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Technical Note

Seismic response of high plasticity clays during extreme events

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ABSTRACT

Mexico City high plasticity clays exhibit a small degree of nonlinearity for shear strains as large as 0.1%, which leads to both moderate shear stiffness degradation and small to medium damping increment, even for long duration subduction strong ground motions, such as the 8.1M_w 1985Michoacan earthquake. Nonetheless, current seismic design criteria of strategic infrastructure used worldwide have striven for having larger return periods for establishing the seismic environment, considering recent large magnitude ($M > 8.5M_w$) events. This paper presents the study of the seismic response of typical high plasticity clays found in the so-called Texcoco Lake, in the surrounding of Mexico City valley, for larger to extreme earthquakes. The shear wave velocity profile was characterized using a down-hole test. The seismic environment was established from a set of uniform hazard response spectra developed for a nearby rock outcrop for return periods of 125, 250, 475 and 2475 years. A time-domain spectral matching was used to develop acceleration time histories compatible with each uniform hazard response spectrum. Both frequency and time domain site response analyses were carried out considering each seismic scenario. Ground nonlinearities were clearly observed in the soil response during extreme ground shaken, which increases rapidly with the return period. This fact must be taken into account to avoid costly and potentially unsafe seismic designs.

1. Introduction

Traditionally, high plasticity clays (i.e. plasticity index larger than 250%), such as those found in the Mexico City valley, have been considered to exhibit a very small amount of soil nonlinearity during strong ground shaking, such as that observed in the 8.1M_w, Michoacan Earthquake, even for shear strains as large as 0.1% [1–3]. Current seismic design criteria of strategic infrastructure used worldwide have striven for having larger return periods to characterize the seismic environment when dealing with major strategic infrastructure, within a probabilistic seismic hazard analysis framework, PSHA. Nevertheless, when performing a site response analysis, large return periods can increase the seismic demand unrealistically when soil nonlinearity is not accounted for, missing both spectral accelerations magnitude as well as frequency content, leading to costly and sometimes unsafe seismic designs. The importance of accounting nonlinear effects on ground motion attenuation as well as frequency content modification has been established in the past by several authors, for low plasticity clays and sands [4,5]. However, this still remains a controversial topic between seismologist and geotechnical earthquake engineers when dealing with strong to extreme ground shaking of high plasticity clays deposits, where the effect of plasticity index, which is among the most important parameters defining the amount of soil degradation during seismic loading [6], is often ignored. This paper presents the study of the seismic response of common high plasticity clay deposits found in Mexico City Valley subjected to large and extreme ground shaking. From the results gathered, is evident the importance of accounting for soil nonlinearities when dealing with return periods larger than 125 years, even in high plasticity clays, to avoid costly and, in some cases, unsafe seismic designs.

2. Seismic parameters characterization

Typical subsoil conditions found at the former Texcoco Lake has been studied by several researchers. A full description of these conditions can be found in [7,8]. Cone penetration, and standard penetration tests, along with selective sampling recovery were conducted to establish a representative high plasticity clay deposit (Fig. 1a). The shear wave velocity distribution was measured at the site using a down-hole test. Due to the lack of site-specific experimental data, the empirical model proposed by Darendeli and Stokoe [9] was used to generate modulus degradation and damping curves, which take into account confining pressure effects, σ', plasticity index, PI, over consolidation ratio, OCR,

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loading frequency, *f*, and the number of loading cycles, *N* (Fig. 2a). The OCR was taken as one, considering that the studied zone is located in the virgin former Texcoco lake, and that the over consolidation of the soil due to desiccation occurred only in the first couple of meters. Uniform hazard spectra, UHS, for four return periods, T_r, 125, 250, 475, and 2475 years, were developed for a nearby rock outcrop identified as TXCR seismological station, conducting a probabilistic seismic hazard assessment, PSHA, as described by Osorio and Mayoral, 2013 [8]. These UHS are presented in Fig. 2b. Each of these spectra is used to derive the input motion for site response analyses. To develop time histories in which response spectra reasonably match the design response spectrum, a selected seed time history was adjusted using the method proposed by Lilhanand and Tseng [10] as modified by Abrahamson [11]. The seed ground motion is a long duration record (i.e. 200 s) typical of the subduction Pacific Coast, with a PGA of 0.0026 g. This ground motion was measured in September, 14 of 1995 at seismological station TXRC during a 7.3M_W earthquake. Station TXCR is located, as previously stated, in a rock outcrop, about 19.20 km away from the studied site [8]. The epicenter event was in the coast of Guerrero state, about 122 km from Acapulco City. The corresponding 5% damping response spectra of the modified ground motions compared with those of the targets are also shown in Fig. 2b for each return period.

