Development of Computer-Aided Soil Cone-Penetrometers and Data Processing

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Introduction

Physical properties of soil are measured to estimate the possibility of doing field works as well as to investigate general soil conditions. Soil bearing capacity is one of the most important indexes of soil physical properties. Various kinds of testers to measure soil bearing capacity have been introduced. Among them, the SR-II type tester for soil physical properties developed by the Institute of Agricultural Machinery, Japan, has been widely adopted as a field soil tester among agricultural engineers in Japan. The SR-II type soil tester is able to measure easily several kinds of soil physical properties, i.e., soil bearing capacity by using cones or rectangular plates and vane shearing test in the field. However, it has a problem in accuracy of measurement due to visual inspection of spring deflection. To know precisely soil properties and field conditions a large number of measurements are needed, and as a result works to compile a large amount of data are required.

Various types of cone-penetrometers have been introduced to improve measurement accuracy and efficiency, since a prototype of the automatic recording type cone-penetrometer was developed in 1969. Most of the improved cone-penetrometers consist of metering and recording devices in the use of electronic power. In general, either a pen recorder or a magnetic data inscriber is adopted as a recording device, while the strain gage type of load cell is employed as a metering device. In case of the magnetic data inscriber, data are transferred to a computer through an A/D converter. These instruments are much more costly and heavier than the conventional type. In addition, much more time is sometimes required to compile the data. Hence, this type is not widely adopted yet.

As the result of the recent remarkable development of micro-electronics, not only hand-held battery-operated computers but also metering devices which can directly transfer data to the computer are available cheaply in the market. By making use of these new instruments, the present authors attempted to develop two types of computer-aided cone-penetrometers for the purpose of improving the efficiency as well as accuracy of measurement in the field. The data processing systems including data transfer were also developed.

The objective of this paper is to describe the two types of computer-aided cone-penetrometers and to show an example of field measurement.

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Computer-aided cone-penetrometer system

A computer-aided cone-penetrometer system consists of a cone-penetrometer, a hand-held computer and a desk top personal computer as schematically shown in Fig. 1. Two persons are required to conduct the measurement in the field due to the size of hand-held computer.

1) *The features of the computer-aided cone-penetrometer*

(1) Measurement can be carried out easily by less than two persons.

(2) Penetration resistance and penetration depth are obtained in the field during measurement.

(3) Results are obtained immediately for every measurement.

(4) All of the data obtained can be stored in the hand-held computer in the field.

(5) Transfer of the data to a personal computer after a series of measurements can easily be carried out for further analysis.

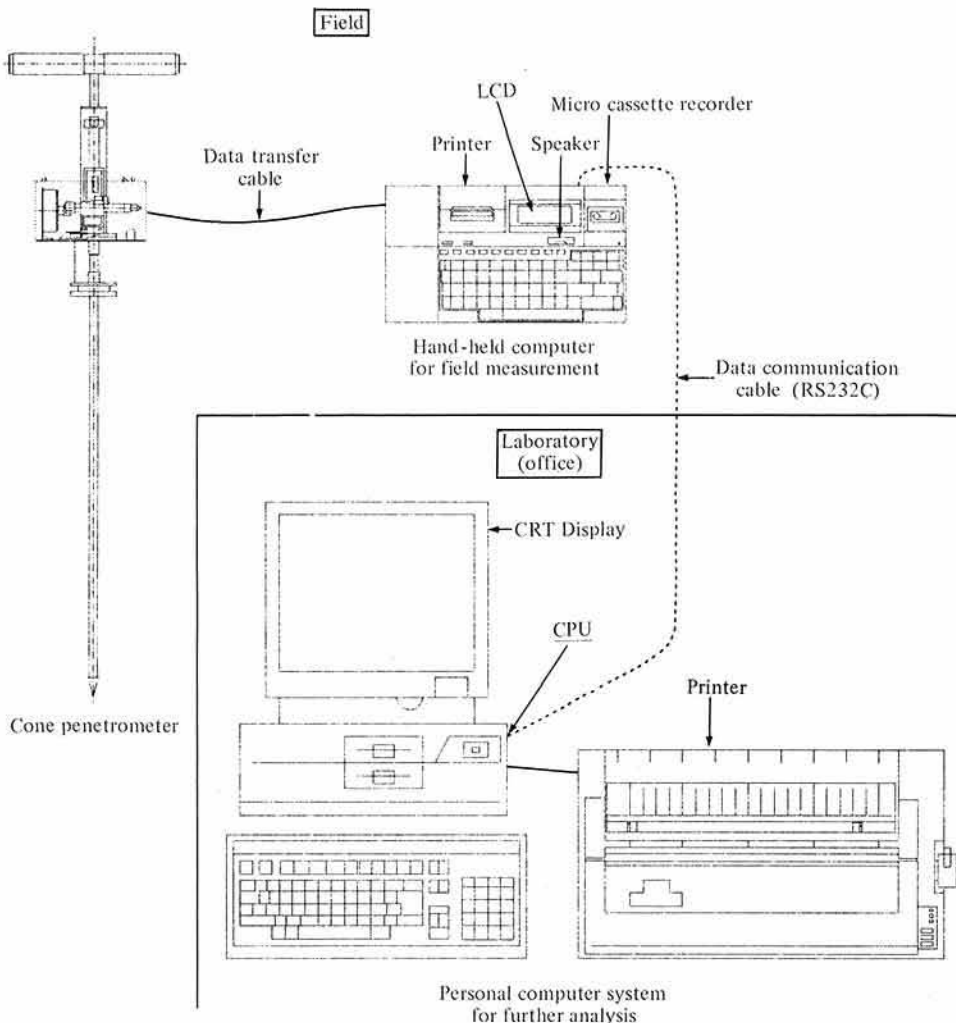*2)* *Structure of the computer-aided cone-penetrometer system*

