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Seismic response characterization of high plasticity clays

Juan M. Mayoral *, Ernesto Castañon, Leonardo Alcantara, Simon Tepalcapa

Coordinacion De Geotecnia, Universidad Nacional Autonoma De Mexico, Mexico City, Mexico

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ABSTRACT

An experimental study was undertaken to characterize the seismic response of high plasticity clays found in the Texoco Lake region of the Mexico City valley. Series of resonant column and triaxial tests were carried out in twin samples, and empirically-derived well known modulus degradation and damping ratio models were used to simulate the measured response. A total of forty three tests were conducted in twin samples. The results gathered appear to indicate that the reference strain, γ_r, instead of the plasticity index, PI, constitutes the best parameter to properly establish the modulus degradation and damping curves for high plasticity clays, increasing the accuracy of the model predictions. Appropriate values of γ_r were obtained for the high plasticity Texcoco clays directly from the experimental data, to determined modulus degradation and damping curves. The approach was validated throughout the analysis of four cases study. Site response analysis predictions were compared with actual measurements at three seismological stations and one vertical array, considering several recorded moderate to large seismic events. The computed ground motions are in good agreement with the measured response.

1. Introduction

Seismic properties determination of high plasticity clays, such as those found in the Mexico City Valley and its surroundings have been only marginally studied. It is well known that these soils exhibit no significant reduction in shear modulus even for shear strains as high as 0.1%. Similarly, there is no significant increase in the damping ratio until angular distortions of the order of 0.3% are reached (e.g., [1–4]). Thus, the response of clayey soil deposits is nearly elastic even for shear strains as high as 0.3%, which leads to a high potential of amplification of the seismic waves. Due to this fact, amplification factors up to 5 (between peak ground acceleration, PGA, observed at soft soil with respect to those of rock outcrops) were reached during the 8.1 M_w 1985, Michoacan earthquake. Spectral ordinates for 5% structural damping of measured ground acceleration at the surface ranged from about 0.4–1.0 g at periods of 2 s (e.g., [2,3]).

This paper describes an experimental study carried out to characterize the seismic response of high plasticity clays, such as those found in the former Texoco Lake, in the Mexico City valley. From the geological stand point, this area is located in a region associated with Pleistocene lakes that existed in the valleys and volcanic zones that were part of the Mexican Volcanic Belt [5]. Nowadays, the lake is almost drained and instead there are highly compressive clay deposits. A total of forty three resonant column and triaxial tests were conducted. The results gathered appear to indicate that the reference strain, γ_r, instead of the plasticity index, PI, constitutes the best parameter to properly establish the modulus degradation and damping curves for high plasticity clays. Moreover, important dispersion is observed when the reference shear strain, γ_r, is related to the effective confining pressure, σ'_c and plasticity index, PI. This fact is often ignored. Initially, empirically-derived well known modulus degradation and damping ratio models ([6–8]) were used to replicate the experimental data in order to assess their prediction capabilities without accounting for the definition of γ_r (i.e. shear strain associated to 50% degradation of the shear stiffness). These empirical models were employed in previous research to simulate the hysteretic response of high plasticity Texcoco Lake clays ([2–4]). Then, appropriate values of γ_r were obtained directly from the experimental data, to evaluate if the model-derived modulus degradation and damping curves were closer to the measured response. The estimation improved significantly. From the experimental data it was found that values of γ_r for Texcoco Lake clays range from 0.24 to 1.4%. The best set of curves were obtained with the Darendeli and Stokoe's model [6] with the appropriated soil parameters. The forecasting capabilities of this model, used with appropriated site-specific soil parameters, was further revised throughout the analyzes of four cases study. Predicted ground motions are in good agreement with the measured response.

* Corresponding author. Tel.: +52 55 5623 3600x8469; fax: +52 510 5162 0784.
E-mail address: jmayoralv@iingen.unam.mx (J.M. Mayoral).

