SEISMIC HAZARD ASSESSMENT FOR THREE MEXICAN CITIES

A. Gama-Garcia[1], A. Gomez-Bernal[2] & H. Juarez-Garcia[2]
[1]*Universidad Autonoma de Guerrero, Mexico*
[2]*Universidad Autonoma Metropolitana-Azcapotzalco, Mexico*

SUMMARY
Due to the well-known “Guerrero Gap”, and the possible occurrence of large earthquakes in this zone, there is a need to evaluate the seismic risk for different cities in Mexico. Acapulco, Chilpancingo and Mexico City are three cities that are expected to sustain damage at their building population due to an earthquake event in this gap. There is a reliable data base of recorded earthquakes over the past 30 years; the data base includes earthquakes for different soils, from sedimentary to rock sites; and it also includes events from different seismic sources.

In order to predict accurate seismic hazard values, for different soil sites, and considering local conditions of each city; we present a comparative study with different attenuation models. In this paper we will use typical regional and global models for subduction zones; and we will also present the seismic hazard and risk assessments for Acapulco, Chilpancingo and Mexico City.

Keywords: Attenuation, Relationships, Spectra, Earthquake, Subduction.

1. INTRODUCTION

The seismic instrumentation in the State of Guerrero and all of Mexico began in 1960. The measure of the amount of energy released by an earthquake, through magnitude values (Mw), began in the 70s; this is why the Mexican seismic catalogues have limitations in terms of magnitude values, location and focal mechanisms for large historical earthquakes occurred before the 1970s. The limitation for predicting strong ground motion parameters is due to the short period of comprehensive earthquake measurements (1970–2012), and the scarcity of instrumental stations built in those 42 years. For Mexico City, Chilpancingo and Acapulco, there are no earthquake records for large earthquakes (e.g. 1957 or 1907).

Special attention should be paid to three subduction earthquakes: July 28th, 1957(M7.7); March 14th, 1979(M7.4) and September 19thand 21st, 1985(M8.1 andM7.6):

Earthquake	Seismic Source	MMI values		Damage observed
July 28th, 1957	Acapulco-San Marcos	Acapulco	V	Minor
		Mexico City	VII	Moderate
		Chilpancingo	VIII	Severe
March 14th, 1979	Petatlan	Acapulco	VI	Minor
		Chilpancingo	VI	Minor
		Mexico City	VI-VII	Moderate
September 19th and 21st, 1985	Michoacan	Acapulco	VII	Moderate
		Chilpancingo	VII-VIII	Severe
		Mexico City	VIII-IX	Heavy

Figure 1 shows the geographical location and Figure 2 shows the location of the accelerometric stations of Acapulco, Chilpancingo and Mexico City.

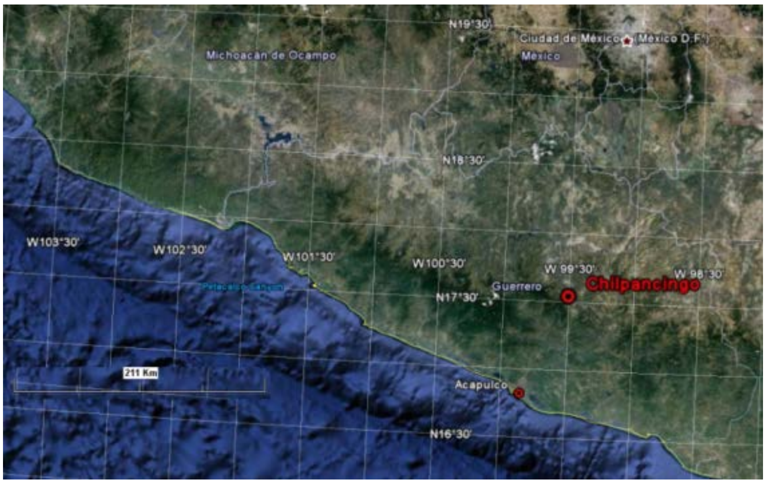

Figure 1. Geographical location of Acapulco, Chilpancingo and Mexico City (Google Earth).