Fig. 1. Computer-aided cone–penetrometer system

The cone-penetrometer itself was based on the automatic cone-penetrometer with the trade name of DIK-5520 sold by Daikirika Kogyo, Japan. The indication devices for penetration depth and penetration resistance were modified from mechanical ones to electronic ones.

Penetration depth is measured using strings with weight and the whirlspool assembler. Penetration of the rod causes the change in the length of the string. The change is converted to rotational displacement by the whirlspool which is detected by the digital micrometer (Mitutoyo-Seisakusyo, MD-25) as rotation of the operation knob.

Penetration resistance is measured through transformation of the spring, which is detected with the digital caliper (Mitutoyo-S, CD-15M).

These devices are used in combination with the hand-held computer (Mitutoyo-S, DP-20) which can acquire data directly. As a result, the automatic cone-penetrometer does not need a magnetic data inscriber and an A/D converter.

For the hand-held computer the BASIC languages in the Microsoft system can be used except for the data acquisition. The methods not only of the data acquisition but also of the data processing can be reformed easily by modifying the program. The newly developed computer-aided cone-penetrometer is about 4.0 kg in weight excluding the hand-held computer which is about 2.0 kg in weight, 31 cm in length and 23 cm in width. A LCD display, a 25 characters dot-matrix printer and a micro-cassette drive are installed in the frame without using any wire. For measurements in the field this computer-aided cone-penetrometer shows many advantages such as: (1) the data can be printed in the field immediately, (2) the data can easily be stored in the micro-cassette, and (3) the program and the data can be held in the memory, even if the hand-held computer is turned off.

### 3) Procedures of operation and data processing in the field

Two methods of field measurement were prepared, i.e., continuous measurement and intermittent measurement. In the continuous method, data acquisition was carried out at the interval as short as the computer allows, whenever the penetrating cone proceeds more than 0.1 cm. This method is suitable for detailed analysis on a site. On the contrary, in the intermittent method, data acquisition is done every 5.0 cm of the penetration depth. It is suitable to carry out in a short period the measurement at many sites in a field.

The measurement stops automatically when the penetration depth reaches 40 cm or the penetration resistance shows 490 N (50.0 kgf), because these values are the limits of the rod length and of spring capacity. The data collected in the hand-held computer can be transferred to a host computer (NEC PC9801F2) in a laboratory through the RS232C.

Two kinds of software for the computer-aided cone-penetrometer system are prepared for data acquisition and data analysis. The programs for the hand-held computer are used to measure the data in the field and to transfer the data to the host computer in the laboratory. The programs for the host computer are prepared to receive the data from the hand-held computer in accordance with the procedure of the measurement and to analyze the data.

