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Soil amplification response of Mexico City clay deposits during the M_S7.1 Puebla, 2017 earthquake

Réponse d'amplification du sol des gisements d'argile de Mexico lors du tremblement de terre de M_S7.1 à Puebla en 2017

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ABSTRACT: Soil response of soft alluvial deposits along Mexico City valley is examined during the 19 September 2017, M_S7.1 Puebla earthquake. The seismic event occurred approximately 120km south-east of the capital Mexico City, and the recorded peak ground accelerations were lower than 0.2 g on the top of deep soft deposits. However, substantial damage was inflicted on residential infrastructure with numerous collapses and many victims in Mexico City. Recordings were available in more than 50 stations in Mexico City, including motions on rock and on soft clay profiles. The response spectra amplification ratio is calculated and presented for the most characteristic soil profiles, not only for the M_S7.1 Puebla event but also for previous earthquakes with magnitude larger than 7. Site effects are studied in terms of simple one dimensional wave propagation of simplified profiles. The effect of three different G-γ and ξ-γ curves (Vucetic & Dobry, Darenteli, and elastic) on the overall soil response is investigated. Comparison of the calculated with recorded accelerations is presented as well as their response spectra.

RÉSUMÉ: La réponse de sol de dépôts alluviaux mous le long de la cuvette de Mexico est examinée pendant le 19 septembre 2017, M_S7.1 Puebla le séisme. L'événement sismique s'est produit environ 120 kms au sud-est de la capitale Mexico et les accélérations de terre maximales enregistrées étaient plus basses que 0.2 g sur le haut de dépôts mous profonds. Pourtant, le dommage substantiel a été infligé sur l'infrastructure résidentielle avec de nombreux effondrements (plus de 44) et 228 victimes à Mexico. Les enregistrements étaient disponibles dans plus de 50 stations à Mexico, en incluant des mouvements sur la roche et sur les profils de glaise mous. Le rapport d'amplification est calculé et présenté pour les profils de sol les plus caractéristiques, pas seulement pour le M_S7.1 Puebla l'événement, mais aussi pour huit séisme précédent avec l'étendue plus grande que 7. Les effets de site sont étudiés du point de vue de simple la propagation de signe dimensionnelle de profils simplifiés. L'effet de G-γ et de ξ-γ les courbes sur la réponse de sol générale est enquêté. Comparaison du calculé avec les accélérations enregistrées est présentée aussi bien que leurs spectres de réponse.

Keywords: soil amplification; Mexico City clay; Puebla 2017 earthquake

1 SEISMOTECHTONICS OF MEXICO

Mexico's proximity to a subduction zone makes the country prone to strong earthquakes. In particular, the Cocos Plate is gradually sinking beneath the continental plate of North American, creating at their collision the Middle American Trench (Fig.1).

In 1985 Michoacan M_s 8.0 earthquake, which originated in the Middle Atlantic Trench, inflicted almost 20,000 deaths in Mexico City and severe damage to building infrastructure. On the 32nd anniversary of the 1985 earthquake, a M_s 7.1 earthquake struck: the Puebla 2017 event.

2 THE M_S7.1 PUEBLA 2017 EQ

The Puebla earthquake occured at 19 September 2017 at 1:14 p.m (local time) at a focal depth of 51 km in the Puebla Municipality at a distance of 120 km from the Mexico City. Fig.1 demonstrates the epicenter of the 2017 earthquake. On the contrary to the 1995 event which took place at the subduction zone, the 2017 earthquake was an "intra-plate" type on a moderately dipping normal fault.

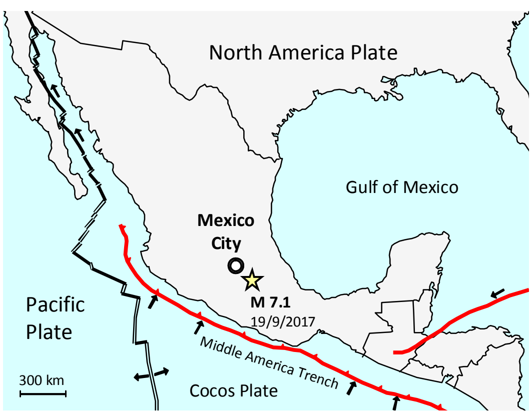


Figure 1. Seismotectonic map of Mexico.

