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Backpressure Saturation Effects on the Mechanical Behaviour of a Quasi-saturated Compacted Residual Soil

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ABSTRACT: The use of saturation methods in triaxial tests is a common practice to obtain the strength parameters of the soil in effective terms. However, these methods may influence the results obtained in the laboratory negatively. For instance, undesirable volumetric variations in the sample may be created depending on the saturation stages applied to the samples. Furthermore, these methods commonly require large backpressure values to saturate samples even if their saturation corresponds to the "quasi-saturated state". This quasi-saturated state (related to saturation values above 90%) is commonly found in the engineering practice for fills of embankment compacted above the optimum water content. At this state, the soil is expected to behave as a saturated soil and the suction of the soil tends to be zero. This paper studies the effect of two saturation processes in a residual soil from São Paulo, Brazil, compacted in the quasi-saturated state. CIU triaxial tests were performed with fully saturated and quasi-saturated samples. Both processes lead the samples to different wetting paths and volumetric changes that, as a result, influenced the pore-water pressure development and the effective strength parameters.

KEYWORDS: Quasi-saturated state, Pore-water pressure development, Saturation laboratory methods, Residual soil

1. INTRODUCTION

Compaction is one of the most common processes utilised to improve the geotechnical characteristics of natural soils. Usually, the soil is compacted in the vicinity of the optimum water content of the compaction curve. Triaxial tests are commonly used to estimate the mechanical properties of the compacted soil. Commonly, a saturation stage precedes the consolidation stage in order to obtain the effective parameters (c' and φ'). Yet, when the soil possesses low degree of saturation (S), large backpressures are required to saturate the samples and undesirable volumetric variations can be generated (Pinto, 1979). In tropical regions with prolonged rain seasons, compaction on the wet-side of the optimum water content is adopted to meet the deadlines of construction projects. When compacted on the wet-side, S of the soil is commonly above 90% defined as "quasi-saturated state". Since S is close to full-saturation, smaller and less disturbing backpressure values can be utilised to saturate the samples. At high initial S values, the saturation method used can influence (a) the effective strength parameters, and (b) the pore-water pressure development. Therefore, experimental results are required to assess the influence of saturation methods on the stress-strain-strength behavior.

2.1 Quasi-saturated state

Unsaturated soils can exhibit two behaviours in mechanical terms: unsaturated and a quasi-saturated behaviour. For instance, soils compacted on the wet-side possess quasi-saturated behaviour. In this condition, the soil strength behaviour follows the effective stress principle similar to a saturated soil. The quasi-saturated behaviour have been studied by several authors (e.g. Vaughan, 1982; Cruz & Maiolino, 1985; Sandroni, 1985; Lins & Sandroni, 1994; Shahu et al., 1999; Marinho et al., 2002, Leroueil & Hight, 2013, among others). Two approaches used in defining the transition between the unsaturated and quasi-saturated behaviour are: (a) based on the parameter B of the soil defined by Skempton (1954), and (b) based on the soil water retention curve (SWRC).

Casagrande & Poulos (1964) and Shahu et al. (1999) defined that for the soil to behave as a quasi-saturated material, the initial B ($\Delta u/\Delta\sigma_3$) value should be higher than 0.3 or 0.4, with a degree of saturation above 93 or 95%. However, the relationship between B and S is nonlinear and soils with high stiffness may present B values close to zero even at degrees of saturation above 95% (e.g. Black & Lee, 1973; Pinto et al. 1970). Alternatively, White et al. (1970) and Vanapalli et al. (1996) used the SWRC to define the transition among both behaviours. The SWRC is divided into four zones based on the degree of unsaturation known as: boundary effect zone, primary transition zone, secondary transition zone, and residual zone (from low to high suction values, respectively). Figure 1 presents the zones for a hypothetical SWRC. The boundary effect zone presents degrees of saturation between 100% and the air entry value, with continuous water voids and air voids in an occluded state. The primary transition zone begins in the air entry value at which air enters into the largest pores of the soil. The secondary transition zone presents large air voids and a reduction in water voids and small differences in suction values produce great variations in the water content. Finally, in the residual zone, large increments in suction are required to produce a small change in the water content. The quasi-saturated state is represented by the boundary effect zone in the model proposed by Vanapalli et al. (1996).

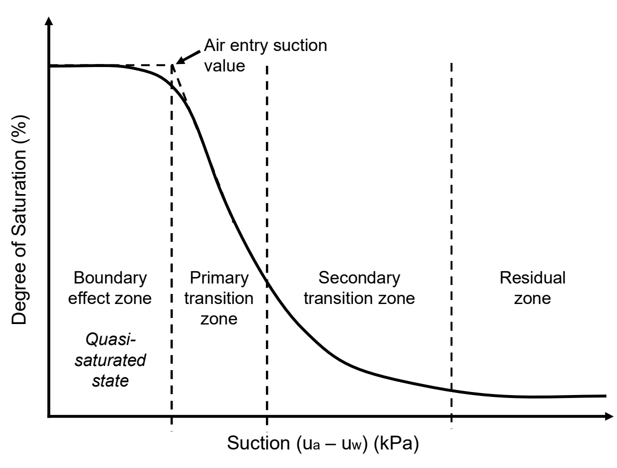

Figure 1 Desaturation zones in a hypothetical SWRC (modified from Vanapalli et al. 1996)

