RELATIONSHIPS BETWEEN INSTRUMENTAL GROUND MOTION PARAMETERS, AND MODIFIED MERCALLI INTENSITY IN GUERRERO, MEXICO

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ABSTRACT :

This paper presents regression relationships between Modified Mercalli Intensity (MMI) and peak ground acceleration (PGA), and between MMI and peak ground velocity (PGV), for ten Mexican Pacific earthquakes. Correlations were developed for the MMI range of III≤ IMM ≤ IX. When these relationships are compared with others correlations of California reported by others investigators, we found significant differences. Thus, PGA relationship are higher than those obtained in this study. But PGV relations are similars in higher intensities. In order to estimate expected response spectra for the July 18, 1957, Guerrero Earthquake, period dependence was associated, using results of regressions of observed response spectra with MMI, from accelerations from ten earthquakes.

KEYWORDS: Modified Mercalli Intensity, Ground motion parameters, Regression relationships.

1. INTRODUCTION

The seismic intensity traditionally has been used as a parameter for quantify the pattern of shock and the extension of the damage caused by earthquakes. Although it has been used before the coming of the present modern seismic instrumentation, continues providing useful means of description of the shock level, in a simplified way. Since a long time, attempts have been in order to establish relations among the Mercalli Modified Intensity (MMI), the Peak Ground Acceleration (PGA), and the Peak Ground Velocity (PGV), when relating the records of the strong ground motion to the intensities observed during strong earthquakes (see for example Wood and Neumann, 1931; and Richter, 1958). Later, from the studies of Trifunac and Brady (1975) on this subject, until today, a considerably great amount of data exists on strong ground motion, particularly from earthquakes with important intensity. When PGA is related with the MMI a useful criterion is to correlate only those values of the stations located at no more of 3 kilometers of the observed intensity.

The first comparisons between the peak of the ground movements and intensities were based mainly on the regressions of intensity with PGA, and in few cases, with the velocity, and with the maximum displacement. The goal of this study is to develop relations that can be used to estimates accelerations and velocities of past earthquakes, which seismic intensities are known, as well as inferring approximated values of PGA and PGV during future earthquakes.

2. RELATIONS BETWEEN SEISMIC INTENSITY AND STRONG GROUND MOTIONS PARAMETERS

In Table 2.1 is presented a summary of several relations of the Intensities with PGA, with PGV, or with PGD. These relations were developed for different seismic regions of the world (see Trifunac and Brady (1975). Thus, in the decade of the 40s and 50s, Gutenberg and Richter in 1942, Kawasumi in 1951 (see Trifunac and Brady, 1975), Neumann in 1954 (see Trifunac and Brady, 1975), and Hershberger in 1956, they were first in developing functional of the form: $\log a = A+B*I$, where a is the PGA, A and B are adjustment coefficients, and I is the seismic intensity. Each one of those expressions is applicable only to the region from which the data belong. Trifunac and Brady (1975), considered horizontal and vertical components separately, as can be observed in the functional of Table 2.1. Also, they grouped the records in such way that the effect of geology in each level of intensity could be identified. When their results are compared, they find that the values for acceleration, velocity and displacement are greater than those obtained in previous works.

Table 2.1 Data for relations from several studies.

