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Spectral Comparison of Real Spectra with Site Effects Included vs MOC-2008 Teorical Spectra for Guadalajara City, Mexico

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ABSTRACT

Guadalajara city is the capital of the Mexican federal state of Jalisco. It is located close to the Pacific coast and is subjected to a large seismic risk. We present a seismic response study for some sites along the city. We calculated response spectra of shear-waves by using seismic records of actual earthquakes registered on rock and near the source as Green functions and propagated them trough a flat and horizontal layered media using a linear equivalent method to compare them with the response spectra calculated according to the Federal Commission of Electricity (CFE) seismic design buildings Manual (MOC-2008, 2008) which is widely used as reference on construction projects in Mexico. Our results show that MOC-2008 manual underestimates the spectral amplitudes and frequency band for the response spectra.

Keywords: Response Spectra; Guadalajara; Seismic Records; Green Function

1. Introduction

It is well known that seismic damage distribution is strongly influenced by physical and dynamic properties of the soil. The cyclical load response capacity to earthquakes for example, depends on these properties. Seismic response evaluation is one of the most important problems to solve in seismic engineering. The Analysis of the seismic response of the soil is used to predict the response of the seismic movement in the surface, which in turn is essential to obtain the design spectra to evaluate the risk. Evaluation is especially important in places with potentially liquefaction risk.

Design spectra is a tool that allows us to evaluate the forces to which the structures will be submitted in dependency on its own dynamic characteristics. Guadalajara city occupies the second site in Mexico, on population and economy growth. During the last years, more modern and greater civil structures have appeared at the whole city (**Figure 1**).

Figure 1. Large buildings appear each year in Guadalajara city.

Federal Commission of Electricity (CFE) seismic design buildings Manual [1] has been used as a quasi-official reference for construction since its appearance in 1993. A building regulation update, based on this type of studies is required as the recurrence cycle of earthquakes for this region of México which is about 80 to 100 years, and with the knowledge that the last devastating earthquake occurred on June 1932 [2], and it turns clear that this type of studies should be the bases to carry out a review of the building regulations.

In this article we estimate seismic response at eight sites distributed within the urban zone of Guadalajara city using records from real earthquakes occurred in along the subduction zone assuming one-dimensional propagation in order to test the current regulation.

Seismic records and earthquakes used are shown in **Table 1**.

2. Earthquakes and Seismic Records

Site effect due to geological conditions is one of the main factors which contribute to damage distribution during earthquakes. Subsoil impedance contrasts can significantly amplify the shaking level, as well as increase the duration of strong ground motion. The first action to take to prevent damages is to know site effect distribution. Subsoil dynamic properties allow us to predict the site response when it is submitted to earthquakes or dynamic charges.

In order to estimate the seismic response we chose earthquakes occurred along the subduction zone and seismic records (accelerations) from the closest stations installed over hard rock in order to prevent site effect to be used as Green Functions. We selected seismic stations far enough to assure vertical incidence at Guadalajara sites.

We selected three earthquakes: Tecomán, 2003 (Mw 7.5) recorded at Manzanillo station 65 km northwest from the epicenter, Colima, 1995 (Mw 7.3) recorded at the same station 25 km northeast from the epicenter and Oaxaca, 1999 (Mw 7.5) recorded at LANE station 19 km west from the epicenter. Locations of earthquakes used in this study are shown in **Figure 2**.

Table 1. Main features of earthquakes used in this study.

Date	Site	LAT	LON	Mw	PGA (g)
20030122	Colima	18.60	104.72	7.5	0.379
19951009	Colima	18.74	104.67	7.5	0.395
19990930	Oaxaca	15.95	97.03	7.5	0.250

Basic information from earthquakes used are shown in **Table 1**. PGA column refers to maximum acceleration on the station. Seismic records used as Green functions are shown in **Figure 3**. As the interest is on SH waves propagation, we used only the horizontal components.

3. Sites of Study

We selected eight sites distributed within the urban zone of Guadalajara city (**Figure 4**) where Lazcano Diaz [3] performed a site characterization which included thicknesses, density, shear-wave velocity (Vs) among other parameters.

Table 2 shows some basic parameters at each site: location, shear-wave velocity for the first 30 m (Vs30), dominant period from Federal commission of electricity CFE [1] calculated with PRODISIS [4] using the velocity profile, dominant period from Lazcano Diaz [3] and NEHRP [5] soil classification. In all cases, classification corresponds to rigid soil with shear velocities between 180 to 360 m/s.

