Estimation of the seismic impact in a metropolitan area based on hazard analysis and microzonation — an example.

The town of Lisbon

INTRODUCTION

The evaluation of the seismic impact of future earthquakes in the metropolitan area of Lisbon aiming at (i) determination of the areas of higher risks and (ii) quantification of losses in terms of death toll and damaged buildings, requires the development of different tasks, the most important ones dealing with hazard, microzonation, building vulnerability and population distribution along the day. The social economic impact must be considered.

The main parameters connected to each one of the tasks above and the proposal for a model for prediction of earthquake losses in a consistent basis will be discussed.

1. PRELIMINARY CONSIDERATIONS

In historical times, the town of Lisbon was struck by the occurrence of important earthquakes, (Ref. 1). The 1755 Lisbon earthquake destroyed a large portion of the town, causing 5-10 % victims and a tremendous impact that lasted for the remaining eighteenth century. The study of this quake (Ref. 2), based on description of damage of several hundred monumental buildings showed remarkable differences in damage distribution throughout the town, Fig. 1. The February 28, 1969 North Atlantic earthquake, not causing a great deal of damage, Fig. 2, created a disruption on the everyday life and also showed differences of intensity of shaking in the town.

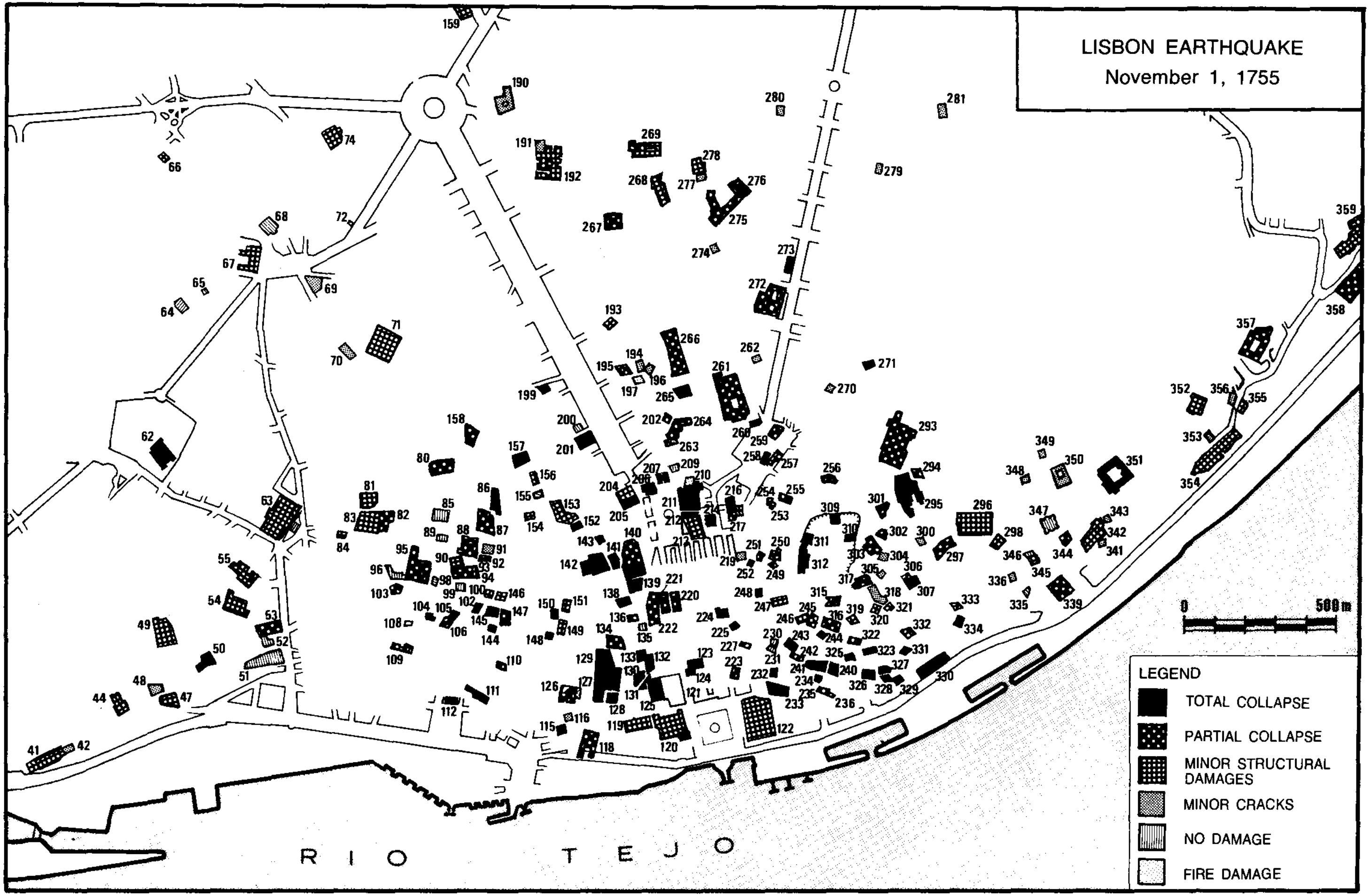


Fig. 1. Damage distribution of the 1755 earthquake at Lisbon.

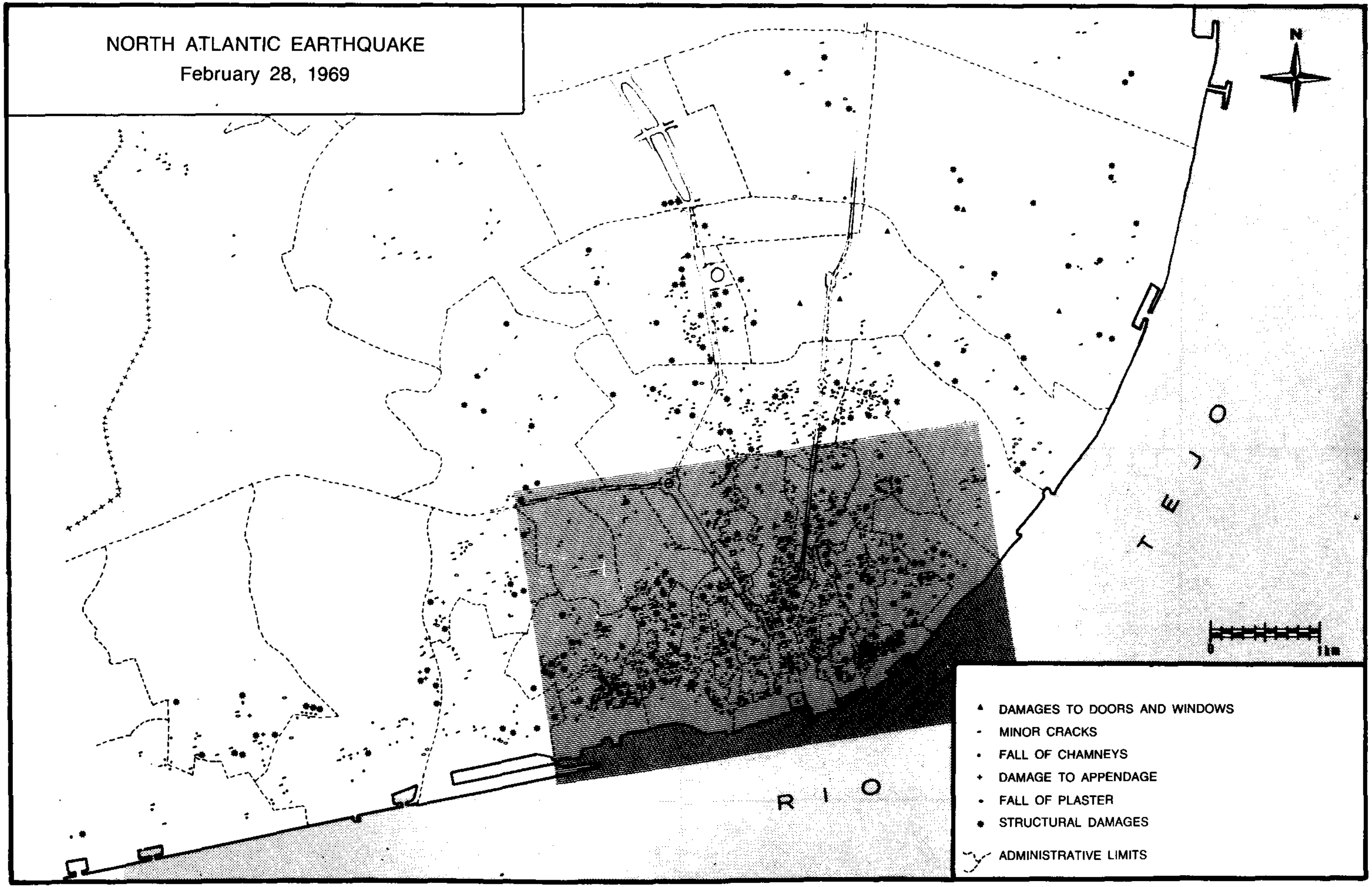


Fig. 2. Damage distribution of the 1969 earthquake in Lisbon.

