11 WCEE

Copyright © 1996 Elsevier Science Ltd
Paper No. 1029. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

EFFECT OF SOIL-MICROSTRUCTURE ON THE DYNAMIC PROPERTIES OF A NATURAL CLAY

J.A. DIAZ-RODRIGUEZ and L. LOPEZ-FLORES

Department of Civil Engineering, Universidad Nacional A. de México
Ciudad Universitaria, Apartado Postal 70-165, 04510 México D.F., MEXICO.

ABSTRACT

The key soil property in a number of dynamic response analyses as well as in most analyses and designs of building-foundation systems subjected to dynamic loads is the dynamic shear modulus. As is well known, there are several factors which have effect on it. Then the study reported herein has been conducted to the evaluation of soil-microstructure on shear modulus and damping of Mexico City clays (MCC). Undisturbed samples at three depths were investigated from a soil column using multistage resonant-column tests. The tests were carried out under several different states of isotropic consolidation, from very low effective stresses to effective stresses in excess of the critical stress, σ'_b, then the destructuration of the intact clay samples was studied. The soil-microstructure is destroyed when the clay is brought to a normally consolidated state.

For sustained-pressures less than critical stress, σ'_b, the shear modulus incresed about linearly with the logarithm of confinement time with no obvious kink at the completion of the primary consolidation. For confining pressures in excess of the critical stress the shear modulus values resulted in curvilinear relationships.

It appears from the results that the confining pressure may influence the form of the G_0 versus time curves, but it has very little influence on the G/G_0 vs strain curves.

The damping ratio of MCC remarkably decreses with time of confinement implying that in-situ clay will exhibit smaller damping ratio than that measured in the laboratory.

KEYWORDS

Shear modulus, damping ratio, time effect, soil-microstructure, critical stress, dynamic, laboratory test, Mexico City clay, destructuration.

INTRODUCTION

Intact natural clays as encountered in-situ posses a structure as a result of a combination of phenomena: deposition environment, aging, thixotropic hardening, possibly cementation and leaching.

The soil-microstructure is one of the governing factors that are responsible for the mechanical behaviour of clay. It is generally recognized that the microstructure has a substantial influence on soil response under static loading and relatively little research has been done to study the influence of the microstructure on its dynamic behaviour.

Mechanical properties such as preconsolidation pressure, shear strength and shear modulus are all directly representative of that structure. The soil-microstructure is destroyed when the clay is brought to a normally consolidated state.

A number of studies have been done to determine the response of soil to various dynamic loadings, such as explosions, steady-state vibration machinery, and earthquakes. To evaluate the response of soil to different dynamic loading, it is necessary to determine the moduli and damping factors of the various soil layers.

The research reported in this paper was directed toward the evaluation of the stress-history and soil-microstructure effects which caused variations in the low-amplitude shear modulus of Mexico City clays.

MATERIALS AND METHODS

The site from where soil specimens were sampled is located in the lacustrine zone of Mexico City. The selected site is located in the central part of the Ramón López Velarde Park, in the neighbourhood of one of the most damaged areas during the seismic event of 1985. All the samples were recovered by a 127 mm-diameter thin-walled Shelby tube.

For the present study, three undisturbed samples were taken at depths of 11.06, 15.2, and 19.28 m. The properties of Mexico City clays are usually variable from place to place and in depth as well, then the average soil properties of the soil samples are given in Table 1.

Table 1. Index properties of soil samples

Properties	Z_1	Z_2	Z_3
w, Natural water content, %	331	292	222
γ, Unit weight, ton/m^3	1.13	1.18	1.22
w_L, Liquid limit, %	388	304	280
w_P, Plastic limit, %	80	146	77
z, Depth, m	11.06	15.2	19.28
σ_b, Critical stress, kgf/cm^2	0.80	0.66	1.20

In the following, the term Mexico City clay refers only to the samples that were tested in this research.

