Effect of sampling disturbance on the stress strain behavior of a structured collapsible soil

Effet de la Perturbation Dans le Comportement Tension-Déformation d'un Sol Structuré et Collapsible

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ABSTRACT

The secant Young's modulus determined at different strain level is a key issue in the geotechnical field to predict settlement of foundations. Most research works attribute to the effect of sampling disturbance as the main source of error in the measurement of the elastic modulus performed in laboratory samples. It seems that some kind of destructuration occurs when the soil is sampled in the field and thereafter trimmed for testing in laboratory. This work presents a fundamental study performed to evaluate the sampling effect of Argentinean loess. Block samples where recovered from open trenches and tested in the lab. The program includes laboratory and field measurement of shear wave velocity, and a battery of plate load and triaxial tests. The result allow us to conclude that the sampling procedure is performed correctly, and that the effect of sampling scale may produce a misinterpretation of laboratory results as the presence of local cemented aggregates increases the value of the measured wave velocity respect to the average field velocity.

RÉSUMÉ

Le module de Young déterminé à différents niveaux de déformations est une question important dans le domaine de la géotechnique pour prévoir l'ancre des fondations. La majorité des travaux de recherche attribut à l'effet de perturbations comme la principale source d'erreur dans la mesure du module d'élasticité effectués en échantillons de laboratoire. Il semble que certains types de déstructuration se produit comme le sol est échantillonné et par la suite parés pour les essais en laboratoire. Ce travail présente une étude réalisée pour évaluer l'effet de l'échantillonnage de l'Argentin lœss. Block où les échantillons on été récupérés des tranchées et testé en laboratoire. Le résultat nous permet de conclure que la procédure d'échantillonnage est correct, et que l'effet de l'échantillonnage produire une interprétation erronée des résultats de laboratoire que la présence d'agrégats cémentés augmente la valeur de la mesure de la vitesse des ondes l'égard de la vitesse moyenne des terrain.

Keywords : collapse, cementation, structured soil, sampling, sample disturbance

1 INTRODUCTION

Loess deposits in the central area of Argentina, as most natural soils, have some degree of weak cementation given mainly by the presence of soluble salts, silica amorphous, calcium carbonate, gypsum and iron oxide distributed at particle contacts and also concentrated as nodules. The structure of Argentinean loess has been extensively described in the previous works of Rinaldi et al., 2001 and 2007. The role of pore fluid has significant effect on loess stability (Rinaldi and Capdevila, 2006). Thus, highly acidic leachate as organic acids solves carbonates while alkaline waters promote the development of silica bonding in presence of hydroxides. The strengthening of soil structure due to cementing agents are sometimes difficult perceive since most of them weakens in front of water. The main distinctively effect of cementation in soils is a markedly elastic-plastic stress-strain behavior. The stress level at which yielding occurs is usually termed as collapse. Beyond the yielding stress, significant plastic strains occur, whereas within the yield locus strains are relatively small and recoverable.

Differences between stiffness and strength parameters measured in the field and laboratory can be important in most soils, mainly due to stress relaxation and microcracks development during sampling, aging of the specimen after sampling, boundary conditions in the testing cell (i.e. cap effects), soil heterogeneities and scale effect (samples are not representative), frequency and wavelength effects (field tests are performed at much lower frequencies as compared to laboratory test), and soil anisotropy (see: Ladd et al. 1977; Jamiolkowski et al. 1985, Tatsuoka and Shibuya 1991, Leroueil and Hight 2003). Several parameters have been used to assess the extent of sample disturbance in soils, including: volumetric change during recompression to the in situ state of stress (Andresen and Kolstad 1979, "specimen quality designation" in Terzaghi et al. 1996), vertical strain $\Delta\varepsilon/\varepsilon_o$ at the in situ state of stress as a function of overconsolidation ratio (Lunne et al. 1997), residual pore pressure or sampling effective stress (Ladd and Lambe 1963), change in stiffness at moderate strains (Jardine 1994), change in small strain stiffness G_{max} (Landon et al. 2007), and imaging techniques such as X-rays.

Deformation properties of loess are of primary importance in the design of the foundations for light weight structures. Thus, the main goal of this work was to evaluate the effect of sampling on stress-strain parameters measured in the field and in the laboratory at different strain levels. Block samples were recovered from open trenches and tested in the laboratory. A battery of laboratory and field tests was performed including plate load, cross-hole, odometers and triaxial tests. The results allowed us to evaluate the effect of sampling on soil stiffness as measured in the lab and field at small and large strain levels.

