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PREDICTION OF PEAK, HORIZONTAL GROUND MOTION PARAMETERS IN MEXICO CITY FROM COASTAL EARTHQUAKES

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RESUMEN

La necesidad de predecir el movimiento del terreno en la ciudad de México producido por temblores en la costa se ha hecho cada vez más importante. Sin embargo, las peculiares condiciones del sitio en que se encuentra la ciudad y la escasez de datos de movimientos fuertes en el pasado, han dado lugar a dudosas relaciones de atenuación. Actualmente se cuenta con acelerogramas de 16 temblores de la costa ($5.6 \leqslant M_s \leqslant 8.1$, $282 \leqslant R \leqslant 466$km) registrados en la estación UNAM (CUIP) en la zona de lomas, incluyendo los sismos de Michoacán del 19 de septiembre de 1985 ($M_s = 8.1$), dos de sus réplicas principales, y otros 8 eventos que no habían sido analizados previamente.

De las 16 aceleraciones máximas (a_{max}) y 14 velocidades máximas (v_{max}), se proponen las siguientes relaciones de atenuación para CUIP:

$$\log a_{max} = 0.429\, M_s - 2.979 \log R + 5.396 \ (\sigma = 0.15)$$
$$\log v_{max} = 0.348\, M_s - 2.439 \log R + 4.052 \ (\sigma = 0.16)$$

donde a_{max} está dado en gals, v_{max} en cm/seg y R es la distancia mínima al área de ruptura, en km.

Los rangos de magnitud y distancia cubren adecuadamente los futuros temblores críticos a lo largo de la zona mexicana de subducción. Los parámetros del movimiento del terreno en varios otros sitios de la ciudad (la mayoría en la zona del lago) pueden ser estimados a partir de los factores de amplificación dados en este artículo. En promedio, la amplificación relativa de a_{max} y v_{max} en los sitios de la zona del lago con respecto a CUIP son 3.0 y 4.3, respectivamente.

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ABSTRACT

While the need for prediction of peak ground motion in Mexico City from coastal earthquakes is evident, the peculiar site conditions in the city and the paucity of strong motion data in the past have given rise to doubtful attenuation relations. We now have strong motion recordings of 16 coastal earthquakes ($5.6 \leqslant M_s \leqslant 8.1$) at a hill zone site in Ciudad Universitaria (CUIP) ($282 \leqslant R \leqslant 466$ km) including those from the 19 Sep 1985 ($M_s = 8.1$), Michoacán earthquake, two of its aftershocks, and 8 other events which were not analyzed previously. From 16 peak horizontal acceleration (a_{max}) and 14 peak horizontal velocity values (v_{max}) we propose the following attenuation relations for CUIP

$$\log a_{max} = 0.429\, M_s - 2.976 \log R + 5.396\ (\sigma = 0.15)$$
$$\log v_{max} = 0.348\, M_s - 2.439 \log R + 4.052\ (\sigma = 0.16)$$

where a_{max} is in cm/s^2, v_{max} is in cm/s, and R is the closest distance (in km) from the rupture area. The magnitude and the distance range of the events adequately cover future critical earthquakes along the Mexican subduction zone. Peak ground motion parameters at several other sites in the city (many in the lake bed zone) can be estimated from the site amplification factors given in this paper. On an average, the relative amplification of a_{max} and v_{max} at sites in the lake bed zone with respect to these values at CUIP are 3.0 and 4.3 respectively.

INTRODUCTION

The importance of predicting ground motion in Mexico City from earthquakes along the Mexican subduction zone can hardly be overemphasized. Some studies have already been made in this direction. For example, Esteva and Villaverde (1973) derived an attenuation relation based on a data set that included Mexican earthquakes. Recently, Bufaliza (1984) proposed an attenuation relation using only Mexican data. Since in Bufaliza's study much of the data came from Mexico City, it would appear that his results would, generally, be valid for the city. In Bufaliza's regressions, however, data from sites other than Mexico City were also included. Recent results suggest that the seismic waves propagating along the coast attenuate faster than those propagating inland. Furthermore, even 'firm' sites in Mexico City show unusual amplifications (Singh *et al.*, 1986). It follows that the regressions based on all data may lead to unreliable ground motion predictions for Mexico City.

Our approach here is to analyze strong motion data from coastal earthquakes recorded at a single 'firm' site, Ciudad Universitaria (CUIP), located in the hill zone in Mexico City. We selected CUIP because more earthquakes have been recorded at this site than at any other in Mexico City. The strong motion records at CUIP from coastal earthquakes now total 16. These include records from the 19 Sep 1985, Michoacán earthquake ($M_s = 8.1$), two of its large aftershocks (21 Sep 1985, $M_s = 7.6$;

30 Apr 1986, $M_S = 7.0$), and eight other events ($5.6 \leqslant M_S \leqslant 7.0$) which were not analyzed previously. The data from these 11 earthquakes were not available at the time of Bufaliza's analysis. Because of the magnitude and distance range covered by the recordings at CUIP ($5.6 \leqslant M_S \leqslant 8.1$; $282 \leqslant R \leqslant 466$ km), the attenuation relations derived in this paper should provide reliable estimations of peak ground motion at CUIP from future critical earthquakes along the Mexican subduction zone. The ground motions at other sites in México City may be roughly predicted from the relative amplifications given in this paper.