Author	**Relation**	**Interval**	**Region**
Gutenberg-Richter (1942)	log a = -0.5+0.33**I**	MM	
Kawasumi, (1951)*	log $\bar{a}$ = -0.35+0.5**I**	JMA	Japan
Neumann, (1954) *	log a = -0.041+0.308**I**	Between 15 and 25 millas	
Hershberger, (1956)	log a = -0.9+0.43**I**		
*Trifunac-Brady, (1975)	log a_v = -0.18+0.30I_{MM} ,log a_H =0.014+0.30I_{MM} log v_v = -1.10+0.28I_{MM}, log v_H = -0.63+0.25I_{MM} log d_v = -1.13+0.24I_{MM}, log d_H = -0.53+0.19I_{MM}	IV<I_{MM}<X IV $\leq$ I_{MM} $\leq$ X V $\leq$ I_{MM} $\leq$ X	West USA
Barrientos, (1980)	I=1.3844M-3.7355$\log_{10}$(r)-0.0006r+3.8461 I-Intensity, r: Hip. Dist. (km), M: Magnitude Ms		Chile
Wald, et al., (1999)	I_{mm}= 3.66log(PGA)-1.66; (σ=1.08) I_{mm}= 3.47log(PGV)+2.35; (σ=0.98)	V $\leq$ IMM $\leq$ VIII V $\leq$ IMM $\leq$ IX	California
Boatwright, et al., (2006)	I_{instr} = 3.66logPGA+1.99 PGA (%g) I_{instr} = 3.47logPGV+2.35 PGV (cm/seg)	I_{instr} $\leq$ 5 I_{instr} $\geq$ 6 MM	San Fco California
D. Benouar, (2007)	Msc=A_1+A_2(I_i)+A_3(R_i)+A_4logR_i+σP I=B_1+B_2(Ms)+B_3(R)+B_4logR+ σP		Algeria
Atkinson and Kaka (2007)	MMI=4.37+1.32(logPGV)logPGV $\leq$ 0.483 MMI=3.54+03(logPGV)logPGV $\geq$ 0.48	MMI <0.48 MMI $\geq$0.48	California

More recently, Wald et al. (1999) obtained relations, that define the intensity from the acceleration or from the velocity, as I_{mm}= A log (PGA) +B, and I_{mm}= C log (PGV) +D, respectively. These relations are applicable for a range of MMI between V-VIII and V-IX, respectively. Their results determine values considerably greater than those obtained by Trifunac and Brady (1975). On the other hand, Boatwright et al. (2006), developed expressions for California, as much for the acceleration as for the velocity. They extended their study when considered relations between MMI and pseudo-acceleration spectra, with the purpose of considering maps based on spectral ordinates for the San Francisco earthquake of 1906. Atkinson and Kaka (2007) propose an equation that relates MMI with instrumental parameters. This relation is based on data of moderate earthquakes of the central region of the United States. These data correspond to acceleration records and seismograms. The data were calibrated and extrapolated from observations of California earthquakes in order to determine maps of strong movement.

Additionally, several expressions have been developed to correlate Intensity I, with magnitude. Some cases are presented in Table 2.1, like Benouar (2007) that related the intensity, the magnitude and the distance. On the other hand, Barrientos (1980), related the intensity to the magnitude and the hypocentral distance for Chilean subduction earthquakes. Whereas Lopez Casados et al. (2000), presented relations for the Iberian Peninsula according to the MSK European scale

3. SISMICITY IN GUERRERO MEXICO

In the Guerrero State occurs about 25% of the total seismicity of the Mexican territory. This is due to the subduction of the Cocos Plate under the North American Plate. The contact between these tectonic plates happens in the Mexican Pacific coasts, since the State of Jalisco, to the state of Chiapas. The Guerrero Gap considers a site with high seismicity, and a high probability of occurrence of a destructive event, like the earthquake of July, 28 of 1957. The earthquake of 1957 with magnitude M=7.8, caused severe damages both in the City of Mexico, and the city of Chilpancingo, Capital of Guerrero State. A value of IX in MMI scale was assigned close to the epicenter. In the corresponding intensities map for this event, stand out two pronounced zones, one in Chilpancingo and other in the City of Mexico.

An intensity of VIII was assigned to the city of Chilpancingo for the 1957 earthquake (Duke et al., 1959). It was considered that approximately a third of the buildings between one and three storey, had some type of damages, since cracks to the complete collapse of the structure. It was not observed any variation in the pattern of the damage among the several types of construction: masonry, adobe, and structures of reinforced concrete. During the earthquake, the buildings in construction, suffered a serious damage. Systematic variation in the damage between buildings located on slopes with respect to other buildings located on the bottom of the valley was not observed, except some damage in the direction West of the slope of the valley. The city of Chilpancingo is located in the central part of a valley which rest on not consolidated alluvium deposits of more than 100 meters. If variation of the geologic conditions near the surface is considered, it is possible to be explained partially, the great intensity observed in the city of Chilpancingo.

