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Compaction characteristics of calcareous sands for distilled water, saline, and isopropyl alcohol pore fluids.

Caractéristiques de compactage des sables calcaires pour les eaux interstitielles, les solutions salines et les fluides de l'alcool isopropylique

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ABSTRACT: Calcareous soils have become more frequently used in densely populated coastal areas to expand land mass for development. The engineering properties are often derived from laboratory testing using purified water, such as when determining optimal compaction characteristics and relative densities. However, laboratory samples with purified water in pore space may not accurately represent field conditions. While recent research has indicated that calcareous soil behavioral characteristics can be opposite of silica soils, geotechnical practice assumes the dredged calcareous sands will exhibit similar compaction characteristics as quartz-silica based soils. Therefore, the purpose of this study is to investigate the impact of the pore fluid on the compaction characteristics of a typical dredged calcareous sand. The pore fluids investigated are purified water, distilled water, de-aired water, saline solution, and 91% isopropyl alcohol solution. Results show compaction characteristics for calcareous sands are highly dependent on the pore fluid chemistry and that achieving an optimal field compaction might not be possible depending on the pore fluid used.

RÉSUMÉ: Les sols calcaires sont de plus en plus utilisés dans les zones côtières densément peuplées pour étendre la masse continentale au développement. Les propriétés techniques sont souvent dérivées d'essais en laboratoire utilisant de l'eau purifiée, par exemple lors de la détermination des caractéristiques de compactage optimales et des densités relatives. Cependant, les échantillons de laboratoire contenant de l'eau purifiée dans les pores peuvent ne pas représenter avec précision les conditions de terrain. Des recherches récentes ont montré que les caractéristiques de comportement des sols calcaires peuvent être opposées à celles des sols siliceux, mais la géotechnique suppose que les sables calcaires dégraissés présenteront des caractéristiques de compactage similaires à celles des sols à base de quartz-silice. Par conséquent, le but de cette étude est d'étudier l'impact du fluide interstitiel sur les caractéristiques de compactage d'un sable calcaire typique dragué. Les liquides interstitiels étudiés sont: l'eau purifiée, l'eau distillée, l'eau désaérée, une solution saline et une solution à 91% d'alcool isopropylique. Les résultats montrent que les caractéristiques de compactage pour les sables calcaires dépendent fortement de la chimie du fluide interstitiel et que l'obtention d'un compactage optimal au champ pourrait ne pas être possible en fonction du fluide interstitiel utilisé.

Keywords: laboratory testing, compaction, calcareous soils

1 INTRODUCTION

Calcareous soils are increasingly used to expand land mass in densely populated coastal areas (King and Lodge 1988; Alba and Audibert 1999; Wang et al. 2011). Soil engineering properties are often derived from laboratory testing using distilled water per ASTM D-4254 (ASTM 2016b) and ASTM D-4253 (ASTM 2016a) for determining optimal compaction characteristics and relative densities (Ohno et al. 1999; Wang et al. 2011). However, materials dredged from the seafloor used in the creation of new land masses, e.g., the World Islands or South China Sea, have a different pore fluid (saline) than that used in laboratory investigations (distilled water), both of which are different than the pore fluid that remains in washed calcareous material used for land expansion construction activities such as Incheon Airport in Korea.

This study investigates the impact of pore fluid on the compaction characteristics of a typical dredged calcareous sand. Three different pore fluids were selected, i.e., 1) a purified distilled water is used in accordance with the ASTM D-4253 as a measure for typical laboratory index properties, e.g., maximum and minimum void ratios defining the relative densities, 2) a saline solution used for professional saltwater reef aquariums represents the typical ocean water of hydraulically dredged material, and 3) an isopropyl alcohol, the third pore fluid, was to investigate the particle chain development as defined by Santamarina (2001) and observed by Cho and Santamarina (2001). Unlike distilled water, the isopropyl alcohol does not exhibit any surface tension characteristics, suction, or cementation that is associated with distilled water and saline fluids. Therefore, only the particle rotation, granular shape, and compactive effort contribute to the particle chain development and the sample density. Note that isopropyl alcohol is not used in practice, but by reducing/eliminating external factors impacting granular interlocking, the isopropyl alcohol specimens provide a baseline measure of the compaction characteristics of the calcareous-grained soils.

