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Strain rate behavior of Mexico City soils

Comportement a vitesse de déformation des sols de Mexico

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ABSTRACT

The purpose of the investigation reported in this paper was to study the influence of strain rate on stress-strain and strength relationships of Mexico City lacustrine soils from the Central Park site (Alameda). An isotropic consolidation test to define the yielding stress, σ'_y (= 95kPa), was done by triaxial-cell method. The paper describes results from 16 consolidated-undrained triaxial compression tests on Mexico City lacustrine soils. Specimens were consolidated to four confinement pressures (σ'_c = 40, 80, 160, and 300 kPa), and for each, σ'_c, undrained shear was performed using four axial strain rates (1%, 5%, 100%, and 800%/h). The results show that the peak shear resistance increased about 336% in passing from the slow to the fast strain rate for the structured domain. For destructured domain, the increase was about 229%.

RÉSUMÉ

Le but de la recherche signalée dans cet article était d'étudier l'influence de la vitesse de déformation sur le comportement contrainte-déformation et la résistance des sédiments des sols lacustres de la Alameda Central de la ville de Mexico. Une épreuve de consolidation isotropique pour définir la pression cédante, σ'_y (=95 kPa), a été faite par la méthode de cellule-triaxiale. L'article décrit les résultats de 16 essais de compression triaxiale sur les sols lacustres de Mexico. Les spécimens on été consolidés pour quatre pressions latérales σ'_c (= 40, 80, 160 et á 300kPa) et pour chacun, σ'_c non-drainé a été exécuté en utilisant quatre vitesses de déformation axiale (1%, 5%, 100%, et 800%. Les résultats montrent que la résistance de cisaillement a augmenté d'environ 336% en passant d'une vitesse lente de déformation à une vitesse rapide dans le domaine structuré. Pour le domaine déstructuré, l'augmentation a été d'environ 229%.

1 INTRODUCTION

This paper presents experimental results to characterize the strain rate dependent undrained shear behavior of Mexico City lacustrine soils. Two aspects of undrained strain rate effects are reviewed: strain rate effects on undrained strength and the effect of consolidation stress history on strain rate behavior.

This phenomenon has been studied extensively since the pioneering work of Taylor (1943). Casagrande and Wilson (1951) suggested that this rate-effect upon strength might be caused by a change in the excess pore pressure generated during the shear process.

Triaxial tests performed by Lo and Morin (1972) on St-Vallier clay demonstrate a strain rate effect on the strength envelope of the overconsolidated soil. Similar results were obtained for other eastern Canada clays (Tavenas et al. 1978; Vaid et al. 1979; Leroueil and Tavenas 1979).

Vaid and Campanella (1977) performed a variety of triaxial tests on the undisturbed Haney clay. In particular, they performed undrained compression tests at different strain rates and undrained compression tests in which the strain rate changed at a given strain.

Several studies (Alberro and Santoyo 1973, Tavenas et al. 1978; Vaid et al 1979; Leroueil and Tavenas 1979; Martínez-Vásquez 2004) have shown that the undrained strength measured in the laboratory during conventional shear tests depends on the speed of testing, the increase in strength with the speed of testing being more pronounced in clays with a higher plasticity index.

2 MATERIALS PROPERTIES AND EXPERIMENTAL METHODS

2.1 *Site location*

The site from where the specimens were sampled is located in the lacustrine zone of Mexico City. The selected site (19.26°N, 99.08°W) is located in the Central Park (Alameda), in the neighborhood of one of the most damaged areas during the 19 September 1985 Mexico City earthquake (Ms magnitude 8.1 and intensity IX in parts of the city). The properties of Mexico City lacustrine soils are usually variable from place to place and in depth as well (Díaz-Rodríguez et al. 1998), some physical properties of the soil samples are summarized as follows:

- Natural water content = 190%
- Liquid limit = 193%
- Plastic limit = 60.6%
- Plasticity index =132.4
- Void ratio = 4.4
- Specific gravity = 2.6

In the following, the term Mexico City lacustrine soils, refers only to the soil that was tested in this investigation.