The isotropic consolidation to define the critical stress was done by triaxial-cell method on 36-mm-diameter and 75-mm-height specimens. The base pedestal, upon which the specimen was 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 2 kgf/cm^2. The critical stress or yielding (Díaz-Rodríguez *et al.*, 1992) corresponds to the passage from the structurated range to the destructurated range.

The dynamic properties were determined by resonant-column method using 35-mm-diameter and 75-mm-height soil specimens in a similar manner than in the triaxial cell just described. Resonant column equipment used in this study is of the fixed-free type. The base pedestal, upon which the specimen was placed, was connected to a drainage line. The basic operational principle is to excite the cylindrical specimen in its first-mode torsional motion. Once the first mode is established, measurements of the resonant frequency, coil voltage, amplitude of vibration and free-vibration-decay curve are made. These measurements are combined with equipment characteristics and specimen size to calculate the shear-wave velocity, shear modulus and shearing strain amplitude using elastic theory. Material damping ratio is calculated from measurement of the free-vibration-decay curve by assuming a damped, single-degree-of-freedom system.

A fluid jacket cylinder was used. The jacket provided an annular ring of fluid (silicon oil) around the sample in order to reduce the leakage of air through the membranae.

The tests were conducted under several different states of isotropic consolidation, from very low effective stresses to effective stresses in excess of the critical stress, then the destructuration of the intact clay samples was studied. Drainage was permitted during all phases of consolidation at each stage. Shearing strain amplitudes were less than 0.04 % in all but one test series.

Each pressure increment was applied to all samples for a time interval much greater than the primary consolidation time in order to study the behaviour during the period of secondary compression.

RESULTS AND DISCUSSION

In the following subsections, results on the effect of various parameters on the shear modulus and damping ratio will be discussed.

The effect of consolidation time during low-amplitude tests

Typical test results obtained in this study are shown in Figs. 1 through 4. Figs. 1 through 3 show the variation of the shear modulus with duration of confinement and confining pressure, the depth and the critical stress are indicated in each figure. It can be observed in Figs. 1 through 3 that for confining pressures less than critical stress the change in shear modulus can be approximated to a straight line on the semilogarithmic graph with no obvious kink at the completion of the primary consolidation. For confining pressures in excess of the critical stress the change in shear modulus gave curved relationships, then the secondary compression can not be approximated to a straight line as mentioned in the literature (Afifi *et al.*, 1971, Afifi *et al.*, 1973, Anderson *et al.*, 1976, Anderson *et al.*, 1977) for other clays.

This behaviour probably reflects the unique physical-chemical characteristics of Mexico City clays. Significant rearrangement of the soil structure took place as larger increments of confining pressure were applied. The modulus increase is believed to result largely from approach of particles and strengthening of physical-chemical bonds.

Fig. 4 shows the variations of the damping ratio with time and confining pressure. The scatter in Fig. 4 is indicative that factors such as clay structure are significant, however the tendency of the damping ratio is to decrease while time of confinement increases. This decreasing indicates that the clay will exhibit much lower damping in-situ than the value measured in laboratory.

