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PRACTICAL EVALUATION OF THE VULNERABILITY OF ONE FAMILY HOUSES AGAINST SEISMIC EFFECTS

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SUMMARY

A rapid methodology for evaluation of the Damage Index in dwellings due to the effect of earthquakes, is presented in this paper. Twelve different dwellings were evaluated, and the results obtained were compared with those obtained by using a table based on Modified Mercalli Intensity Scale (MSK). The evaluation was complemented by calculating the ultimate shear capacity and the shear earthquake demand ratio (C/D).

THE METHODOLOGY OF THE EVALUATION

Due to the destructive effect of earthquakes on buildings, there is an overbearing need to evaluate existing buildings with the aim of determining their security and/or vulnerability.

During last years, a great number of research studies had been conducted in the area of seismic evaluation of high-rise or essential buildings (Refs. 1,2), specially hospitals and school buildings. In spite of the important number of housing programs developed by governmental institutions and private companies, as well as houses constructed by owners, little research had been done in the area of seismic perfomance of low-rise residential buildings.

A practical process for evaluation is proposed in this paper. This evaluation method will allow the practicing structural engineer to determine, in a rapid and approximate way, the vulnerability of local residential buildings, in particular those of reinforced concrete, to the effect of earthquake forces. The procedure include a comparison of the calculated Damage Index (I_d) of the structure with that obtained from the Modified Mercalli Intensity Scale (MSK-1964). In this methodology, dwellings with low Damage Index are rejected and with high Seismic Index, a further quantitative evaluation is demanded.

Defining the Problem The Building perfomance, and obviously, its Damage Index, depends on the properties of the earthquake motion, the soil thickness and the profile type, at the building site, and on the characteristics of the structural building system, such as indicated in equation 1:

$$I_d = f(\text{ earthquake, soil, building}) \tag{1}$$

Seismic Influence The clasification of damage are shown in Table 1. This table was constructed taking into account the expected buiding damage as suggested by MSK-64 (Ref. 3) and the magnitude is related by the equation from Gutenberg and

Richter $M = 2I_o/3 + 1$, in which M is the magnitud and I_o is the intensity of the earthquake.

Soil Influence There is a close relationship between building performance and properties of the soil in which the building is founded. Thus, in liquefiable soils the building is highly vulnerable $I_d = 1$. This value will be also adopted in buildings located in potential landslide sites. For any of this two cases the damage index should not be evaluated.

Damage Index in dwellings On looking back at damage in low-rise residential buildings caused by major earthquakes in Latin-American countries, the main damages have been due to different factors, among them deficient building construction type, poor structural configuration, biggest excentricities of the floors, low density (length of the walls/area of the floor) or unsatisfactory distribution of infilled walls and inadequate connections between elements.

Table 2, was constructed, taking into account all factors stated above. In this table, vulnerability varies from 0 to 1, depending upon different characteristics of the dwellings being evaluated. Moreover, a weight is assigned vulnerability according to his experience and taking into account the existing condition of the structure. Partial vulnerabilities are obtained by multiplying the assigned vulnerability by its assigned weight. The damage index (I_d) of a dwelling is obtained adding all the partial vulnerabilities and dividing this value by an average factor which is taken as 10.

Comparing Table 1 and 2, it may be observed that for earthquakes of intensity higher than VII, reinforced concrete buildings could suffer damage. Thus, for a damage index (I_d) higher than or equal to 0.4, the dwelling could experience damage and consequently a quantitative evaluation (a more complete evaluation) is required. Fig. 1 is a flow chart depicting the steps to be followed in using this methodology.

