisition systems are very costly. Therefore, it was decided to fabricate a hydraulically operated penetrometer with a computerized data acquisition system that records depth and cone index data on computer diskettes.

MATERIALS AND METHODS

The penetrometer developed consisted of 3 systems; Penetrometer assembly, hydraulic system and data acquisition system. The penetrometer assembly, illustrated in Figure 1, had a frame to facilitate lateral movement of the penetrometer. The provisions for attaching the penetrometer to the three point linkage of a tractor were fixed on to the frame. The entire frame was mounted on two wooden boards for stability and for distributing load over a larger area. The cone had an apex angle of 30^0 and a base area of 3.2 cm^2.

The hydraulic circuit, illustrated in Figure 2, was used to control the rate of penetration and to limit the maximum force on the penetrometer. The hydraulic cylinder had a 3.8 cm bore and a 30 cm stroke. A pressure and temperature compensated flow control valve was used to regulate flow rate from cylinder and thereby control the penetration rate at 3 cm/s. A manually operated, three-position, tandem centre, 4-way directional control valve was used to extend or retract the cylinder.

Penetrometer carriage illustrated in Figure 1 included a frame to guide the penetrometer probe and was attached with a limit switch. The carriage had an aluminium bar on which "V" shaped grooves were cut at 1 cm intervals along the outer edge. The limit switch moving over these grooves sent a "CONVERT" signal to the data acquisition system. Whenever the probe was unable to penetrate into the soil, the entire frame was lifted.

