Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VII)

13-1-5

SEISMIC IMPACT OF FUTURE EARTHQUAKES IN THE TOWN OF LISBON: AN EXAMPLE OF APPLICATION

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SUMMARY

In a previous paper (Ref.1) we developed the basic methodology for the evaluation of the metropolitan areas of higher seismic risks and for the quantification of losses in terms of victims, injuries and damaged buildings. Herein we discuss its application to a group of 5000 buildings, approximately 10% of the entire Lisbon stock.

These buildings are classified into 5 different categories based on their main structural properties (no. of stories, type of construction, configuration in plan and height and conservation). Vulnerability functions for buildings and population were obtained from data gathered during recent earthquakes and the basic building cost value is attributed according to location, business and utility.

Expected seismic risk is obtained for those buildings and their population as the convolution of the variables representing the seismic action with the variables representing building and population vulnerability.

INTRODUCTION

Mitigation of seismic risks in a metropolitan area in case of future earthquakes requires the evaluation of higher risks and estimation of global human and material losses.

Several very simple methodologies have been proposed to deal with this subject. In 1984 we developed a multi-step comprehensive analysis of the entire problem. It incorporates all features of source, wave propagation, site effects and building performance. In that paper(Ref.1) we developed studies that led to the definition of several earthquake scenarios for the metropolitan area of Lisbon. Each one represents upper and lower bounds in Mercalli Modified intensities corresponding to a given source. Soil influence was incorporated through a microzonation study. However, at the time we did not had any comprehensive study either on building stock or building vulnerability. Nevertheless seismic risk was computed three different zones of the town in order to test the methodology. The parameter values for building stock and vulnerability were based exclusively "expert opinion" estimates. In this work we improved the model, by considering more adequate variables, and apply it to two zones of the town covered with a detailed inquire for building survey. As it will be seen in a latter section, we selected for this pilot study a small portion of the Lisbon area which correspond to about 1/10 of the total stock of buildings in the town, and exhibits a wide variety of building types.

METHODS

Man-made structures in Lisbon consists primarily of modern buildings of middle size for housing and more large office buildings, and old buildings. Buildings of different types, ages, number of stories and material properties have to be classified, or grouped, by categories in order to allow a more correct understanding of their behaviour under the scenario of simulation. In Lisbon, buildings have been classified according to their age and structural type, as follows:

A - Masonry stone buildings prior to 1755, low rise, most in bad shape. (Freq. > 3Hz)

B - Masonry stone buildings constructed during the period 1755-1880 with horizontal ties and good shape (Freq. > 2.5Hz)

C - Brick masonry tall buildings constructed during the period 1880-1940. Floors are in wood. (Freq. > 2Hz)

D - Dual structures with masonry resistant walls + RC slabs or RC moment resistant frames heavily infilled with non-resistant brick walls constructed in the period 1940-1960. (Freq. > 2.5Hz)

E - Modern RC buildings constructed after 1960, designed for lateral load. (Freq.> 2Hz)

The structural characterization of building stock is defined using most of the 29 parameters of a general inquire specially designed for this study. To fill the inquire sheets (Table I) teams have been formed by geographers, architects and engineers directly trained to carry out this task. Homogeneity of the data collection(Ref 2) is thus partially granted.

An example of the output results of the inquire is given in Table II. The results of the inquire were not significantly different from "expert opinion" about the stock building types in three smaller test areas as it is shown in Table III.

The inquire revealed also the occupancy of dwellings around the clock, the composition of the social equipment, firms, manufacturing plants and eventually the location of important and special buildings, such as hospitals, government centres, schools, and monuments. Building vulnerability (Table IV) can be obtained either from theoretical studies on dynamic response and on damage surveys conducted in areas of past earthquakes. The dynamic behaviour of the building under seismic loads depends strongly on the internal parameters such as regularity, symmetry and strength, and on the external parameters such as topographic location, street arrangement and sanitary composition. The internal parameters are considered in the structural analysis of modern reinforced concrete building that will take into consideration all the contributing elements. The external parameters are not usually taken into account in the structural analysis; meanwhile, they have a pronounced influence on their behaviour as it was demonstrated during the last catastrophics Mexico and Kalamata (Refs.3,4) earthquakes. In some cases additional measurements may be useful such as the frequency of vibrations.