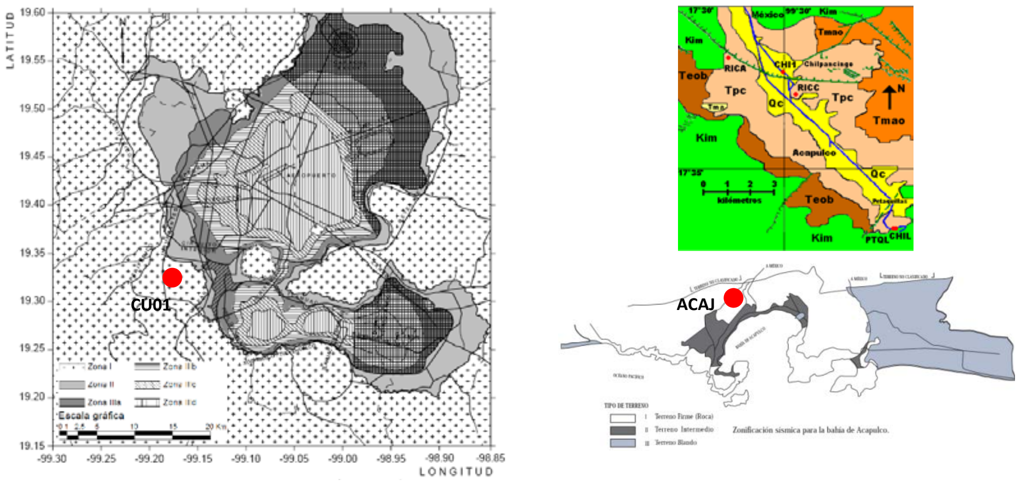

Figure 2. Location of the accelerometric stations of Acapulco, Chilpancingo and Mexico City.

2. ATTENUATION MODEL

An attenuation relationship is a mathematical expression that states the change of value, in a seismic parameter, from the seismic source to the study site, for an earthquake with a known magnitude. The attenuation relationships have been studied or over 50 years (Gutenberg and Richter, 1956, Trifunac and Brady, 1975, Seed et al., 1976 and Young et al., 1997, among others). Attenuation relationships include several variables, such as depth or soil type.

2.1. Methodology

Attenuation relationships usually express ground motion parameters as a function of magnitude, distance, and other variables, Equation 1:

$$Y = f(M, R, P_i) \tag{1}$$

Where Y is the seismic parameter, its magnitude M, R a measure of the distance from the source to the site, and P_i represents other parameters to characterize the source of the earthquake, the path of seismic waves and local site conditions. A typical relationship can be expressed with the following equation (Kramer, 1996):

$$\ln Y = c_1 + c_2 M + c_3 M^{c_4} + c_5 \ln[R + c_6 \exp(c_7 M)] + c_8 R + f(\text{source}) + f(\text{site}) \qquad (2)$$
$$\sigma_{\ln Y} = c_9$$

Equation 2 represents a general attenuation relationship. The term $\sigma_{\ln Y}$ describes the uncertainty in the values of the seismic parameters.

2.2. Attenuation Models for Chilpancingo

Youngs et al., (1997) used 60 ground motions measured in rock sites, and numerical ground motion simulations, with magnitude values Mw ≥ 8, to develop attenuation relationships for subduction zones, Equation 3.

$$\ln\big(\mathrm{PHG(g)}\big) = C_1 + C_2 M_w + C_3 \ln[C_4 \exp(C_5 M_w)] + C_6 Z_t \qquad (3)$$
$$\sigma_{\ln PHA} = C_7 + C_8 M_w$$

The Youngs et al., (1997) model was used in Chilpancingo, Equations (4), (5), (6) and (7) were developed for two focal mechanisms at sedimentary soil and rock:

$$\ln(PGA) = C_1 + C_2 M_w + C_3 \ln(R) + C_4 S_1 + C_5 S_2 \qquad (4)$$
$$\ln(PGA) = C_1 + C_2 M_w + C_3 \ln(R) + C_4 M_w^3 + C_5 S_1 + C_6 S_2 \qquad (5)$$
$$\ln(\mathrm{PGA}) = C_1 + C_2 M_w + C_3 \ln[R + 22.5(M_w - 6) - 0.0015H] + C_4 S_1 + C_5 S_2 \qquad (6)$$
$$\ln(\mathrm{PGA}) = C_1 + C_2 M_w + C_3 \ln(R + 25) + C_4 S_1 + C_5 S_2 \qquad (7)$$

Attenuation models at sedimentary soil in Chilpancingo

Figure 3 shows the relationship of magnitude (M_w) versus epicentral distance (km), (stations RICC and CHI1 located at sedimentary soil). The criteria used to obtain the PGA values consisted in taking maximum peak value of the horizontal components of the seismic record.

