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Effect of saline water on the strength behavior of beach sand from northeastern Brazil coastline

Effet de l'eau saline sur la résistance du sable de plage du littoral nord-est du Brésil

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ABSTRACT: This study addresses the effect of saline water on the strength of Pacheco Beach sand, located on the northeast coast of Brazil. Although several studies in the literature deal with the influence of saline water on the behavior of soils in coastal areas, information regarding the behavior of Brazilian coastal sands is scarce, justifying the need for this current research. The study is particularly important for maritime works, such as foundations for offshore wind towers in new exploration potential areas like the northeast coast of Brazil. For this purpose, two samples were collected and subjected to characterization tests and direct shear tests at normal stresses of 50, 100, and 200 kPa. The specimens were saturated with distilled water and saline water for the loose state. The results demonstrate that the presence of salts in water significantly influences the shear strength of sands, as well as the values of friction angles, indicating alterations in the mechanical properties of these soils. In direct shear tests, saturating a sample in saline water resulted in a 6% increase in friction angles compared to samples saturated in distilled water.

RÉSUMÉ: Cette étude aborde l'effet de l'eau salée sur la résistance du sable de la plage de Pacheco, située sur la côte nord-est du Brésil. Bien que plusieurs études dans la littérature traitent de l'influence de l'eau salée sur le comportement des sols dans les zones côtières, les informations concernant le comportement des sables côtiers brésiliens sont rares, justifiant ainsi la nécessité de cette recherche actuelle. L'étude est particulièrement importante pour les travaux maritimes, tels que les fondations des tours éoliennes en mer dans de nouvelles zones à fort potentiel d'exploration comme la côte nord-est du Brésil. Dans ce but, deux échantillons ont été prélevés et soumis à des tests de caractérisation et des tests de cisaillement direct à des contraintes normales de 50, 100 et 200 kPa. Les spécimens ont été saturés d'eau distillée et d'eau salée pour l'état lâche. Les résultats démontrent que la présence de sels dans l'eau influence significativement la résistance au cisaillement des sables, ainsi que les valeurs des angles de frottement, indiquant des altérations dans les propriétés mécaniques de ces sols. Dans les essais de cisaillement direct, la saturation d'un échantillon dans de l'eau salée a entraîné une augmentation de 6% des angles de frottement par rapport aux échantillons saturés dans de l'eau distillée.

Keywords: Coastal soils; saline water; direct shear tests; salinity influence.

1 INTRODUCTION

Knowledge about the variables that can affect soil strength plays an extremely important role in geotechnical engineering. One of the key properties governing structure stability is the soil's shear strength, influenced by several factors, including soil genesis, particle distribution and shape, degree of preconsolidation, saturation level, as well as the nature of the fluid present in the subsurface.

It's worth noting that the water saturation level of soils is subject to constant changes due to seasonal activities, climate variations, and numerous human interventions that can alter the physical, chemical, and mechanical properties of the soil. Studies indicate that the solution's pH strongly influences the geotechnical characteristics of the soil (Osuolale et al., 2012; Sunil, et al., 2006). Rahman and Nahar (2015) demonstrated that the shear strength of sandy soil increases with an increase in the soil's pH value. Moreover, the type and concentration of the solution affect the soil's shear properties (Naeini and Jahanfar, 2011).

As noted by several studies, the presence of saline solution in the soil increases shear strength (Ajalloeian et al., 2013; Elsawy and Lakhouit, 2020; Geng et al., 2022) and frictional resistance (Geng et al., 2022; Taha and Fall, 2014). However, other studies indicate that this shear strength increases to a certain point and then decreases afterward, as highlighted by Naeini and Jahanfar (2011) and Wilson and Vasudevan (2021).

Regarding the effect of seawater on the consistency limits of clayey soils, there are discrepancies in the literature: Mahasneh (2004) observed an increase in liquid and plastic limits with the use of saline water. However, according to Nguyen et al. (2019), the liquid and plastic limits decrease when the soil is submerged in seawater. Arasan and Yetimoglu (2008) state that high saline concentrations can either reduce or increase the plastic limit depending on the clay classification.

Concerning water salinity, numerous studies analyze the influence of saline solution on soil (Emami Azadi, 2008; Mahasneh, 2004; Tiwari et al., 2005; Yukselen-Aksoy et al., 2008). However, in Brazil, particularly in coastal regions, there is a scarcity of studies addressing this issue, highlighting the need for additional research to fill this knowledge gap.

Therefore, it's observed that the presence of salinity significantly influences the resistance properties and behavior of soils. This factor should be further analyzed, especially concerning coastal, maritime, and offshore structures, which are directly subjected to saline water. Even in these cases, such as in maritime construction projects during the foundation design phase, shear tests are commonly conducted only with distilled water, which may not accurately represent the soil's actual behavior. In this regard, this study investigates the resistance of coastal sand under the influence of saline water compared to distilled water through direct shear tests.

