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EARTHQUAKE SCENARIOS IN GUERRERO MEXICO, AN EARTHQUAKE HAZARD CHARACTERIZATION

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SUMMARY

In a first stage, the hazard seismic analysis was performed, which includes attenuation relationships for peak ground accelerations and response spectra accelerations for subduction zone inter-plate and intra-plate earthquakes, and for shallow crustal earthquakes, of moment magnitude M5.5 and greater and for distances of 100 to 600 km. The relationships for peak accelerations were developed by regression analysis. We find that the rate of attenuation of peak motions from inter-plate earthquakes is lower than that for intra-plate earthquakes; and that the rate from shallow-crustal earthquakes is lower than that for inter-plate earthquakes. Next, in order to establish the seismic risk for Chilpancingo the seismic vulnerability of 1306 structures, in a particular area of Chilpancingo, and estimations of the amount of affected structures, their damage patterns and social impacts are assessed.

INTRODUCTION

Chilpancingo, with a population of 200,000 inhabitants, is the capital city of Guerrero, Mexico; it is located in 17º33'05'' N and 99º30'03'' W, and 1250 m above the sea level [1]. The Chilpancingo valley is located in the province called Balsas-Mezcala Basin, that belongs to the so called "*Sierra Madre del Sur*" zone, and classified D according to the seismic zonation maps [2]. Chilpancingo, located about 100 km from Acapulco, is one of the cities with the seismic risk more high in Mexico and in the world; two factors exist at least that therefore indicate it, first that is very short the distance between this city and the zones of rupture of most of the subduction earthquakes that are generated in the state of Guerrero, and second, that the stratigraphy and the geology of the valley, on which the city is located, generate amplifications quite great of the movement of the ground, since it has been evident in the accelerograms of earthquakes recorded in the last 20 years, and as observed in seismic history of Chilpancingo, Table 1.

The high seismicity in the zone of subduction has caused considerable damages throughout history in the city of Chilpancingo, in many occasions the generated earthquakes to relatively short distances have

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caused severe damages in a great amount of constructions. The most recent event with these characteristics happened in July, 1957. Nevertheless, in century XIX and at the beginning of the XX, the periods of recurrence of events of great magnitude (M > 7.5), which they affected the city were very short, for this reason this region at the moment represents a high risk. In this region has not been important activity in the last 45 years old, it is evident, that in a very short time interval, a earthquake in this zone will be originated. The period of recurrence of the different segments from interest is quite uncertain, since also uncertainty in the exact location and the extension of the most recent events exists (1907, 1937 and 1950).

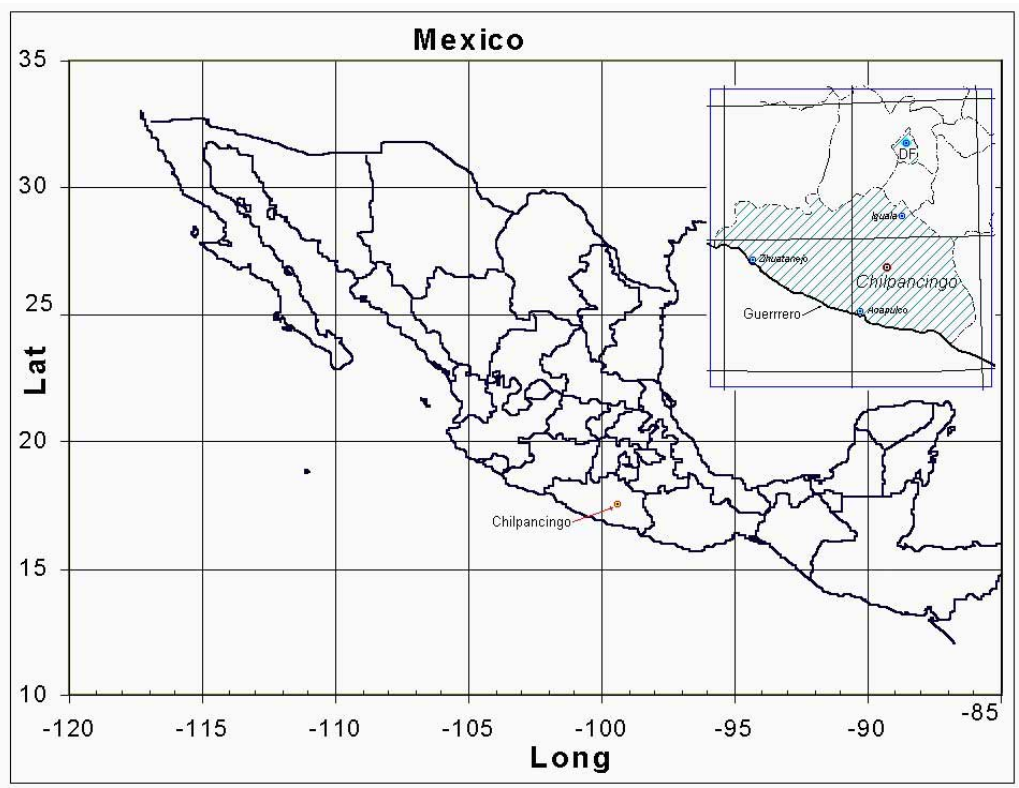
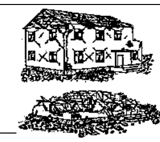
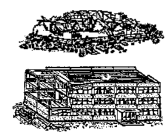
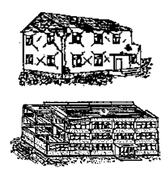
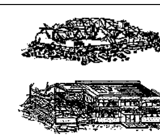
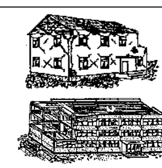


Figure 1: Mexico Map

In past earthquakes it has been observed that amplification of ground motion; lack of technical and professional supervision and the use of poor structural materials are some of the main reasons that structures in Chilpancingo have suffered from moderate to severe damage.