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2 SOIL DESCRIPTION AND TESTING PROGRAM

Block samples of Loess were obtained at the campus of the National University of Córdoba from a 6 meters depth open trench. Samples were immediately conditioned and placed in double plastic bags to keep constant moisture content. Table 1 shows the most significant physical parameters of the soil tested. Undisturbed (structured) specimens were trimmed and tested at natural water content in triaxial and odometer cells. The odometer cell was modified by introducing bender elements to measure shear wave velocity at varied confining pressures (Rinaldi and Clariá 1999; Clariá and Rinaldi 2000). The triaxial cell allows the measurement of strains by means of three local displacement transducers (LDTs) placed on the perimeter of the specimen. The LDTs used here are similar to those described by Goto et al. (1991). A water tensiometer was used to evaluate soil matric suction of the different block samples obtained from the site. The tensiometer was placed inside an open borehole trimmed in the block and sealed with a paraffine resine. The average value of suction determined in this test is presented in the same Table 1.

Three plate load test were performed following the guidelines given in the ASTM D-1194. The steel plate used here was 30 cm in diameter and 2.5 cm in thickness. Settlement was measured using three dial gauge fixed on the plate and distributed at 120º each. The plate was placed on a 1 m depth trench. Soil samples were also recovered from the same trench at the same depth and thereafter tested under triaxial compression. Field and laboratory test were performed al natural water content. Finally, in-situ shear wave velocity was determined by means of the cross-hole test. Two cased boreholes were used in this test up to 6 m depth and the arrivals time were recorded at the different depth. Notice that shear wave velocity is vertically polarized and the direction of propagation is horizontal.

Table 1: Relevant physical parameters of the loess tested in this work.

SUCS	Average Natural Water Content (%)	Plastic Index	Dry Unit Weight [kN/m^3]	Initial Degree of Saturation (%)	Passing Sieve Nº 200	Matric Suction [kPa]
ML	13,4	3.6 %	12.6	55 %	92.4 %	75

3 SMALL STRAIN STIFFNESS

Figure 1 displays the results of the odometer test obtained for the sample recovered from the 1 m depth. Notice that the dependence of shear wave velocity from vertical stress is similar to that described for loess and extensively discussed by Claria and Rinaldi, 2002. The yielding pressure or collapse of the soil structure occurs at the maximum of the wave velocity. Similar results were obtained for the samples recovered at other depth. Figure 2 shows the variation of wave velocity as determined in the field by means of the cross-hole test. At 6 m depth, there was a significant increment in wave velocity due to the presence of a heavily cemented layer of loess located at 6.5 m.

Figure 3 compares the measurements of shear wave velocities determined in the laboratory and the field at the same vertical overburden pressures. Notice that the sample located at 6 m depth displays higher V_{Field} than V_{Lab}. As explained earlier, the presence of the cemented layer located immediately below the 6,5 m level account for this effect. Here the V_{Field} corresponds approximately to that layer while V_{Lab} corresponds to the upper uncemented layer located at 6 m depth. The velocities V_{Lab} for the other samples are slightly higher than V_{Field}. The authors believe that a possible explanation is the influence of heterogeneities due to the localization of cemented aggregates in the samples recovered and tested in the laboratory. Waves propagated through the aggregates at higher velocities than the surrounding medium. This effect is more important as the thickness of the samples decreases. In the present case, the thickness of odometer samples was 36 mm. Here, V_{Field} can be considered as an averaged velocity of the soil while V_{Lab} is a local velocity. The effect of anisotropy in the propagation of shear waves may be also considered as an alternative explanation but it was no evaluated here and it deserves future research.

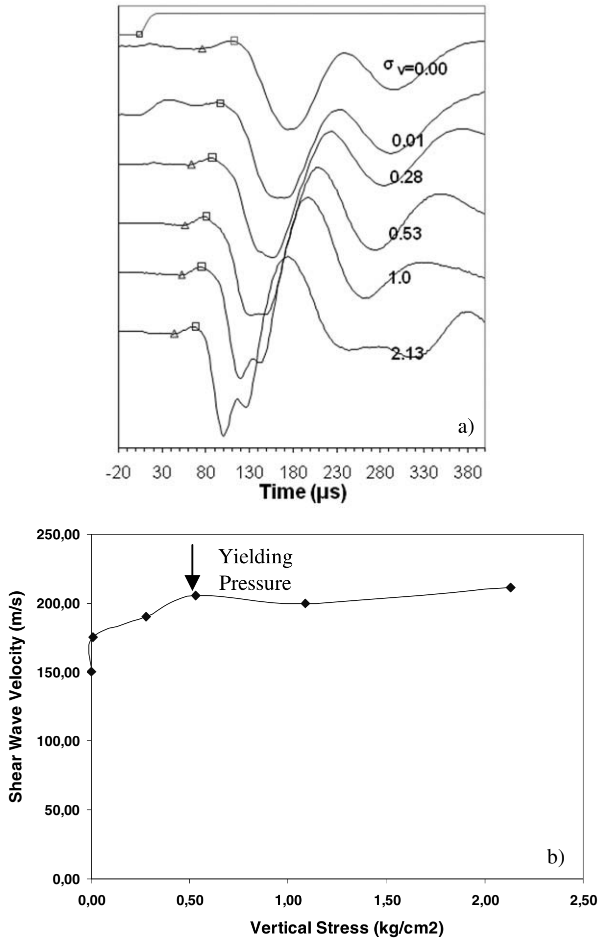

Figure 1: Test results obtained in the odometer cell for the sample corresponding to 1m depth. (a) Signals recorded at the transmitter and receiver bender elements. Dots indicate selected time arrivals, (b) variation of shear wave velocity respect to the vertical pressure.