2 LABORATORY TESTING

2.1 Specimen Material

The calcareous sand used in this study is classified as a poorly graded sand (SP) according to ASTM Standard Test Method D2847 (ASTM 2011). It is ocean-harvested CaribSea^{TM} aragonite sand, readily procurable in 40-lb bags at a local pet store. This aragonite sand contains 1050 ppm Mg, 381000 ppm of Ca, and 7390 ppm of Sr and has a pH of 8.2. The calcareous sand is very uniform, with more than 90 percent of the material retained on the 0.85-mm sieve. The grain size distribution (Figure 1) is bound by D_{90} of 2.0 mm and D_{10} of 0.85 mm with a D_{50} of 1.2 mm. The uniformity coefficient is 1.61, and coefficient of curvature is 0.99. The specific gravity is 2.76.

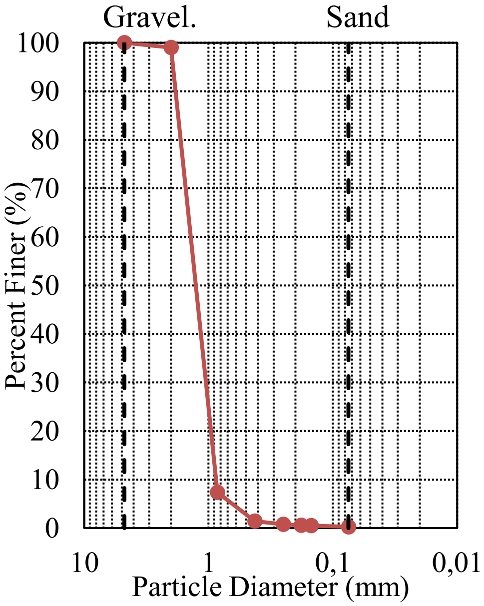

Figure 1. Grain size distribution of the calcareous sand.

2.2 Pore Fluid

Three pore fluids were used in this study, i.e., purified water, saline solution, and isopropyl alcohol solution. The purified water (specific gravity of 1.00 g/cm^3) was distilled and deaired prior to use. The saline solution (specific gravity of 1.025 g/cm^3) contained 35 parts per thousand of dissolved salts, pH of 8.3, 420 ppm of dissolved calcium, and 1300 ppm of dissolved magnesium. The alcohol solution (specific gravity of 0.785 g/cm^3) consisted of 91 percent isopropyl alcohol and 9 percent water. The saline solution and isopropyl alcohol were added to dry soil at the same weights as the water. After compaction testing, moisture content samples for the distilled water and saline solution specimens were taken at the top, middle, and bottom of the compacted specimen. Due to concerns with evaporation, moisture contents for isopropyl alcohol specimens are reported based on the weight of isopropyl alcohol solution added to the dry soil before compaction.

2.3 Material Compaction

Preliminary compaction testing at modified Proctor compaction energy (2707 kJ/m^3) resulted in significant particle breakage due to the fragile nature of the soil, in keeping with Ohno et al. (1999). Particle breakage was not observed at lower compaction energies based on comparisons of post-compaction grain size distributions and those of the pre-compacted material. Therefore, compaction testing for this study was conducted at energies of 200, 600, and 1000 kJ/m^3 wherein no particle breakage was observed, in accordance with Taylor et al. (2017). Eliminating potential particle breakage is required for direct comparison with laboratory maximum and minimum void ratio calculations and typical compaction curves for quartz-silica sands. Specimens were compacted in five layers in a 10.2-cm-diameter compaction mold. The mold, hammer weight, and soil can be seen in Figure 2.

Moisture contents (w) reported herein are gravimetric water contents measured to an accuracy of ±0.01% in accordance with ASTM Standard Test Methods D2216 (ASTM 2010) and D4542 (ASTM 2015).

Figure 2. Compaction mold with hammer and calcareous soil.

3 COMPACTION OBSERVATIONS

During compaction, significant fluid migration was observed within the specimens above moisture contents of about 10 percent. For example, the moisture content samples for the 10.1% distilled water, 1000 kJ/m^3 specimen varied from 9.69% at the top of the compacted specimen to 10.94% at the bottom of the specimen. For the 11.25% distilled water, 1000 kJ/m^3 specimen, the sand was originally mixed with 12% water by weight. After compaction, the top moisture content was 9.56%, and the bottom moisture content was 13.65%. Similar fluid migration was measured in all of the other distilled water and saline solution specimens reconstituted above 10% moisture content. Due to rapid evaporation of isopropyl alcohol, no quantification of fluid migration was made. However, specimens were visually observed to exhibit similar regions of elevated moisture content, in keeping with the other pore fluids tested; thus, it is expected that even with the isopropyl alcohol, significant fluid migration occurs in specimens above 10% moisture content. Because of this migration, compaction testing was not performed for higher moisture contents.