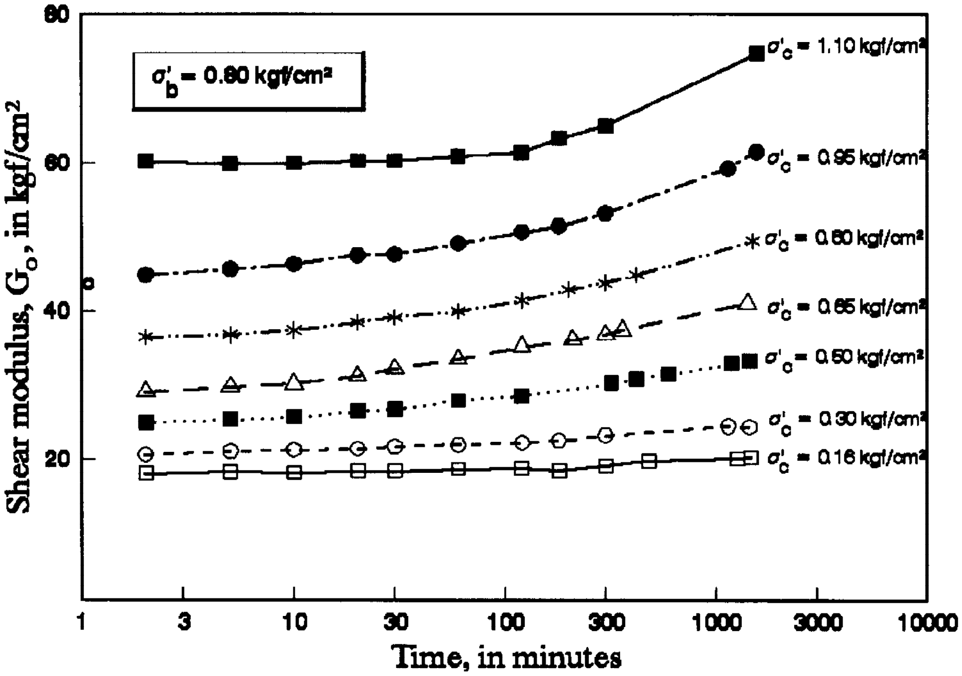

Fig. 1 Variation of shear modulus with time and confining pressure, depth = 11.06 m

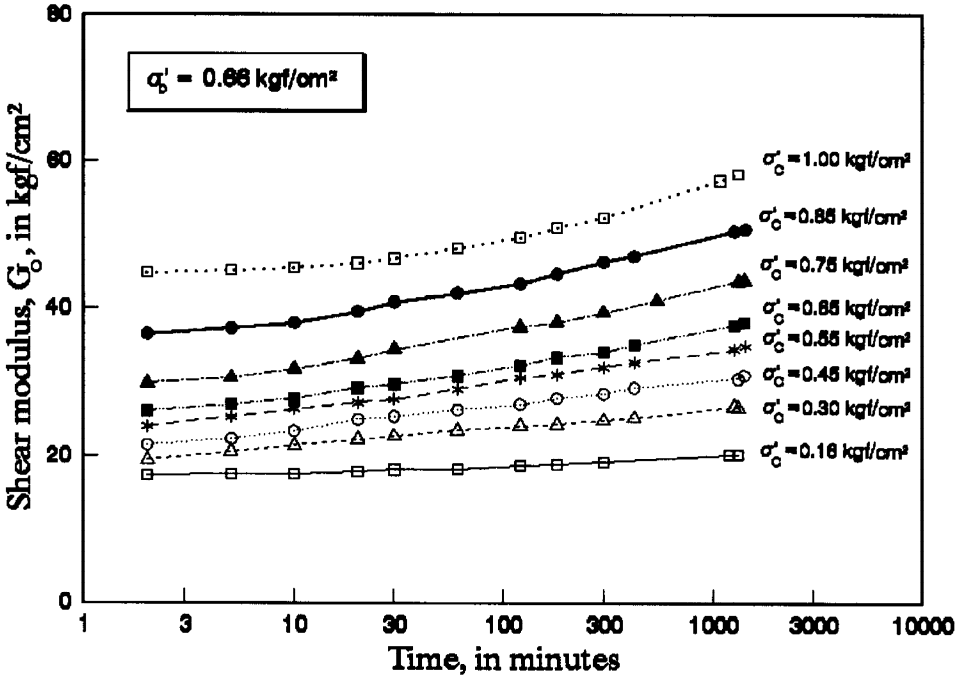

Fig. 2 Variation of shear modulus with time and confining pressure, depth = 15.20 m

