XXXIV CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO
28 de julho a 2 de agosto de 2013 | Costão do Santinho Resort | Florianópolis | SC

Soil compression curve parameters determined from different linear regression methods[1].

<u>Diego Tassinari</u>[2]; Moacir de Souza Dias Junior[3] ; Paula Sant'Anna Moreira Pais[4]; Daniel Rume Casagrande[5]; Maria Luiza de Carvalho Andrade[6]; Ana Cláudia Pereira Cardoso[7].

[1] Work executed with resources from CNPq and FAPEMIG.
[2] Agronomy student, Universidade Federal de Lavras, Lavras/MG, tassinari1420@hotmail.com; [3]PhD. Professor, Departamento de Ciência do Solo, Universidade Federal de Lavras, Lavras/MG; [4]Doctorate student, Departamento de Ciência do Solo, Universidade Federal de Lavras, Lavras/MG; [5]Dr. Professor, Departamento de Zootecnia, Universidade Federal de Lavras, Lavras/MG; [6]Masters student, Departamento de Ciência do Solo, Universidade Federal de Lavras, Lavras/MG; [7]Agronomy student, Universidade Federal de Lavras, Lavras/MG.

ABSTRACT: The continuous increase on machinery power, size and weight enhances the risk of soil compaction, so prevention strategies and compaction modeling, especially when based on soil compression behavior and precompression stress, are of great importance. Soil precompression stress (σ_p) from 72 soil compression curves was calculated using four different methods. The σ_p was determined as the intersection of two lines: one is the line associated with stresses of 800 and 1600 kPa; the other is the regression line obtained from the first two, three, or four points, and as suggested by Dias Junior & Pierce (1995), which combines two methods depending on the sample water content (two points for samples with water content above 100 kPa and four points for samples with water content below 100 kPa). The σ_p and the slope of the secondary compression curve were statistically different depending on the method chosen. The method proposed by Dias Junior & Pierce (1995) and the regression method with the first four points yielded the greatest σ_p values. However, as water content is considered on the first method, σ_p values were lower when the soil is more vulnerable to compaction, i.e. when water content is high. This seems to be the safest path, as the soil load bearing capacity decreases with increasing water content, making the Dias Junior & Pierce (1995) method for calculating σ_p a simple and reliable choice.

Index terms: precompression stress, recompression index, uniaxial compression test.

INTRODUCTION

The continuous increase on machinery power, size and weight enhances the risk of soil compaction (SPOOR et al., 2003). Soil compaction occurs when neither the soil water content nor its bearing capacity are considered when performing mechanized operations (DIAS JUNIOR et al., 2005). As soil compaction amelioration is expensive, time consuming, and demands a great deal of fossil fuels and mechanical power, it seems that prevention is the best strategy for dealing with this issue (SPOOR et al., 2003). Soil mechanical strength at given moisture is quantified by the precompression stress, which is determined by the stress-strain behavior of the soil (HORN & LEBERT, 1994).

For an elemental soil volume, there is a specific relationship between stress and strain, which is characteristic for the considered soil and can be determined by several tests, as the uniaxial confined compression test (HORN & LEBERT, 1994). Such test results on the soil compression curve, that relates changes on soil packing state (given by bulk density or void ratio, among others) as a function of the log of applied pressure (DIAS JUNIOR & PIERCE, 1995). Soil precompression stress (σ_p) represents the point of maximum radius of the compression curve (CASAGRANDE, 1936) and separates it in two distinct regions: the virgin compression line (VCL), where deformations are plastic; and the secondary compression curve, where deformations are elastic and the risk of soil compaction is minimized (DIAS JUNIOR & PIERCE, 1995; KELLER et al., 2004; CAVALIERI et al., 2008).

Soil compression behavior, or its resistance to compaction, is dependent upon soil moisture (KONDO & DIAS JUNIOR, 1999; SPOOR et al., 2003; AJAYI et al., 2009), texture (IMHOFF et al., 2004), structure (AJAYI et al., 2009; AJAYI et al., 2010), mineralogy (AJAYI et al., 2009; AJAYI et al., 2010), stress history (DIAS JUNIOR & PIERCE, 1995) and management (LIMA et al., 2004; PIRES et al., 2012). In addition, σ_p also depends upon the soil compression test applied (KELLER et al., 2004) and the method used to calculate the precompression stress (DIAS JUNIOR & PIERCE, 1995; CAVALIERI et al., 2008).

