INTERNATIONAL SOCIETY FOR
SOIL MECHANICS AND
GEOTECHNICAL ENGINEERING

This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

https://www.issmge.org/publications/online-library

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

The paper was published in the Proceedings of the 8th International Symposium on Deformation Characteristics of Geomaterials (IS-PORTO 2023) and was edited by António Viana da Fonseca and Cristiana Ferreira. The symposium was held from the 3rd to the 6th of September 2023 in Porto, Portugal.

# The sensitivity of Prazeres clay – some results on reconstituted samples

*Mafalda* Lopes Laranjo[1#] and *Manuel* Matos Fernandes[2]

[1] *proMetheus, Instituto Politécnico de Viana do Castelo, Rua Escola Industrial e Comercial Nun'Álvares, 4900-347 Viana do Castelo, Portugal*

[2]*Faculdade de Engenharia da Universidade do Porto, Civil Engineering, Rua Dr. Roberto Frias, 4200-465 Porto*

[#]*Corresponding author: mlopes@estg.ipvc.pt*

## ABSTRACT

Soil's structure is defined as the issue responsible for the differences observed in the mechanical response of natural soil samples compared to the intrinsic behaviour of reconstituted samples. The parameter that incorporates the differences in microstructure of intact and reconstituted clays is designated by stress sensitivity. The influence of microstructure and fabric on the behaviour of soils has been evaluated by comparing strength and compressibility characteristics of intact and reconstituted samples of the same material. Included on a broad characterization study of Lisbon Miocene *Prazeres* clay held at Porto University, some oedometer and triaxial tests were undertaken on intact and reconstituted samples. In this paper, the process of preparing reconstituted samples and consolidating them in a large oedometer to the in-situ stress is thoroughly described. The results of oedometer and triaxial tests on reconstituted samples are presented and compared with results for intact samples from the same site. A proposal for parameterisation of the intrinsic characteristics of this clay is established on the basis of test results. Concerning compressibility, oedometer test results show good adjustment to the isotropic compression line (ICL). Triaxial test results for intact samples in the light of critical states soil mechanics are similar to those obtained in *s'-t* space for the reconstituted samples. The intrinsic parameters show good agreement with those described in the literature for soils of the same nature.

**Keywords:** Miocene clays; intrinsic properties; stress sensitivity.

## 1. Introduction

*Prazeres* clay is an overconsolidated Miocene clayey formation that can be found in Lisbon region. It stays at the base of the Miocene Series, formed in the Lower Tagus Basin during the Neogene. Its geological history is very complex and results from the interaction of tectonic movements and sea level variations (Almeida 1991, Antunes et al. 1987, Antunes and Pais 1993, Antunes et al. 1998b). The Miocene Series results from the continuous sedimentation during 16 MY along the Basin, compensated by subsidence phenomena, that some authors believe are still occurring (Antunes et al. 1998a, Galopim de Carvalho 1984). In the Aquitanian, the sea entered the current Lisbon region, and the first *Prazeres* clay deposits were formed, comprising conglomerates, sands, marls and glauconiferous silts, followed by several transgressive and regressive events, that led to the formation of 300 m thick deposits (Almeida 1991). This formation underlies a large part of Lisbon area, where many relevant construction works have been developed in the last decades. Its importance to the geotechnical community is unquestionable, as design becomes more demanding and geotechnical projects more elaborated.

Since overconsolidated clays are highly complex materials, its behaviour at the macro scale cannot be dissociated from microscale phenomena related to its genesis, composition and geological history (Lopes Laranjo, Matos Fernandes and Almeida e Sousa 2011, Locat et al. 2002, Hight and Leroueil 2002). There are some relevant aspects of the mechanical behaviour of these clays that can only be studied when we extract from the original soil the influence of its geological/stress history. This can be achieved by preparing reconstituted samples and testing them to derive parameters that are inherent to the material, hence independent from *in situ* conditions (Burland 1990, Burland et al. 1996). This procedure provides a sound basis to evaluate intact material properties and to study the influence of microstructure on soil behaviour. Assuming the same basic sedimentation structure obtained in reconstituted samples, the differences in clay response can be attributed to its composition. Despite of this influence, it is possible to establish a model of mechanical behaviour for reconstituted samples, since the composition will not affect the response pattern, but parameter values (Cotecchia, Mitaritonna and Vitone 2011).