Seismic history in Chilpancingo shows that there is a pattern of affected zones along the city, one of them located in the downtown area of the city. Typical damages were observed in unreinforced masonry or adobe structures, without aseismic design. Observed damages referred to poor connection at corner walls, diagonal shear cracking, out of plane failure of walls, and excessive bearing stresses on walls due to heavy floor systems. Reinforced masonry structures were damaged due to inadequate structural configurations and lack of technical advice. Steel and concrete structures are considered to have shown good aseismic behaviors; failures and damages are related to poor structural configurations and lack of engineering advice. Construction materials and aseismic designs have been increased and developed through years of seismic activity in Chilpancingo, mainly because of the substitution of materials and developing techniques that have been tested by past earthquakes.

Table 1. Seismic history of Chilpancingo

Date	Epicenter		Richter Magnitude	MMI	Damage description	Damage Degree DD
	Lat	Long				
7/04/1845	17º01'N	101º11' W	7.0º	VIII	Damage to service and housing buildings.	
19/07/1881			7.5	VII	Damage to historical building "*Palacio de los Poderes*", constructed in 1870. Masonry DD 3.	
29/05/1887				IX	Damage to service and housing buildings.	
16/01/1902	16º37' N	99º53' W	7.0º	VIII-IX	Service buildings collapsed. Housing was affected (614 collapsed, 182 were heavily damaged). Masonry DD 5 in some buildings.	
14/04/1907			7.8	X	61% of housing destroyed, 4% were in proper conditions. 35% needing repair. Health and service facilities were out of service. Government and religious facilities were heavily damaged. Masonry DD 5. Concrete DD 4.	
30/07/1909	16º47' N	99º53' W	7.7	X	Housing, government and religious buildings were heavily damaged. Masonry DD 4. Concrete DD 4.	
28/07/1957	16º21' N	99º13' W	7.8º	X	80% of buildings were heavily damaged. Collapse on service and housing buildings. Highway from Zumpango to Chilpancingo showed landslides and falling rocks onto pavement Masonry DD 5. Concrete DD 5.	
19/09/1985	18º05' N	102º56' W	8.1º	VII	Severe damage to medium rise concrete buildings, 3 to 6 stories. Masonry DD 4. Concrete DD 4.	

The seismic vulnerability is determined with a relationship between the peek ground acceleration values and the European Macroseismic intensity scale (EMS). The EMS classifies the structures by construction materials and vulnerability classes; it also classifies damage by range and presents damage patterns by construction materials. A description and characterization of structures was developed in order to specify the type of structures in the studied zone of Chilpancingo.

A seismic hazard was conducted in order to establish the ground acceleration values for future earthquakes in Chilpancingo, attenuation relationships for peak ground accelerations and response spectra accelerations for subduction zone inter-plate, and intra-plate earthquakes, and for shallow crustal earthquakes, of moment magnitude M5.5 and grater and for distances of 100 to 600 km. Next, the intensities were estimated by using the EMS and the acceleration values obtained from the seismic hazard analysis. There were 1306 structures studied in Chilpancingo, this data was useful in the estimation of the damage structures, ranging from light damage to collapse; therefore it was possible to obtained the amount of affected inhabitants in Chilpancingo.

METHODOLOGY

It was necessary to determine a zone of study for Chilpancingo, the downtown area of Chilpancingo was selected, where past earthquakes inflicted severe damage, Figure 3; a description of structures was constructed by the structural census of more than 1300 structures and a data base was established. The seismic hazard analysis for Chilpancingo was started since 1999 [3]. The EMS (98) was selected because it considered different types of structures, such as adobe structures, masonry structures, and those with no technical advice; values for intensities and peak ground acceleration values were determined and used by Münchener [4]. The characterization of more than 1300 structures was carried out with a census, in order to identify those typical structures for the studied zone of Chilpancingo. It was necessary to slightly modify the EMS 98, so it can be possible to estimate the damage and vulnerability for those particular structures. The methodology proposed for this paper is illustrated in Figure 2.

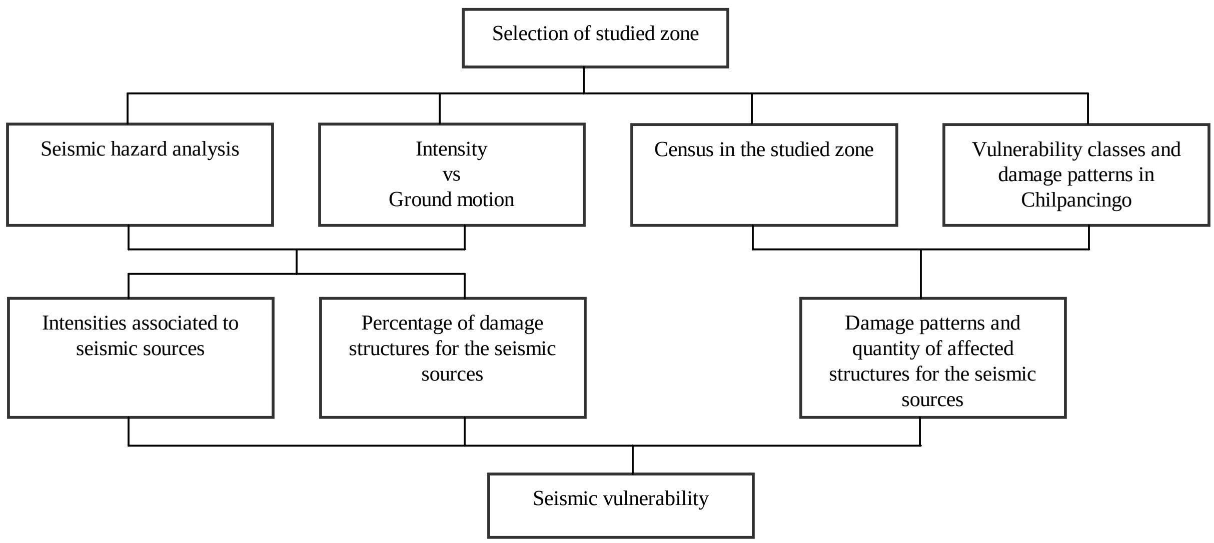


Figure 2: Methodology

A relationship among seismic hazard analysis, earthquake intensity and ground motion values were constructed. It was necessary to identify degrees of expected damage for every type of structures for the studied zone of Chilpancingo, and therefore an estimation of the percentage of damaged structures was calculated. Calculations were carried out with these data, and thus it was possible to determine the quantity of damaged structures, the impact upon the systems of emergency, and the economic losses for the studied zone of Chilpancingo, Guerrero.