4. RELATIONS BETWEEN PGA, PGV AND SEISMIC INTENSITY IN GUERRERO MEXICO

In this study we used information of iso-intensities maps from ten earthquakes of great magnitude, which affected to the Guerrero state, and specially to the city of Chilpancingo. In addition, maps with the lines of equal horizontal PGA (iso-accelerations) were constructed, corresponding to all the studied earthquakes. These ten earthquakes with magnitudes between 6.8 and 8.1, (see Table 4.1), all they have caused a considerable intensity in the city of Chilpancingo. In Figure 1 are presented simultaneously both maps (MMI and PGA) for all the earthquakes. The used records correspond to stations located on firm soil.

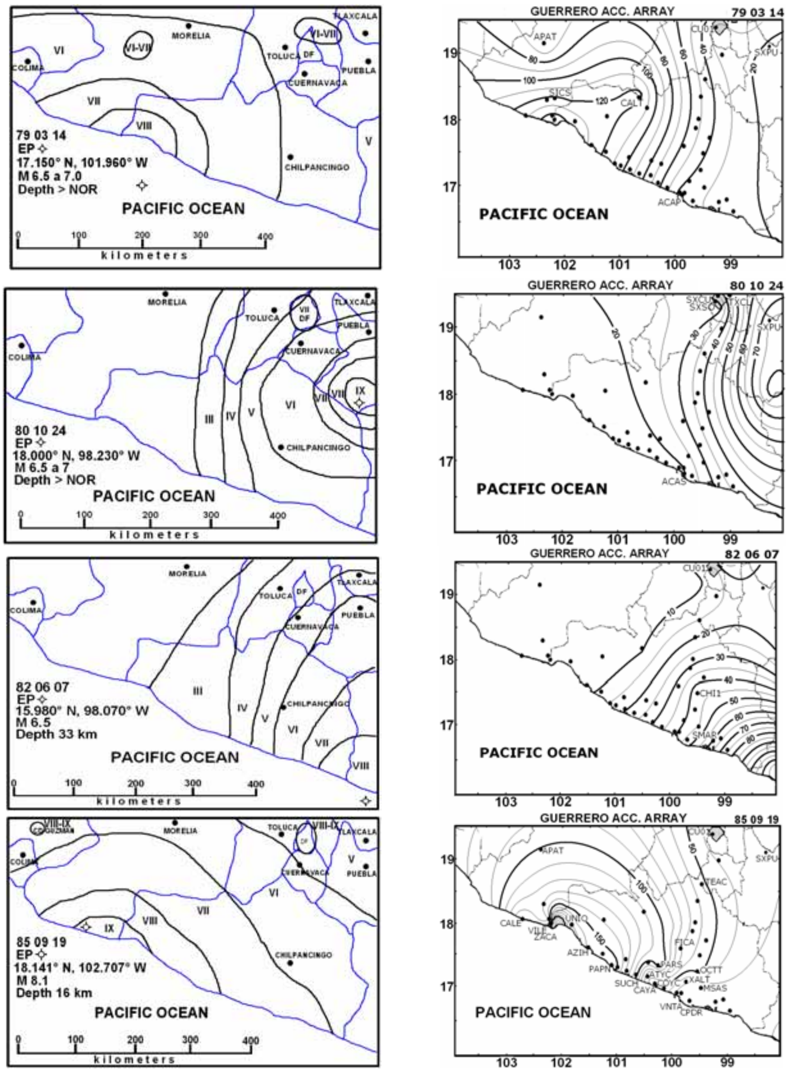

Figure 1. MMI intensities and contours of accelerations for the studied earthquakes.