The human loss inflicted by the Puebla event is 370 victims. More than 40 buildings totally collapsed at the Mexico City and widespread damage observed at the Morelos and Puebla regions.

2.1 *Infrastructure Damage*

The paper may be written in either English or in French. The title of the paper should be given in both English and in French, with the title in the language of the paper appearing first.

Damage surveys by GEER and ATC reconnaissance teams revealed that most of the collapsed buildings in Mexico City had been erected in 1960s and 1970s with unreinforced masonry walls confined by non-ductile concrete frames. Two general types of building failures are observed. Stracturally driven damages: soft floors, pancake collapses, short columns, pounding; and soil driven failures: foundation rocking leading to permanent rotation. The last soil-driven type of failure is of more interest to us, as it is a consequence of the soft Mexico City clay presence and the SSI effects.

Figure 2. The Osa Mayor rocking failure: (a) plan view of the 15-floor RC double L-shaped building, (b) the openingbetween the two L-buildings as seen from the 11th floor, and (c) detail of the uplifted corner (with the turquoise double end arrow is noted thehorizontal gap induced by the rocking motion of the building).

For example, in Fig.2 is pictured a 15-story residential building at Osa Mayor neighborhood, constructed during 1970s and consisting by two L-shaped buildings connected at their corners through the staircase and elevator shaft. The building lays on top of a 80 meter soft clay deposit, and its foundation consists of a mat RC slab with friction piles. Severe damage was inflicted to the structure during the Puebla earthquake, leading to the permanent evacuation of it. Apart from the local structural damage at every floor, total separation along the staircase was induced by the rocking motion of the right L-shaped building. The response of the structure and its subsequent damage was dominated by the 80 m soft clay seismic response and interaction.

2.2 *Ground motions*

CIRES (Centro de Instrumentación y Registro Sísmico) strong motion network had installed about 78 acceleroghraph devices in Mexico City. Seven of them (those with the strongest recordings from the 2017 Puebla EQ) are chosen as indicative of the seismic severity of the earthquake. Their elastic response spectra are portrayed in Fig.3.

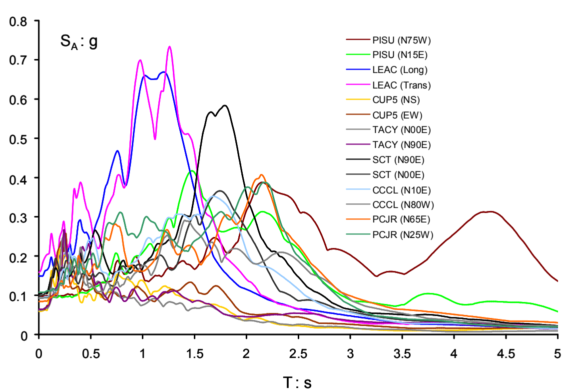


Figure 3. Acceleration response spectra of the horizontal components of ground motions recorded at seven stations of Mexico City during the 2017 Puebla earthquake.

As can be seen from Fig.3, the maximum values recorded on the ground are under 0.2 g. Neverthe less, the spectral values exceed 0.5 g for a wide range of periods, confirming the motions' destructive potential.

3 THE SCT AND CAO SITES

Mexico City is located on top of a volcanic plateau surrounded by volcanic mountains. Fig.4 is a crude geologic map of Mexico City, presenting the three geological zones and the location of the accelerograph stations that are studied here. The Lake Zone consists by lacustrine clay, which is extremely deformable. The Hilly Zone consists of basaltic and andesitic lava whereas the Transition Zone lies between the Hilly and Lake Zones with clay lower than 20 m.

