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LOW-COST ELECTRO-MECHANICAL PRESS FOR DETERMINING PRE-CONSOLIDATION PRESSURE

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KEYWORDS

uniaxial compression, soil compaction, consolidation test, soil load support capacity.

ABSTRACT

The pre-consolidation pressure is a soil parameter indicating the maximum load that can be supported without irreversible deformation. However, the commercially available equipment for such determination is very expensive, limiting studies on this subject. The objective of this study was to develop a low-cost press model for determining a soil pre-consolidation pressure. The press comprised an electric jack for lifting a soil sample against a fixed piston. A compression cell was built using Technyl®. The stability and smoothness of the applied loads were controlled using springs with different dimensions and strengths. The load and deformation data were obtained using an indicator connected to the load cell and a dial indicator, respectively. The equipment was tested by determining the pre-consolidation pressure in an Oxisol cultivated with cotton and under an area of native Cerrado. The pre-consolidation pressures for a soil water tension of 10 kPa were 50.8 kPa and 61.1 kPa for the soil under the native Cerrado and cotton crop, respectively, and the compressibility indexes were 0.71 and 0.37, respectively. The main advantages of this equipment are its low cost, ease of construction, and simplicity of operation. However, the equipment is non-automatic; thus, the data necessary for the construction of the compression curve must be collected by an operator.

INTRODUCTION

The pre-consolidation pressure is a soil mechanical property indicating the maximum load that can be supported without the occurrence of irreversible additional deformations. Its determination and the study of its influencing factors, such as the soil texture, bulk density, soil moisture, organic matter, and adhesion and cohesion forces, are important for defining management methods for increasing the soil capacity to support loads without causing additional compaction (Moraes et al., 2019).

Instrumentally, the pre-consolidation pressure can be determined using pneumatic consolidometers, which use compressed air to accurately compress the soil without disturbance. In addition, these instruments allow the data to be automatically obtained for the construction of the soil compression curve. However, they incur an excessively high cost, especially in cases where there is a need to import such equipment, hindering data acquisition and studies on the subject in institutions with low fundraising.

As an alternative to pneumatic systems, mechanical presses with manual actuation also allow for the application of axial loads in a precise manner. In this case, a load application mechanism can be achieved using a system of hanging weights suspended from a mechanical lever arm. In terms of cost, this type of equipment is much more affordable than pneumatic mechanism equipment. However, the disadvantage is the need for the manual application of the axial loads using weights, which can make the process time-consuming, tiring, and sensitive to disturbances. In the same line of mechanical presses, there are those that use a hydraulic jack as a load application mechanism, as demonstrated by Pacheco (2010) and Pacheco & Cantalice (2011).

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To solve the above problems, Silva et al. (2007) and Figueiredo et al. (2011) developed the first consolidometer prototypes in Brazil. Both pieces of equipment, although different from each other, had a pneumatic load application mechanism. The efficiency of this equipment was demonstrated through uniaxial compression tests, proving the functionality and quality of the measurements. Later, Silva et al. (2015) developed a more sophisticated pneumatic consolidometer with a human-machine interface for enabling real-time processing, systematization, and management of the physical and mechanical indexes of the soil.

Despite the efforts of these authors to popularize consolidometers for performing uniaxial compression tests, it is clear that the study on this subject remains restricted to a few research centers. It is possible that the main obstacle is the high cost of commercial consolidometers or even the construction of the equipment by the researcher himself when there is a need for specific parts, as in the case of pneumatic consolidometers.

In this work, the first version of a simple, low-cost, electromechanical press which can be built by the researcher is proposed. In the first version, the recording of the necessary data for the construction of the compression curve (deformation x load) is performed manually, and the load application is intermediated by an electric jack with speed control. The main objective is to provide an initial prototype subject to updates, with the aim of contributing to the dissemination of soil compaction studies focused on agricultural and engineering areas.

MATERIAL AND METHODS

The electromechanical press consists of the following parts, as shown in Figure 1. An axial load application mechanism composed of an electric jack (DC 12V 11A) moves the compression cell against a static piston 53 mm in diameter. The electric jack has the following characteristics: rated voltage of DC 12 V; rated current of 11 A; output power of 75 W, and maximum load of 1500 kg.

The compression cell (Figure 1, item b) is a floating ring-type sample conditioning device, consisting of two 20-mm thick and 100-mm diameter Technyl® discs. Between the discs, there are four compression springs placed 90° apart and 5.0 mm from the edge (Figure 1, item e2). The springs are 12 mm in diameter and 38 mm in height and have 11 turns. The function of these springs is to ensure stability and smoothness during the application of the lowest axial loads (< 200 kPa). The upper disc has a recess in its central portion (5.0 mm deep and 55 mm in diameter) for allocation of the soil sample.

