SEISMIC VULNERABILITY ASSESMENT OF MASONRY APARTMENT BUILDINGS IN ACAPULCO CITY (MEXICO)

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ABSTRACT

Acapulco city is located over the subduction zone between American and Pacific plates, which is the highest Mexican seismic hazard zone. For this reason, buildings are subjected to high ground acceleration and, sometimes, have been damaged by strong earthquakes. In order to assess the seismic vulnerability of masonry apartment buildings, a research Governmental project was developed. The procedure is composed by several steps as follows: a) A survey of a stock of apartment buildings was carried out in order to collect the most important characteristics of each building, age, construction materials and building dimensions, number of apartments and response design spectra; b) Different typologies were identified according to the area, wall characteristics, architectonic and structural features of the building; c) The shear strength was estimated for each building; d) The seismic capacity index was evaluated with respect to the design spectra in order to obtain the seismic vulnerability of the buildings. Due to large amount of buildings in Acapulco, it was necessary to define two limits: buildings with three or more stories; and residents with a lower or moderate income. Then, 1,387 buildings divided into 17 blocks and 41 typologies were surveyed. Structures are 3 - 9 story buildings with 5-20 apartments. Age of constructions goes from 1970 up to 1990. From this study, results show that 1,228 buildings (89 %) have a high seismic vulnerability, estimated with respect to the response design spectra.

KEYWORDS: buildings, capacity index, masonry walls, strength, seismic design, simplified method

INTRODUCTION

Acapulco city, located in the Southern Mexican Pacific Coast, is on the subduction zone of Pacific and American tectonic plates. Therefore, this area has been frequently affected by strong earthquakes with magnitudes greater than 6; see Figure 1a [1, 2]. Historical data show that Acapulco city was damaged by the 1957 earthquake [3]. This high seismic hazard was considered to define the earthquake design spectra, where acceleration is up to 0.86 g on soft soil [4].

In other way, Acapulco is the largest city of Guerrero State; it is also an important national and international beach resort destination with 673,479 inhabitants [5]. According to previous studies [6], the 20-29 percent of the population (120,000 inhabitants) lives in buildings made of masonry.

Nowadays, reinforced or confined masonry is the most common material used to construct apartment buildings in Mexico; up to 90% of total stock. Unfortunately, poor quality masonry units are commonly produced as not quality control survey is undertaken during their manufacture. Thus, their mechanical properties usually show a large variability. Additionally, inadequate quality control during the building construction process contributes to increase their seismic vulnerability [6]. By considering the stated situation and in order to evaluate the seismic capacity of existent apartment blocks, a large program developed by local State Government was undertaken. Local Universities as well as Guerrero Sate Societies of Civil Engineers and Architects participated also in this project.

CHARACTERISTICS OF BUILDING BLOCKS

According to the survey that was carried out, 17 complexes of buildings constructed from 1970 to 1990 (3 - 9 stories) were identified. These buildings have between 3 to 9 stories. Figure 1b shows the location of the building complex. The biggest complex is called "El Coloso", which has 705 of the 1387 buildings that were surveyed. Table 1 describes the structural systems observed on field while Table 2 shows the typology, quantity of buildings, stories, structural system, age of construction, type of soil and foundation as well as floor and roof materials.

a) b)

Figure 1: a) Epicenters of strong earthquakes registered near Acapulco City [1, 2, 3], b) Apartment building blocks location

The names of building blocks surveyed are:

1 Guerrero 200 (GU)	7 Saturacion Progeso (SP)	13 Arqueologica Mozimba (AM)
2 Flamingos (FL)	8 Cuauhtemoc (CU)	14 Farallon (FA)
3 Pablo Galeana (PG)	9 Costa Azul (CA)	15 Centro Acapulco (CE)
4 Los Palomares (LP)	10 Mozimba (MO)	16 El Coloso (CL)
5 Colosio (CO)	11 Vicente Guerrero (VG)	17 Alta Progreso (AP)
6 Las Colinas (LC)	12 Multifamiliar (MU)	

