Ain Shams University
Faculty of Engineering
Department of Structural Engineering

EXPERIMENTAL STUDY OF THE GEOTECHNICAL BEHAVIOR OF CALCAREOUS SOIL IMPROVED USING DIFFERENT ADMIXTURES - A COMPARATIVE STUDY

Thesis

Submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Civil Engineering
Department of Structural Engineering

BY

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Thesis: Experimental Study of the Geotechnical Behavior of Calcareous Soil Improved using Different Admixtures- a Comparative Study.

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STATEMENT

This dissertation is submitted to Ain Shams University, Faculty of Engineering, Structural Engineering Department, for the degree of Doctor of Philosophy in Civil Engineering.

The work included in this thesis was carried out in geotechnical laboratory at Construction Research Institute- National Water Research Center, from May 2015 to April 2018. The registration date is 13 / 6 / 2015.

No part of this thesis has been submitted for a degree or qualification at any other university or institution.

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Title of thesis:

Experimental Study of the Geotechnical Behavior of Calcareous Soil Improved using Different Admixtures- a Comparative Study

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ABSTRACT

The calcareous soil formations are commonly composed of calcium carbonates greater than 10%. Generally, the calcareous soils are extensively found near the coastal areas of Egypt, such as the northern coast. The fundamental geotechnical features of calcareous sand are the structural weakness of particles, variable cementation, and high void ratio. Accordingly, the performance of calcareous soils is usually connected with different interdependent problems, such as crushability, compressibility, and chemical dissolving. Furthermore, the aforementioned problems affect the development of projects; such as soil replacement, excavation works for water channels, roads, and railways. In earthworks applications, the calcareous soil is unable to respond effectively to the imposed stresses and become a dominant factor responsible for structure

damages. Therefore, calcareous soils with such conditions need stabilization to be suitable as a construction material.

The main goal of the present study is to explore the feasibility of applying a treatment approach in the improvement of calcareous soils toward mixing the calcareous soil with Kaolinite clay. Additionally, the effects of salinity on geotechnical properties of the carbonate soil were investigated through investigating the effect of different types of water (e.g fresh and sea water) used in compacting the soil. An extensive experimental program was performed. Whereas, the laboratory tests included chemical analysis (to evaluate some predominant chemical characteristics, e.g. carbonate content and the power of hydrogen "pH"); mechanical tests on compacted material (to reveal the geomechanical behavior, e.g. shear parameters by triaxial test) after different soaking periods in fresh water (zero, four and ninety days), and compaction tests, in addition to the California Bearing Ratio-(CBR). Consequently, some of geotechnical aspects (e.g. modulus of subgrade reaction "K_s" and modulus of elasticity "E") estimated from California Bearing Ratio-(CBR) are investigated. Additionally, physical tests (to ascertain the soil physical properties, e.g. particles gradation). To explore the crushability analyses, sieve and hydrometer analyses were applied on three different states of loading and soaking in fresh water. Thus, the first state is "natural state whether without soaking in fresh water or without applying compaction test" (NS); the second state is "after applying compaction test only" (CS); and the third state is "after applying both of soaking in fresh water for three months and compaction test" (SCS). These tests are complemented by permeability test to investigate the effect of Kaolinite that added to the carbonate sand on the coefficient of permeability.

The results of the experimental study have shown that, in all of the tested Kaolinite – calcareous sand mixtures whether compacted with fresh or sea water, the addition of Kaolinite up to 9% to the mixture significantly decreased the optimum water content but increased the maximum dry density. Wherein, both of the decrease ratio in optimum water content and the increase ratio in maximum dry density became more significant in the state of sea water. Lowering the optimum water contents are due to the significant lower water holding capacity of Kaolinite; the lubrication wherein the platy-shaped of Kaolinite minerals help the sand grains to slip against each other. Moreover, for all samples compacted at optimum water content "O.M.C" whether with fresh or sea water, the California Bearing Ratio "CBR" the California Bearing Ratio "CBR" value of the Kaolinite – carbonate sand is increasing with the addition of Kaolinite from 3% to 9%. However, after soaking in fresh water for three months, the California Bearing Ratio "CBR" value is lowered than it in the same soil but when it unsoaked. Accordingly, the stress – penetration curves of these mixtures might show initial slight slopes due to the chemical dissolving of the outer surface of grains. It is quite obvious that the soaking period has a significant effect on the California Bearing Ratio (CBR) indicating that the four days soaking period for the carbonate soil can lead to a serious false estimation of the soil strength. Wherein, the drop in California Bearing Ratio CBR is very sharp after about four days. Consequently, it is recommended to use soaked CBR test values. Both of the modulus of subgrade reaction "K_s" and the modulus of elasticity "E" take the same trend of California Bearing Ratio-(CBR) because they proportional directly with it.

