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OVERCONSOLIDATED MEXICO CITY CLAY UNDER CYCLIC LOADING

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SUMMARY

This paper describes two series of undrained cyclic triaxial tests on undisturbed soil samples of Mexico City clay. The tests were conducted to determined the undrained shear strength and stress-strain characteristics of normal consolidated and overconsolidated of Mexico City clay. Empirical relationships about equivalent Young's modulus, equivalent damping ratio and cyclic stress level associated to cyclic strain level, were obtained. Of particular concern was the possible loss in undrained shear strength caused by cyclic loadings.

INTRODUCTION

The intense ground shaking during the 19 September 1985 Mexico City earthquake, magnitude 8.1 (Ms) and intensity 9 in parts of the city, caused many foundation to undergo excessive settlement and tilting, resulting in either collapse or substantial damage of superstructures (Ref. 1). It is believed that the characteristics of soil in Mexico City played a key role in these disastrous events; of particular concern is the possible loss in undrained shear strength caused by cyclic loading.

Previous studies had showed that the strength of cohesive soils under monotonous loading conditions increased as the speed of loading increases. Other studies consistently revealed that the behavior of cohesive soils subjected to repeated cycles of loading and unloading may differ considerably from their behavior during a single loading cycle. It is therefore useful to study the effect of repeated loading under undrained conditions in the laboratory.

In practice, an earthquake may produce oscillations of buildings and their foundations. In a simple way, a soil element below a foundation may be considered to be subjected to an initial sustained stress together with superimposed vertical cyclic stresses. The strength of the soil under those conditions differs from that determined by a normal type of compression test. Thus it was decided to conduct laboratory studies by subjecting each specimen to a sustained stress, allowing the sample to reach equilibrium and then applying a series of transient stress applications representative of an earthquake.

SOIL DESCRIPTION

The undisturbed soil samples used in the present investigation were obtained with shelby tubes from 11.30 m depth. The soil was the following average properties: Specific gravity, 2.24; natural water content, 366 %; liquid limit, 456; plastic limit, 92 %; void ratio, 8.76 and unit weight, 1.10 t/m^3.

TESTING PROGRAM

The solution to several practical problems require a knowledge of the strain induced by cyclic loading and the peak strength of the soil after a limited number of repeated loading cycles. Thus an specific testing program was followed, (Ref. 2).

The final trimmed size of the test specimens was 39 mm in diameter and 95 mm in height. No side drains were used and regular end platens with porous stone at top and bottom of the specimen were used.

Two series of undrained cyclic triaxial tests were conducted, the details are outlined in Table 1.

TABLE 1. Summary of Cyclic Loading Program

	Test number	Initial consolidation stress	final consolidation stress	Single stress amplitude	Cyclic stress ratio
		σ'_{ci}	σ'_{cf}	q_c	R
	No.	Kg/cm^2	Kg/cm^2	Kg/cm^2	%
Series A q_{sf} = 0.858 in Kg/cm2 OCR = 1	A 2	0.43	0.43	0.15	17
	A 3			0.19	22
	A 4			0.25	29
	A 5			0.32	38
	A 6			0.43	50
Series B q_{sf} = 1.134 in Kg/cm2 OCR = 2	B 2	0.86	0.43	0.18	16
	B 3			0.23	20
	B 4			0.25	23
	B 5			0.32	28
	B 6			0.40	35

Test series A consisted of one static test and five cyclic tests. Each sample was isotropically consolidated to an effective stress equivalent to the existing effective overburden pressure of 0.43 Kg/cm^2 using a back pressure of 1.7 Kg/cm^2.

Test series B consisted of one static test and five cyclic tests. Overconsolidated specimens were obtained by first consolidating the specimens to a maximum stress of 0.86 Kg/cm^2 using a back pressure of 1.7 kg/cm^2 and then unloading to the final stress of 0.43 Kg/cm^2, thus inducing an overconsolidation ratio of 2.

The undrained normal static strength tests (CU-static test) were conducted to provide a reference for interpreting the results of the undrained cyclic triaxial tests with stress controlled loading (CU-cyclic tests) at various stress levels; one hundred deviatoric stress cycles (sinusoidally varing loading at 0.5 Hz) were applied to the samples. If the sample did not fail during the cyclic loading then a conventional static undrained compression test using controlled stress was carried out on the same sample. No drainage was allowed during any part of cyclic or post-cyclic tests.