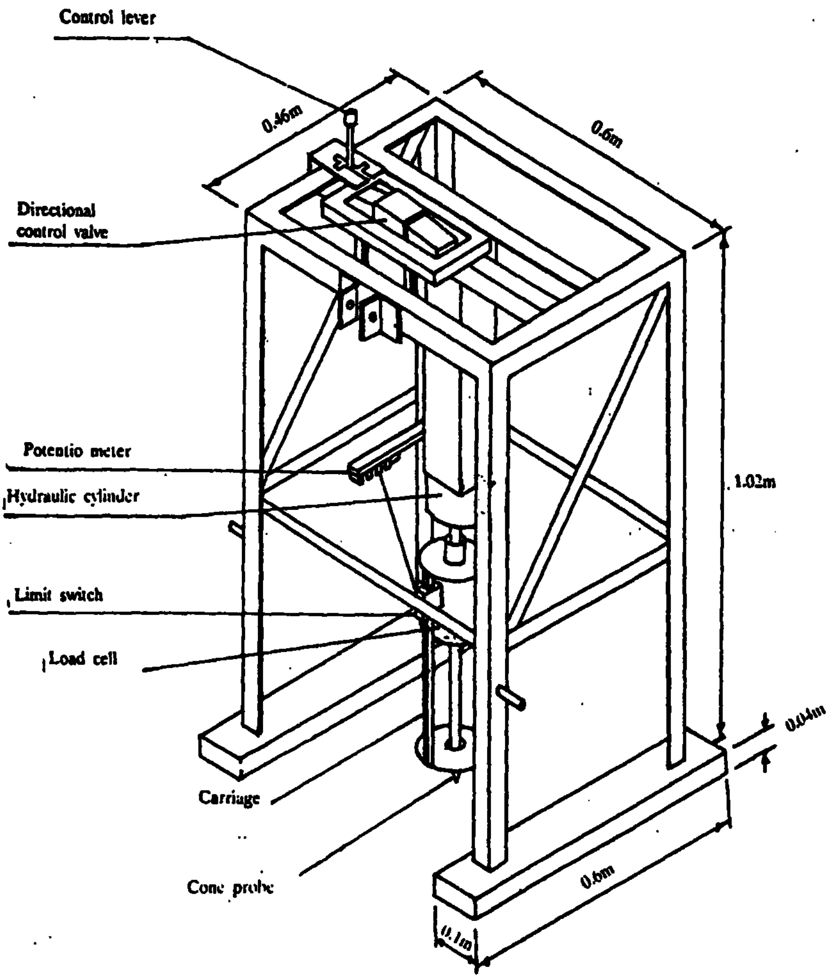

Figure 1. Penetrometer assembly

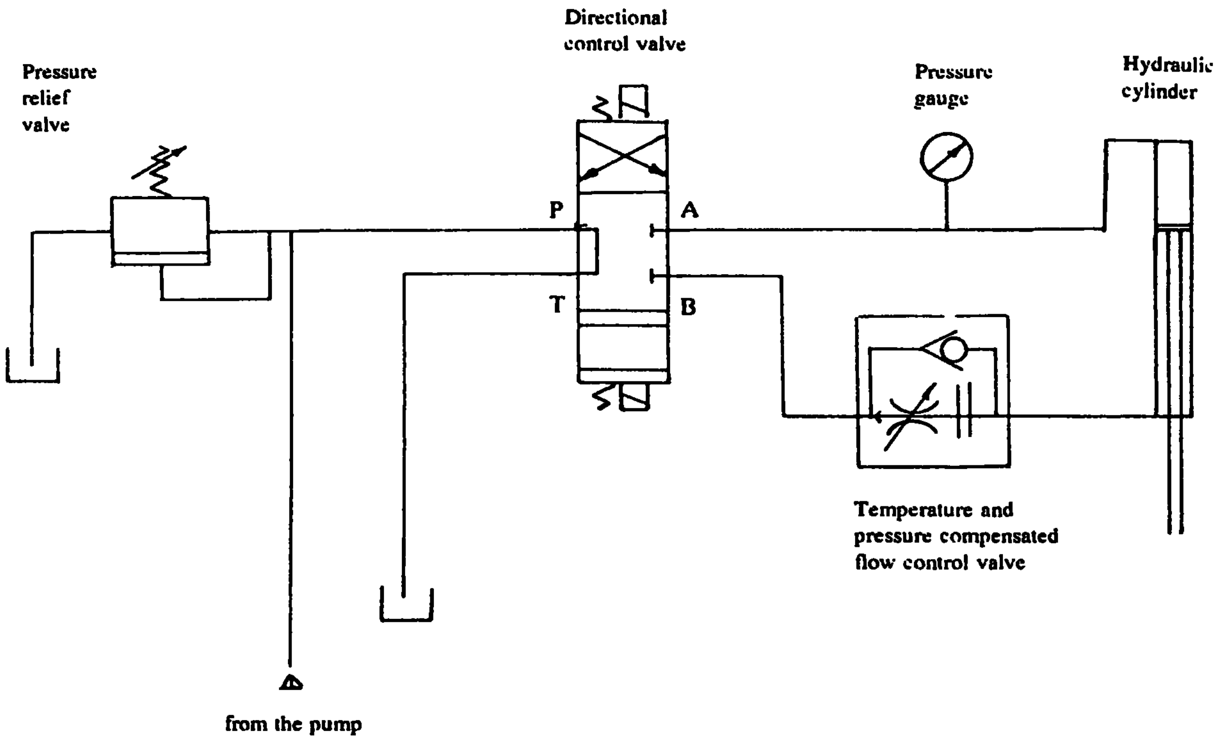

Figure 2. The schematic of the hydraulic system

This arrangement made the limit switch not to operate in such an event and prevented misleading data being recorded.

The data acquisition system (Figure 3) was powered from the 12V DC tractor battery through a DC/DC converter that supplied +15V, -15V and +5V lines. A load cell of 250 kg capacity sensed the penetration resistance. A multi-turn potentiometer sensed the depth. The depth and force transducers were supplied with an input voltage of +9.5V DC using a DC/DC converter.

When the "CONVERT" signal was received, A/D converter first converted the depth sensor output. The 12 bit A/D output was sent to the computer through the serial port at 4800 baud rate after dividing into 8 and 4 bit portions. Then it converted the amplified load cell output and the data were sent to the computer.

The program written in Quick BASIC language recorded the background information and instructed the operator to activate the penetrometer. At the end of the penetration, the user is given a chance to view retrieved data in a table form (Figure 4), where the digitized depth and penetration resistance values appear in columns labelled "POT" and "LC" respectively, and graphically (Figure 5). Viewing data helped the user to identify tunnels or obstructions such as rocks or large roots and to decide whether to save data on the diskette or to discard them and repeat the test.

A Dillon dynamometer (250 kg capacity) was used to adjust the amplifier and to calibrate the load cell. The rate of penetration was set by measuring the time taken by the hydraulic cylinder to extend a given distance.

RESULTS

During the calibration tests the data acquisition system sensed depth (0-25 cm) and penetration resistance (0-250 kg) accurately (R^2 = 0.99989). Data recorded on the diskettes could be retrieved into a LOTUS spreadsheet for reduction and analysis.