As it is important to understand shear-wave propagation obtained in this study, we reproduce shear-wave velocity profiles from Lazcano Diaz [3] in **Figure 5**.

4. Wave One-Dimensional Propagation. The Linear Equivalent Method

We propagated through a one-dimension layered media SH waves computed from the horizontal components of

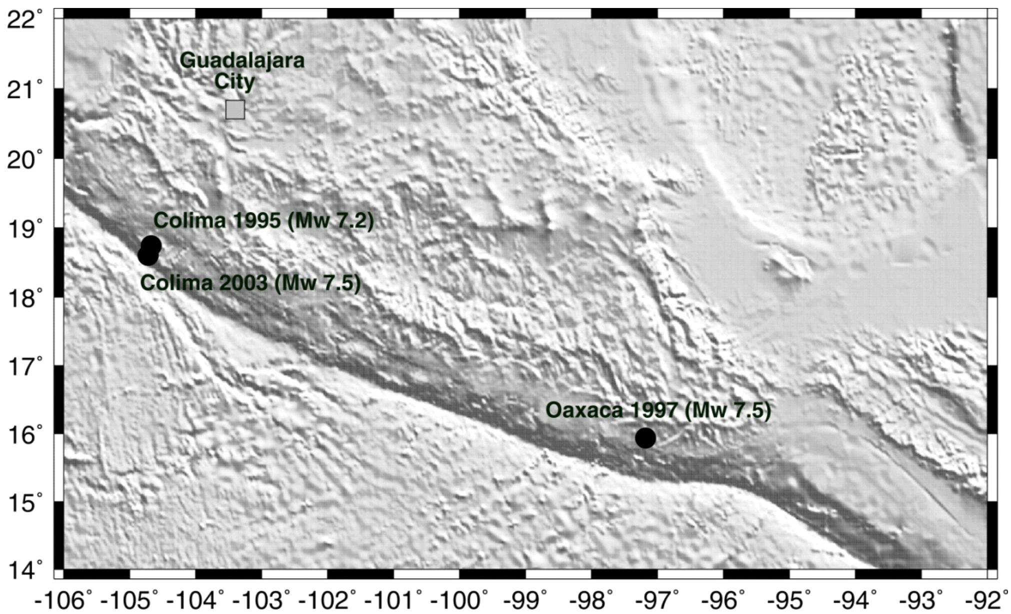


Figure 2. Location of Guadalajara city and earthquakes used in this study.

Table 2. Main features of the sites used in this study.

Site	Latitude N	Longitude W	Ts (CFE2008) (sec)	Ts (sec)	Vs30 (m/s)	NEHRP (1993)
BIBLIOTECA	20.61	103.348	0.38	0.47	253.20	D
ROTONDA	20.677	103.347	0.40	0.47	261.14	D
J. DEL BOSQUE	20.666	103.385	0.46	0.53	312.93	D
TORRENA	20.646	103.405	0.40	0.80	334.70	D
GRAN PLAZA	20.666	103.385	0.40	0.52	356.98	D
EULOGIO PARRA	20.692	103.390	0.42	0.53	270.96	D
AV. PATRIA	20.711	103.381	0.32	0.39	366.00	D
U.PANAMERICANA	20.682	103.439	0.43	0.63	318.11	D

As it is important to understand shear-wave propagation obtained in this study, we reproduce shear-wave velocity profiles from Lazcano Diaz, 2007 in **Figure 5**.