STUDIED ZONE FOR CHILPANCINGO

According to the seismic history of Chilpancingo, it was observed that damages pattern occurred without systematic variation in the city. In Figure 3, Huacapa river is depicted in a black line, in colored squares are presented the blocks in the studied zone of Chilpancingo, the downtown area of the city, those blocks of the city include commercial, service and residential structures.

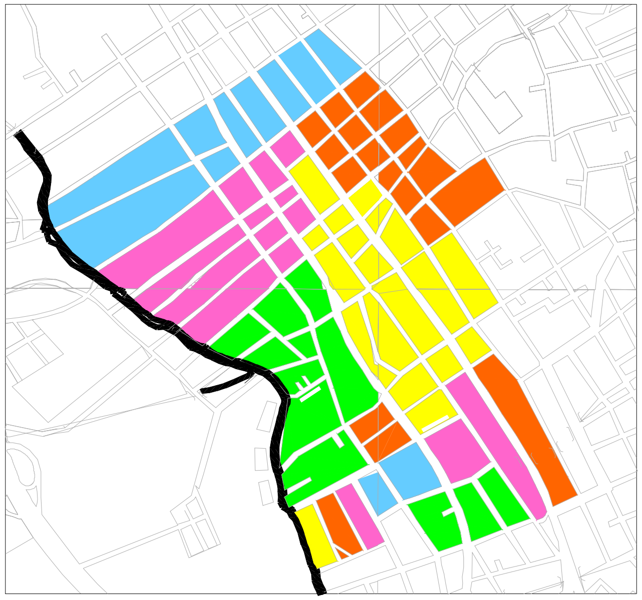


Figure 3: Studied zone for Chilpancingo, Guerrero.

Structural patterns were identified with the structural census and the data base. The data base contributed in the characterization of structures in the studied zone of Chilpancingo (SZCh) and therefore, comparisons between this SZCh and others sites of Chilpancingo were established by Juárez et al [5].

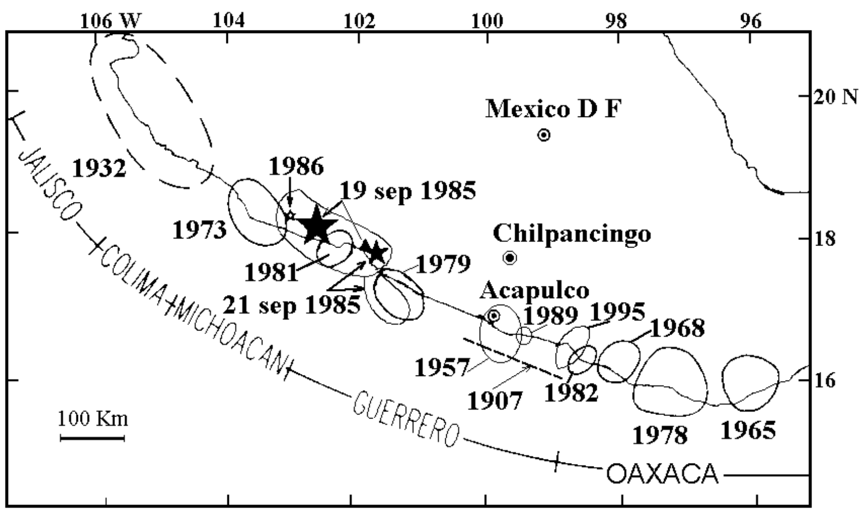


Figure 4. Rupture areas from earthquakes with magnitude M>7.0, between 1932 and 1995.

SEISMIC HAZARD ANALYSIS

Chilpancingo is located in the region of highest seismic risk in Mexico. Thus, in the past, Chilpancingo has been destroyed during violent ground motions. Furthermore, analyses of recent earthquakes show spectacular amplification effects during subduction events. This city is on 20 m or less of recent alluvium, with a shear-wave velocity between 300 to 500 m/sec, which provides a soft to moderately firm foundation for structures. Underlying the alluvium are about 100 m of the unconsolidated *Chilpancingo* *formation*, then about 300 m of relatively unconsolidated continental clastic of the *Balsas group* (approximately 1000 m/sec in s-wave velocity); and finally the *Mezcala formation*, a firm Cretaceous deposit. On the easterly slope of the valley, the *Chilpancingo formation* is at the surface. On the westerly slope the formation of the *Balsas group* are exposed. The variation in near-surface geologic conditions in Chilpancingo appears to explain the spectacular amplifications in ground motions, as has been studied by Gomez-Bernal and Saragoni [6].

Attenuation Relationships for Inter-plate, Intra-plate and Crustal Shallow Earthquakes

At the moment is scare the information on firm soil accelerations in the Chilpancingo region, however the number of accelerograms of registered intense earthquakes in soft soil is relatively ample, as shows Table 2. Strong ground motion have been registered from 1981, as it is possible to be seen in Table 2, at the moment exist acceleration records of 10 events with magnitude, M_w, greater or equal to 7, and there are 9 events with magnitude, M_w, between 6 and 6.9. The distances from the source vary between 115 to 650 kilometers. Events 1 to 5 of the table were registered at station CHI1 (out of operation), and the rest (6 to 24) at station RICC. These are two sites that are separated to each other more than 5 km. The quotient between the absolute vertical peak ground acceleration (PGAV) and the absolute horizontal peak ground acceleration (PGAH), in all the cases fluctuates between 0.37 to 0.91 g. The relation between both components is very high.