2.2 *Laboratory testing*

The isotropic consolidation to define the yield stress, σ'_y , was done by triaxial-cell method on 36-mm-diameter and 75-mm-height specimens (Fig. 1). The yielding stress (Díaz-Rodríguez *et al.* 1992) corresponds to the passage from the structured range to the beginning of the destructured range.

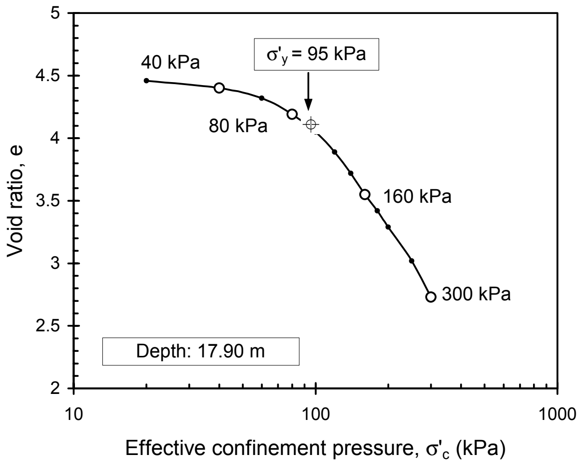

Figure 1. Void ratio with effective confinement pressure

Table 1 Tests results

Test number	σ_c	ε	$(\sigma_1 - \sigma_3)_{max}$	ε_f	u_f	p'	q	M	ϕ'
	kPa	%/h	kPa	%	kPa	kPa	kPa		°
CU 1	40	1	68.80	3.29	32.50	29.50	68.80	1.94	47.29
CU 2	80		118.43	3.87	61.00	55.30	118.43		
CU 3	160		152.77	5.52	120.30	88.50	152.77		
CU 4	300		230.95	6.05	220.70	149.70	230.95		
CU 5	40	5	122.57	3.80	35.80	43.60	122.57	2.11	52.88
CU 6	80		139.27	3.47	66.40	55.50	139.27		
CU 7	160		155.18	4.84	118.90	91.40	155.18		
CU 8	300		227.05	5.43	196.50	161.50	227.05		
CU 9	40	100	142.64	3.56	36.20	49.90	142.64	2.45	61.67
CU 10	80		154.18	3.15	67.50	59.00	154.18		
CU 11	160		182.36	4.78	138.60	80.10	182.36		
CU 12	300		346.18	5.38	246.60	168.00	346.18		
CU 13	40	800	147.25	3.33	37.30	49.80	147.25	2.71	72.42
CU 14	80		178.40	3.30	76.80	59.90	178.40		
CU 15	160		217.16	4.76	153.10	78.40	217.16		
CU 16	300		314.73	4.66	252.90	147.50	314.73		