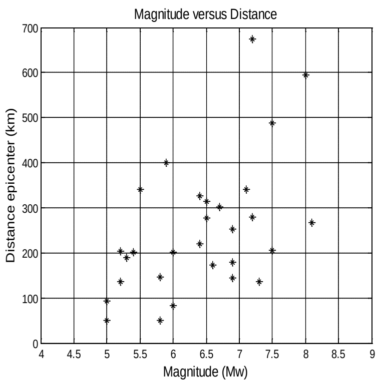

Figure 3. Magnitude (M_w) versus epicentral distance (km) at sedimentary soil sites for Chilpancingo.

All the attenuation models (Equation 4 to 7) were tested for a Mw = 8.1 earthquake, with two focal mechanisms (subduction and deep earthquakes), and a depth of 25 km. A nonlinear regression was performed. In all figures, (CV) stands for vertical component and (CH) for horizontal component. Four equations were obtained: two for subduction and deep earthquakes and two for horizontal and vertical components.

Equation (4): Figure 4 shows the attenuation relationships and Equations 8 to 11 were developed.

$$\ln(\mathrm{PGA})_h = -1.56 + 1.44 M_w - 1.80 \ln(R) - 2.22 \qquad (8)$$
$$\ln(\mathrm{PGA})_h = -1.56 + 1.44 M_w - 1.80 \ln(R) - 1.14 \qquad (9)$$
$$\ln(\mathrm{PGA})_v = -1.42 + 1.40 M_w - 1.90 \ln(R) - 2.07 \qquad (10)$$
$$\ln(\mathrm{PGA})_v = -1.42 + 1.40 M_w - 1.90 \ln(R) - 1.02 \qquad (11)$$

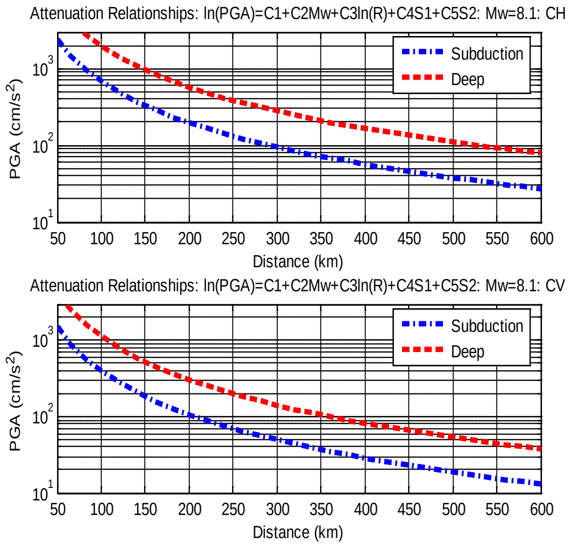

Figure 4. Attenuation model derived from Equation (4).

Equation (5): Figure5 shows the attenuation relationships and Equations 12 to 15 were developed.

$$\ln(\mathrm{PGA})_{\mathrm{h}} = -1.51 + 1.42\mathrm{M_w} - 1.80\ln(\mathrm{R}) + 0.0002\mathrm{M_w^3} - 2.16 \quad (12)$$
$$\ln(\mathrm{PGA})_{\mathrm{h}} = -1.51 + 1.42\mathrm{M_w} - 1.80\ln(\mathrm{R}) + 0.0002\mathrm{M_w^3} - 1.09 \quad (13)$$
$$\ln(\mathrm{PGA})_{\mathrm{v}} = -1.46 + 1.43\mathrm{M_w} - 1.91\ln(\mathrm{R}) - 0.0002\mathrm{M_w^3} - 2.12 \quad (14)$$
$$\ln(\mathrm{PGA})_{\mathrm{v}} = -1.46 + 1.43\mathrm{M_w} - 1.90\ln(\mathrm{R}) - 0.0002\mathrm{M_w^3} - 1.07 \quad (15)$$

