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Suction effects in unsaturated soil

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Introduction : Unsaturated soils have higher strength than saturated soils. But once the wetting (decrease in suction) takes place, there occurs a marked difference in shear strength and volume of the soils. In the worst case, collapse of the structures or foundations might occur. It is very difficult to estimate the amount of changes in the shear strength (safety against failure) and the volume (deformations) due to change in suction value (or degree of saturation). In such case, Kohgo's elastoplastic model could be used for estimation of amount of changes in shear strength and volume. Accordingly, the model is based on two suction effects: (i) an increase in suction increases the effective stress and (ii) an increase in suction induces an increase in both yield stress and stiffness against plastic deformations. The first suction effect could be estimated from the following equation: $\sigma' = \sigma - u_{eq}$; $u_{eq} = u_a - s$ for $s < s_e$;

$u_{eq} = u_a - \left[s_e + \left\{s^*(s_c - s_e)/(s^* + a_e)\right\}\right]$ for $s \geq s_e$ where u_{eq} equivalent pore pressure, s^* effective suction, s_c critical suction, s_e air entry suction and a_e material parameter.

The second suction effect could be estimated from the state surface concept which is the relationship between logp', s^* and e in space. The relationship between e-logp' is assumed to be linear and a family of such curves could be plotted from the following relationships:

$e = -\lambda^* \log p' + \Gamma^*$; $y = \left(e^n - e_o^n\right)/\left(e_o^o - e^n\right) = \left(s^*/a_s\right)^{n_s}$ where a_s and n_s are the material parameters, e_o^o and e_o^n are void ratios at the initial conditions and superscript n denotes the n^{th} s^*- e curves.

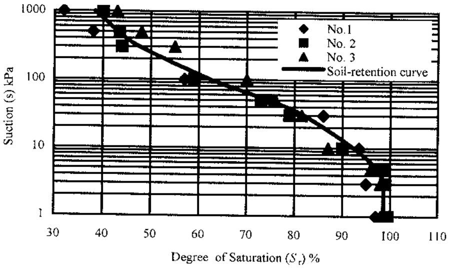

Fig. 1 Soil-retention curve

Experimental results : The soil was classified as 'SC'. The soil-retention curve shown in Fig. 1 was drawn from the pressure plate test results and three saturation states were identified; Insular air($s \leq 10$ kPa), Fuzzy saturation ($10 \leq s \geq 200$ kPa) and Pendular saturation ($s \geq 200$ kPa). The air entry value was found to be 10 kPa.

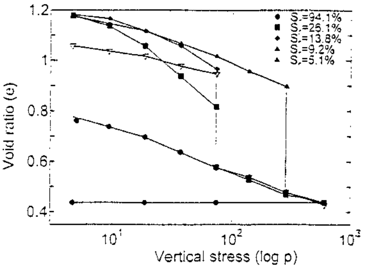

Fig. 2 Relationship between e and σ_v with soaking

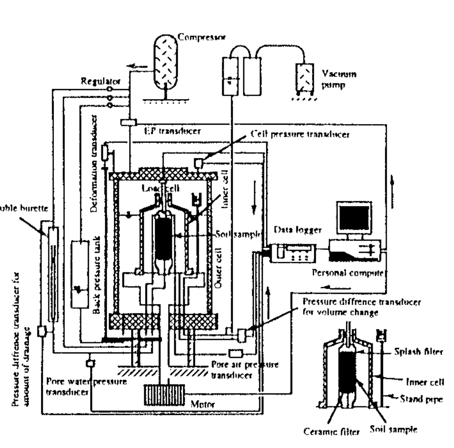

Fig. 3 Modified triaxial apparatus

The instantaneous decrease in volume during wetting tests in oedometer indicated that the soil is collapsible one and after collapsing, they follow the saturated loading path (Fig. 2). The collapsing phenomenon depends upon the vertical stress applied to the specimen. In Fig. 2, we could also observe the increase in yield stress and the decrease in slope of e-logσ_v curves with the increase in suction. The triaxial compression tests were carried out in a specially designed triaxial apparatus (Fig. 3). The stress-strain curves thus obtained showed the increment in deviator stress with the increase in suction values at same confining pressure and strain rate but different constant suction (Fig. 4). The volume change behavior during shear were explained in Fig. 5. We could observe that there was decrease in the amount of volume change with the increasing suction. The reason being that the suction inhibits the plastic deformation of the soil specimens. The e-log$p$ curves $(p = \sigma_m - u_a)$ during shearing (Fig. 6) showed that there

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was increase in yield stresses and decrease in the slopes as the suction increases. The strength parameters obtained from the tests are M=1.361 and ϕ'=33.7° and c=0 kPa. From the formulations of first suction effect, the effective stress parameters obtained are s_e=10 kPa, s_c=25.2 kPa and a_c=15.2 kPa. Using the second suction effect, state surface parameters calculated are e^0_o=1.290, a_s=3500 kPa, n_s=0.50, λ=0.27 and Γ=1.140.

