Study on Hydro-Mechanical Behavior of Unsaturated Soils

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1. INTRODUCTION

Behaviour of unsaturated soils is more complex than saturated soils. Recently, solutions of the problems are based on many conservative assumptions in order to simplify the behaviour of unsaturated soils. To give a good solution needs study of the behaviour of unsaturated soils.

This paper is focused to measure matric suction using filter paper method and effect on hydro-mechanical behavior of unsaturated soils. Hydraulic behavior of unsaturated soil can be observed by soil water retention curve (SWRC) which shows relation between matric suction and water content of soils. Filter paper method to measure matric suction was performed to determine SWRC. Also, other approaches to estimate SWRC was performed based on grain size distribution and and knowledge-based system. Mechanical behavior of unsaturated soil was observed by using direct shear test to obtain the relationship between strength parameter of soil and soil suction.

2. UNSATURATED SHEAR STRENGTH

Fredlund et al. (1978) have proposed an equation to describe the strength of unsaturated soil, known as extended Mohr Coulomb failure criterion. The equation is presented as follow.

$$\tau = c' + (\sigma - u_a)\tan\varphi' + (u_a - u_w)\tan\varphi^b \quad (1)$$

The matric suction term in **Equation 1** can be considered as contributing to the cohesion of the soil (Ho and Fredlund, 1982), as presented in **Equation 2**. It means that the suction in unsaturated soil increases the cohesion.

$$c = c' + (u_a - u_w)\tan\varphi^b \quad (2)$$

where c = the total or apparent cohesion of an unsaturated soil [kPa].

In this paper, a non-linear relationship between cohesion and matric suction is proposed, expressed in **Equation 3**. This proposed equation assumed that cohesion of soil below air entry value of matric suction is equal to saturated cohesion. While for matric suction higher than air entry value, cohesion of soil increases nonlinearly along with the increase of matric suction. Rifa'i (2002) has compared the measured and calculated cohesion using both equations shown in **Figure 1**. The result shows that both of those equations are applicable for matric suction less than 250kPa.

$$c = c' + r_c\sqrt{(s - s_e)\cdot p_a} \quad (3)$$

where r_c is a dimensionless evolution parameter of cohesion and determined using **Equation 4**, c' is cohesion of soil at saturated state, s is matric suction, s_e is the air-entry value, and p_a is atmosphere pressure.

$$r_c = r_k \frac{\sqrt{3}(3 - \sin\varphi')}{6\cos\varphi'} \quad (4)$$

where r_k is a dimensionless evolution parameter and φ' is internal friction angle of soil at saturated state.

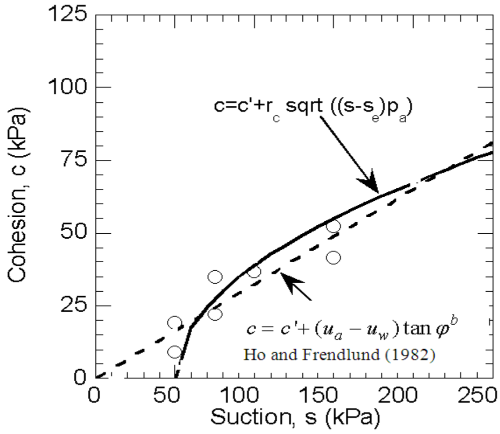

Figure 1 Evolution of cohesion due to increase of matric suction (Rifa'i, 2002)

3. SOIL WATER CHARACTERISTIC CURVE

Fredlund et al. (1997) has proposed several procedures to determine unsaturated soil properties using laboratory test results and knowledge-based system. In this research, matric suction of soil was measured using contact filter paper (ASTM D 5298). Soil classified into silt with high plasticity (MH) was used in this research. Plasticity index of soil is about 44.95% and dry density is about 1.01 g/cm^3. The result of filter paper test is then to be compared with other soil which has similar grain size distribution. **Figure 2** shows soils that have similar grain size distribution with soil which is studied in this research. Those soils are collected from SOILVISION database.

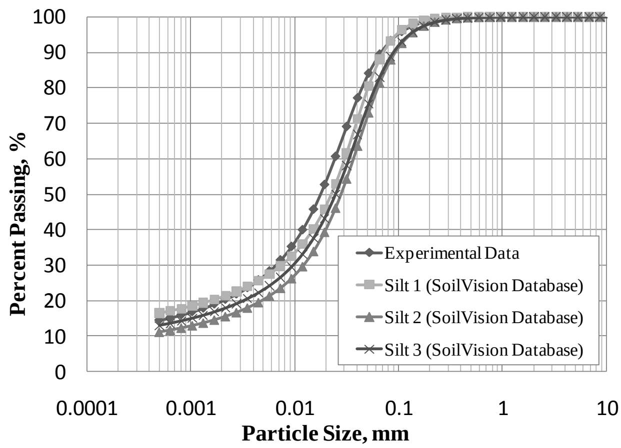

Figure 2 Matching similar grain size distribution of silt based on SOILVISION database

Soil water characteristic curve for soils that has similar particle distribution is shown in **Figure 3**. The SWCC of Fredlund and Wilson prediction seems to be close with all data from SOILVISION database. The result of SWCC from filter paper method is higher than other. This gap occurs probably because of the difference in Plasticity

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Index of soil. Zapata et al. (2000) have researched that the SWCC of fine grained soil is influenced by multiplication of percent passing no 200 and plasticity index (wPI). The greater value of wPI is the higher value of soil suction. From filter paper test, the air entry value of soil is about 24.55 kPa. This parameter is used in the proposed equation in this paper to determine the strength of unsaturated soil.