Further studies integrating the results of deterministic evaluations of the structural damage based on the dynamic behaviour of buildings are being persued. They will allow the identification of improved functions of vulnerability. Some of the research in progress (Ref.5) is directed to the establishment of vulnerability functions of buildings exhibiting geometrical irregularities, both in plan and height, located in a block, in a steep street, etc. These findings will be incorporated in the model when sufficient confidence and good correlation with damage statistics can be obtained. Then the variables of the general inquire will be used.

It is well known that the percentage of victims and injuries varies tremendously, unabling the correlation with building damage and earthquake intensity. The number of casualities will depend in part on the occupancy conditions prevailling at the time of the event. It is sometimes considered that the San Fernando data can give a reference estimation (Table V). These estimates are meant to be median. Actual casualities can be less than or greater than the estimates. It also appears reasonable to estimate that there is probability of two-thirds that actual casualities will occur in the region of

0.5 to 1.5 times these figures. This means for instance, that with a MMI VII, the probability of from 5 to 15 casualities per 10^6 population is approximately 0.67.

MODEL OF IMPACT AND EVALUATION

1. Parameters
    (a) The metropolitan area of Lisbon was divided into 23 unit areas, $j(j = 1, u)$;
    (b) The existing buildings were grouped into classes $i(i = 1, c)$, in each the mean number of stories $n_{i,j}$ and area $aI_{i,j}$ are integrated;
    (c) The seismic scenarios of disaster (source), $k(k = 1, cs)$, with associate probability of occurrence $F_k(.)$
    (d) The local topography and ground behaviour are include into classes of intensity, $(l = 1, int)$ corresponding to the MMI, VI to XI;
    (e) The time occurrence of the earthquake is considered, $m(m = 1, P)$: in Lisbon 5 periods have been studied: 0-7:30; 7:30-9:30; 9:30-18:30; 18:30-20; 20-24 hours.

2. Variables

    $V_{i,j,k,l}$ - mean vulnerability, for spectrum $S_{i,k,l}(w)$ (in the unit j, source k, and intensity l), in building of class i, with area $a_{i,j}$, and $n_{i,j}$ stories

    $V^P_{i,j,k,l}$ - mean value (percentage) of population affected by the building vulnerability $V_{i,j,k,l}$

    A_j - area of the unit j

    $N_{i,j}$ - total amount of the buildings of class i in the unit j

    $al_{l,j}$ - area of intensity l in the total area of unit j

    $P_{j,m}$ - total amount of population in unit j during the period m

    $C_{i,j}$ - mean household value per square meter of building of class i, in unit j

3. Functions

    Individual Loss Function: $ILF_{i,j,k} = C_{i,j} a_{i,j} n_{i,j} \sum_l V_{i,j,k,l} \frac{aI_{l,j}}{A_j} N_{i,j}$

    Global Loss Function: $GLF_{j,k} = \sum_i ILF_{i,j,k}$

    Affected Population: $AP_{j,k,m} = \sum_i \sum_l V^P_{i,j,k,l} \frac{aI_{l,j}}{A_j} N_{i,j} P_{j,m}$

    Density of Losses Index: $DL_{j,k} = GLF_{j,k} / \sum_i C_{i,j} a_{i,j} N_{i,j} n_{i,j}$

    Density of Population Affected Index: $DPA_{j,k} = 1/P \sum_m AP_{j,k,m} / P_{j,m}$

    The influence of all seismic sources is obtained by the convolution:

$$RGLF_j = \int GLF_{j,k} dF_k$$

PARAMETER ASSESSMENT AND RESULTS OF SIMULATION

To carry out the evaluation of seismic impact of future earthquakes in the town of Lisbon, two zones, Alameda and Anjos, were selected for analysis (see Table for general characteristics of these zones). From previous studies we used two seismic scenarios, the Gorringe scenario (s1) and the Lower Tagus Valley scenario (s2), which caused the distribution of MM intensities presented in Table VI. The Gorringe scenario corresponds to earthquakes with large epicentral distances and high magnitude range. The annual probability of its occurrence, from hazard studies, is 1/3000 for MMI=10. The lower Tagus Valley scenario corresponds to short epicentral distance and moderate magnitude values with a probability of 1/10000.

