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NOTES FOR THE CHARACTERISATION OF THE SEISMIC VULNERABILITY OF BUILDING CONSTRUCTION IN LISBON

Introduction

The city of Lisbon has gone through the experience of several strong earthquakes during the last few centuries, separated by large periods of quiescence. These earthquakes have marked the course of construction techniques in the town. Even though the population has always been aware of the perils of the seismic activity, it seems that the wide intervals between consecutive events erases the memory and, consequently, the quality of construction has decreased with elapsed time since last occurred event. This has happened at least during the period of quiescence towards the end of last century.

The present paper presents a summary of the main ancient construction techniques practised in Lisbon, classifies the existing stock of buildings into several typologies, describes the parameters controlling their seismic behaviour, and tries to evaluate the general vulnerability of the different typologies. It concludes with recommendations for future studies which are necessary to reduce uncertainties on vulnerability assessments. A large number of references on the topic are also presented.

Building types - Building stock

The behaviour of buildings during earthquakes is very difficult to predict and depends upon a great number of parameters. In the town of Lisbon there are buildings of different types, ages, number of stories and material properties, usually supported laterally by each other and showing discontinuities in height and plan. The buildings may be located on a flat or steep area and may be in a good structural condition or in a bad one, due to lack of repairing.

The main types of ancient construction (before the onset of reinforced concrete construction) can be viewed through Figs. 1 to 7, in which a general description of construction techniques is described: Fig. 1 presents typical masonry buildings prior to 1755 and Fig. 2 the case, still present nowadays, of jetty structures. Fig. 3 gives an example of the Pombaline construction developed after the Lisbon earthquake of 1755 in the reconstruction of the destroyed downtown. It follows the already used timber skeleton inside the masonry wall as known the "gaiola" structure. Fig. 4 presents the detail in the connection between masonry walls and wooden floors, a quite old technique for tying together the different masonry elements. This technique was used in more recent building construction such as the masonry building at the end of 19th century, Figs. 5 and 6. Unfortunately, as many years have passed over the 1755 event without other important earthquakes, the construction techniques was not so effective for lateral loading as the previous ones. In many cases the interior "gaiola" almost disappeared. At this period of time concrete as well as steel elements were used as shown in Fig. 7 where concrete slabs forming small arches are supported by steel beams ("abobadilha").

An important earthquake in 1909 (Benavente), with epicenter 25 km to the north of Lisbon, gave rise to a revision of some of the construction practices requiring further attention to the treatment of masonry walls.

The period in "early 1900" to 1940 is characterised by a transition to the reinforced concrete technology, and the main evolution since then is given by the existence of regulatory code of practice, the first one in 1958 (RSCS, 1958), then in 1963 (RSEP, 1963) and, finally, in 1983 (RSA, 1983)

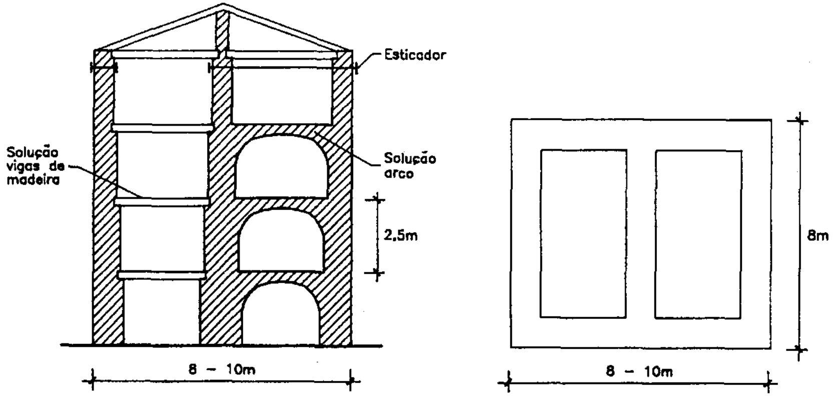
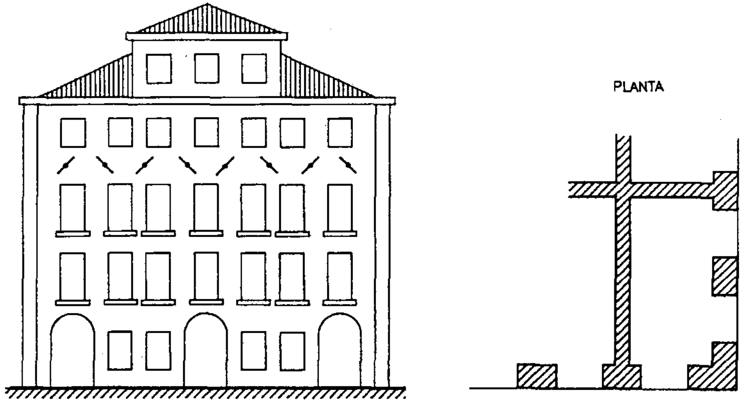


Fig. 1 - Masonry buildings prior to 1755.



a)

b)

Fig. 3 - Pombaline construction: a) façade; b) interior "gaiola".

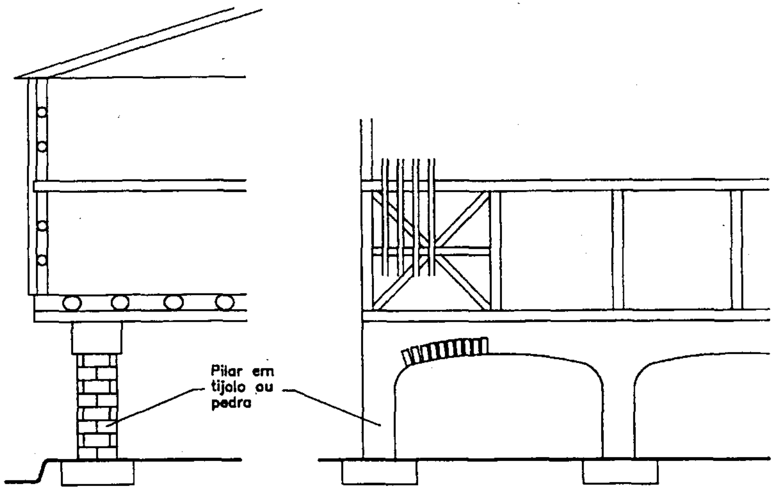


Fig. 2 - Jetty structure.

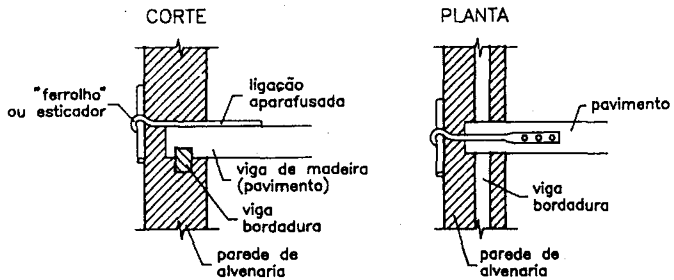


Fig. 4 - Detail in the connection between masonry walls and wooden floors.