Table 1: Structural systems of buildings (SSB)

#	Walls	#	Walls
1	Confined masonry	5	Reinforced Masonry and reinforced concrete walls
2	Confined masonry and reinforced concrete walls	6	Reinforced masonry and reinforced concrete frames
3	Confined masonry and reinforced concrete frames	7	Reinforced concrete walls
4	Reinforced Masonry		

The mean values obtained after the survey are 2.40 m for story height, 0.14 m thickness for concrete walls and masonry walls, apartment surface area between 50 and 80 square meters. Regarding the type of foundations, we have only identified the footings of 17 apartment building blocks. Of those, one has a slab of reinforced concrete, 14 have wall footings of the same material; and two building complexes are built over wall stone foundations.

Figure 2 presents the architectural layout corresponding to the typology number # 30. According to Table 2, there are 328 buildings of this type located at “El Coloso” (CL) building block. Building dimensions are 22.96 m x 5.65 m and there are two apartments in each story.

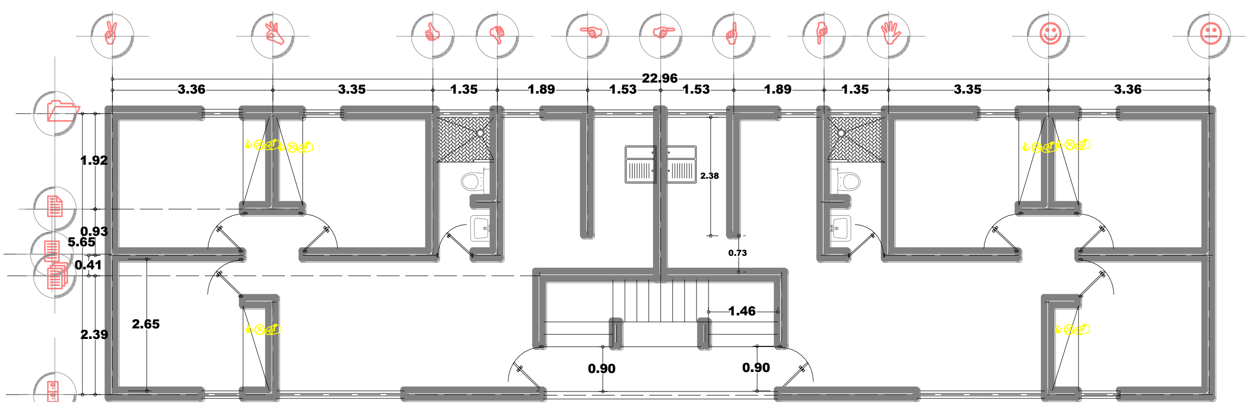

Figure 2: Architectural layout of typology # 30 at El Coloso block

According to the building survey, two types of factors were identified as the main causes of structural problems.

1. Environment causes. a) Salt weathering caused by the marine environment, which produces the cover concrete spalling and corrosion of reinforcing steel, b) Attacks of bacteria, which feeds lichens and algae; it can generate structural or non-structural damage, see Figure 3.
2. Human causes. a) Design and construction errors: Inadequate wiring for both plumbing and electrical installations. It is the origin of foundation settlement, moisture in walls, corrosion of reinforcing steel, and damage of painting finishes; b) Structural modifications, which modify the behavior of buildings, see Figure 4 and 5.