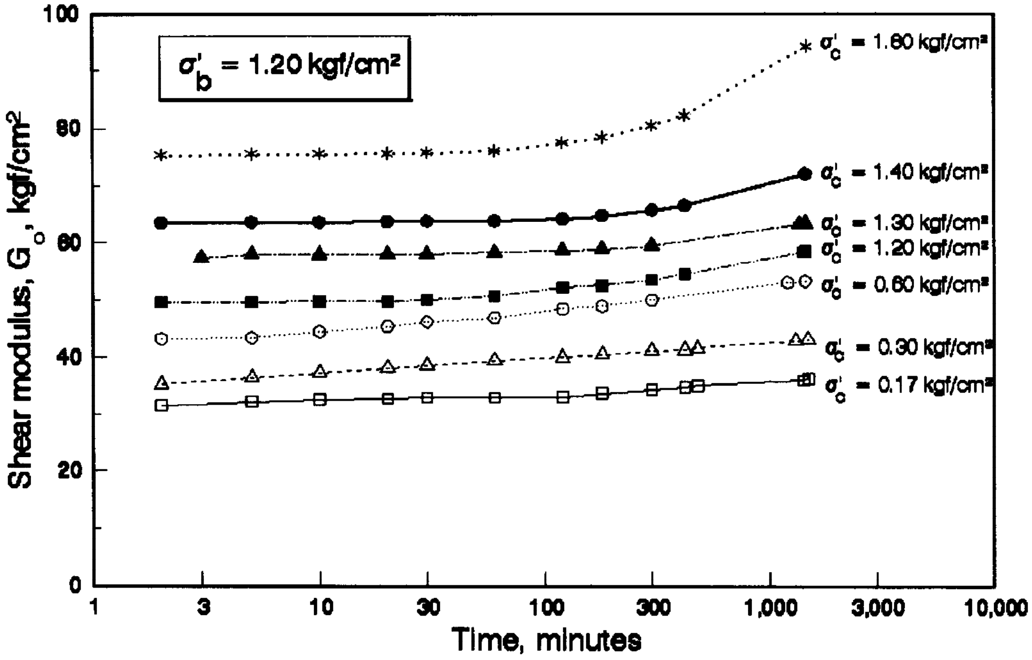

Fig. 3 Variation of shear modulus with time and confining pressure, depth = 19.28 m

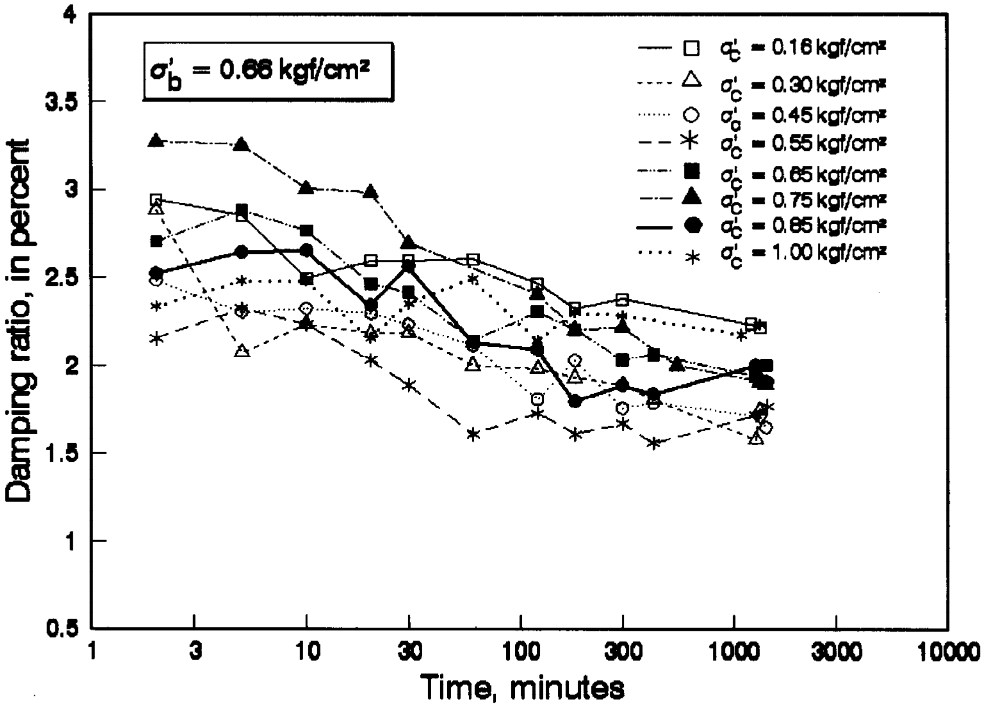

Fig. 4 Variation of damping ratio with time and confining pressure, depth = 15.20 m