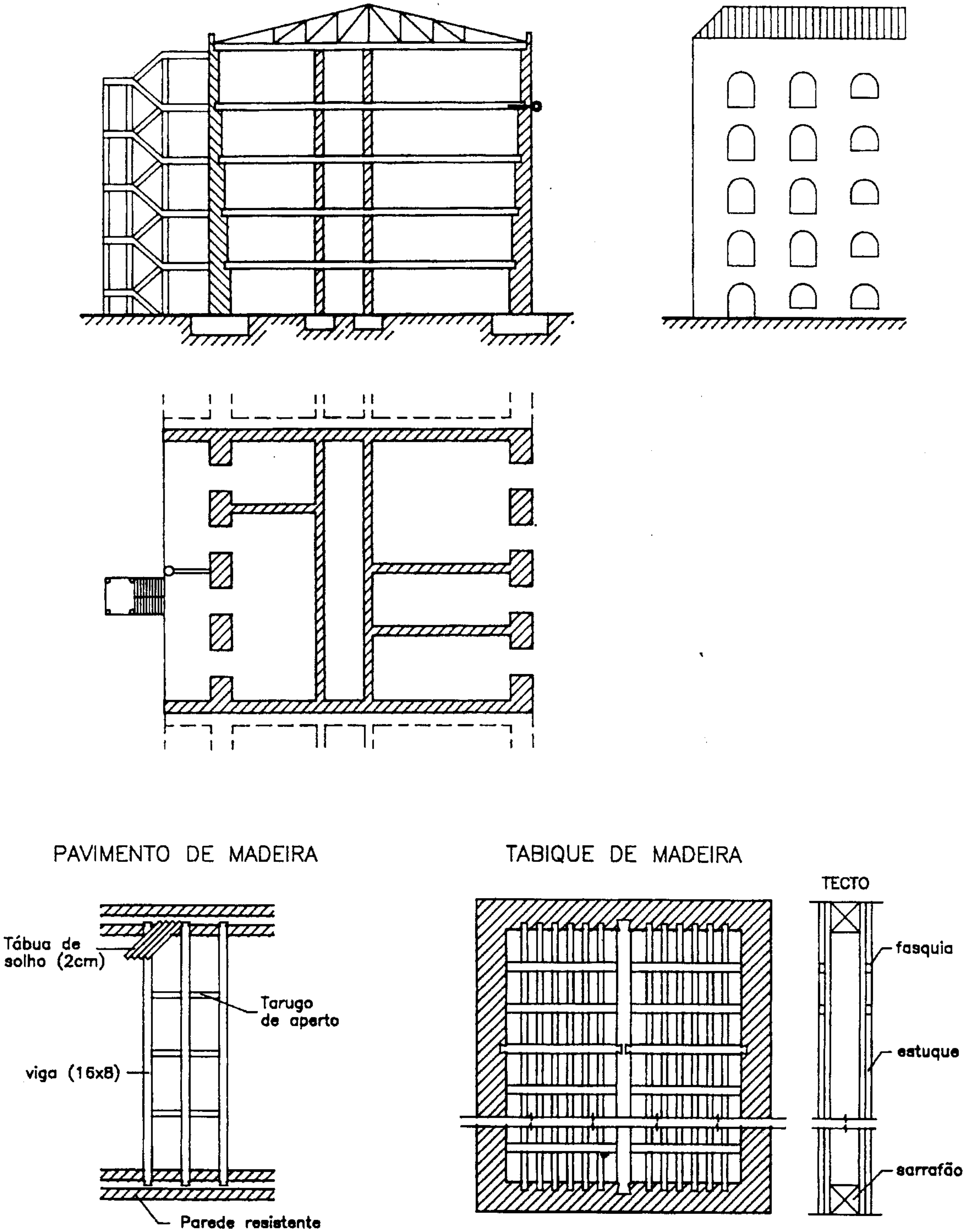


Fig. 5 - Masonry building at the end of 19th century.

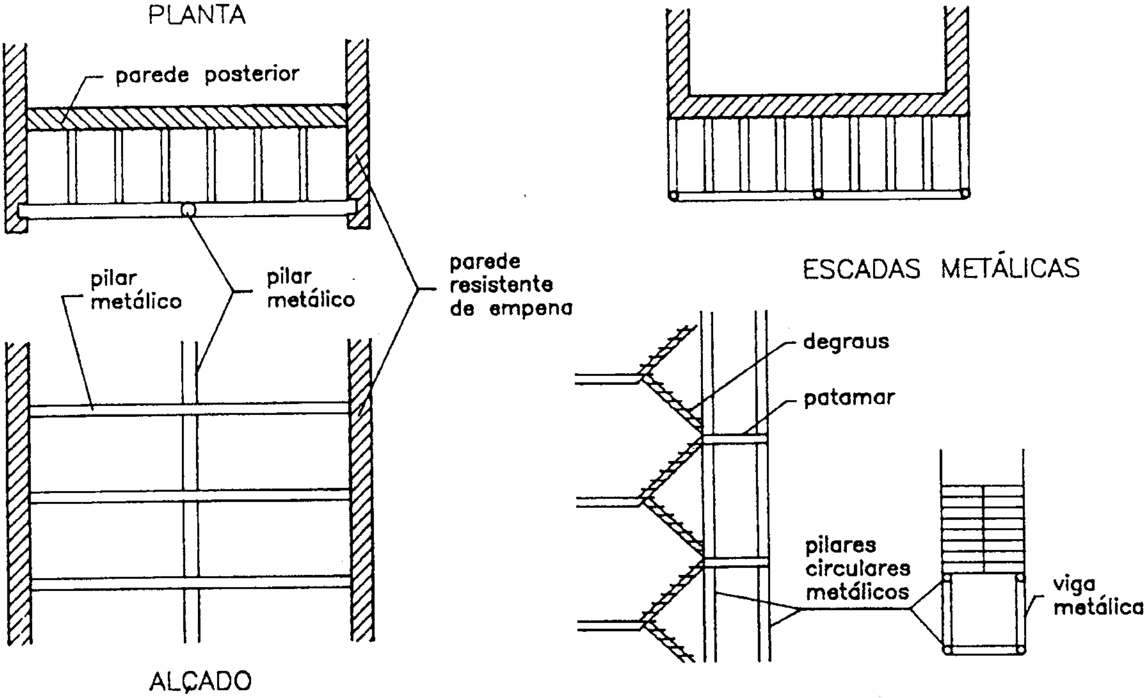


Fig. 6 - Typical back façade of 19th century building.

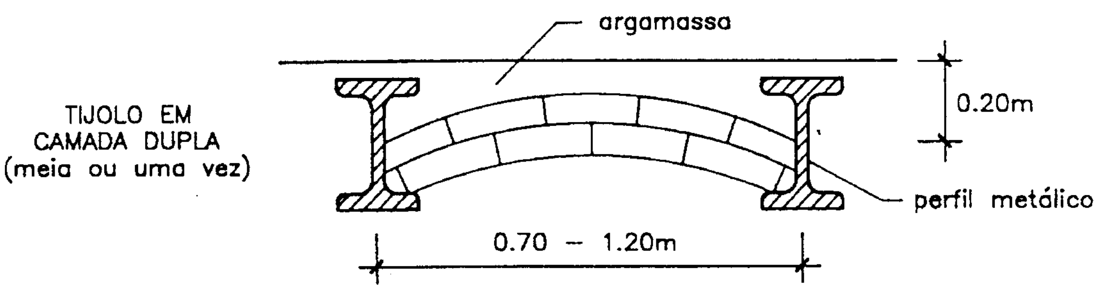


Fig. 7 - Concrete slabs with steel beams ("abobadilha").

