Wave velocities in Mexico valley clays under the influence of different consolidation stress paths.

Des vitesses d'onde dans des argiles de vallée du Mexique sous l'influence de différentes trajectoires d'efforts de consolidation.

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ABSTRACT: This paper shows the results obtained of testing clay samples from the former Texcoco Lake (*CU* test), the samples were tested in a triaxial cell fitted with piezoelectric transducers (bender elements and piezoelectric discs). Different effective stress paths were used during the consolidation phase with values of effective stresses ratio ($K = \sigma_h'/\sigma_v'$ = 0.4, 0.5, 0.6 and 1.0). Compression and shear wave velocities records (V_p and V_s) were taken at the end of each increment of effective stress during the stages of saturation, isotropic consolidation and anisotropic consolidation where a sinusoidal signal with 100 volts amplitude and an excitation frequency of 40 kHz for piezoelectric discs and 0.5 to 7.0 kHz for bender elements was applied. The compression and shear wave velocities were analyzed using a method proposed in another work, where the fundamental frequency were obtained by employing transfer functions to minimize the near field effect in the arrival times of shear wave. Finally, the behavior of compression and shear wave velocities were analyzed during the test, emphasizing the influence of the effective stress path in shear wave velocities during consolidation and therefore over the soil elastic parameters.

1 INTRODUCTION.

Nowadays, many techniques and equipment are used in field and laboratory to measure compression and shear wave velocities in the soil (V_P and V_S). In this work, we used a technique employing piezoelectric transducers to measure these velocities at very low strains.

This work shows the results of signals analysis which were obtained measuring the shear wave velocity (V_S) in clay soil specimens of the former Texcoco Lake. The samples were tested in a triaxial cell fitted with piezoelectric transducers and using different stress paths during consolidation (isotropic and anisotropic).

2 TEST MATERIAL.

The soil samples used in the tests presented come from an area of the Valley of Mexico which belongs to the former Texcoco Lake, It is about 14 km to the northeast of Mexico City International Airport (AICM). According to the Geotechnical Zoning corresponds to Zone III (lake area).

The subsoil in this area is constituted by very soft and compressible lacustrine clays whose predominant classification according to the USCS is CH (high compressibility clay).

Undisturbed soil samples were recovered by selective sampling at a depth between 15.00 and 16.30 meters as shown in Table 1. The material is near of 300% water content. The clay strata are combined with thin layers of volcanic glass and fine sand. In general, the soil presents low consistency.

3 EXPERIMENTAL TECHNIQUES.

An automated triaxial pneumatic equipment was used. This equipment is instrumented with piezoelectric transducers and it can control the trajectories of isotropic and anisotropic consolidation during the triaxial test. It operates under a controlled load or displacement regime. It has a submersible load cell to measure axial stresses, transducers to measure confining pressure, back pressure and pore pressure, differential pressure transducers for measuring volumetric changes and displacement transducers (LVDT´s) to measure the axial deformation.

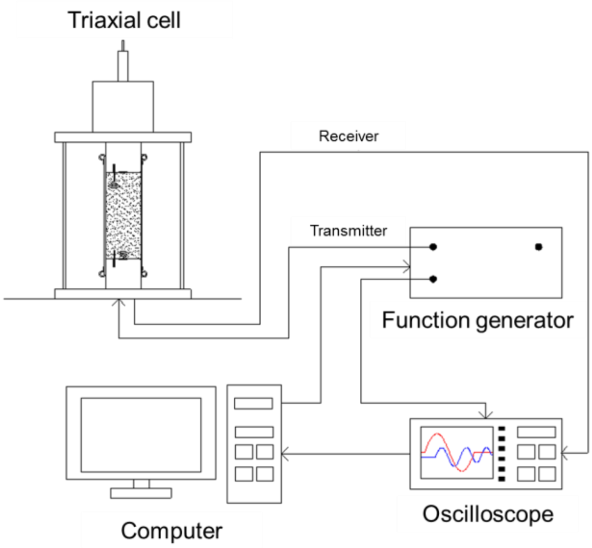

Figure 1. Data acquisition system.

In addition, a system of generation and acquisition of the excitation signal was used (Figure 1). It consist of a program developed in Lab VIEW (Laboratory Virtual Instrumentation Engineering Workbench), a function generator that sends a known signal (sinusoidal) to triaxial equipment and to an oscilloscope which it is possible to visualize in real time the emitting and receiving signals.

Table 1. Soil samples properties

Specimen	Depth (m)	K	ω %	ω_L %	ω_P %	PI %	LI	G_S	e	G_ω	γ g/cm^3	USCS
SS6-M2	15.00 - 15.90	0.4	287.6	303.9	57.7	246.2	0.934	3.07	8.9	99.62	1.21	CH
SS1-M4	15.40 - 16.30	0.5	239.4	284.2	72.4	211.8	0.788	3.03	7.5	96.95	1.21	CH
SS6-M2	15.00 - 15.90	0.6	288.0	303.9	57.7	246.2	0.935	3.07	9.1	97.34	1.18	CH
SS6-M2	15.00 - 15.90	1.0	271.4	303.9	57.7	246.2	0.868	3.07	8.5	98.36	1.20	CH

4 EXPERIMENTAL RESULTS.

Four *CU* triaxial tests were realized where the specimens were consolidated by keeping constant the coefficient of effective stress $K = \sigma'_h / \sigma'_v$ (effective horizontal stress/effective vertical stress). Different values of *K* were used (0.4, 0.5, 0.6 and 1.0) as shown in Figures 2 and 3, we can observe that in the anisotropically consolidated samples a first isotropic consolidation stress was applied to move away from the theoretical failure line. The shear wave velocities were determined during the different stages of the test (saturation, isotropic consolidation and anisotropic consolidation). In all cases sinusoidal signals were applied to the soil specimen by varying the excitation frequencies (0.5-7.0 kHz).