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

The detailed study of the most important earthquakes has given a first estimate of seismic impacts (extend of damage) as a function of the magnitude, type, epicentral distance and of the existing buildings at the date of occurrence. Studies of tectonics, propagation of seismic waves, local geology and topography, enable us to improve the definition of seismic actions in the different areas of the town. Mapping of construction throughout the town and the definition of a vulnerability function (year and type of construction, number of stories, etc.) allows the quantification of material losses ; the distribution of the population during the day informs on the human and social impacts at different hours.

2. STRATEGY

The formulation of the problem considered above was prepared by a group of specialists of the different interesting disciplines and lead to the approach contained in the flow diagram here presented.

It was possible to organize groups dealing with the matters contained in each box thanks to the great willingness of the respective public departments and the ability of the leaders.

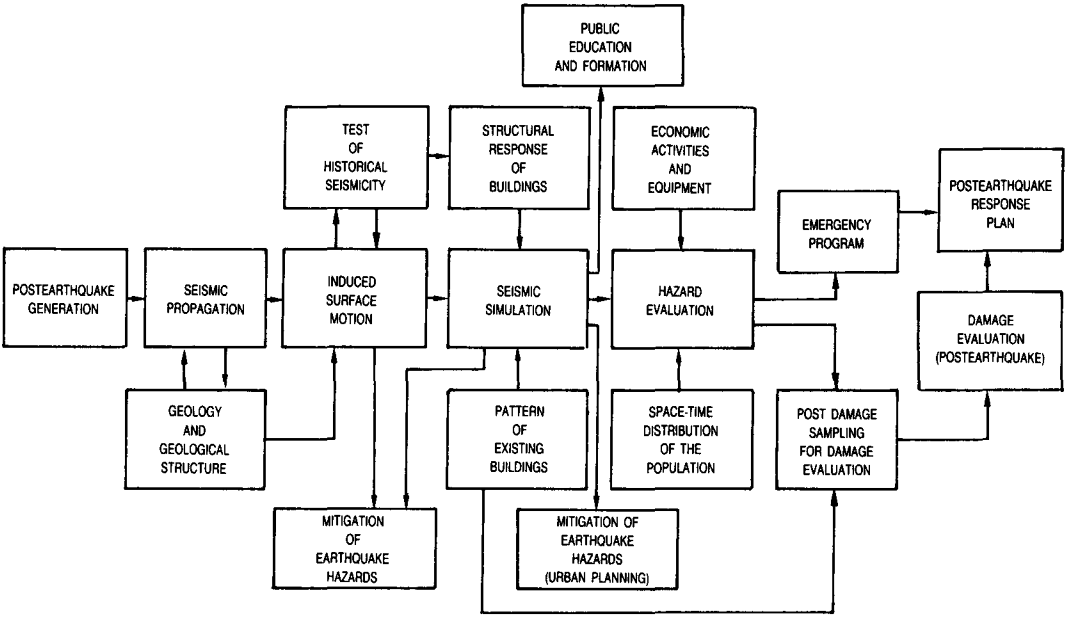


Schéma 1.

Schéma 2.

