Strength and Permeability of Biostabilized Sand

E. Yee, J. H. Lee, Y. S. Kim, S. R. Chung, H. Y. Kim, and B. S. Chun

Abstract

Shallow backshore sands in the coastal zone are continually left in a relatively loose state due to coastal processes and human behavior. Because of this, backshore construction usually involves some form of soil improvement or alternative foundation design. To address these issues, an investigation into the application of an eco-friendly organic acid for soil improvement is conducted. Test results show the organic acid focuses on the proliferation of local microbes to cement and restructure the sand matrix, thus making the application a more sustainable option. Unconfined compression, California bearing ratio, and permeability tests were performed to assess the degree to which the sample sand was improved. After 96 days, results showed compressive strength to increase by at least 60 % and a decrease in permeability of at least 49 %. California bearing ratios increased modestly. The results are promising and shed some light into the application of an organic acid for soil improvement.

Keywords

Backshore • Sand • Soil improvement • Foundations • Microbes

1 Introduction

The coastal areas of many countries are typically densely populated with permanent and recreational residents. Living or visiting coastal areas continues to grow and developments to service and manage so many visitors face many challenges (Crossett et al. 2004). One such challenge is the development of onshore infrastructure, more specifically the construction of structures or pipelines in sandy backshore regions.

Sandy coastal systems in well developed areas typically house loose sands at shallow depths. This is primarily due to Aeolian processes and human recreational behavior. These loose sands show good permeability but are prone to erosion and are not ideal for certain structural foundations. As an example, the first author was on a project where helical piles were used for the beach foundation as other foundation types were not suitable. Typically, such soils are stabilized to improve their engineering properties for construction.

This investigation explores the use of an alternative biological soil stabilization technique. This technique uses an organic acid to stimulate general microbe growth and encourage biological cementation. The effects of the organically induced cementation are identified through unconfined compression, California bearing ratio, and permeability tests.

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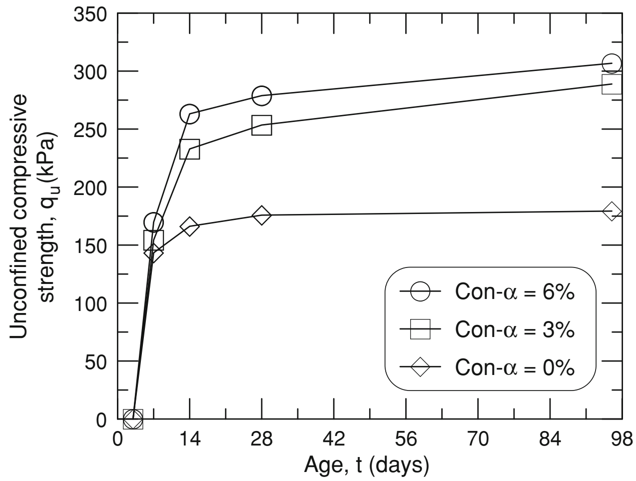

Fig. 1 Unconfined compressive strength of sand samples mixed with Con-α

2 Soil Stabilization

Two methods are commonly used for soil stabilization: mechanical or chemical. Mechanical soil stabilization techniques generally involve some sort of compaction or reinforcement. There are a variety of approaches to soil compaction, some of which include compaction rollers, vibroflotation, dynamic compaction, blasting and compaction grouting (e.g. Narsilio et al. 2009; Rollins and Kim 2010; El-Kelesh et al. 2012).

On the other hand, chemical stabilization techniques typically involve adding or mixing chemicals or additives, such as cementitious materials, into the soil. Some of these cementitious materials include cement, lime, fly ash, coal ash, silica fume, and even rice husks, with a wealth of research on their use and performance (e.g. Akbulut and Saglamer 2003; Lin et al. 2007). Although chemical stabilization techniques are great for increasing soil strength, there is some concern over the toxicity and sustainability of the more commonly used cementitious materials (Mohanty and Chugh 2006; Dombrowski et al. 2010).

In addressing these concerns, a recent alternative method in soil stabilization is the use of microorganisms to biologically treat soils. DeJong et al. (2006) and Dove et al. (2011) showed microbially induced calcite precipitation (MICP) to produce substantial increases in strength, while Van Paassen et al. (2010) applied a similar MICP approach to develop a bio-grout.

3 Organic Acid

An organic acid material produced by Osaki Corporation was considered for this study. This material, Con-α, is a mixture of different types of organic acids and plant extracts in powder form.