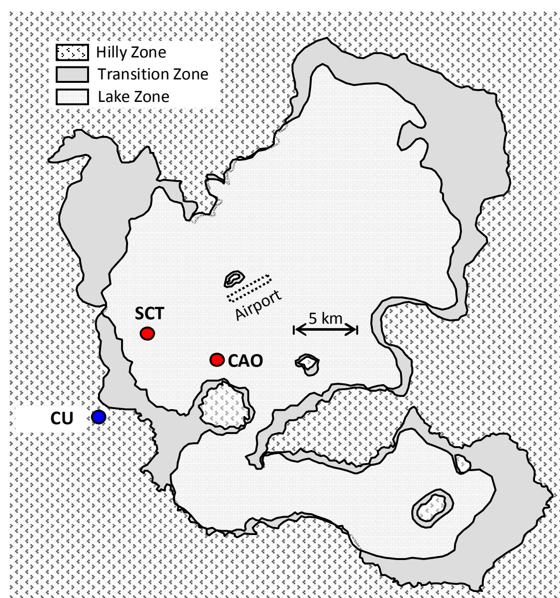
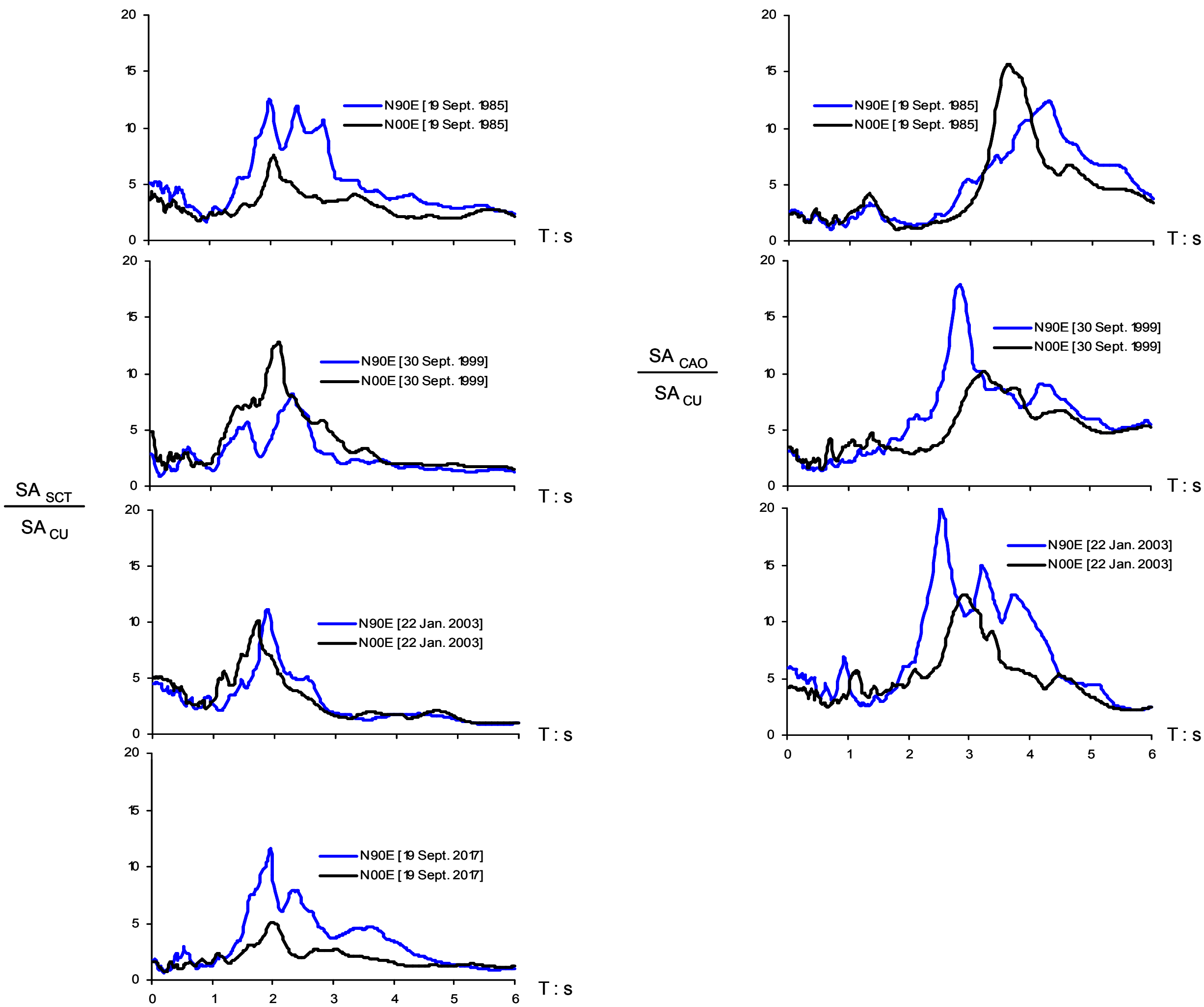