2.2 Saturation stage in triaxial tests

Saturation stage is conducted in order to compress and dissolve air in the soil specimen by applying water pressure (Bishop & Henkel, 1962). Several methods are used in research and commercial laboratories. When the soil suction $(u_a - u_w)$ goes to zero by applying saturation methods, its drained shear strength parameters (c' and ϕ') must be the same regardless of the method applied. Nonetheless, a research conducted by Carvalho (2012) shows that, in terms of the soil structure and genesis, some saturation methods affected the stress-strain-strength behavior of residual soils from Rio de Janeiro (Brazil). Particularly, the saturation method based on percolating water by suction with a low cell pressure followed by a continuous and simultaneous increase of backpressure (automatic saturation) was the most suitable method observed by Carvalho (2012). The saturation method of elevating backpressure in just one stage shows a greater negative influence on the stress-strain-strength behavior when compared to other methods.

In this paper, the effects of saturating soil specimens by using backpressure and percolation method on CIU test are compared. It is shown that the backpressure technique reduces the c' and increases the pore-water pressure during the shearing stage.

2. MATERIALS AND METHODS

2.1 Soil characteristics

The soil tested is a residual soil of gneiss from the city of São Paulo (campus of the University of São Paulo) from the research carried out by Carnero (2014). The soil possess 23% clay, 45% silt and 32% sand. Liquid limit and plasticity index are 48% and 19%, respectively, with a specific gravity of 2.71 g/cm^3. Standard Proctor compaction test (ASTM D698) was used to obtain the maximum dry density (MDD) as well as the optimum water content (OWC). The OWC and MDD are 21.5% and 16.35 kN/m^3 respectively. Although the characterization of the studied soil (expansion index) does not demonstrate expansibility, a one-dimensional swell test (ASTM D4546 – 08) carried out on the soil demonstrated a swelling of 3.6% when soaked. Nogami & Villibor (1995) attributed the expansibility to the soil mineralogy (mica and kaolinite crystals in the silt fraction) and the peculiar structure formed after compaction. They suggested that mica and kaolinite are presented as tortuous macro-crystals that swell when the soil attains saturation.

2.2 Preparation of the specimens

In order to evaluate the development of pore-water pressure and the mechanical behavior in the quasi-saturated state, three points of compaction water content were studied: the OWC (Point O), +2% and +4% above the OWC; known as points P and Q, respectively. Six specimens where moulded at each study point to perform the triaxial tests. Figure 2 presents the compaction curve along with the initial conditions of the statically compacted specimens used in both tests (6 specimens moulded at each study point).

The samples were collected at the experimental campus in the University of Sao Paulo. The samples were dried and passed through the 2mm sieve (#10) and homogenized. The compaction was performed by static compaction in five layers, scratching the top of each layer prior to the next layer. All tests were conducted straightaway after the static compaction.

2.2 Triaxial tests

Two kinds of triaxial tests were performed based on the saturation procedure utilized, (a) CIU using backpressure in order to saturate the samples and (b) CIU using percolation of water with a small backpressure. The procedures were called Procedure 1 and Procedure 2, respectively. The triaxial tests were performed under strain control using a Bishop & Wesley cell with automatic control using the software Triax 5.1.8 (Durham University). An external volume gauge connected to the triaxial chamber was used to measure the volume variation based on the inflow or outflow of water from the sample. In both procedures, the specimens tested were consolidated under isotropic pressure and sheared under undrained condition (CIU) with a rate of shear of 0.3 mm/min. As presented in Figure 2, three initial conditions for points O, P and Q were defined. Six samples were prepared for every study point. The taxonomy of the specimen in Table 1 and 2 is defined as follows: the two initial characters indicate the type of procedure (P1: Procedure 1 and P2: Procedure 2). The letter before the numbers represents the study point (O, P or Q). Finally, the number represents the confining pressure used.

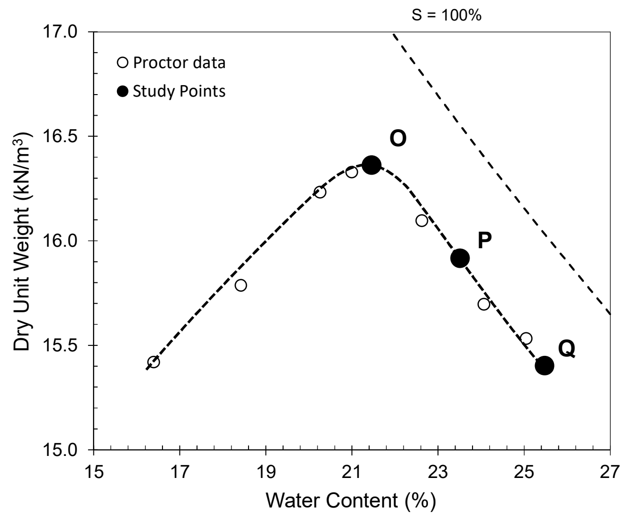

Figure 2 Compaction curve and study points O, P and Q, located at the OWC, +2%OWC and +4%OWC, respectively