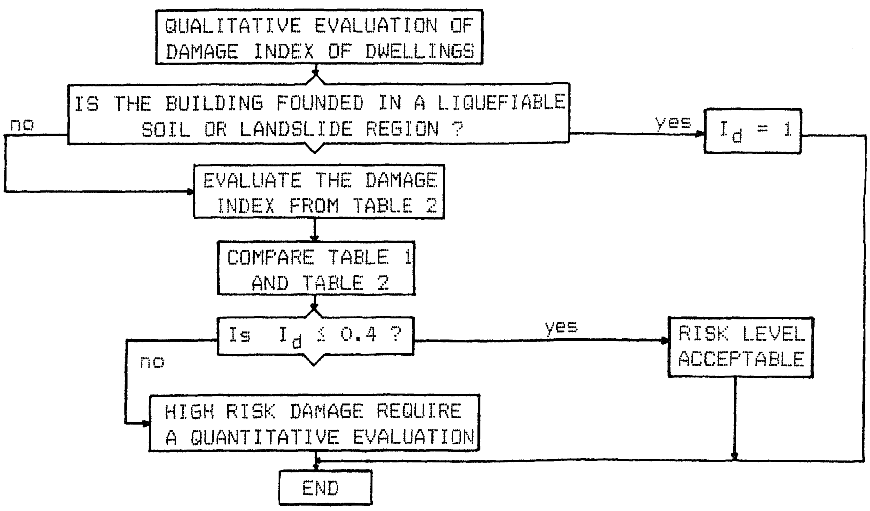

Fig. 1 Steps in the Methodology

Complementary Evaluation The seismic resistant coefficient of columns in a specific building is obtained in this section. This step is presented as a complementary evaluation of that obtained using Table 2. With the purpose of simplifying calculations in this first evaluation, direct shear seismic forces are determined in each direction, assuming that torsional effect is approximately absorbed by infilled walls which are not taken as structural elements. The translational effects are considered taken into account the Venezuelan Code for Earthquake-Resistant Structures (Ref. 4).

Table 1 Ranges of the Damage Index

MSK-64	MAGNITUD	EXPECTED DAMAGE	DAMAGE INDEX
VI	5.00	Damage of grade 1 is sustained in single buildings of type B and in many of type A. Damage in few buidings of type A is of grade 2.	0.0 - 0.2
VII	5.67	In many buildings of type C damage of grade 1 is caused; in many buildings of type B damage is of grade 2. Many buildings of type A suffer damage of grade 3, few of grade 4.	0.2 - 0.4
VIII	6.33	Many buildings of type C suffer damage of grade 2, few of grade 3. Many buildings of type B suffer damage of grade 3 and few of grade 4, and many buildings of type A suffer damage of grade 4 and few of grade 5.	0.4 - 0.6
IX	7.00	Many buildings of type C suffer damage of grade 3, a few of grade 4. Many buildings of type B show damage of grade 4; a few of grade 5. Many buildings of type A suffer damage of grade 5.	0.6 - 0.8
X	7.67	Many buildings of type C suffer damage of grade 4, a few of grade 5. Many buildings of type B show damage of grade 5; most of type A have destruction of grade 5.	0.8 - 1.0

For residential- buildings with high density of infilled walls, the actual period is low and therefore the design aceleration A_d it can be considered constant. For dwellings located in Mérida City (Zone 4, Horizontal Peak Acceleration $A_o = 0.3$) on soil type S1, A_d is simplified to $A_d = 0.66/D$. Where the Ductility Factor D varies from 2.5 to 1, due to the deficient joint confinement, the low transverse sectional area of the columns, the poor anchorage and details no considered by Codes up to 1982.

The ultimate shear strength of columns of a specific level (V_{ur}), is provided by concrete V_c plus the strength provided by shear reinforcement V_s, that is $V_{ur} = V_c + V_s$. When allowable shear capacity and earthquake shear demand ratio in columns is greater than 1, then the lateral force resisting system can perform efficiently.

<u>Aplication of the evaluation methodology and discussion of results</u> Twelve different dwellings were evaluated applying this methodology and the results are presented on Table 3. The first nine dwellings where constructed by private companies and the remaining by Venezuelan National Housing Institute. Ten of the buildings had a reinforced-concrete moment resisting frame system, one had a shear wall resisting system and one had steel structure. As shown on Tables 3 and 4, dwelling N° 6 has a damage Index I_d higher than 0.4 and C/D ratio lower than 1; therefore, it requires a quantitative evaluation to complement the one proposed in this methodology. The evaluation of dwelling N° 8 yields almost an acceptable damage index, nevertheless a more complete evaluation is recommended.

