TENSILE STRENGTH, SHEAR STRENGTH, AND EFFECTIVE STRESS FOR UNSATURATED SAND

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ABSTRACT

It is generally accepted in geotechnical engineering that non-cohesive materials such as sands exhibit no or negligible tensile strength. However, there is significant evidence that interparticle forces arising from capillary and other pore-scale force mechanisms increase both the shear and tensile strength of soils. The general behavior of these pore-scale forces, their role in macroscopic stress, strength, and deformation behavior, and the changes that occur in the field under natural or imposed changes in water content remain largely uncertain.

The primary objective of this research was to experimentally examine the manifestation of capillary-induced interparticle forces in partially saturated sands to macroscopic shear strength, tensile strength, and deformation behavior. This was accomplished by conducting a large suite of direct shear and direct tension tests using three gradations of Ottawa sand prepared to relatively “loose” and relatively “dense” conditions over a range of degrees saturation. Results were compared with previous experimental results from similar tests, existing theoretical formulations to define effective stress in unsaturated soil, and a hypothesis proposed to define a direct relationship between tensile strength and effective stress.

The major conclusions obtained from this research include: Theoretical models tended to underpredict measured tensile strength. Analysis of results indicates that shear strength may be reasonably predicted using the sum of tensile strength and total normal stress as an equivalent effective stress ($\sigma' = \sigma_t + \sigma_n$). Analysis also indicates that Bishop’s (1959) effective stress formulation is a reasonable representation for effective stress by setting $\chi = S$ and by back-calculating χ from shear tests. Tensile strength and apparent cohesion measured exhibited double-peak behavior as a function of degree of saturation. Relatively dense specimen with water contents approaching the capillary regime start behaving as a loose specimen. Horizontal displacement at failure in tension exhibited double-peak behavior as a function of saturation. The two-peak behavior tends to flatten out as the grain size increases.