The flow chart of programs for data acquisition and processing is shown in Fig. 2. The data acquisition program consists of the data acquisition, displaying the data, and storing the data in the micro-cassette. As mentioned above, the program contains that for timing of acquiring data (for every 0.1 cm of penetration depth). The data are also stored in the internal memory at the same time of the measurement. The hand-held computer displays penetration resistance at a 10 cm interval of penetration depth and makes a sound for convenience of the operators. Immediately after each measurement, the hand-held computer prints out the following items: (1) data and time of measurement, (2) the size of the sampling in a site, (3) the actual depth
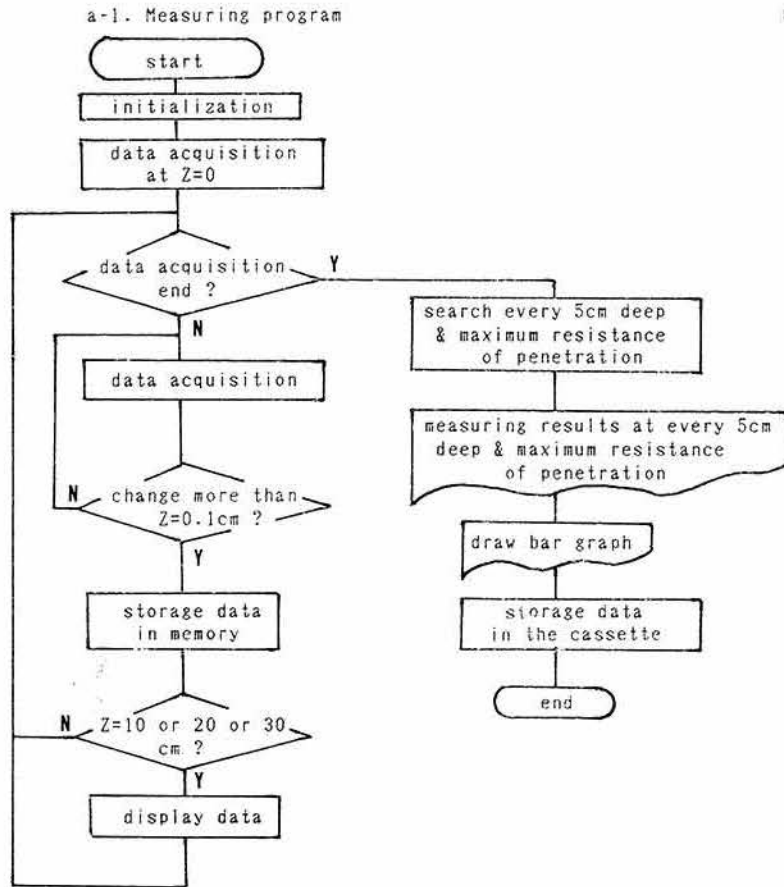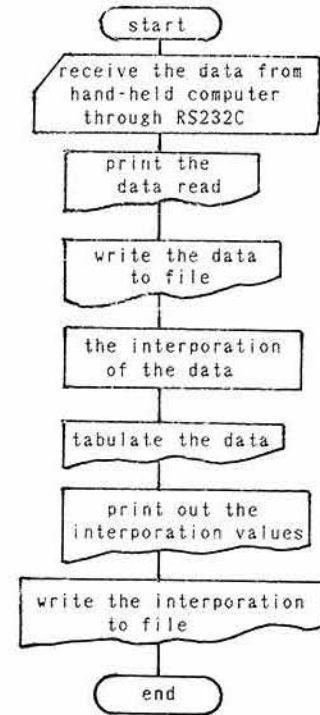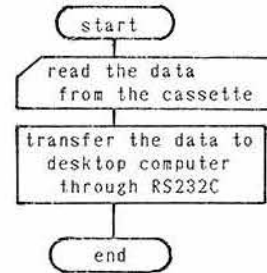
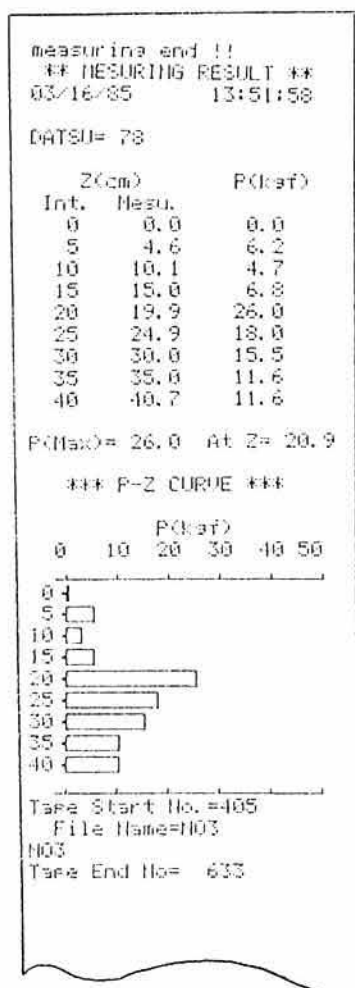Fig. 2. Flow chart of programs for data acquisition and processing data