DATA

Table 1 lists the earthquake data and the peak horizontal ground motions at CUIP. The following comments are useful in understanding the quality and selection of the strong motion data.

(1) Events 1 to 10, 12 and 13 were recorded on AR-240 accelerograph (sensitivity 12.9 mm/g).

(2) Events 8, 10 and 11 were recorded by the FM telemetered SISMEX network.

(3) Events 14 to 16 were recorded by a digital strong motion unit.

(4) The calibration of SISMEX network was not reliable. Furthermore, playback of the taped data was known to cause distortion of the signal. Since events 8 and 10 were recorded by both AR-240 and SISMEX we compared the data recorded by both systems. While the SISMEX data agreed well with the AR-240 data for event 10, the SISMEX recording of event 8 differed significantly, both in peak acceleration and spectral shape, from the AR-240 data. The peak acceleration from AR-240 (7.4 cm/s^2), which is much less than that from SISMEX (18.0 cm/s^2), is in better agreement with felt and damage reports in Mexico City. Because of the problems with the SISMEX network, we chose AR-240 data over SISMEX whenever both recordings were available. The only data from SISMEX listed in Table 1 is for event 11.

(5) We digitized all events recorded on AR-240 with the exception of events 4 and 9 whose traces had very small amplitude. [Events 1 and 3 had been digitized and analyzed by Rascón *et al.* (1977). The peak ground motions listed in Table 1 for these two events differ somewhat from those given by Rascón *et al.* Because of improved digitizing and processing techniques, the values listed in Table 1 seem more reliable]. The digitized records were processed using the programs

TABLE 1

EARTHQUAKE DATA AND PEAK, HORIZONTAL GROUND MOTIONS AT CIUDAD UNIVERSITARIA (CUIP), MEXICO CITY.

Event No.	Date	Location Lat°N	Location Long°W	Depth (km)	M_s[14]	R_1[15] (km)	R_2[15] (km)	a_{max} cm/s^2	v_{max} cm/s
1	23 Aug 1965	16.28	96.02[1]	16[8]	7.8	476	466	6.4	1.7
2	3 Feb 1968	16.67	99.39[7]	29[7]	5.9	297	-	6.0	1.8
		16.67	99.39[11]	16[12]		297	-		
3	2 Aug 1968	16.25	98.08[1]	16[8]	7.4	361	326	14.9	3.6
4	23 Apr 1975	16.47	98.86[7]	17[7]	6.2	320	-	2.9	-
		16.47	98.86[11]	16[12]		320	-		
5	1 Feb 1976	17.15	100.23[7]	47[7]	5.6	270	-	2.3	0.9
		17.03	100.30[11]	16[12]		282	-		
6	7 Jun 1976	17.45	100.65[7]	48[7]	6.4	264	-	13.4	2.9
		17.20	100.88[11]	16[12]		292	-		
7	19 Mar 1978	16.85	99.90[2]	16[9]	6.4	285	-	5.0	0.9
8	29 Nov 1978	16.00	96.69[1]	18[8]	7.8	454	414	7.4	2.0
9	26 Jan 1979	17.53	100.79[7]	40[7]	6.6	265	-	4.9	-
		17.25	101.00[11]	16[12]		300	-		
10	14 Mar 1979	17.46	101.46[3]	20[8]	7.6	318	287	19.5	3.7
11	25 Oct 1981	17.75	102.25[4]	20[4]	7.3	368	339	13.4	2.5
12	7 Jun 1982	16.35	98.37[5]	20[10]	6.9	341	304	11.9	3.5
13	7 Jun 1982	16.40	98.54[5]	15[10]	7.0	332	303	7.9	2.0
14	19 Sep 1985	18.14	102.71[6]	16[6]	8.1	395	295	34.7	10.3
15	21 Sep 1985	17.62	101.82[6]	20[6]	7.6	337	318	14.8	3.9
16	30 Apr 1986	18.42	102.99[13]	16[9]	7.0	414	-	4.5	1.5
		18.20	103.10[11]	16[9]		431	409[16]		

References and Notes to Table 1

1 L. Quintanar and L. Ponce (personal communication, 1985).
2 From accelerograms at Acapulco.
3 Gettrust *et al*. (1981).
4 Havskov *et al*. (1983).
5 E. Nava (personal communication, 1985).
6 UNAM Seismology Group (1986).
7 ISC bulletins.
8 Chael and Stewart (1982).
9 From inspection of teleseismic P waveform.
10 Astiz and Kanamori (1984).
11 Projected S45°W to the coast.
12 Depth fixed at 16 km.
13 PDE bulletin.
14 From Singh *et al*. (1984a) and PDE.
15 R_1 = hypocentral distance to CUIP.
R_2 = closest distance from the rupture area to CUIP. The underlined value is taken as R in regressions (Equation 3).
16 A rupture area of 33 x 33 km^2, parallel to the coast, assumed.

of Trifunac and Lee (1973). Due to the low sensitivity of AR-240, difficulties were encountered in obtaining peak velocity in some cases. The peak velocities, listed in Table 1, were obtained after several trials with a high-pass Ormsby filter. The listed peak velocities are necessarily less reliable than the peak accelerations.