The aim of this work was to compare different methods for calculating precompression stress from soil compression curves derived from uniaxial confined compression tests.

MATERIALS AND METHODS

Minimally disturbed soil cores were collected from pasture plots submitted to different renovation strategies (fertilization, tillage, and crop rotation with

XXXIV CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO
28 de julho a 2 de agosto de 2013 | Costão do Santinho Resort | Florianópolis | SC

corn) and from a nearby area (within 300 m radius) under natural vegetation, on the same soil unit (clayey Distroferric Oxisol) at the Universidade Federal de Lavras campus. The samples (total of 72) were collected at 0-5 cm depth with an Uhland sampler. As the sampling was carried out on September 2012 (dry season), water was applied to the soil prior to sample collection. The soil cores were than covered with plastic film and storaged until analysis were performed.

At the laboratory, soil cores were carefully trimmed and the exceeding soil was used on granulometric, particle density and organic carbon analysis, by the pipeth (DAY, 1965; EMBRAPA, 1997), ethanol (BLAKE & HARTGE, 1986a), and wet combustion (EMBRAPA, 1997) methods, respectively. Soil cores were saturated and/or air dried until different water contents were obtained, being than submitted to the uniaxial compression test on compressed air consolidometers (Terraload Consolidation Device S-450, Durham Geo Slope Indicator, USA). The stress sequence applied was 25, 50, 100, 200, 400, 800, and 1600 kPa (standard sequence according to Bowles, 1986), and loads were applied until 90% of maximum deformation was obtained (TAYLOR, 1948; DIAS JUNIOR et al., 2005; AJAYI et al., 2009). After the test, soil cores were oven dried (105 ± 5 °C) and water content and bulk density were determined (BLAKE & HARTGE, 1986b). Two soil cores per area (pasture and natural vegetation) were used for determining the water content at 100 kPa on Richards chamber (EMBRAPA, 1997).

Precompression stress was determined as the intersection of two regression lines. One is the regression line obtained from the points associated with stresses of 800 and 1600 kPa (virgin compression line). The other is the regression line obtained from the first two (2PTO), three (3PTO), or four (4PTO) points, and as suggested by Dias Junior & Pierce (1995), which combines two methods depending on the sample water content: regression of the first two points for samples with water content below 100 kPa, or as the regression of the first four points for samples with moisture above 100 kPa (this treatment was identified as DJ&P). The recompression index (RI) represents the slope of the secondary compression curve, and also changes with the chosen method. Other parameters, such as the compression index (slope of the virgin compression line), maximum density (obtained at the end of the test), and initial bulk density do not depend on the method chosen and were not included on this work.

The compression curve parameters precompression stress (σ_p) and recompression index (RI) were submitted to ANOVA using the software SISVAR (FERREIRA, 2000) and when significant differences were observed, Tukey test at 5% significance level was applied, with the same statistical package.

RESULTS AND DISCUSSION

The physical characterization for the soil used in this study is presented on Table 1. This soil is a clayey Dystroferric Oxisol, i.e. a very old and weathered soil, with high clay content and low soil organic carbon (SOC).

Table 1 – Soil properties on studied areas.

Método	PASTO	MATA
Sand (g kg^{-1})	162	160
Silt (g kg^{-1})	184	110
Clay (g kg^{-1})	654	720
SOC (g kg^{-1})	21.1	24.5
Dp (g cm^{-3})	2.61	2.61
$U_{100\ kPa}$ (cm^3 cm^{-3})	0.30	0.33

PASTO = soil under pasture; MATA = soil under natural vegetation; SOC = soil organic carbon; D_p = particle density; $U_{100\ kPa}$ = gravimetric water content at 100 kPa

The precompression stress (σ_p) was statistically different according to the method chosen for its determination (Table 2). This can be explained by the significant differences also observed on the recompression index. As the slope of the secondary compression curve changes, its place of intersection with the virgin compression line (VCL) also changes. As the slope increases, the precompression stress also increases: because the VCL is the same for all methods, the higher the slope of the secondary compression curve, the further it will intersect the VCL and, as a consequence, higher will be the σ_p. Calculating σ_p from regression methods could be problematic due to this fact. The slope of the secondary compression curve represents the rate of change of soil packing sate as a function of the applied pressure: higher slope means greater variation on packing density per unit of variation on log of applied pressure, which means higher susceptibility to compaction. Nevertheless, it became possible to identify the best method among the differences observed.