Quantifying microstructure effect is a rather arduous task. The influence of microstructure and fabric on the behaviour of soils can be evaluated by comparing the strength and compressibility characteristics of intact and reconstituted samples of the same material (Burland et al. 1996, Rampello, Calabresi and Callisto 2002, Amorosi and Rampello 2007, Gasparre et al. 2007, Sorensen, Baudet and Simpson 2007)

Stress sensitivity is the parameter that incorporates differences in microstructure between intact and reconstituted samples. This parameter reflects the distance between the strength of intact material and intrinsic strength, meaning that structure effect applies only to the response magnitude, given that its shape does not change (Cotecchia and Chandler 2000).

Included in a broad characterization study of Lisbon Miocene clay, oedometer and triaxial tests were carried out on intact and reconstituted samples. This allowed to establish stress sensitivity for *Prazeres* clay and to compare it with other overconsolidated sedimentary clays described in the literature. This paper presents some results on *Prazeres* clay stress sensitivity and intrinsic parameters, and thoroughly describes the process of reconstituting samples and consolidating them to the *in situ* stresses.

## 2. Materials and methods

### 2.1. Slurry preparation

Slurry for reconstituted samples was prepared using material collected from an experimental site (Lopes Laranjo 2013) where *Prazeres* clay can be found at a relatively shallow depth. Initially, soil was broken up into smaller pieces to allow the removal of shells and other coarse material from the existing sandstones and ferrous intercalations. The soil was then dried on trays in a 60 ºC air circulation oven for 24 hours. After drying, soil was placed in a jaw machine to disintegrate and reduce the pieces to loose particles, ready to be mixed with distilled water. This equipment was regulated so as not to crush the soil particles but only to disaggregate the existing lumps. Soil was then weighted and distilled water was added so that water content could reach around 1.5 times the liquid limit (Burland 1990). This mixture was obtained by adding small amounts of soil particles to the calculated volume of water, using a mechanical mixer, with non-cutting paddles. During the process it was necessary to add more water than the initially calculated to ensure a good particle's dissolution. Once the slurry was complete, the mixer was then left to run at a slow speed for some time to de-aerate it and it was then stored into an airtight container to preserve the water content.

**Figure 1.** Slurry preparation using a mechanical mixer: adding the soil to the mixture (left); final aspect of the slurry (right).

Fig. 1 shows some aspects of slurry preparation. Using this methodology, approximately 17 ℓ of slurry were prepared and water content before storage was around 100 %, which corresponds to about 2 times the liquid limit for this soil. However, on putting the lid on the consolidometer, this consistency proved to be too low, as the slurry flowed over the lid and out of the consolidation cell. It was then necessary to add dry material to the slurry in order to correct the water content. At the end of the correction, the water content of the slurry placed in the consolidometer was 70%, which is about 1.5 times the liquid limit.

### 2.2. Reconstituted samples consolidation

Slurry consolidation was performed using a consolidometer with 230 mm in diameter and 315 mm in height, with a 1:33 ratio arm. The equipment consists of a base, a consolidation cell and a top plate. Two geotextile filters are placed at the base and top of the slurry to act as the porous stones of the oedometer test. The consolidation cell is submerged and there is a small hole on its base to provide some suction. Fig. 2 shows some aspects of the assembly and the consolidometer.

**Figure 2.** Slurry in the consolidation cell, prior to the placement of the drainage system and lid (top left); submerged cell, prior to load adjustment (top right); consolidometer (bottom).

Top and base drainage systems comprised circular shaped non-woven geotextile and filter paper. Usually, to prevent friction to affect the consolidation process, the cell's inner walls are lubricated with vaseline (Cotecchia 1996, Abdulhadi, Germaine and Whittle 2011). However, given the very low permeability of *Prazeres* clay, it was decided to perform the radial drainage by placing filter paper strips, so vaseline was not placed in order not to compromise the operation of the drains. Loading started about 24 hours later, and loads were progressively applied to ensure the assemblage stability, increasing until the desired value of 80 kPa, that corresponds to the approximate effective vertical stress at rest of the block from which intact samples were trimmed. Table 1 shows the loading sequence.