List of important earthquakes causing damage in Lisbon after the 14^{th}century

DATE	PROBABLE EPICENTRAL LOCATION AND MAGNITUDE	TYPE OF EARTHQUAKE	MAXIMUM MM INTENSITY IN LISBON	DAMAGE DESCRIPTION	DAMAGED AREA
1344 July-Aug.	NE of Lisbon in a radius of 30 km (M_L ~6.5)	Local - II Related to the NE-SW fault trend	VII - VIII	Damage to houses and churches. Numerous victims	Lisbon and surroundings
1356 Aug, 24	200 to 300 km SW of Lisbon in the main fracture zone Azores-Gibraltar (M_L ~ 7.5)	Global - I Great duration; one year of after shocks	VII - VIII	Great damages to houses and churches. Numerous victimes	Algarve, Spain, Lisbon and surroundings
1512 Jan, 28	Area of Lisbon (M_L = 5-6)	Local - I May have been a landslide	VII	200 houses destroyed and 2000 people killed	Lisbon North
1531 Jan, 26	10 to 20 km NE of Lisbon in the lower Tagus fault (M_L = 6.0)	Local - II Related to the NE-SW fault trend; 2 large impulses; large amount of fore and aftershocks;tsunami due to landslide	VIII - IX	Great damage to houses, old churches. One landslide. Reduced number of victims due to foreshock activity	Lisbon and surrounding in a 100 km diameter
1597 July, 22	Area of Lisbon -	Local I Most probably was a landslide	VII	110 houses in 3 streets pushed in a landslide	Lisbon West
1755 Nov, 1	150-200 km SW of Lisbon near the main fracture zone Azores-Gibraltar	Global - I Great duration; many after shocks; Great tsunami	VIII - IX (Variations of 3 MM Degrees in town)	Great damages to houses and churches. .5 to 10% population killed	Algarve, Lisbon and surroundings, Spain, Marrocos
1909 April, 23	30 km NE of Lisbon in the tower tagus fault. (M_L = 6.0)	Local - II Impulse type; large amount of after shocks	VI	Slight damage to chimneys	Area of 20 km from Benavente in the Lower Tagus Valley
1941 Nov, 25	1000 km W of Lisbon north of the main fracture zone-Azores-Gibraltar	Global - II Great duration	V	Felt only	All coast of Portugal with great attenuation inland
1969 Feb, 28	250 km SW of Lisbon in the main fracture zone, Azores-Gibraltar (M_L = 7.8)	Global - I 30 sec duration with a peak acceleration of 0.05g; small tsumani; no aftershocks	VI	Some damage to masonry chimneys, minor structural cracks	Algarve, Lisbon and surroundings

If some of the tasks can be easily performed others will involve strategic considerations that will result from large interdisciplinary discussions. The leaders of the different specialized groups had the opportunity to meet frequently in seminars in order to prepare this flow diagram.

3. OPERATIONAL CONSIDERATIONS

To obtain a microzonation map of Lisbon associated with a certain probability of occurrence, the following aspects were considered :

a. More than 120 earthquakes were felt in the Lisbon area since the 11th century, 9 of them caused important damage, Schéma 2. These events give great insight into occurrence plus attenuation models and serve to test seismic disaster scenarios.

b. Identification of tectonic structures that can generate earthquakes important to the town (Ref. 3).

Two main situations were studied as they represented the most common cases, Fig. 3. The Gorringe structure generates large interplate earthquakes which are felt in Lisbon with long duration and predominance of low frequency waves and the local intraplate faults generating moderate earthquakes which are felt in Lisbon with short duration or impulsive type, and predominance of high frequence content.

c. From local explosions, the model of the upper crust, the attenuation of surface waves and the existence of differentiated spectral behavior of soils, were derived for the region of Lisbon. Fig. 4 reveals that waves attenuate

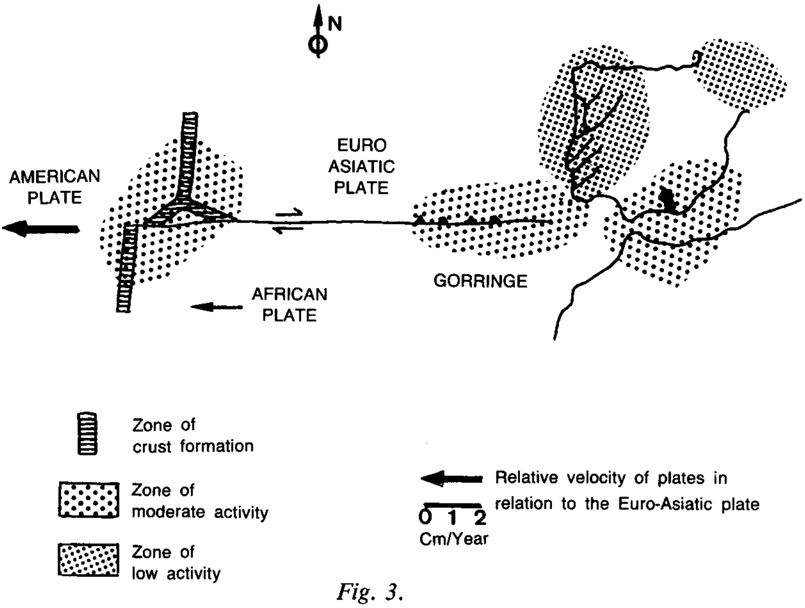


Fig. 3.