In order to allow a more correct understanding of their seismic behaviour, and according to their main structural properties, Lisbon's buildings have been classified into six different categories, five of them already mentioned in Oliveira *et al.*, 1984:

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 in good shape (Freq. > 2.5 Hz);

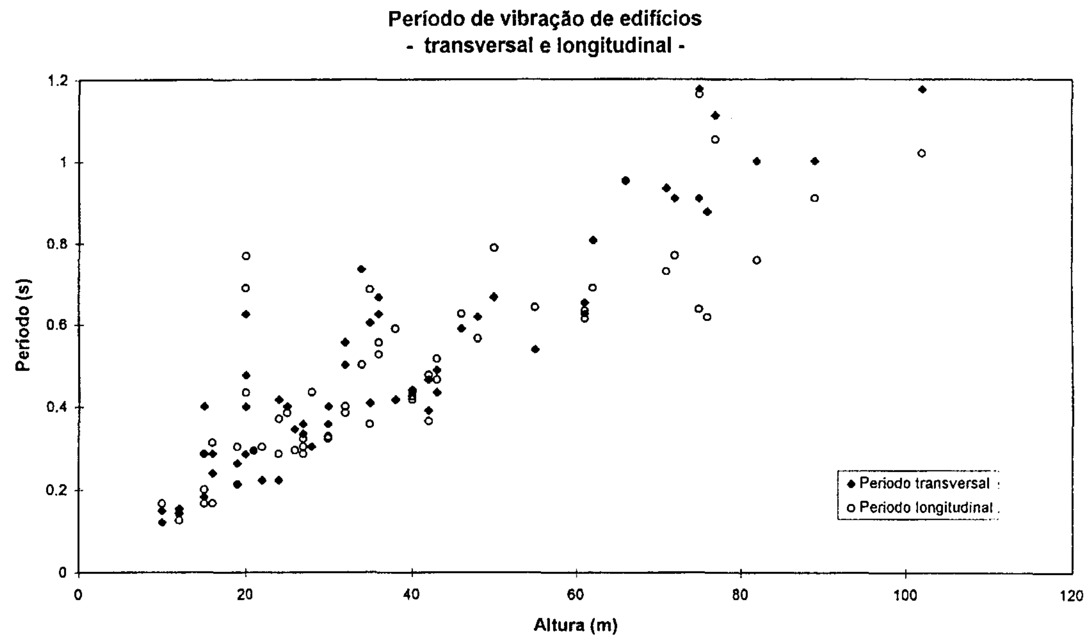
C - Brick masonry tall buildings constructed during the period 1880-1940, wooden floors (Freq. > 2 Hz);

D - Dual structures with masonry resistant walls and reinforced concrete (RC) slabs or RC moment resistant frames heavily infilled with brick walls, constructed during the period of 1940-1960 (Freq. > 2 Hz);

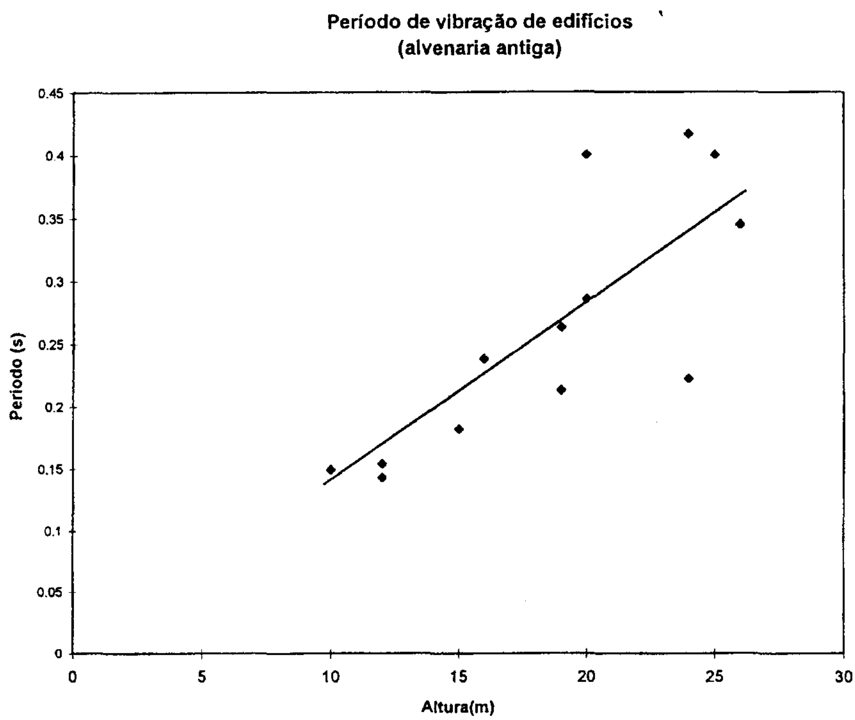
E - RC framed buildings with infills, constructed in the period 1960-1985, designed according to uniform lateral load requirements of first types of modern codes (Freq. < 2.5 Hz).

F - Modern RC buildings with shear walls, constructed after 1985, designed according to the most recent lateral load requirements (Freq. < 2.5 Hz).

The range of frequencies presented above can be depicted from Fig. 8 where the fundamental first periods of vibration of building constructions, obtained through *in situ* measurements, are presented for all building typologies and for old masonry structures.



a)



b)

Fig. 8 - Fundamental first periods of vibration of building constructions - *in situ* measurements: a) all building types; b) old masonry structures.

Dynamic behaviour

The dynamic analysis of these structures is very complex due to the difficulty in determining the constitutive equations of all components, specially for large amplitude values. Table I enumerates several experimental techniques for the characterisation of dynamic behaviour of old buildings. Several research programmes are now being launched in Portugal as well as in other southern European countries, in order to better understand that behaviour. The effect of connections between the various components, such as masonry and timber, is one topic which deserves great attention. Others are:

- behaviour of well cut and arranged stone walls in its own plan and the perpendicular direction;
- behaviour of rubble stone walls in its own plan and the perpendicular direction;
- behaviour of corners between walls;
- the influence of horizontal diaphragms, either in timber or concrete slabs;
- the influence of inner partitions, either in simple masonry, in plywood or mixed;
- the influence of stairways, either in stones, in timber or mixed;
- the influence of a discontinuous first floor level, either by the use of arches or vaults, or by beams;
- the influence of the type of roof;
- the influence of adjacent buildings, either of the same size and material, or of different size and material.

To understand these behaviours and influences, several techniques have been devised. They deal with either the whole structure or parts or components of the structure, to characterise the constitutive laws, using dynamic analysis for low amplitude testing or, on the other hand, static large amplitude tests. The modulus of elasticity for different types of masonry walls, according to the experience gained with ambient and forced vibration testing, and compared with static testing, show great variations from material to material and with the geometric arrangements of stones; but they are quite low for structures of poorer masonry quality. In the last case, the yielding limits are barely above the dead loads, and the non-linear part has, however, an extremely long resilient plafond.