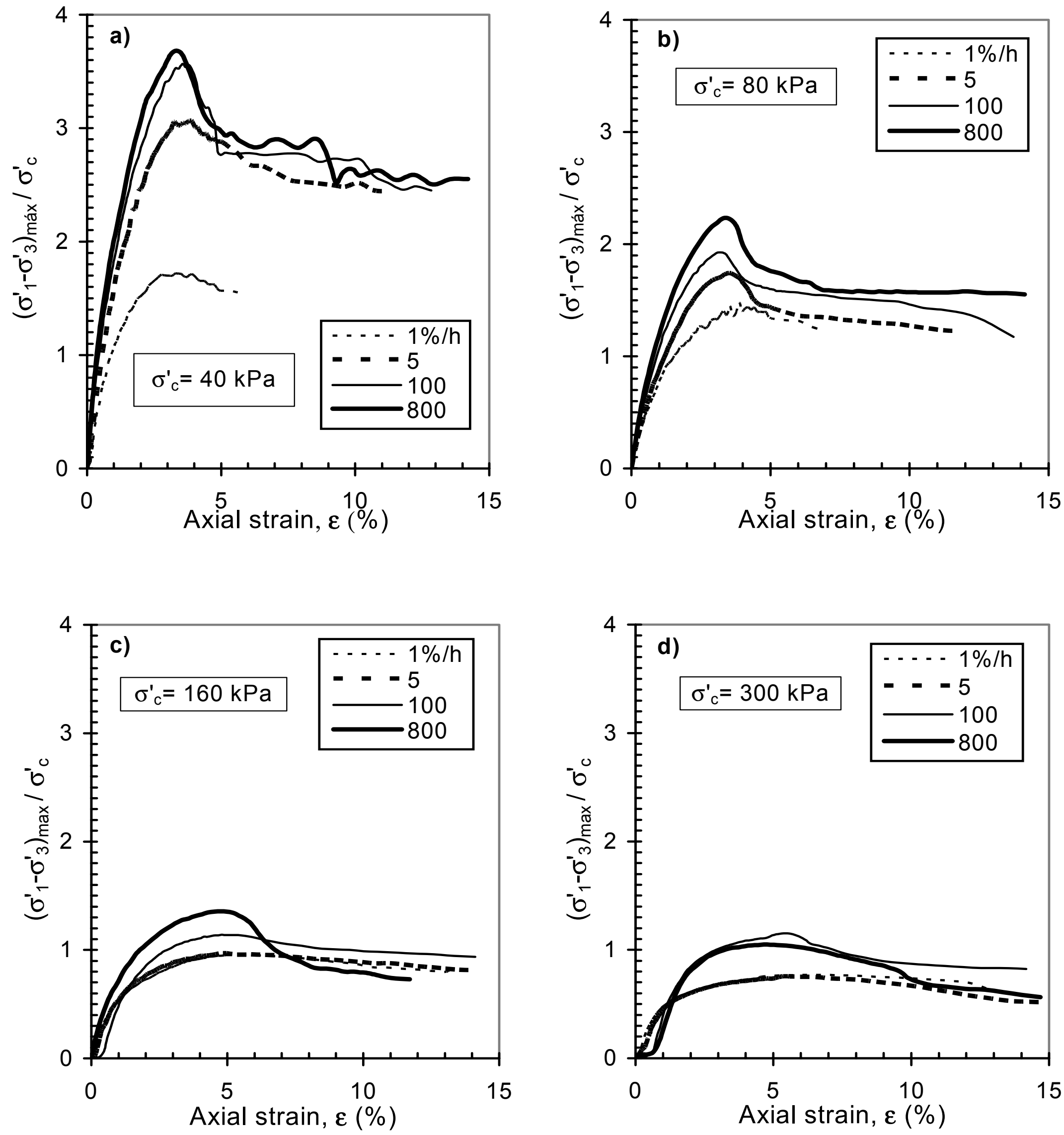

Figure 2. Stress-strain curves for triaxial compression test at constant strain rate

The base pedestal, upon which the specimens were placed, is connected to a drainage line. The specimens were encased in two membrane 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 340 kPa.

The tests were conducted under several different states of isotropic consolidation, from very low effective stresses (σ'_c = 40 kPa) to effective stresses in excess of the yield stress, σ'_y (= 95 kPa) then the process of destructuration of the intact clay samples was studied. Drainage was permitted during all phases of consolidation at each stage.

3 RESULTS AND INTERPRETATION

A summary of tests result is shown in Table 1. In all cases failure was assumed at maximum deviator stress. The influence of variation in the constant rate of strain on the resulting stress-strain response is shown in Fig. 2. Curves for four confinement pressures (σ'_c = 40, 80, 160, and 300 kPa), and for each, σ'_c, four axial strain rates (1%, 5%, 100%, and 800%/h) are shown. The deviator stress, q = (σ'_1 - σ'_3), has been normalized to the consolidation pressure, σ'_c. Fig. 2 shows that the stress-strain relation for Mexico City soils is dependent on the rate of strain. The peak deviator stress at the fastest rate (800%/h) was as much as 336% larger than the corresponding value at the slowest rate (1%/h) for a consolidation pressure, σ'_c = 40 kPa (structured domain). It is interesting that the axial strain at peak deviator stress was essential independent of the rate of strain and was 3.5% ± 0.24 SD.

The peak deviator stress at the fastest rate (800%/h) was as much as 185% larger than the corresponding value at the slowest rate (1%/h) for a consolidation pressure, σ'_c = 80 kPa, notice that this consolidation pressure is close to the yielding stress. It is interesting that the axial strain at peak deviator stress was essential independent of the rate of strain and was 3.45% ± 0.31 SD.

