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Development of Cone Penetrometer for Investigation of Soil Compaction Caused by Agricultural Vehicles in Meadows

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Abstract

The authors developed an instrument that enables to measure the penetration resistance easily and accurately to evaluate the extant of soil compaction generated by the traffic of vehicles in the meadows. The instrument is composed of a cone as a penetrating part, a part for measuring the penetration resistance, a part for measuring the penetration depth, a part for recording data, a part for horizontal positioning, and a handing part. It was possible for the cone to penetrate into the soil with a constant speed through the motor of the penetrating part, and to penetrate vertically even in the case of sloping land by using the part for horizontal positioning. A carries was used to move among the measured points in the field. Measurement area was limited to the area where vehicles moved, namely the inclination of the area for measurement was less than about 25°. The average time required for one measurement was about 2.3 min. It was confirmed that the use of this instrument enabled to measure the penetration resistance easily and frequently and to generate a distribution map of the penetration resistance to determine the position or spread of the hard pan.

Discipline: Agricultural machinery/ Grassland
Additional key words: penetration resistance, instrument, measurement, soil structure

Introduction

In meadows, agricultural vehicles run repeatedly for application of fertilizers or harvest. Soil compaction associated with these operations adversely affects grass production[1,2,6]. The actual condition of the soil compaction in meadows in Japan has not been fully evaluated. To determine the degree of soil compaction, the penetration resistance can be measured. There are several methods for the measurement of the penetration resistance. In most of these methods, manual cone penetration is applied. Penetration resistance at some intervals of depth is read by an assistant or written in a form or input into a computer[3]. The use of this method in meadows is laborious and inaccurate, particularly in compact meadows and meadows on slopes. To alleviate these shortcomings, the authors developed a cone penetrometer that was suitable for the investigation of soil compaction caused by agricultural vehicles in meadows. Objectives of this cone penetrometer are as follows: (1) Operator can measure the penetration resistance in meadows on sloping land up to an inclination of 25°. (2) Operator can measure the penetration resistance without effort. (3) Method of measurement is convenient. (4) Personal or mechanical error is negligible. (5) Operator can observe the measured data just after the measurement. (6) Operator can handle many data skillfully.

Description of cone penetrometer

A cone penetrometer is set in a carrier (Figs. 1, 2 & Table 1). Power source is a 12 V battery. Penetration device consists of a cone with an apex angle of 30° and base area of 2.0 cm^2. Penetration device moves mechanically by using an alternating current motor. If the cone encounters stones in the ground, the cone penetrometer has a fail-safe structure that prevents the main body from being lifted or broken. The cone penetrometer is equipped with a device positioned horizontally that enables the cone to penetrate in a gravitational direction regardless of the inclination of the ground. The operator can