Table 2: Characteristics of building blocks

IB	T	B	S	YC	TS	SSB	SL	IB	T	B	S	YC	TS	SSB	SL
GU	1	38	4	1983	II	4	CR	FA	24	1	9		I	6	CR
FL	2	3	5		II	3	CR		2	6	5		I	3	CR
PG	3	5	5		I	1	VB CR		25	3	9		I	6	CR
LP	4	23	5	1986	I	7	CR		2	2	6		I	3	CR
CO	5	169	3		II	5	CR	CE	26	10	5	1986	I	7	CR
LC	6	8	5		I	1	CR		27	17	5	1985	I	1	CR
	2	8	6		I	3	CR		28	3	5	1985	I	1	CR
SP	7	4	5		II	3	CR		29	12	5	1985	I	1	CR
	8	2	5		II	3	CR	CL	30	328	5	1990	II	1	VB, CR
CU	9	9	4	1982	I	1	CR		31	7	5	1990	II	4	VB, CR
	10	15	5	1982	I	1	CR		32	200	5	1990	II	4	VB, CR
CA	11	2	5	1980	II	1	CR		32	25	3	1980	II	4	VB, CR
	12	8	5	1980	II	1	CR		33	49	5	1986	II	5	VB, CR
MO	2	2	5		I	3	CR		34	96	5	1984	II	4	VB, CR
	13	1	5		I	3	CR	AP	22	14	5	1980	I	4	CR
	7	2	5		I	3	CR		35	39	5	1980	I	4	CR
VG	14	30	5	1980	I	2	CR		36	12	7	1980	I	7	CR
	15	9	6	1980	I	2	CR		37	4	7	1980	I	4	CR
	16	23	5		I		SR*		38	54	5	1975	I	4	CR
MU	17	1			I		SR*		39	34	6	1975	I	7	CR
	18	1	5	1958	I	6	CR		32	35	5	1975	I	4	VB, CR
	19	1	5	1958	I	6	CR		34	3	5	1980	I	4	CR
AM	20	22	6	1979	I	4	CR		40	15	5	1980	I	4	VB, CR
	21	8	5		I		SR*		41	14	5	1980	I	4	CR
	22	6	5	1979	I	4	CR		Survey results: 41 typologies and 1387 buildings						
	23	4	5	1979	I	4	CR								

Symbols in Table 2 are:

Column # 1. **IB**: Identification of building block, see Figure 1b.

Column # 2. **T:** Typology of building

Column # 3. **B**: Number of buildings

Column # 4. **S**: Number of stories of the building

Column # 5. **YC**: Year of construction

Column # 6. **TS**: Type of soil

Column # 7. **SSB**: Structural system, see Table 1

Column # 8. **SL**: Slab materials (CR indicates slab of reinforced concrete; VB- CR means brick vault and beam for intermediate floors and reinforced concrete for roofs). SR* indicates typology without data.

Figure 3: Current physical condition of buildings: a) and b) Cover concrete spalling and corrosion of reinforcing steel; c) Moisture in walls of upper stories; d) Shrubs growing on the roof

Figure 4: a) Bad plumbing systems producing moisture on walls; b) Inadequate electrical system installation

a) b) c) d)

Figure 5: Structural alteration of original architectural system: a) and b) Additions in lower stories; c) and d) Additions in upper stories

SIMPLIFIED METHOD FOR EVALUATION OF THE SEISMIC CAPACITY

A simplified method, developed and tested with the buildings damaged by the Mexico City 1985 earthquake, was employed to evaluate the shear strength of buildings. This method does not consider the beneficial contribution of vertical stress on the shear strength [7, 8]. The calculated parameter is the seismic capacity (K), see Equation 1, along two orthogonal directions of the building's base. It defines the ratio of lateral strength (S V_R) respect to the lateral force calculated according to the seismic design spectra (V_A). Parameters required are defined in Equations 2 -4.

$$K = S\,V_R\,/V_A \tag{1}$$

$$V_R = F\,[\alpha_1(\,V_M + V_{SC}) + \alpha_2\,V_{WC} + \alpha_3\,V_{CC}] \tag{2}$$

$$V_A = F_C W_T\,C/Q \tag{3}$$

$$S = q_1\,q_2\,q_3\,q_4\,q_5 \tag{4}$$

Where:

