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REVIEW ARTICLE

Effect of percentage of low plastic fines on the unsaturated shear strength of compacted gravel soil

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Abstract Low plastic fines in gravel soils affect its unsaturated shear strength due to the contribution of matric suction that arises in micro and macro pores found within and between aggregates. The shear strength of five different types of prepared gravel soils is measured and is compared with a theoretical model (Fredlund et al., 1978) to predict the unsaturated shear strength. The results are consistent to a great extent except the case of dry clayey gravel soil. It is also found that on inundation of gravel soils containing plastic fines greater than 12% a considerable reduction in both the strength and the stiffness modulus is noticed. This 12% percentage is close to the accepted 15% percentage of fines given by ASTM D4318 (American society for testing material). The angle of internal friction that arises due to matric suction decreases with the increase of degree of saturation of soil. The hysteresis of some tested gravel soils is measured and found that it increases by increasing the percentage of fines.

1. Introduction

The unsaturated shear strength of soil is greater than the saturated strength due to increase in soil shear parameters as a result of rise in total suction. Total suction equals the sum of matric and osmotic suction. Osmotic suction is due to difference in pore water salt concentration within the soil while matric suction get rise due to capillarity action of micro and macro-pores in compacted soil. Total suction equals matric suction in case there is homogeneity in pore water salt concentration. The soil is often unsaturated and pore moisture stability takes place where no moisture flow or flux exists and when soil water content becomes constant with time.

The shear strength equation of unsaturated soil proposed by Fredlund et al. [1] is as follows:

$$\tau_f = c + (\sigma_n - u_a)\tan \emptyset' + (u_a - u_w)\tan \emptyset^b \quad (1)$$

The shear parameters c, ϕ and ϕ^b in the previous equation are determined from locating the shear envelope of unsaturated tested soil drawn in three axis (τ_f, $\sigma_n - u_a$ and $u_a - u_w$). c and ϕ are the intercept and slope of shear envelope with respect to τ_f and $\sigma_n - u_a$ axis while ϕ^b is the slope of shear envelope with respect to τ_f and $u_a - u_w$ axis. Modified direct shear box or modified triaxial cell is adapted to measure the shear strength of unsaturated soil at controlled suction.

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Nomenclature

c	effective cohesion of the soil
ϕ'	effective angle of shearing resistance for saturated soil
ϕ^b	angle of internal friction with respect to the matric suction
u_w	pore water pressure
u_a	pore air pressure
$(u_a{-}u_w)$	matric suction
$(\sigma_n{-}u_a)$	net normal stress
θ_w	volumetric water content
θ_r	residual water content
θ_s	saturated water content at zero suction
OMC	optimum moisture water content
PI	plasticity index in %
LL	liquid limit
P_{200}	% passing U.S. sieve # 200
w(h)	gravimetric water content (ratio between the weight of water and weight of solids)
e	void ratio of soil
G_s	specific gravity of soil
h	matric suction $= u_a - u_w$
h_r	residual suction (the suction below which there is no free pore water (see residual condition in Fig. 2)
SWCC	soil water characteristic curve
C(h)	an adjustment factor which forces the SWCC to reach zero water content at high suction values 10^6 kPa (dry soil condition)
a_f, b_f and c_f	fitting parameters for SWCC
GI	group index of soil
w	soil water content
ψ_a	air entry value

Vanapalli et al. [2] emphasize that the soil water characteristic curve is closely related to the shear strength of unsaturated soil. Fredlund et al. [3] introduced the following empirical equation

$$\tau_f = c + (\sigma_n - u_a)\tan \emptyset' + (u_a - u_w)\left[\tan \emptyset'\left(\frac{\theta_w - \theta_r}{\theta_s - \theta_r}\right)\right] \qquad (2)$$

The relationship between τ and $(u_a - u_w)$ is assumed to be linear. Escario and Juca [4] determined that this relationship is actually non-linear. Later several other researchers observed a non-linear relationship between apparent cohesion (intercept of shear envelope with shear stress axis at zero normal stress) and matric suction (Fredlund et al. [5], Wheeler [6], Ridley [7], Ridley et al. [8]).

Modified direct shear box and triaxial cells using axis translation techniques are examples of modified shear devices which can control soil suction. The friction angle decreases with increasing the size of direct shear box size and that is consistent with the decrease in friction angle with the increase in footing size found in model and prototype scale foundation tests (Amy and Alan [9]). According to ASTM D 3080-90, the direct shear box test has several particle-sizes to box-size requirements when preparing specimens for testing. It is recommended that the minimum specimen width should not be less than ten times the maximum particle-size diameter and the minimum initial specimen thickness should not be less than six times the maximum particle diameter. The minimum specimen width-to thickness ratio should be 2 to 1. Other works in the literature are much stricter on the particle-size to box-size requirement. Jewell and Wroth [10] suggest a ratio of shear box length to average particle size in the range of 50 to 300.

Soil suction can be determined using various techniques. The filter paper method was developed in Europe in 1920 and was transferred to the United States in 1937 by Gardner [11]. The method requires a calibration for suction versus water content relationship of the filter paper. Mcqueen and Miller [12] introduced the calibration curve shown in Fig. 1 for filter paper water content versus suction. These curves convert the filter paper (Whatman 42 type) water content values to suction values.

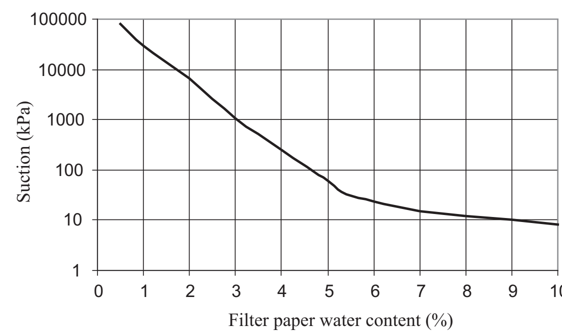

Figure 1 Calibration curve for filter paper water content *versus* soil suction (Mcqueen and Miller [12]).

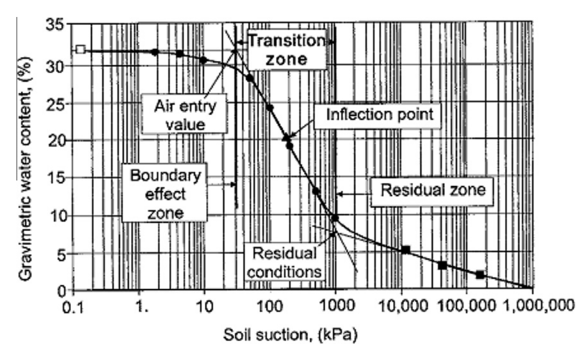

Figure 2 Illustration of the in situ zones of de-saturation defined by a SWCC (after Fredlund) [3].

Basically, the filter paper comes to equilibrium if sealed with the soil either through vapor (total suction measurement) equilibrium or through liquid contact (matric suction measurement) equilibrium. At equilibrium (water content of filter paper gets constant with time), the suction value of the filter paper and the soil will be equal. The filter paper water content is measured. By using the calibration curve of filter paper water content versus suction, the corresponding soil suction