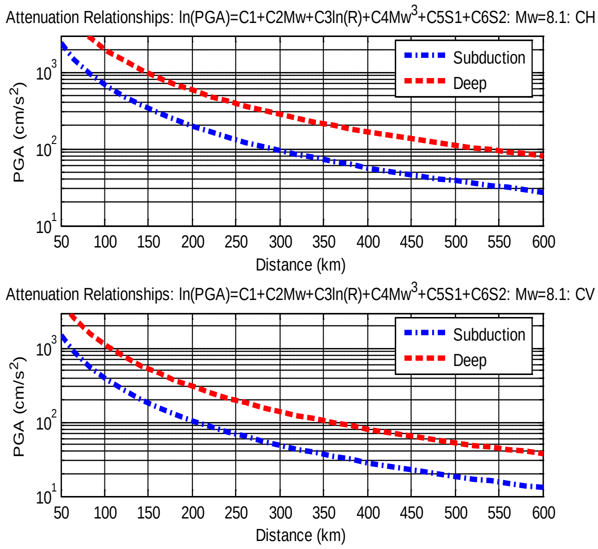

Figure 5. Attenuation model derived from Equation (5).

Equation (6): Figure 6 shows the attenuation relationships and Equations 16 to 19 were developed.

$$\ln(\mathrm{PGA})_{\mathrm{h}} = -2.55 + 1.56\mathrm{M_w} - 1.56\ln[\mathrm{R} + 22.5(\mathrm{M_w} - 6) - 0.0015\mathrm{H}] - 3.2 \quad (16)$$
$$\ln(\mathrm{PGA})_{\mathrm{h}} = -2.55 + 1.56\mathrm{M_w} - 1.56\ln[\mathrm{R} + 22.5(\mathrm{M_w} - 6) - 0.0015\mathrm{H}] - 2.17 \quad (17)$$
$$\ln(\mathrm{PGA})_{\mathrm{v}} = -2.43 + 1.54\mathrm{M_w} - 1.69\ln[\mathrm{R} + 22.5(\mathrm{M_w} - 6) - 0.0015\mathrm{H}] - 3.08 \quad (18)$$
$$\ln(\mathrm{PGA})_{\mathrm{v}} = -2.43 + 1.54\mathrm{M_w} - 1.69\ln[\mathrm{R} + 22.5(\mathrm{M_w} - 6) - 0.0015\mathrm{H}] - 2.05 \quad (19)$$

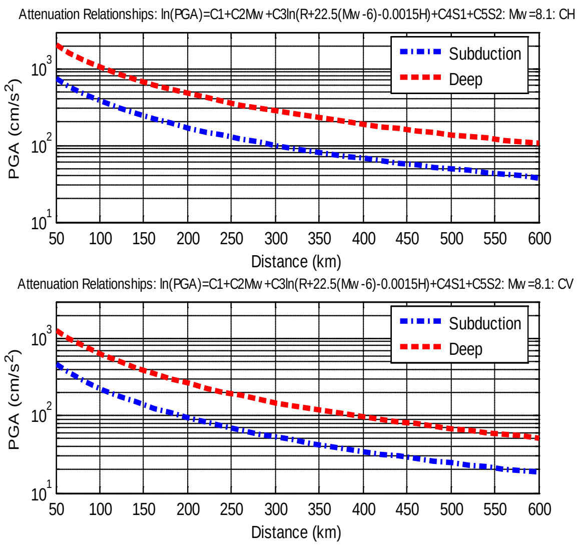

Figure 6. Attenuation model derived from Equation (6).

Equation (7): Figure 7 shows the attenuation relationships and Equations 20 to 23 were developed.

$$\ln(\mathrm{PGA})_h = -0.58 + 1.47M_w - 2.14\ln(R+25) - 1.24 \quad (20)$$
$$\ln(\mathrm{PGA})_h = -0.58 + 1.47M_w - 2.14\ln(R+25) - 0.15 \quad (21)$$
$$\ln(\mathrm{PGA})_v = -0.43 + 1.42M_w - 2.23\ln(R+25) - 1.08 \quad (22)$$
$$\ln(\mathrm{PGA})_v = -0.43 + 1.42M_w - 2.23\ln(R+25) - 0.02 \quad (23)$$