2 MATERIALS AND METHODS

The studied sands were collected from the northeastern coast of Brazil, specifically at Pacheco Beach, in the municipality of Caucaia, Ceará. The tests were conducted on disturbed samples, and for the direct shear tests, the specimens were reconstituted. Initially, characterization tests were performed, determining the maximum and minimum void ratios, X-ray fluorescence, and determining the pH of the saline water (collected from the sea at the same location as the soil collection). It is important to note that distilled water is free from salts and any impurities, with a neutral pH (close to 7), while seawater is naturally saline and composed of various salts.

To study the influence of water salinity, 12 direct shear tests were conducted on two samples of Pacheco soil, PCH1 and PCH2, in their loose state, that is, with void proportions close to the maximum value. Six tests used distilled water, and six used saline water, under normal tensions of 50, 100, and 200 kPa. Additionally, three direct shear tests were performed on PCH2 samples saturated with saline water in the compacted state. In this procedure, the soil sample was previously saturated in either saline (S) or distilled (D) water before being subjected to shear stress under a determined rupture plane, with controlled normal tension. The rupture speed was adjusted to 0.2 mm/min to ensure effective drainage during the shear test.

3 RESULTS AND DISCUSSIONS

3.1 Soil properties

Samples PCH1 and PCH2 are classified as well-graded sand (SW) and well-graded sand with silt (SW-SM), respectively, according to the Unified Soil Classification System (USCS). The particle size distribution curve are presented in Figure 1. The elemental composition of the samples obtained from the X-ray fluorescence test can be verified in Table 1, and the geotechnical characterization is presented in Table 2. The pH of the collected seawater showed a more alkaline content with a value of 7.48.

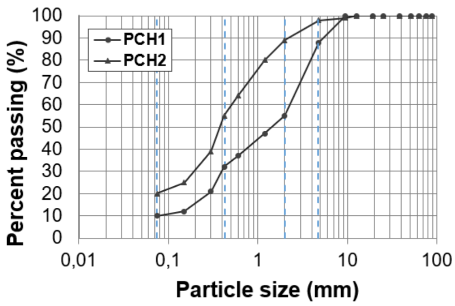


Figure 1. Grain size distribution curves of Pacheco sand (PCH1, PCH2).

3.2 Direct shear test

3.2.1 Saline water effect

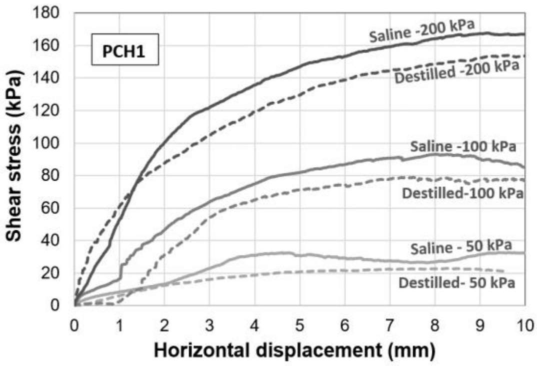
In Figures 2(a) and 2(b), the stress-strain curves of shear stress versus horizontal displacement of samples (PCH1 and PCH2, respectively) saturated with saline water and distilled water are compared. It can be observed that sample saturation with saline water resulted in higher shear stresses for both samples and studied stress levels, supporting the results presented by Tiwari et al. (2005).

Table 1. Mineralogical composition of Pacheco Sands (samples PCH1 and PCH2).

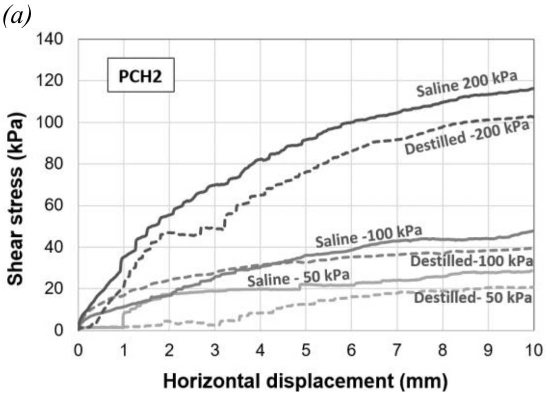
Composition (%)	PCH1	PCH2
Al_2O_3 - Aluminum Oxide	14.89	15.51
SiO_2 – Total Silica	52.55	52.32
dFe_2O_3 – Oxide of iron	2.99	3.78
K_2O - Potash	2.96	3.07
Rb_2O - Rubidium Oxide	1.64	-
SrO - Strontium Oxide	1.12	-
Ta_2O_5 - Tantalum Pentoxide	-	0.96
CaO - Lime	0.89	0.85
TiO_2 – Oxide of Titanium	0.78	0.85
Cl - Chlorine	0.54	0.36
P_2O_5 - Phosphorus Pentoxide	0.4	0.42
ZrO_2 - Zirconium Dioxide	0.17	0.15
MoO_3 - Molybdenum Trioxide	0.21	-

Table 2. Geotechnical properties (PCH1 and PCH2).