As a general observation, none of the specimens exhibited compaction curves typically associated with terrestrial soils, e.g., quartz-silica based sands (Figures 3-5). The shape of the calcareous compaction curves is an inverse of the typical compaction curve for cohesionless sands and sandy gravels (Foster 1962). Details of each variation of pore fluid is present in subsequent sections.

3.1 *Distilled Water*

Specimens prepared using distilled water exhibited little variation in dry density, less than 0.08 g/cm^3 over the range of tested compactive energies for any given water content. Generally, the lower water contents exhibited a more dense packing; however, there is not a significant variation in dry density to quantify an optimal compaction moisture content below a gravimetric water content of 4%.

3.2 *Saline Pore Fluid*

Specimens prepared using a saline pore fluid did not exhibit an appreciable trend in dry density with moisture content. Additionally, the amount of compactive effort applied had a negligible effect on the resulting dry density. The magnitude of the range of dry densities was similar to that of the distilled water specimens, i.e., between 1.34 and 1.48 g/cm^3.

3.3 *Isopropyl Alcohol Pore Fluid*

Specimens prepared with a 91% isopropyl alcohol solution exhibited a compactive trend with increasing compactive effort at each moisture content. Moisture contents less than 4% exhibited the highest dry densities. Overall, the range of the dry densities were in excess of the corresponding dry densities for either the distilled water or saline pore fluids. The magnitude of the range of dry densities was between 1.34 and 1.52 g/cm^3.

4 IMPLICATIONS

Geotechnical engineers use relative density when considering shear strength, foundation bearing capacity, deformational properties of soil, and dynamic behavior of soil. However, the pore fluid can significantly impact the particle packing and density of the calcareous material. Estimations of strength or behavior made through the reference to a relative density must also consider the pore fluid. Table 1 shows the impact of the pore fluid on the resulting void ratio and relative density of the calcareous material at a gravimetric water content of 4%. As illustrated, the void ratio of the saline pore fluid remains loose irrespective of the compaction effort. The distilled water shows a slight increasing compaction trend with increasing compaction effort. The isopropyl alcohol pore fluid achieves a denser compaction, even at low compaction effort, well in excess of the standard laboratory calculation of the minimum void ratio.

While no strength tests are presented in this paper, it is evident that these results illustrate that the pore fluid plays a significant role when attempting to field-compact reclaimed land to a design dry density. For example, the design optimal density determined from previous studies or laboratory investigations involving distilled water will not be achieved for oceanic dredged material.

Table 1. Implication of pore fluid variability on the calculated relative density of the calcareous material at a water content of 4%.

Compactive Effort	Distilled Water			Saline Solution			Isopropyl Alcohol		
kJ/m^3	γd [g/cm^3]	e	Dr	γd [g/cm^3]	e	Dr	γd [g/cm^3]	e	Dr
1000	1.472	0.875	82.9%	1.423	0.988	65.2%	1.502	0.444	150.3%
600	1.470	0.878	82.5%	1.450	0.951	71.0%	1.485	0.461	147.8%
200	1.423	0.940	72.8%	1.423	0.988	65.2%	1.417	0.531	136.8%

Note: e_{min} and e_{max} are 0.766 and 1.405 respectively from Wang et al. (2011)

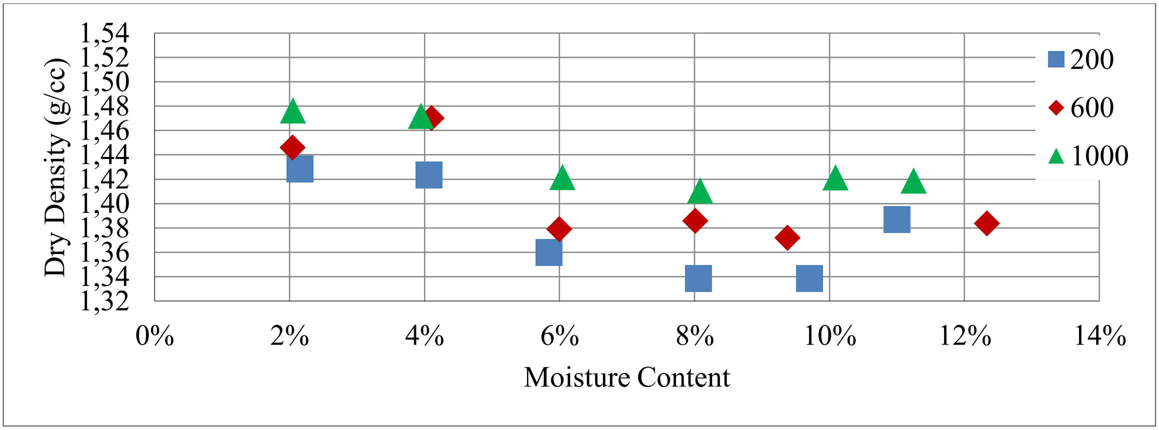

Figure 3. Compaction results with distilled water.