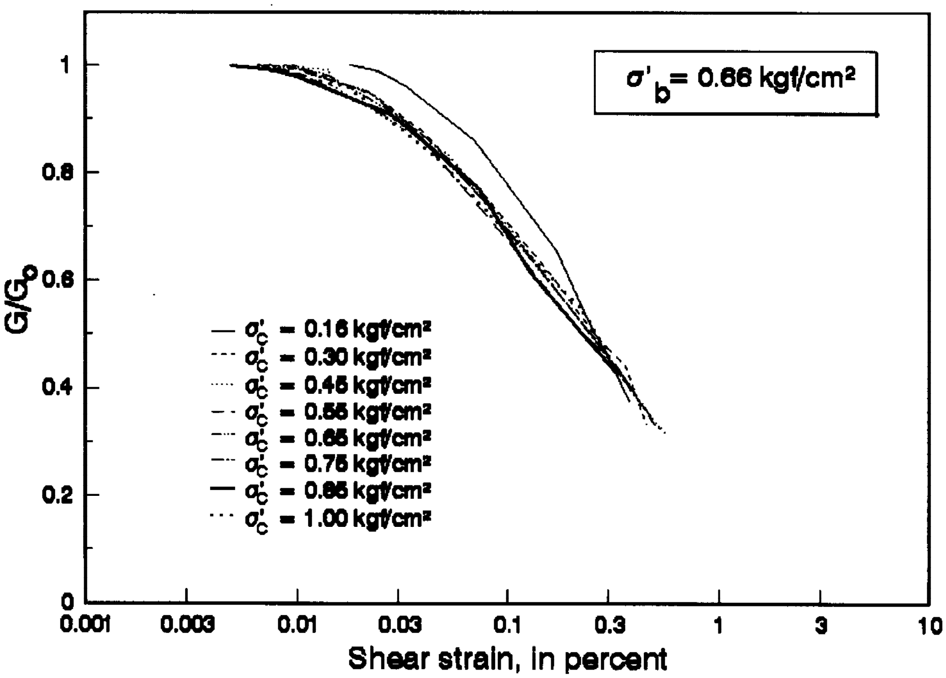

Fig. 5 Effects of shear strain on G/G_0, depth = 15.20 m

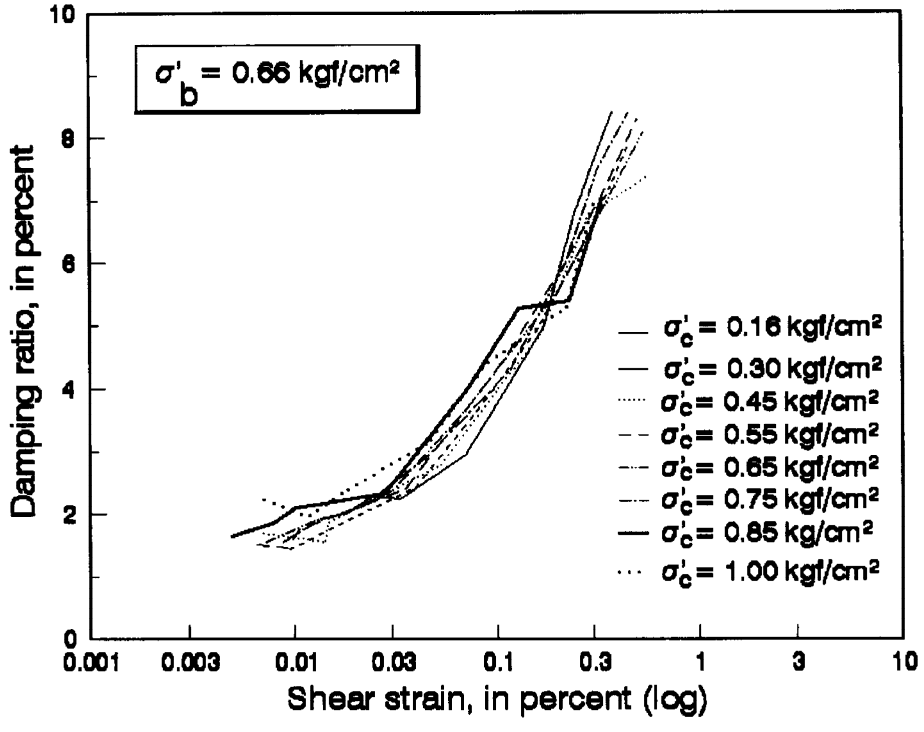

Fig. 6 Effects of shear strain on damping ratio, depth = 15.20 m

Effect of strain amplitude

Typical normalized shear modulus reduction curves for MCC are shown in Fig. 5. It can be seen that all the curves fall within a reasonably narrow band, despite the different confining pressure.

High-amplitude straining caused a decrease in shear modulus once shearing strains exceeded a threshold level as shown in Fig. 5. As can be observed, the threshold level was between 0.001% and 0.01%, when strains exceeded that level a decrease in modulus occurred. It appears from these results that the confining pressure may influence the form of the G_0 versus log time curves, but it has very little influence on the G/G_0 vs strain curves.

Typical damping ratio vs strain curves of MCC are shown in Fig. 6. It can be seen that all curves fall within a reasonably narrow band, despite the different confining pressure. A consistent decrease of the damping ratio is clearly seen for all confining pressures in the figure.

CONCLUSIONS

This research considered the effects of time of confinement, confining pressure and strain on the shear modulus and damping ratio of Mexico City clays.

For confining pressures less than critical stress the change in shear modulus can be approximated to a straight line on the semilogarithmic graph with no obvious kink at the completion of the primary consolidation. For confining pressures in excess of the critical stress the change in shear modulus gave curvilinear relationships.