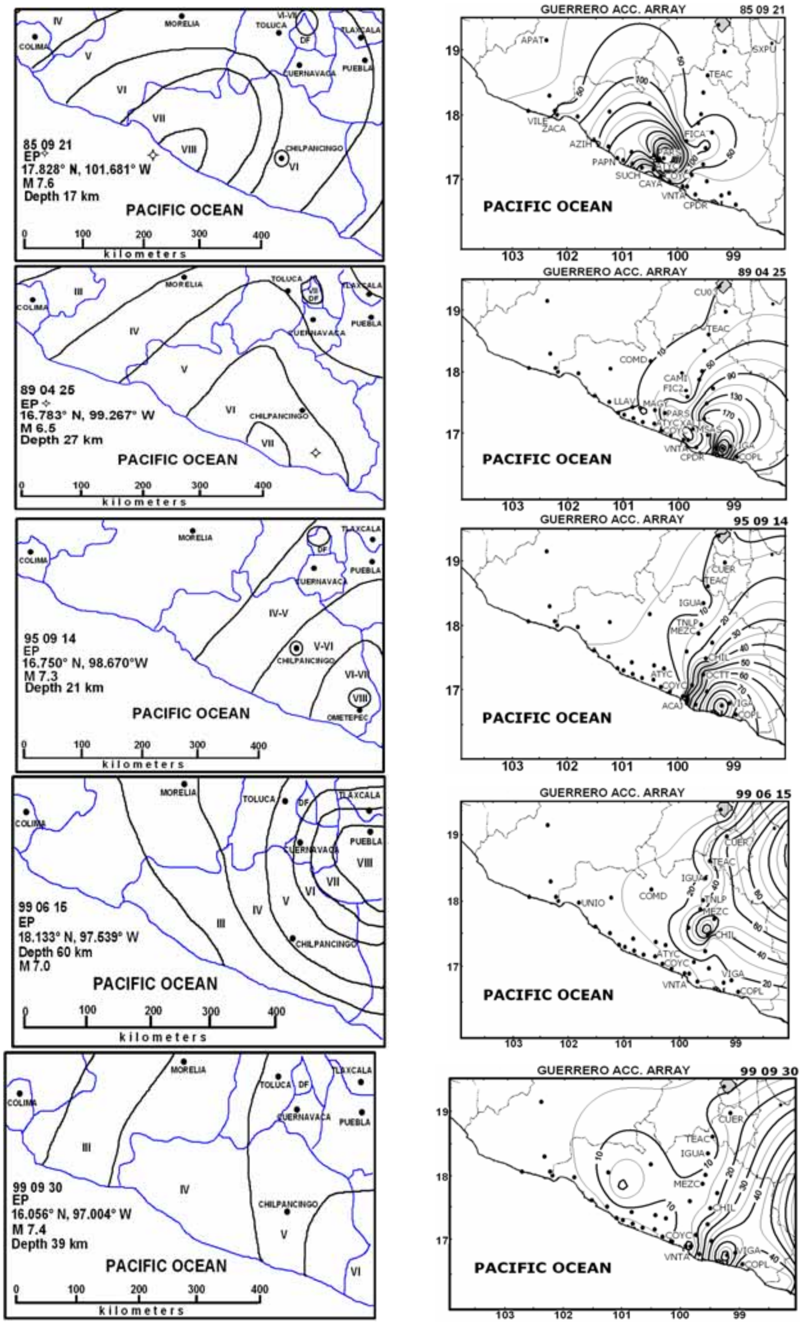

Figure 1 (cont). MMI intensities and contours of accelerations for the studied earthquakes.

Table 4.1 Data for earthquakes used in this study

Seismic source	Date (GMT)	Time, GMT	Latitude N	Longitude W	Depth (km)	Mag.	MMI
Central Guerrero	1979/03/14	11:07:15	17.75	-101.26	25	7.4	VIII
Depth	1980/10/24	14:53:36	18.17	-98.22	65	7.1	IX
Ometepec	1982/06/07	06:52:33	16.42	-98.25	6	6.9	VIII
Ometepec	1982/06/07	10:59:40	16.52	-98.34	19	7.0	VIII
Michoacan	1985/09/19	13:17:49	18.42	-102.47	15	8.1	IX
Michoacan	1985/09/21	01:37:14	17.828	-101.681	17	7.6	IX
Acapulco-S.M.	1989/04/25	14:29:03	16.80	-99.28	23	6.8	VII
Ometepec	1995/09/14	14:04:33	16.75	-98.67	21	7.3	VIII
Depth	1999/06/15	20:42:00	18.13	-97.53	60	7.0	VIII
Oaxaca	1999/09/30	16:31:13	16.06	-97.00	39	7.4	VIII