Building vulnerability was essentialy based on world statistics of damage patterns (Ref.1), but to take into account the differences of ground motion caused by (s1) and (s2), we used the statistics of the Mexico City (Ref.3) earthquake of 1985 and of the Kalamata earthquake of 1986 (Ref.4), respectively. This selection was made on the basis of great similarities with the portuguese situation.

Building costs were based on property values in the two different zones, on the use-type (parameter no.18-Table I) and on the building category: $A = 25\%$; $B = 35\%$; $C = 40\%$; $D = 60\%$; $E = 100\%$. The values in Table VII are given in relative terms.

The Table VII summarizes the results obtained. From all results presented, DL, DPA and AP are the more relevant ones. The following main comments can be made:

- Seismic scenarios s1 and s2 can give quite different estimates, specially for the affected population.
- The differences observed in the two zones reflect the composition of the building stock, emphasizing the vulnerability of older buildings which are more dominant in Anjos.
- The influence of the period of the day is not very significant as the two areas do not have great population variations along the day (the numbers presented are death toll in each zone.
- Convolution of all variables shows that Alameda zone exhibits much higher global losses due to greater number of buildings, populations and area. However, loss indexes (DL, DPA) have opposite variations because of the normalizing criteria used.

CONCLUSIONS

The presented studies show that it is possible to estimate the upper and lower bounds on human and material losses due to earthquake motion. These bounds are still quite large but its decrease will be possible when vulnerability is better characterized. In spite of this, the method is quite powerful to distinguish among zones of different risks. The inquire set up was also quite balanced, and the survey proved to be effective and adequate for these pilote zones. It should be referred that the results of the inquire match to a great extent "expert opinions" obtained prior to the inquire. Now that the main properties of these buildings are known, we recommend that this procedure may be used together with sampling techniques and extended to other areas of the town.

We do not minimize the importance of the vulnerability functions involved in all stages of the model and also of the mean household value; nevertheless, based on the effects of recent earthquakes we reconsider that the model is well behaved. The assessment of more realistic vulnerability behaviour may be obtained by the implementation of studies based on the referred inquire and the consideration of non-linear response of some structures. Further work includes also the sensitivity study of other relevant parameters such as the ones referring intensities, and hazard analysis.

The model developed constitutes a very useful tool for disaster planning and is a basis to direct retrofiting policies of old towns.

ACKNOWLEDGEMENTS

We thank the members of the teams involved in the survey, and Mr. Victor Duarte from LNEC for their valuable contributions. Ms. Anabela Martins prepared this manuscript.

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1. County
2. Street
3. Police number
4. County number
5. Process number
6. Block number
7. Building number inside the block
8. Construction
9. Number of stories above ground
10. Number of stories below ground
11. Structural alterations
12. Elevator
13. Plan width
14. Plan depth
15. Plant configuration
16. Plant openings
17. Elevation configuration
18. Use
19. Number of dwellings
20. Structural type
21. Structural type of back façade
22. Implantation
23. Appendages
24. Inclination of ground in the longitudinal direction
25. Inclination of ground in the transverse direction
26. System for fire detection
27. State of conservation of front
28. State of conservation of back façade
29. Structural design

Construction period (8)

1. Exact date of construction
2. Before 1755
3. 1755-1850
4. 1850-1890
5. 1890-1920
6. 1920-1940
7. 1940-1958
8. After 1958

Use (18)

1. Housing
2. Industry
3. Business
4. Offices
5. Warehouse
6. Hybrid: Housing + offices
7. Hybrid: Industry or business + Housing
8. For demolition

Structural type (20)

1. Wood
2. Masonry walls + wooden slabs
3. Masonry walls + metalic supports.
4. Masonry walls + concrete slabs
5. Masonry walls + concrete slabs + first floor with mom frame
6. R.C. mom resisting frame + infilled brick walls
7. R.C. mom resisting frame
8. Other

TABLE I - Enquire for evaluation of building stock in the town of Lisbon. Typical options.