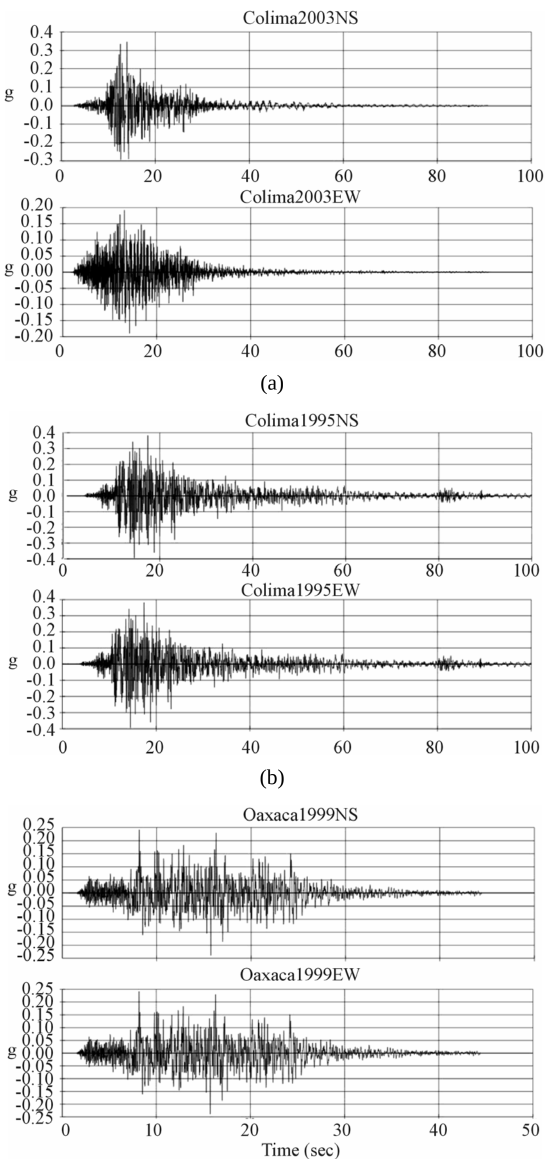


Figure 3. Horizontal acceleration records used. (a) Colima 2003 (Mw 7.5), (b) Colima 1995 (Mw 7.5), (c) Oaxaca 1999 (Mw 7.5).

the records described above using a linear equivalent methodology (LEM) [6]. Soil shear modulus depends on the deformation resistance of the soil. Damping ratio is associated with dissipative behavior of the soil to cyclic inputs. In a linear equivalent scheme, non-linear behavior of shear modulus and damping ratio are represented by curves as those shown in **Figure 6** proposed by many authors ([7,8], among others).

We used ProShake [9] software to obtain the shear-wave propagation in order to add site effect to the original record assuming:

- Harmonic waves: Waves are periodic at the fundamental frequency.
- Propagation: Wave propagation is vertical and we consider only horizontal component (SH).
- Layered and horizontal media. The only variables that define the media are: depth, thickness, density, shears modulus (G) and damping factor (D).
- Shear-wave propagation isotropic homogeneous media.

5. Spectra (5%) and Design Spectra MOC-2008

Using the seismic records mentioned above and a layered media, we built seismic records with site effect included for each site. We then used them to calculate, the response spectra using Degtra program [10].

Response spectra are usually estimated for a damping of 5% because it is representative of the observed damping of reinforced concrete and structural steel. **Figures 7** and **8** show the response spectra for a damping of 5% for each site. We show the spectra for both horizontal components using each real record as well as the mean plus standard deviation.

Seismic parameters of any project from a probabilistic point of view (the deterministic way is no longer used), requires certain knowledge of seismic activity of the area. The probability of occurrence of a seismic event greater than a reference is given by

Figure 4. Location of sites selected for this study (triangles).