S: Reduction strength factor according to the current physical conditions, repair and age of buildings. The q_i-values are showed in Table 3.
F: Ductility factor for short concrete columns and masonry infill walls, equal to 0.8 if V_{WC} and V_{SC} are different to zero or 1.0 if V_{WC} and V_{SC} are equal to zero.
α_i: Stiffness factor by considering the structural system, see Table 5
V_M: Shear strength of masonry walls
V_{SC}: Shear strength of short concrete columns
V_{WC}: Shear strength of concrete walls
V_{CC}: Shear strength of concrete columns
F_C: Load factor equal to 1.1
W_T: Total weight of building
C: Normalized acceleration for earthquake design spectra, see Table 6 and Figure 6
Q: Seismic behavior factor

Table 3: Values of reduction factors

	0.80	0.90	1.0
I Configuration in plant, q_1	$e/B > 20\%$ $DA > 30\%$	$10\% < e/B \le 20\%$ $10\% < DA \le 30\%$ $L/l > 3$	$10\% < e/B \le 20\%$ $10\% < DA \le 30\%$ $L/l \le 3$
II Configuration in elevation , q_2	$DA > 30\%$	$10\% < DA \le 30\%$ Weak 1st story	$DA \le 10\%$
III Foundation, q_3	$d > 2\%$ $h > 40$ $hD/l > 0.008$	$1\% < d \le 2\%$ $20\% < h \le 40$ $0.004 < hD/l \le 0.008$	$D \le 1\%$ $H \le 20$ $hD/l \le 0.004$
IV Seismic pounding with neighboring buildings	$s/H < sr$	$sr \le s/H < 2sr$	$s/H \ge 2sr$
V Building deterioration degree, q5	> 30 years Previous local repair	10 – 30 years Previous extensive repair	< 10 years No previous damage

I e/B: Ratio of eccentricity to plan length in analyzed direction
DA: Area of irregularities in plan as percentage of the area of the considered floor
L/l: In plan building ratio dimensions
II DA: Percentage change on plan area or cross area of columns and walls from lower floor
III d: Building vertical tilting slope
h: Settlement in cm
hD/l: Differential settlement for adjacent columns bases
IV s/H: Ratio of distance among neighboring buildings to lowest height of them. Sr is equal to 0.006 or 0.007 for type soil I or II, respectively.
V damage classification according to Table 4

Table 4: Damage classification

Type of damage	Description
0 Non structural	Damage only in non structural elements
1 Light	Cracks width less than 0.5mm in concrete elements Cracks width less than 3 mm in masonry walls
2 Medium	Cracks width from 0.5 mm to 1 mm in concrete elements Cracks width from 3 mm to 10 mm in masonry walls
3 Severe	Cracks width more than 1 mm in concrete elements Holes in masonry walls Crushed concrete, broken ties and buckled bars in beams, columns and shear walls Punching cracks in waffle flat slabs Tilting greater than 1%. Settlement or emersion greater than 20 cm

Table 5: Stiffness factor for different structural systems

Failure mode	α_1	α_2	α_3
Failure of brick walls and short columns	1.0	0.7	0.5
Failure of shear concrete walls	0.0	1.0	0.7
Failure of columns	0.0	0.0	1.0

Table 6: Normalized acceleration of design spectrum [4]

Structural system, Table 1	Behavior seismic factor, Q	Type of soil	Seismic coefficient, C
1,2,3,7	2	I	0.50
4,5,6	1.5	II, III	0.86