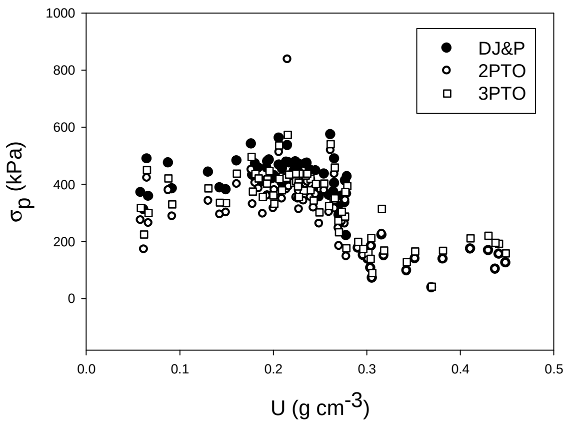
Table 2 – Precompression stress (σ_p) and recompression index (RI) obtained from the different methods.

Method	σ_p (kPa)	RI
DJ&P	365.1 a	0.068 a
2PTO	305.4 c	0.044 c
3PTO	334.9 b	0.061 b
4PTO	381.4 a	0.079 a

Means followed by the same letter (column) do not differ from each other by Tukey test at 5% significance level. DJ&P = Dias Junior & Pierce, 1995; 2PTO = regression two first points; 3PTO = regression three points; 4PTO = regression four points.

Two methods yielded higher values for σ_p: DJ&P and 4PTO. In relation to 2PTO and 3PTO, the DJ&P method seems to over predict σ_p at lower water contents; but at higher moisture (below 100 kPa), it was equal to 2PTO and under predicted in comparison to 3PTO. Dias Junior & Pierce (1995) found that regression with two or four points for the secondary compression curve resulted in better fit to the 1:1 line, lower RMSE, and higher R^2 when compared to Casagrande (1936) graphical procedure, being than chosen as more suitable for estimating σ_p. Cavalieri et al. (2008) compared different methods for determination of σ_p, also reporting different results for different methods. These authors point out that wrong conclusions regarding compaction avoidance or amelioration can emerge from overestimates or underestimates for σ_p.

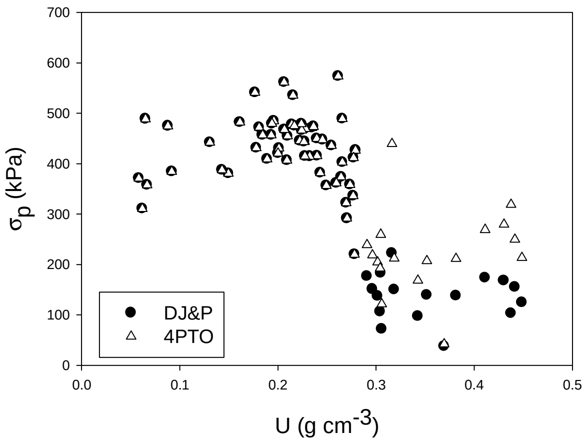
Figure 1 - Precompression stress (σ_p) calculated from two different methods as a function of gravimetric water content.



DJ&P = calculated according to Dias Junior & Pierce (1995); 2PTO = regression with two first points; 3PTO = regression with three first points

It seems, however, that when taking overestimates and underestimates into account, the safer choice would be a method that has greater correlation to the standard method (an information provided by Dias Junior & Pierce, 1995) and that underestimates the value for σ_p when the soil is weaker, i.e., when it has higher water content. And this is exactly what the method proposed by Dias Junior & Pierce (1995) does, as it chooses the method after knowing if the sample moisture is above or below the value of 100 kPa. This can be seen on figure 2, that compares DJ&P with the four points regression method.

Figure 2 - Precompression stress (σ_p) calculated from two different methods as a function of gravimetric water content.