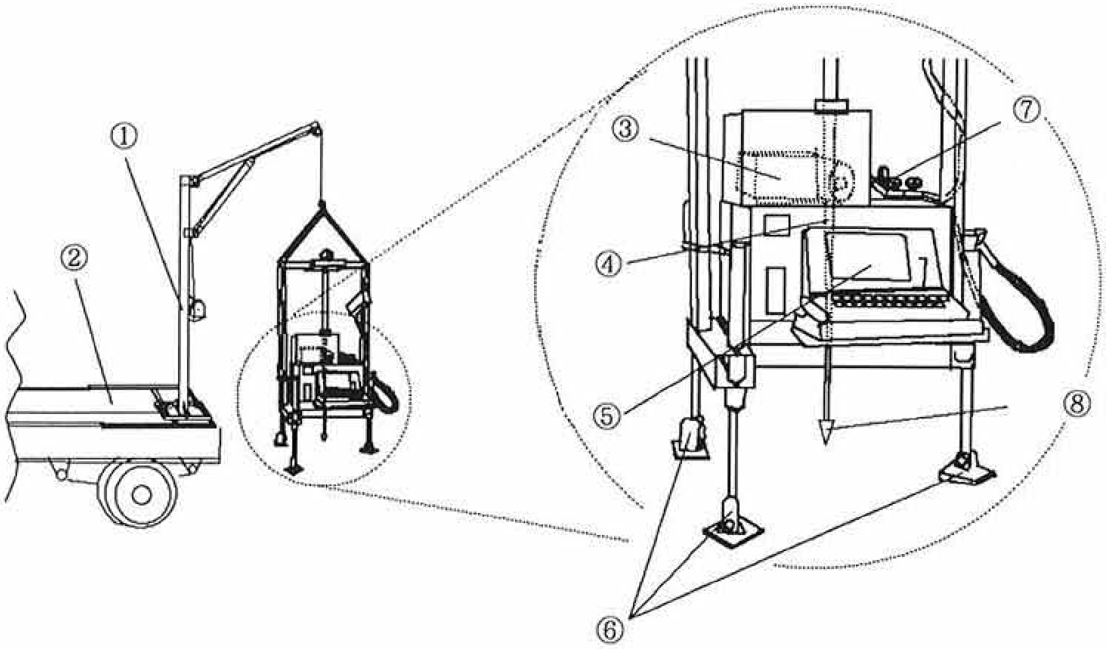

Fig. 1. Attachment of cone penetrometer to the carrier
①: Part for hanging, ②: Carrier, ③: Penetrating part, ④: Part for measuring the penetration resistance, ⑤: Part for control and recording, ⑥: Part for horizontal positioning, ⑦: Part for measuring the penetration depth, ⑧: Cone.

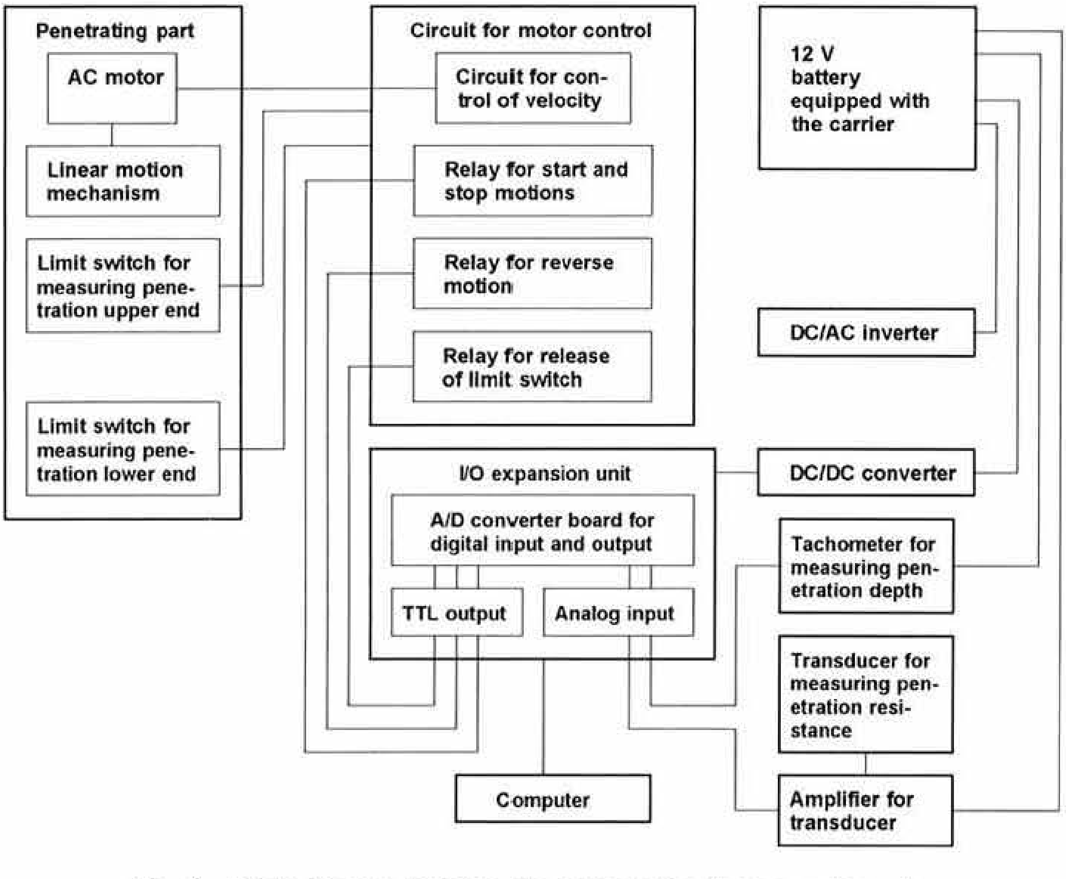

Fig. 2. Block diagram depicting the components of cone penetrometer

Table 1. Specifications of cone penetrometer

Length	790 mm
Width	805 mm
Height	1,850 mm
Mass	154 kg
Maximum permissible penetration depth	450 mm
Maximum permissible penetration resistance	6.86 MPa

start the measurement easily. Penetration device can be automatically stopped and returned after the end of penetration. The relationship between the penetration resistance and depth is recorded just after the measurement (Fig. 4-a). The cone penetrometer is composed of a penetrating part, part for measuring the penetration resistance, part for measuring the penetration depth, part for control and recording, part for horizontal positioning, and hanging part.