a) Procedure 1

Procedure 1 follows the method described by Head (1986) and Lowe & Johnson (1960) where the backpressure is increased in steps. Nine specimens were tested following Procedure 1, three for each study point. After compaction, the specimens were placed in the triaxial cell, a confining pressure of 50 kPa was applied at once and the pore-water pressure measured with a normal pressure transducer in order to obtain the initial B value of the sample. Then, the saturation stage is started by increasing the cell pressure in increments of 50 kPa at a rate of 1 kPa/min. At the end of each increment, the backpressure was increased to a value 10 kPa lower than the cell pressure at each step. B was measured in every of these increments. The saturation stage ended when B > 0.9, similar as adopted by Oliveira (2004). The maximum backpressure used to saturate the specimens varied between 400 and 500 kPa. Samples from Point O requires 500 kPa since were drier than samples molded at Points P and Q, respectively. Volume changes are measured along by an external volume gauge. Then, the consolidation stage is started by increasing the cell pressure until reach the effective confining pressures of 50, 100 and 200 kPa, respectively, with a rate of 1 kPa/min. Finally, the shear stage was performed at a rate of 0.3 mm/min. Procedure 1 is expected to lead to a higher S compared to Procedure 2. Table 1 presents the initial conditions of the specimens tested using Procedure 1.

b) Procedure 2

Procedure 2 increases the water content of the specimens by using percolation of water at a low pressure. This method should induce less disturbance to the specimen and allows the specimen to absorb water according to its initial suction condition. Nine specimens were tested following Procedure 2, three for each study point. The measurement of the initial B value of the samples was performed in the same fashion as Procedure 1.

The saturation and consolidations stages were performed concurrently. First, a backpressure of 20 kPa was applied, to percolate water into the specimens at low pressure. Simultaneously, cell pressures of 70, 120 and 220 kPa where applied in order to achieve effective pressures of 50, 100 and 200 kPa, respectively. The stage was maintained for a minimum of 16 hours, and stopped when no variation in the void ratio of the specimens was observed.

Table 1 Characteristics of the specimens of Procedure 1

Taxonomy	σ'3 (kPa)	wi (%)	γdi (g/cm3)	e	S (%)
P1-O50	50	21.6	1.632	0.66	88.8
P1-O100	100	21.7	1.631	0.66	88.9
P1-O200	200	21.6	1.634	0.66	88.8
P1-P50	50	23.8	1.583	0.71	90.6
P1-P100	100	23.6	1.589	0.71	90.5
P1-P200	200	23.1	1.593	0.70	89.3
P1-Q50	50	25.8	1.529	0.77	90.6
P1-Q100	100	25.1	1.54	0.76	89.5
P1-Q200	200	25.7	1.532	0.77	91.0

Table 2 Characteristics of the specimens of Procedure 2

Taxonomy	σ'3 (kPa)	wi (%)	γdi (g/cm3)	e	S (%)
P2-O50	50	21.3	1.636	0.66	88.1
P2-O100	100	21.4	1.635	0.66	88.4
P2-O200	200	21.4	1.634	0.66	88.2
P2-P50	50	23.3	1.591	0.70	89.6
P2-P100	100	23.3	1.59	0.70	89.6
P2-P200	200	23.8	1.584	0.71	90.6
P2-Q50	50	25.6	1.531	0.77	90.1
P2-Q100	100	25.7	1.529	0.77	90.2
P2-Q200	200	25.5	1.636	0.77	90.0

During the saturation-consolidation stage, the initial suction of the samples dropped due to the applied backpressure. In order to quantify this reduction, the suction of a specimen molded in the Point O was monitored using a high capacity tensiometer (HCT). The equipment is located in the base of a load control triaxial cell described in other investigations where further details regarding the equipment can be found (e.g. Carnero-Guzman & Marinho, 2015; Marinho et al. 2016). The specimen was placed on top of the HCT and suction was monitored in real time and recorded while backpressure and cell pressure of 20 and 70 kPa respectively where applied. Figure 3 shows that the initial suction of the specimen (134 kPa) reached an equilibrium with the imposed backpressure of 20 kPa after 800 minutes.

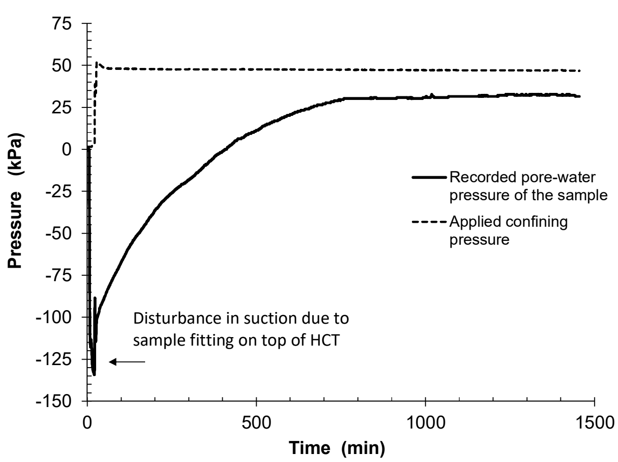

Figure 3 Suction development from a "Point O" sample during the saturation-consolidation stage in Procedure 2

The degree of saturation, *S*, increased from 88% to 96%. Meaning that, only occluded air remains in the specimen and, because there is no effective connection among the occluded air, the positive pressure reached equilibrium with the applied backpressure (Sandroni, 1985). Therefore, the target effective pressures where reached at the end of the saturation-consolidation stage. Thus, the suction of Procedure 2 is minimum and tends to zero, thus, the effective strength parameters can be obtained using this Procedure. Table 2 presents the initial conditions of the specimens tested using Procedure 2. For both Procedures, the shear stage started with a pore-water pressure equal to the applied backpressure in each case. Then, the pore-water pressure is zeroed to obtain the non-drained deviatoric stress and the excess pore-water pressure along the tests.

