Author manuscript, published in "W(H)YDOC 08 : 3rd international workshop of young Doctors in geomechanics, France (2008)"

hal-00510563, version 1 - 19 Aug 2010

EFFECTS OF PARTIAL SATURATION ON THE BEHAVIOUR OF A COMPACTED SILT

Francesca Casini (francesca.casini@igt.baug.ethz.ch)
Institute of Geotechnical Engineering, Swiss Federal Institute of Technology Zurich, Switzerland

ABSTRACT. The effects of partial saturation on the behaviour of a compacted silt was investigated. In the first part of the work the compatibility of the experimental data carried out at Università di Napoli Federico II to investigate the effects of partial saturation on the volumetric behaviour and on the initial shear stiffness of a compacted silt with a Bishop Stress Modeln (BSM) were discussed. In the second part of the work the results of a centrifuge model of a shallow foundation relying of a layer of unsaturated soil and submitted to axial load for different water level were discussed. The tested material is an eolian silt from Jossigny, East of Paris. This work was done with the support of MUSE network. The objective of the work was to represent a foundation of 1.5 m in diameter on a 15 m soil layer.

1. Introduction

The results obtained at Università di Napoli Federico II of a compacted clayey silt (Vassallo *et al.* 200/) were reinterpreted using a Modified Cam Clay Model extended to unsaturated conditions (Jommi 2000, Tamagnini R. 2004). The model predicts correctly the influence of Sr on compressibility also for tests which included compression stage and, then, wetting drying cycle (Casini et al. 2008).
The state of partial saturation play an important rule on the behaviour of a shallow foundation at failure. The objective of the second part of the study was to provide experimental data on the effect of suction (unsaturated soil) on the behaviour of a shallow foundation and to validate numerical results for the case of a foundation relying over a layer of unsaturated silt and submitted to axial load for different water levels.
In order to keep as much control as possible over the conditions of the problem, a reduced model of the foundation was builted into a centrifuge. The material studied is a low plasticity silt remoulded. The model was prepared for static compaction, controlling the speed of displacement and read the force by a load cell.

2. Modelling of experimental results with a Bishop Stress Model

The tested material is the Po silt: a clayey-slightly sandy silt representative of the materials used for the construction of the embankments on the Po river (Italy). It is classified as inorganic silt of medium/high compressibility. The classic Bishop equations for the effecrive stress is adopted:
$\sigma' = \sigma - u_a + S_r(u_a - u_w)$ (1) where σ_{ij} are total stresses, u_a is the air pressure, u_w is the water pressure, δ_{ij} is the Kronecker delta, $\chi(Sr)$ is a weighing parameter which can account for the effects of surface tension. In this work $\chi(Sr)$ was assumed equal to Sr. The evolution of the scalar internal variable p'c (overconsolidation pressure) depends not only on the rate of plastic strains but also on the variations of degree of saturation:

$$\dot{p}'_{c\,unsat} = -bp'_c\,\dot{S}_r \tag{1}$$

The integration yields to the equation:

$$p'_c = p'_{c\,sat} \cdot exp[b(1 - S_r)] \tag{2}$$

b is a new parameter that controls the rate of change in p'_c caused by variation in S_r.
The hardening is so regulated so as irreversible give it development of the plastic volumetric strains (evolution of p'_{csat}) so as reversible by change in degree of saturation.
The model requires a hydraulic constitutive relationship describing the water storage mechanism. The retention curve $\theta_w = \theta_w(s)$ obtained upon an imbibition process differs from that obtained upon drying (hysteresis) (Figure 1a). Equilibrium at a given suction may be obtained with different θ_w. The two main curves are linked by scanning curves that can be linear or not. In this study the equation proposed by Van Genuchten (1980):

$$\theta_w = \theta_{wsat}\left[\frac{1}{1+(\alpha s)^n}\right]^m \tag{3}$$

is used, where θ_w is the volumetric water content, θ_{wsat} is the volumetric water content under saturated conditions and s is matric suction. All the available experimental data from equalization stages for all triaxial and resonant column tests together with the adopted water retention relationship are repoted in figure 1b.

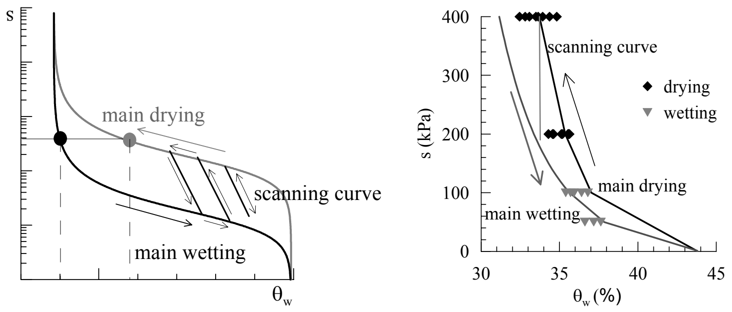


Figure 1. Water retention curves: (a) relationship adopted; (b) experimental results versus adopted WRC.