Although results of evaluation of the remaining buildings are within safety range of this proposal, when the building presents particular features that could increase its vulnerability, some repairing recommendations are given to the owner.

Table 2 Part 1 General Factors

ASPECT	CHARACT.	VULN. RANGE	VULN. ASSIG.	WEIGTH	PARTIAL VULN.
AGE	BEFORE 1967 1967-1982 AFTER 1982	0.7 - 1.0 0.4 - 0.7 0.0 - 0.4		0.35	
STORIES	ONE TWO MORE	0.0 - 0.3 0.3 - 0.5 0.5 - 1.0		0.25	
NEAR BUILDINGS	DANGER NO DANGER	0.0 - 0.5 0.5 - 1.0		1.00	
MAINTENANCE	ACCEPTABLE REGULAR DETERIORATED	0.0 - 0.3 0.3 - 0.6 0.6 - 1.0		0.50	
FOOTINGS	WITH BEAMS NO BEAMS	0.0 - 0.3 0.3 - 1.0		0.50	

PARTIAL SUM 1 :

Table 2 Part 2 Infill Walls and Details

ASPECT	CHARACT.	VULN. RANGE	VULN. ASSIG.	WEIGTH	PARTIAL VULN.
WALL DENSITY	NORMAL MEDIUM LOW	0.0 - 0.3 0.3 - 0.6 0.6 - 1.0		0.50	
LOCATION OF WALLS	SYMETRIC INTERM. ASYMETRIC	0.0 - 0.1 0.1 - 0.6 0.6 - 1.0		1.00	
CONSTRUCTI-VE DETAILS	DEVIAT. AXIS INAD.SUPPORT DEFIC.CONEC.	0.0 - 1.0 0.0 - 1.0 0.0 - 1.0		1.00	
NON-ESTRUC. ELEMENTS	LIGHT WALLS BALCONY,GARD GLASS ELEM.	0.0 - 1.0 0.0 - 1.0 0.0 - 1.0		0.25 0.25 0.25	
DIAPHRAGM	RIGID INTERM. FLEXIBLE	0.0 - 1.0 0.1 - 0.5 0.5 - 1.0		0.50	

PARTIAL SUM 2 :

Table 2 Part 3 Structural Characteristics

ASPECT	CHARACT.	VULN. RANGE	VULN. ASSIG.	WEIGTH	PARTIAL VULN.
STRUCTURAL SYSTEM	WELL STRUCT. MED. STRUCT. BAD STRUCT.	0.0 - 0.2 0.2 - 0.4 0.4 - 1.0		1.00	
MASS AND RIGIDITY	BALANCE INTERM. UNBALANCE	0.0 - 0.2 0.2 - 0.5 0.5 - 1.0		1.00	
IRREGULARI-TIES	SOFT STORY SHORT COLUMN DISC. DIAPH. ASYM. STAIR	0.0 - 1.0 0.0 - 1.0 0.0 - 1.0 0.0 - 1.0		1.00 1.00 1.00 1.00	
PREVIOUS DAMAGES	BEAMS, COLUMN SHEAR WALL SLABS INFILL WALLS	0.0 - 1.0 0.0 - 1.0 0.0 - 1.0 0.0 - 1.0		1.00 1.00 1.00 1.00	

PARTIAL SUM 3 :

