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A STUDY OF SOIL MICROSTRUCTURE USING BENDER ELEMENT TESTS

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ABSTRACT

An application of bender elements to measure the effect of soil microstructure in shear wave velocity is presented. A testing program was carried out on Mexico City sediments using a triaxial cell fitted with bender elements. Shear wave velocities were measured during isotropic consolidation and during failure. From the results of these tests simple expressions were obtained which describe the variations of shear wave velocity with the current state in terms of the effective stress and axial deformation.

KEYWORDS

Soil microstructure, bender elements, shear wave velocity, triaxial cell, consolidation, failure.

INTRODUCTION

The microstructure of soils implies the combined effects of fabric, chemical composition, mineralogical constitution, and interparticle forces. Thus, the microstructure of a soil reflects all facets of the soils composition and history, including electrochemical environment, accumulation rate, turbulence during sedimentation, post-depositional changes, and other factors.

Particle rearrangement and consequent fabric changes occur at middle and large strains ($\gamma > 10^{-2}$). Particle deformation depends mainly on the interparticle contact response and material properties. The effect of fabric changes on wave-propagation parameters has been addressed by Santamarina and Cascande (1996).

This paper explores what can be learned about microstructure of Mexico City sediments using a conventional stress path triaxial cell with benders elements in the top and bottom platens.

Results presented next were obtained as part of a comprehensive research program on the microestructure of Mexico City sediments which is being conducted at the National University of Mexico (UNAM). The purpose of this study is to gather new information about Mexico City soils, in order to facilitate the interpretation of the deposit evolution leading to the current microstructure and ensuing engineering properties of this peculiar stratigraphic sequence, including its dynamic response.

SOIL DESCRIPTION

Mexico City soil is a volcanic lacustrine silty clay deposit, interbedded with thin sand layers of pyroclastic materials of sand and silt size. Physical, chemical and mineralogical properties of a core from Mexico City sediments has been described by Díaz-Rodríguez et al. (1998) and will not be repeated here. The soil specimens were obtained from the City Park (Alameda Central). All soil samples were obtained by using 127 mm-diameter thin-walled Shelby tubes.

Geotechnical properties of Mexico City sediments are usually variable from place to place and with depth, but the soil samples used here were relatively homogeneous. Some physical properties of the soil are summarized in Table 1.

Table 1. Index Properties of soil samples (depth=15 m)

Properties	Value
Natural water content	362
Unit weight, kN/m³	11.05
Liquid limit, %	461
Plastic limit,%	84
Specific gravity	2.39

TESTING PROGRAM

A triaxial testing program was designed to study the pattern of shear wave velocity: (1) during isotropic consolidation (Series C) and (2) during one effective isotropic pressure followed by failure (Series F).

The isotropic consolidation series to define the yielding stress, p'_Y , was done by triaxial-cell method on 36-mm-diameter and 75-mm-height specimens. The base pedestal, upon which the specimens were placed, is connected to a drainage line. The specimens were encased in two membranae separated by a film of silicon oil. Filter paper strips were used along the length of the specimen to accelerate drainage. The cell was equipped with a ball-bearing air bushing to reduce the friction along the piston. All tests were carried out at a back-pressure about 250 kPa. The yielding stress (Díaz-Rodríguez *et al.* 1992) corresponds to the passage from the structurated range to the beginning of the destructurated range. A summary of testing program and results for Series C is shown in Table 2.

Table 2. Summary of testing program: isotropic consolidation

Test number	Confining	Volume	Initial wave	Final wave	Wave velocity
	pressure	change	velocity	velocity	change
No.	σ_c'	ΔV	$(Vs)_i$	$(Vs)_f$	ΔVs
	kPa	cm^3	m/s	m/s	m/s
C1	14.71	0.168	59.64	60.46	0.818
C2	49.02	2.205	59.59	61.99	2.398
C3	80.88	5.46	57.63	62.09	4.465
C4	95.59	8.043	60.05	63.35	3.299
C5	110.29	11.046	63.22	67.58	4.366
C6	147.06	15.876	67.58	74.07	6.488

An additional series of six CU triaxial tests using effective stresses varying between 28 to 147 kPa before undrained compression under stress control was carried out. All tests were led to failure. A summary of testing program and results for Series F is shown in Table 3.

LABORATORY TECHNIQUE FOR MEASURING Vs

The first application of bender elements in soils was described by Shirley and Anderson (1975). Brunson and Johnson (1980), Schultheiss (1981), Dyvik and Madshus (1985), Thomann and Hryciw (1990) and De Alba and Baldwin (1991) have reported results using bender elements inserted directly into the soil specimen.