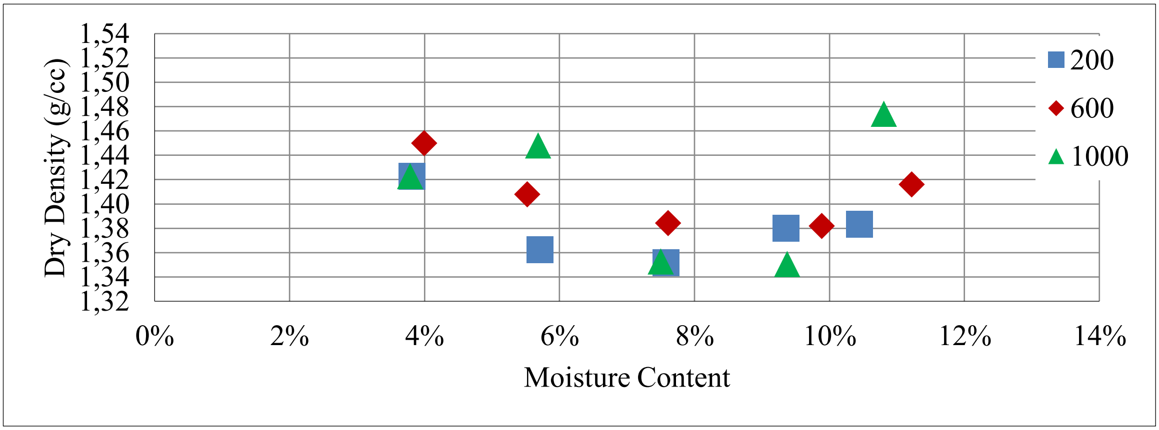

Figure 4. Compaction results with saline solution.

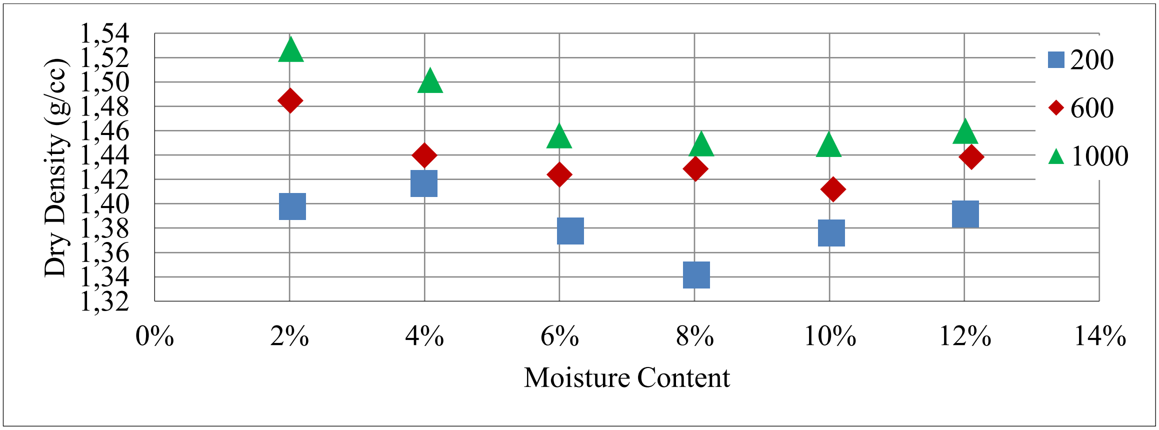

Figure 5. Compaction results with 91% isopropyl alcohol.

5 CONCLUSIONS

A study was performed to investigate the impact that various pore fluids have on the compaction characteristics of a calcareous sand. The results indicate that for the same compactive effort, the calcareous material may exhibit slight compaction (distilled water pore fluid), no compaction (saline pore fluid), or significant compaction (isopropyl alcohol). These results support the need for further research in field compaction efforts and use of relative density in strength and bearing capacity calculations for calcareous materials because the pore fluid chemical make-up may impact the relative density results.

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