Role of Suction in Unsaturated Soils

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Abstract: Soil suction, which regulates the interaction between the soil's water and air phases, plays a major role in the behavior of unsaturated soils. The shear strength, compressibility, and permeability are greatly influenced by suction, which is made up of matric and osmotic components. The stability and deformation of infrastructures can be impacted by significant changes in soil performance brought on by variations in suction caused by external factors like rainfall or evaporation. For proper prediction and modeling of unsaturated soil behavior, it is consequently crucial to comprehend the function of suction. The ability to include suction as a key variable in geotechnical analysis and design has been significantly improved by developments in constitutive modeling and suction measuring techniques. Many scholars proposed empirical methods to predict the suction strength (matric suction contribution) of unsaturated soils. While some of these methods are based on mathematical fitting techniques; others are based on the soil-water characteristic curve (SWCC) and the saturated shear strength parameters. An improved suction strength formula is put forward in this work. The validity of the proposed improvement method is examined for a few suction strength data of different kinds of soils. It was found that the suction strength values predicted from the proposed equation are in well agreement with the experimental results.

Keywords: ***Unsaturated soil, Matric suction, SWCC, Suction strength.***

Introduction

The presence of water and air in the pore spaces of unsaturated soils essentially controls their behavior, resulting in complex hydro-mechanical interactions that are very different from those in totally saturated or completely dry soils. Soil suction, or the soil's capacity to hold or release water, is a crucial factor that characterizes and affects the behavior of unsaturated soils (Fredlund and Rahardjo, 1993). The sum of matric suction (the difference between pore air and pore water pressures) and osmotic suction (the result of variations in solute concentration) is commonly used to describe suction, which is caused by capillary and adsorptive forces operating within the soil matrix. Additionally, as suction directly influences important engineering parameters like shear strength, volume change, permeability, and soil-water characteristic connections, an understanding of suction is crucial. According to Vanapalli et al. (1996), variations in suction, which are frequently caused by changes in environmental variables like rainfall or evaporation, can result in considerable changes in soil strength and deformation behavior, which can lead to stability difficulties. Therefore, the study of suction serves as the basis for creating more dependable and sustainable geotechnical designs and to bridging the gap between soil mechanics and hydrogeology.

Shear Strength Functions for Unsaturated Soils

Unlike saturated soils, unsaturated soils' shear strength is determined by two independent stress-state variables: matric suction (μ_a-μ_w) and net normal stress (σ-μ_a). Considering that Bishop (1959) proposed shear strength equation for unsaturated soils by extending Terzaghi's principle of effective stress for saturated soils, which is-

$$\tau_f = c' + (\sigma - \mu_a)\tan\varphi' + \chi(\mu_a - \mu_w)\tan\varphi' \quad (1)$$

Fredlund et al. (1978) proposed the following equation for the shear strength of unsaturated soils-

$$\tau_f = c' + (\sigma\text{-}\mu_a)\tan\varphi' + (\mu_a\text{-}\mu_w)\tan\varphi^b \quad (2)$$

Where,

c′= effective cohesion,

ϕ'= effective friction angle,

(σ-μ_a)= net normal stress,

(μ_a-μ_w) = matric suction,

χ= effective stress parameter depending on the degree of saturation,

ϕ^b is the angle indicating the rate of increase in shear strength relative to the matric suction.

However, the direct measurement of χ and ϕ^b are very complicated, expensive, time consuming and require specialized testing equipment in practice. Because the rate of increasing matric suction and the rate of desaturation is not the same. A typical shear strength vs matric suction curve (Figure 1) explains why the increasing rate of suction strength decreases with increasing matric suction and will attain a roughly constant value under dry or almost dry conditions.

Proposed Suction Strength Function and its Validity

The proposed improved suction strength equation of unsaturated soils which is the modification of Kong et al. (2005) formula gassy fine sand. The proposed equation is-

$$\tau_{\mu s} = \frac{a(\mu_a\text{-}\mu_w)^b}{1+c(\mu_a\text{-}\mu_w)^b} \quad (3)$$

Where, a, b and c are fitting parameters.

If matric suction (μ_a-μ_w) is zero, $\tau_{\mu s}$ is also equal to zero. The value of c is greater or equal to zero and the value of b ranges between 0 to 1. From the formula (3), it can easily be seen that the a/c has the physical meaning of suction strength ($\tau_{\mu s}$) limit value, b reflects suction strength-matric suction relation curve shape, and a is the reciprocal of slope for the relation of $1/\tau_{\mu s}$ to $1/(u_a\text{-}u_w)^{b}$.

Some published unsaturated shear strength data are also used to analyze the validity of the proposed equation. These published laboratory data are extracted from either the graphs or tables of the original publications. A summary of these data is given in Table 1. The selected soils include undisturbed soil, compacted soil, residual soil and expansive soil with varying plasticity index and grain size distributions. The calculated suction strength using proposed equation is fitted well with the measured suction strength of different types of soils (Figure 2). Therefore, it can be stated that the proposed improvement equation is suitable for different types of soils.

In this study, Miao et al. (2002) data are used to compare the proposed and published prediction type equations. The proposed equation and Vanapalli et al. (1996) model provide a better comparison between the predicted and experimental suction strength values whereas Tekinsoy et al. (2004) model provide reasonable comparison, and the others published equations provide poor comparison (Figure 3).