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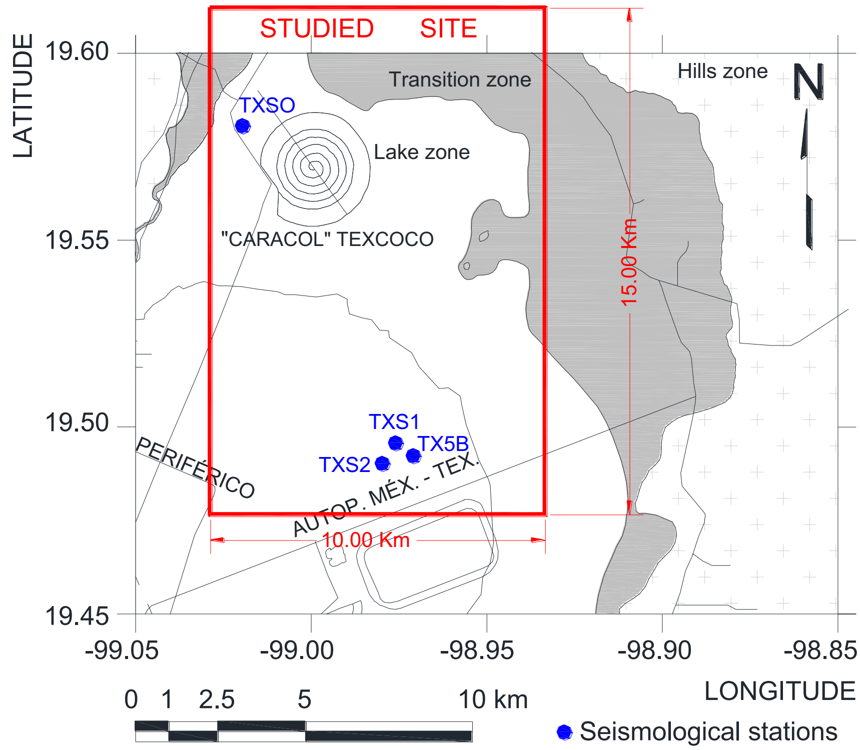

Fig. 1. Studied site location.

Table 1
Laboratory testing program.

Site	Boring	Description	Depth [m]	Test type	Effective confining stress, σ'_c [kPa]
TXS1	SM-2	M-7	4.80–5.00	CR	66.70, 88.29
				TC	44.15, 66.70, 88.29
TXS1	SS-1	M-1	17.40–	CR	68.67, 103.01, 168.73
			17.60	TC	68.67, 103.01, 168.73
TXS1	SS-1	M-2	25.60–	CR	84.37, 126.55
			25.80	TC	84.37, 126.55, 168.73
TXS1	SS-1	M-3	34.20–	CR	101.04, 152.06, 203.07
			34.40	TC	101.04, 152.06, 203.07
TXS1	SS-1	M-6	51.80–	CR	136.36, 204.05, 271.74
			52.00	TC	136.36, 204.05, 271.74
TXS2	SM-1	M-7b	4.20–4.40	CR	19.62, 73.58
				TC	9.81, 19.62, 73.58
TXS2	SM-1	M-15	9.20–9.40	CR	19.62, 49.05
				TC	49.05
TXS2	SM-1	M-40	25.80–	CR	52.97, 79.46, 107.91
			26.00	TC	52.97, 79.46, 107.91
SOSA	SM-1	M-1b	2.40–2.60	CR	29.43, 49.05, 73.58
				TC	29.43, 49.05, 73.58
SOSA	SM-1	M-9	5.60–5.80	CR	66.71, 101.04, 134.39
				TC	66.71, 101.04

CR: resonant column TC: cyclic triaxial.

2. Description of the studied area

The soil samples for the experimental study were retrieved from the former Texcoco Lake zone (Fig. 1). Commonly the soil profile at this zone presents a desiccated crust of clay at the top extending up to a depth of 1.0 m, which is underlain by a soft clay layer approximately 30.0 m thick, with interbedded lenses of sandy silts and silty sands. Underlying the clay there is a 4.0 m thick layer, in average, of very dense sandy silt, which rests on top of a stiff clay layer which goes up to a 60.0 m of depth. Underneath this elevation a competent layer of very dense sandy silt is found. The distance from the National University of Mexico, UNAM, to the polygon center that encloses the studied area is approximately 31.70 km. The region studied is instrumented with three seismic stations, TXSO, TXS1, and TXS2. Undisturbed samples were retrieved from the study area using Shelby tube at each seismological station site (Fig. 1). Continuous standard penetration tests, and piezocone test were also carried out to properly establish the in-situ stress conditions based on soil stratigraphy and hydraulic conditions. Special care was exercised to ensure that the soil samples were representative of the whole mass, and that any particular geological feature was properly identified. The nearest seismological station placed in a rock outcrop is TXRC, which is located to the east, about 18.70 km away from the studied site.

Table 2
Index properties of samples tested in resonant column and cyclic triaxial.

Site	Boring	Sample	Water content, w (%)	Liquid limit w_L (%)	Plastic limit, w_P (%)	PI (%)	G_s
TXS1	SM-2	M-7	370	284	90	194	2.65
TXS1	SS-1	M-1	275	311	107	204	2.78
TXS1	SS-1	M-2	303	360	71	288	2.82
TXS1	SS-1	M-3	280	243	108	135	2.53
TXS1	SS-1	M-6	139	173	122	51	2.4
TXS2	SM-1	M-7b	308	302	75	226	2.7
TXS2	SM-1	M-15	399	326	125	201	2.51
TXS2	SM-1	M-40	280	310	81	229	2.82
SOSA	SM-1	M-1b	331	368	159	210	2.45
SOSA	SM-1	M-9	311	306	156	150	2.74

2.1. Experimental characterization of high plasticity clays

A total of forty three resonant column and cyclic triaxial tests were conducted, for several effective confining pressure, σ'_c, in