Fig. 3. Printed out example by hand-held computer (continuous method)

expressed as "Mesu." in Fig. 3 and penetration resistance at about 5 cm intervals, (4) maximum penetration resistance, and the depth of penetration where it occurs, and (5) the bar graph of resistance vs. depth is shown in Fig. 3.

Then the computer prompts to record the data into the micro-cassette. The data can be recorded into the micro-cassette with indexes of tape locations and the file name, if necessary.

4) Data processing in the laboratory

Further analysis, i.e., statistical analysis, interporations and plotting graphs can be carried out with a personal computer, to which the data have been transferred from the portable computer through RS232C interface. The result of processing data of 20 sites of measurement is shown in Fig. 4. In the graph of Fig. 4, dots show average values of penetration resistance, and bars indicate standard deviation every 5 cm of penetration depth. The rectangular frame in the graph shows ranges of standard deviation of the depth and of resistance at the point where maximum penetration resistance was observed. The relationship between the depth and the resistance is tabulated (in Fig. 4) every 5 cm of penetration depth from 0 to 40 cm, as a result of the data interpolation. The data processing in the host computer for Fig. 4 required only 5 min.

Simple cone-penetrometer

The authors have developed another type of computer-aided cone-penetrometer which is attached with a board computer and simpler than the above-mentioned one in structure and functions and named the simple cone-penetrometer (Plate 1). The board computer consists of a CPU, A/D converter, and printer interface. The methods of sampling and printing out are similar to the former one. The only difference is that the new one utilizes the board computer.

Resistance and depth of penetration can be measured in the field with one man operation because it has automatic data acquisition and printing system.

The simple cone-penetrometer is characterized by higher portability and easier operation in the field, but yet it can print out the data in the installed printer. At present, data communication interface is not installed in the board computer and hence the data read can not be transferred to a personal computer for further analysis.
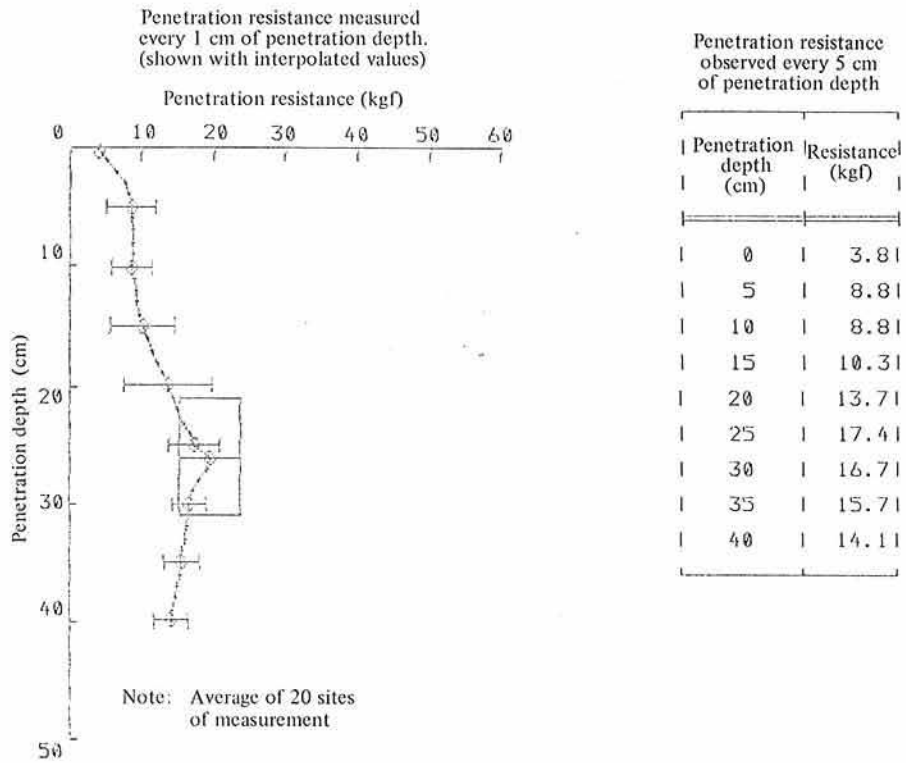
Penetration resistance measured
every 1 cm of penetration depth.
(shown with interpolated values)