DJ&P = calculated according to Dias Junior & Pierce (1995); 4PTO = regression with four first points.

CONCLUSION

The method proposed by Dias Junior & Pierce (1995) seems to be a good and reliable choice for calculating precompression stress form compression curves, as it is of simple appliance and yields lower values of σ_p when the soil load bearing capacity is smaller, i.e. when it has higher water content.

ACKNOWLEDGEMENTS

To CNPq, CAPES, FAPEMIG and DCS/UFLA.

REFERENCES

AJAYI, A. E. et al. Strength attributes and compaction susceptibility of Brazilian Latosols. Soil & Tillage Research, 105:122-127, 2009.

AJAYI, A. E. et al. Assessment of vulnerability of Oxisols to compaction in the Cerrado region of Brazil. Pedosphere, 20:252-260, 2010.

BLAKE, G. R. & HARTGE, K. H. Partycle density, In: KLUTE, A. (Ed.). Methods of soil analysis. 2.ed. Madison: ASA/SSSA, 1986a. p. 377-382.

BLAKE, G. R. & HARTGE, K. H. Bulk density. In: KLUTE, A. (Ed.). Methods of soil analysis. 2.ed. Madison: ASA/SSSA, 1986b. p. 363-375.

BOWLES, J.A. Engineering Properties of Soils and their Measurements, 3rd edition. New York: McGraw-Hill Book Company, 1986. 218 p.

CASAGRANDE, A. Determination of the preconsolidation load and its practical significance. In: International Conference on Soil Mechanics and Foundation Engineering, Cambridge, 1936. Proceedings. Cambridge: Harvard University, 1936. p. 60-64.

CAVALIERI, K. M. V. et al. Determination of precompression stress from uniaxial compression tests. Soil & Tillage Research, 98:17-26, 2008.

DAY, P. R. Particle fractionation and particle-size analysis. In: BLACK, C. A. (Ed.). Methods of soil analysis. Madison: America Society of Agronomy, 1965. p. 545-567.

DIAS JUNIOR, M. S. & PIERCE, F. J. A simple procedure for estimating preconsolidation pressure from soil compression curves. Soil Technology, 8:39-151, 1995.

DIAS JUNIOR, M. S. et al. Traffic effects on the soil preconsolidation pressure due to Eucalyptus harvest operations. Scientia Agricola, 62:248-255, 2005.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. Centro Nacional de Pesquisas do Solo. Manual de métodos de análise de solo. 2.ed. Brasília, Produção de informação, 1997. 212p.

FERREIRA, D. F. SISVAR - Sistema de análise de variância para dados balanceados. Lavras: UFLA, 2000.

HORN, R. & LEBERT, M. Soil compactibility and compressibility. In: SOANE, B. D.; OUWERKERK, C. van. (Ed.). Soil compaction in crop production. Amsterdam: Elsevier, 1994. p. 45-69.

IMHOFF, S. et al. Susceptibility to compaction, load support capacity, and soil compressibility of Hapludox. Soil Sci. Soc. Am. J., 68:17-24, 2004.

KELLER, T. et al. Soil precompression stress II. A comparison of different compaction tests and stress-displacement behavior of the soil during wheeling. Soil & Tillage Research, 77:97-108, 2004.

KONDO, M. K. & DIAS JUNIOR, M. S. Efeito do manejo e da umidade no comportamento compressivo de três latossolos. Revista Brasileira de Ciência do Solo, 23:497-506, 1999.

LIMA, C. L. R. et al. Compressibilidade de um solo sob sistemas de pastejo rotacionado intensivo irrigado e não irrigado. Revista Brasileira de Ciência do Solo, 28:945-951, 2004.

PIRES, B. S. et al. Modelos de capacidade de suporte de carga de um Latossolo Vermelho-amarelo sob diferentes usos e manejos. Revista Brasileira de Ciência do Solo, 36:635-642, 2012.

SPOOR, G; TIJINK, F. G. J.; WEISSKOPF, P. Subsoil compaction: risk, avoidance, identification and alleviation. Soil and Tillage Research, 73:175-182, 2003.

TAYLOR, D. W. Fundamentals of soil mechanics. New York: J. Wiley, 1948. 770 p.