The performance of the model was verified for tests included a compression stage and, then, wetting-drying cycles as test MP07 reported in figure 2. The predictions of the model are in good qualitative and quantitative agreement with the experimental data in terms of specific volume changes plotted versus mean effective stress.

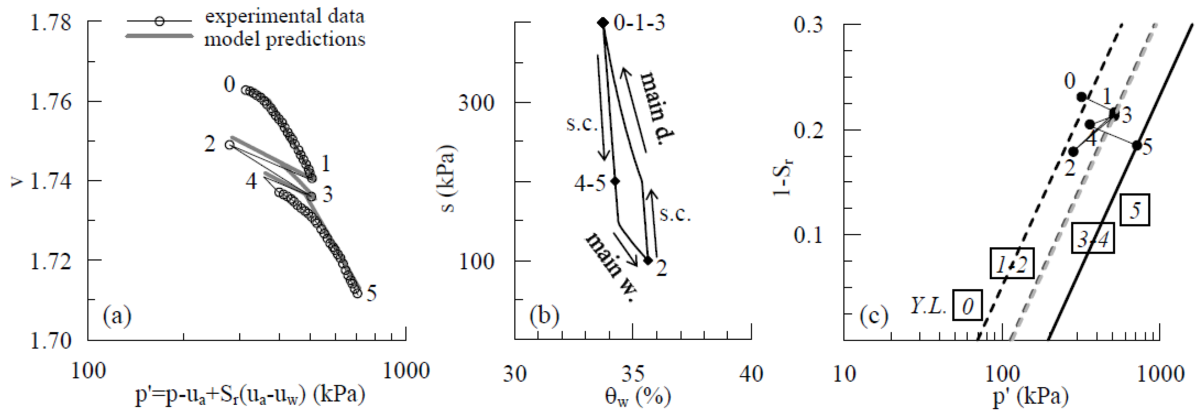


Figure 2. Test MP07. Experimental data versus prediction in p':v plane: (a) prediciton in $p':v$ plane (b) in $\theta_w : s$ plane and (c) in $p':(1-S_r)$ plane.

hal-00510563, version 1 - 19 Aug 2010

3. Centrifuge modeling of a shallow foundation on a layer of collapsible soil

The tested material is a low plasticity silt with clay. Jossigny silt has a liquid limit w_L = 32.3%, a plastic limit w_P = 17%, 25% of particles less than 2 μm and a unit weight of solid particles γ_s = 26.4 kN/m^3.

Saturation tests

Ten tests in a oedometric standard cell were performed at various initial void ratio and water content w=13%. The samples was statically compacted at target dry densities. The stress path followed was a compression stage until to a σ_v = 200 kPa (one test until a σ_v = 100 kPa) and a saturation phase. It was done in order to reproduce a stress path follow by an element of soil in the lower part of model, and to understand its behaviour when it was connected with water.

In Figure 3a it was reported the results in the plane e-logσ_v. When the initial void ratio lower also lower the reduction in volume induced by saturation. The collapse" for saturation disappear for a e_0<0,7. Also at σ_v = 100 kPa it was measured a reduction induced by saturation. In Figure 3b is reported the deformation induced by saturation in function of initial dry unit weight. It was decided to prepare the model to a γ_d=14,5 kN/m^3 and w= 13% (Sr≅42%).