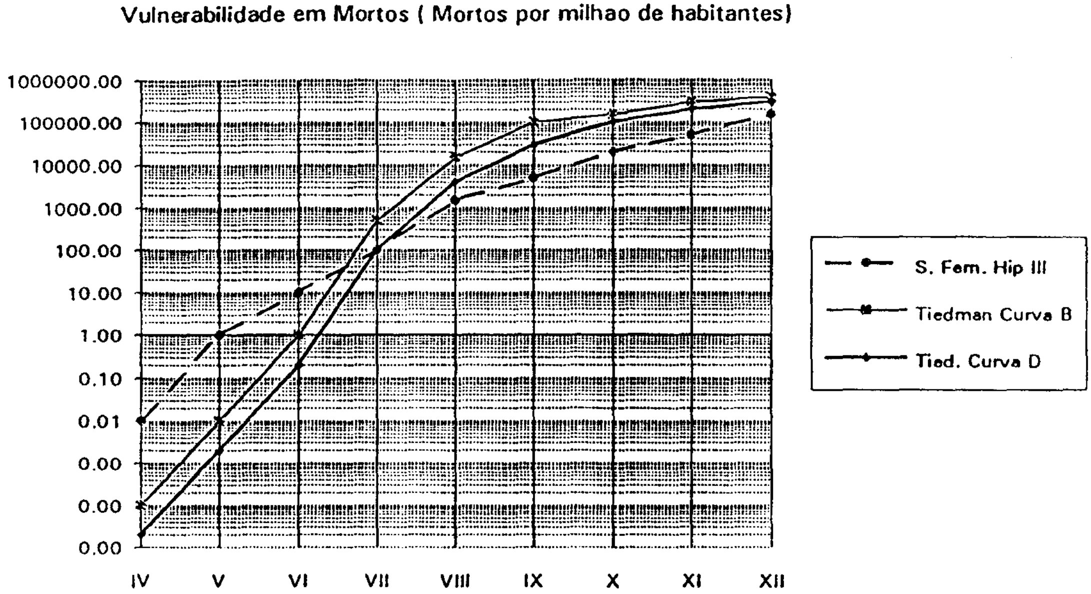
Vulnerability and fragility analysis

Estimation of damage to people and property requires the knowledge of vulnerability and fragility of different classes of building structures under different seismic strong motion conditions. By definition, while **vulnerability** represents the damage (to human and material property) percentage, **fragility** represents the part of total sampled population, in percent, which is affected by certain degree or type of damage. These two concepts are naturally related to each other, specially if one thinks that the data to produce them is exactly the same. The difference comes only from the way analysis is performed.

Depending on the objective under prospection (output variable), use of one or the other should be made. As an example, to obtain global distribution of damage, one prefers to work with vulnerability, but if the number of homeless is the output variable, then it is easier to work with fragilities, Rojahn, 1993.

Many authors have been collecting data from past earthquakes to create data-bases dealing with all kinds of damage types. Statistical information is consequently becoming available, allowing not only to derive vulnerability and fragility curves with much higher confidence limits, but also permitting a better way to compare with analytic and experimental results. Among the most recent works, one should refer Coburn et al., 1992, Spence et al., 1992, Murakami, 1992, Gulkan et al., 1992, and Tiedemann, 1992.

The vulnerability curves were assigned to each category in Lisbon based in the type of construction, natural period of vibration and on statistics obtained from several word wide earthquakes, Mendes-Victor et al., 1993, and Tiedmann, 1992, Fig. 9 for human casualties and for damage ratio. In Fig. 10 are presented fragility curves for the same set of typologies, adapted from Coburn et al., 1992), for two limit states: a) severe damage and b) collapse.



a)

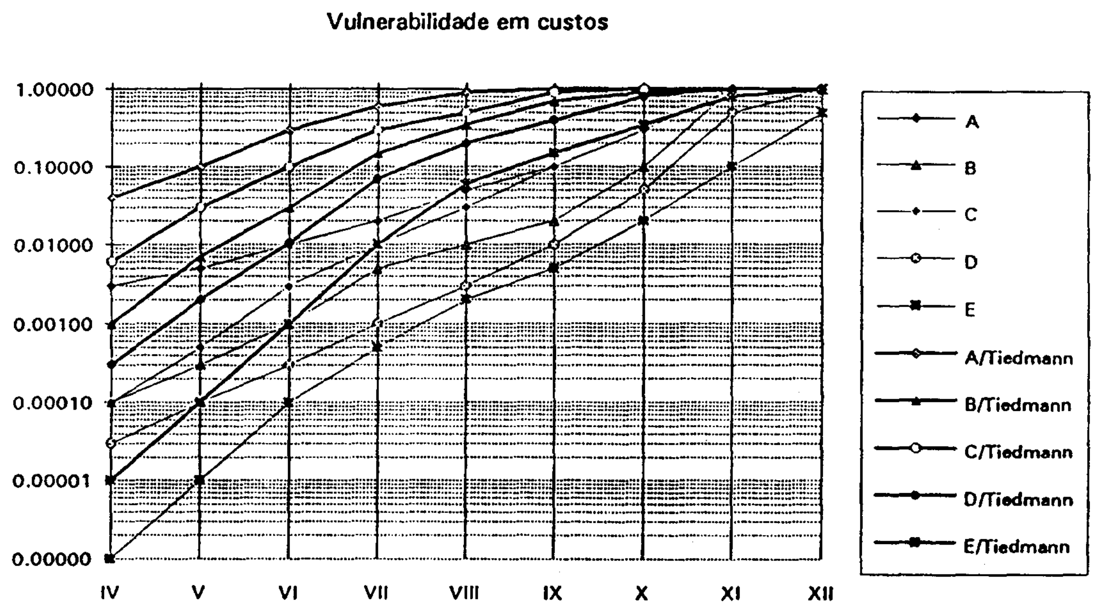


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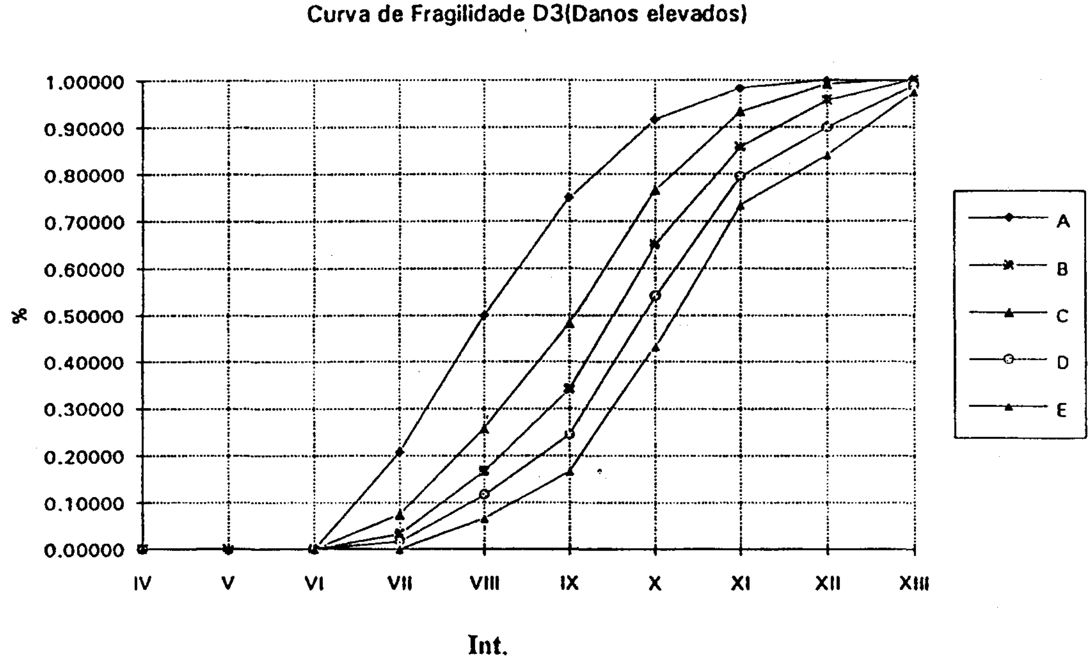
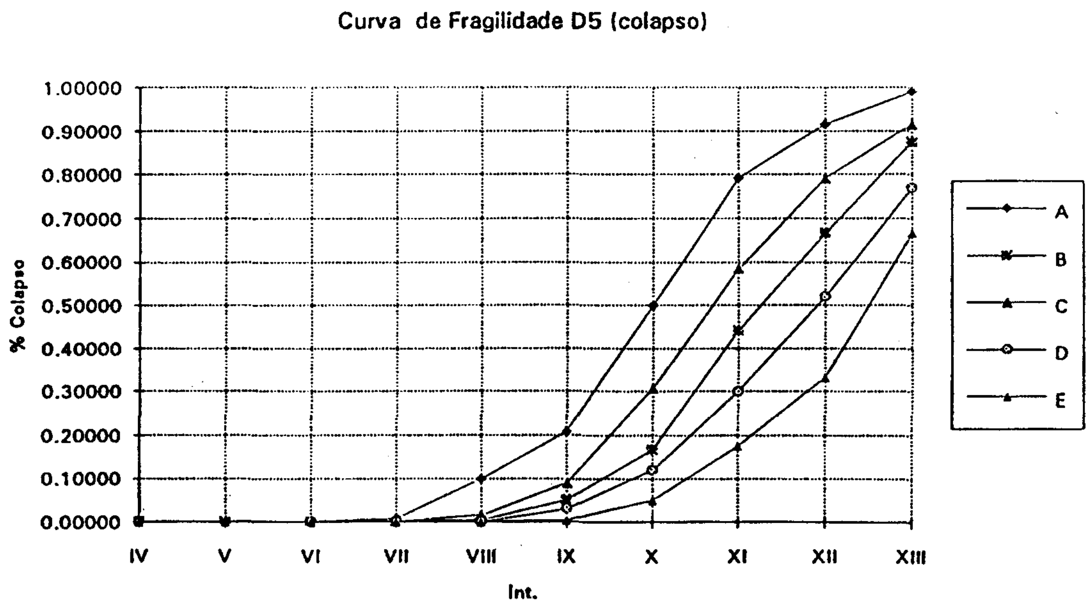
Fig. 9 - Vulnerability function for different typologies - (preliminary results, adapted from Tiedmann, 1992): a) for human casualties (units: per million inhabitants); b) for damage ratio.