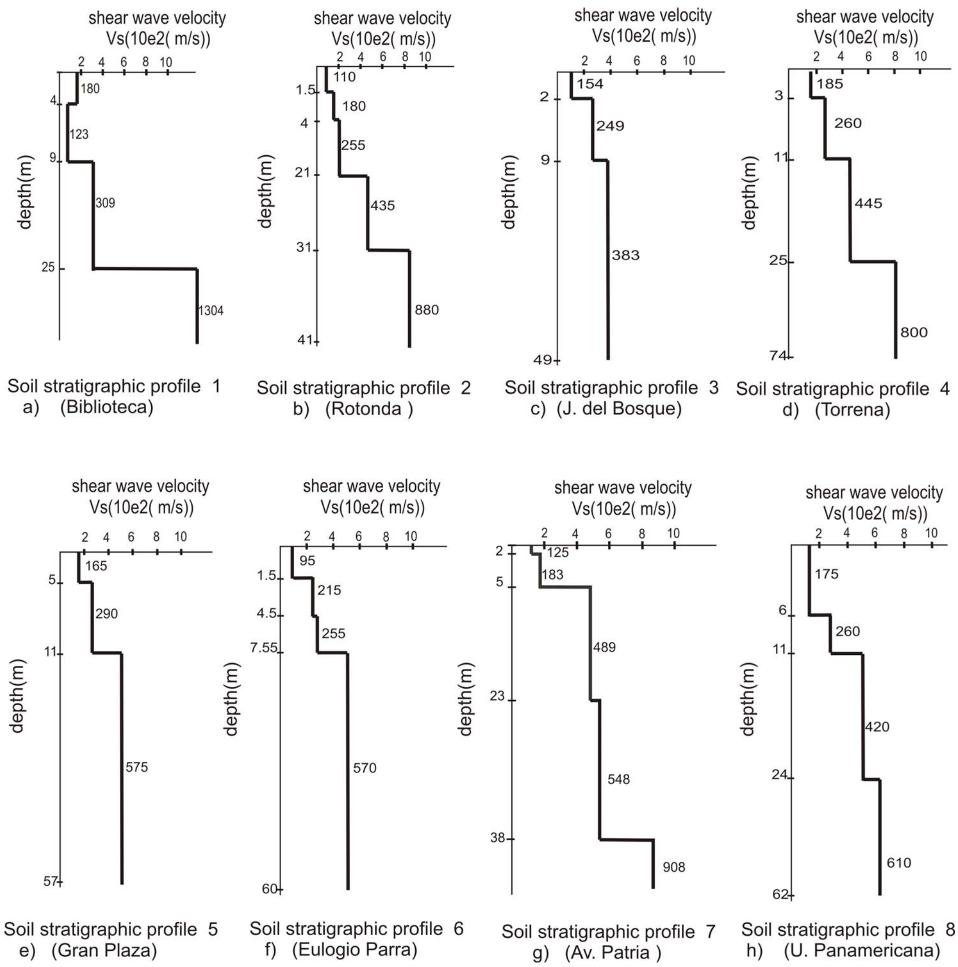
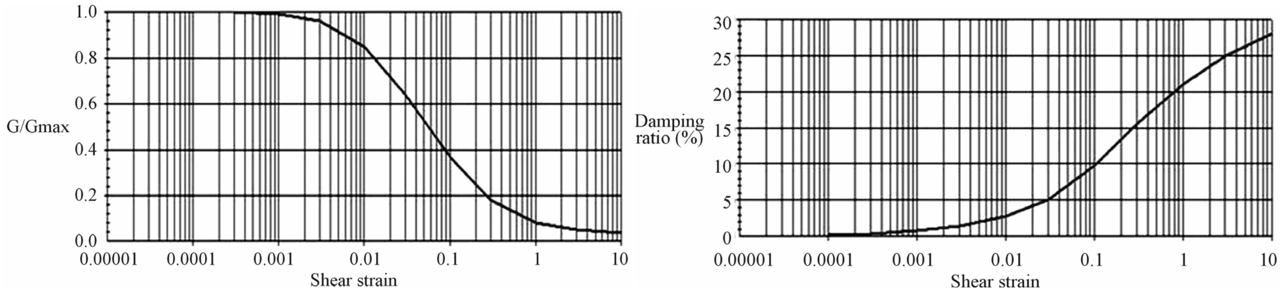


Figure 5. Vs profiles of the eight sites used in this study. (a) Biblioteca; (b) Rotonda; (c) J. del bosque; (d) Torrena; (e) Gran Plaza; (f) Eulogio Parra; (g) Av. Patria; (h) U. Panamericana.



(a) (b)

Figure 6. (a) Shear modulus vs shear-strain; (b) Damping ratio vs shear-strain [7,8].