BEHAVIOR DURING UNDRAINED CYCLIC LOADING

In all specimens, Series A and B, the level of repeated stress did not cause failure even under 100 stress cycles and an equilibrium state was achieved in which the stress-strain curves followed closed hysteresis loops with no additional changes in pore water pressure or strain occurring with load repetition.

The relationship between cyclic stress ratio, R, in percent defined as deviator cyclic stress, q_c, divided by static strength, q_{sf}, versus axial cyclic strain, ε_c, in percent was plotted in Fig. 1 and geometric regression analysis was run obtaining the following empirical relationships:

$$R = 38\ \varepsilon_c^{0.62} \qquad \text{for OCR = 1} \qquad (1)$$

$$R = 27.8\ \varepsilon_c^{0.70} \qquad \text{for OCR = 2} \qquad (2)$$

As shown in Fig. 1, normally consolidated specimens were less deformable that overconsolidated ones.

The equivalent Young's modulus, E, was determined from the slope of a line through the end points of the loops. The equivalent damping ratio, λ, was calculated using the well known expression:

$$\lambda = \frac{1}{4\pi}\ \frac{\text{Area of hysteresis loop}}{\text{Area of triangle}} \qquad (3)$$

Fig. 2 shows the relationships between E/q_{sf}, in percent versus single axial cyclic strain amplitude, ε_c, in percent.

It has been shown (Refs. 3,4) that, for a cyclic stress level below a critical value a non-failure equilibrium state is reached, closed stress-strain hysteresis loops occur and the soil behavior is essentially elastic. The specimens of Mexico City clay exhibited elastic behavior in spite of its very high water content. On the basis of a geometric regression analysis, the following equation for equivalent Young's modulus were obtained:

$$E/q_{sf} = 37.85\ \varepsilon_c^{-0.38} \qquad \text{for OCR = 1} \qquad (4)$$

$$E/q_{sf} = 27.78\ \varepsilon_c^{-0.51} \qquad \text{for OCR = 2} \qquad (5)$$

The relationship between equivalent damping ratio, λ, in percent and single axial cyclic strain amplitude, ε_c, in percent is shown in Fig. 3. A linear regression analysis was run obtaining the following empirical relationships:

$$\lambda = 9.05 + 2.43\ \varepsilon_c \qquad \text{for OCR = 1} \qquad (6)$$

$$\lambda = 8.22 + 2.14\ \varepsilon_c \qquad \text{for OCR = 2} \qquad (7)$$

The applications of a shear stress can set up a negative pressure in the water in the pore space between the particles which persists even after the removal of the stress. Measurements were made of the excessive pore pressure during the cyclic loading. In the normally consolidated specimens the residual pore pressure was positive, in all overconsolidated specimens except one (sample B 6) the residual pore pressure was negative.

STRENGTH AFTER CYCLIC LOADING

It has been shown (Ref. 5) that the strength deteriorating effect due to cyclic loading becomes more pronounced as the proportion of the cyclic stress amplitude increases relative to the static component of stress applied initially to the specimen.

A convenient way of expressing the possible loss in undrained shear strength is to use the failure ratio, Rf, defined as deviator stress failure after cyclic loading, q_{cf}, divided by the static strength, q_{sf}. A non-dimensional plot of failure ratio, Rf, versus cyclic stress ratio, R, is shown in Fig. 4. The results obtained by Díaz-Rodríguez, (1988) were drawing as a reference for the results of this paper, it is clear that the strength loss with the cyclic stress ratio is practically zero for $R < 50$ %.

CONCLUSIONS

The result presented above support the following conclusions concerning to the behavior of the Mexico City clay tested under cyclic loading conditions. It is realized that the observations apply strictly only to the type of soil and conditions of test employed in the experiments.

1. Normally consolidated specimens were less deformable that overconsolidated ones.
2. Cyclic loading can produce a sustantial decrease in the modulus of soil.
3. Post-cyclic static tests indicate that the strength was essensibly unchanged due to prior cyclic loading if $R < 50$ %.