4 HIGH STRAIN STIFFNESS

Figure 4 shows the triaxial test results obtained for the undisturbed samples at natural water content and at various confining pressures. At high confining pressures yielding of unsaturated soils occurs gradually due to suction forces that becomes dominant respect to cementation. At low confining pressure the behavior becomes brittle and the curves approximate to a bilinear behavior (see Rinaldi and Capdevila 2006). In Figure 5, it can be observed that degradation curve of the secant modulus obtained from triaxial results does not decay smoothly but describe some kind of jumps which is attributed here to a sudden and partial breakage of cemented bonds. Figure 6 displays the results obtained for the plate load test performed at natural moisture content. There are a large number of equations that allow evaluating the elastic modulus from the plate load test results (eg. Poulos and Davis 1991; Das 1983). A parametrical back analysis was performed in this work to compare their predictive accuracy using the software Plaxis. From this study, the model of D'Appolonia (1970) yielded the best approximate.

$$E = \frac{q \cdot D \cdot I \cdot (1+\nu)(1-2\cdot\nu)}{s\cdot(1-\nu)} \tag{1}$$

Where q is the load, D is the plate diameter, ν is the Poisson coefficient, s is the plate settlement corresponding to a given load q, and I is the influence factor (here was used 0.65).

The reference main stress $\sigma_o = (\sigma_v + 2\,\sigma_h) / 3$ (being σ_v and σ_h the vertical and horizontal stresses respectively) was assumed in this analysis to be located at a depth of 3/4 D (Terzahi y Peck 1948; Lambe y Whitman 1969; Lomize y Kravtsov 1969; Abramov *et al*. 1973; Tsytovich *et al*. 1979).

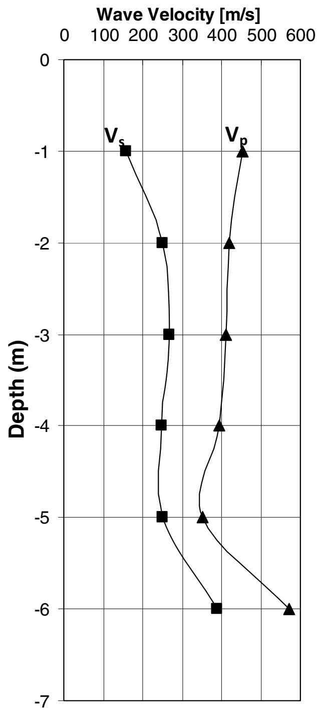

Figure 2: Shear and compression wave velocities obtained from the field by means of the cross-hole test. Notice the increment of wave velocity at 6 m depth.

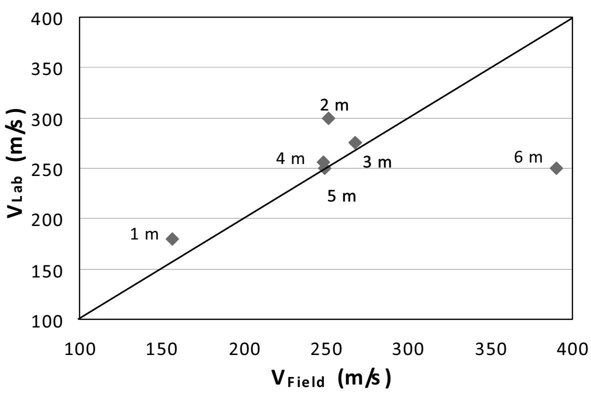

Figure 3: Comparison of shear wave velocities determined in the field and from laboratory test at the same vertical overburden pressures. Numbers indicates depth in meters.

Figure 7 displays the variation of the secant modulus determined in the triaxial cell and the plate load test as a function of the mean confining pressure and strain level. At a given strain level, the curve increases exponentially as typically observed in most soils. The exponent of the curve becomes higher as the strain level decreases. Notice that there is a good agreement between measurements obtained in the lab and that determined in the field. The dispersion of results seems to increase as the strain level decreases. Here, the effect of heterogeneities can be considered as the responsible for this effect, since as observed on Figure 5 the secant modulus fluctuates significantly at small strain levels.