DAMAGE INDEX I_d=(SUM1 + SUM2 + SUM3)/10

Table 3 Summary of the Evaluation results

DWELLING No.(year)	STORIES	STRUCTURAL SYSTEM	WALL DEN. 1st./2nd.	DAMAGE INDEX	Vur/Vu 1st.Flr.	2nd.Flr.
1 (1966)	2	Beam/Col./Rib.Slab	.33/.52	0.26	1.86	3.50 (*)
2 (1966)	4 Niv.	Beam/Col./Rib.Slab	.40/.44	0.25	1.02	1.62 (*)
3 (1975)	2	Beam/Col./Rib.Slab	.39/.39	0.30	1.14	2.04 (*)
4 (1964)	2	Beam/Col./Rib.Slab	.43/.48	0.30		(*)
5 (1973)	2	Beam/Col./Rib.Slab	.41/.54	0.25	1.60	2.54 (*)
6 (1963)	2	Beam/Col./Rib.Slab	.38/.47	0.49	0.71	1.17 (▪)
7 (1982)	2	Beam/Col./Rib.Slab	.45/.64	0.23	2.49	3.60 (*)
8 (1981)	3 Niv.	Beam/Col./Conc.St.	.42/.44	0.40		(▪)
9 (1982)	1	Beam/Col./Wood S.		0.31		( )
10 (1986)	1	Shear W. /Ligh Rf.	0.60	0.11	24.0	(*)
11 (?)	2	Beam/Col./Rib.Slab	.61/.69	0.36	1.13	1.88 (*)
12 (?)	1	Beam/Col./Mac.Slab	0.78	0.33	1.68	(*)

(*) --> Acceptable ; (▪) --> Need Quantitative Evaluation

Table 4 Dwelling Nº 6. Example of Evaluation

ASPECT	CHARACT.	VULN. RANGE	VULN. ASSIG.	WEIGTH	PARTIAL VULN.
AGE	BEFORE 1967	0.7 - 1.0	0.90		0.32
	1967-1982	0.4 - 0.7		0.35	
	AFTER 1982	0.0 - 0.4			
STORIES	ONE	0.0 - 0.3			
	TWO	0.3 - 0.5	0.40	0.25	0.10
	MORE	0.5 - 1.0			
NEAR BUILDINGS	DANGER	0.0 - 0.5		1.00	
	NO DANGER	0.5 - 1.0			
MAINTENANCE	ACCEPTABLE	0.0 - 0.3			
	REGULAR	0.3 - 0.6	0.40	0.50	0.20
	DETERIORATED	0.6 - 1.0			
FOOTINGS	WITH BEAMS	0.0 - 0.3		0.50	
	NO BEAMS	0.3 - 1.0			
WALL DENSITY	NORMAL	0.0 - 0.3			
	MEDIUM	0.3 - 0.6	0.30	0.50	0.15
	LOW	0.6 - 1.0			
LOCATION OF WALLS	SYMETRIC	0.0 - 0.1			
	INTERM.	0.1 - 0.6		1.00	
	ASYMETRIC	0.6 - 1.0	0.70		0.70
CONSTRUCTIVE DETAILS	DEVIAT. AXIS	0.0 - 1.0			
	INAD.SUPPORT	0.0 - 1.0		1.00	
	DEFIC.CONEC.	0.0 - 1.0	0.40		0.40
NON-ESTRUC. ELEMENTS	LIGHT WALLS	0.0 - 1.0		0.25	
	BALCONY,GARD	0.0 - 1.0		0.25	
	GLASS ELEM.	0.0 - 1.0		0.25	
DIAPHRAGM IN ROOF	RIGID	0.0 - 1.0			
	INTERM.	0.1 - 0.5		0.50	
	FLEXIBLE	0.5 - 1.0			
STRUCTURAL SYSTEM	WELL STRUCT.	0.0 - 0.2			
	MED. STRUCT.	0.2 - 0.4		1.00	
	BAD STRUCT.	0.4 - 1.0	0.60		0.60
MASS AND RIGIDITY	BALANCE	0.0 - 0.2			
	INTERM.	0.2 - 0.5	0.30	1.00	0.30
	UNBALANCE	0.5 - 1.0			
IRREGULARITIES	SOFT STORY	0.0 - 1.0	0.40	1.00	0.40
	SHORT COLUMN	0.0 - 1.0		1.00	
	DISC. DIAPH.	0.0 - 1.0		1.00	
	ASYM. STAIR	0.0 - 1.0	0.60	1.00	0.60
PREVIOUS DAMAGES	BEAMS,COLUMN	0.0 - 1.0		1.00	
	SHEAR WALL	0.0 - 1.0		1.00	
	SLABS	0.0 - 1.0	0.70	1.00	0.70
	INFILL WALLS	0.0 - 1.0	0.40	1.00	0.40

DAMAGE INDEX I_d= 4.87/10 = 0.49

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