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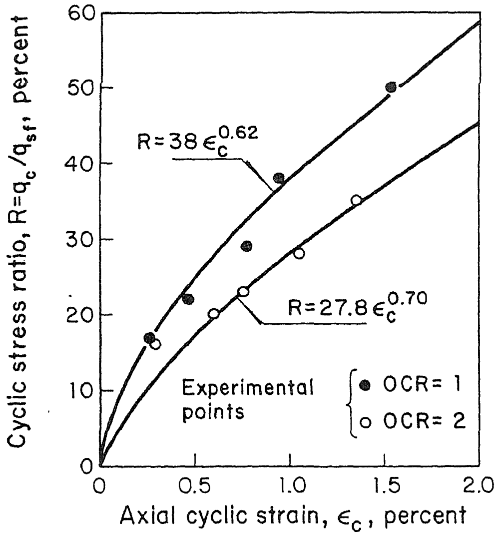

Fig 1 Cyclic stress ratio *vs* axial cyclic strain

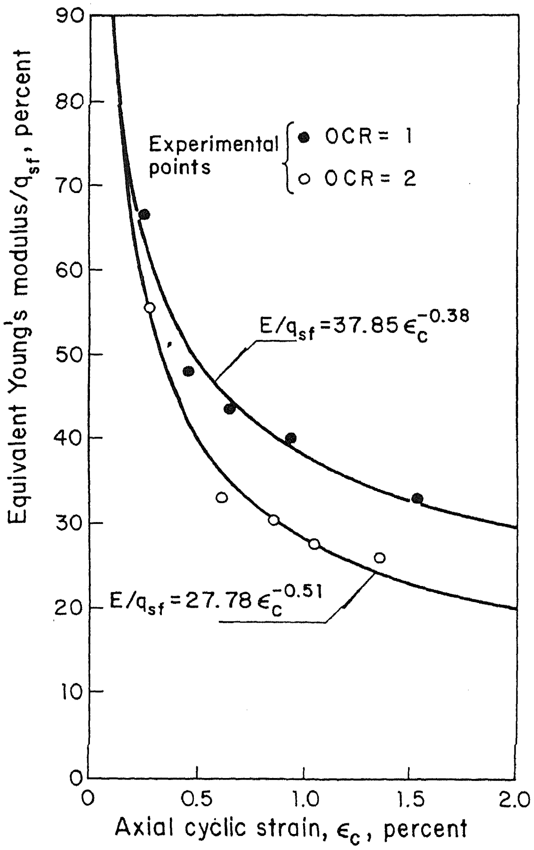

Fig 2 Normalized Young's modulus *vs* axial cyclic strain

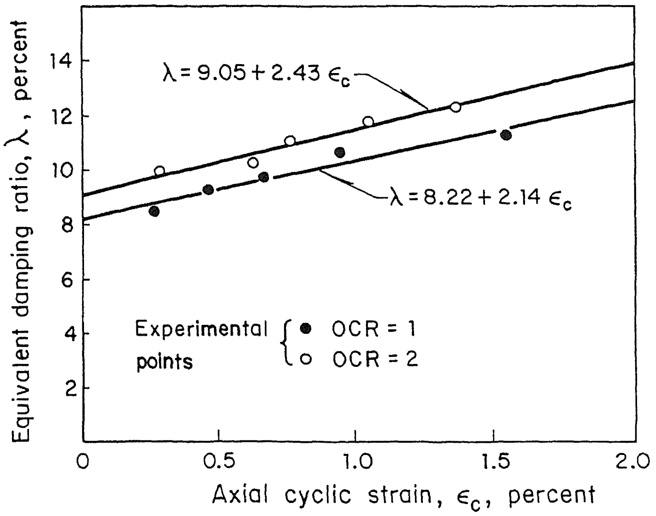

Fig 3 Equivalent damping ratio *vs* axial cyclic strain

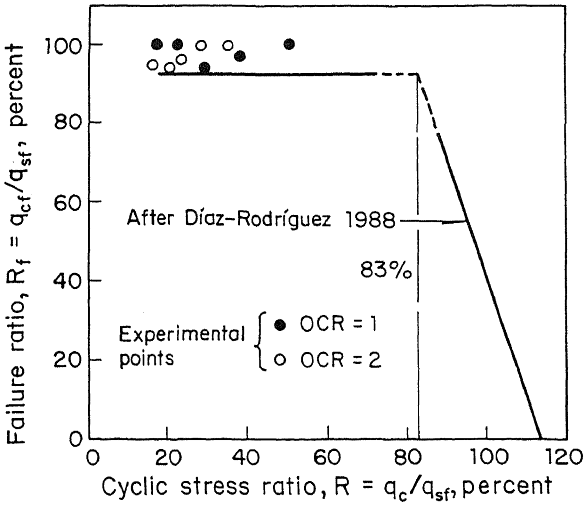

Fig 4 Failure ratio *vs* cyclic stress ratio