3. RESULTS AND ANALYSIS

Information at failure from the tests performed using Procedures 1 and 2 are presented in Tables 3 and 4, respectively. The table contains the estimated final degree of saturation, S_n, the excess of pore-water pressure, Δu_f, s'- t' (MIT) effective values, the deviatoric stress, q_f, and the pore-water pressure parameter ($\bar{A}_f$ =Δu/Δq).

Table 3 Details of the CIU triaxial tests of Procedure 1 at failure

Spec.	S_n (%)	Δu_f (kPa)	s'_f (kPa)	t'_f (kPa)	q_f (kPa)	$\bar{A}_f$
P1-O50	100	24.3	91.5	63.5	126.8	0.19
P1-O100	100	39	134.4	84.7	169.4	0.23
P1-O200	100	78.5	236.6	134.8	293.1	0.27
P1-P50	100	22.7	89.5	61.3	115.1	0.20
P1-P100	100	45.7	135.5	93.7	167.4	0.27
P1-P200	100	117.1	199.1	117.2	234.3	0.50
P1-Q50	100	22	73.2	48.7	97.5	0.23
P1-Q100	100	29.8	119.7	67.2	134.4	0.22
P1-Q200	100	110.7	192.5	103.4	206.8	0.54

Table 4 Details of the CIU triaxial tests of Procedure 2 at failure

Spec.	S_n (%)	Δu_f (kPa)	s'_f (kPa)	t'_f (kPa)	q_f (kPa)	$\bar{A}_f$
P2-O50	91.2	3.8	157.7	109.5	218.9	0.02
P2-O100	91.1	12.3	235	145.8	291.6	0.04
P2-O200	91.0	16.5	422.6	237.4	474.9	0.04
P2-P50	92.1	6.8	133.9	88.5	177.0	0.04
P2-P100	92.0	9.1	226.8	136	272.0	0.03
P2-P200	92.6	17.1	402.5	218.3	436.6	0.04
P2-Q50	92.3	6.1	128.6	84.5	168.9	0.04
P2-Q100	92.3	12.1	207.4	117.2	234.4	0.05
P2-Q200	91.8	356	192.1	365.4	35.6	0.10

3.1 Influence of the saturation procedure in the volume changes paths

For Procedure 1, volume changes are related to the water phase of the soil and were measured by the external volume gauge mentioned in the item 2.2. Therefore, it was obtained that the S_n from Procedure 1 is 100%. During Procedure 2, water goes into the samples and increases the water content, yet some air in occluded state remains in the structure. Since the saturation and consolidation stages were carried simultaneously, a portion of the initial amount of air is compressed and dissolved. The estimation of compression and dissolution of air in this scenario is possible applying the Boyle-Mariotte and Henry laws, respectively. Boyle-Mariotte law (expressed in Eq. 1) states that the absolute pressure exerted by a given mass of an ideal gas is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged within a closed system (Levine, 1978).

$$P_1V_1 = P_2V_2 \tag{1}$$

where P_1 and V_1 represent the initial pressure and volume of air, respectively, and P_2 and $V2$ represent the final pressure and volume of air of the specimen. Henry law (Eq. 2) estimates the amount of dissolved gas in the water by assuming that the dissolved gas is proportional to its partial pressure in the gas phase (Levine, 1978).

$$P = K_H C \tag{2}$$

where P is the partial pressure of the air, K_H is the Henry's Law constant for the air in the water, and C is the concentration of the dissolved gas. Finally, in order to apply both equation, four assumptions are required based on the triaxial data obtained: (1) the pressure of water and air are equal, (2) the water from the specimen and the backpressure system are saturated with air at atmospheric pressure, (3) the volume increment of the water is the registered by the software, and lastly, (4) the final moisture content is the one calculated by the software using the volume change measured. Thus, S_n was estimated for Procedure 2. An increment between 2 and 3% in S_n (Table 4) occurred when compared with the initial S value (Table 2).

The volumetric variations from both Procedures can be analysed. Figure 4 shows the void ratio at the beginning of the test, after saturation (Procedure 1) and after the consolidation stage, respectively. Procedure 1 samples increased their void ratio after saturation, and, then, there is a reduction in the void ratio due to the consolidation stage. For a same test condition (initial water content and effective stress) the final void ratio is similar to the ones reached by Procedure 2 samples. Dryer samples shows closer values among both Procedures. It can be stated that, although the final void ratio is similar in both Procedures, Procedure 1 produced a deformation path that includes (a) swelling and (b) consolidation that might generate a new structure in the soil due to the expansibility of the kaolin and mica minerals as per observed by Nogami & Villibor (1995).

3.2 Influence of the saturation procedure in the final degree of saturation

Figure 5 presents the differences between the initial and final degree of saturation for both procedures. The final degree of saturation of samples from Procedure 1 increased between 9 to 11%, whereas the specimens from Procedure 2 presented an increment between 2 to 3%. S_n for Procedure 1 was 100% for all specimens, although this parameter varied between 91% and 93% for Procedure 2. Thus, sin the suction in Procedure 2 was zero (or close to zero), the remaining air of the sample is in occluded state and the effective stress principle is applicable for analyzing the shear strength results (e.g. Sandroni, 1985; Vanapalli et al. 1996).