a)



b)

Fig. 10 - Fragility function for different typologies - (from Coburn et al., 1992): a) severe damage; b) collapse.

Studies for the Inventory of Building Stock

Many different techniques have been developed to obtain the main structural characteristics of a building, essentially depending on the detail of vulnerability analysis. The Italian group for civil protection has devised three levels of inquires, the first referring simple geometric values, the second a good description of geometry, and the third requiring the knowledge of the mechanical properties of the materials. In Portugal, specific studies for Lisbon have been conducted in the basis of the typologies above mentioned and on the organisation of building blocks, Fig. 11.

Figure 12 presents a schematic spatial distribution of the first five above mentioned building categories according to expert opinion, Oliveira *et al.*, 1985.

The structural characterisation of Lisbon's building stock, covering different areas, Fig. 13, was made up to now using several types of questionnaire surveys. Fig. 14 summarises the inquire for building survey used by Laboratório Nacional de Engenharia Civil (LNEC).

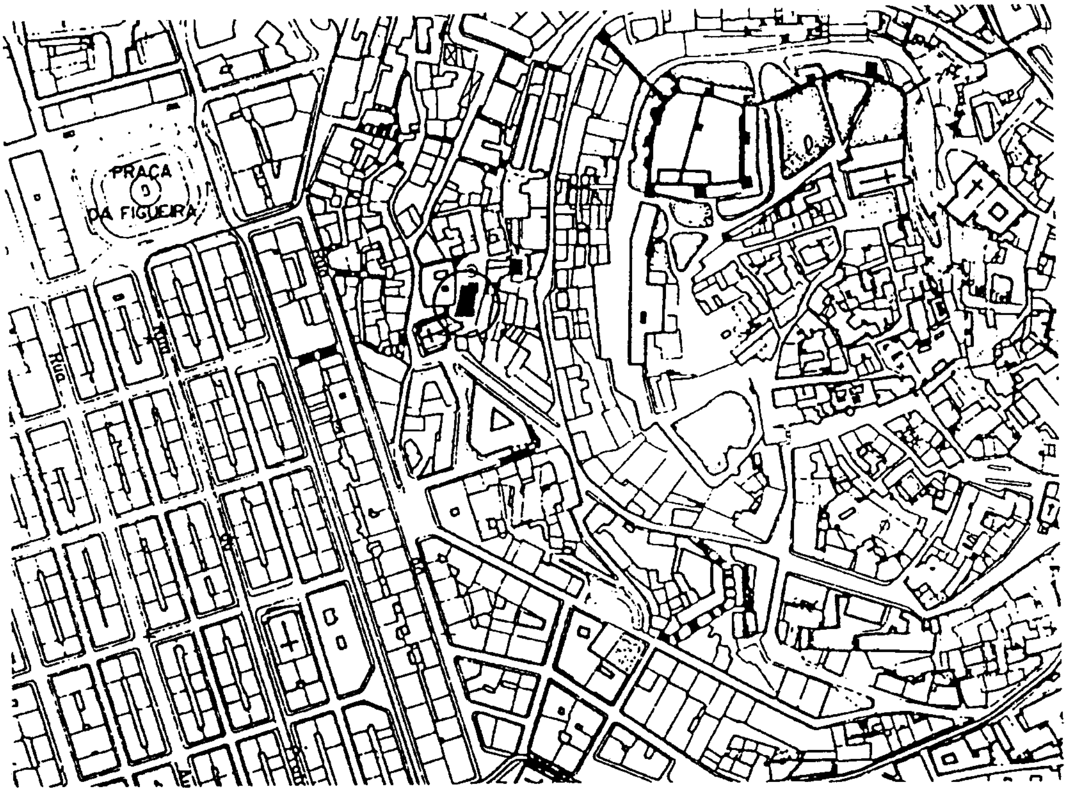
1. The survey covering the areas of Alameda, Anjos-Pena and Western Rivershore area was made under LNEC's (National Laboratory of Civil Engineering) supervision and was specially designed for future seismic impact studies. The survey sheets had 30 different parameters to fill, and trained teams of geographers, architects and engineers were formed for that purpose to assure, as far as possible, the homogeneity of data collection.

2. The survey covering the areas of Lisbon's historical centre and other ancient quarters, now under a rehabilitation process, was made by Lisbon's City Council Municipal Department of Urban Rehabilitation. Most of the parameters contained in this survey are similar to the ones used in LNEC's survey.