hal-00510563, version 1 - 19 Aug 2010

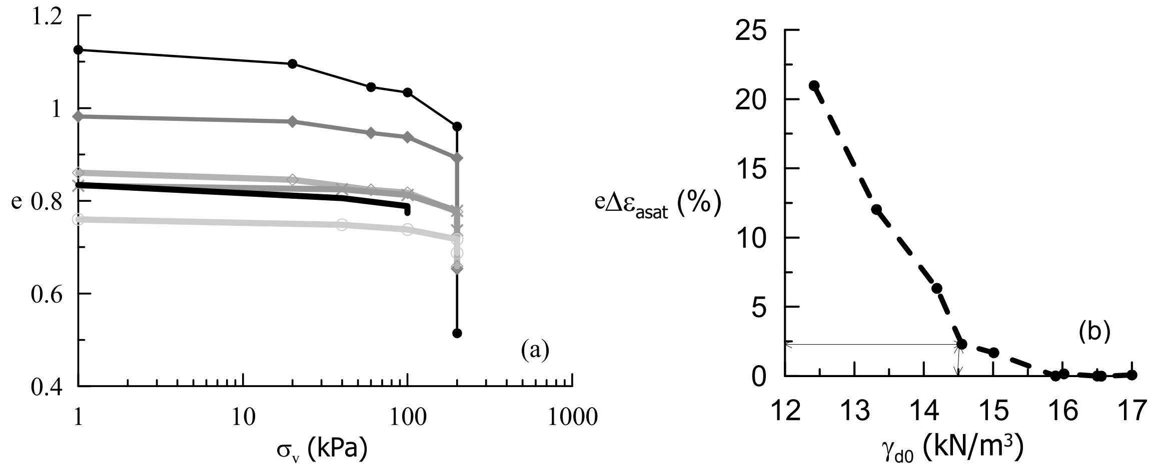
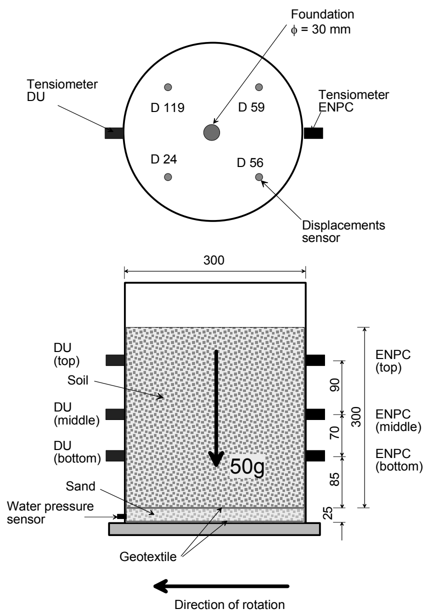


Figure 3. Oedoemetric tests at various initial void ratio: (a) samples collapsible at saturation, (b) deformation at saturation- initial dry unit weight (Casini et al. 2008).

Model and instrumentation

The samples was compacted statically in a cylindrical container using a 5.0 ton load frame. The procedure set-up used it was the same of previous campaigns performed at ENPC (Cui et al.2005). It have been prepared in total eight samples (each one weight 35 kg), the properties are reported in table 2 (Muñoz et al. 2008 in prep.). In Figure 4 is reported the instrumentation and its position on the sample. It was installed six tensiometers (five in the first campaign) on the diametral opposite sides. Three tensiometers provided by CERMES (labelled ENPC) and three provided by Durham University (labelled DU) in the figures. The elevation are reported in the figure 4. One water pressure transducer was installed at the base of metallic container in the sandy layer in order to control the water pressure in the model.



Sample	*w (%)*	*γ_d (kN/m3)*	*σ_{vc} (kPa)*	Laboratory
F-1	13.17	14.36	296	ENPC
F-2	16.85	14.12	65	ENPC
I-A	13.9	14.30	189	LCPC
I-B	13.28	14.24	220	LCPC
I-C	13.75	14.54	196	LCPC
II-D	13.75	14.44	208	LCPC
II-E	15.1	14.29	180	LCPC

Figure 4. Instrumentation on the sample in centrifuge and sample properties.

Results

The load of foundation was performed for three height of water level. Defined H_w the height of water level measured from bottom of layer, H the height of layer, the load of foundation was performed for H_w=H, H=H/2 and H_w=0. In Figure 5a are depicted the pore water pressure profiles at the following chronological times: end of equilibration stage at 1g with no water inflow (no connection with water container); end of the flight at 50 g with no water inflow; end of the flight at 50 g with water level at the bottom of the sample (connection to water container);end of the flight at 50 g with water level at the top of the sample. The theoretical profile (a) is at constant water content and thus constant suction. Value of suction is calculated from the compaction water content and dry density through the retention curve of the material. The value measured was higher than theoretical ones at 1g. In figure 5b are depicted the pore water pressures profile for test D. The theoretical profile at 1g was in good agreement with measures. Also the comparison was good when the water level was increased. In Figure 5c is reported the load-displacement curves obtained in the test A (Hw=H complete saturation), test B (Hw=0) and test D (Hw=H/2 anda then saturation). The experimental results highlight the influence of partial saturation on failure load of foundation. The comparison of load between test A and test B show a load two magnitude much smaller in complete saturation.