After consolidation, the cell was removed from the consolidometer and the block was extracted from the mould using a hydraulic jack, as shown in Fig. 3. The block was then divided into four equal parts, and stored in a wet room, properly protected by clingfilm and liquid paraffin in order to preserve its water content.

**Table 1.** Loading scheme used in the consolidometer

| Load | Weight (kg) | Sample stress (kPa) | Duration |
|---|---|---|---|
| PT | 8.794 | 2.08 | 14 days |
| 1+PT | 9.794 | 9.87 | 14 days |
| 2+PT | 10.794 | 17.66 | 10 days |
| 4+PT | 12.794 | 33.24 | 10 days |
| 6+PT | 14.794 | 48.83 | 12 days |
| 8+PT | 16.794 | 64.41 | 10 days |
| 10+PT | 18.794 | 79.99 | 10 days |

**Figure 3.** Mould removal and block extraction.

## 2.3. Sampling

In order to perform oedometer and triaxial tests on reconstituted samples, it was necessary to extract good quality samples from the slurry block. Oedometer samples were extracted from the block by slowly crimping the ring into a piece of soil initially separated from the main block. Since the metal ring from oedometer test is relatively small in height, this was an easy sampling process. Triaxial specimens were more challenging, as low plasticity did not allow sample's extraction from the metal tube without dragging a lot of material. Samples were therefore prepared on a lathe, slowly cut to the desired diameter, as illustrated in Fig. 4. Top and bottom were protected with a filter paper to avoid the soil to stick to the supports, and the sample was cut with a wire to ensure the desired dimensions.

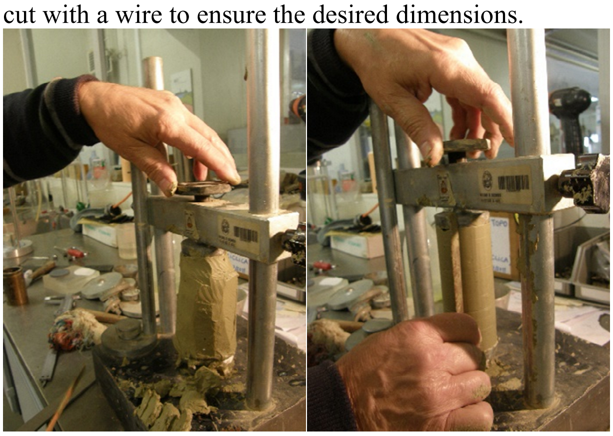

**Figure 4.** Trimming samples for triaxial tests.

# 3. Results

## 3.1. Grain size distribution

Before using the reconstituted sample for triaxial and oedometer tests, one grain size distribution curve was determined to check if the reconstituted sample was representative of the original soil, in terms of composition. The grain size distribution curve for the reconstituted samples is presented (in red) in Fig. 5, and shows a very good agreement with the grain size distribution range (dashed lines) obtained for intact samples of the same material (Lopes Laranjo 2013).

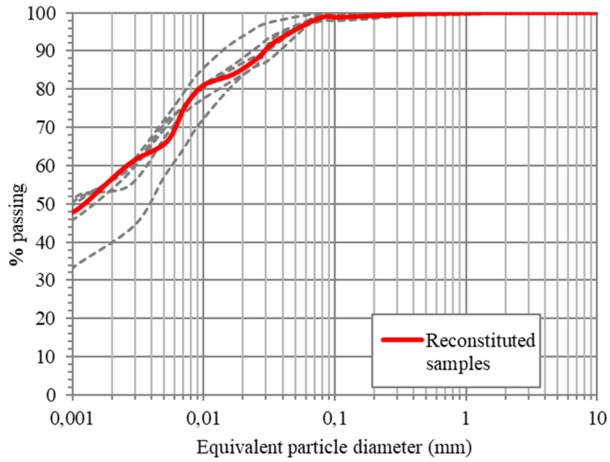


**Figure 5.** Grain size distribution curve for one of the reconstituted samples.

## 3.2. Triaxial tests

Two isotropic consolidation triaxial tests were performed on reconstituted samples, using consolidation pressures of 200 kPa (R1) and 120 kPa (R2). Stress paths obtained for both samples were quite similar in shape, and stress–strain curves evolved as expected for normally consolidated samples, as shown in Fig. 6. Excess pore pressures are shown in Fig. 7, and were typical for normally consolidated soils.