According to Osaki Corporation (2011), when Con-α is mixed with water and soil, inherent microbes such as aerobic and anaerobic bacteria will be able to proliferate due to the availability of a new energy source. The increase in the number of microbes follows with an increase in microbe-related by-products, one of which is believed to be microbially induced cementation. Instead of focusing on specific types of microbes (i.e. DeJong et al. 2006), the use of Con-α allows a variety of microbes to grow.

4 Materials and Preparation

A granitic clean sand from the southern part of the Korean peninsula was used to conduct our testing. The coefficient of uniformity, $C_u = 7.8$ and the coefficient of curvature, $C_c = 1.1$. This soil was classified as a well-graded sand, SW, according to USCS.

To prepare specimens for testing, the powder form of Con-α was simply spread over the sand in a pan and mixed with water until it appeared visually well distributed. Batches of 3 and 6 % of Con-α, by total weight, with a water content of 10 % were used. Mixing took a few hours and the pan was allowed to rest outdoors a few hours before samples were taken for biological and image analyses. While curing, 500 ml of water was supplied to the batch.

The mixed sand was also placed in three different test molds. One mold was 200 mm in height and 100 mm in diameter. These samples were compacted in accordance with ASTM D1557, using a 2.5 kg hammer in 10 layers and 36–37 blows per layer giving an estimated compaction energy of 2,700 kN-m/m^3. These samples were used for unconfined compression strength (UCS) testing in accordance with and ASTM D2166. Another mold measuring 150 mm in diameter and 170 mm in height was used to estimate the California Bearing Ratio (CBR) using the method outlined in ASTM D1883. The other mold was for triaxial permeability testing and measured 100 mm in height and 50 mm in diameter in accordance with ASTM D5084.

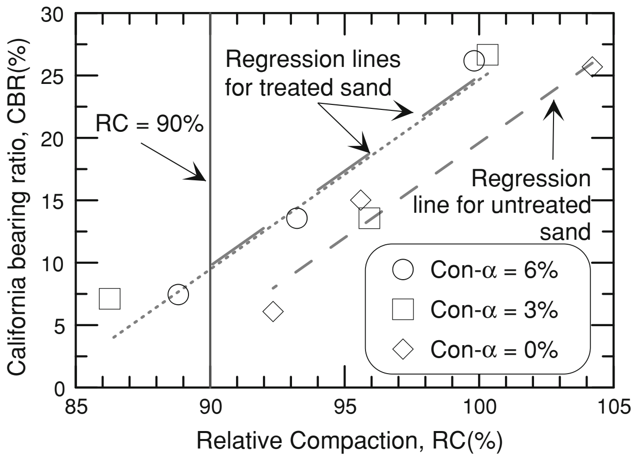

Fig. 2 CBR of sand samples mixed with Con-α

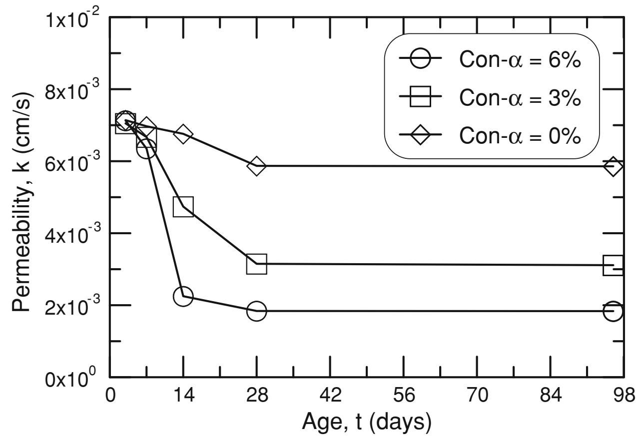

Fig. 3 Permeability of sand samples mixed with Con-α

5 Results

5.1 Unconfined Compressive Strength

Specimens aged 3, 7, 14, 28, and 96 days were tested for unconfined compressive strength, q_u. Three specimens from each age duration were tested and the average for each duration is plotted in Fig. 1.

Figure 1 shows an obvious improvement in unconfined compressive strength when Con-α is added and marginal increases in strength when Con-α concentration is increased. After 96 days, the untreated granitic sand had a $q_u = 179$ kPa, while 3 and 6 % Con-α concentrations yielded $q_u = 289$ and 307 kPa respectively, which is a 61 and 72 % increase in unconfined compressive strength respectively. Figure 1 also shows this strength increase to be gradual, with a majority of the strength attained after 28 day. We surmise this gradual strength increase is due to the process of cementation and perhaps a decrease in microbial activity because of less Con-α.