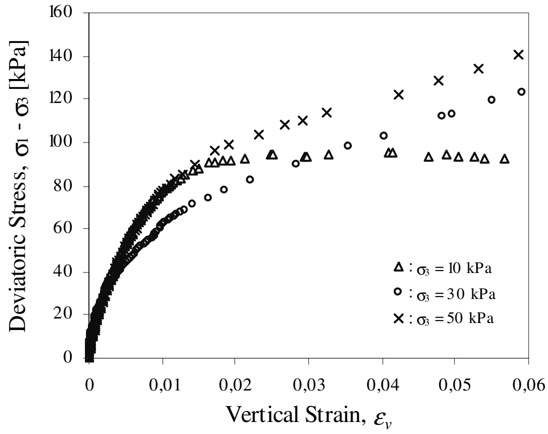

Figure 4: Stress-strain triaxial test results obtained for undisturbed samples of loess at natural water content.

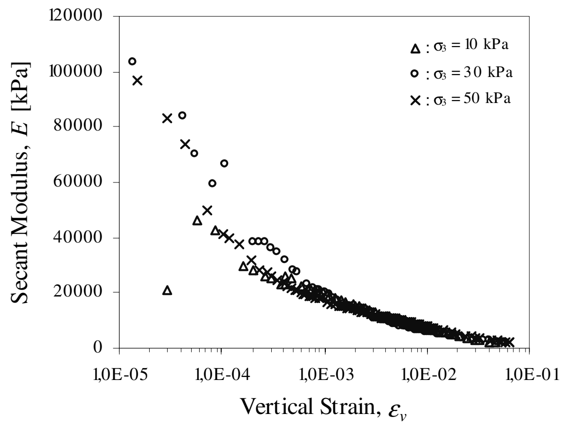

Figure 5: Modulus degradation curves obtained for undisturbed samples of loess at natural water content.

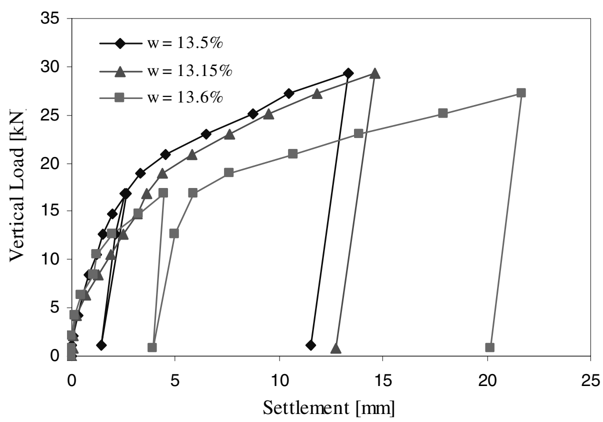

Figure 6: Results of the three plate load tests performed in this work.

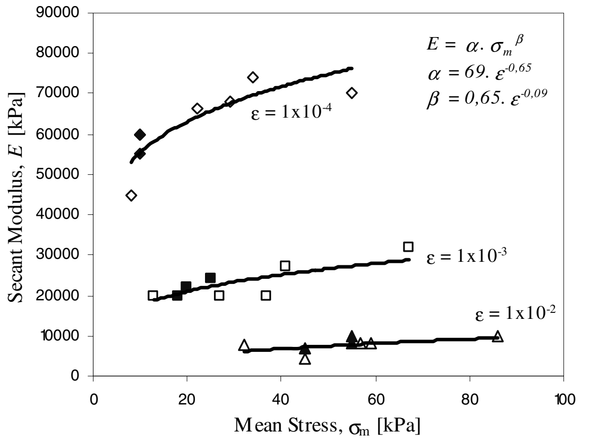

Figure 7: Variation of the secant modulus of loess at natural water content with respect to the mean confining stress and strain level (ε). Filled dots correspond to plate load test results and empty dots to triaxial test results.

5 CONCLUSIONS

Loess samples in Argentina are usually obtained as block from open trenches. This paper examines the effect of the sampling procedure on soil stiffness. The methodology used in this work to achieve the objectives was to compare soil stiffness obtained by means of laboratory and field tests at different strain levels. The main conclusions of the work presented here can be summarized as follow:

a) The effect of scale seems to be important at small strains. Thus, the presence of nodules or cemented aggregates may increase shear wave velocity measured in thin specimens as is the case of those samples tested in the odometer cell.
b) Field velocity obtained by means of the cross-hole test becomes more representative of the whole soil mass.
c) Secant modulus obtained by means of triaxial apparatus using LDTs and plate load test agrees very well if both tests are compared at the same mean confining pressure and strain levels.
d) The presence of cemented nodules and aggregates make difficult the measurement of the modulus at small strain levels.
e) The sampling procedure used here can be considered acceptable for loess.
f) The size of the samples to be tested in laboratory should be larger respect to the nodules distributed in the soil mass.

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