The lack of definition observed for sample R1 was due to the use of an external load cell, that lacked accuracy in recording load variations for low consistency samples. When testing sample R2, an internal load cell was used.

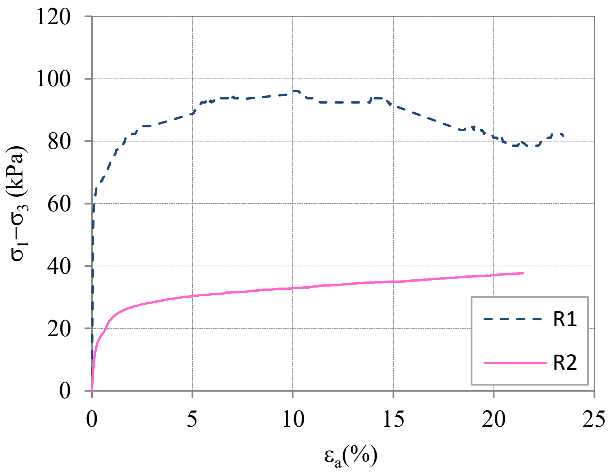


**Figure 6.** Stress-strain curves for CIU tests on reconstituted samples.

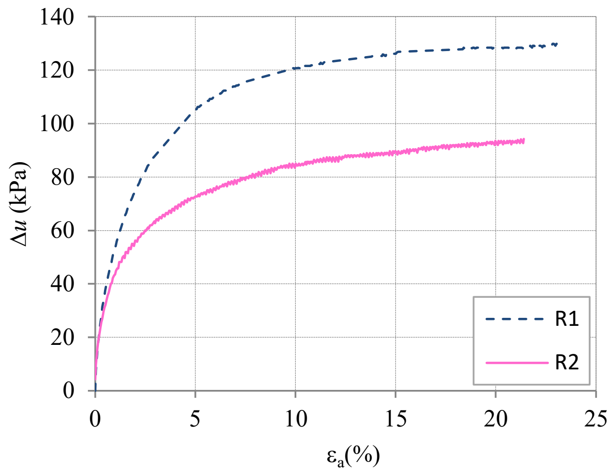


**Figure 7.** Excess pore pressures vs axial strain for CIU tests on reconstituted samples.

Stress paths in *q-p'* space are shown in Fig. 8, together with the Critical State Line (CSL).

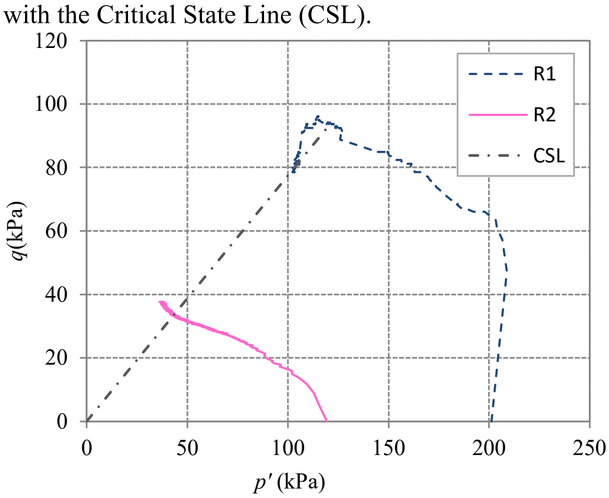


**Figure 8.** Stress paths on reconstituted samples in *q-p'* space for reconstituted samples.

Average normal stress, *p'* decreases during shear, as expected for a normally consolidated soil. These curves were compared with results for high pressure CIU triaxial tests on intact samples, tested in normally consolidated conditions. The slope *M* for reconstituted samples at failure was 0.77, which, according to Eq. (1) (Leroueil 1997), corresponds to a friction angle of 20.1º. This value is very close to the one found at critical state on intact samples, that was 21º (Lopes Laranjo and Matos Fernandes 2022, Lopes Laranjo 2013).

$$M = \frac{6 \cdot \sin(\phi')}{3 - \sin(\phi')} \quad (1)$$

### 3.3. Oedometer tests

Two classic oedometer tests were performed on reconstituted samples of *Prazeres* clay. One of the tests was performed without any intermediate unloading, contrary to the other. Physical properties of the tested reconstituted samples are given in Table 2.