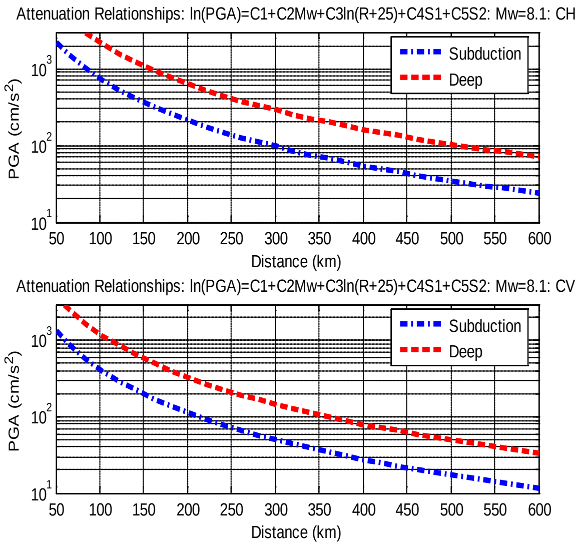

Figure 7. Attenuation model derived from Equation (7).

Equations (4), (5) and (6) produced better estimations of PGA values for sedimentary soil in Chilpancingo. Thus, we used the attenuation model proposed in Equation (4) to estimate PGA values at rock.

Attenuation models at rock in Chilpancingo

Figure 8 shows the database used in this paper at rock sites in Chilpancingo. The attenuation model (Equation4) was tested for a Mw=7.4 earthquake, with two focal mechanisms (subduction and deep earthquakes), and a depth of 25 km.

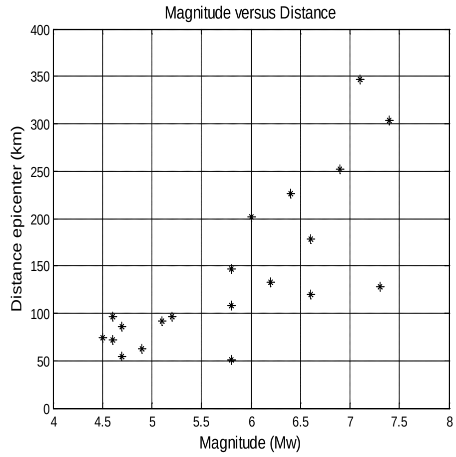

Figure 8. Magnitude (M_w) versus epicentral distance (km) at rock in Chilpancingo.

Equation (4): Figure 9 shows the attenuation relationships and Equations 24 to 27 were developed.

$$\ln(\mathrm{PGA})_h = -1.9047 + 0.6618M_w - 0.8861\ln(R) - 2.4832 \quad (24)$$
$$\ln(\mathrm{PGA})_h = -1.9047 + 0.6618M_w - 0.8861\ln(R) - 2.0865 \quad (25)$$
$$\ln(\mathrm{PGA})_v = -1.7767 + 0.7533M_w - 1.1000\ln(R) - 2.4680 \quad (26)$$
$$\ln(PGA)_v = -1.7767 + 0.7533M_w - 1.1000\ln(R) - 1.8206 \quad (27)$$

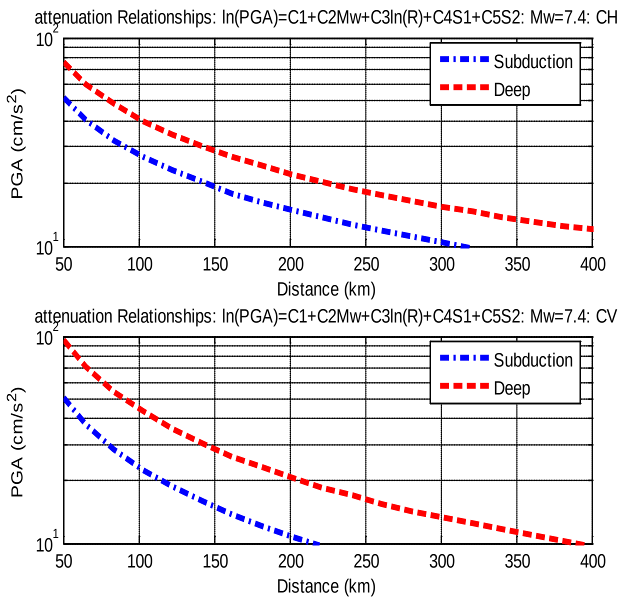

Figure 9.Attenuation model derived from Equation (4).