Table 4.2 Dates used in this study for estimate the relations between MMI and PGA or PGV

station	PGA_H (cm/sec^2)	PGV_H (cm/sec)	MMI	station	PGA_H (cm/sec^2)	PGV_H (cm/sec)	MMI	Station	PGA_H (cm/sec^2)	PGV_H (cm/sec)	MMI
Earthquake: March 14, 1979				INMD	34.17	2.24	VI	CHIL	21.95	1.41	V
ACAP	35.87	2.00	V	PAPN	249.41	9.13	VIII	COMD	17.13	2.37	IV
APAT	61.33	2.80	VI	PARS	577.48*	20.05*	VII	COPL	10.20	1.75	IV
CALT	119.68	3.46	VII	SUCH	81.93	11.20	VII	COYC	9.07	2.26	III
CU01	19.65	1.95	V	SXPU	24.82	2.21	V	COYQ	9.83	0.87	III
INCM	118.54	6.20	VIII	TEAC	32.32	6.98	V	CSER	195.40	17.65	VIII
SICS	157.10	8.29	VIII	TXCL	35.14	5.83	VI	CUER	45.01	3.03	VI
SXCU	16.21	1.37	V	UNIO	87.93	13.36	VII	HUIG	13.02	-	III
SXPU	15.22	2.03	V	VILE	46.23	14.08	VI	IGUA	19.53	1.28	V
TXSO	52.49	5.14	VI	VNTA	15.80	2.96	V	INMI	7.87	0.52	III
Earthquake: October 24, 1980				XALT	16.39	4.06	V	INMI	7.87	0.52	III
ACAS	18.37	0.65	IV	ZACA	79.15	9.82	VII	LVIG	4.65	0.44	III
MINA	9.95	0.51	III	Earthquake: April 25, 1989				MADR	6.00	2.99	IV
OAXM	158.68	3.17	VII	ACAP	101.18	6.06	VII	MEZC	28.91	2.23	V
PAJA	31.31	1.23	IV	ATYC	18.08	2.93	V	OCLL	8.73	1.16	III
SXCU	27.22	1.96	V	CAMI	28.92	2.69	VI	OXIG	37.82	1.43	VI
SXPU	78.69	5.45	VI	COMD	8.89	2.06	IV	PENI	2.81	0.22	III
SXSO	34.28	3.00	V	COPL	103.82	4.87	VII	PET2	3.74	0.88	III
TEMD	40.71	1.48	VI	COYC	81.05	3.06	VII	PNIG	3.29	0.05	III
TXCL	47.67	3.67	VI	CPDR	99.05	8.67	VII	POZU	19.48	1.72	IV
Earthquake: June 7, 1982				CSER	15.53	2.77	IV	RICC	104.65	16.11*	VI
CHI1	57.17	4.97	VI	CU03	12.49	4.65	IV	RITC	5.45	1.27	IV
CU01	11.69	1.67	IV	FIC2	15.93	3.97	V	SMR2	8.10	1.45	IV
MADM	12.81	0.79	IV	LLAV	11.76	1.86	IV	SOLI	5.51	0.75	III
OAXM	36.97	1.77	VI	MAGY	7.10	1.80	IV	TEAC	41.29	5.55	V
SMAR	51.48	1.52	VI	MSAS	108.78	10.89	VII	TNLP	36.46	5.97	V
TXSO	34.54	4.89	V	OCLL	33.65	2.81	VI	UNIO	2.53	0.94	III
Earthquake: September 19, 1985				OCTT	208.45*	9.50	VII	VIGA	18.07	2.44	IV
ACAP	27.70	1.62	VI	PARS	116.90	4.57	VII	VNTA	7.16	1.00	III
APAT	81.30	9.43	VII	SMR2	164.73	36.90*	VII	YAIG	66.65	2.79	VI