Fig. 9 presents oedometer test results on these samples and clearly shows behavioural differences for stresses above 80 kPa, which was the preconsolidation pressure. Table 3 summarizes the intrinsic parameters for *Prazeres* clays derived from these results.

**Table 2.** Physical properties of the reconstituted samples tested on the classic oedometer.

| Sample | Initial conditions | | Final conditions | |
|---|---|---|---|---|
| | $e_0$ | $w_0$ (%) | $e_{fin}$ | $w_{fin}$ (%) |
| RS1 | 1.23 | 43.91 | 0.86 | 32.47 |
| RS2 | 13.38 | 48.10 | 0.84 | 33.87 |

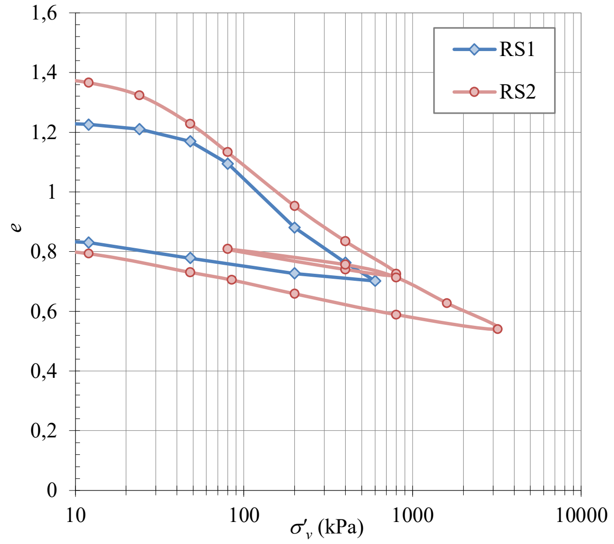


**Figure 9.** Oedometer test results over reconstituted samples.

Intrinsic properties, defined as those that are inherent to the soil, hence independent of its natural state, are usually represented using an asterisk, and normalized compression behaviour can be obtained using the void index ($I_v$) defined by Eq. (2), where $e^*_{100}$ and $e^*_{1000}$.are the void ratios for vertical effective stresses equal to 100 kPa and 1000 kPa, respectively, and $C^*_c$ is the intrinsic compression index (Burland 1990).

$$I_v = \frac{e - e^*_{100}}{e^*_{100} - e^*_{1000}} = \frac{e - e^*_{100}}{C^*_c} \quad (2)$$

In this normalized space, reconstituted material compression curves will fall into a unique curve called the Isotropic Compression Line (ICL), that can be defined as a function of the effective vertical stress or from empirical equations that relate $e^*_{100}$ and $C^*_c$ with the void index for the liquid limit ($e_L$). Compression curves for reconstituted *Prazeres* clay samples in the normalized space $I_v$-*log* $\sigma'_v$, are presented in Fig. 10, together with results from high pressure oedometer tests performed on intact samples (OED1, OED2, OED3), collected from a block that was trimmed *in situ* at an experimental field at 4 m depth (Lopes Laranjo 2013). The Isotropic Compression Line (ICL), defined by Eq. (3), and the Sedimentation Compression Line (SCL) are also drawn (Burland 1990). SCL is a linear regression defined from several sedimentation curves for natural normally consolidated clay deposits (Skempton 1970).

$$I_v = 2.45 - 1.2385 log\,(\sigma'_v) + 0.015 log\,(\sigma'_v)^3 \quad (3)$$

**Table 3.** Compressibility parameters for reconstituted samples tested on the classic oedometer (intrinsic properties).

