Procedia Engineering
Volume 143, 2016, Pages 111–118
Advances in Transportation Geotechnics 3 . The 3rd International Conference on Transportation Geotechnics (ICTG 2016)

Tensile Strength Properties of Sand-bentonite Mixtures Enhanced with Cement

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Abstract
Measurement of tensile strength of soil by direct methods can be challenging due to difficulties in sample preparation and in fixing the specimen while applying uniaxial tension forces. However the tensile strength of soil samples can be measured by indirect tests, such as the Brazilian and double punch tests, assuming that tensile stress is distributed uniformly on the failure plane. In this study, the tensile strength of statically-compacted sand bentonite and cement-enhanced sand bentonite mixtures is measured in varying curing time periods using the "double punch" test. The compressive strengths of samples are also measured using the unconfined compression test, and the correlation between tensile and compressive strength is discussed in relation to curing time. A simple method is also applied to determine the undrained cohesion and internal friction angle of samples through the Mohr-Coulomb circle method, using the double punch tensile strength and unconfined compressive strength. The results show that cohesion increases in both sand bentonite and sand bentonite-cement samples along with curing time.

Keywords: sand-bentonite, cement, tensile strength, double punch, strength parameter

1 Introduction

In most countries, the primary method of waste disposal is the use of landfills, which are containment facilities that prevent or minimize pollutant migration into underground water and the local environments. Compacted mixtures of sand-bentonite are commonly used as landfill barriers due to lower susceptibility to frost damage and their lower potential for volumetric changes during wetting and drying processes (Montanez, 2002). Bentonite, as a clay material with high amounts of montmorillonite, appears to be a good option when used together with sand, due to its high water absorption capacity and very low hydraulic conductivity. It is the sand that holds the main structure of the compacted mixture together.

Selection and peer-review under responsibility of the Scientific Programme Committee of ICTG 2016

doi:10.1016/j.proeng.2016.06.015

On the other hand, earth structures, such as landfill liners and covers, develop tensile cracks when subjected to desiccation, differential settlement, or other external loads. Tensile cracking may adversely affect the performance of the structure by reducing the overall strength and bearing capacity of soil, thus increasing the hydraulic conductivity of barriers. Tensile cracks represent Mode I failure as described in fracture mechanics. This phenomenon is not very well studied in geotechnical approaches, mainly due to lack of a standard laboratory testing technique devised for soils (Fang and Chen, 1972; Kim et al., 2012). The importance of studying tensile characteristics of compacted soils is emphasized by various researchers. Leonards and Narain (1963) investigated the cracking behavior of earth dams by testing the flexural strength (tensile-bending) of a clay-beam. Conlon (1966) performed unconfined tensile testing (direct tension) on soft silt by necking the mid portion of the specimens so as failure occurred in this zone. Suklje (1969) indicated that when cohesive layers at the base of open excavations are subjected to artesian water pressures, tensile fissures can appear, and the critical hydraulic gradients depend on the shearing strength as well as tensile resistance of soil. The effect of tensile strength in cohesive slopes was studied by Spencer (1968) and Suklje (1969) who indicated that creep and critical state stresses with tensile principal stress develop in the upper parts of slopes. George (1970) and Sih and Fang (1972) applied fracture mechanics theory in assessing the tensile characteristics and cracking in various highway materials.

On the other hand, it is well accepted that knowing strength parameters of soils cohesion, c, and internal friction angle φ is essential in conventional analyses of the stability of soil systems. However, the test methods used for determining these parameters are generally expensive and time-consuming. In this study a modified Mohr-Coulomb failure, suggested by Chen and Drucker (1969), is adopted which utilize tensile and compressive strength data for predicting undrained cohesion and friction angle of the compacted samples using a graphical solution.

2 Materials and Sample Preparation

The materials used are sea sand, Na-bentonite, and cement. Sand is a poorly graded uniform carbonate sand obtained from the Famagusta coast in the eastern part of Cyprus with specific gravity 2.68, mean diameter (D_{50}) 0.20 mm, effective diameter (D_{10}) 0.14 mm, uniformity coefficient (C_u) 1.53, and coefficient of curvature (C_c) 0.99. Na-bentonite is obtained from Karakaya Bentonite Inc., Turkey, with liquid limit and plastic limit of 486% and 433% respectively, and a specific gravity of 2.51. The cement used in this study is ordinary Portland cement type I. The mixtures of 15% bentonite-85% sand and 80% sand-15% bentonite and 5% cement were prepared according to percentage of the dry mass. The material was prepared by pre-drying sand and bentonite in an oven, with the drying temperature not exceeding 60 ° C for bentonite. Sand was then passed through a 2.00mm sieve to eliminate impurities. The optimum water content and maximum dry density of the mixtures were obtained by standard Proctor compaction test according to ASTM D698-12. The measured optimum water content was 17% for both mixtures and maximum dry densities were 1.624 g/cm^3 for 15% bentonite-85% sand and 1.663 g/cm^3 for 80% sand-15% bentonite-5% cement. In order to attain homogenous moisture content within each sample, the batches were mixed thoroughly in a mechanical mixer, sealed in double nylon bags, and kept for 24 hours prior to compaction. For cement-included samples, the required percentage of cement by dry mass of sand-bentonite mixture was added directly before compaction, ensuring that the mixing and compacting period would not exceed the setting time. In order to achieve identical samples, Proctor maximum dry-density and optimum water-content values were used to prepare statically compacted samples required for strength tests with an acceptable error margin of ±5%. The mold sizes for unconfined compression and double punch tests were 36 x 76 mm and 101.6 x 116.8 mm in diameter and height respectively.