ATYC	59.80	8.34	VII	TEAC	13.93	3.70	IV	ZIIG	1.98	0.36	III
AZIH	155.26	21.61	IX	VNTA	58.94	7.12	VII	Earthquake: **S**eptember 30, 1999			
CALE	152.21	34.52	IX	VIGA	314.63*	24.19*	VII	ACAJ	9.29	0.65	IV
CAMI	84.25	5.49	VII	XALT	57.99	5.82	VI	ANGI	3.59	0.30	III
CHI1	177.08	17.22	IX	Earthquake: September 14, 1995				CAIG	5.18	0.38	III
COYC	42.00	7.81	VI	ACAJ	13.80	1.84	V	CARI	10.13	0.97	IV
CPDR	25.80	3.89	VI	ATYC	7.32	0.94	IV	CENA	9.35	4.89	IV
CUIP	33.10	9.45	VI	CAIG	6.04	1.08	IV	CHII	6.84	0.47	III
FICA	69.15	4.62	VII	CAMI	9.50	1.18	IV	CHIL	17.53	1.26	V
INMD	142.00	8.25	VIII	CHIL	29.09	2.65	VI	COIG	0.72*	0.20*	II
MADI	9.78	2.40	IV	COPL	75.03	11.94	VII	COPL	31.41	4.21	VI
MSAS	22.30	4.13	V	COYC	12.10	1.45	IV	COYC	15.20	1.22	IV
OCTT	54.66	5.68	VII	CUER	12.90	3.36	IV	COYQ	22.18	0.90	V
PAPN	151.61	8.69	VIII	CUP1	11.80	4.19	IV	CSER	41.75	6.00	VI
PARS	103.92	10.20	VII	IGUA	7.78	1.32	IV	CUER	16.92	2.13	V
SUCH	107.03	14.32	VII	MADI	5.76	1.30	IV	HUIG	141.54	3.77*	VIII
SXPU	32.60	7.09	V	MEZC	13.20	1.05	IV	IGUA	6.05	1.86	IV
TEAC	49.11	8.52	VI	OAXM	42.63	3.52	VI	INMI	4.09	0.23	III
UNIO	191.90	35.16	IX	OCLL	11.70	1.29	IV	LVIG	3.59	0.61	III
VILE	103.53	42.51*	VIII	OCTT	60.10	3.23	VII	MEZC	12.75	1.52	IV
VNTA	18.81	8.77	V	POZU	41.70	1.38	VI	MOIG	3.00	0.90	III
XALT	23.63	7.65	V	RIPC	13.80	3.95	V	OCLL	11.01	1.31	IV
ZACA	**273.16**	**35.96**	IX	RITC	5.90	0.88	IV	OXIG	186.23	5.85	VIII
Earthquake: September 21, 1985				TEAC	11.70	1.70	IV	PENI	6.08	0.91	III
ACAP	25.96	0.88	V	TNLP	11.55	2.66	IV	PET2	4.58	0.69	III
APAT	19.59	1.07	V	VIGA	100.06	10.05	VII	PNIG	32.30	0.69	VI
ATYC	78.68	9.73	VII	Earthquake: June 15, 1999				POZU	26.30	1.24	V
AZIH	142.40	23.21	VIII	ACAJ	5.69	0.52	III	SLUI	3.18	0.60	III
CARI	62.41	1.48	VII	AGCA	11.14	1.90	III	SOLI	2.55	0.57	III
CAYA	57.76	2.37	VI	ATYC	7.25	1.77	III	TEAC	8.77	2.96	IV
CHI1	117.92	8.09	VII	CAIG	4.50	0.43	III	VIGA	67.54	4.01	VI
COYC	47.05	3.91	VI	CARI	16.29	1.52	IV	VNTA	7.15	1.03	IV
CPDR	13.28	1.89	IV	CENA	7.42	1.05	IV	YAIG	17.40	1.05	V
FICA	53.32	2.36	VI	CHII	5.24	0.58	III	ZIIG	2.28	0.27	III