| Sam. | $e_0$ | $C^*_c$ | $e^*_{100}$ | $\frac{C^*_c}{1+e_0}$ | $C^*_s$ | $C^*_r$ |
|---|---|---|---|---|---|---|
| R1 | 1.23 | 0.34 | 1.03 | 0.16 | - | 0.05 |
| R2 | 1.38 | 0.38 | 1.05 | 0.16 | 0.08 | 0.14 |

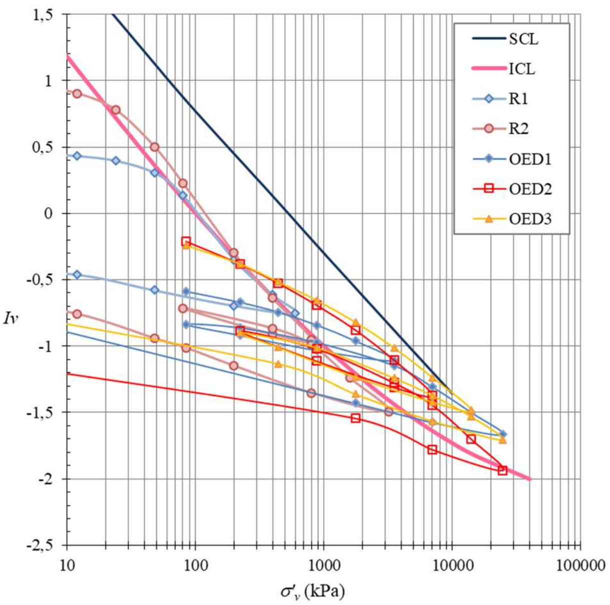


**Figure 10.** Compression curves in $I_v$-*log* $\sigma'_v$ space for intact and reconstituted *Prazeres* clay samples.

Fig. 10 shows good agreement between the curves from the reconstituted samples and the ICL. Several authors have mentioned that the water content for which the reconstituted samples are obtained can change the position of the compression curve in the $I_v$-*log* $\sigma'_v$ space (Yin and Miao 2013, Zeng, Hong and Cui 2015, Cotecchia and Chandler 2000, Chandler 2010). It has been emphasized that water content should be equal to 1.5 times the liquid limit, as has been obtained in these samples. It is also possible to observe that compression curves for samples OED1, OED2 and OED3 tend to the SCL as effective vertical stress increases. This was expected, given the SCL is the geometrical space for normally consolidated samples.

## 4. Discussion

Although triaxial tests in reconstituted samples were limited, the comparison between CIU tests on reconstituted and intact samples, shows that intrinsic properties obtained from reconstituted samples are in close agreement to critical state properties obtained for intact samples tested in normally consolidated conditions. Reconstituted samples are usually stable, meaning that they don't weaken with deformation, and its study in the light of critical states theories allows to establish connections between micro and macro scale behaviour.

Oedometer tests on reconstituted samples allow to determine stress sensitivity ($S_\sigma$), which corresponds to the measure of natural strength in relation to the reconstituted material. Considering that the SCL was obtained from the normalization of several sedimentation compression curves, and the latter reflect the sedimentation structure during virgin compression (Cotecchia 1996), compressibility index will only depend on the liquid limit, if we exclude soil structure and sample disturbance (Skempton 1944, Gasparre 2005). Sensitivity can be determined by Eq. (4), where $\sigma'_y$ is the yielding stress, corresponding to failure by compression of the natural structure, and $\sigma'^{*}_e$ is the equivalent stress at the ICL, for the same void index.

$$S_\sigma = \frac{\sigma'_y}{\sigma'^{*}_e} \tag{4}$$

For *Prazeres* clay, stress sensitivity varied between 2.45 and 3.1, which is in good agreement with results for other overconsolidated clays (Cotecchia, Mitaritonna and Vitone 2011, Amorosi and Rampello 2007, Burland et al. 1996).

Yield stress obtained in the normalized space for intact samples was higher than preconsolidation stress determined from oedometer test using different approaches, meaning that the structure of this material might have suffered changes from post depositional processes. In fact, SEM observations have shown a significant amount of framboidal pyrites, which are related with sulfur diagenesis, which is often connected with bonding (Ballas et al. 2018, Gasparre 2005, Lopes Laranjo 2013).