1) Penetrating part

The penetrating part is composed of an alternating current motor, rack and pinion, and circuit of motor for speed control. Penetration speed can be modified in a range from 0.63 to 1.25 cm/s. The maximum permissible penetration resistance is 1.37 kN at 1.0 cm/s speed. Penetration speed is constant regardless of resistance and depth.

2) Part for measuring the penetration resistance

The penetration resistance is measured by a load transducer that is set under the rod connection part (Fig. 3). As the cone rod is encased in a steel pipe, only the penetration resistance of the cone can be measured.

3) Part for measuring the penetration depth

The penetration depth is measured by the combination of a rack, transmission gear, sensing revolution gear, and tachometer. The minimum scale value of penetration depth is 0.125 cm.

4) Part for control and recording

The part for control and recording is composed of a computer, I/O expansion unit, power control circuit of an alternating current motor. Measured data are sent from the measuring part through an A/D converter in an I/O expansion unit to a computer. Measured data which are displayed on the panel of the computer are recorded on a floppy disk. Power control circuit of an alternating current motor

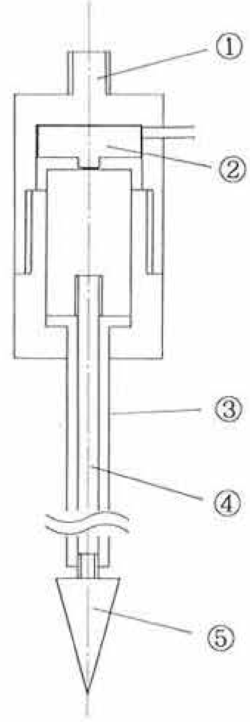

Fig. 3. Part for measuring the penetration resistance
①: Part connected to the rack, ②: Penetration resistance transducer, ③: Steel pipe, ④: Cone rod, ⑤: Cone.

is composed of a switching circuit of transistor and relay. By sending the order of input and output to the I/O port, the relay of the motor power control circuit moves the motor for the start, stop, and reverse motions. The program for the control and recording is written in BASIC. The program is composed of some subroutines, including the start, stop, and reverse motions of the penetration device, measurement of the penetration resistance, display of the relation between the penetration resistance and penetration depth, recording, and obstacle evasion. Flowchart of the program is as follows. When the program starts, calibration value 0 and penetration resistance of 9.8 kN are automatically recorded on the floppy disk. Furthermore, the program requests the operator to adjust the starting position of the cone by an arrow key on the keyboard of the computer. After adjustment, the operator pushes the return key. Cone penetrates at a speed of 1 cm/s. Cone goes down and penetrates to a depth of 45 cm. Cone automatically returns to the starting position. Penetration resistance is A/D-converted every time the pulse generated from the tachometer is recorded on the floppy disk. The measurement representing

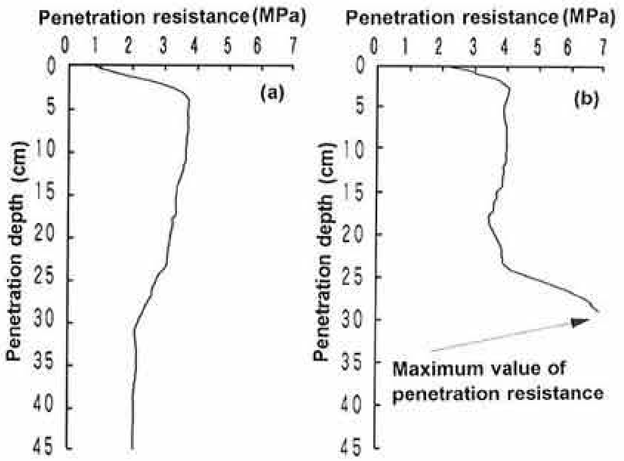

Fig. 4. Measurement under normal conditions (a) and evasion of obstacles (b)