4.1.Correlation of records and predictive equations

Table 4.2 contains information about PGA and PGV calculated from the acceleration records of stations located in the Guerrero State. This data, of the earthquakes of Table 4.1, was used for estimate the relations between MMI and PGA_H and between MMI and PGV_H. The data correspond to subduction earthquakes (interplate), and deep earthquakes (intraplate).

In order to observe the variability of the data displayed in Table 4.2, in Figure 2 are plotted PGA and PGV values against MMI. The used data are between intensities of III and IX. It can be observed that the maximum acceleration value is 273.16 cm/sec^2, while the maximum PGV is 35.96 cm/sec.

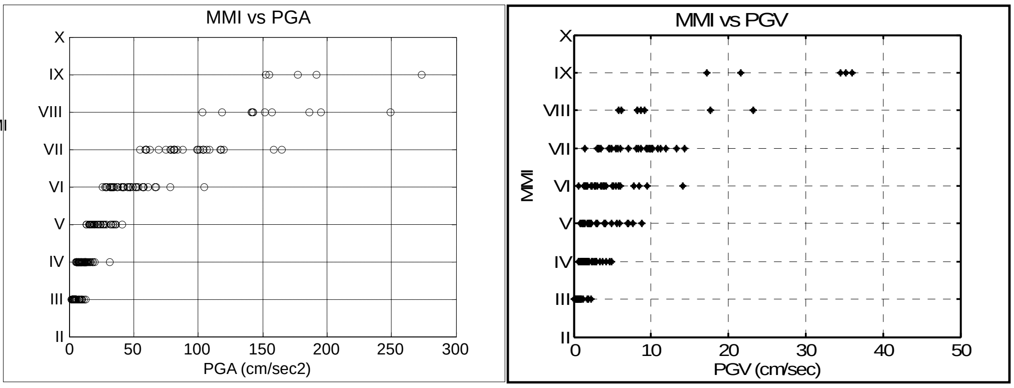

Figure 2. Distribution of data used in this study: PGA vs MMI and PGV vs MMI.

The ground motion predictions must be in the form of relatively simple equations, in this case, in terms of intensity. The functional forms adopted here are similar to the model used previously by Trifunac y Brady (1975), and by Wald, et al. (1999):

$$\textbf{IMM} = C_1 \log(\textbf{PGA}_\textbf{H}) + C_2 \quad (1)$$

$$\textbf{IMM} = C_3 \log(\textbf{PGV}_\textbf{H}) + C_4 \quad (2)$$

When PGA is in cm/sec^2 and PGV in cm/sec. Using the data of table 4.2, we obtained that:

$$IMM = 3.0262*\log(PGA_H) + 1.0195; \quad \sigma=0.523; \quad Bias = 0.0 \quad (3)$$

(for the intervalue of: III$\leq$ IMM $\leq$ IX).

$$IMM = 2.7451*\log(PGV_H) + 4.0785; \quad \sigma = 0.933; \quad Bias = 0.0 \quad (4)$$

(for a intervalue of: III$\leq$ IMM $\leq$ IX)

Figure 3, shows our results, for the predicted relation between PGA (right) and PGV (left), besides these relations are compared with the equations obtained by Trifunac and Brady (1975), and by Wald, et al. (1999). In the case of the PGA, the equation obtained in this study estimates that, for the same intensity Mexican earthquakes produce less accelerations than the calculated with the equations obtained by Trifunac and Brady (1975), and by Wald, et al. (1999). While, in the case of PGV, the situation is similar for intensities less than VII, however, for values of intensity greater than VIII, with the Trifunac and Brady equation, are obtained greater velocities.

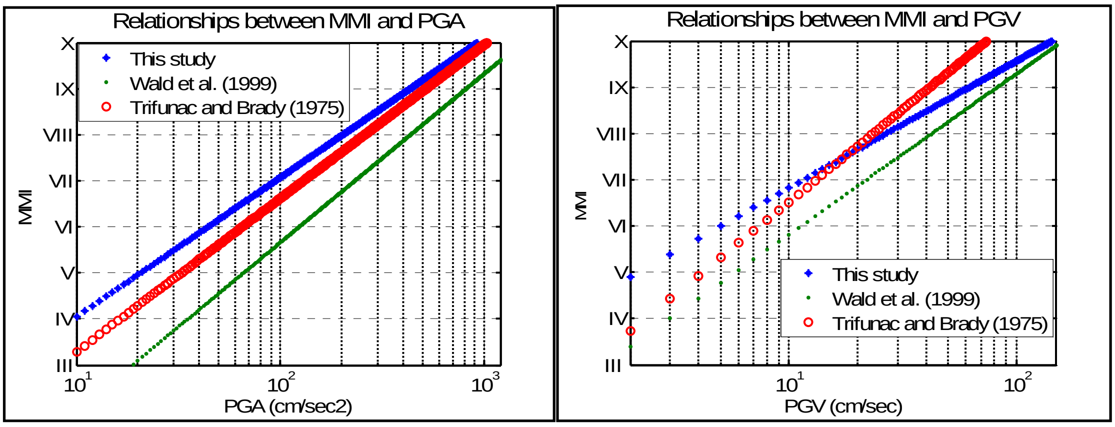

Figure 3. Correlation of PGA and PGV with the intensities from the ten subduction earthquakes of Table 3.2.