Penetration resistance
observed every 5 cm
of penetration depth

Penetration depth (cm)	Resistance (kgf)
0	3.8
5	8.8
10	8.8
15	10.3
20	13.7
25	17.4
30	16.7
35	15.7
40	14.1

Note: Average of 20 sites
of measurement

Fig. 4. Result of processing (by the desk top computer) of the data obtained
from 20 sites of the measurement
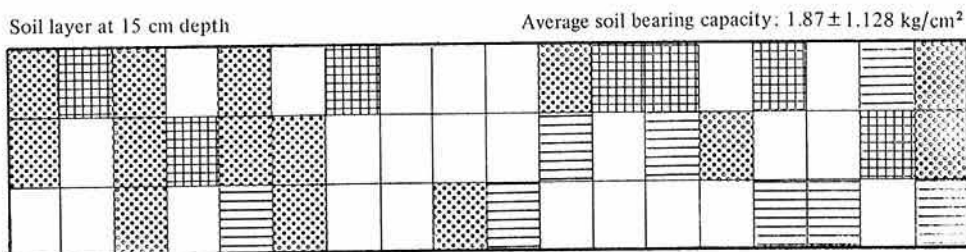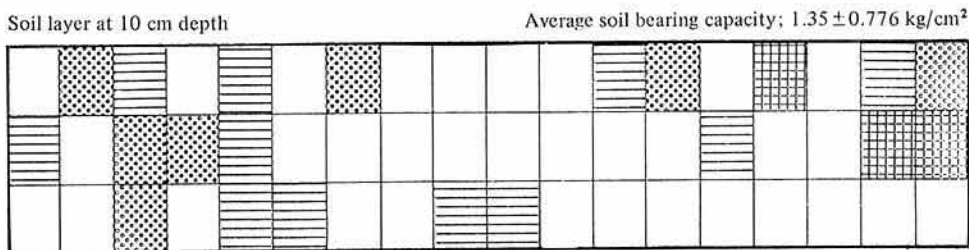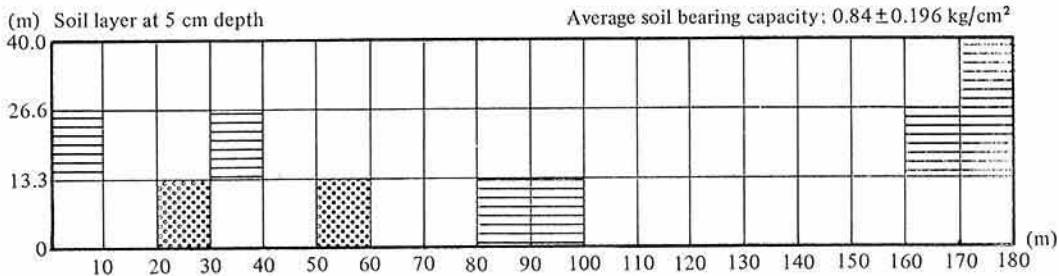

Plate 1. Simple type computer-aided cone-penetrometer with one-man
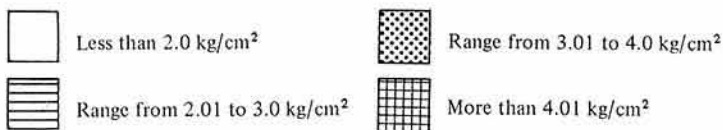operation

Examples of soil bearing capacity measured with the computer-aided cone-penetrometer in the Muda irrigation area, Malaysia