3.3 Influence of the saturation procedure in the effective stress paths

Since both procedures lead the specimens to saturation (Procedure 1) or absence of suction (Procedure 2), the triaxial results are expressed in effective stress terms. Figures 6 to 8 show the effective stress paths for Points O (Figure 6), P (Figure 7) and Q (Figure 8). The paths are presented until failure was achieved. The paths are grouped by the initial water content, although the specimens reached different final water contents. The influence of Procedure 1 is reflected in the effective stress paths for the three initial water content conditions. Procedure 1 generates a larger amount of excess of pore-water pressure (as per comparison between Table 3 and 4). Therefore, Procedure 1 paths are displaced at the left of their total stress paths, which will be located at 45° with the horizontal axis. Once the failure was achieved, the pore-water pressure reduced, thus, the paths follow the shear strength envelope. On the other hand, the Procedure 2 paths (S_n > 91%) produced less excess pore-water pressure, thus, the paths are almost 45° with the horizontal axis, close to the total stress paths.

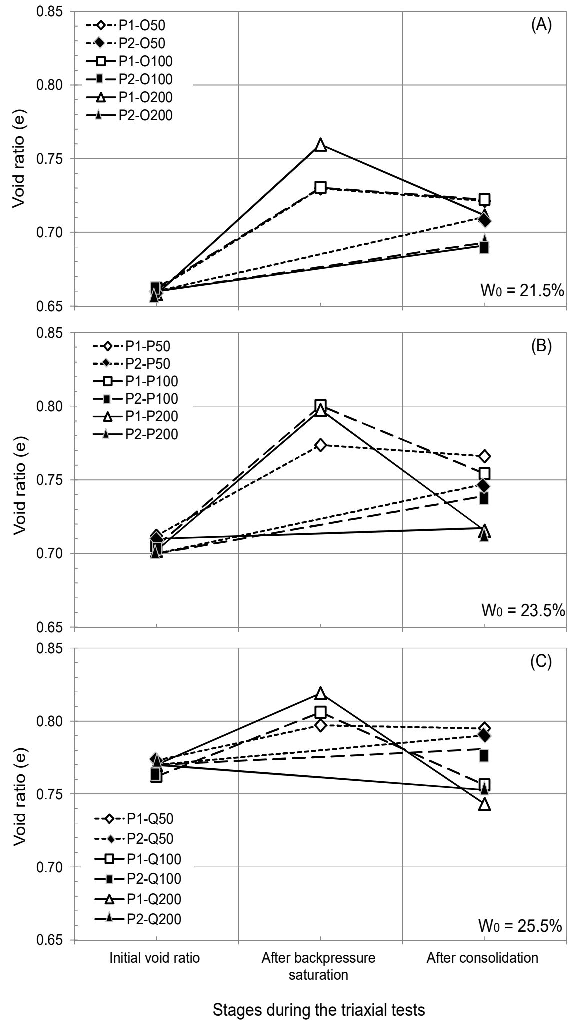

Figure 4 Void ratio variation along the triaxial tests stages for Procedures 1 and 2. (a) Point O, (b) Point P, (c) Point Q

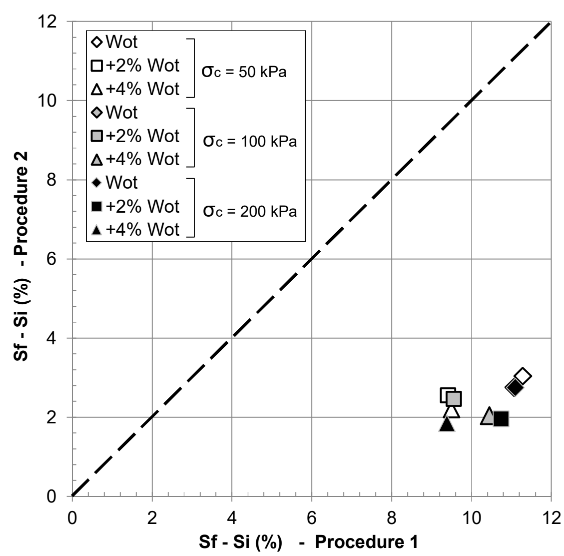

Figure 5 Difference between the final and initial degree of saturation (S_n - S) between Procedure 1 and 2

For this procedure, failure was attained at low deformations, then, the paths follow the shear strength envelope due to the decrease in the excess pore-water pressure, similar as Procedure 1. For both procedures, parameter d reduced with the increment in the initial water content, while β is almost constant for all the studied cases.