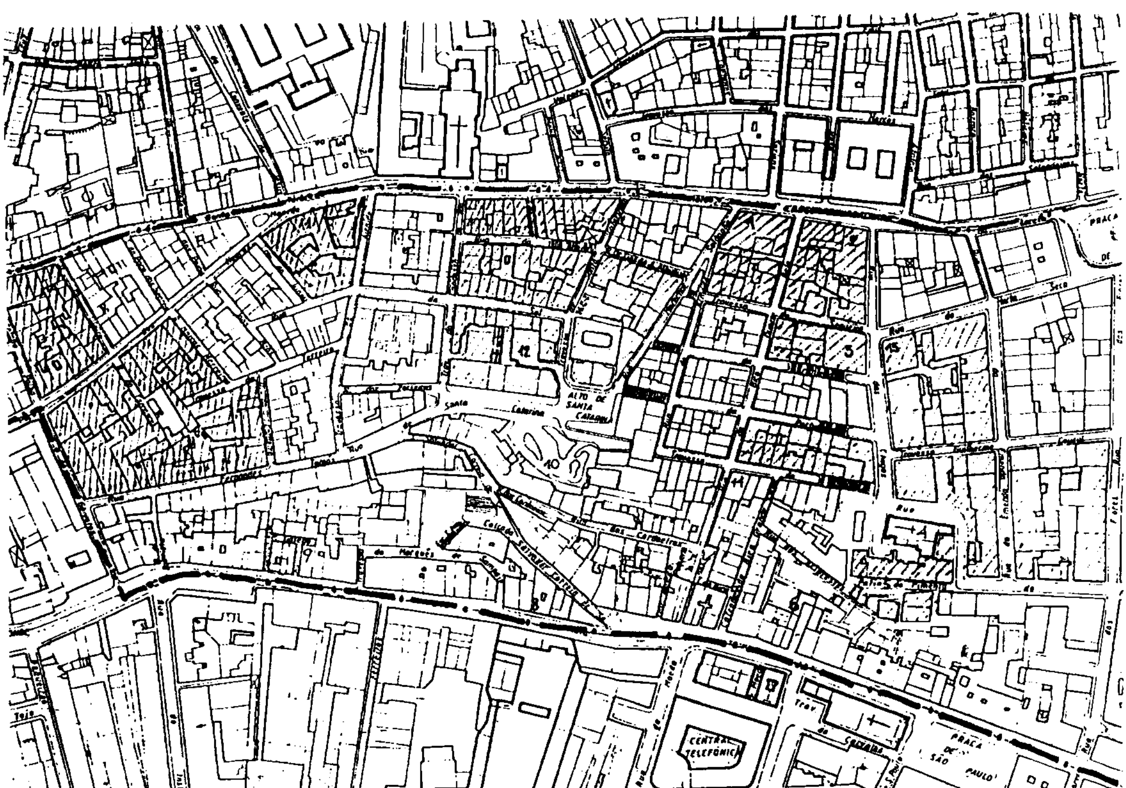
3. In the areas not yet directly covered by the two previous surveys, the Population and Housing Census of 1981 and 1991 were used, INE, 1991. The data contained in the Census were completed with an expeditious field work. This work, covering representative modern urban areas, used sampling techniques to determine the number of stories and the land covered area.

Typical results of the survey are presented in Fig. 15 either in quantitative terms or using graphic geographical systems.

In many different locations around the world several methods have been tentatively used for studies of earthquake impact (see papers published on NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*).



a)



b)

Fig. 11 - Organisation of building blocks: a) older part of Lisbon, arround the Castle and reconstruction pos-1755 earthquake; b) 19th century urban development.

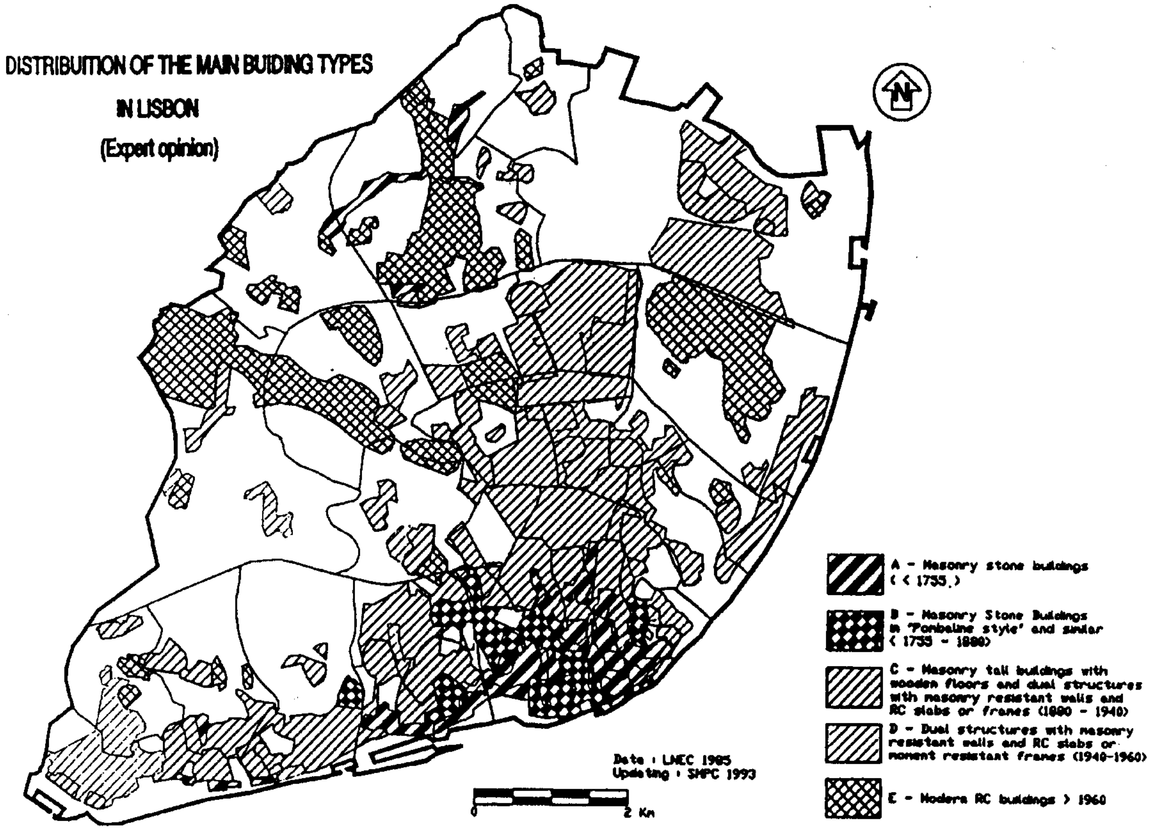


Fig. 12 - Geographic distribution of typologies in the city of Lisbon.