The bender element is a transducer, which is capable of converting mechanical energy to electrical signal, or vice versa. The element consists of two transverse expander plates bonded together so that a voltage applied to electrodes causes the plates to deform in opposite directions. This opposition causes the element to bend. Conversely, a mechanical bending of the element produces a voltage between the electrodes. This property of bender elements allows to apply small shear waves in soil specimen without modify the inherent properties of soil. The bender elements may be connected in series or in parallel. In this work, the connection of bender element (0.5" x 0.315" x 0.24") was in series.

Since, as the bender element is a high impedance device, it cannot be exposed directly to moisture conditions because of short circuit , therefore it must be covered with thin film of epoxy varnish. For fixing the bender element to a slot of the porous stone, it must be encased in epoxy resin. In addition, to avoid the electric charge of the soil specimen, it was covered with conductive ink and finally grounded.

The arrangement of the bender elements is illustrated in Fig. 1. A function generator (Goldstar, model FG 2002C) was used to apply the excitation voltage to transmitter element; to acquire the signal response of the receiver element, a digital oscilloscope card coupled in a personal computer was used. The oscilloscope used (Beta Instrument, model SCP 202 ISA) has two channels (A, B) of 8 bits of resolution each and maximal sample rate of 40 MSamples/s. In this study the frequency sample was 2.5 MSamples/s, therefore the time resolution is 0.4 μs.

For measuring the travel time signal, a square wave (20 Vpp, 7 Hz) was applied to transmitter element. The oscilloscope records the signal applied and response signal in the channel A and channel B respectively. The travel time of the shear wave is determined as the difference between the rise of the square wave and the first significant peak in the receiver signal. A program in Visual Basic was developed for calculating the travel time interacting with the oscilloscope. This program calculates the travel time, averaging eight readings; this average cancels the effects of noise, improving so the result.

The travel time and the travel length of the shear wave yield the shear wave velocity by

$$Vs = Li / Ti \tag{1}$$

Where

Vs = shear wave velocity
Li = length of travel of the shear wave, and
Ti = time of travel of the shear wave.

The shear strains produced by the transmitter, when placed in a soil sample, are on the order of 10^{-5}.

Table 3. Summary of testing program: CU test

Test number	Initial water content	Final water content	Confining pressure	Volume change	Initial wave velocity	Final wave velocity	Wave velocity change	Initial wave velocity	Final wave velocity	Wave velocity change	Excess pore pressure	Axial strain to failure
No.	W_i	W_f	σ_c'	ΔV	$(Vs)_i$	$(Vs)_f$	ΔVs	$(Vs)_i$	$(Vs)_f$	ΔVs	ΔU	ε_f
	%	%	kPa	cm³	m/s	m/s	m/s	m/s	m/s	m/s	kPa	%
Consolidation								**Failure**				
F1	362	358	28.43	0.189	55.29	56.91	1.620	56.90	51.60	-5.290	24.510	4.186
F2	362	281	49.02	2.961	55.44	60.66	5.216	60.97	55.17	-5.799	38.235	4.223
F3	362	347	58.82	3.696	56.63	63.55	6.921	64.32	56.44	-7.878	46.078	5.134
F4	362	328	117.65	13.608	52.84	70.66	17.823	73.54	63.88	-9.666	78.431	6.898
F5	362	194	132.32	13.776	56.08	79.51	23.432	79.76	69.61	-10.149	91.176	5.943
F6	362	287	147.06	16.002	57.63	82.91	25.287	87.29	77.11	-10.182	101.961	5.977