The previously analyzed data set at CUIP consisted of only five recordings (events 1, 3, 8, 10 and 11). As discussed above, the SISMEX recording of event 8 was wrong.

As dependent variable we choose the maximum ground motion on either of the two horizontal components. As independent variable we shall use surface-wave magnitude, M_S, and the closest distance from the rupture area to CUIP.

There are three reasons for our choice of M_S as the measure of earthquake size rather than the moment magnitude. First, the seismic moments (M_o) are known for only nine of the events listed in Table 1 (see Table 2). Second, there are two ways one can compute moment magnitude. Assuming constant strain drop of 10^{-4} the moment magnitude M_W is given by (Kanamori, 1977; Hanks and Kanamori, 1979; Singh and Havskov, 1980)

$$M_W = \frac{2}{3} \log M_o - 10.73 \qquad (1)$$

Alternatively, we can estimate the moment magnitude M'_W from the following definition (Kanamori, 1977)

$$M_W = \frac{2}{3} [\log M_o + \log \frac{\Delta\sigma}{\mu} - 12.1] \qquad (2)$$

with $\Delta\sigma/\mu$ evaluated for each event. In Table 2 we give M_W and M'_W for the nine events for which M_o and one-week aftershock area are known. In computing M'_W from equation (2) we have taken $\mu = 5 \times 10^{11}$ dyne/cm^2. In Table 2 we note that for most events $M_S \gtrsim M_W \geqslant M'_W$. Taking $\mu = 3 \times 10^{11}$ dyne/cm^2 would increase M'_W by 0.15 of all events but even then M'_W would, generally, remain less than M_W. $M_W > M'_W$ reflects less-than-average strain drop for Mexican earthquakes, which either (a) may be a characteristic of this region, or (b) may result from systematic overestimation of rupture area from one-week aftershock locations. At least for the 19 Sep 1985 Michoacán earthquake, the analysis of near-field strong motion data supports (a) (Anderson *et al.*, 1986). For the purpose of this paper the foregoing discussion may be moot since moment magnitudes cannot be computed for all events in Table 1. Yet the question of whether to compute M_W or M'_W may be of some importance for other studies.

TABLE 2

COMPARISON OF M_S AND MOMENT MAGNITUDE OF THOSE EVENTS IN TABLE 1 WHOSE SEISMIC MOMENTS AND RUPTURE AREAS ARE KNOWN

Date	M_S	$M_0 \times 10^{27}$ (dyne-cm)	LxW, km^2	$\Delta\sigma$ [11] (bars)	M_W [12]	M_W' [13]
23 Aug 1965	7.8	1.7 [1]	84x55 [5]	6	7.42	6.79
2 Aug 1968	7.4	1.0 [1]	65x65 [5]	3	7.27	6.46
29 Nov 1978	7.8	3.2 [1]	90x70 [6]	6	7.61	6.99
14 Mar 1979	7.6	2.7 [1]	70x35 [7]	27	7.56	7.38
25 Oct 1981	7.3	1.3 [2]	40x20 [8]	69	7.35	7.44
7 Jun 1982	6.9	0.27 [3]	38x38 [9]	4	6.89	6.16
7 Jun 1982	7.0	0.27 [3]	38x38 [9]	4	6.87	6.13
19 Sep 1985	8.1	10-17 [4]	170x50 [10]	20-34	7.94-8.10	7.67-7.98
21 Sep 1985	7.6	2.9-4.7 [4]	66x33 [10]	34-56	7.58-7.72	7.46-7.75

References and Notes to Table 2.

1 Chael and Stewart (1982)

2 Lefevre and McNally (1985), Singh et al. (1984b)

3 Astiz and Kanamori (1984)

4 Eissler et al. (1986), Priestley and Masters (1986)

5 L. Quintanar and L. Ponce (personal communication, 1985)

6 Singh et al. (1980a)

7 Valdés et al. (1982)

8 Havskov et al. (1983)

9 E. Nava (personal communication, 1985)

10 UNAM Seismology Group (1986)

11 $\Delta\sigma = \frac{8M_0}{3\pi L W^2}$

12 $M_W = \frac{2}{3} \log M_0 - 10.73$

13 $M_W' = \frac{2}{3} \{\log M_0 + \log(\Delta\sigma/\mu) - 12.1\}$

Finally, there is no evidence of saturation of the M_s scale for Mexican earthquakes. Given the rupture area of a future earthquake along the Mexican subduction zone, it would seem that its M_s can be estimated from existing relations (*e.g.*, Wyss, 1979; Singh *et al.*, 1980b) with the same, or even better, reliability as its moment magnitude.

For all earthquakes with $M_s > 7.0$ in Table 1 the locations, depths, and rupture areas are well known. For these events, distance from hypocenter to CUIP (R_1, km) and closest distance between the rupture area and CUIP (R_2, km) are listed in Table 1.