Table 2. List of Earthquakes Used to Develop Attenuation Relationships

#	Date	Magnitude (M_w)	Epic Dist.(km)	Depth (km)	PGAH (g)	PGAV (g)	PGAV/ PGAH	Source type
1	25/10/81	7.3	294	32	0.0390	0.0220	0.56	Intra-slab
2	07/06/82[a]	7.0	197	11	0.0560	0.0310	0.55	Inter-plate
3	07/06/82[b]	6.9	179	19	0.0430	0.0210	0.49	Inter-plate
4	19/09/85	8.1	341	21	0.1870	0.0850	0.46	Inter-plate
5	21/09/85	7.5	238	21	0.1180	---	---	Inter-plate
6	04/07/94	6.4	385	15	0.0044	0.0023	0.53	Inter-plate
7	10/12/94	6.4	233	54	0.0350	0.0150	0.43	Intra-slab
8	14/09/95	7.4	138	22	0.0880	0.0570	0.65	Inter-plate
9	09/10/95	7.9	585	10	0.0110	0.0074	0.67	Shallow
10	21/10/95	7.2	650	160	0.0070	0.0031	0.44	Intra-slab
11	15/07/96	6.8	162	22	0.0259	0.0173	0.67	Inter-plate
12	11/01/97	7.2	367	40	0.0305	0.0129	0.42	Intra-slab
13	22/05/97	6.5	265	56	0.0166	0.0092	0.55	Intra-slab
14	15/06/99	7.0	234	69	0.1017	0.0607	0.60	Intra-slab
15	21/07/00	5.9	115	80	0.1267	0.0526	0.42	Intra-slab
16	9/08/00	6.5	336	33	0.0158	0.0094	0.60	Intra-slab
17	08/10/01	5.9	95	15	0.0678	0.0615	0.91	Shallow
18	9/11/01	5.5	203	15	0.0108	0.0040	0.37	Shallow
19	23/01/02	5.0*	94	5	0.0101	0.0072	0.71	shallow
20	30/01/02	5.9	383	116	0.0032	0.0028	0.88	Intra-slab
21	18/04/02	6.3	215	15	0.0030	0.0025	0.83	shallow
22	7/06/02	5.5*	341	22	0.0025	0.0013	0.52	Inter-plate
23	19/06/02	5.5	214	24	0.0054	0.0029	0.54	Inter-plate
24	22/01/03	7.5	524	23	0.0275	0.0230	0.84	Inter-plate
25	01/01/04	6.0	244	21	0.0123	0.0064	0.52	Inter-plate

Attenuation relationships for both horizontal and vertical peak ground acceleration (PGA_h and PGA_v) were evaluated by performing regression analyses on the data in Table 2 (events 19 and 22 no were included). The regression model follows the form:

$$\ln PGA = C1 + C2\, M_w + C3 \ln\left(R + 23\,(6 - M_w)\right) + \Sigma\, C_i\, S_i \qquad (1)$$

where $R = (D^2 + H^2)^{1/2}$, D is the closest distance to the surface projection of the fault in kilometers, H is the focal depth, and S_i the type of fault, it is a dummy factor with the value of 1 for each fault type and 0 for others. Ci, are coefficients of regression. The term 23(6-M)) considers the fault rupture area.

The horizontal and vertical attenuation models obtained by fitting model (1) are given by:

$$\ln PGA_h = -\,0.6932 + 1.5958\, M_w - 2.4135 \ln\left(R + 23\,(6 - M_w)\right) - 0.2973\, S_1 + 0.2973\, S_2 - 0.8462\, S_3 \qquad (2)$$

$$\ln PGA_v = -\,1.1816 + 1.5917\, M_w - 2.3901 \ln\left(R + 23\,(6 - M_w)\right) - 0.5007\, S_1 - 0.0065\, S_2 - 1.1816\, S_3 \qquad (3)$$

Figure 5 shows the PGA predictions from the attenuation models (2) and (3), for $\mathbf{M_w}$ 8.1 events (top) and for $\mathbf{M_w}$ 7.6 events (bottom). This figure compares the PGA curves among the three groups used in this work: intra-plate, inter-plate, and shallow crustal. The results of the regression analyses indicated that intra-plate earthquakes produce peak motions that are on average about 70 percent higher than those for inter-plate earthquakes for the same magnitude and distance. This difference in peak motion is the same when comparison is made between inter-plate and shallow crustal events.