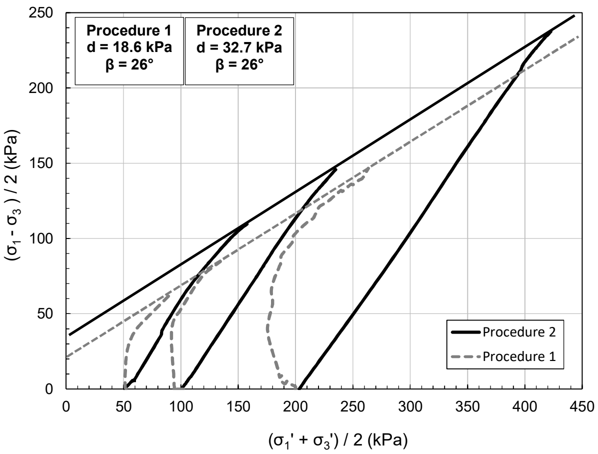

Figure 6 Point O effective stress paths for Procedures 1 and 2

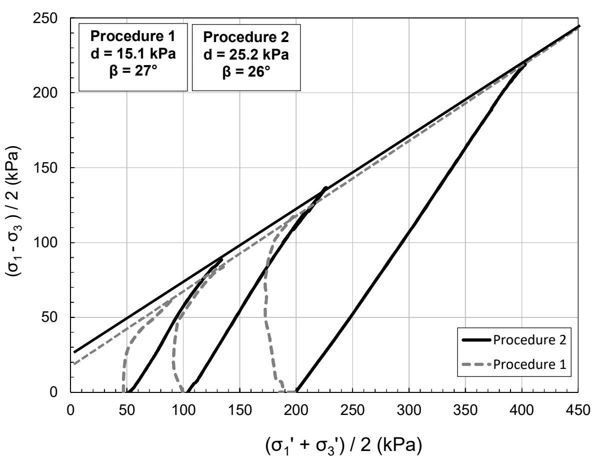

Figure 7 Point P effective stress paths for Procedures 1 and 2

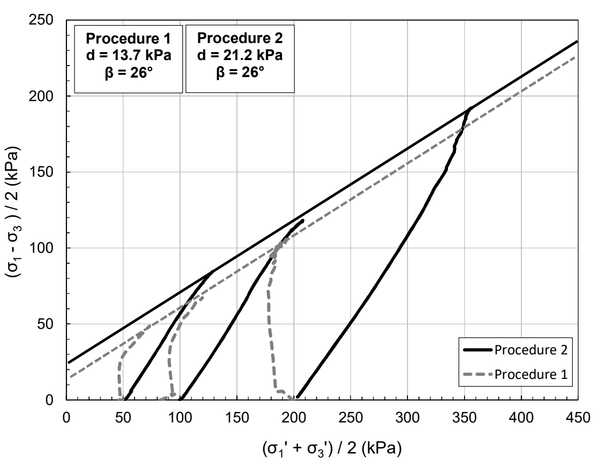

Figure 8 Point Q effective stress paths for Procedures 1 and 2

3.4 Influence of the saturation procedure in the excess of pore-water pressure at failure

As shown in Tables 3 and 4, the excess of pore-water pressure is greatly different between both procedures. The fact is also reflected in parameter $\bar{A}_f$. Figure 9 compares the $\bar{A}_f$ obtained for Procedures 1 and 2. The wetter the compaction condition, the higher is the $\bar{A}_f$ parameter. In addition, the value of $\bar{A}_f$ for Procedure 2 did not change significantly regardless of the initial water content and the consolidation stress applied. The $\bar{A}_f$ values are < 0.1. The result indicates that Δu at failure is between 4 and 10% of the $(\sigma_1 - \sigma_3)$ applied. Conversely, in Procedure 1, $\bar{A}_f$ increases with the initial water content and reached values of 0.3 and 0.54, for OWC and +4% OWC, respectively, which means that, Δu is 30% to 54% of the $(\sigma_1 - \sigma_3)$ applied. Procedure 1 produces an excess pore-water pressure greater than Procedure 2, which, as presented in the effective stress paths, leads the specimens to reach the failure envelope at lower shear stresses that might be related to the volume change path in Procedure 1 samples (swelling followed by consolidation).

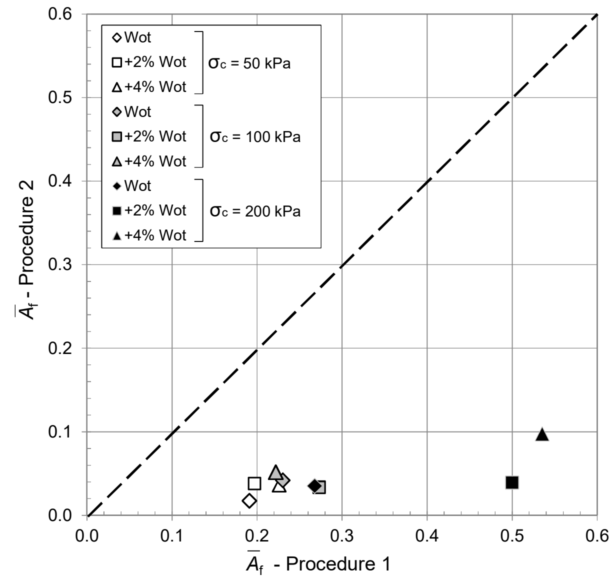

Figure 9 Parameter at failure, $\bar{A}_f$, obtained from the tests performed with Procedures 1 and 2

3.5 Influence of the saturation procedure in the deviator stress at failure

Figure 10 presents the deviatoric stresses at failure for the two Procedures used for the different initial water contents and consolidation conditions. For a sole consolidation applied stress, higher deviatoric stresses were obtained for drier samples. It was expected that samples consolidated under 200 kPa would expel more air, becoming more saturated, and, as a result, similar deviator stress should be attained by both Procedures. Nevertheless, a greater distance from the 45° line occurs while the consolidation stress is increased. The results suggest that Procedure 1 produced more pore-water pressure at failure. Pore-water pressure from Procedure 1 is 5 to 6 times greater than Procedure 2, for the OWC, and +4%OWC, respectively as shown in Tables 3 and 4. It is plausible to state that the volume change path of Procedure 1 resulted in a different final structure that generates more pore-water.