The equipment has a mechanism for control and load indication (Figure 1, item d). It is composed of a load cell (Z model of traction/compression) with a capacity of 500 kg and sensitivity of 2.0 mV/V, and a digital load indicator with an accuracy of 0.2% at full scale. The load cell was calibrated using a digital load indicator according to the manufacturer's recommendations. The deformation indicator comprises an analog dial indicator with an accuracy of 0.01 mm and capacity of 10 mm (Figure 1, item f).

The second part is a control panel (Figure 2). It comprises a switched-mode power supply (power supply: 12 V; current: 30 A) for supplying power to the electric jack, a PWM microcontroller module (DC 10–60 V; current: 20 A) for electric motor speed control, and a toggle switch with three positions and six pins to control the direction of the compression cell (up or down).

The equipment has high-compression springs (Figure 1, item e1). These springs are 218 mm high, 55.3 mm in diameter, and have 12 turns. Their objective is to stabilize the highest axial load (> 200 kPa) during compression. The fine adjustment is composed of a 6.0 mm screw for performing fine adjustment of the applied loads (Figure 1, item g). The force exerted by the screw is applied to the shaft attached to the load cell, which in turn moves vertically, compressing the soil sample. The screw is supported on a steel plate 12-mm thick and 550-mm long.

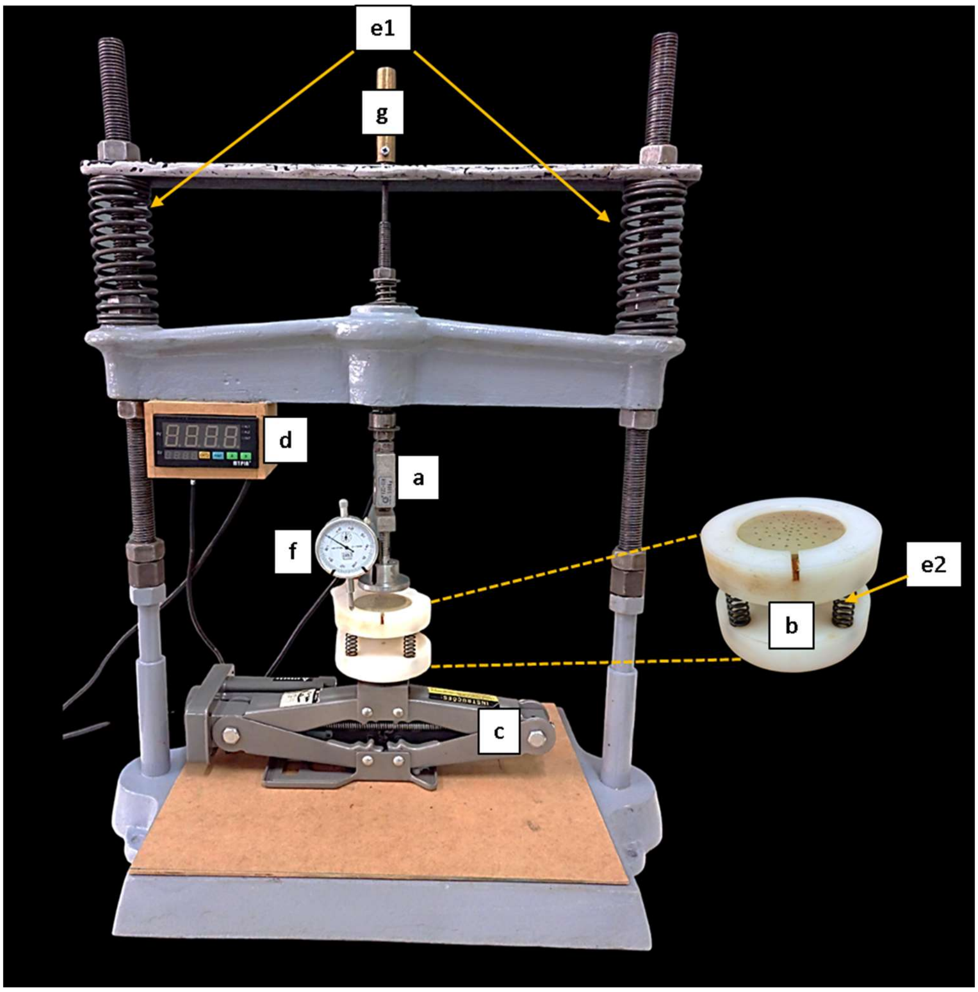

FIGURE 1. Low-cost electro-mechanical press to perform the uniaxial compression test. Components: a – load cell 500 kg; b – compression cell; c – electric jack; d – Digital Weighing Controller Load-cells Indicator; e1 – springs for stabilizing larger loads; e2 – springs for stabilizing smaller loads; f – dial indicador; g – screw for fine load adjustment.