For many events with $M_s \leqslant 7.0$, the rupture areas are not known. For these events the locations and depths, taken from the bulletins of International Seismological Centre (ISC) (Preliminary Determination of Epicenters, PDE, for event 16), are listed in Table 1. ISC and PDE epicenters of Mexican events show a tendency of being shifted by about 30 km towards N45°E from their true locations (Singh and Lermo, 1985). Also the depths in these bulletins are not reliable. To correct for the possible bias we projected these epicenters along S45°W up to the coast. Events 2 and 4 did not need any projection because they were located on the coast. The depths were fixed to 16 km since all well studied coastal events yield roughly this depth. Except for event 16, no correction for rupture area was made. The projected locations and R_1 values are listed in Table 1. We shall assume that $R_1 = R_2$ for all events whose rupture areas are not known with the exception of event 16 whose estimated R_2 is given in Table 1.

THE REGRESSION

We shall use the following functional form to express the peak horizontal ground motion

$$y_{max} = \frac{10^{\alpha M_s + \beta}}{R^c} \tag{3}$$

where y_{max} is either the peak acceleration (a_{max}, cm/s^2) or the peak velocity (v_{max}, cm/s) and $R = R_2$ if R_2 is listed in Table 1, otherwise $R = R_1$. The chosen R values are underlined in Table 1. Note that no anelastic attenuation term is included in equation (3). Because of the limited range of R, a more complicated functional form than equation (1) appears unwarranted. We rewrite equation (3) as:

$$\log y_{max} = \alpha M_s - c \log R + \beta . \tag{4}$$

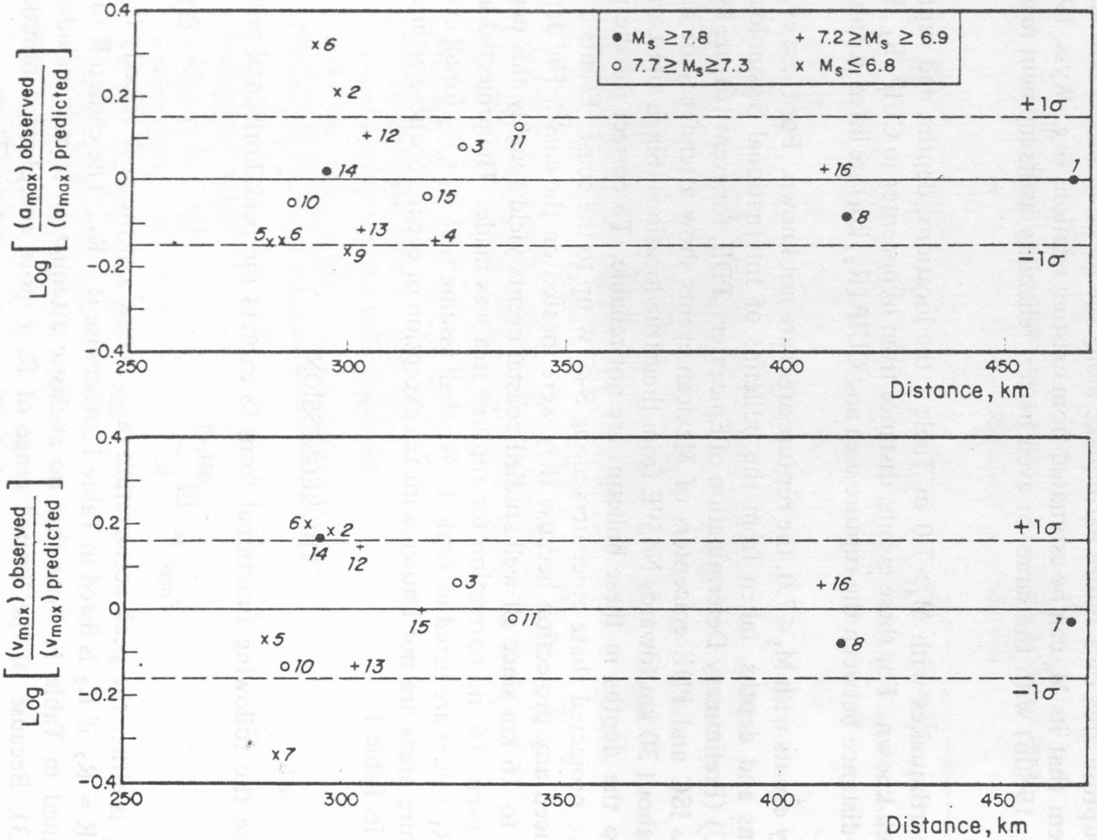

Fig. 1. Residuals of data with respect to predictions (equations 5 and 6). Top: for peak horizontal acceleration, a_{max}. Bottom: for peak horizontal velocity, v_{max}.

Since for each earthquake we consider only one recording (at CUIP), the two-step regression proposed by Joyner and Boore (1981) and Boore and Joyner (1982) is not needed. The results of multiple regression analysis are:

$$\log a_{max} = 0.429\, M_s - 2.976 \log R + 5.396 \tag{5}$$

$$\log v_{max} = 0.348\, M_s - 2.439 \log R + 4.052 \tag{6}$$

with a standard deviation (σ) in $\log a_{max}$ and $\log v_{max}$ of 0.15 and 0.16, respectively. The residuals as a function of R are plotted in Figure 1. Since these do not show any trend, we regard equation (5) and (6) adequate for prediction of peak ground motions at CUIP.