4.2.Response Spectra in Chilpancingo Guerrero

During the July, 18, 1957, Guerrero Earthquake, Chilpancingo city was severely damaged, it was estimated that approximately one third of the buildings were damaged. A value of VIII in MMI intensity was assigned in this city. This earthquake was the largest event to have occurred in the Chilpancingo region in the last 50 years. This event was not recorded, nevertheless, in the last 20 years an important acceleration data from several close moderate earthquakes, and from some far large earthquakes has been recorded. Motivated for this situation we developed MMI-spectral relations. The functional forms adopted here is the give by the equation (5):

$$\mathbf{MMI} = \alpha_1(T) \log (\mathbf{SA(T)}) + \alpha_2(T) \qquad (5)$$

Where MMI is the observed intensity in Chilpancingo. In order to estimate the response spectra, we used data from 10 recorded earthquakes in the soft soil of the valley. In the left part of Figure 4 are presented the 5% critical damping response spectra for the 10 studied events; whereas in the right part of Figure 4, are presented the expected spectra calculated with the regression equation 5, using 3 different intensities, including the MMI=VIII as the intensity assigned during the July, 18, 1957 earthquake.

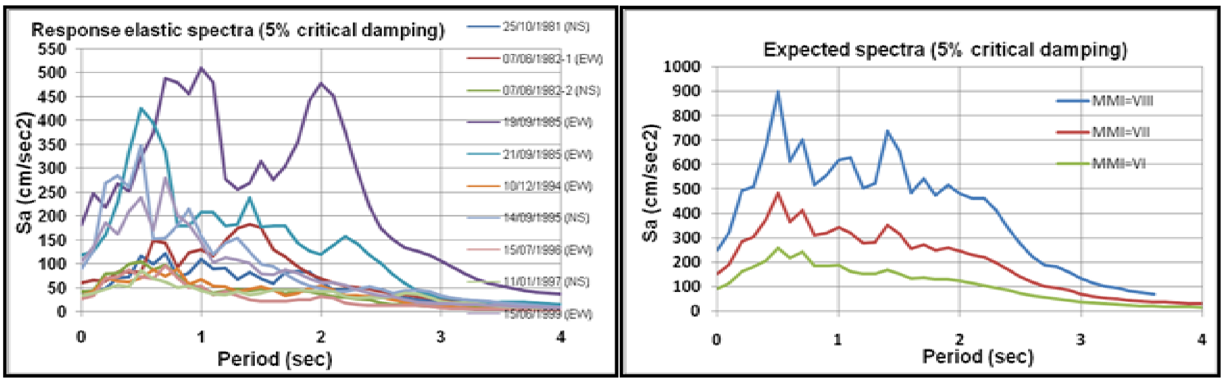

Figure 4. Observed Response Spectra from the studied earthquakes. And, calculated spectra at soft soil in Chilpancingo for tree different intensities.

CONCLUSIONS

In this study we developed regression relationships between Mercalli Modified Intensity (MMI) and peak ground acceleration (PGA), and between MMI and peak ground velocity (PGV), for ten Mexican earthquakes. Correlations were developed for the MMI range of III≤ IMM ≤ IX. When these relationships are compared with others correlations obtained in other regionns such as California in USA, we found a significant difference both for PGA and PGV. Relationship of peak ground acceleration, reported by previous investigators, are higher than those obtained in this study over the intensity range. But relations of peak ground velovity are similars in higher intensities.

An important variability of the correlated data was observed for the studied earthquakes, between MMI and PGA, and with PGV. In accelerations, with respect to Trifunac and Brady (1975); a significant difference is observed in low intensities, but there are coincidences in high intensities, considering an interval of IV≤IMM≤X. But with respect to Wald et al. (1999), significant differentiates in all the rank from intensities is observed, being a little more pronounced this difference in high intensities, considering the rank V≤IMM≤VIII. In the case of PGV, similarity for high intensities exists if it is compared with Wald et al. (1999); whereas a significant differences is observed in low intensities, in the interval of V≤IMM≤IX. In the other hand, respect to Trifunac and Brady (1975), it exist similarity for average intensities, but significant difference both with high as with low intensities, considering a rank of IV≤IMM≤X. Finally, in order to estimate expected response spectra for the July, 18, 1957, Guerrero Earthquake, period dependence was associated, using results from regressions of observed response spectra with MMI, using acceleration from ten earthquakes.

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