## 5. Conclusions

Natural clays mechanical behaviour is strongly dependent on its composition and mineralogy and governed by its structure. Reconstituted samples are deprived of structure and bonding, hence allow to study the intrinsic properties of natural soils.

The water content for which reconstituted samples are consolidated is of major importance, given that once structure effects are excluded, compression behaviour is highly dependent on liquid limit. This study has shown that for a water content equal to 1.5 times the liquid limit, sedimentation compression curves for *Prazeres* clay fall in the ICL.

Sedimentation curves for intact samples tend to the SCL, as effective vertical stress increases and overcomes preconsolidation stress. This can only be represented by using high pressure oedometers that allow to apply loads on the virgin branch of the compression curve.

Stress sensitivity values for *Prazeres* clay are in good agreement with those obtained for other overconsolidated clays, indicating that this formation has suffered from post depositional processes.

Triaxial test results on reconstituted samples were quite limited, but strength parameters were close to the ones found for high pressure triaxial compression tests, in a critical state analysis. More triaxial tests should be performed on reconstituted samples in order to establish with greater confidence a critical state framework for *Prazeres clays*.


## Acknowledgements

The project presented in this paper is supported by proMetheus – Research Unit on Materials, Energy and Environment for Sustainability, FCT Ref. UID/05975/2020, financed by national funds through the FCT/MCTES. This work was also supported by UID/ECI/04708/2019—CONSTRUCT—Instituto de I&D em Estruturas e Construções, funded by national funds through FCT/MCTES.

The authors wish to thank the Geotechnical Laboratory at the University of Coimbra and the colleagues from the geotechnical department for all the help provided.

## References


Abdulhadi, N.O., John T. Germaine, and A.J. Whittle. "Experimental study of wellbore instability in clays", J Geotech Geoenviron, 137 (8), pp. 766-776, 2011.

Almeida, I.M. "Características geotécnicas dos solos de Lisboa." PhD, Universidade de Lisboa, 1991.

Amorosi, A., and S. Rampello. "An experimental investigation into the mechanical behaviour of a structured stiff clay", Geotechnique, 57 (2), pp. 153-166, 2007. https://doi.org/10.1680/geot.2007.57.2.153.

Antunes, M.T., J.P. Calvo, M. Hoyos, J. Morales, S. Ordonez, J. Pais, and C. Sese. "Ensayo de correlacion entre el Neogeno de las areas de Madrid y Lisboa (Cuencas Alta y Baja del rio Tajo).", Ensayo de correlacion entre el Neogeno de las areas de Madrid y Lisboa (Cuencas Alta y Baja del rio Tajo). 73 (1/2), pp. 85-102, 1987.

Antunes, M.T., H. Elderfield, P. Legoinha, A. Nascimento, and J. Pais. "Sequências deposicionais, biostratigrafia e idades isotópicas do Miocénico da bacia do Baixo Tejo (Lisboa, Península de Setúbal, Portugal) ", In: V Congresso Nacional de Geologia, 1998a, pp. A130-133.

Antunes, M.T., and J. Pais. "The Neogene of Portugal", The Neogene of Portugal, 12, pp. 7-22, 1993.

Antunes, M.T., J. Pais, J.L. Cardoso, A. Nascimento, M. Simões, P. Legoinha, and A. Balbino. "Principais acontecimentos na parte terminal da bacia do Baixo Tejo." [online] Available at: http://www.dct.fct.unl.pt/CEGUNLP/Geoverao/Events.html, accessed 09/01/2009.

Ballas, G., S. Garziglia, N. Sultan, E. Pelleter, S. Toucanne, T. Marsset, V. Riboulot, and S. Ker. "Influence of early diagenesis on geotechnical properties of clay sediments (Romania, Black Sea)", Influence of early diagenesis on geotechnical properties of clay sediments (Romania, Black Sea), 240, pp. 175-188, 2018. https://doi.org/10.1016/j.enggeo.2018.04.019.

Burland, J.B. "On the Compressibility and Shear Strength of Natural Clays", Geotechnique, 40 (3), pp. 329-378, 1990.