Figure 4. Geologic map of Mexico City and locations of the three stations studied in the article.

CU is located in the Hilly Zone of the city, and as a rock-outcrop station its recording is employed as excitation at the base of our models. SCT and CAO stations rest on the Lake Zone at a 40 m and 60 m thick clay deposit respectively. With the assumption of a mean shear wave velocity V_s = 80 m/s for the Mexico City clay, the fundamental periods of these deposits are estimated to be 2 seconds for the SCT and 3.5-4 seconds for the CAO sites. To this end, Fig.5 depicts the amplification ratio of the recorded SCT and CAO motions for the seismic events of Table 1 with respect to the CU rock motions. It is evident for all earthquake cases, that the period in which the maximum amplification occurs is in fully agreement with our estimation.

Table 1. List of earthquakes with magnitude larger than 7, that studied herein.

Earthquake Name	Date	Magnitude
Michoacan	19 Sept. 1985	8.1
Oaxaca	30 Sept. 1999	7.4
Colima	22 Jan. 2003	7.5
Puebla	19 Sept. 2017	7.1



Figur 5. Amplification ratio of the SCT (left) and CAO (right) response spectra over the CU spectra. The CAO station stopped its operation in 2010, therefore there was no recording for the 2017 event.

4 SOIL AMPLIFICATION ANALYSES

The 1D analysis of the SCT and CAO site responses is performed analytically (with SHAKE, Schnabel et al. 1972) using CU records as rock-outcrop excitation. Fig.6 presents the simplified soil profiles analysing herein. For both of them, the mean average shear-wave velocity is taken equal to 80 m/s, and the specific soil's weight 12 kN/m^3. The dynamic properties of Mexico City's clay is described by the G-γ, ξ-γ curves of: Vucetic & Dobry (1987) for plasticity indeces PI = 100 and PI = 200, and Darendeli (2001) for plasticity index PI =100 and mean effective stress σo' = 25 kPa.