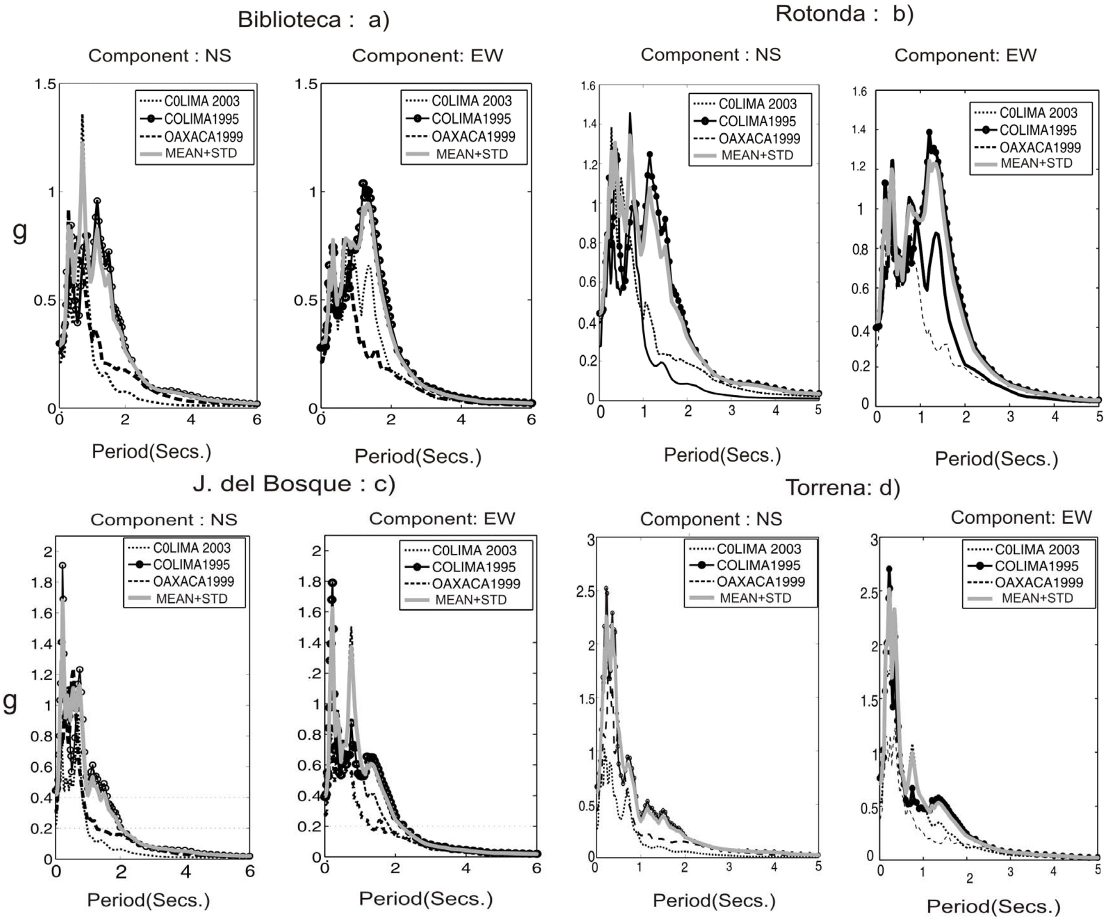


Figure 7. Response spectra for 5% damping for the eight sites using real records propagating through a layered media. Continuous line represents spectra using the Colima 2003 record, continuous line with dots, the spectra using Colima 1995 record, dotted line represents spectra from the Oaxaca 1999 record. Green line is the mean plus standard deviation. (a) Biblioteca site; (b) Rotonda site; (c) J. del bosque site; (d) Torrena site.

$$P(X < x) = F\ X(x,t). \tag{1}$$

where "*P*" is the probability that an "*X*" event is less than an *x* event previously defined in a time *t*. This probability in terms of the project can be defined considering the probability of the usual buildings which is of 10% in 50 years. It is associated with the existence of an earthquake which occurs every 450 years and it is named "rare earthquake" in building codes.

For the same sites, we calculated the response spectra for each site according to MOC-2008 [1] procedure which is based on probabilistic criteria. **Figures 9** and **10**, shows mean plus standard deviation response spectra for both horizontal components calculated in this study and the responses for a rock site, for edge state of service and for collapse according to MOC-2008 [1] procedure.