It appears from these results that the confining pressure may influence the form of the G_0 versus time curves, but it has very little influence on the G/G_0 vs strain curves.

The damping ratio of MCC remarkably decreases with the consolidation time, implying that the in-situ clay layer will exhibit smaller damping ratio than that measured in the laboratory.

Dynamic properties of MCC such as the shear modulus, the damping ratio and their strain-dependency are possibly more variable due to physical, chemical and mineralogical properties.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support provided by La Dirección General de Apoyo al Personal Académico at the National University of Mexico. The authors owe special thanks to Eng. Fernando Favela in providing some support for this research. The superb assistance of Guadalupe Salinas in typing and editing the manuscript and figures is gratefully acknowledged.

REFERENCES

Afifi, S.S. and R.D. Woods (1971). Long-term pressure effects on shear modulus of soils. *J. of the Soil Mechanics and Foundation Division, ASCE*, **97 (10)**, 1445-1460.

Afifi, S.S. and F.E. Richart, Jr. (1973). Stress-history effects on shear modulus of soils. *Soils and Foundations*, **13 (1)**, 77-95.

Anderson, D.G. and R.D. Woods (1976). Time-dependent increase in shear modulus of clay. *J. of the Geotechnical Engineering Division, ASCE*, **102 (5)**, 525-537.

Anderson, D.G. and K.H. Stokoe (1977). Shear modulus: A time-dependent soil property. *Dynamic Geotechnical Testing, ASTM STP* **654**, 66-90.

Díaz-Rodríguez, J.A., S. Leroueil and J.D. Alemán (1992). On yielding of Mexico City clay and other natural clays. *J. Geotechnical Engineering, ASCE*, **118** (7), 981-995.