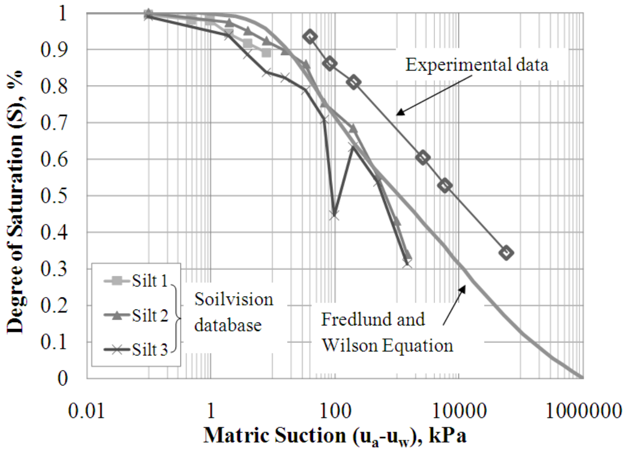

Figure 3 Soil water retention curves (SWRC)

4. RELATIONSHIP BETWEEN STRENGTH PROPERTIES AND MATRIC SUCTION

Suction measurement and direct shear test result can show the relationship between matric suction and shear strength as shown in **Figure 4**. The curves show that shear strength increase non-linearly due to increase in matric suction at high range. For low range of matric suction, it can be approached using linear function, as shown in **Figure 5**. Linear function between shear strength and matric suction gives value of internal friction angle due to matric suction about 5.6˚ based on Fredlund et al. (1978) equation.

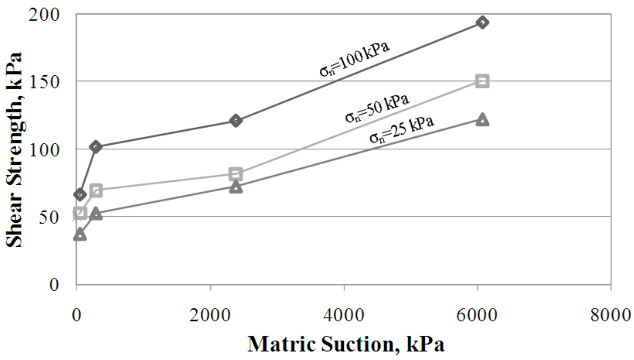

Figure 4 Evolution of shear strength in respect with matric suction for silt soil

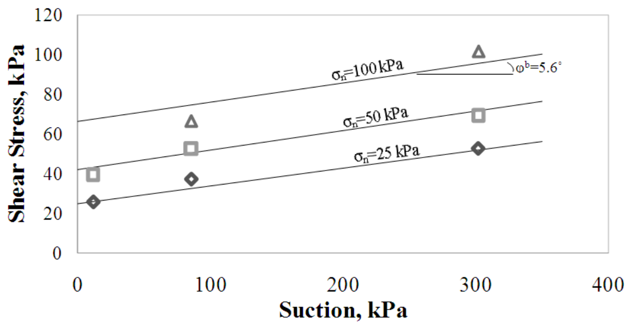

Figure 5 Linear function of shear strength versus matric suction at relatively low suction for silt (below 286.07kPa)

In this paper, two equations were compared. The first is Fredlund et al. (1978) equation which provides linear relationship between matric suction and shear strength, and the second is Rifa'i (2002) equation that provides nonlinear relationship. **Figure 6** shows the comparation between laboratory test, Rifai equation and Fredlund equation. This curve uses logarithmic scale for the axis because the matric suction is too high, reach around 5000kPa based on SWCC using filter paper test. It seems that Fredlund equation fit with laboratory data for low matric suction. But for higher matric suction, linear equation result overestimated strength, shown in **Figure 6**. By using nonlinear equation, strength prediction will approach better than using linear equation in high range matric suction.

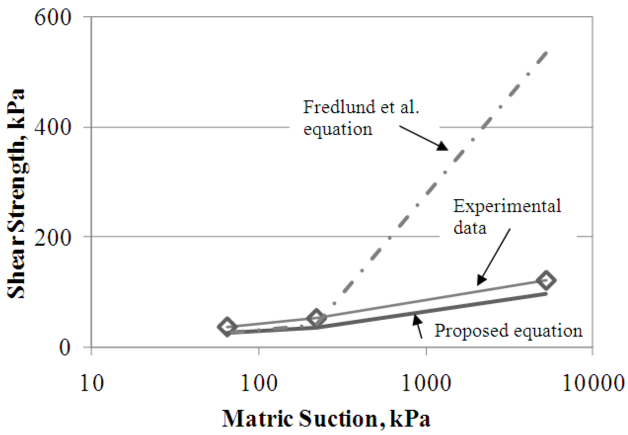

Figure 6 Evolution of cohesion and φ' with matric suction

5. CONCLUSION

Filter paper can be used to measure matric suction indirectly. In order to match the experimental data for clay or silt soil, it is needed to include the influence of Plasticity Index to the value of matric suction, especially for soil which has high plasticity value. In this paper, an unsaturated shear strength equation to evaluate the nonlinearity relationship between matric suction and shear strength for matric suction above the air entry value is proposed. The value of air entry value and dimensionless constant r_k are the important parameters in this equation.

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