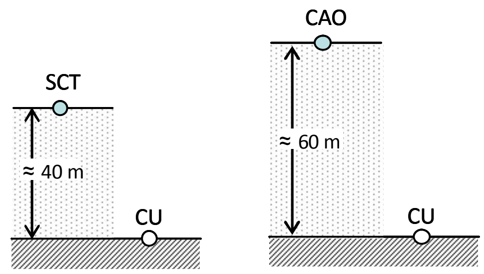
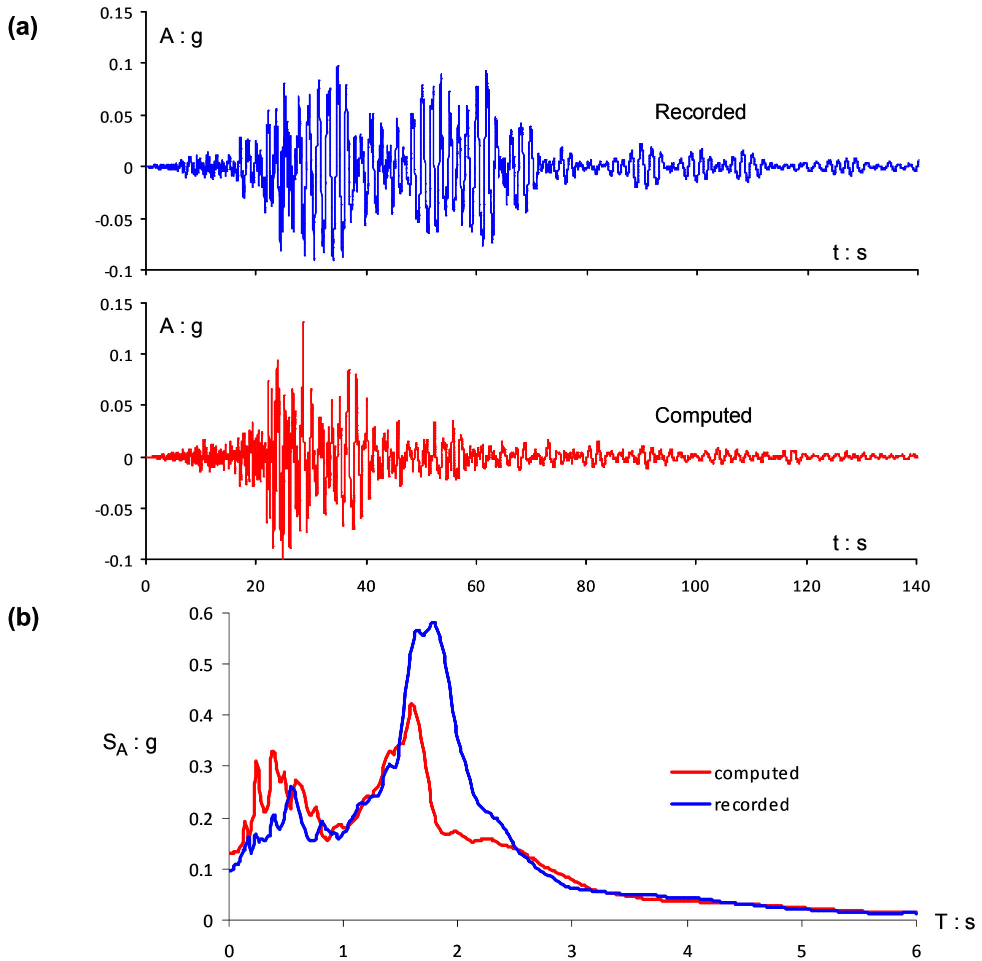


Figure 6. Sketches of the simplified soil profiles of the SCT and CAO sites (after Romo & Seed, 1987).



Figur 7. Comparison of the computed (red line) and recorded (blue) SCT response in terms of: (a) detailed acceleration time histories and (b) response spectra, for the 2017 earthquake. [utilised the Vucetic & Dobry 1987 curves for PI = 100.

Acceleration response spectrum on the ground surface of the SCT is compared in Fig. 7(b) with the spectrum of the N90E horizontal component of the 2017 record. Also, the detailed acceleration time histories are compared in Fig.7(a). The peak acceleration value is captured along with the first part of the signal (for t < 45 s). However, for t > 45 s, 1D analysis does not reproduce adequatly the real record. In terms of the response spectra, soil amplification analysis approximates quite well the real one; at the frequency region of 1.5 s < T < 2.5 s, analysis underestimates the spectral response.

4.1 Influence of G-γ and ξ-γ curves

The sensitivity of soil response to the employed G-γ, ξ-γ curves is shown in Fig.8 and Fig.9 for the SCT and CAO sites, respectively.

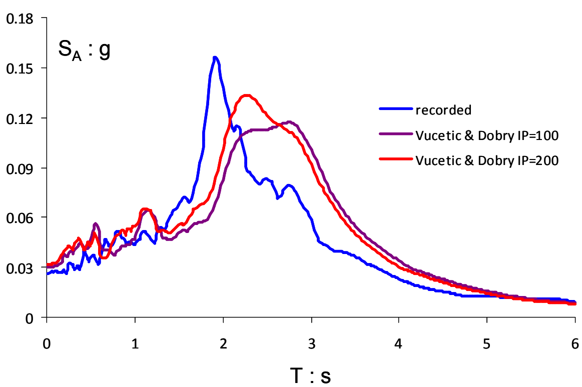


Figure 8. Comparison of the 1999 earthquake SCT response spectrum (blue line) with the computed response spectra obtained by utilising the Vucetic & Dobry curves with PI = 100 (dark red) and PI = 200 (red).