To test the sensitivity of the results on possible errors in R we carried out regressions using the distances to CUIP from the reported ISC (PDE for event 16) hypocenters for events with unknown rupture areas. The results are:

$$\log a_{max} = 0.441\, M_s - 2.699 \log R + 4.599 \qquad (\sigma = 0.16) \tag{7}$$

$$\log v_{max} = 0.366\, M_s - 2.435 \log R + 3.904 \qquad (\sigma = 0.16) \tag{8}$$

Although the corresponding coefficients in equations (5) and (7) and equation (6) and (8) differ, the predicted values are very similar. This gives us confidence that the predictions are not very sensitive to possible errors in R.

In Figure 2 we compare predicted a_{max} from relations given by Esteva and Villaverde (1973), Bufaliza (1984), and Joyner and Boore (1981) with that given by equation (5). The comparison of a_{max} as a function of magnitude is made at fixed R = 280 km, a likely distance for future large earthquakes in the Guerrero gap. We note that the data set consisted of $20 \leq R \leq 200$ km in Esteva and Villaverde (the type of magnitude is not specified here), $100 \leq R \leq 500$ km and $4.5 \leq M_s \leq 7.8$ in Bufaliza, and $R \leq 380$ km, $5.0 \leq M \leq 7.7$ (M = moment magnitude) in Joyner and Boore. The relations have been extrapolated in Figure 2. Both the 50 percentile (mean) and the 84 percentile (mean + one σ) lines are shown. The fact that the predicted a_{max} from Joyner and Boore is much lower than those from the other three relations is not surprising; Joyner and Boore's relation, based on California data, was neither intended nor should be used for México. At the 50 percentile level, predicted a_{max} from Esteva and Villaverde, and from Bufaliza are greater than from equation (5) for $5.5 \leq M_s \leq 7.2$. The predictions are about equal for $7.3 \leq M_s \leq 8.1$. Because of greater standard deviations in the relations given by Esteva and Villaverde ($\sigma(\log a_{max}) = 0.28$) and Bufaliza ($\sigma(\log a_{max}) = 0.27$) than in equation (5), at the 84 percentile level the predicted a_{max} from these relations are greater than that from equation (5).

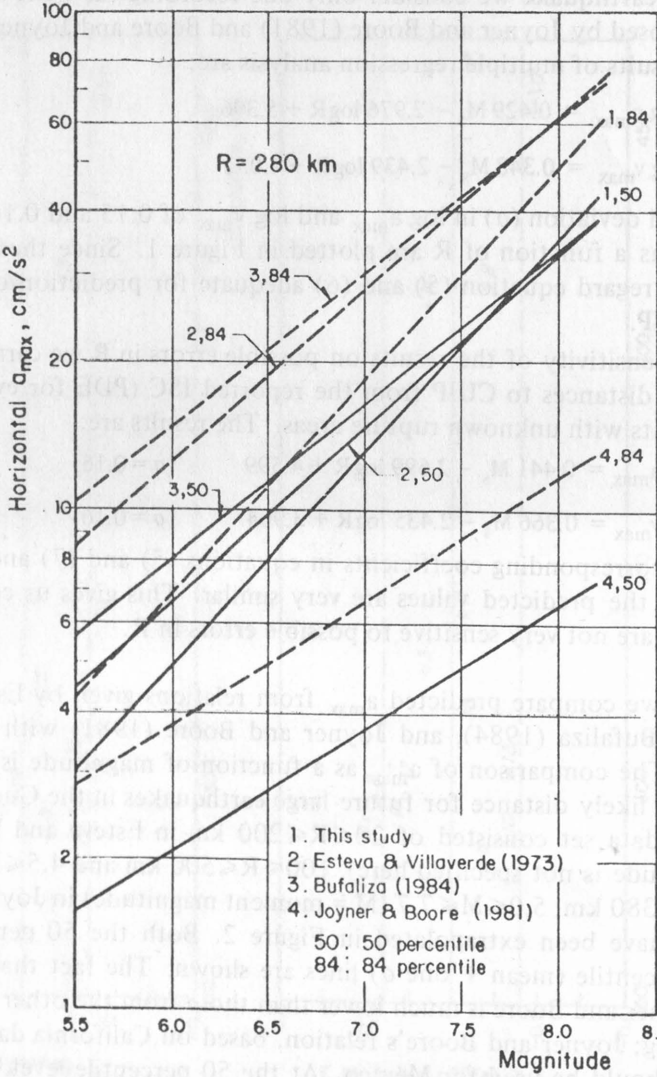

Fig. 2. Comparison of predictions of peak horizontal acceleration (a_{max}) from four attenuation relations at R = 280 km. Both 50 (mean) and 84 percentile (mean + one σ) lines are shown.

Predicted v_{max} are compared in Figure 3. Here we have excluded Joyner and Boore's relation. This is because the peak velocity data in that study covered only a range of $R \leqslant 100$ km and the extrapolated v_{max} are about an order of magnitude smaller than the observed values at CUIP. At the 50 percentile level the predicted v_{max} from Esteva and Villaverde, and from Bufaliza are smaller than from equation (6). At the 84 percentile, Esteva and Villaverde predict slightly higher v_{max} for magnitudes > 7.7 than equation (6). Since Bufaliza (1984) did not report standard deviation in log v_{max} regression, no comparison at 84 percentile level is made.