Burland, J.B., S. Rampello, V.N. Georgiannou, and G. Calabresi. "A Laboratory Study of the Strength of Four Stiff Clays", Geotechnique, 46 (3), pp. 491-514, 1996.

Chandler, R.J. "Stiff sedimentary clays: geological origins and engineering properties", Geotechnique, 60 (12), pp. 891-902, 2010.

Cotecchia, F. "The Effects of Structure on the Properties of an Italian Pleistocene Clay." PhD, Imperial College of Science Technology and Medicine, 1996.

Cotecchia, F., and R.J. Chandler. "A general framework for the mechanical behaviour of clays", Geotechnique, 50 (4), pp. 431-447, 2000.

Cotecchia, F., G. Mitaritonna, and C. Vitone. "Investigating the influence os microstructure, loading history and fissuring on the clay response." In: Fifth International Symposium on Deformation Characteristics of Geomaterials, Seoul, 2011, pp. 53-83.

Galopim de Carvalho, A.M. "Aspectos gerais da geomorfologia da Península Ibérica", Geonovas, 1 (7), pp. 133-142, 1984.

Gasparre, A. "Advanced Laboratory Characterization of London Clay." PhD, Imperial Colege of London, 2005.

Gasparre, A., S. Nishimura, N.A. Minh, M. R. Coop, and R.J. Jardine. "The stiffness of natural London Clay", Geotechnique, 57 (1), pp. 33-47, 2007.

Hight, D.W., and S. Leroueil. "Characterisation of soils for engineering purposes." In: Characterisation and Engineering Properties of Natural Soils, Singapore, 2002, pp. 255-360.

Leroueil, S. "Critical state soil mechanics and the behaviour of real soils." In: Recent Developments in Soil and Pavement Mechanics Rio de Janeiro, Brazil, 1997, pp. 41-80.

Locat, J., H. Tanaka, T.S. Tan, G.R. Dasari, and H. Lee. "Natural Soils: Geotechnical behaviour and geological knowledge." In: Characterisation and Engineering Properties of Natural Soils, Singapore, 2002, pp. 3-29.

Lopes Laranjo, M. . "Argilas Miocénicas de Lisboa. Parametrização para o Dimensionamento de Estruturas Geotécnicas." PhD, Porto, 2013.

Lopes Laranjo, M., and M. Matos Fernandes. "Undrained shear strength of Lisbon Miocene clay: a reappraisal based on triaxial and pressuremeter test results", SN Appl. Sci., 4 (1), pp. 1-14, 2022. https://doi.org/10.1007/s42452-021-04832-w.

Lopes Laranjo, M., M. Matos Fernandes, and J. Almeida e Sousa. "Some basic trends on the geotechnical characteristics of Lisbon Miocene Clays." In: Proceedings of the 15th European Conference on Soil Mechanics and Geotechnical Engineering, 2011, pp. 351-356. https://doi.org/ 10.3233/978-1-60750-801-4-351

Rampello, S., G. Calabresi, and L. Callisto. "Characterization and Engineering Properties of a Stiff Clay Deposit." In: Characterisation and Engineering Properties of Natural Soils, Singapore, 2002, pp. 1021-1045.

Skempton, A.W. "Notes on the compressibility of clays", J Geol Soc London, 100 (1-4), pp. 119-135, 1944.

Skempton, A.W. "The consolidation of clays by gravitational compaction", J Geol Soc London, 125 (1-4), pp. 373-411, 1970.

Sorensen, K. K., B. A. Baudet, and B. Simpson. "Influence of structure on the time-dependent behaviour of a stiff sedimentary clay", Geotechnique, 57 (1), pp. 113-124, 2007.

Yin, Jie, and Yonghong Miao. "Intrinsic compression behavior of remolded and reconstituted clays-reappraisal", Open j. civil eng, 3 (3), pp. 8-12, 2013. https://doi.org/10.4236/ojce.2013.33B002.

Zeng, Ling-Ling, Zhen-Shun Hong, and Yu-Jun Cui. "Determining the virgin compression lines of reconstituted clays at different initial water contents", Can. Geotech, 52 (9), pp. 1408-1415, 2015. https://doi.org/10.1139/cgj-2014-0172.