2.3. Comparison within local and regional attenuation models

Figure10 shows the four attenuation relationships obtained for sedimentary soil at Chilpancingo, it can be seen that Equations 4, 5 and 7 are very consistent with each other. Figure 11 shows attenuation relationships at rock sites, for different regions in the world. The attenuation relationships were estimated with a magnitude Mw = 7.4 earthquake. The PGA values obtained from the attenuation models for Chile (Saragoni et al., 2004) and Peru (Casaverde and Vargas, 1980) are higher than those proposed for Mexico (Ordaz et al., 1989; and this research) and those for the US (Youngs et al., 1988). We observed that attenuation relationships for Mexico and US produce lower PGA values than those observed for the subduction mechanisms in South America (Nazca and South American plates).

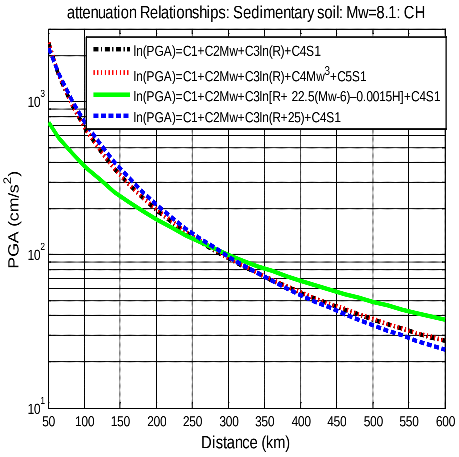

Figure 10. Attenuation model comparison for sedimentary soil at Chilpancingo**.**

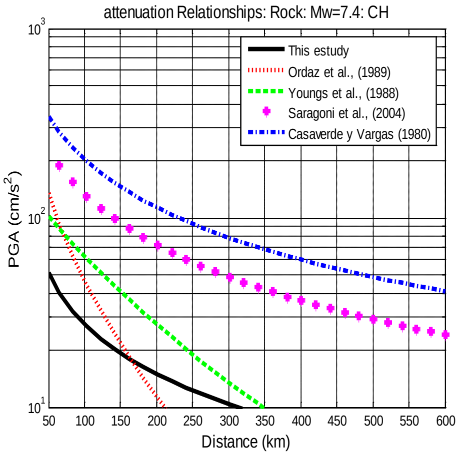

Figure 11. Comparative regional of attenuation relationships estimated at rock.

3. SPECTRAL ATTENUATION MODEL

The development of spectral attenuation relationships began in the 1970s, McGuire (1974) and Trifunac and Anderson (1978). The Seismological Research Letter, 1997 and Earthquake Spectra, 2008 recently published the next generation of attenuation relationships for spectral values. The objective of this research is to estimate aspectral attenuation relationships applicable to rock and sedimentary soil in Chilpancingo. In order to evaluate the absolute pseudo acceleration spectra, with 5% of critical damping, we used the attenuation model proposed by Youngs (1988, 1997), Equation (28).

$$\ln \mathrm{Sa}(\mathrm{T}) = \mathrm{a}_1(\mathrm{T}) + \mathrm{a}_2(\mathrm{T})(\mathrm{M}) + \mathrm{a}_4 \ln(\mathrm{R}) \tag{28}$$

Spectral model at rock in Chilpancingo

Subduction and deep earthquakes were used, with magnitude between 4.5≤Mw≤7.4, recorded at PTQL and CHIL stations. The epicentral distances range between 43 and 345 km. The response spectra, used for regression, considered the direction of maximum PGA horizontal values. Figure 12 left shows the estimated response spectra at rock, with an epicenter distance of 90 kilometers away from Chilpancingo, with magnitudes 7.3, 7.0 and 6.0. Figure 12 right shows the spectra for earthquakes with magnitudes 7.4, 7.0 and 6.0, considering subduction and deep earthquakes with magnitudes between 4.5≤Mw≤7.4.