3.6 Influence of the saturation procedure in the effective shear strength parameters

Figure 11 presents the Mohr's circles and shear strength envelopes from both Procedures for the three initial water content conditions.

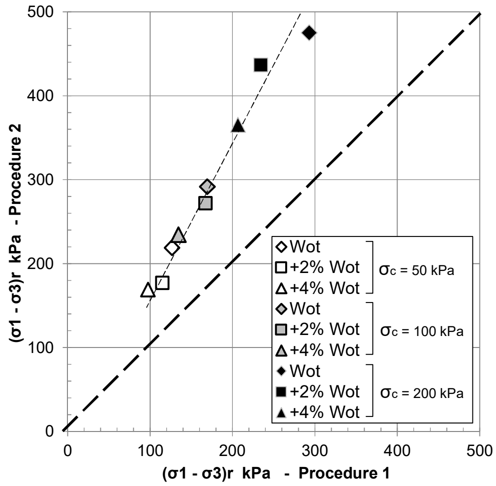

Figure 10 Deviator stresses in failure for same initial water content and consolidation conditions

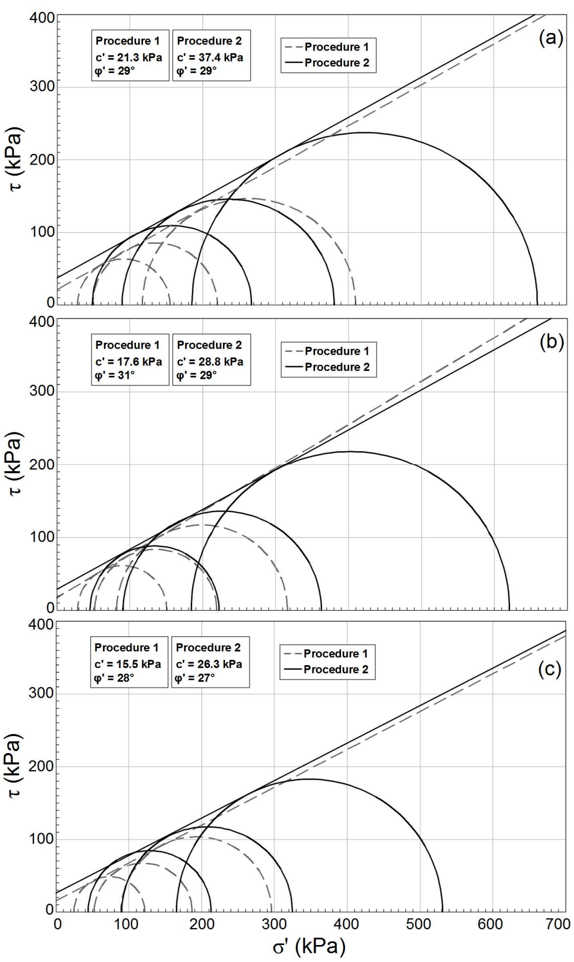

Figure 11 Mohr's circles and shear strength envelopes from Procedures 1 and 2. (a) Point O, (b) Point P, (c) Point Q

The Mohr's circles from Procedure 1 are smaller than Procedure 2. Based on the three figures presented, one can infer that the friction angle is similar among both Procedures and the effective cohesion increases when Procedure 2 is used. Table 5 summarises the effective parameters obtained. Figure 12 shows a comparison of c'obtained from both procedures. The effective cohesion decreases while the initial water content increases. At each initial water content, c' from Procedure 1 is approximately only 60% of *c*' of Procedure 2. Furthermore, the results present the same trend as shown in Figure 10 with respect to the deviator stress at failure which indicates the relationship among the effective cohesion and the deviator stress at failure. The results suggest that *c*' is influenced by the saturation procedure and its value can be affected when high backpressures are applied along with the volume change path presented in Figure 4. Since the effective friction angle ϕ' results are similar in all the envelopes obtained, the *c*' values can be analyzed as a function of the final dry unit weight of the specimens. Figure 13 shows the relationship between the final dry density and the effective cohesion.

Table 5 Effective shear strength parameters

Study Point	ϕ' (°)		c' (kPa)	
	P1	P2	P1	P2
O	29	29	21.3	37.4
P	31	29	17.6	28.8
Q	28	27	15.5	26.3

P1: Obtained from Procedure 1
P2: Obtained from Procedure 2

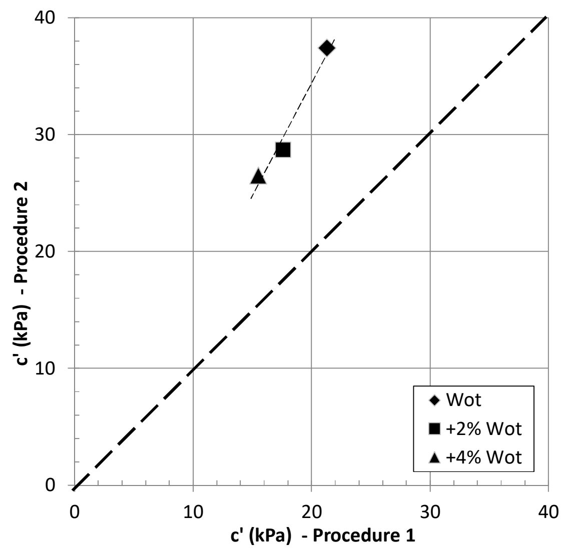

Figure 12 Effective cohesion for same initial water content and consolidation conditions