In case of the SCT site, as can be seen in Fig.8, the effect of plasticity index on soil's response is not prominent. The only differences are noted in the vicinity of the peak: spectral response for PI = 200 exceeds slightly that for PI =100. The explanation is straight-forward: the larger the plasticity index, the more elastic the soil becames. Thus, for the same lenel of shear strain, the reduction of shear modulus is smaller and the same is true for the increase of damping.

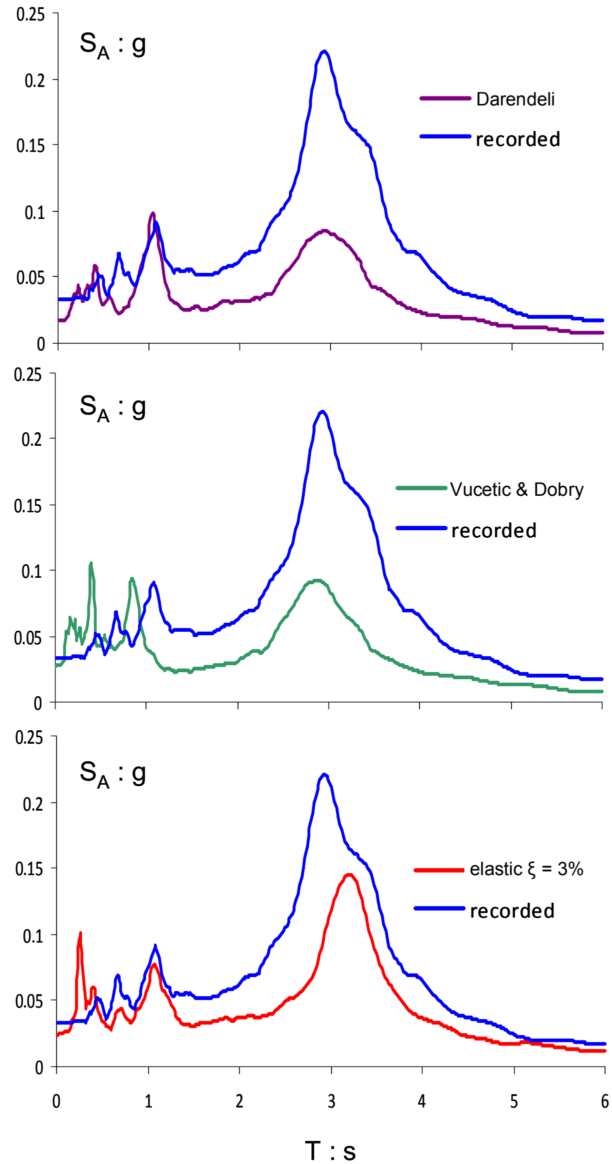


Figure 9. Comparison of the 1999 earthquake CAO response spectrum (blue line) with the computed response spectra obtained by utilising: the Darendeli (purple), Vucetic & Dobry (green) curves and the elastic response (red) as well.

For the case of CAO site, the influence of G-γ, ξ-γ curves is significant (Fig.9). The elastic response (no reduction of G, constant damping of 3%) leads to better results than the induced spectrum using the Darendeli (PI = 100, σ_o' = 25 kPa) or the Vucetic and Dobry (PI = 200) curves. The reason is the almost elastic behaviour of the Mexico City clay, as we mention before for the SCT site.

5 CONCLUSION

One-dimensional wave propagation analysis can explain adequately both the resonant period and the resonant spectral value, of Mexico City clay's response, at least for the two presented locations of SCT and CAO stations.Nonetheless, several other phenomena than the propagation of vertical shear waves might substantial in order to fully capture Mexico City clay's response. For instance, the topoghraphy of Mexico Valley (Bard & Bouchon, 1995) and the soil-structure interaction (Celebi, 2007), among others. Special attention should be paid in the G-γ, ξ-γ curves utilised to describe the dynamic properties of the soil, as Mexico's clay demonstrates a unique seismic behaviour.

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