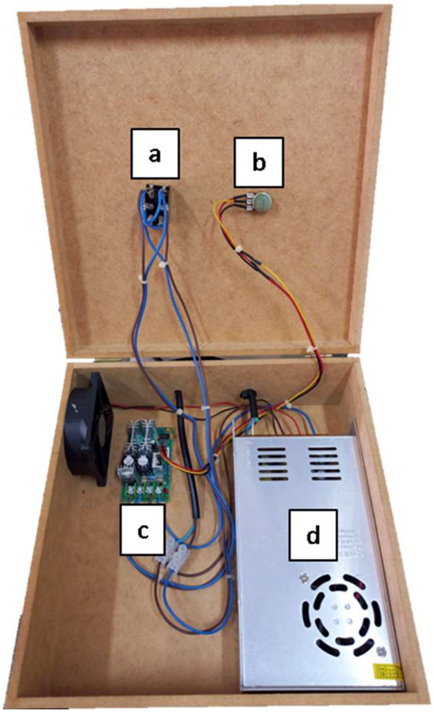

FIGURE 2. Control panel of low-cost electro-mechanical press. a: three position 6-terminal toggle switch; b: potentiometer; c: 12V 30A DC Motor Speed Controller; d: DC 12V power suplly.

To evaluate the equipment, the relationship between the force (F), i.e., the vertical load transmitted to the soil sample, and the area of the soil sample (A) was considered.

The evaluation of the equipment efficiency was verified by performing a uniaxial compression test for an Oxisol clay loam texture (41% clay, 40% sand, 19% silt) located in the experimental area of the Federal University of Rondonópolis, Mato Grosso, Brazil. Soil samples were collected at this site in a native Cerrado area and in another area with a conventional cotton crop. At each site, undisturbed soil samples were collected from the 0.0–0.1 m layer. Cylindrical rings of galvanized steel were used for the soil sampling, with a height of 20, internal diameter of 53.5 mm, and wall thickness of 4.0 mm. Thus, the ratio between the inner diameter and ring height was 2.675, meeting the minimum requirement of 2.5 (Dias Junior & Martins, 2017).

The undisturbed soil samples were initially saturated in a tray with water up to 2/3 of the sample height for 24 h. Subsequently, they were submitted to 10 kPa suction on a tension table. After stabilization, the undisturbed soil samples were placed in the compression cell and subsequently subjected to pressures of 12.5, 25, 50, 100, 200, 400, 800, and 1.600 kPa (Dias Junior & Martins, 2017). Considering that the area of the soil sample used in the equipment was 0.002248 m^2, the smallest and largest applied loads were approximately 3.0 kg (12.5 kPa) and 360 kg (1600 kPa), respectively. In general, each pressure was applied until 90% of the maximum deformation was achieved. For this verification, the deformations were recorded at 0.25, 0.50, 1, 2, 4, 8, 15, 30, 60, and 120 min. The time required to reach 90% of the maximum deformation was determined using the square root of the time method (Taylor, 1948).

After obtaining the soil compression curve, the pre-consolidation pressure (σ_p) was determined using the method described by Casagrande (1936). In addition, the soil physical parameters (bulk density, total porosity, and void ratio) in the initial condition, pre-consolidation pressure (σ_p), and pressure at the end of the compression test were calculated. The plugin developed by Gubiani et al. (2017) and implemented in Microsoft Excel® was used.

RESULTS AND DISCUSSION

Figure 3 shows examples of the soil compression curves for pressures of 200 and 1600 kPa, whose times required to reach 90% of the deformation are 12 and 13 min, respectively. The load application time is an important variable for obtaining the soil mechanical parameters, such as the pre-consolidation pressure and compressibility index. Mazurana et al. (2017) highlighted that while in field conditions, the loads applied to a soil by machines generate a transient and short-duration force, in the laboratory, the applied loads are static and of a long duration. The authors evaluated the effect of two compression times, 30 s and 10 min, on the determination of certain soil mechanical parameters. Although the pre-consolidation pressure was not influenced by the compression time, the same did not occur with the compressibility index, where shorter times resulted in lower indexes.