Since *c*' depends directly on the dry unit weight, one would expect a unique relationship, independent of the procedure used. However, two relationships were obtained according to the saturation procedure, as shown in Figure 13. The acquired relationships suggested an almost parallel trend with 11 kPa separation between both. This result suggests that there is a difference in the structure of specimens used in both procedures. If the soil expands during saturation (Procedure 1), and then compresses, the *c*' might represent a disturbed condition due to the volume changes registered by the application of large backpressure. In contrast, if the soil only experiences consolidation (path followed by Procedure 2) and no expansion, the *c*' represents the non-disturbed condition better than Procedure 1.

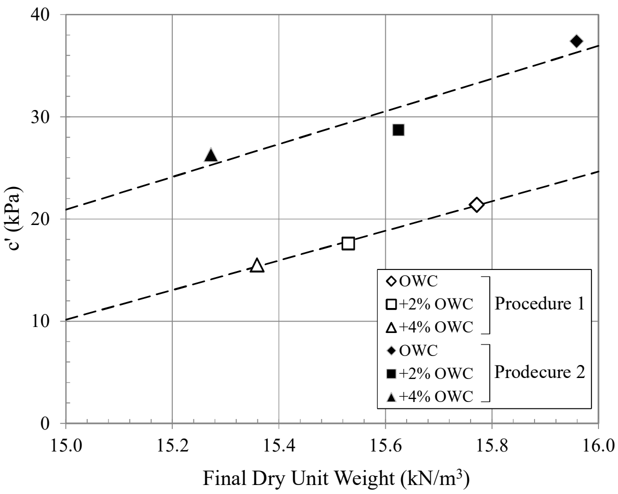

Figure 13 Effective cohesion values related to different final dry unit weight before shear for Procedures 1 and 2

The final values of dry density and water content could be plotted with the compaction curve and the final position of the study points (final dry density versus final moisture content). Figure 14 presents this analysis relating the average final position of the tests for different molding and procedure conditions with the effective cohesion value obtained. Even with a lower density and similar water content, the effective cohesion obtained using Procedure 2 is considerately superior to the results obtained using Procedure 1.

According to these analyses, a conclusion where the backpressure saturation process may affect the initial structure of the studied soil is defined and the use of Procedure 2 as saturation process in this kind of residual soils is recommended when the soil is compacted in the optimum and wet side of the compaction curve.

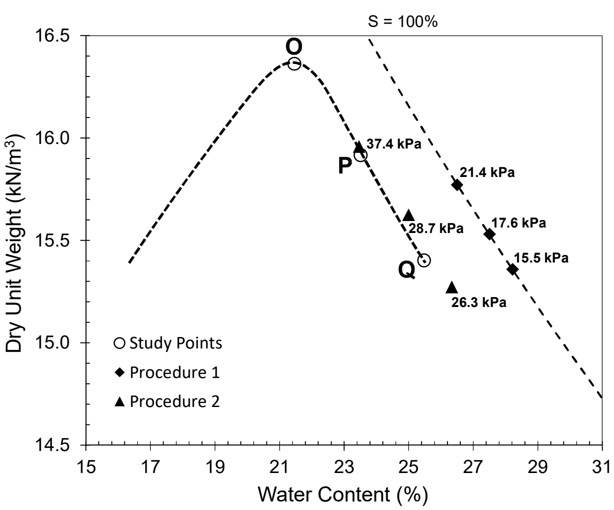

Figure 14 Average final position of the samples related to its effective cohesion value obtained for both Procedures.

4. CONCLUSIONS

An experimental investigation of the behaviour of a residual soil compacted at optimum and above optimum water content was presented. Eighteen triaxial CIU tests were performed in quasi-saturated specimens submitted to two-saturation procedures prior to shear. The two procedures led to different final degrees of saturation and induced differences in the shear strength envelope. The following conclusion can be drawn from the test performed:

– The effective friction angle was not affected by the saturation procedure used.
– The effective cohesion was lower for tests performed with Procedure 1.
– The two procedures led to degrees of saturation above 90%. However, specimens saturated with Procedure 1 presented higher degree of saturation.
– The volumetric path followed by the specimens may also have affected the particle arrangement induced by the backpressure saturation process. This aspect needs further investigation.
– Deviator stresses obtained for Procedure 1 were 54% of the values obtained for Procedure 2 due to the pore-water pressure developed at failure for Procedure 1. In some cases, the deviator stresses were seven times higher than those obtained for Procedure 1.
– The pore water pressures parameter, $\bar{A}_f$, was always less than 0.1 for Procedure 2 and varied from 0.2 to 0.52 for Procedure 1.
– The authors recommend the use of Procedure 2 as the saturation procedure in triaxial tests in the studied soil for high initial degrees of saturations.
– The saturation procedure needs to be defined for soils prior conduct laboratory tests in order to obtain the most realistic values of the soil.
– The process of water absorption in the field may control the actual behaviour of the soil. Conservative results may be obtained by testing compacted soils inducing saturation by backpressure. The results suggest that if the soil does not reach full saturation after compaction, wet fills could present higher cohesion and lower pore-water pressure during construction.

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