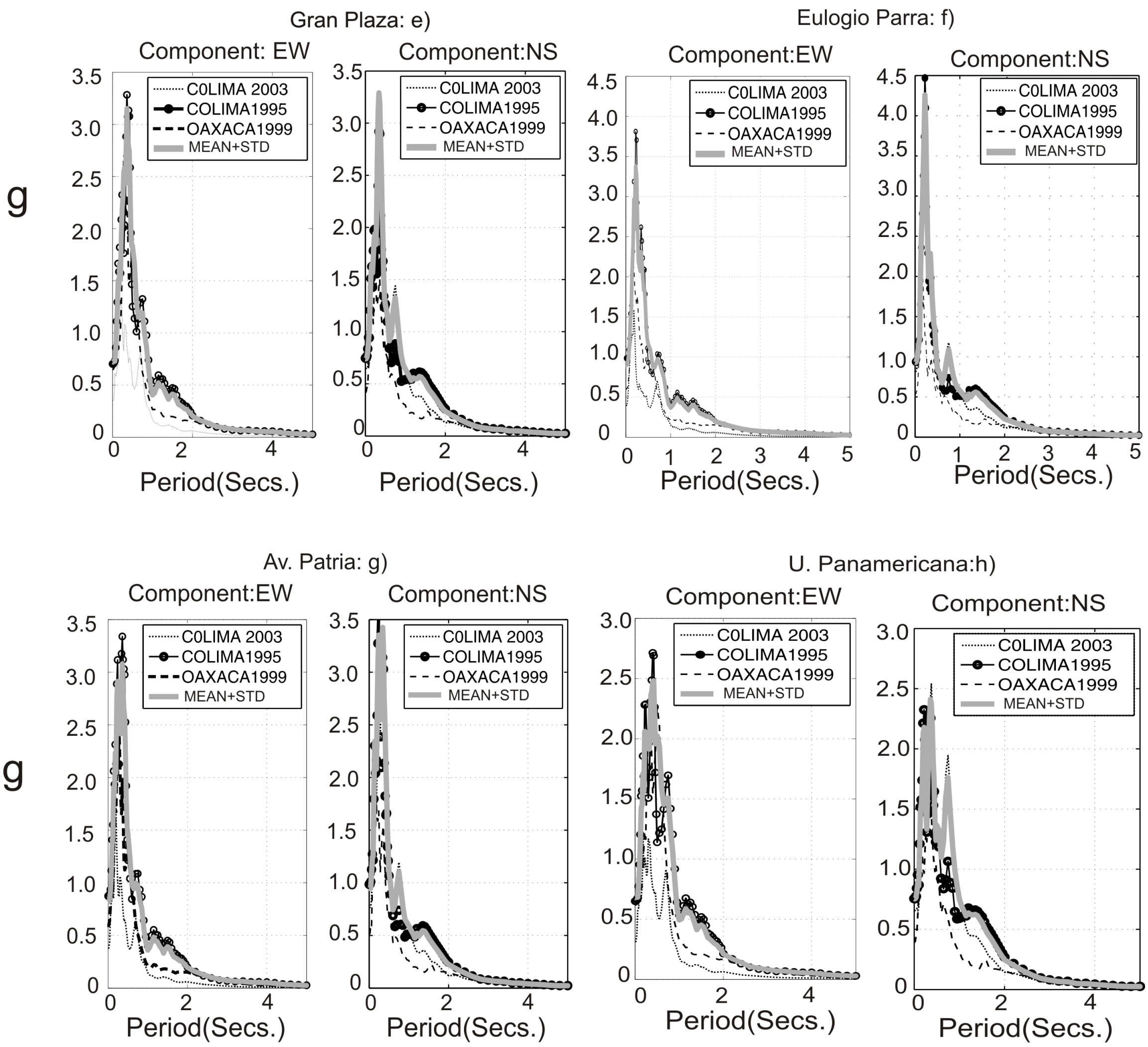


Figure 8. Response spectra for 5% damping for the eight sites using real records propagating through a layered media. Continuous line represents spectra using the Colima 2003 record, continuous line with dots, the spectra using Colima 1995 record, dotted line represents spectra from the Oaxaca 1999 record. Green line is the mean plus standard deviation. (e) Gran Plaza site; (f) Eulogio Parra site; (g) Av. Patria, site; (h) U. Panamericana site.

We observe the higher amplitudes at sites Av. Patria and Eulogio Parra of around 4 g while amplitudes at U. Panamericana, Torrena, J. del Bosque and Gran Plaza where of around 3.12 g and the lower amplitudes of around 1.2 g at the sites located in downtown, Biblioteca and Rotonda. Amplitudes are higher for response spectra using seismic records and frequency band is shorter for response spectra from MOC-2008 [1]. The flat zone in the last case is from about 0.1 to 1.6 sec while significant amplitudes from seismic records extend up to 1.6 seconds.