ESTIMATION OF PEAK GROUND MOTIONS AT OTHER SITES IN MEXICO CITY

The subsoil of Mexico City has been divided in three zones: the lake bed zone (consisting of a 25 to 80 m deposit of highly compressible, high water content clay underlain by resistant sands), the hill zone (characterized by a surface layer of lava flows or volcanic tuff), and the transition zone (composed of sandy and silty layers of alluvial origin with occasional intervals of clay). It is well known that the ground motions at lake bed sites are amplified with respect to hill zone sites (see, *e.g.*, Rosenblueth, 1960; Zeevaert, 1964; Herrera *et al.*, 1965; Faccioli and Reséndiz, 1976; Romo and Jaime, 1986; Singh *et al.*, 1986). Most of the damage to Mexico City from earthquakes occurs in the lake bed zone.

Equations (5) and (6) predict peak ground motion parameters from coastal earthquakes at CUIP, a hill zone site. We present a_{max} and v_{max} recorded at other sites in Mexico City along with their ratios with respect to the values at CUIP in Tables 3 and 4, respectively. In these tables we have included the earthquakes of 6 Jul 1964 (18.28°N, 100.41°W, H = 45 km, M $\simeq$ 7) and 24 Oct 1980 (17.90°N, 98.15°W, H = 65 km, m_b = 6.3). These were not listed in Table 1 because they were normal faulting earthquakes (Molnar and Sykes, 1969; Yamamoto *et al.*, 1984). Data in Tables 3 and 4 may be used to roughly estimate the peak ground motion amplification with respect to CUIP at some sites in the city. Note that any given site in the lake bed zone shows large variations in the amplifications during different earthquakes (see later discussion). In order to obtain an average relative amplification factor for the lake bed sites from coastal earthquakes we exclude 1964 and 1980 earthquakes and also ignore data from NONS site (the records may be contaminated from soil-building interaction because the accelerograph was located in the courtyard). The average amplification of a_{max} at the lake bed sites with respect to CUIP is 3.0 (range = 3.0 ± 1.2); the corresponding value of v_{max} is 4.3 (range = 4.3 ± 2.0).