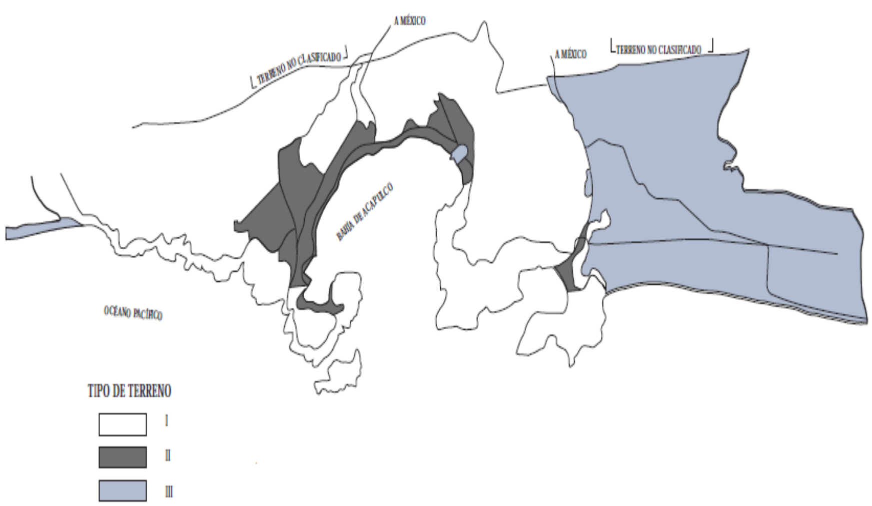

Figure 6: Seismic zonation of Acapulco [4, 9]

Resistant force of structural elements was obtained by multiplying the cross sectional area (A_e) by the average shear strength (v_e) according Table 7.

Table 7: Average shear strength (v_e) for structural elements

Element group	Characteristics	v_e (MPa)
Brick infill wall		0.2
Concrete shear wall 1	With columns at both of the ends	1.96
Concrete shear wall 2	With columns at one of the ends	1.57
Concrete shear wall 3	Without columns at ends	1.19
Short column	$H/h \leq 2$	1.47
Column 1	$2 \leq H/h \leq 6$	0.98
Column 2	$6 \leq H/h \leq 10$	0.69
Column 3	$10 \leq H/h$	0.49

RESULTS

Table 8 contains the lowest values of the seismic capacity index calculated for the 41 identified structural typologies according to Equation 1. Figure 7 summarizes the seismic capacity index (K) of the apartment building blocks in Acapulco City.

Table 8: Seismic capacity index (K)

IB	**Dir**	**T**	Shear Strength (Ai in m^2, Vi in KN)										V_A	K
			A_M	V_M	A_{SC}	V_{SC}	A_{WC}	V_{WC}	A_C	V_C	S	V_R		
GU	Y	1	3.29	647			0.82	965			0.6	609	1936	0.31
FL	X	2	3.44	676	2.72	1846					0.8	2018	1025	1.97
PG	X	3	4.85	952							0.9	761	1275	0.60
LP	X	4					3.49	4110			0.9	3699	1226	3.02
CO	Y	5	5.03	789							0.7	568	1343	0.42
LC	X	6	4.83	948					0.36	176	0.9	745	1648	0.45
	X	2	3.44	676	2.72	1846					0.8	2018	1020	1.98
SP	X	7	2.35	461	4.55	3124					0.9	2582	2021	1.28
	Y	8	1.44	2826					3.50	1717	0.7	657	1971	0.33
CU	X	9	4.64	912							0.7	525	877	0.60
	X	10	4.13	811							0.8	519	1004	0.52
CA	X	11	3.75	736							0.9	530	1699	0.31
	X	12	3.47	681							0.8	436	1815	0.24
MO	X	2	3.44	676	2.72	1846					0.8	2018	1020	1.98
	X	13	6.89	1352	5.52	3738					0.8	3296	1834	1.80
	X	7	2.35	461	4.55	3124					0.9	2582	1099	2.35
VG	Y	14	7.21	1417			0.72	848			0.8	1286	1279	1.01
	X	15	0.93	182			0.57	671			0.6	1129	1708	0.66
		16												
MU		17												
	X	18	17.67	3463							0.6	1589	3904	0.41
	X	19	10.62	2080							0.6	862	3618	0.24

Table 8 (Cont): Seismic capacity index (K)