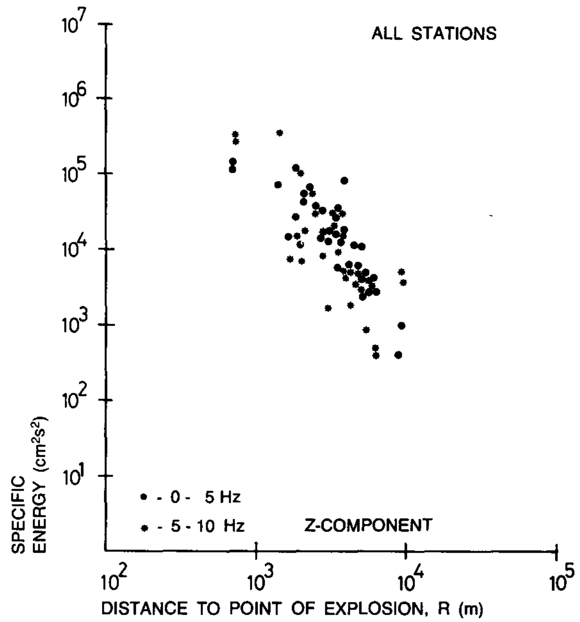


Fig. 4.

with $R^{-0.97}$ and natural frequencies of vibration vary from 2.5 Hz to 6.0 Hz (Ref. 4).

d. A detailed study of surface geology (Ref. 5), at a scale 1 : 10 000 allowed the identification of 5 categories of soils and their location. Considering velocity of the S waves we will consider :

A — surface deposits with two categories
I) $90\ \mathrm{ms}^{-1} < V_s < 150\ \mathrm{ms}^{-1}$
II) $150\ \mathrm{ms}^{-} < V_s < 200\ \mathrm{ms}^{-1}$

B — Tertiary formations with weak aggregation
$400\ \mathrm{ms}^{-1} < V_s < 600\ \mathrm{ms}^{-1}$

C — Tertiary rocks (general consolidated)
$1000\ \mathrm{ms}^{-1} < V_s < 1500\ \mathrm{ms}^{-1}$

D — Rocks with high consistency, such as limestones, basalts and pyroclastics of the volcanic complex of Lisbon
$V_s < 1500\ \mathrm{ms}^{-1}$

4. SCENARIOS

The first two items above referred were essential to determinate hazard curves for Lisbon, Fig. 5. This Figure, showing the contributions of the offshore and the onshore quakes, represents also the return periods of the large earthquakes felt in Lisbon. Items c) and d) were used as elements for establishing differential behavior of soils in Lisbon (Ref. 7). The concept of

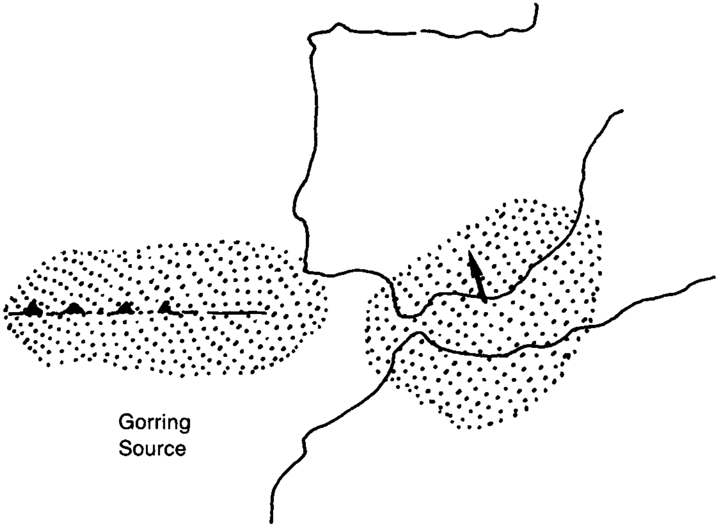

Gorring
Source

Fig. 5a.

