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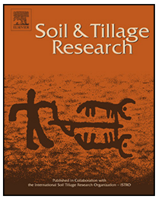

Exploring the correspondence between precompression stress and soil load capacity in soil cores

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ABSTRACT

The soil precompression stress (σ_p) has been used as an estimator of the soil load bearing capacity, but a few researches have evaluated the correspondence to each other. In this study, we first evaluated in prepared soil cores the time needed for σ_p to reach a quasi-stable state. Afterwards, we waited the same time for using another set of soil cores to evaluate the changes on σ_p after the soil core received loads equal to its σ_p. The two experiments were performed using two Rhodic Hapludox (RH1 and RH2) and one Typic Paleodult (TP). In both experiments the σ_p was denominated as σ_{p2R}, because it was calculated using the two-line intersect method proposed by Dias Junior and Pierce (1995). In the first one, σ_{p2R} increased asymptotically over time after sample preparation. When the increasing rate of σ_{p2R} decreased down to 0.05 kPa d^{-1}, we assumed that the increase in soil structure strength over time was small and had little effect on σ_{p2R}, which took place at 21 days for RH1, 26 days for RH2, and less than 1 day for TP. The second experiment was performed after these times of structure strengthening. Four times in each soil, the σ_{p2R} was measured (σ_{p2Ri}) and this value was applied as a new load on the soil. Thus, σ_{p2Ri} was assumed as the maximum load previously received by the soil core, which was related to the subsequently measured $\sigma_{p2R(\sigma p2Ri+1)}$. The results indicate that σ_{p2R} overestimated the maximum load previously received by the soil, because the σ_{p2Ri+1} was generally greater than σ_{p2Ri}. Also there were evidences that applying on soil a load equal to σ_{p2R} can increase soil compaction. If this tendency is confirmed by further studies using more sensitive techniques to evaluate soil structure changes, as computed tomography, the load limit to be applied to the soil should be less than $\sigma_{p2R,}$ because loads equal to such value may overcome the soil load bearing capacity and progressively increase in the degree-of-compactness.

1. Introduction

Soil compaction is the result of external stresses applied mainly by machinery traffic and animal trampling. The increase in the degree-of-compactness may affect the sustainability of agriculture production (Beutler et al., 2001; Collares et al., 2011; Cortez et al., 2014). Compaction occurs from the applied stress causing an irreversible deformation with a significant reduction of porous space, when the counteracting forces preventing reversible displacement of soil particles is overcome. This threshold force on a given area defines a pressure (P, kPa), which is closely linked to the soil load-bearing capacity (σ_{cs}, kPa) to which Casagrande (1936) proposed the estimator called soil precompression stress (σ_p, kPa).

Although σ_{cs} is theoretically a well-known physical quantity, experimental techniques for direct quantification of σ_{cs} have not been developed or not been used in this research topic. Therefore, the σ_p has been used as an estimator of the σ_{cs} (An et al., 2015; Dastjerdi and Hemmat, 2015; Dias Junior, 1994; Iori et al., 2012; Marasca et al., 2012; Silva et al., 2002b; Veiga et al., 2007).

The σ_p is determined from a uniaxial compression curve of a specimen (soil sample) and quantified in a strictly-graphical approach or by means of mathematical procedures. Several researchers have proposed methods for determining the σ_p. The original method developed by Casagrande (1936) is an empirical laboratory test that determines the σ_p by visual analysis of the graphical relationship between void ratio versus the logarithm of applied loads. Some researchers (Baumgartl and Köck, 2004; Gregory et al., 2006) proposed mathematical approaches to

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determine the σ_p using compression curve by relating voids ratio to the logarithm of the applied loads. Others (Assouline, 2002; Dias Junior and Pierce, 1995; Fritton, 2001) use the compression curve relating soil density to the logarithm of the applied loads. Consequently, there are distinct results of σ_p determined by different methods (Cavalieri et al., 2008; Rosa et al., 2011), one of the reasons being the nonlinearity of the relationship between soil void ratio and bulk density (Gubiani et al., 2016). Therefore, the σ_p calculated by a particular method can not be a good estimator of σ_{cs}, and this concern has hindered the use of σ_p to guide traffic management in agricultural areas (Cavalieri et al., 2008).

Studies determining σ_p usually do not quantify σ_{cs} of the same soil. Therefore, it is unknown how much σ_p deviates from σ_{cs}. Gregory et al. (2006), Peth and Horn (2006) and, more recently, Dastjerdi and Hemmat (2015) stated that the maximum stress applied to a soil sample before determining σ_p was a measure of σ_{cs}. These authors found out that σ_p generally overestimated σ_{cs}. This approach can be used to reevaluate the σ_p calculation methods, an urgent requirement according to Schaffer et al. (2010) and Keller et al. (2011).

Regardless of the σ_p calculation procedure, some assumptions are necessary. If the soil from which the specimen was removed receives a lower load than its σ_p, the soil will experience elastic, reversible deformation, without increasing the degree-of-compactness. If the load applied is greater than σ_p, the before mentioned deformation will occur, increasing the degree-of-compactness (Assouline, 2002; Dias Junior and Pierce, 1995 ; Dias Junior and Pierce, 1996 ; Fritton, 2001; Iori et al., 2012; Marasca et al., 2012; Ortigara et al., 2014; Silva et al., 2002b Fritton, 2001; Iori et al., 2012; Marasca et al., 2012; Ortigara et al., 2014; Silva et al., 2002b).