According to Dias Junior & Martins (2017), for some Brazilian soil classes, 15 min is sufficient to reach 90% of the maximum deformation in partially saturated soil conditions. However, Moraes et al. (2019) used a compression time of 5 min to obtain 99% of the maximum deformation in an Oxisol. Based on the considerations described above, Figure 3 demonstrates that the equipment can satisfactorily generate the soil compression curve for defining the time required for the load application.

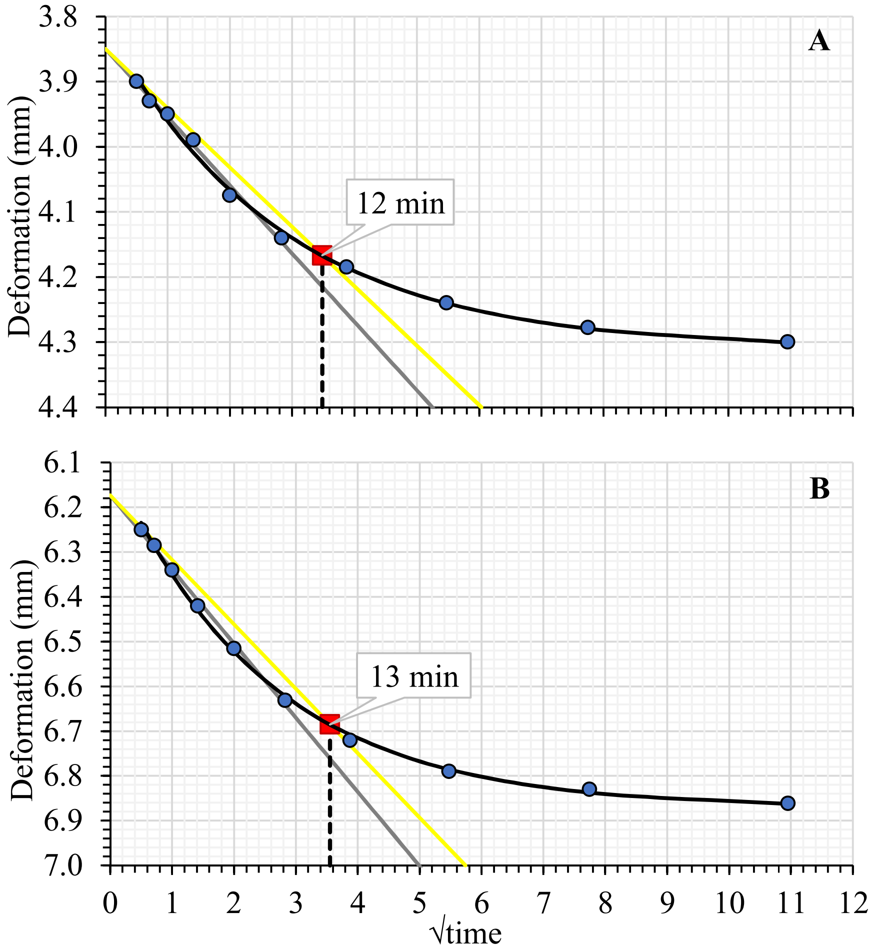

FIGURE 3. Soil compression curve to determine the time required to reach 90% of the maximum deformation for load of 200 (A) 1600 kPa (B), using the square-root of the time method (Taylor, 1948).

The pre-consolidation pressure of the soil under native Cerrado is 50.8 kPa, and that of the soil under the cotton crop is 61.1 kPa (Figure 4 and Table 1).

The pre-consolidation pressure is specific for each soil and depends on several factors, such as the granulometry, soil bulk density, soil moisture, organic matter content, and type of structure. However, the values found in this study are similar to those determined by Neiva Júnior et al. (2014) for Oxisol with clay-sandy texture, for a suction of 10 kPa, in an area of native forest (σ_p = 71 kPa).

It can also be seen that the compression index is much higher for the soil under native Cerrado (0.71) when compared to the soil under the cotton crop (0.37), indicating greater susceptibility to soil compaction under native Cerrado (Table 1). According to Ortigara et al. (2014), the compression index indicates the slope of virgin compression, which is inversely related to the soil bulk density. These authors related the compression index to the soil bulk density in areas of rotational grazing, native forest, and conventional tillage under Oxisol. Using the exponential model presented by the authors, soil under native Cerrado with an initial bulk density of 0.9 g cm^{-3} (Table 1) would present a compression index of 0.76, whereas a soil under cotton crop with an initial bulk density of 1.2 g cm^{-3} would have a compression index of 0.28, similar to those found experimentally.