For confining pressures in excess of yielding stress the results were as following: 243% and 214% for σ'_c = 160 kPa and 300 kPa respectively. The axial strains at peak deviator stresses were 5% ± 0.36 SD and 5.38% ± 0.57 SD, respectively.

Figure 3 shows the change in undrained shearing with log (strain rate) of Mexico City soils for different confining pressures given in Fig. 1. Undrained shearing resistance increase linearly with increasing log (strain rate). The change in shearing resistance with strain rate can be conveniently described by the parameter $\rho_{0.1}$ (Graham et al. 1983) defined as the change in shearing resistance caused by a tenfold change in strain rate, expressed as a percentage of shearing resistance measured at 0.1% per hour. The values of $\rho_{0.1}$ in Fig. 3 were as following: 17% and 41 % for σ'_c = 300 kPa and 40 kPa respectively. The results suggest that $\rho_{0.1}$ may increase with overconsolidation ratio.

Tests reported elsewhere suggest that at a low strain rate, the gradient of shear stress-log (strain rate) relationship can decrease markedly. This threshold strain rate has been reported to be about 0.2% per hour for Haney clay (Vaid and Campanella 1977) and about 0.05% per hour for Drammen clay (Berre and Bjerrum 1973). In this study there is no evidence of a threshold strain rate.

Figure 4 shows the results of Mexico City lacustrine soils for four different confining pressures plotted according to Kulhawy and Mayne (1990)

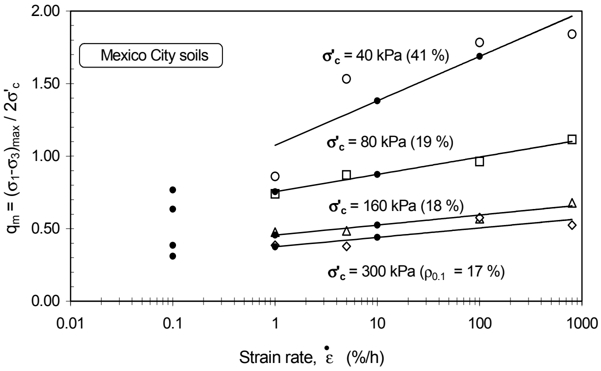

Figure 3. Change in undrained shearing with log (strain rate)

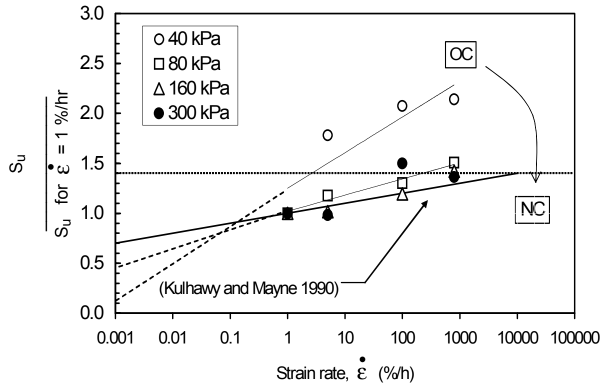

Figure 4. Influence of strain rate on undrained strength measured in triaxial compression tests on Mexico City soils.

4 CONCLUSIONS

This paper describes results from 16 consolidated-undrained triaxial compression tests on Mexico City lacustrine soils. Specimens were consolidated to four confinement pressures (σ'_c = 40, 80, 160, and 300 kPa), and for each, σ'_c, undrained shear was performed using four axial strain rates (1%, 5%, 100%, and 800%/h).

The following conclusions can be drawn from this study:

- Mexico City lacustrine soils exhibit significant time-dependent stress-strain characteristics.
- The results show that the peak shear resistance increased about 336% in passing from the slow to the fast strain rate for the structured domain.
- For destructured domain, the increase was about 229%
- The changes in shearing resistance with strain rate expressed by the parameter $\rho_{0.1}$, were 17 and 41% for σ'_c = 300 kPa and 40 kPa respectively. The results suggest that $\rho_{0.1}$ may increase with overconsolidation ratio.
- The increase in strength with the speed of testing being more pronounced in clays with a higher plasticity index.

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