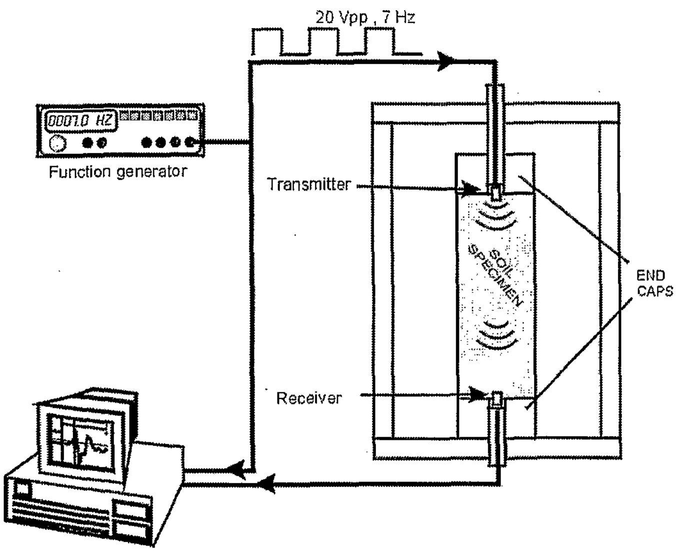

Fig.. 1 Laboratory test apparatus

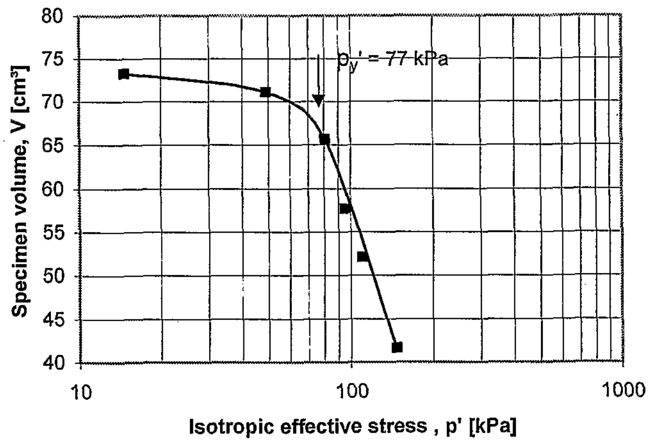

Fig. 2 Volume change with effective stress

LABORATORY TEST RESULTS

Fig. 2 shows the relationship between sample volume and the logarithm of effective pressure p', observed in isotropic consolidation tests. Even if the passage from the overconsolidated elastic domain (structurated branch) to normally consolidated (destructurated branch), plastic range is curved, a yield stress can be defined as the intersection of the two straight lines characterizing these domains. The yield stress obtained by this method was 77 kPa.

Variation of Vs with isotropic state

These tests examined the variation of Vs with isotropic effective pressure p' and consolidation time. Fig. 3 shows the values measured at the states indicated en Fig. 2. The data show that the value of Vs increases with the consolidation time and effective pressure p'. Although the variation is non-linear, the values of Vs identify two patterns of behavior, defined by the yielding stress.

An additional series of six triaxial tests (F1 to F6) were isotropically consolidated to effective stresses varying from very low effective stresses to effective stresses in excess of yielding stress (28 to 147 kPa), then the process of destructuration of the intact clay samples was studied, before undrained compression under stress control was carried out. The corresponding results are shown in Fig. 4.