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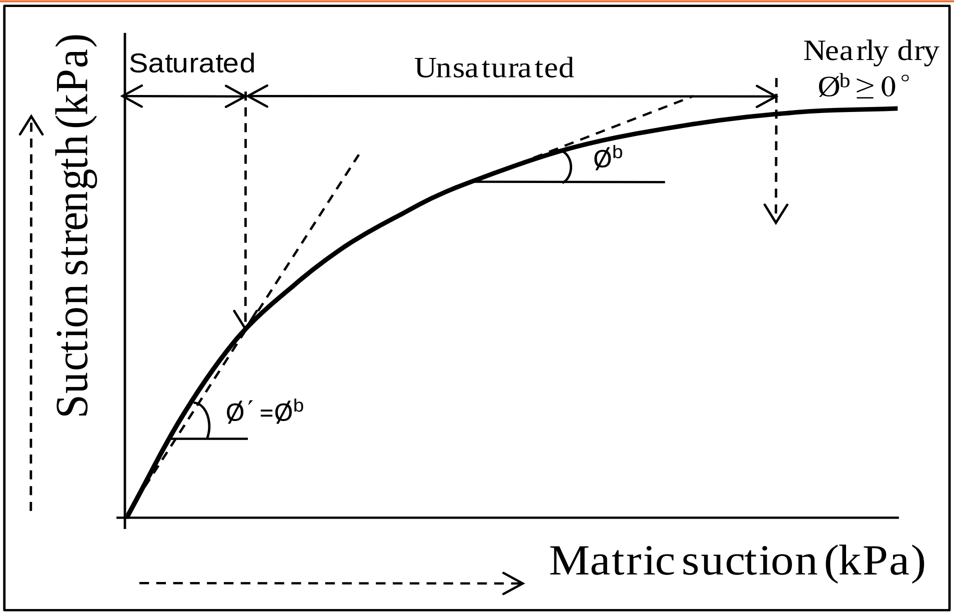

Figure 1, A typical suction strength versus matric suction curve.

Table 1, Summary of the published data

Authors and Materials	Soil type	c´	ϕ´
Vanapalli et al. (1996), Compacted Glacial Till	CL	0	23°
Miao et al. (2002), Expansive soil	CH	32.0	21.3°
Kayadelen et al. (2007), Residual soil	CH	14.8	21.9°
Nam et al. (2011), Silty soil	MH	15.8	32.0°
Schnellmann et al. (2013), Silty sand	SW-SM	0	33.6°

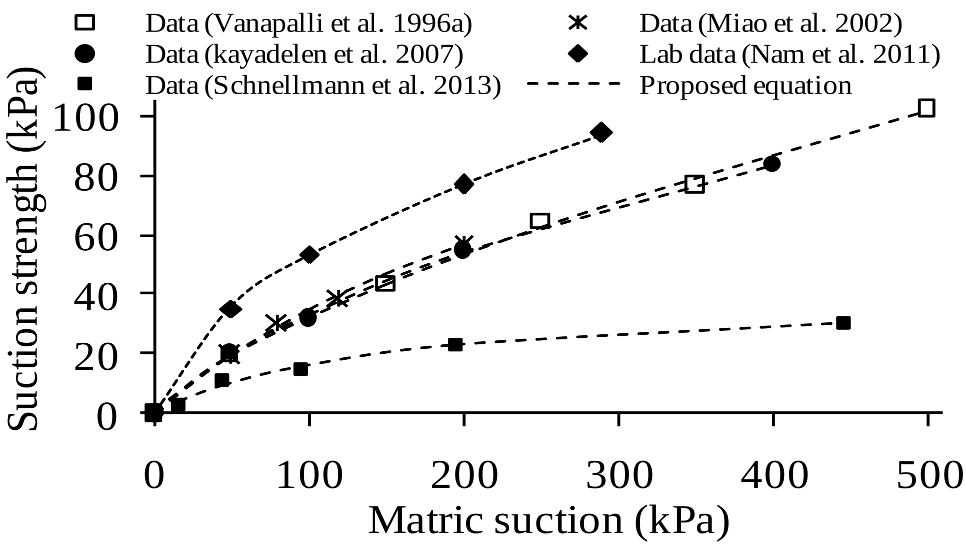

Figure 2, Fitting curve of proposed equation with different types of soils.

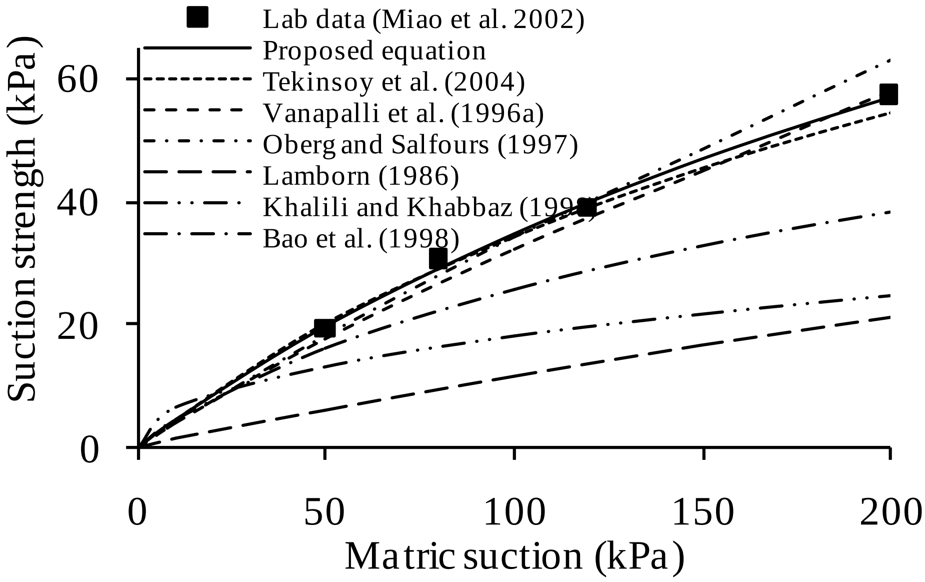

Figure 3, Comparison of proposed and published predicted type suction strength equations for Nanyang expansive soil.