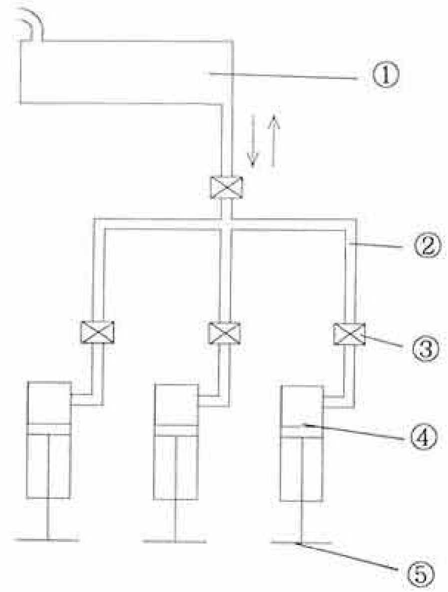

Fig. 5. Part for horizontal positioning
①: Oil tank, ②: Hose-assembly,
③: Solenoid-controlled stop valve,
④: Single-acting cylinder,
⑤: Bearing plate.

the relationship between the penetration resistance and depth is displayed on the screen of a computer. Obstacle evasion is achieved as follows. In advance, the operator sends the maximum permissible penetration resistance value to a computer. Computer always monitors the penetration resistance. When the penetration resistance exceeds the permissible value for penetration, the computer sends the order for the discontinuation of the penetration motion. The values which do not exceed the maximum permissible penetration resistance are displayed and recorded (Fig. 4-b). It takes about 90 s from the start to the end of the program. The duration can be shortened when the operation for obstacle evasion is completed.

5) Part for horizontal positioning

The part for horizontal positioning is composed of a bearing plate, single-acting cylinder, hose assembly, solenoid stop valve, oil tank and oil (Fig. 5). Hose assembly from oil tank has three branches, each connected with a single-acting cylinder. Solenoid valve is set between each hose assembly and single-acting cylinder. Bearing plate is set at the top end of the piston rod of the single-acting cylinder. The cone penetrometer is hanged by electric motion by a winch that keeps the cone rod in the direction of gravity. Horizontal positioning is achieved as follows. Solenoid valve is opened. The oil in the oil tank flows in the single-acting cylinder through the hose assembly. The piston rod of the single-acting cylinder goes down due to the weight of the piston rod and bearing plate. Operator lowers down the cone penetrometer with a winch until the pointed part of the cone reaches the ground surface. When the solenoid valve is closed, the oil flow in the piston rod is interrupted. Operator lowers further down the cone penetrometer. By these operations, the cone penetrometer can be positioned horizontally in the range of 25° inclination to the ground. The cone penetrometer is stable and does not fall even during the penetration.

6) Part for hanging

The part for hanging is composed of a stay attached to the carriage, electric winch, a boom, and a wire. The part for hanging can be set on both a truck and tractor.

7) Power supply

The cone penetrometer receives electricity from the battery of the carriage, the computer from the battery attached to the computer and the alternating current motor of cone penetrating part from the DC/AC converter.

Examples of measurement using the cone penetrometer

The measurements were performed in meadows of the Alpine Region Branch on July 22, 1994 and 135 measurements were taken. The area of the meadow was 1.3 ha with an average inclination of 8°. The total amount of time required for the measurement was 5.1 h. The net total measurement time was 66%, and the rest of the time was used for moving measured points or adjusting the starting position of the cone. The measurement could be performed in any area in the meadows since the ground inclination was less than about 25°. Operator could calculate the maximum penetration resistance and the position of the cone and draw a frequency distribution graph such as that indicated in Fig. 6 easily on the basis of the data measured in the laboratory. Attempts were made to draw a map of the distribution of the cone resistance. The map was drawn to observe visually the cone resistance in a limited area[4,5]. Also by using the cone penetrometer which we developed, a distribution map could be drawn to measure the cone resistance at 20 cm intervals along a line or a plane. For example, we could determine the effectiveness of a pan-breaker in detail by analyzing the cone resistance distribution on the map drawn on the basis of measurements taken before and after the pan-breaking treatment (Plate 1). If the map describing the cone resistance distribution could be drawn on the basis of measurements involving the whole area in the meadow, the soil structure could be readily analyzed and the management of the meadow field could be carried out