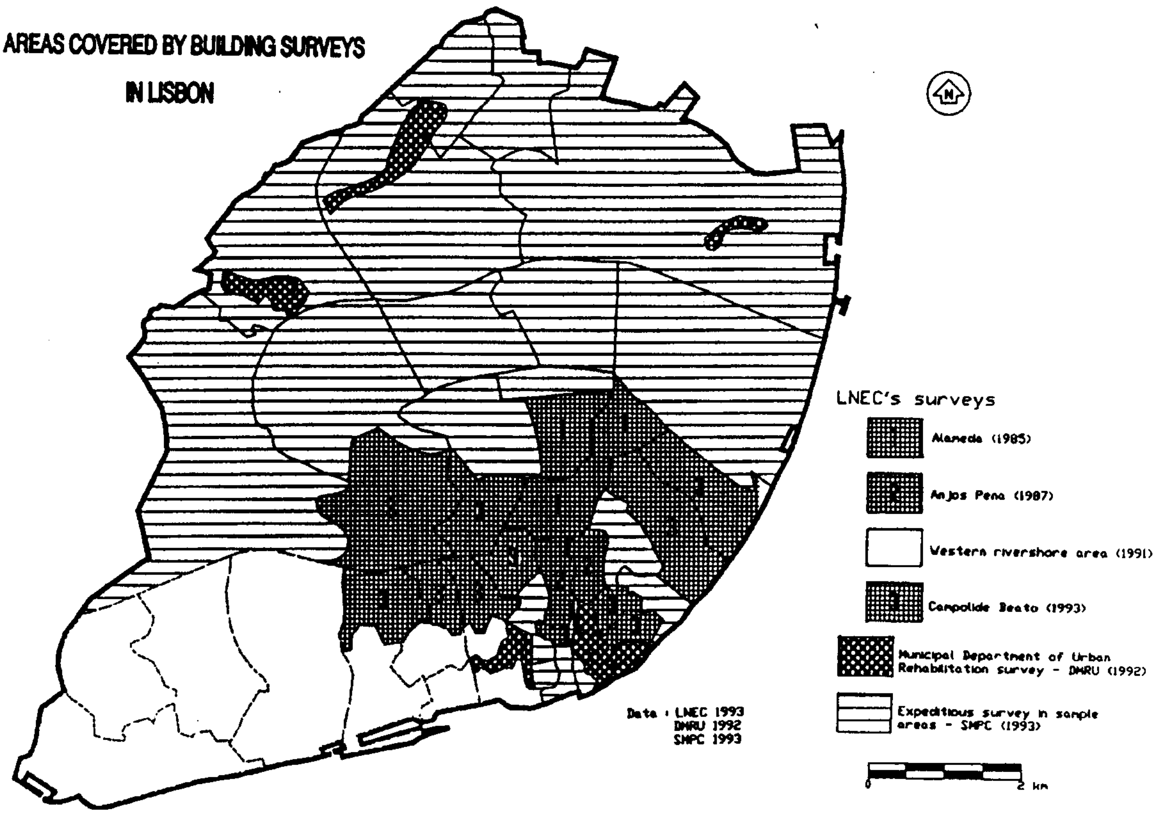


Fig. 13 - Area covered by building surveys

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

Fig. 14 - Enquire for building survey.

	Alameda	Anjos	Western Rivershore	Total
Geographic area	286 ha	105 ha	1644 ha	2035 ha
No. of blocks	185	46	729	960
No. of buildings	3273	1877	10355	15505
Total no. of stories	15692	4710	31577	51979
Total no. of dwellings	22264	6411	44445	73120
Average no. of stories	4.32	3.52	3.07	3.49
Predominant epochs	1870-1940: 55%	1870-1940: 47.5%	1755-1889: 37.7%	-
Average area per building	280 m^2	202 m^2	521 m^2	431 m^2
Average area per dwellings	112 m^2	99 m^2	138 m^2	127 m^2
Predominant uses: housing	42.0%	47.2%	71.9%	53.7%
mixed	46.0%	35.2%	20.0%	33.7%
State conservation: average	55.0%	54.5%	43.0%	50.8%
bad	20.0%	28.0%	18.0%	22.0%
Population	64520*	30243*	96848**	-
Employees in the area	47912*	18636*	69812**	-
Occupation: Land covered/ geographic area	0.32	0.36	0.08	0.13
Use: Construction area/ geographic area	1.56	1.26	0.32	0.54

* - Data from Marin et. al. (1983); ** - Data from S.M.P.C. - C.M.L. (1993a)

Fig. 15 - Typical results: a) in quantitative terms; b) in graphic systems.


FREGUESIA DAS MERCES
Media do numero de pisos acima do solo (V9)
< 3
03 - 04
04 - 05
0
150m
FREGUESIA DAS MERCES
Percentagem de edifícios desacompanhados (V22)
>50%
0
150m
FREGUESIA DAS MERCES
Estado de Conservacao da Fachada Principal (V27)
0
150m
FREGUESIA DAS MERCES
Estado de Conservacao da Fachada Posterior (V28)
0
150m

Fig. 15 b)

Future studies

- A classification of building types should be done in a very detailed way. In doing so, inquires to evaluate building stock and the determination of vulnerability functions need further development.
- This would require studies at various levels which have to be performed for the particular case of the area under analysis.
- In relation to the inquires and the procedures for the field work, great care should be exercised in order that they are easily and accurately filled up and treated.
- In relation to the vulnerability functions, special emphasis should be given to the behaviour of structures in past events, to analytical and experimental techniques, merging all available information. One important improvement of the model is the incorporation of strong motion in terms of spectral content, which is a function of magnitude and focal distance.
- In the particular case of Lisbon´s stock of buildings, reinforced concrete buildings are the type of structures deserving higher consideration. They represent a large portion of the recent stock of buildings, and were constructed under three different seismic codes without a clear quality control. That's why they pose large uncertainties as far as performance for seismic actions are concerned.
- On the other hand, the traditional masonry structures prevails in the buildings constructed before 1960. Their natural spatial organisation is the block which should be considered as the unit for this analysis.
- The study of vulnerability to the population deserves also particular attention. A few authors did already some work in this direction analysing data from past events, taking into account the degree of damage in the building, the type of building and population concentration, Murakami, 1992. This information can be built into a more sophisticated damage model. Also, instructions to the population can address topics of evacuation, how and how long, preparation for aftershocks, etc.
- The study of important structures, including the life-lines networks, need to be done in great detail, on the basis of individual analysis. The sole exceptions are the cases of repetitive structures, such as certain types of schools, industrial facilities, etc., for which a single complete study is enough.
- Special treatment as far as relief instructions in these structures should be addressed. A detailed emergency plan should be provided for each structure, assigning all check list points. If they contribute to the emergency plan of other systems (hospitals,...), their operationally should be granted at all means, and easily checked.
- Monuments, libraries, art exhibitions, etc., require a different treatment. Their cultural value cannot be jeopardised without prior knowledge.

Selected references

Alva-Hurtado, J.H. (1993) - "Seismic Safety of the Lima Metropolitan Area", Proceedings NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*, Istanbul, M. Erdik and B. Tucker, editors.

Appleton, J.; Baião, M. (1994), "Building Inspection for the Diagnosis of their Patology", Proceedings 2° ENCORE, LNEC, Lisboa.

Balassanian, S.; Manukian, A. (1993) - "Seismic Risk of the Terretory of the City of Yerevan, Armenia", Proceedings NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*, Istanbul, M. Erdik and B. Tucker, editors.

Campos-Costa, A.; Oliveira, C.S.; Sousa, L.N. (1992) - "Seismic Hazard-Consistent Studies for Portugal", Proceedings 10^{th} World Conference on Earthquake Engineering, Madrid 19-24 July, pp. 477-482, A.A. Balkema.

Castaño, J.C.; Zamarbide, J.L. (1992) - "A Seismic Risk Reduction Program for Mendonza City, Argentina", Proceedings 10th World Conference on Earthquake Engineering, Madrid, Vol. 10, pp 5953-5958, A.A. Balkema, Rotterdam.

Coburn, A.W.; Spence, R.J.S.; Pamonis, A. (1992) - "Factors Determining Human Casualty Levels in Earthquakes: Mortality Prediction in Building Collapse", Proceedings 10th World Conference on Earthquake Engineering, Madrid, Vol. 10, pp. 5989-5994, A.A. Balkema, Rotterdam.

ELSA (European Laboratory for Structural Assessment), Joint Research Centre, Italy.

Erdik, M. (1992) - "Disaster Management Education on Earthquakes", Proceedings 10th World Conference on Earthquake Engineering, Madrid, Vol. 10, pp 6079-6084, A.A. Balkema, Rotterdam.

Erdik, M.; Tucker, B. (1993) - "An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas", NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*, Istanbul, M. Erdik and B. Tucker, editors.

Fidalgo, C. (1994), "As Abobadilhas Alentejanas", Proceedings 2º ENCORE, LNEC, Lisboa.