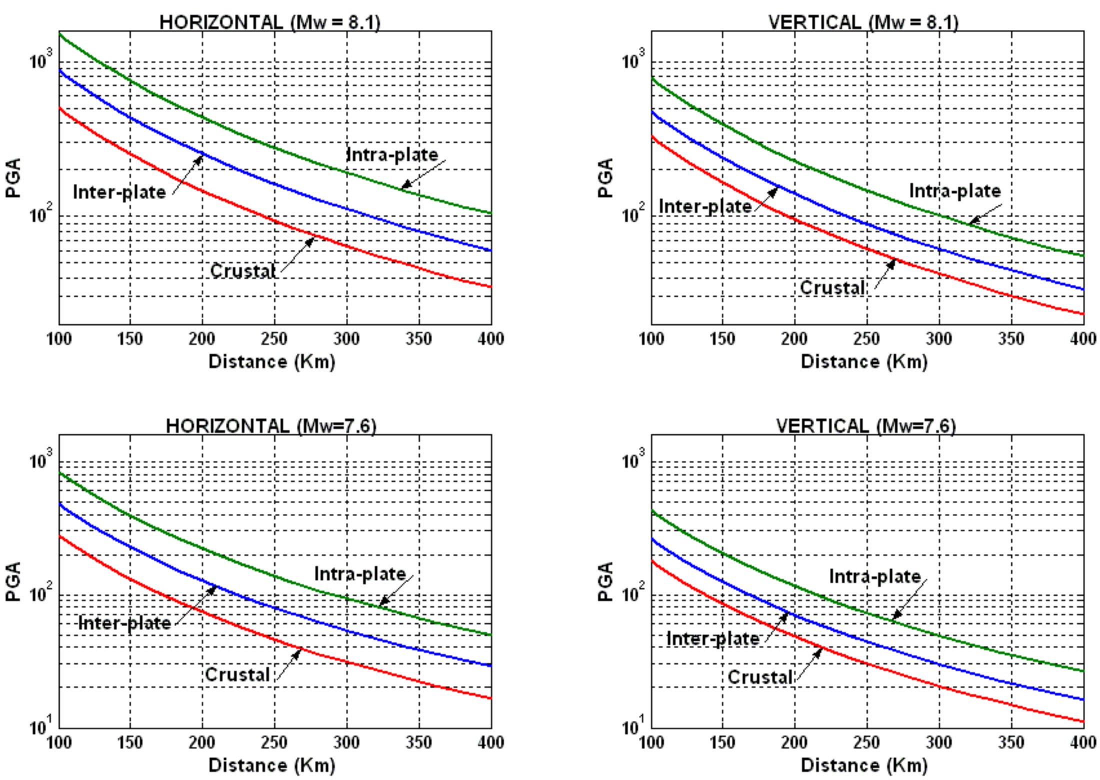


Figure 5. Attenuation relationship fit to soft soil site of Chilpancingo city, using regression model (1), and the data from Table 2, for inter-plate, intra-plate and shallow crustal earthquakes. Accelerations are in cm/s^2.

Analysis of Response Spectra

In order to estimate expected spectrum it is possible to calculate peak spectral ordinates. Nevertheless, in Chilpancingo there are no acceleration records from earthquakes with magnitude, Mw, higher than 7.5 and originated at less than 200 km. In the other hand, accelerograms recorded at distances less than 270 kilometers, indicate that spectral shapes are very similar. In order to estimate expected response spectra, in this work, average response spectra from earthquakes originated at 270 km were considered. Figure 6 contains all the normalized response spectra of earthquakes with magnitude greater to 6.5 registered in the stations CHI1 and RICC (Table 2). As it is to expect that very distant earthquakes do not produce important damage in this city, only the events originated to less than 270 kilometers were taken into account. The figure shows the spectra average of these earthquakes and the spectra average plus the standard deviation. The enveloped of the normalized spectra of earthquakes originated to less than 270 kilometers also appears in Figure 6, and it is possible to define this curve like:

$$A(T) = 1 + 14 \times T x \exp(-1.7 x T) \qquad (4),$$

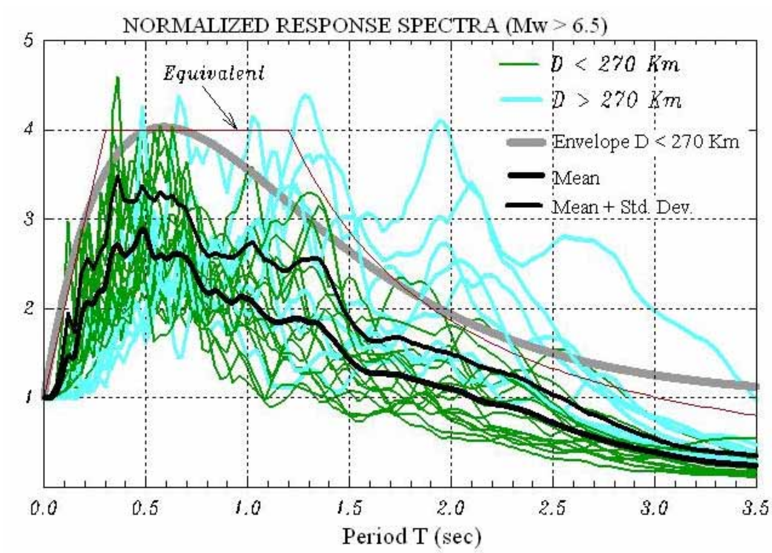


Figure 6. Acceleration response spectral shapes (SA/PGA, 5% damping) for the soil site of Chilpancingo computed using events with Mw > 6.5. Also shown are spectral shapes for the mean computed from events with D < 270 km, and the envelope spectra.

The predicted envelope-spectra was estimated in this work acording equation (4), and with basis in the attenuation relationship. The four scenarios (A, B, C and D), were selected according to Gomez-Bernal *et al*. [3]. The cooresponding curves are shown in Figure 7, and were calculated according with:

A (intra-plate, M_w=7.7, D=200 km, PGA=0.25 g): SA(i) = 0.25*(1+14*T(i)*exp(-2*T(i))) (5)

B (inter-plate, M_w=8.0, D=150 km, PGA=0.39 g): SA(i) = 0.39*(1+14*T(i)*exp(-1.7*T(i))) (6)

C (inter-plate, M_w=7.7, D=100 km, PGA=0.52 g): SA(i) = 0.52*(1+14*T(i)*exp(-1.7*T(i))) (7)

D (shallow-crustal, M_w=7.0, D=70 km, PGA=0.28 g): SA(i) = 0.28*(1+14*T(i)*exp(-1.7*T(i))) (8)