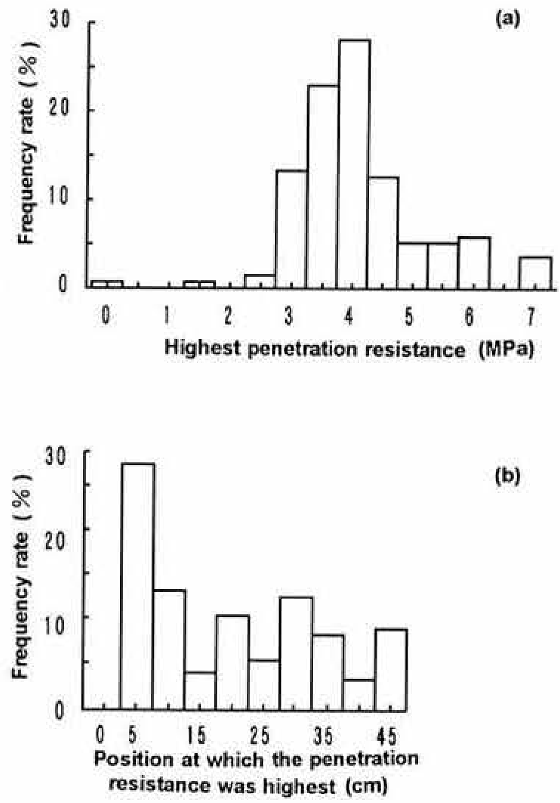

Fig. 6. Distribution of the highest penetration resistance (a) and distribution of the position at which the penetration resistance was highest (b)

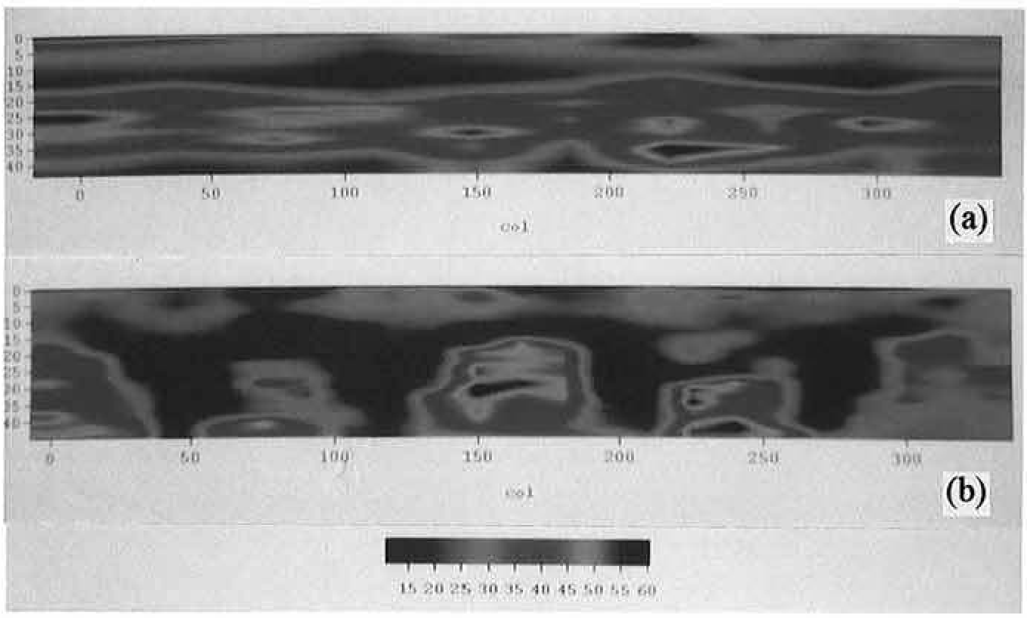

Plate 1. Map of distribution of penetration resistance
(a): Before pan-breaking, (b): After pan-breaking.
The part which is colored in blue in (b) corresponds to the soil softened by pan-breaking.

appropriately. However, problems relating to the selection of suitable intervals for measurements, number of measurements and the extrapolation of non-measured points must be solved in order to draw a reliable map describing the distribution of the cone resistance over a whole field.

Conclusion

By using the cone penetrometer which we developed, we were able to perform readily a large number of measurements of the cone resistance. It is anticipated that this instrument may enable to obtain information about the soil compaction of a whole field. It is desirable that the measured data of the soil structure be utilized for the proper management of a meadow. Also this instrument could be used to analyze the distribution of the plow sole pan in other fields such as meadows for grazing or paddy fields.

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