Several studies, however, showed that repeating a load (cyclic compressibility) lesser or greater than soil σ_p causes a progressive increase in soil bulk density (Krummelbein et al., 2008; Peth and Horn, 2006). This behavior indicates that the alleged elastic and plastic portions separated by σ_p were not well attested by the cyclical compressibility analysis. Furthermore, it indicates that repeating loads equal or smaller than σ_p progressively increases soil compaction. Therefore, this is a mandatory investigation that must be performed before the use of σ_p as an indicator of σ_{cs}.

Soil σ_p is affected by many soil properties, such as bulk density and degree of saturation (Fidalski et al., 2006; Filho et al., 2007; Hu et al., 2012; Silva et al., 2002a; b), cohesion and friction between soil particles (Braida et al., 2007a,b; Lebert and Horn, 1991), and change in soil structure stability, due to changes in the energy of particle–particle bonds (Kemper et al., 1987).

Thus, laboratory studies are useful to promote variations only in the selected factors of interest. This experiment was performed with soil cores prepared on laboratory from three soils. The objective was to determine the changes of soil σ_p over time and the changes in soil σ_p if the soil core receive a load equivalent to its σ_p

2. Material and methods

A sample of approximately 20 kg of soil was collected at a single point, from the 0–20 cm soil layer, in three kaolinitic soils of Rio Grande do Sul state, Brazil. The soils were a Rhodic Hapludox (RH1) – Latossolo Vermelho distroférrico típico; Rhodic Hapludox (RH2) – Latossolo Vermelho distrófico típico; Typic Paleudults (TP) – Argissolo Vermelho-Amarelo Distrófico típico, by Soil Taxonomy (USDA, 2014) and Brazilian Soil Classification System (Santos et al., 2013), respectively. The granulometric composition expressed in kg kg^{-1} of sand, silt and clay were, respectively, 0.13, 0.25 and 0.62 in RH1; 0.68, 0.09 and 0.23 in RH2; and 0.76, 0.09 and 0.15 in TP. In the laboratory, the samples were air-dried, large aggregates were disrupted, and the sample was passed through a 2-mm mesh diameter sieve to obtain air-dried fine soil (ADFS).

The study was conducted in two steps, herein called Step 1 and Step 2, in which the ADFS was moistened to yield moist fine soil (MFS) that was packed into metal rings of 5.7 cm diameter and 3 cm height for Step 1, and 7.6 cm diameter per 7.6 cm height for Step 2. These compacted samples are named as CS. For all CSs, the degree-of-compactness (D) was fixed at 0.87, which was calculated by $D = \rho/\rho_m$, where ρ_m (Mg m^{-3}) is the maximum bulk density obtained in the Normal Proctor compaction test. The D value of 0.87 was used so that the ρ values of CS, of 1.30, 1.57 and 1.63 Mg m^{-3}, respectively for the RH1, RH2 and TP would correspond to approximately the field soil bulk density. Soil ρ_m of 1.49, 1.80 and 1.88 Mg m^{-3}, respectively for the RH1, RH2 and TP, were estimated as a function of clay content (C, kg kg^{-1}), using the equation described by Marcolin and Klein (2011):

$$\rho_m = -0.0092C + 2.0138 \quad (1)$$

Once defined the ρ of CS and using the measured particle density (ρ_s, Mg m^{-3}) for each soil, ρ_s of 2.7, 2.65 and 2.65 Mg m^{-3}, respectively for RH1, RH2 and TP, the amount of water to be added to ADFS was calculated for volumetric water content of the CS (θ, m^3 m^{-3}) to yield a degree of saturation S of 0.65 (Eq. (2)) in the MFS. We used a S value of 0.65 so that the water content of CS of 0.34, 0.27 and 0.26 m^3 m^{-3}, respectively for RH1, RH2 and TP, was sufficient to allow for deformation during stress application (step 2).

$$S = \frac{\theta}{1 - \frac{\rho}{\rho_s}} \Rightarrow \theta = S\left(1 - \frac{\rho}{\rho_s}\right) \quad (2)$$

The MFS of each CS was partitioned in two parts, which were separately packed into rings, in order to reduce the heterogeneity of ρ in CS. Soil compaction was done manually using a wooden cylinder struck by a rubber hammer, in a way that the volume of each half of MFS was adjusted to its corresponding half volume in the ring. At the end of the preparation, the CS were covered with plastic wrap to avoid water loss.

2.1. Step 1: time shift of the precompression stress

For this step we used for each soil the 15 CS, which were prepared in 5.7 cm-diameter and 3.0 cm-height rings. A completely randomized design with 15 experimental units, five treatments, and three replications was defined for each soil. The treatments consisted of different time (0, 14, 28, 56 and 112 days) since the sample preparation for the soil σ_p measurements. The CS were covered with plastic wrap to prevent water loss and remained at room temperature varying between 18 and 22 °C, throughout the experiment.

The uniaxial compression test was performed according to the Brazilian Standard NBR 12007/90, but changing the loading time 5 min as proposed by Silva et al. (2000) and using an oedometer provided with an deformation gauge (precision of 0.025 mm). The sequence of loads of 12.5, 25, 50, 100, 200, 400, 800 and 1600 kPa was applied to the CS, and for each of loading the vertical soil deformation was measured and, at the end of the trial, samples were oven-dried at 105 °C for 48 h to obtain the dry soil mass, and calculate ρ as described by Gubiani et al. (2016). Soil σ_p was then determined as the two-line intersection method proposed by Dias Junior and Pierce (1995). The secondary compression line was drawn with the three first data pairs (ρ, $\log_{10}\sigma$), corresponding to σ 12.5, 25 and 50 kPa, and the virgin compression line with the last two pairs of data (ρ, $\log_{10}\sigma$), corresponding to σ of 800 and 1600 kPa.