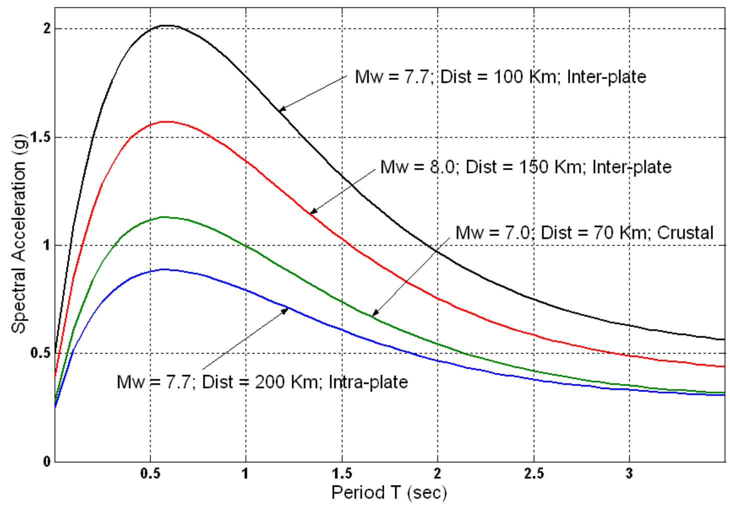


Figure 7. Maximum Spectral Ordinates (SA) computed for the most critical seismic scenarios in Chilpancingo.

INTENSITY AND MAXIMUM GROUND MOTION RELATIONSHIP

A relationship between ground motion and intensities was obtained, and thus structural damages and seismic parameters can be related. Estimations of the quantity structures that can suffer damage and the associated type of damage is calculated in this paper; the relationship between intensity and ground motion is considered to be approximate, Table 3, Münchener [4]. The percentage values of damage were taken from EMS-98 by Grünthal [7]. In this study, it was difficult to calculate the amount of damage structures with accurate precision, but a range of values was assigned as described: few, from 0 to 15%; many, from 15 to 55%; and all, from 55 to 100%, of the total of structures. Notice that for structures with damage degree (5) and quantity values described as most, did not necessarily mean that all the structures of this type have collapsed.

Table 3. Relationship among intensity, ground motion and quantity of damage.

EMS	Definitions of intensity degrees	Damage												Acel. % g
		A		B		C		D		E		F		
		Grade	%	Grade	%	Grade	%	Grade	%	Grade	%	Grade	%	
I	Not felt													0.0
II	Scarcely felt													0.0<-0.15
III	Weak													0.15-0.2
IV	Largely observed													0.5-2
V	Strong	1	0-15	1	0-15									2-5
VI	Slightly	1	15-55	1	15-55	1	0-15							5-10
	damaging	2	0-15	2	0-15									
VII	Damaging	3	15-55	2	15-55	2	0-15	1	0-15					10-20
		4	0-15	3	0-15									
VIII	Heavily	4	15-55	3	15-55	2	15-55	2	0-15					20-50
	damaging	5	0-15	4	0-15	3	0-15							
IX	Destructive	5	15-55	4	15-55	3	15-55	2	15-55	2	0-15			50-80
				5	0-15	4	0-15	3	0-15					
X	Very destructive	5	55-	5	15-55	4	15-55	3	15-55	2	15-55	2	0-15	80-130
			100			5	0-15	4	0-15	3	0-15			
XI	Devastating			5	55-100	4	55-100	4	15-55	3	15-55	2	15-55	150-200
						5	15-55	5	0-15	4	0-15	1	0-15	
XII	Completely	Destruc-	100	Dest.	100	Dest.	100	Dest.	55-100	Dest.	55-100	Dest.	55-100	>200
	devastating	tion												

CHARACTERISTIC OF STRUCTURES AND VULNERABILITY CLASSES

Stone masonry structures
Two types of structures are considered:

Rough stone walls. Mainly constructed with river stones with large dimensions, that are attached with poor quality mortars. These structures are constructed with heavy walls without lateral resistance structural elements. Floor systems are generally made of wood, with two slopes, and a central timber beam that does not provide stiffness in its plan. The vulnerability class assigned is: A.

Simple stone walls. Stones are shaped by hand, in order to provide flat surfaces, which improve the adherence between the mortar and the stone. The vulnerability class assigned, for structures made with walls of these stones, is: B. When labor and construction procedures lack expertise engineering supervision and maintenance, the vulnerability class assigned should be: A.

Adobe masonry structures
There are different types of adobe masonry structures, and therefore difference among their seismic behaviour.

Unreinforced adobe walls. Walls are generally made of mud bricks, enriched with straw fibers, and attached with mortar made of the same material. Valencia [8] indicates that house plans are rectangular, with 30 to 40 m^2 of surface, with one story, and four walls. The floor systems have one or two slopes, supported with wooden trusses, and covered with clay tiles. Resistance can be improved when mortar quality is observed, but the *vulnerability class* assigned should be: *A*.

Reinforced adobe walls. Damages occurred in past earthquakes is the main reason of the reinforcement observed in some of the adobe wall structures. It is likely to improve the seismic behavior when beam (dalas) and columns (castillos) are embedded in walls. *Vulnerability class* assigned should be: *B*. When a concrete slab, or peripheral beams (dalas) are embedded in the top of the walls of the structure, the *vulnerabilty class* assigned should be: *C*.

Bajareque walls. Walls are made of bamboo grids, mud and sometimes debris. Two bamboo grids are made and spaced with 5 to 10 cm of mud and debris infill. The bamboo grids are made with wooden poles or large bamboo canes attached vertically and horizontally, with 5 to 10 cm spacing. These structures have four walls and a light floor system, with one or two slopes. Because of poor behaviour in extreme weather conditions, *vulnerability class* assigned should be: *A*. If proper maintenance is accomplished in this type of structures, *vulnerability class* assigned should be: *B*.

Masonry structures
Clay and mortar bricks are widely used in Guerrero, those artificial bricks are made in an artesian form. There are different types of structures which use walls made of these materials. And a great variety of seismic behaviors are observed for masonry structures.

Unreinforced masonry walls. The walls are laid with bricks and a cement mortar, with no other structural elements to achieve good seismic behavior. If a good connection is achieved in the corner of the walls, then the *vulnerability class* assigned should be: *B*. Lack of proper connection in corner of walls lead to *vulnerability class*: *A*.