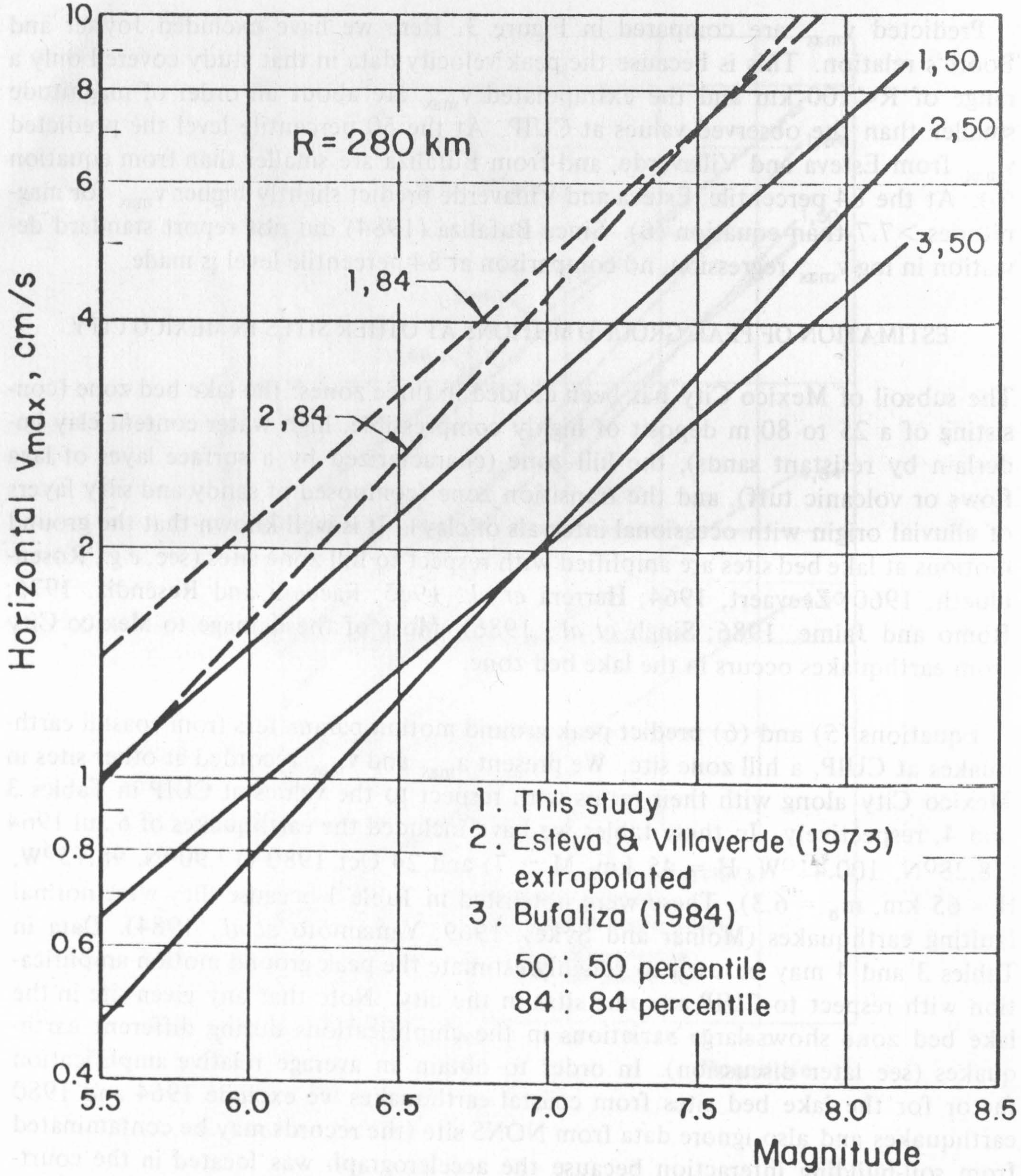

Fig. 3. Comparison of predictions of peak horizontal velocity (v_{max}) from three attenuation relations at R= 280 km. Both 50 (mean) and 84 percentile (mean+ one σ) lines are shown.

If only the 19 Sep 1985 Michoacán earthquake is considered then the average amplification factors for a_{max} and v_{max} are 3.2 and 4.4, respectively. Note that the amplification factors are based on data obtained at only a few sites and therefore these factors are not likely to be representative of the entire lake bed zone.

A check on equations (5) and (6) and the amplification factors discussed above is possible from the Acapulco-San Marcos earthquakes of 28 Jul 1957 ($M_s = 7.7$, $R \sim 280$ km), 11 May 1962 ($M_s = 7.2$), and 19 May 1962 ($M_s = 6.9$). For the 1957 earthquake equation (5) predicts an a_{max} of 26.1 cm/s^2 at CUIP. The corresponding a_{max} in the lake bed zone may be estimated as 78.3 cm/s^2 (range of 47.0 to 109.6 cm/s^2). From measurements of relative displacements between different floors of the Latin American Tower an a_{max} of 60 cm/s^2 at the base of the building was inferred for this earthquake (E. Rosenblueth, personal communication, 1986). The two estimates are in reasonably good agreement with each other.

The earthquakes of 11 May and 19 May 1962 were recorded at Alameda Central (Zeevaert, 1964). The earthquake data including the observed and the predicted a_{max} and v_{max} are given in Table 5. The predicted values are in good agreement with the observed ones. [Note that R is only approximately known for the 1957 and the 1962 earthquakes].

DISCUSSION

Singh *et al.* (1986) found that the spectral acceleration ratio of a given site in the lake bed zone with respect to CUIP is nearly the same for different earthquakes. In other words, the transfer function (as a function of frequency) of a given site with respect to CUIP is nearly constant. The spectra of earthquakes at CUIP, of course, vary. The peak acceleration at CUIP generally occurs at about 1 s period whereas the spectral peak is at a higher period at least for coastal earthquakes (Castro *et al.*, 1987). On the other hand, accelerograms at the lake bed sites show a well dispersed character so that the period of a_{max} very roughly corresponds to that of the peak in the spectra of that site. If the peak in CUIP spectra occurs at the same period as the peak in the site transfer function then large accelerations are expected. An example is the SCT1 record of the 19 Sep 1985 earthquake. The site transfer function at SCT1 is peaked at about 2.2 s where its value is about 10. Since the spectral peak for this earthquake at CUIP also occurred at 2.2 s, the ground motion at SCT1 was greatly amplified. The variability in the amplification factor of a_{max} and v_{max} of a

Table 3

Peak horizontal acceleration (a_{max}, cm/s^2) at different sites in Mexico City and their ratios with respect to CUIP for different earthquakes

Earthquake	NONS/CUIP	NONP/CUIP	TXSO/CUIP	TXCL/CUIP	ALOL/CUIP	SCT1/CUIP	CDAF/CUIP	CDAO/CUIP	TLHB/CUIP	TLHD/CUIP	TACY/CUIP	SXVI/CUIP	SXHO/CUIP
6 Jul 1964	(24/20) = 1.2	(44/20) = 2.2											
23 Aug 1965	(21/6.4) = 3.3												
2 Aug 1968	(41/14.9) = 2.6	(46/14.9)=3.1											
29 Nov 1978		(25/7.4) =3.4											(4.7/7.4)=0.6
14 Mar 1979	(41.6/19.5)=2.1		(54.9/19.5)=2.8	(48.2/19.5)=2.5	(37.7/19.5)=1.9	(33.5/19.5)=1.7							(13/16.6)=0.8
24 Oct 1980	(33.0/25.3)=1.3		(42.5/25.3)=1.7	(47.2/25.3)=1.9		(33.7/25.3)=1.3						(46.6/25.3)=1.8	
25 Oct 1981	(14.0/13.4)=1.1		(30.0/13.4)=2.2	(22.0/13.4)=1.6	(26/13.4) =1.9							(15.5/13.4)=1.2	(8.2/13.4)=0.6
19 Sep 1985			(103.0/34.7)=3.0	(79/34.7) =2.3		(167.9/34.7)=4.8	(95/34.7) =2.7	(80/34.7) =2.3	(136/34.7)=3.9	(117/34.7)=3.3	(34/34.7) =1.0	(44.6/34.7)=1.3	
21 Sep 1985							(42.4/14.8)=2.9	(48.7/14.8)=3.3			(14.8/14.8)=1.0	(26.3/14.8)=1.8	
30 Apr 1986								(32/4.5) =7.1				(5.3/4.5) =1.2	

Notes to Table 3.