3. Site response analyses

Initially, the computer code SHAKE [12] was used to conduct the 1D equivalent linear site response analysis. Then, a fully nonlinear site response analysis was carried out with the program FLAC^{3D} [13], to further study soil nonlinearities. The finite

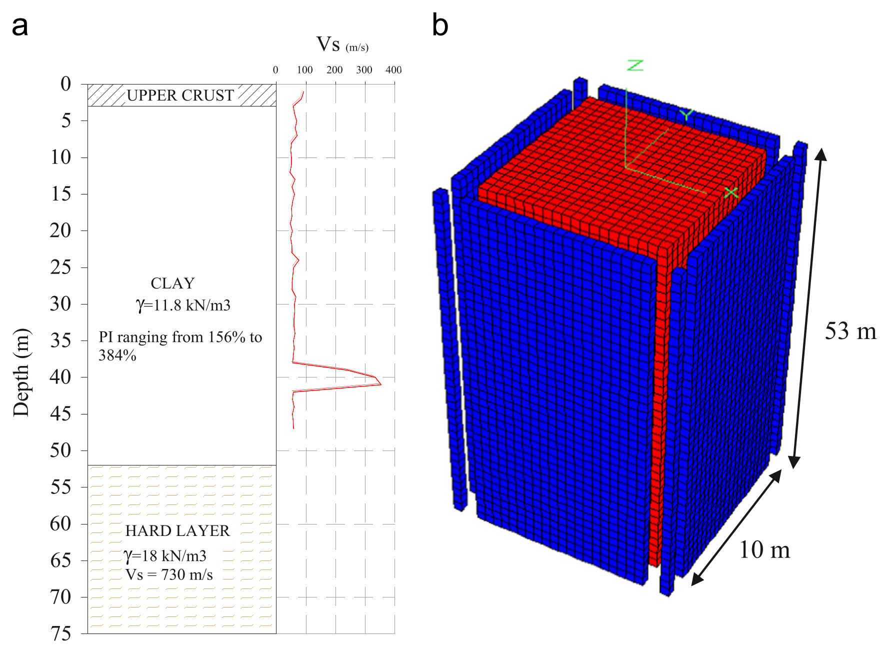

Fig. 1. (a) Soil profile and (b) tridimensional finite differences model considered in the study.

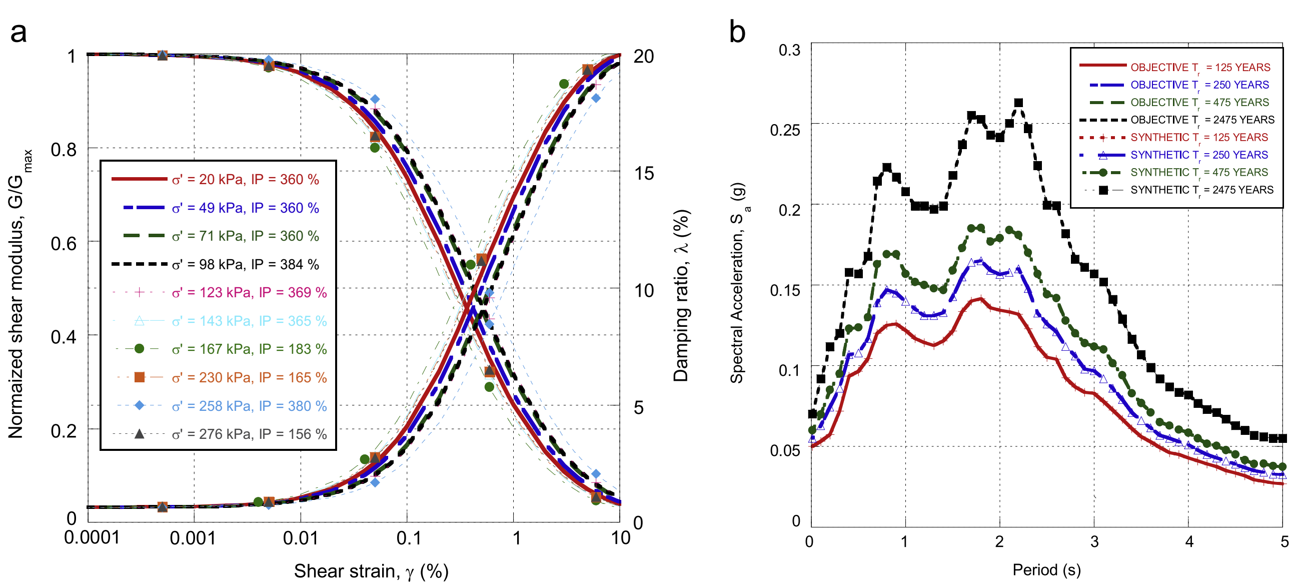

Fig. 2. (a) Clay shear modulus degradation and damping curves and (b) UHS and response spectra of synthetic ground motions.