Unreinforced masonry walls with connected structural elements on the floor system. When walls are connected with structural elements such as, reinforced concrete slabs or beams (cadenas), then the seismic behavior is improved, *vulnerability class* assigned if good corner connection of walls and structural elements surrounding the top of walls, should be: *C*. Irregularities in elevation and plan, lack of secondary walls, deficiencies in connection of walls and the floor system elements, and lack of proper corner connections lead to *vulnerability class*: *B.*

Reinforced masonry walls. Concrete and steel elements are used to reinforce the masonry walls. These reinforced walls provide great aseismic behavior and ductility, *vulnerability class* assigned should be: *D*. If good quality control and engineering advice is involved then *vulnerability class* could be: *E*. Irregularities in elevation and plan, poor quality control, and no engineering advice involved should drop *vulnerability class* to: *C*.

Concrete structures. Structures with frames or walls of concrete structures, vulnerability class range from B to E. Although earthquake-resistant design codes are used in Chilpancingo, it is reliable to consider a *vulnerability class*: *D*. High engineering advice, as well as supervision and maintenance should lead to *vulnerability class*: *E*. If there is a lack of expertise advice and poor structural configurations, such as irregularities in plan and elevation, *vulnerability class* could drop to *C* and *B*.

Steel structures.
Structures with steel frames, and walls or other structural elements controlling lateral displacements, have a proper seismic behavior, vulnerability class range from B to E. Although earthquake-resistant design codes are used in Chilpancingo, it is reliable to consider a *vulnerability class*: *D*. High engineering advice, as well as supervision and maintenance should lead to *vulnerability class*: *E*. If there is a lack of expertise advice and poor structural configurations, such as irregularities in plan and elevation, *vulnerability class* could drop to *C* and *B*.

Wooden structures.
Vulnerability classes could be *B* or *C*, according to the type of constructions observed in Chilpancingo these two classes can be found. If wooden structures have minimum supervision, and lack of expertise advice then, *vulnerability class* should be: *B*, otherwise should be *C*.

VULNERABILITY CLASSES

According to the EMS scale [6], there are five vulnerability classes for structures, as shown in Table 4.

Table 4. Vulnerability classes

Class	A	B	C	D	E	F
Description	Highest	High	Medium	Low	Lower	No vulnerability

The previous data, summarized in Table 4, presents a relationship between structures and vulnerability classes for the structures of the studied zone of Chilpancingo. In Table 5, x is the most probable vulnerability class; p the normal vulnerability class, and e the exceptional vulnerability class observed.

Table 5. Structures and vulnerability clases

	Structures	A	B	C	D	E	F
	Rough	x					
Stone	Simple	e	x				
	Massive	p	x	e			
	Unreinforced	x					
	Wooden reinforcement	p	x				
Adobe	Concrete reinforcement		x	p			
	Steel rod reinforcement	p	x				
	Bajareque	x	e				
	Unreinforced	p	x	e			
Masonry	Floor system reinforcement		p	x			
	Reinforced			e	x	p	
	No seismic design		p	x	e		
Frames	Moderate seismic design			p	x	p	
	Good seismic design				p	x	P
	No seismic design		e	x	p		
Concrete Walls	Moderate seismic design			e	x	p	
	Good seismic design				e	x	P
Steel Structures				p	x	p	
Wooden structures		x	p				

CHARACTERIZATION OF STRUCTURES

According to the three seismic sources, the maximum ground motions and the data base for the studied zone of Chilpancingo [3], the number of damaged structures can be calculated. A selection of vulnerability for structures is performed, vulnerabilities marked with an x are selected, Table 5. The three seismic sources are: I, intensity VII; II, intensity VIII; III, intensity IX. It is important to indicate that the zone included 1306 structures. The different types of structures are shown in Table 5, as well as the vulnerability class assigned.

Patterns and damage degrees

The definitions of damage patterns are shown in Figures 8 and 9.

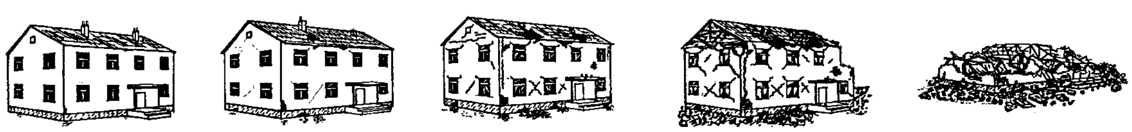
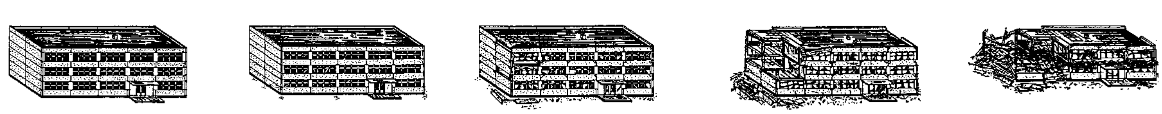


Figure 8. Damage degrees for masonry structures.



Grade 1 **Grade 2** **Grade 3** **Grade 4** **Grade 5**

Figure 9: Damage Degrees in Concrete Structures.

Considering the maximum ground motion in Chilpancingo, damage to structures is observed in Table 6. In Table 6 are shown the types of structures, the vulnerability class assigned and the damages expected in the three sources.

Table 6. Damage to structures.