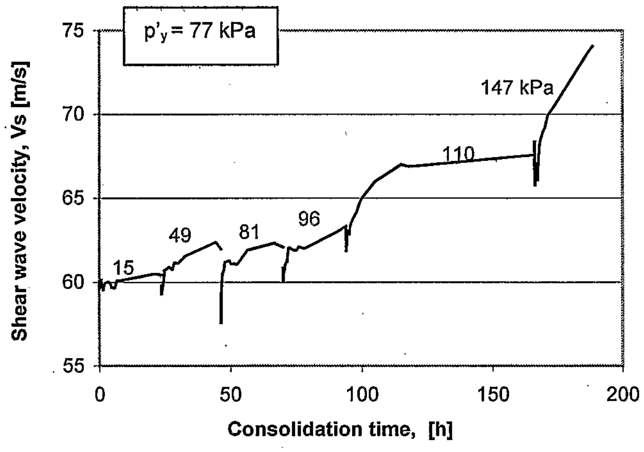

Fig. 3 Variation of Vs with stress and consolidation time

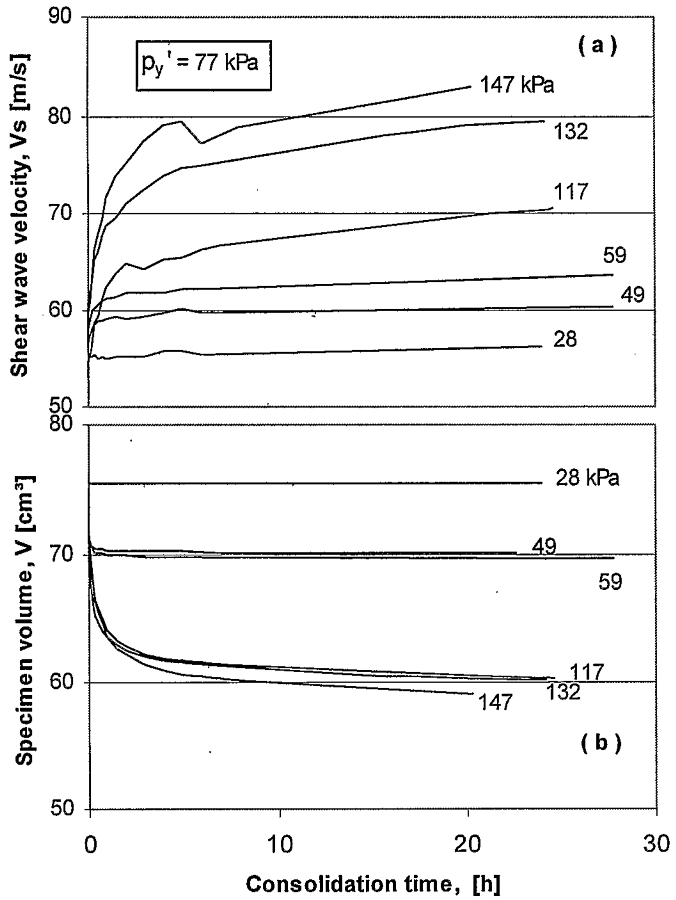

Fig. 4 Variation of Vs with stress and specimen volume

Variation of Vs during triaxial compression

Figure 5 depicts the shear wave velocity against axial strain relationships for various confining pressures, during the process to failure. According to this figure all the lines have different intercept (coefficient A) and slopes (coefficient B).

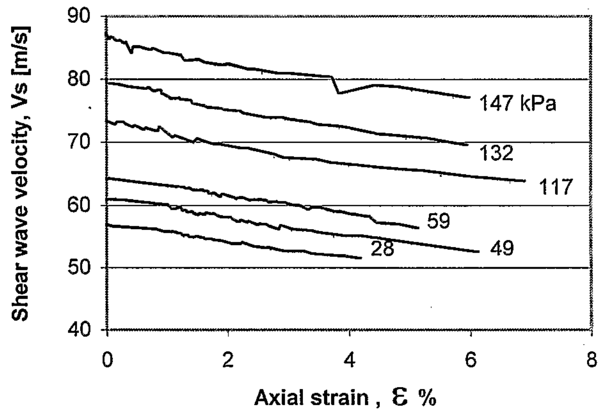

Fig. 5 Variation of Vs during failure

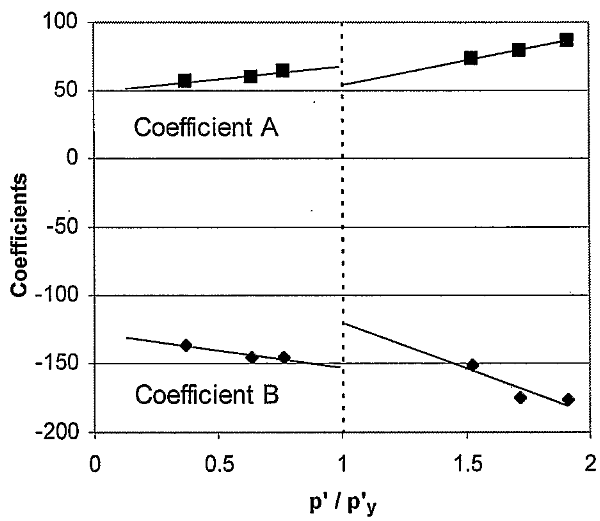

Fig. 6 Variation for the parameters A and B extracted from the data in Fig. 5

Figure 6 shows the values of A and B coefficients obtained from the data in Fig. 5 plotted against p'/ p'$_Y$. Linear regression analysis were run obtaining the following empirical relationships:

For structurated branch ($p/p'_Y < 1$)

$$A(p') = 23.3p' + 50 \quad (2)$$
$$B(p') = -33p' - 128 \quad (3)$$

For destructurated branch ($p'/p'_Y > 1$)

$$A(p') = 44.3p' + 19.7 \quad (4)$$
$$B(p') = -84p' - 54.1 \quad (5)$$

Combining the foregoing expressions, the following empirical expressions were obtained:

For structurated branch ($p'/p'_Y < 1$)

$$Vs = (-33\,\varepsilon + 23.3)\,p' - 128\,\varepsilon + 50 \quad (6)$$

For destructurated branch ($p'/p'_Y > 1$)

$$Vs = (-84.3\,\varepsilon + 44.3)\,p' - 54.1\,\varepsilon + 19.7 \quad (7)$$

SUMMARY AND CONCLUSIONS

The work investigated what can be learned about microstructure of Mexico City sediments using a conventional triaxial cell fitted with bender elements. Shear wave velocities were measured during isotropic consolidation and during failure. From the results of tests on typical Mexico City sediments, the following main conclusions can be drawn.

1. The variation of shear wave velocity during isotropic consolidation from very low stresses to effective stresses in excess of yielding stress identify two patterns of behavior, defined by the yielding stress.

2. The variation of shear wave velocity during undrained failure showed a family of straight lines with different intercepts and quite similar slopes

3. A simple expression was obtained which describe the variations of shear wave velocity as a function of isotropic effective pressure and axial deformation for structurated branch ($p'/p'_Y < 1$).

4. A simple expression was obtained which describe the variations of shear wave velocity as a function of isotropic effective pressure and axial deformation For destructurated branch ($p'/p'_Y > 1$).

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