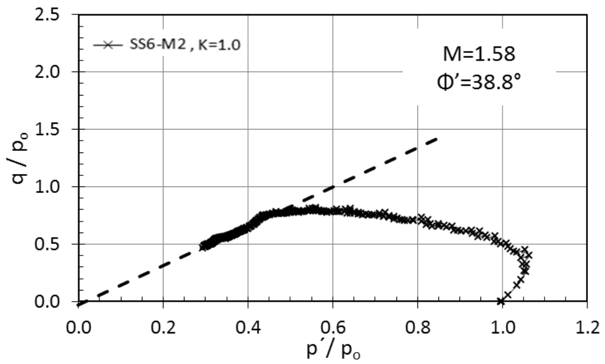

Figure 2. Trajectory of normalized effective stresses in an isotropically consolidated sample.

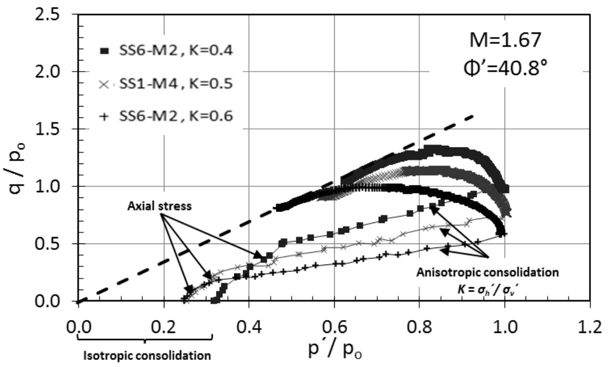

Figure 3. Trajectory of normalized effective stresses in anisotropically consolidated samples**.**

4 .1 *Signal analysis*

To accurately determine the arrival time of the shear wave in this type of test, the procedure proposed by Diaz Pardave (2014) was adopted to minimize the near-field effect.

This technique consists in using the fundamental frequency of the system (f_0) obtained by transfer functions to determine the parameter (R_d) proposed by Sanchez-Salinero et al. (1986).

$$R_d = \frac{L_e}{\lambda} \tag{1}$$

Where: L_e is the peak to peak distance between bender elements and λ is the wave length.

It is observed how the value of R_d varies as the excitation frequency changes, but remains constant when the excitation frequency exceeds 4 kHz, this constant value is called R_d * and the frequency from which R_d remains constant is called Critical frequency, f_{crit} (Diaz Pardave, 2014).

Figure 4 shown the relationship between shear wave velocities (V_s) and effective stress in overconsolidated and normally consolidated soil samples.

Finally, the relationships between the V_s values and the effective stress are analyzed according to the power law model proposed by Hardin and Drnevich (Hardin and Drnevich, 1972, Hardin, 1978).

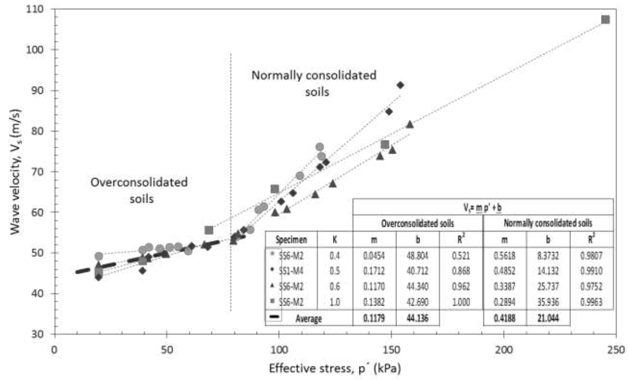

Figure 4. Variation of the trajectory of V_s by increasing the octahedral stress with respect to the overconsolidation stress.

5 CONCLUSIONS

- We applied the signal analysis methodology proposed by Diaz Pardave (2014), concluding that under frequencies above 4 kHz, the parameter R_d proposed by Sánchez-Salinero et al. (1986) to separate the near field effect is constant.
- Shear wave velocities have important changes when the effective stress increase during consolidation but this variation is more significant in normally consolidated soils, because with a smaller increase of effective stress, we have a bigger change in void ratio (*e*). Also the slope of the trajectory V_S - p' increases as the ratio of effective stresses (*K*) decreases.
- Twin samples were tested under different stress paths, concluding that the stress ratio defined by *K* in the consolidation phase, has directly influence in the shear wave velocity paths.
- Applying the power laws model to analyze the shear wave velocities in the consolidation phase, the n_s exponent shows a significant change from previous investigations where $ns \approx 0.25$. This change can be attributed to it is not an ideal means of viscoplastic perfect spheres with an uniform arrangement and this model has been little used to analyze the behavior of Valley of Mexico clays .

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