	Alameda	Anjos
Geographic area	286 ha	105 ha
No of blocks	185	46
No of buildings	3273	1877
Total no of stories	15692	4710
Total no of dwellings	22264	6411
Average no of stories	4.32	3.52
Predominant epochs	1870-1940 55%	Pomb. epoch 41.6% 1870-1940 37.9%
Average area per buildings	$280m^2$	$202m^2$
Average area per dweling	$112m^2$	$99m^2$
Predominant uses: housing	42.0%	47.2%
mixed	46.0%	35.2%
Aver. state conservation: aver	55.0%	54.5%
bad	20%	28.0%
Population	64520	30243
Employees in the area	47912	18636
Occupation: $\frac{Land\ covered}{geographic\ area}$	0.32	0.36
Use: $\frac{construction\ area}{geographic\ area}$	1.56	1.26

Table II

CATEGORIES			A	B	C	D	E
	S. JORGE DE ARROIOS		1.0%	6.5%	59.5%	13.8%	19.2%
	S. JOÃO DE DEUS		-	0.7%	46.0%	40.2%	13.1%
	ALTO DO PINA		-	0.3%	54.0%	35.5%	10.2%
	TOTAL	%	0.6%	4.2%	55.2%	23.5%	16.5%
		No. STORIES	(1-4)	(2-6)	(2-7)	(2-7)	(2-11)
"EXPERT OPINION"		%	5%	-	47.0%	28.0%	20.0%
		No. STORIES	(2-5)	-	(3-6)	(4-7)	(5-12)

Table III

Table IV Vulnerability variables

	BUILDING TYPES									
M.M. Intensity	A		B		C		D		E	
VII	0.2	1.0	0.05	0.15	0.5	1.0	0.05	0.08	0.1	0.1
VIII	1.0	5.0	0.1	0.3	1.0	2.0	0.1	0.15	0.5	0.5
IX	2.0	10.0	1.0	3.0	5.0	10.0	1.0	1.5	0.8	0.8
X	10.0	50.0	10.0	30.0	10.0	20.0	2.0	3.0	1.0	1.0
	s1	s2	s1	s2	s1	s2	s1	s2	s1	s2

Source: 1 - Gorringe; 2 - Lower Tagus Vally

Table V - Population Vulnerability

Intensity (MMI)	Estimated Human Casualities per 10^6 inhabitants
VI	..............None
VII	10
VIII	150
IX	500

Table VI Values of $aI_{l,j}$ (ha)

MMI	Alameda	Anjos	Alameda	Anjos
VII	86	25	-	-
VIII	180	65	36.6	19.1
IX	-	-	54.9	66.2
X	20	15	8.5	14.7
-	Scenario s2		Scenario s1	

Table VII - Seismic impact for the selected area (Alameda, Anjos)

	Buil. cat.	$N_{i,j}$	$n_{i,j}$	$a_{i,j}$	$C_{i,j}$	ILF x 10^3		GLF x 10^3	
						s_1	s_2	s_1	s_2
Alameda	A	21	2.3	193.4	2.06	0.5	1.3	312.2	211.7
Pop. 64520	B	137	3.6	220.1	2.89	4.5	7.3		
Buil. 3273	C	1806	3.6	229.4	3.30	195.0	145.6		
Tot.	D	768	5.2	362.9	4.95	54.2	23.4		
Area 268ha	E	541	5.8	317.2	8.25	58.1	34.1		
Anjos	A	78	2.5	168.0	0.97	1.0	3.3	60.6	67.1
Pop. 30243	B	782	3.5	149.5	1.36	11.9	25.1		
Buil. 1877	C	712	3.5	198.7	1.56	37.4	32.6		
Tot.	D	147	4.3	240.5	2.33	3.5	1.9		
Area 105ha	E	158	4.6	312.9	3.89	6.8	4.2		

DL (%)		DPA/10^6		Periods	AP	
s_1	s_2	s_1	s_2		s_1	s_2
1.5	1.0	88.2		0:00 - 7:30	5.8	18.3
				7:30 - 9:30	6.6	20.7
			276.0	9:30 - 18:30	9.1	28.6
				18:30 - 20:00	7.5	23.4
				20:00 - 24:00	6.3	19.6
2.3	2.6	111.0		0:00 - 7:30	3.6	15.4
				7:30 - 9:30	3.5	15.1
			471.0	9:30 - 18:30	4.3	18.3
				18:30 - 20:00	3.9	16.5
				20:00 - 24:00	3.7	15.7

	Alameda	Anjos
RGLF	125.13	26.90