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VARIATION OF UNDRAINED SHEAR STRENGTH OF UNSATURATED POROUS MEDIA WITH TEMPERATURE AND SUCTION

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ABSTRACT

At present, the thermo-hydro-mechanical coupling in unsaturated porous media is an interested subject since the environmental issues have been raised worldwide. Thus, this paper presents simulation results of effects of temperature and suction on undrained shear strength of unsaturated porous media, which is an important parameter in geotechnical design and analysis. The equation of undrained shear strength including thermal effect was used to estimate the results at various temperatures and matric suctions. Typically, the results show that the undrained shear strength decreases with increasing temperature for all values of matric suction. However, the undrained shear strength increases with increasing matric suction for all values of ambient temperature.

Keywords: porous media, unsaturation, thermal effect, suction.

INTRODUCTION

The thermo-mechanical behaviors of porous media in the field of geotechnical engineering have been investigated during the past five decades (e.g. Campanella and Mitchell, 1968; Plum and Esrig, 1969; Hueckel and Borsetto, 1990; Graham *et al.*, 2001; Uchaipichat, 2005, Uchaipichat, 2013). The examples of porous media in this field of study are porous rocks, fracture rocks, sands and clays. The temperature changes in these porous media are typically caused by some facilities generating heat, such as buried hot pipe and nuclear waste repository.

In order to design and analyze foundations of these types of facility, the undrained shear strength, which is a very important parameter, are required. Uchaipichat (2013) derived the equation of undrained shear strength of saturated porous media at particular ambient temperature based on critical state concept.

However, almost 40 percent of natural soils and rocks on the earth surface are in arid and semi-arid regions. They are actually in unsaturated state and their undrained shear strength is dependent of suction within the pores (e.g. Vanapalli *et al.*, 1996; Khalili and Khabbaz, 1998; Cunningham *et al.*, 2003; Thu *et al.*, 2006; Zhou and Sheng, 2009; Uchaipichat, 2010).

Thus, the main purpose of this paper is to perform the simulation of the effect of temperature and matric suction on undrained shear strength of unsaturated soil using the soil parameters reported by Uchaipichat (2005).

THERMAL EFFECT ON POROUS MEDIA

The thermal effects of porous media have been investigated by several investigators. Uchaipichat (2013) derived the equation of undrained shear strength of saturated porous media at particular ambient temperature T based on critical state concept, which can be expressed as,

$$S_u = \frac{p_o' M}{2}\left(\frac{OCR}{r}\right)^{\frac{\lambda-k}{\lambda}} EXP\left[-\frac{nv}{k}\left(\alpha_f-\alpha_s\right)\left(T-T_o\right)\right] \qquad (1)$$

in which, S_u is the undrained shear strength, p_o' is the initial mean effective stress at temperature T_o, M is the slope of the critical state line on the mean and deviator stresses plane, OCR is the over consolidation ratio, r is the pressure ration on any particular unloading-reloading line between the normal compression and critical state lines, n is the porosity of soil, v is the specific volume, k is the is the slope of the unloading-reloading line in the semi-logarithmic compression, α_f and α_s are the coefficients of thermal expansion of fluid and solid phases, respectively. λ and k are the slopes on the plane between specific volume and logarithm of mean stress of the normal loading and reloading lines, respectively.

SIMULATIONS OF VARIATION OF UNDRAINED SHEAR STRETGH WITH TEMPERATURE AND SUCTION

The simulation was performed using the material parameters reported by Uchaipichat (2005) which are shown in Table-1. The initial value of OCR was assumed to be 2.0. The undrained shear strength of porous media was calculated using Equation (1).

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Table-1. Material parameters.

Parameters	Values
κ	0.006
λ	0.09
n	0.36
M	1.17
α_s	3.4×10^{-5}
α_f	4.0×10^{-4}
n	0.36
r	2
s_e	18 kPa

The value of OCR can change with temperature and matric suction,

$$OCR = \frac{p'_T}{p'_c} \tag{2}$$

in which, p'_T is the mean effective stress at temperature T which can be expressed as,

$$p'_T = p'_o \ EXP\left[-\frac{nv}{k}\left(\alpha_f - \alpha_s\right)\left(T - T_o\right)\right] \tag{3}$$

The value of p'_c can be expressed as,

$$p'_c = EXP\left(\frac{N - v}{\lambda}\right) \tag{4}$$

in which, N is the specific volume at the mean effective stress of 1 kPa and varies with temperature and matric suction. The values of N for different temperatures and matric suctions are shown in Table-2.

Table-2. Values of N at different temperatures and matric suctions (Uchaipichat, 2005).

Matric suction (kPa)	N		
	$T = 25^oC$	$T = 40^oC$	$T = 60^oC$
0	2.049	2.044	2.039
18	2.049	2.044	2.039
100	2.058	2.050	2.043
300	2.068	2.058	2.051

Figure-1 shows a variation of undrained shear strength with temperature at various values of matric suction. It is obvious that the undrained shear strength decreases with increasing temperature for all values of matric suction. This corresponds to change in effective stress with increasing temperature as shown in Figure-2. However, the over consolidation ratio increases with increasing temperature as shown in Figure-3.