Gavarini, C. (1992) - "Towards the Systematic Use of Expert Systems in Seismic Risk Reduction", Proceedings 10th World Conference on Earthquake Engineering, Madrid, Vol. 10, pp 6297-6302, A.A. Balkema, Rotterdam.

Gomes, A.M.; Appleton, J.A.; Nero, J.M.G. (1994), "Adaptation of Nondestructive Tests to Characterize the Plasters with Traditional Mortars", Proceedings 2º ENCORE, LNEC, Lisboa.

Gulkan, P.; Sucuoglu, H. (1992), "Earthquake Vulnerability, Loss and Risk Assessment in Turkey", Proceedings 10th World Conference on Earthquake Engineering, Madrid, Vol. 1, pp 539-543, A.A. Balkema, Rotterdam.

INE (1991) - "Census 91 (População e Habitação)", Instituto Nacional de Estatística, Lisboa.

Kaneko, F. (1993) - "Earthquake Disaster Counter Measures in Saitana Prefecture, Japan", Proceedings NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*, Istanbul, M. Erdik and B. Tucker, editors.

Klyachko, M.A. (1993) - "The Arguments and Facts in Favour of Desperate Extremity to Mitigate the Earthquake Disaster in Kamatchaka Region", Proceedings NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*, Istanbul, M. Erdik and B. Tucker, editors.

Mader, G.G. (1993) - "Creating the Scenario and Drafting Earthquake Hazard Reduction Initiatives", Proceedings NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*, Istanbul, M. Erdik and B. Tucker, editors.

Manos, G. (1994) - "In situ Measurements of Structures under Real Earthquakes", Personal Communication.

Mascarenhas, J.M.D. (1994) - "Baixa Pombalina, Algumas Inovações Técnicas", Proceedings 2º ENCORE, LNEC, Lisboa.

Mendes-Victor, L.A.; Oliveira, C.S.; Pais, I.; Teves-Costa, P. (1993) - "Earthquake Damage Scenarios in Lisbon for Disaster Preparedness", Proceedings NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*, Istanbul, M. Erdik and B. Tucker, editors.

Murakami, H.O. (1992) - "A Simulation Model to Estimate Human Loss for Occupants of Collapsed Buildings in an Earthquake", Proceedings 10th World Conference on Earthquake Engineering, Madrid, Vol. 10, pp 6079-6084, A.A. Balkema, Rotterdam.

Murakami, S.; Sadohara, S. (1992) - "Basic Study on the Computer-aided Mapping System for Earthquake Disaster Mitigation", Proceedings 10th World Conference on Earthquake Engineering, Madrid, Vol. 10, pp 5923-5926, A.A. Balkema, Rotterdam.

Oliveira, C.S.; Carvalho E.C.; Pereira J. (1982), "Dynamic Characterization of Existing Buildings based on Experimental Measurements", Proceedings 7th European Conference on Earthquake Engineering, Athens, Greece, A.A. Balkema.

Oliveira, C. S.; Victor, L.A.M. (1984) - "Prediction of Seismic Impact in a Metropolitan Area Based on Hazard Analysis and Microzonation: Methodology for the Town of Lisbon", Proceedings 8th World Conference on Earthquake Engineering, San Francisco, Prentice Hall.

Oliveira, C.S.; Cabrita, A.M.R. (1985) - "Tipificação do Parque Habitacional: Documento Introdutório do Tema", 1° Encontro sobre Conservação e Reabilitação de Edifícios de Habitação, LNEC, Lisboa.

Oliveira, C.S.; Correia Guedes, J.H.; Lucas, A.R. (1993) - "O Sismo dos Açores de 1 de Janeiro de 1980. Danos e Recuperação. - Actas do Simpósio "Catástrofes Naturais - Estudo, Prevenção e Protecção", LNEC/Ordem dos Engenheiros, Lisboa.

Oliveira, C.S.; Martins, A. (1993) - "Vibrações nos Solos e nas Construções - Algumas Medições Efectuadas em Angra do Heroísmo", Relatório Interno 66/93-NDA, LNEC, Lisboa.

Oliveira, C.S.; Pais, I.; Cabral, J.C. (1993) - "Estudos de Microzonagem Sísmica para a Cidade de Lisboa. Definição de Cenários de Danos", Paper presented at the *Seminario sobre Catástrofes Naturais*, Ordem dos Engenheiros/LNEC, Lisboa.

Oliveira, C.S. (1994) - "Seismic Studies for the Águas Livres' Aqueduct in Lisbon", Proceedings 10th European Conference on Earthquake Engineering, Viena, Áustria, A.A. Balkema (in print).

Oliveira, C.S.; Costa, A.G. (1994) - "Segurança Sísmica na Conservação e Reabilitação de Edifícios", Proceedings 2° ENCORE, LNEC, Lisboa.

Oliveira, C.S.; Gil, N.P.; Fragoso, M.R. (1994) - "Estudo Experimental e Analítico do Comportamento Dinâmico de Estruturas de Alvenaria de Pedra. Aplicação à Ponte da Ribeira Grande (São Miguel, Açores)", Proceedings 2° ENCORE, LNEC, Lisboa.

Rojahn, C. (1993) - "Estimation of the Earthquake Damage to Buildings and Other Structures in Large Urban Areas", Proceedings NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*, Istanbul, M. Erdik and B. Tucker, editors.

RSCS (1958) - "Regulamento de Segurança Contra os Sismos".

RSEP (1963) - "Regulamento de Solicitações em Edifícios e Pontes".

RSA (1983) - "Regulamento de Segurança e Acções em Estruturas de Edifícios e Pontes".

Santos, N.B.; Cunha, R.M.; Alves, R.R.; Rodeia, T.B. (1993) - "A Arquitectura e os Processos Construtivos Entre os Séculos XVI e Meados de XVII", Nota Técnica nº. 1/93 - NDA, LNEC, Lisboa.

SNPC (1983) - "Programa para Minimização do Risco Sísmico - Relatório Final", Serviço Nacional de Protecção Civil, Lisboa.

Spence, R.J.S.; Coburn, A.W.; Pamonis, A.; Sakai, S. (1992) - "Correlation of Ground Motion with Building Damage: The Definition of a New Damage-Based Seismic Intensity Scale", Proceedings 10th World Conference on Earthquake Engineering, Madrid, Vol. 1, pp. 551-556, A.A. Balkema, Rotterdam.

Tiedemann, H. (1992) - "Earthquake and Volcanic Eruptions, A Handbook on Risk Assessment", Swiss Re., Zurich.

Tselentis, A.; Karavolas, A.; Christopoulos, C. (1993) - "The City of Patras - W. Greece. A Natural Seismological Laboratory to Perform Seismic Scenario Practices", Proceedings NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*, Istanbul, M. Erdik and B. Tucker, editors.

Ventura, C.E. Schuster, N.D. (1993) - "Seismic Risk and Hazard Reduction in Vancouver, British Columbia", Proceedings NATO Advanced Research Workshop on *An Evaluation of Guidelines for Developing Earthquake Damage Scenarios for Urban Areas*, Istanbul, M. Erdik and B. Tucker, editors.

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List of Tables

Table I - Experimental techniques for the characterisation of dynamic behaviour of old buildings.

	Ambient vibration	*Forced vibration*	*Wave velocity*	*Analysis of components*	*Material testing*	*Shaking table*	*Real earth-quakes*
Amplitude motion	very small	small	very small	large	very large	medium	small to large
Degree of difficulty	simple	more complex	simple	very complex	more complex	very complex	depend on occurrences
Observations	dynamic	dynamic	only for simple material	static dynamic	static	dynamic	dynamic