In analyzing the values of the soil physical parameters, notably, for the soil under the native Cerrado, there is a 68% increase in the soil bulk density after the compression test. For the soil under the cotton crop, the increase is 45% (Table 1). However, when evaluating the increase in the bulk density in the pre-consolidation pressure, the values are 13% and 8% for soils under the native Cerrado and cotton crop, respectively (Table 1), in accordance with Severiano et al. (2011), who demonstrated that the increase in soil bulk density at the pre-consolidation pressure is approximately 10%.

The pre-consolidation pressure is affected by several factors, such as the soil water content, organic matter, texture, bulk density, structure, cohesion, and adhesion forces (Moraes et al., 2019). The increase in deformation with the decreasing initial bulk density has been verified by other authors (Silva et al., 2000; Imhoff et al. 2004; Mendonça et al., 2020). According to Mendonça et al. (2020), there is a general consensus on the positive and linear effects of the initial soil bulk density on the pre-consolidation pressure, that is, there is an expected increase in the soil resistance with an increase in the initial bulk density. This effect can be attributed to the increase in the frictional forces between particles with increasing soil bulk density (Imhoff et al., 2004; Mendonça et al., 2020).

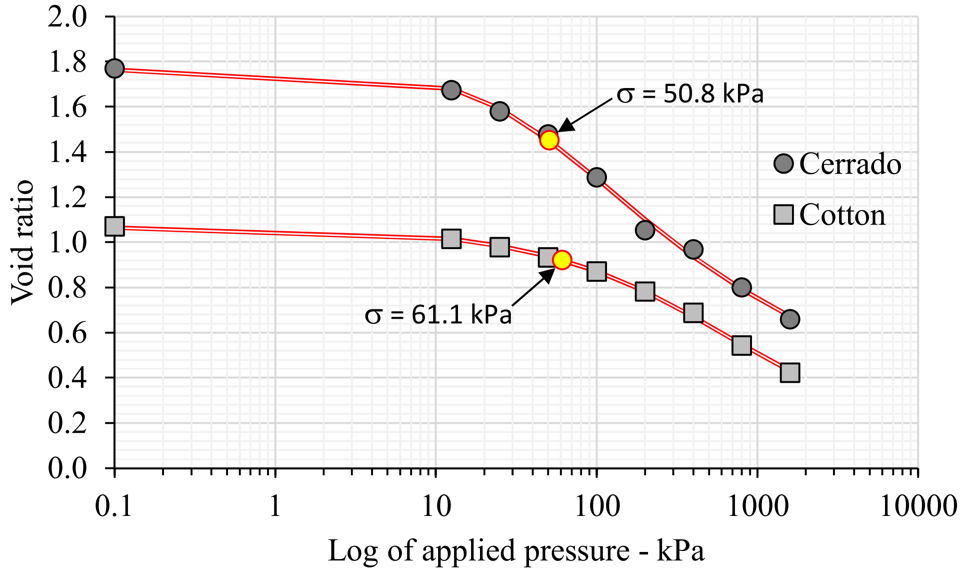

FIGURE 4. Compression curve for Oxisol under native Cerrado and under cotton crop. Pre-consolidation pressure determined by the method of Casagrande (1936) using a plugin implemented in Microsoft Excel (Gubiani et al., 2017).

TABLE 1. Physical parameters of soils in initial condition, in preconsolidation pressure (σ_p), and at final compression test.

Local	Condition	Bulk Density (g cm^{-3})	Porosity (%)	Void ratio	σ_p (kPa)	CI
Native cerrado	Initial	0.90	64	1.77		
	σ_p	1.02	59	1.45		
	Final	1.51	40	0.66	50.8	0.71
Cotton area	Initial	1.21	52	1.07		
	σ_p	1.30	48	0.92		
	Final	1.76	30	0.42	61.1	0.37

CI: compression index.

In this first version, the proposed electro-mechanical press has a total cost of approximately R$ 2000.00. This value represents the cost of all components shown in Figure 1. This value corresponds to approximately 6–7% of the cost of a manual commercial consolidometer of the "Dead-Weight" type.

CONCLUSIONS

An electromechanical press was proposed to determine the mechanical properties of soils, such as the pre-consolidation pressure and compression index. The main advantages of this equipment are its low cost, ease of construction, and simplicity of operation. However, the equipment is characterized as being of a non-automatic type, where the necessary data for the construction of the soil compression curve must be collected by the operator. Automation in data collection will be provided in the second version of the equipment, as well as automation of the application of the axial loads.

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