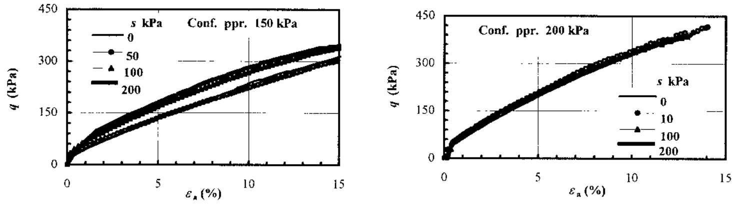

Fig. 4 Stress-strain curve

Normalization curves (Fig. 7) were drawn between q/σ'_3 - ε_a. The σ'_3 were estimated with the utilization of effective stress parameters. Normalized stress-strain curves were not same at lower confining pressures. But at higher confining pressures, they seemed to be one, indicating that effect of suction was dominant at low confining pressures whereas at higher confining pressures, the effect of suction was suppressed. Using state surface parameters, void ratios were estimated and were compared with experimental values (Fig. 8).

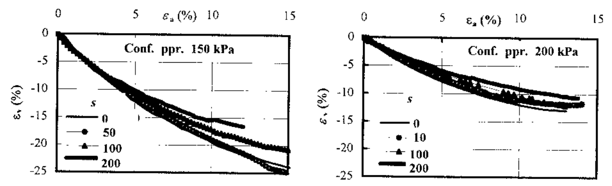

Fig. 5 Relationship between ε_v and ε_a

Conclusion : Comparison of the samples at same confining pressures but different constant suctions showed that shear strength was increased as suction values were increased. But the rate of increment of shear strength was decreased with the increase in confining pressures. In case of volume change, it showed that samples with higher suction values had lower amount of volume change than the samples with lower suction. But with the increase in confining pressures the effect of suction was suppressed. Also, a well agreement between the experimental and estimated void ratios was observed from Fig. 8. Thus, we could conclude that the model could be efficiently used to find the shear behavior and volume change characteristics of the unsaturated soils with the change in suction (or degree of saturation).

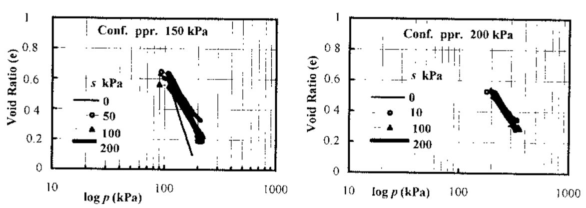

Fig. 6 e-log$p$ curves during shearing

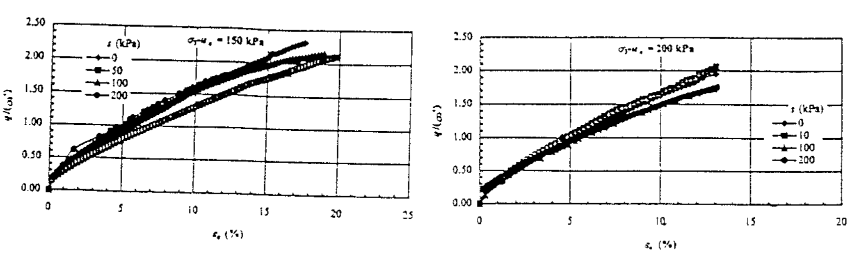

Fig. 7 Normalized Curves (q/σ_3' – ε_a)

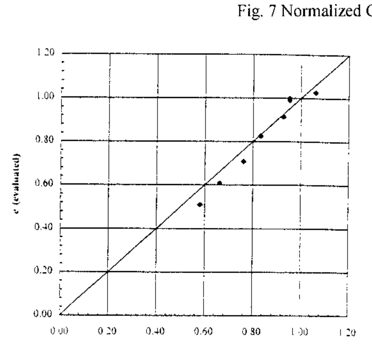

Fig. 8 Measured and predicted void ratios

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