Additionally, all sand specimens aged 3 days were unable to develop the cohesion needed to stand unconfined and thus were unable to be tested.

5.2 California Bearing Ratio

CBR tests are conducted to estimate the bearing capacity and mechanical strength of subgrade soil for pavement design. Tests were performed on samples aged 28 days and their results are presented in Fig. 2. Figure 2 shows CBR = 4 for the untreated sand at a relative compaction, RC = 90 %. When treated with Con-α, the CBR modestly increases to about 10.

5.3 Permeability

Triaxial permeability tests were also conducted on specimens aged 3, 7, 14, 28, and 96 days, with the results shown in Fig. 3. Results also indicate permeability to stabilize after about 28 days. Figure 3 indicates the non-treated sand to have a coefficient of permeability, $k = 6 \times 10^{-3}$ cm/s after 96 days while the 3 and 6 % Con-α concentrations yielded $k = 3 \times 10^{-3}$ and 2×10^{-3} c,/s respectively, which is a 49 and 69 % decrease respectively.

6 Conclusions

The backshore region in many sandy coastal areas remains undeveloped. Natural coastal processes and human recreational behavior render the sand unsuitable for supporting a foundation. Tests were conducted to evaluate the engineering effects of using Con-α as a biological soil stabilization technique. Results showed unconfined compression to increase 61–72 %, CBR to increase from 4 to 10, and permeability to decrease 49–69 % for the concentration levels tested.

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References

Akbulut1 S., Saglamer A. (2003) Evaluation of fly ash and clay in soil grouting. *Proceedings of 3rd International specialty conference on grouting and ground treatment (GSP 120), ASCE* (pp 1192–1199). Louisiana: New Orleans.

Crossett, K. M., Culliton, T. J., Wiley, P. C., & Goodspeed, T. R. (2004). *Population trends along the coastal United States: 1980–2008*. Washington, DC: NOAA.

DeJong, J. T., Fritzges, M. B., Nüsslein, K. (2006) Microbial induced cementation to control sand response to undrained shear. *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, *132*(11), 1381–1392.

Dombrowski, F. J., Ramme, B. W., Okwadha, G. D. O., Kollakowsky, D. (2010) Evaluation of surface water runoff from fly ash–stabilized and nonstabilized soil surfaces. *Journal of Environmental Engineerng*, ASCE, *136*(9), 939–951.

Dove, J. E., Shillaber, C. M., Becker, T. S., Wallace, A. F., Dove, P. M. (2010) Biologically inspired silicification process for improving mechanical properties of sand. *Journal of Geotechnical and Geoenvironmental Engineering,* ASCE, *137*(10), 949–957.

El-Kelesh, A. M., Matsui, T., Tokida, K. (2012) Field investigation into effectiveness of compaction grouting. *Journal of Geotechnical and Geoenvironmental Engineering , ASCE.*

Lin, D. F., Lin, K. L., Hung, M. J., & Luo, H. L. (2007). Sludge ash/hydrated lime on the geotechnical properties of soft soil. *Journal of Hazardous Materials, 145*(1–2), 58–64.

Mohanty, S., & Chugh, Y. (2006). Postconstruction environmental monitoring of a fly ash-based road subbase. *Practice Periodical on Structural Design and Construction, ASCE, 11*(4), 238–246.

Narsilio, G. A., Santamarina, J. C., Hebeler, T., Bachus, R. (2009) Blast densification: multi-instrumented case history. *Journal of Geotechnical and Geoenvironmental Enginering, ASCE*, *135*(6), 723-734.

Osaki Corporation (2011) Construction manual for con-α (translated from Japanese). Osaki Corporation. http://www.osaki-c.co.jp. Accessed 1 February 2011.

Rollins, K. M., Kim, J. (2010) Dynamic compaction of collapsible soils based on u.s. case histories. *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, *136*(9), 1178–1186.

Van Paassen, L. A., Ghose, R., van der Linden, T. J. M., van der Star, W. R. L., van Loosdrecht, M. C. M. (2010) Quantifying biomediated groundiImprovement by ureolysis: large-scale biogrout experiment *Journal of Geotechnical and Geoenvironmental Engineering , ASCE*, *136*(12), 1721–1728.