One of the authors had an opportunity to join the MADA*-TARC** cooperative research program on "Farm Mechanization in the Muda Irrigation Area". In that area, soil bearing capacity of the field is very low in the wet season, although it is very high in the dry season, because montmorillonetic clay soil prevails in that area. In addition, the size of each parcel of field is large. It causes

Legend:

☐ Less than 2.0 kg/cm²

▦ Range from 2.01 to 3.0 kg/cm²

▒ Range from 3.01 to 4.0 kg/cm²

▦ More than 4.01 kg/cm²

(Soil bearing capacity measured with a large cone)

Fig. 5. Distributions of soil bearing capacity in a field parcel
Average sinkage of steering wheel: 20.0 cm. Average sinkage of crawler: 7.0 cm.
Surveyed at Kuala Perlis, Malaysia at the rice harvesting time (Jan. 1988).

* Muda Agricultural Development Authority, Malaysia
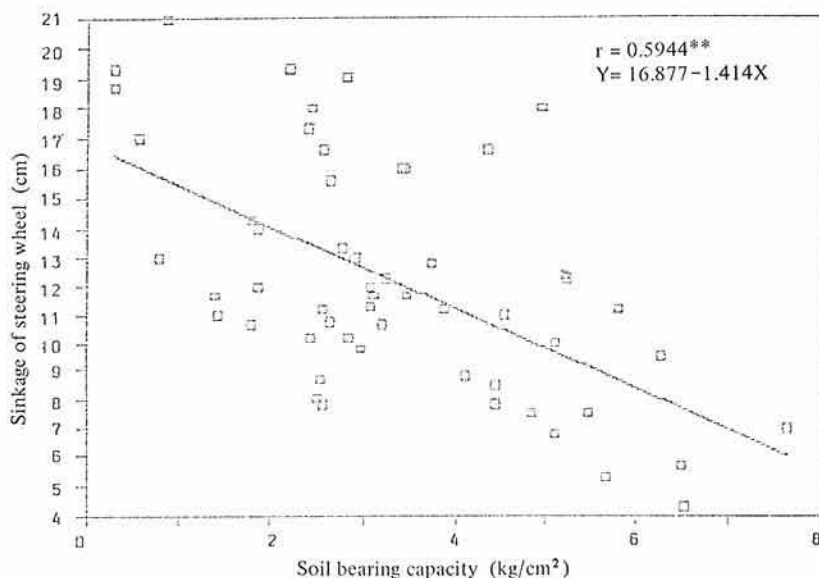** Tropical Agriculture Research Center, Japan

Fig. 6. Relationship between soil bearing capacity at 15 cm of soil depth
and sinkage of steering wheel of the combine
Base area of cone: 6 cm². Conical angle: 30°.

quite different values of soil bearing capacity even within a parcel. Bogging of tractors often occurs in the wet season. To investigate the trafficability and maneuverability of primemovers, it was required to examine the distribution of the soil bearing capacities in a parcel by conducting a lot of measurements. The computer-aided cone-penetrometer is one of the most suitable instruments in view of efficiency and accuracy to conduct this kind of work. Thus, the computer-aided cone-penetrometer was used in the Muda irrigation area. The computer-aided cone-penetrometer operated quite successfully there. It took about 1 hour with two persons to measure the soil bearing capacity at 24 sites in a parcel. The measurement itself did not require so long time but it took much more time for surveying the parcel to decide the sites to be measured. Examples of the compiled data are shown in Figs. 5 and 6.

Summary

Two types of computer-aided cone-penetrometers were newly developed. The first one carries out measurement of soil bearing capacity and data processing, i.e., mapping the distribution of soil bearing capacity, plotting the graph showing the relation between penetration depth and penetration resistance. It uses a hand-held computer for data acquisition. Although only one person is needed for its operation, two persons are enough for fast and efficient measurement, i.e., one for holding and pushing the cone-penetrometer and the other for operating the hand-held computer. The second type called the simple cone-penetrometer was developed mainly to improve the efficiency of measurement. A board computer was attached in a body of cone-penetrometer. It can carry out the measurement with one man operation, and it has the function of automatic printing of penetration depth and resistance.

The computer-aided cone-penetrometer system was applied to examine the distribution of widely different values of soil bearing capacity occurring in a field parcel in the Muda irrigation area of Malaysia.