The variation of undrained shear strength with matric suction at various temperatures was also investigated as shown in Figure-4. It can be seen that the undrained shear strength increases with increasing matric suction for all values of ambient temperature. Figure-5 also shows the increase in effective stress with increasing matric suction. However, the over consolidation ratio decreases with increasing matric suction as shown in Figure-6.

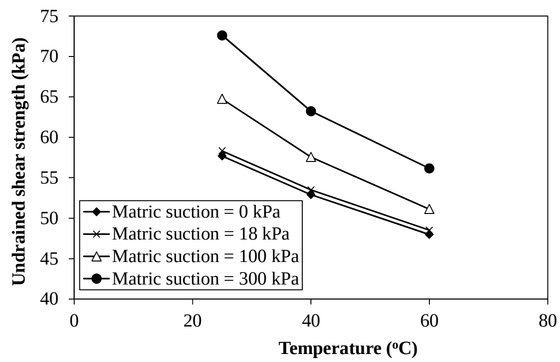

Figure-1. Variation of undrained shear strength with temperature at different values of matric suction.

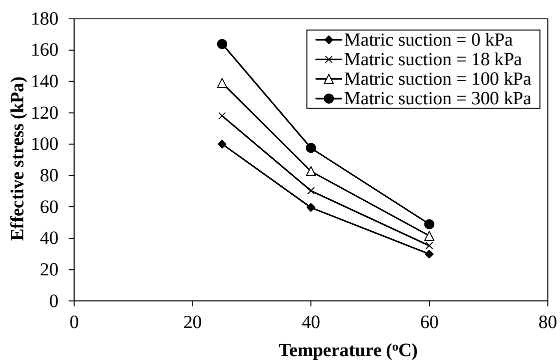

Figure-2. Variation of effective stress with temperature at different values of matric suction.

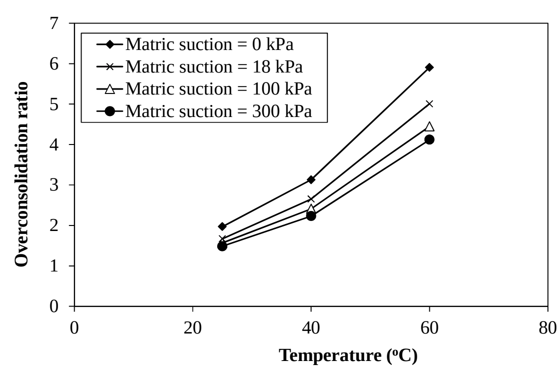

Figure-3. Variation of over consolidation ratio with temperature at different values of matric suction.

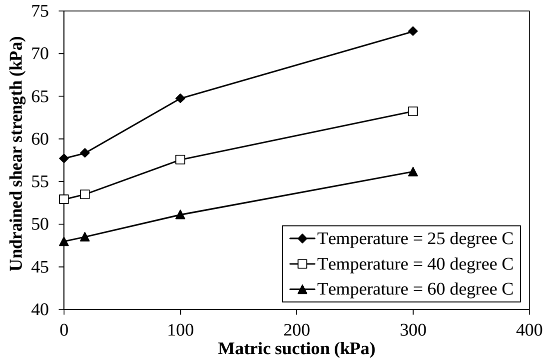

Figure-4. Variation of undrained shear strength with matric suction at different values of temperature.

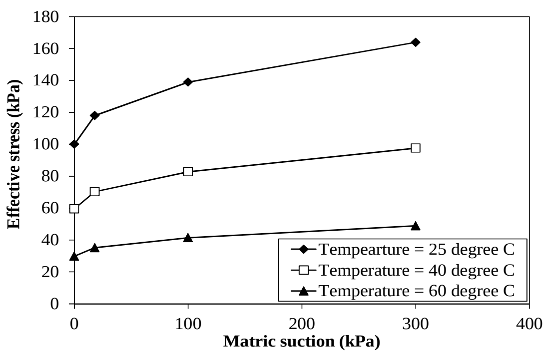

Figure-5. Variation of effective stress with matric suction at different values of temperature.

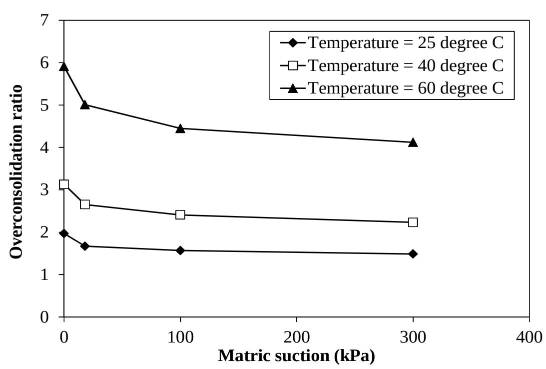

Figure-6. Variation of over consolidation with matric suction at different values of temperature.

CONCLUSIONS

A variation of undrained shear strength of unsaturated porous media with temperature and matric suction was simulated using the equation of undrained shear strength including thermal effect derived by Uchaipichat (2013). The material parameters used in simulation were obtained from Uchaipichat (2005). Typically, the results show that the undrained shear strength decreases with increasing temperature for all values of matric suction. However, the undrained shear strength increases with increasing matric suction for all values of ambient temperature.

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