		PCH1	PCH2
Grain density (G_s)	g/cm³	2.61	2.64
Maximun void ratio ($e_{máx}$)	-	0.78	0.81
Minimun void ratio ($e_{mín}$)	-	0.53	0.52
Specific weigth ($\rho_{mín}$)	g/cm³	1.51	1.51
Specific weigth ($\rho_{máx}$)	g/cm³	1.69	1.8



(a)



(b)

Figure 2. Variation of the shear strength versus horizontal displacement, of samples saturated with saline water and distilled water in the loose state (a) PCH1 (b) PCH2.

In the analysis of the rupture envelopes presented in Figure 3, it is observed that there was no significant variation in the friction angle for the PCH1 sample with the use of saline water. However, for the PCH2 sample saturated with saline water, there was an increase of 6% in the friction angle compared to saturation in distilled water, with values of 31° and 29°, respectively. These results indicate a possible influence of salinity on the shear strength of the soil, which is especially relevant in coastal and maritime works. Furthermore, it is important to highlight that this analysis refers to low normal voltages. It is also observed an increase in the difference in shear stresses between samples saturated with saline water and distilled water as the normal stress increases. Therefore, it is necessary to carry out studies at higher normal stresses to confirm this trend and to evaluate its impact on more sensitive geotechnical applications.

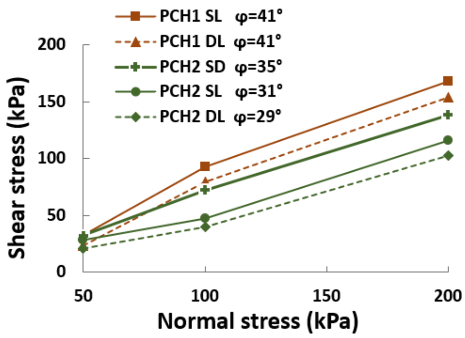


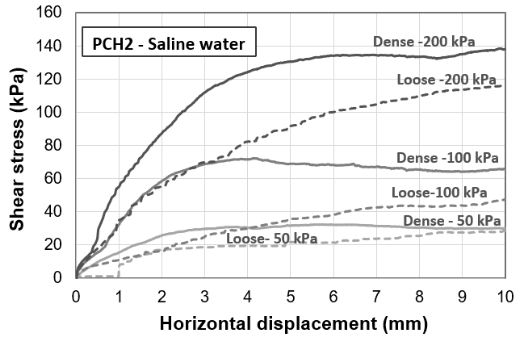
Figure 3. Rupture envelope of samples PCH1 and PCH2 saturated in saline water (S) and distilled water (D) in the loose (L) and dense (D) states.

3.2.2 Saline water effect on relative compaction

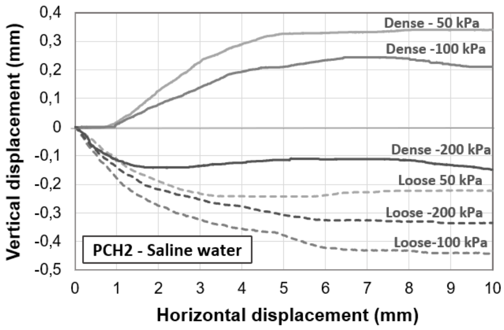
In Figures 4(a) and 4(b), the results of the direct shear test for sample PCH2 saturated in saline water, in loose and compact states, can be observed. It can be seen that for the normal stress of 200 kPa, both the dense and loose states behaved similarly, showing a reduction in vertical displacement. As expected, the most compacted soil exhibited a 13% increase in friction angle compared to the loose soil (Figure 3), with 35° for the dense state and 31° for the loose state.

4 CONCLUSIONS

This study addressed the impact of water salinity on the shear strength properties of the soil, based on direct shear tests. The results revealed an increase in the friction angle of samples saturated in saline water compared to distilled water. Specifically, one of the samples showed a 6% increase in the friction angle when saturated in saline water.



(a)



(b)

Figure 4. Sample PCH2 saturated in saline water in loose and dense states (a) Variation of shear strength versus horizontal displacement, (b) Variation of vertical displacement versus horizontal displacement.

Furthermore, the results point to a greater influence of water salinity at higher normal stresses, which is evidenced by the observed increase in the difference between the shear stresses of samples saturated in saline water and distilled water as the normal stress increases. It is of fundamental importance, however, to conduct more studies under higher normal stress conditions to confirm this trend, especially for coastal and marine geotechnical works.

Thus, it is necessary to carefully consider water salinity in soil behavior, especially when designing geotechnical structures exposed to salt water, aiming to guarantee the safety and durability of these structures in marine environments.

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