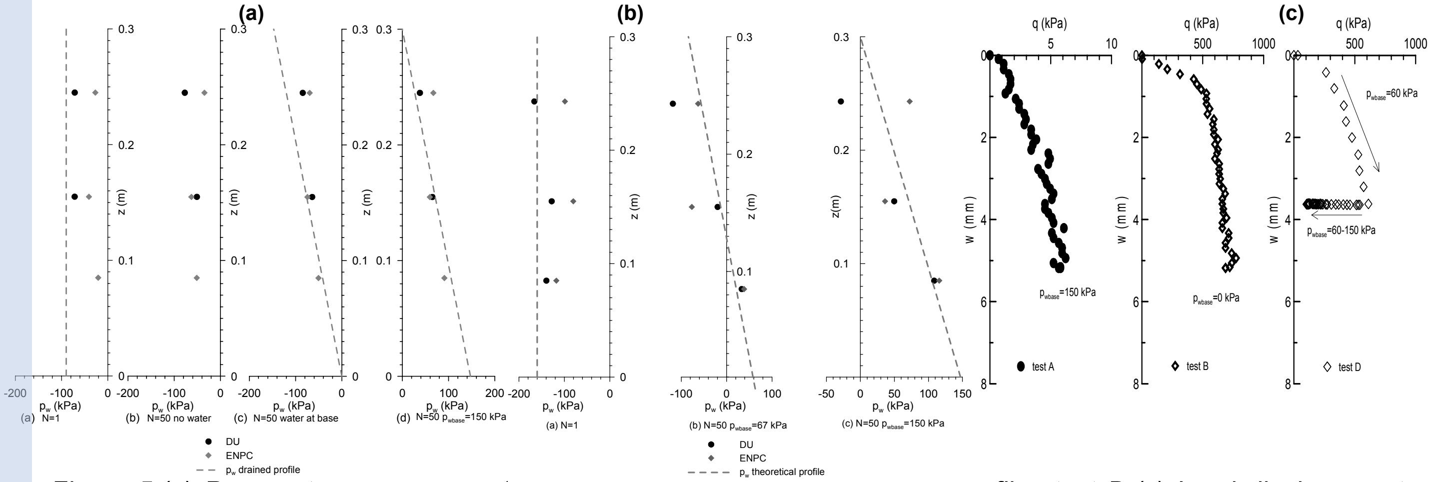


Figure 5.(a) Pore water pressure profiles test F2;(b) Pore water pressure profiles test D;(c) Load displacement curves for tests A, B and D.

ACKNOWLEDGMENT

The MUSE network is gratefully acknowledged. Author wish to express her gratitude to the staff of LCPC; ENPC; UPC and Sapienza Università di Roma.

4. References

Casini F. (2008). Effetti del grado di saturazione sul comportamento meccanico di un limo*, PhD Thesis, "Sapienza" Università degli Studi di Roma*, *Roma, Italy*.

Casini F., Vassallo R., Mancuso C., Desideri A. (2008). Application to a compacted soil of a Cam Clay model extended to unsaturated conditions. *Proc.1st European Conference on Unsaturated Soils (E-UNSAT2008) 609-615, Durham, United Kingdom*

Casini F., Munoz JJ., Lorenco S., Thorel L., Vaunat J., Delage P. & Gallipoli D.(2008). Centrifuge modelling of the bearing capacity of a shallow foundation on a layer of collapsible soil. *Proc. of International Workshop on Unsaturated Soils (IWUS 2008), Trento, Italy (in prep.)*

Chiu C.F., Cui Y.J., Delage P., De Laure E., Haza E. (2005). Lessons learnt from suction monitoring during centrifuge modeling. *Proc. of Advanced Experimental Unsaturated Soil Mechanics (EXPERUS 2005) 3-8, Trento, Italy.*

Jommi C. (2000). Remarks on the constitutive modelling of unsaturated soils. *Proceedings of the International Workshop Experimental Evidence and Theoretical Approaches in Unsaturated Soils, Trento (Italy), 139-153.*

Munoz JJ, Casini F, Lourenço S, Vaunat J, Pereira JM, Alonso EE, Delage P, Garnier J, Thorel L, Gallipoli D, Toll D. Centrifuge model of shallow foundation in unsaturated silt clay *(submitted at International Journal of physical Modelling in Geotechnics)*.

Tamagnini R. (2004). An extended Cam-clay model for unsaturated soils with hydraulic hysteresis*. Géotechnique, 54: 223-228.*

Van Genuchten M.T. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal, 44: 892-898.*

Vassallo R., Mancuso C. & Vinale F. (2007). Effects of net stress and suction history on the small strain stiffness of a compacted clayey silt*. Canadian Geotechnical Journal, 44: 447-462.*

hal-00510563, version 1 - 19 Aug 2010