6. Conclusions

Our results show that the soils located in the northern-zone of Guadalajara city amplify seismic waves greater than those located in the eastern and western zones. Unfortunately we do not have records to analyze in the southern zone. The studied sites show a high value of amplification of the seismic waves despite NERPH soil classification which corresponds to rigid soil with shear velocities between 180 to 360 m/s.

It is obvious to conclude that the actual regulation must not be applied indiscriminately to every site where there is a construction project but it is necessary to make studies of this kind to characterize the site effect at each site. While MOC-2008 manual is based on probabilistic models, a comparison with real records is needed. This kind of studies should be complemented with other studies such as seismic microzonation.

7. Acknowledgements

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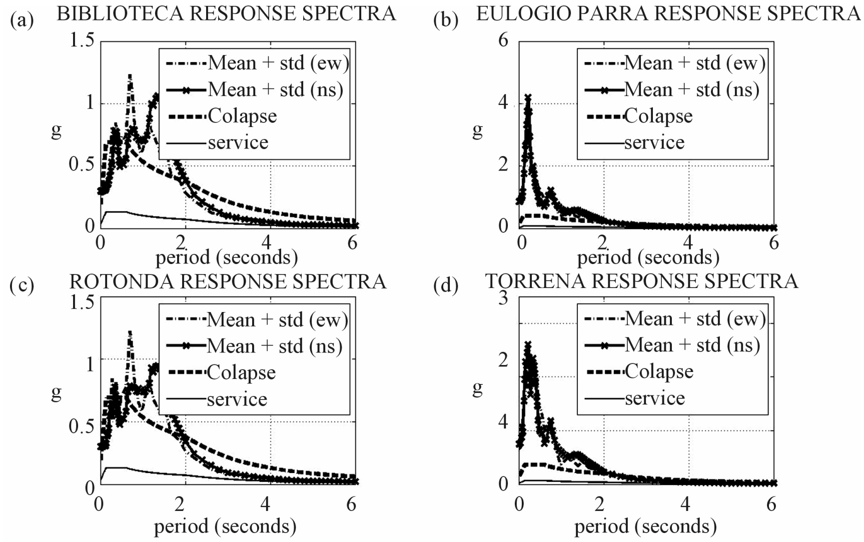

Figure 9. Response spectra calculated according to MOC-2008 procedure vs response spectra using seismic records. The different curves represent mean plus standard deviation response spectra for both components, response for a rock site, for edge state of service and for collapse. (a) Biblioteca site; (b) Rotonda site, (c) J. del bosque site; (d) Torrena site.

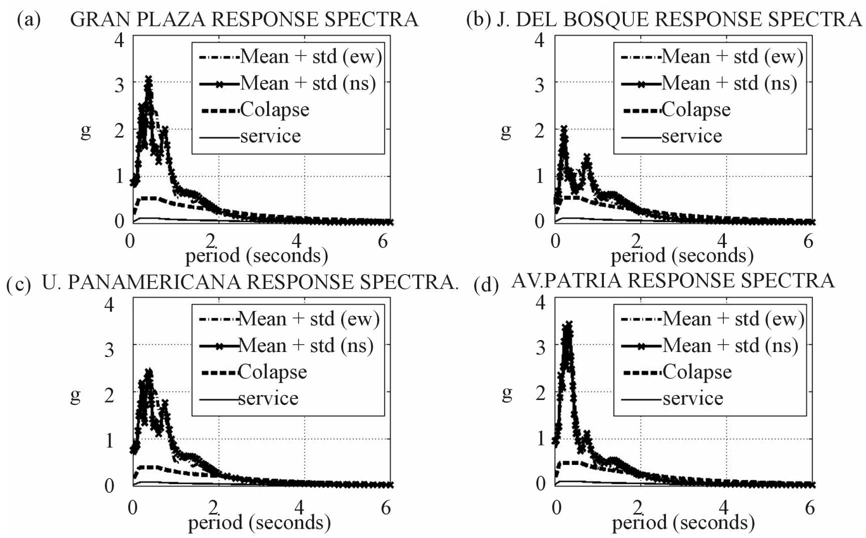

Figure 10. Response spectra calculated according to MOC-2008 procedure vs response spectra using seismic records. The different curves represent mean plus standard deviation response spectra for both components, response for a rock site, for edge state of service and for collapse. (a) Gran Plaza site; (b) Eulogio Parra site; (c) Av. Patria site; (d) U. Panamericana site.

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