Numerator and denominator in parenthesis are peak horizontal accelerations (a_{max}, cm/s^2) at the site and CUIP, respectively.

Station code identification. NONS: Nonoalco Atizapan (Basement), NONP: Nonoalco Hidalgo (Patio), TXSO: Texcoco Sosa, TXCL: Texcoco Centro Lago, ALOL: Alberca Olímpica, SCT1: SAHOP (also called SXSO), CDAF: Central de Abastos (Frigorífico), CDAO: Central de Abastos (Oficina), TLHB: Tlahuac (Bomba), TLHD: Tláhuac (Deportivo), TACY: Tacubaya, SXVI: Viveros, SXHO: Hospital ABC, CUIP: Ciudad Universitaria.

TACY, SXHO, and CUIP are in the hill zone, SXVI is probably in the transition zone, and the rest are in the lake bed zone.

Table 4

Peak horizontal velocities (v_{max} cm/s) at different sites in Mexico City and their ratios with respect to CUIP for different earthquakes

Earthquake	NONS/CUIP	NONP/CUIP	TXSO/CUIP	TXCL/CUIP	ALOL/CUIP	SCT1/CUIP	CDAF/CUIP	CDAO/CUIP	TLHB/CUIP	TLHD/CUIP	TACY/CUIP	SXVI/CUIP	SXHO/CUIP
6 Jul 1964	(14.7/4.9)=3.0	(12.4/4.9)=2.5											
23 Aug 1965	(8.5/1.7)=5.0												
2 Aug 1968	(14.3/3.6)=4.0	(15.2/3.6)=4.2											
29 Nov 1978		(6.3/2.0)=3.2	-										(1.3/2.0)=0.7
14 Mar 1979	(14.2/3.7)=3.8		(15.4/3.7) = 4.2	(16.0/3.7)=4.3	(9.5/3.7)=2.6	(9.8/3.7)=2.7							(3.0/3.7)=0.8
24 Oct 1980	(5.8/3.9)=1.5		(9.1/3.9) = 2.3	(11.1/3.9)=2.9		(6.2/3.9)=1.6						(5.0/3.9)=1.3	
25 Oct 1981			(7.3/2.5) = 2.9	(8.5/2.5)=3.4								(2.9/2.5)=1.2	(1.7/2.5)=0.7
19 Sep 1985			(29.6/10.3)=2.9			(61/10.3)=5.9	(37.5/10.3)=3.6	(41.9/10.3)= 4.1	(64/10.3)=6.2	(36/10.3)=3.5	(14.3/10.3)=1.4	(12/10.3)=1.2	
21 Sep 1985							(12.0/ 3.9)=3.1	(18.2/ 3.9)= 4.7			(2.6/ 3.9)=0.7	(3.3/3.9)=0.9	
30 Apr 1986								(16.5/ 1.5)= 11.0					

Notes to Table 4.

Numerator and denominator in parenthesis are peak horizontal velocities (v_{max}, cm/s) at the site and CUIP, respectively.

Station codes are identified in Table 3.

TABLE 5

OBSERVED AND PREDICTED PEAK GROUND MOTIONS AT ALAMEDA CENTRAL, MEXICO CITY DURING 11 AND 19 MAY 1962 EARTHQUAKES.

Date	M_S	R,km[1]	Observed[1] a_{max} (cm/s^2)	Observed[1] v_{max} (cm/s)	Predicted[2] a_{max} cm/s^2	Predicted[2] v_{max} cm/s
11 May 1962	7.2	260	48	12.6	59.6	20.1
19 May 1962	6.9	260	38	~ 11	44.3	15.7

Notes to Table 5.

1 Values reported by Zeevaert (1964)

2 Predicted values of a_{max} and v_{max} at CUIP from equations (5) and (6) multiplied by 3.0 and 4.3, respectively.

given site for different earthquakes appears to be related to the period at which a_{max} and v_{max} are measured at CUIP and the relation that this period bears with that of the peak in the spectra at CUIP. The largest amplification factor is for the earthquake of 30 Apr 1986 (Tables 3 and 4). This is because the periods of a_{max} and maximum in the spectra at CUIP for this event are the same, namely ~ 2 s.

Since the peaks in the transfer functions of lake bed sites occur at periods $\gtrsim 1.4$ s (Singh *et al.*, 1986) it is obviously important to predict Fourier acceleration spectra at CUIP for these periods. The damage to the city should correlate better with the spectral level at CUIP at periods $\gtrsim 1.4$ s than with peak ground motion values. The prediction of Fourier acceleration spectra at CUIP for coastal earthquakes has been studied by Castro *et al.* (1987).

CONCLUSIONS

In equations (5) and (6) we have derived a site-specific relation to predict peak ground motion at Ciudad Universitaria (CUIP), Mexico City. The range of the data set used in obtaining the relation should permit reliable estimations from future earthquakes along the Mexican subduction zone. The peak ground motions at some other sites in the city may also be predicted with the help of the data given in Tables 3 and 4. On an average, the peak accelerations and velocities at the lake bed sites with respect to CUIP are amplified by 3.0 and 4.3, respectively.

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