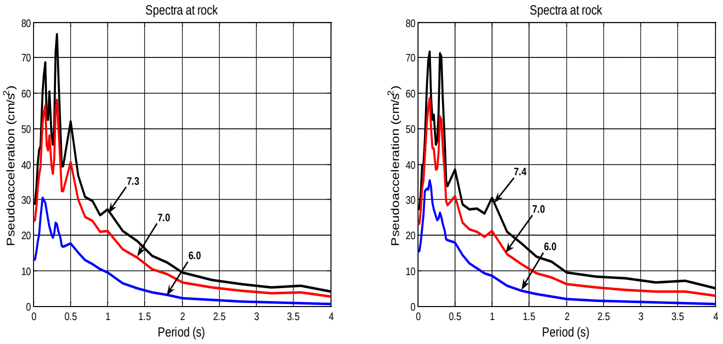

Figure 12. Left estimated spectra for subduction earthquakes, epicenter distance 90 km from Chilpancingo. Right, estimated spectra for subduction and deep earthquakes. 5 % of critical damping was considered.

Figure 13 shows estimated spectra for a magnitude 7.3 subduction earthquake, with epicentral distances 90, 140, 165 and 220 km.

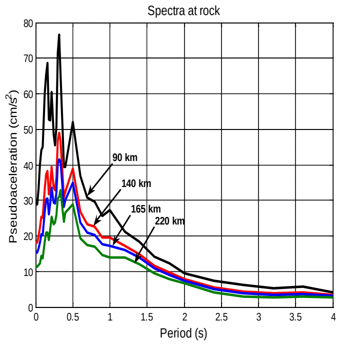

Figure 13. Estimated spectra for a magnitude 7.3 subduction earthquake, with differente picentral distances. 5% of critical damping was considered.

Spectral model at sedimentary soil in Chilpancingo

The selected records were subduction and deep earthquakes with magnitude 5.0≤Mw≤8.1, recorded at CHI1 and RICC stations, with epicentral distances from 47 to 653 km. Figure 14. left shows the estimated spectra (5%) in sedimentary soil, with 90 km of epicentral distance, and subduction earthquake magnitudes 8.1, 7.7, 7.5 and 7.4. The subduction earthquakes considered had magnitudes 5.0≤Mw≤8.1. Figure 14 right shows the estimated spectra (5%) for magnitudes 8.1, 7.7, 7.5 and 7.4. Subduction and deep earthquakes with magnitudes 5.0≤Mw≤8.1 were considered.

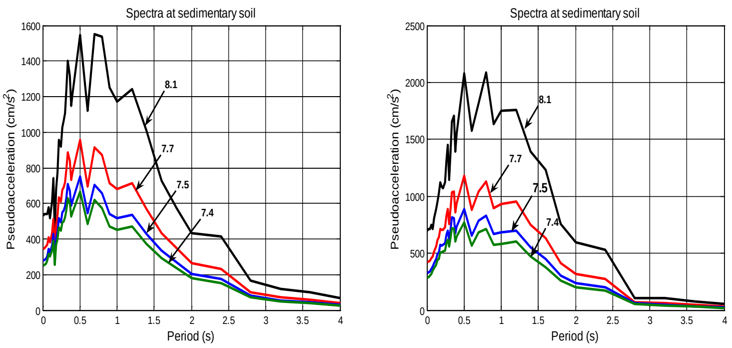

Figure 14. Left estimated spectra for subduction earthquakes, epicenter distance 90 km from Chilpancingo. Right, estimated spectra for subduction and deep earthquakes. 5 % of critical damping was considered.

Figure 15 shows the estimated spectra (5%) in sedimentary soil for magnitude 8.1 subduction earthquake, with epicentral distances 90, 140, 165 and 220 km.

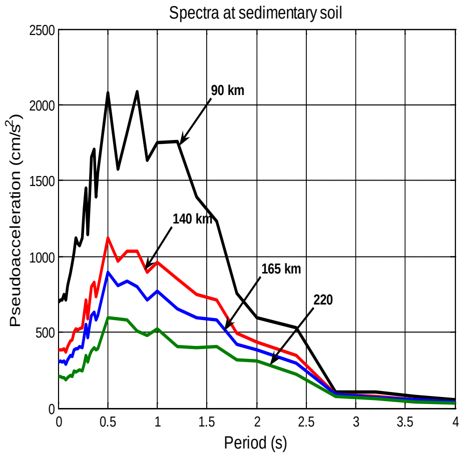

Figure 15. Estimated spectra for a magnitude 8.1 subduction earthquake. 5% of critical damping was considered.