It is found that the friction angles values of the Kaolinite – carbonate sand are decreased with the addition of Kaolinite from 3% to 9%. Accordingly, the cohesion strengths of them were increased. For all samples compacted at optimum water content "O.M.C" whether with fresh or sea water and after soaking in fresh water for three months", the friction angles values of them are lower than them in the same soil but when unsoaked. While, the cohesion strengths value of them are higher than it in the same soil but when unsoaked. At low confining pressures, many effects were observed such as: non particle

crushing; non compressible soil; steep failure envelope; brittle-type; compression is lower and dilation is strong. On the other hand at high confining pressures, it is observed that the particle crushing increased; compressible soil; flat failure envelope and continue to rise at a constant or perhaps a slightly increasing slope; ductile-type (plastic stress-strain curve); compression is greater and dilation is lower.

On the other hand, a gradual decrease in the permeability was shown by increasing the Kaolinite content “from 3% to 9%” which the decrease ratio became more significant when the Kaolinite content is equal to three percent. Particle breakage is reduced by increasing the Kaolinite content to the calcareous sand up to 9%. For the samples “compacted with fresh water”, the crushability values of tested Kaolinite mixtures after soaking for three months in fresh water are slightly higher than them in the same unsoaked soils. Moreover, tendency to crushing in tested Kaolinite - sand mixtures that compacted with seawater is less than the same soil but compacted with fresh water.

Key Words: calcareous soil; Kaolinite clay; Improvement; crushability; CBR; Permeability.

NOTATIONS

B_{10}	: Particle brakeage factor proposed by Lade et al. (1996)
B_{15}	: Particle brakeage factor proposed by Lee and Farhoomand
B_p	: Breakage potential
B_r	: Relative breakage
B_t	: Total breakage
$CaCO_3$	: Calcium carbonate
$CaSO_4$	: Calcium sulphate
CBR	:California Bearing Ratio
C_c	: Coefficient of Concavity
CL	: Chlorine
C_u	: Coefficient of Uniformity
D_{10}	: Grain Diameter Corresponding to 10% of the Material being smaller by weight
D_{10f}	: The final grain diameter corresponding to 10% of the material being smaller by weight after compaction test is applied
D_{10i}	: The initial grain diameter corresponding to 10% of the material being smaller by weight before compaction test is applied
D_{15}	: Grain Diameter Corresponding to 15% of the Material being smaller by weight
D_{15f}	: The final grain diameter corresponding to 15% of the material being smaller by weight after compaction test is applied
D_{15i}	: The initial grain diameter corresponding to 15% of the material

being smaller by weight before compaction test is applied

D_{30}	: Grain Diameter Corresponding to 30% of the Material being Smaller by Weight
D_{60}	: Grain Diameter Corresponding to 60% of the Material being smaller by weight
D_r	: Relative Density
E_{50}	: Secant modulus
G_s	: Specific gravity
HCL	: Hydrochloric acid
H_2O	water
Na^+	:Sodium ions (cations)
NaCl	: Sodium chloride salt
$Al_4 (OH)_8 Si_4 O_{10}$	: Kaolinite Clay
O.M	: Organic material
O.M.C	: Optimum moisture content
P.I	:Plasticity index
pH	: Power of hydrogen
SiO_2	: Silicate content
SO_3	: Sulfate as sulfur trioxide
S_r=100%	: Saturation line
TDS	: Total dissolved salts

W.C	:Water content
L.L	:Liquid limit
P.L	:Plastic limit
S.L	:Shrinkage limit
ε	: Axial Strain
σ	:Normal stress
φ	: Friction angle
$ɣ_{dry\ max}$	: Maximum dry density

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