IB	Dir	T	Shear Strength (Ai in m^2, Vi in KN)										V_A	K
			A_M	V_M	A_{SC}	V_{SC}	A_{WC}	V_{WC}	A_C	V_C	S	V_R		
AM	X	20	6.43	1263							0.8	808	1761	0.46
		21												
	X	22	6.07	1191					0.33	165	0.7	733	2380	0.31
	X	23	3.03	595					0.17	82	0.8	407	1349	0.30
FA	X	24	5.97	1172					4.32	2119	0.8	1442	5312	0.27
	X	2	3.44	676	2.72	1846					0.8	2018	1025	1.97
	X	25	2.98	586					2.16	1059	0.9	803	2871	0.28
	X	2	3.44	676	2.72	1846					0.8	2018	1240	1.63
CE	X	26	5.96	1170							0.9	842	1042	0.81
	X	27	3.46	679							0.9	489	907	0.54
	X	28	5.21	1022							0.9	736	1042	0.71
	X	29	5.8	1139							0.9	738	1069	0.69
CL	X	30	3.85	755			1.44	1697			0.8	1262	1924	0.66
	X	31	6.11	1197							0.8	777	2817	0.28
	X	32	5.12	1005							0.8	651	2455	0.27
	X	32	5.12	1005							0.8	651	1432	0.45
	Y	33	5.93	1165			0.81	107			0.8	1187	2619	0.45
	Y	34	6.74	1324							0.8	858	2698	0.32
AP	X	22	6.07	1191					0.33	165	0.7	733	2380	0.31
	X	35	5.05	994							0.8	635	1444	0.44
	X	36					7.63	8976			0.6	5739	2899	1.98
	X	37	5.17	1010					0.31	214	0.9	808	2217	0.36
	X	38	7.88	1547							0.8	990	1678	0.59
	X	39					2.84	3345			0.6	1927	1637	1.18
	X	32	5.12	1005							0.8	651	1507	0.43
	Y	34	6.74	1324							0.8	858	1571	0.55
	X	40	5.51	1081							0.8	700	1424	0.49
	X	41	4.19	822							0.8	533	1638	0.33

CONCLUSIONS

Current physical conditions as well as the building blocks stock in Acapulco (Mexico) were evaluated in this study. Therein, 1,387 buildings were divided into 17 blocks and 41 different typologies were identified. Even if the methodology used to evaluate the seismic capacity of the buildings is simplified, it has allowed the identifying the seismic vulnerability of a huge stocks buildings. According to Figure 7, the seismic capacity index of 1,228 buildings (89%) is lower than one, which implies high vulnerability of these buildings by considering the current physical condition and the earthquake design spectra. It can be stated that only 127 buildings (9 %) comply the standardized specifications.

This situation could be justified because most of these buildings were constructed before the local code which was updated in 1994, when the values of seismic coefficients were raised in order to improve the seismic capacity of buildings. However, it is compulsory to establish an extensive structural retrofitting program in order to reduce the high seismic vulnerability of these buildings.

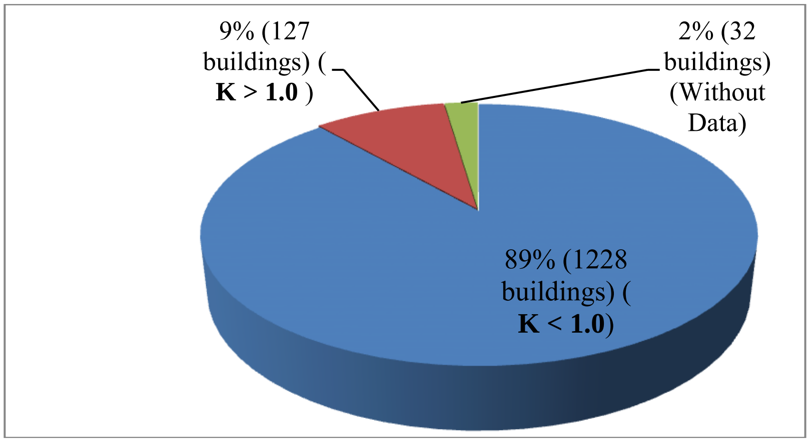

Figure 7: Seismic capacity index of buildings blocks

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