Structure	Qty	Class	Source I Grade					Source II Grade					Source III Grade				
			1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Unreinforced adobe walls	53	A			29	8					29	8					29
Reinforced adobe walls	67	B		37	10					37	10					37	10
Bajareque walls	2	A			1						1						1
Unreinforced masonry walls	15	B		8	2					8	2					8	2
Unreinforced masonry walls with connected structural elements on the floor system	13	C		2					7	2					7	2	
Reinforced masonry walls	1024	D	154						154					563	154		
Frame without Earthquake Resistant Design (ERD)	25	C		4					14	4					14	4	
Frame with moderate level of ERD	15	D	2						2					8	2		
Walls without ERD	12	C		2					7	2					7	2	
Walls with moderate level of ERD	25	D	4						4					14	4		
Steel structures	7	E												1			
Wooden structures	6	A			3	1					3	1					3
Other	42	A			23	6					23	6					23
TOTAL	**1306**		**160**	**53**	**68**	**15**		**0**	**188**	**53**	**68**	**15**	**0**	**586**	**188**	**53**	**68**

SEISMIC VULNERABILITY FOR CHILPANCINGO, GUERRERO

The number of inhabitants per structure can be considered as constant; the average of inhabitants per structure is 4, according with INEGI [1]; when a structure is considered to be in a degree of damage 3, should be subjected to a rehabilitation process, this implies temporary shelters for the affected population. Degree of damage 5, implies heavy damage to total collapse: homeless inhabitants, inhabitants needing healthcare facilities, deceased inhabitants, and rescue and search teams. The inhabitants whose houses have been destroyed, they will probably need social and technical programs for reconstruction and retrofitting. Degrees of damage 1 and 2, does not imply that special support programs will be considered. Degree of damage 3, implies that inhabitants can be considered as affected inhabitants needing special support.

It is considered for source I that the maximum degree of damage will be 4. Structures will suffer some degree of damage, these quantities are shown in Table 6. Eight unreinforced adobe structures will be at a degree of damage (DD) 4, 29 will show a DD 3. In general, for source I, the studied zone will show: 158 affected structures; 632 affected inhabitants; 83 heavy damaged structures, and 332 affected inhabitants; 10 heavily damaged structures, approximately 5 collapses, leaving 40 persons affected, needing emergency specialized equipment, health and temporary facilities. Estimations show that there will be more than 600 persons that will need shelter and medical services; 300 of them will be able to return to their homes, with the recommendation of carrying out repairs and rehabilitation. Approximately 300 inhabitants should be provided with shelter for a longer period of time; 40 inhabitants should be provided with new homes.

Source II will show a maximum DD 5. 363 structures will be affected. 1452 inhabitants will need shelter as a preventive measurement; 146 structures will be damaged with a total of 584 affected inhabitants; 83 heavy damaged structures and 50 collapses. 332 inhabitants will need homes and 850 inhabitants will be able to return to their homes.

Source III will show a maximum DD 5. 956 structures will be affected; 3824 inhabitants will need shelter; 333 structures will be damaged, 1332 affected inhabitants; 130 heavy damaged structures; 50 collapses; 520 inhabitants will need new homes. 2500 inhabitants will be able to return to their homes. 1300 inhabitants will need shelter for a longer period of time.

These estimations were calculated, considering 4 inhabitants per structure. Notice that, in some cases, the structures have a commercial, housing and service use. So that, a large concentration of persons would be able to be greater than the one expected. The seismic vulnerability assessment for Chilpancingo, should be carried out for the whole city, and therefore vulnerability maps could be proposed for the city, so that an accurate seismic response could be drawn for the government and technical societies. As a conclusion, taking into account our hypothesis that structures with DD 2, can be considered as affected by earthquakes. Then a total of 956 structures will be affected of the 1306 of the zone of study, 73%. This percentage indicates that we shall focus our efforts in a proper mitigation program, better technical, emergency and service recommendations, to the state and federal authorities.

CONCLUSIONS

The hazard seismic analysis includes attenuation relationships for peak ground accelerations and response spectra accelerations for subduction zone inter-plate and intra-plate earthquakes, and for shallow crustal earthquakes, of moment magnitude M5.5 and grater and for distances of 100 to 600 km. The relationships for peak accelerations were developed by regression analysis. We find that the rate of attenuation of peak motions from inter-plate earthquakes is lower than that for intra-plate earthquakes; and that the rate from shallow-crustal earthquakes is lower than that for inter-plate earthquakes. The results of the regression analyses indicated that intra-plate earthquakes produce peak motions that are on average about 70 percent higher than those for inter-plate earthquakes for the same magnitude and distance. This difference in peak motion is the same when comparison is made between inter-plate and shallow crustal events.

Vulnerability maps should be proposed for Chilpancingo, so that an accurate seismic response could be drawn for the government and technical societies. We shall focus our efforts in a proper mitigation program, better technical, emergency and service recommendations, to the state and federal authorities.

REFERENCES

1. INEGI, (2001), Tabulados básicos y por entidad federativa base de datos y tabulados de la muestra censal, XII Censo Nacional de Población y Vivienda 2000, INEGI, México.

2. IIE, (1993), Manual de Diseño de Obras Civiles: Diseño por sismo, Instituto de investigaciones Eléctricas, México.
3. Gómez-Bernal A., H. Juárez, and M. Corona, (1999) “Peligro sísmico en el valle de Chilpancingo” Proc. XII Congreso Nacional de Ingeniería Sísmica, vol II, Morelia Mich., pp. 100–109.
4. Münchener, R. (1998), World Map of Natural Hazards, Munchen.
5. Juárez H., E. Arellano, A. Gómez-Bernal, A. Gama (2001). Caracterización de las estructuras en Chilpancingo, Proc. XIII congreso Nacional de Ingeniería Sísmica, Guadalajara Jal.
6. Gómez-Bernal A. and R. Saragoni. (2000) “Radiation and dispersion of surface waves in Mexico from the September, 14, 1995”. *Proc. XII World Conference on Earthquake Engineering*, New Zealand.
7. Grünthal, G. (1998), European Macroseismic Scale 1998, Cahiers de Centre Europeen de Géodynamique et de Séismologie, volume 15, Grünthal (Ed), Luxembourg.
8. Valencia, E., (1981), Eficiencia de sistemas de refuerzo de vivienda económica situada en zonas sísmicas, Thesis , UNAM University, México, (pp. 1-60).