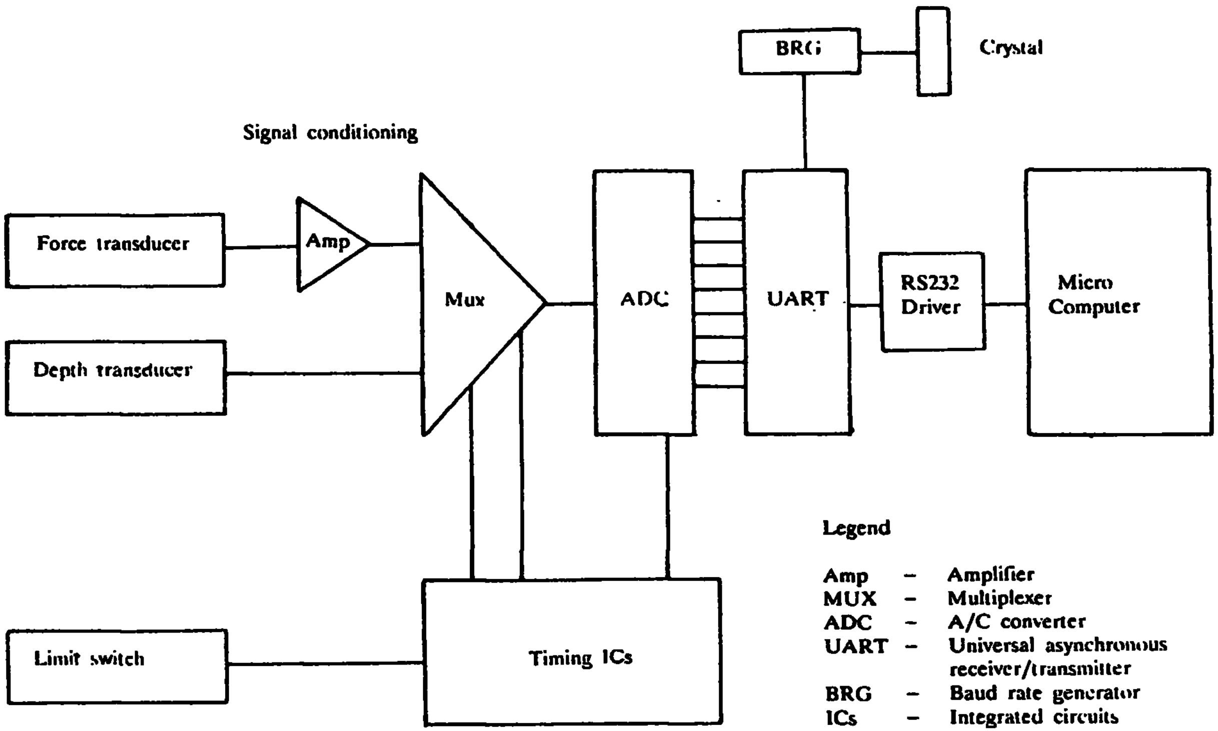

Figure 3. Block diagram of data acquisition system

04-21-1993
08:37:45
Test No. am3
MD2AMR3

No.	HBP	LBP	HBL	LBL	POT	LC
1	20	2	18	0	322	288
2	25	0	25	0	400	400
3	29	14	28	9	478	457
4	35	0	29	15	560	479
5	41	13	34	3	669	547
6	46	15	31	11	751	507
7	51	14	25	15	830	415
8	56	5	28	13	901	461
9	63	0	28	9	1008	457
10	68	11	29	7	1099	471
11	73	4	33	1	1172	529
12	77	1	36	7	1233	583
13	84	5	44	6	1349	710
14	90	2	49	12	1442	796
15	95	1	58	1	1521	929
16	98	8	68	13	1576	1101
17	103	0	76	8	1648	1224
18	108	15	82	3	1743	1315
19	114	7	91	0	1831	1456
20	119	3	101	7	1907	1623
21	122	9	111	2	1961	1778
22	128	5	119	1	2053	1905
23	133	10	132	6	2138	2118
24	138	0	143	0	2208	2288
25	144	4	161	5	2308	2581

Figure 4. Specimen computer output - raw data

A rigid support had to be placed between the drawbar and the tractor chassey to prevent the equipment being lifted during penetration. The assembly being tractor-mounted could easily be transported from and to field. The rate of penetration could be adjusted precisely from zero to a maximum which was a function of the tractor engine speed. The cost of hydraulic components and accessories was Rs. 55000/-. The cost for the parts of the A/D converter was Rs. 7300/-. The load cell was valued at Rs. 22100/-. An imported A/D system having similar capabilities would cost more than Rs. 20000/-. The cost of the load cell could be reduced if fabricated locally.

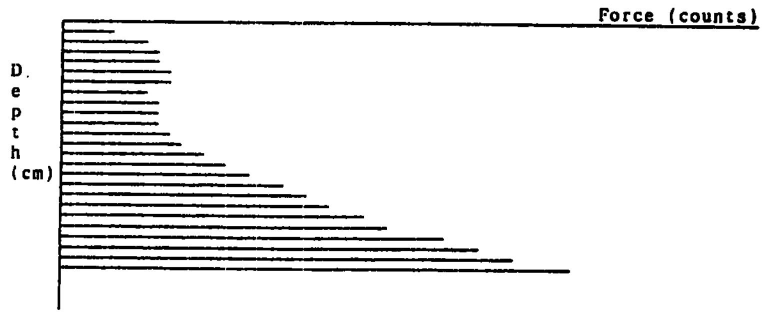

Figure 5. Specimen computer output-bar graph

CONCLUSIONS

The penetrometer developed was capable of exerting large forces and had a precise control over the penetration rate. The unit could be easily operated. The computer-based data acquisition was compact, light weight, low cost and easy to operate. The system gave the operator an instant picture of the penetration resistance beneath the soil surface. Besides data can be stored in floppy diskettes for any future analysis.

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