4. ACAPULCO AND MEXICO CITY

Attenuation relationships were also estimated at rock sites for Acapulco and Mexico City. The accelerometric records used were for station ACAJ (CENAPRED), the following variables were defined; rock site; vertical components; epicentral distance = 50 km, PGA = 50cm/s^2. The following observations were drawn: the variation, in the horizontal component, of the values of PGA with the distance is negligible, the vertical component showed variation with distance. The PGA values in both components are relatively small. This suggests a saturation of the seismic energy at sites, near the seismic source, Figure 16 left.

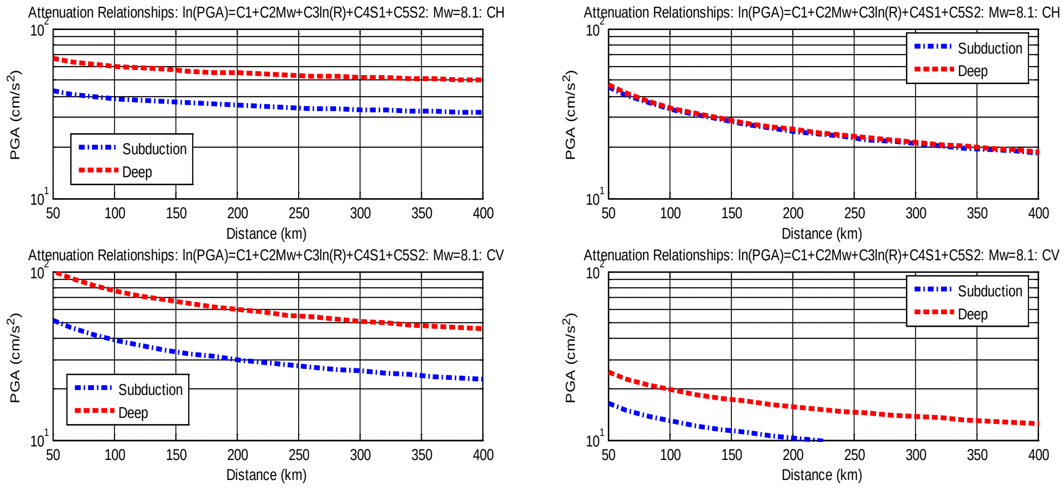

Figure 16. Equation (4) attenuation model for rock site in Acapulco left, Mexico City right.

In the case of Mexico City, the accelerometric database was obtained from station CU01, located in rock site.The variation of PGA values with distance is not constant, although the variation is not significant. The following data was considered: rock site; horizontal components; epicentral distance = 200km; PGA = 25cm/s^2, Figure 16 right. Figure 17 shows the comparison of the horizontal component of the attenuation relationships, rock sites in Acapulco, Chilpancingo and Mexico cities; Mw=7.4 earthquakes were considered and depth = 25km. For Acapulco, epicentral distance = 50km, PGA = 40cm/s^2. For Chilpancingo, epicentral distance = 100km, PGA = 30cm/s^2. For Mexico City, epicentral distance = 200km, PGA = 20cm/s^2.

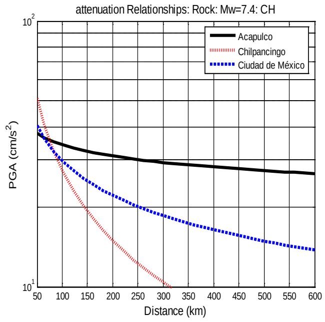

Figure 17. Comparative Attenuation Relationships at rock in Acapulco, Chilpancingo and Mexico City.

CONCLUSIONS

A reliable ground motion database was used, with 30 years of recorded data. The ground motions used were large magnitude eearthquakes, with relatively distant epicenters. All attenuation models showed good results, for sedimentary soft and rock soils. Although for simplicity we used Equation (4) for all the attenuation relationships. Attenuation relationships for Chile and Peru computed higher PGA values than Mexican and US attenuation models. For rock sites, the worst scenario was observed for a 7.3 magnitude earthquake, epicentral distance = 90 km, for subduction earthquakes, with PGA = 77cm/s^2. For sedimentary soft soil, the worst scenario is presented for a 8.1 magnitude earthquake, epicentral distance = 90km,f or subduction earthquakes, PGA = 2000cm/s^2.

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