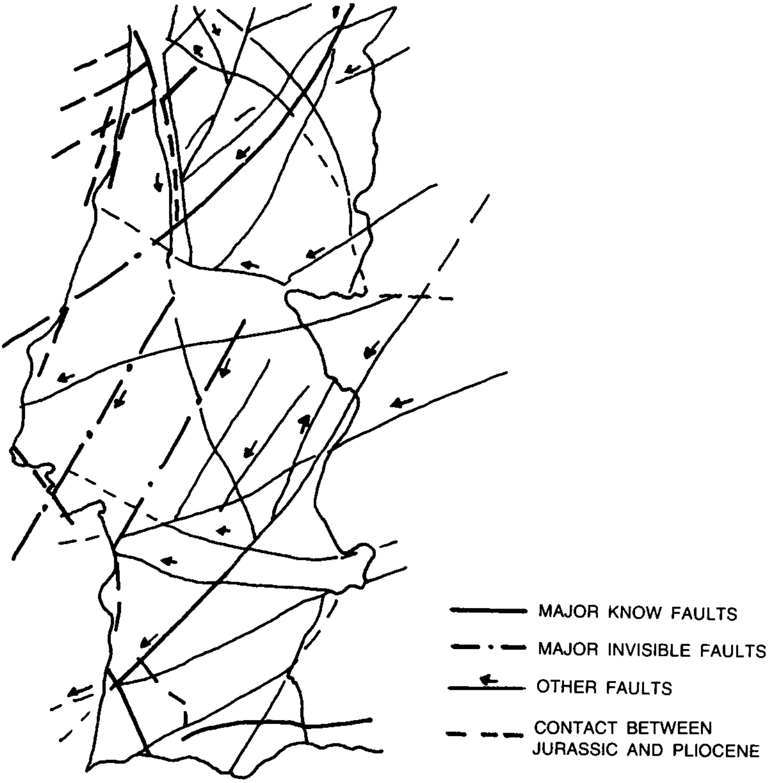

MAJOR KNOW FAULTS
MAJOR INVISIBLE FAULTS
OTHER FAULTS
CONTACT BETWEEN JURASSIC AND PLIOCENE

Fig. 5b.

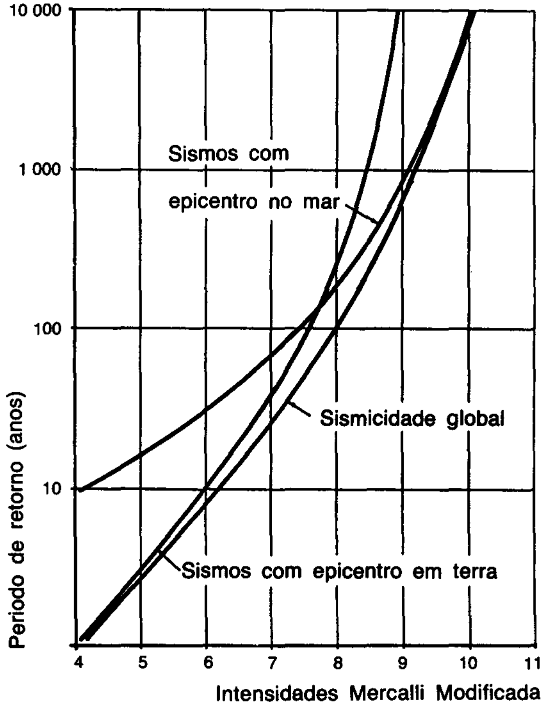


Fig. 5c.

acoustical impedance was used together with noise measurements and historical descriptions. Fig. 6 presents the upperbound estimation of MM intensity of shaking for the Gorringe scenario ; other seismic were throuroughly studied too, with the same approach. The evolution of effects of the lithostratigraphic configurations can be observed considering the table concerning the Gorringe Bank and Inferior Tagus Valley scenarios.

TABLE I. RATIO OF THE SEISMIC INTENSITY (MERCALLI MODIFIED) FOR THE DISTINCT LITHOSTRATIGRAPHIC UNITIES

SCENARIO	GORRINGE AREA	INFERIOR TAGUS VALLEY
BASEMENT	IX-X	IX
A_I/B	IX-VII	VII-IX
A_I/D	XI-IX	IX-X
A_{II}/D	VII-IX	VII-VII
A_{II}/C	VIII-X	VII/VIII-X
A_{II}/D	IX-X	VIII-IX/X
B/C	VII-IX	VI-VIII
B/D	VII-IX	VII-VIII
C/D	VIII-VI	VI-VIII

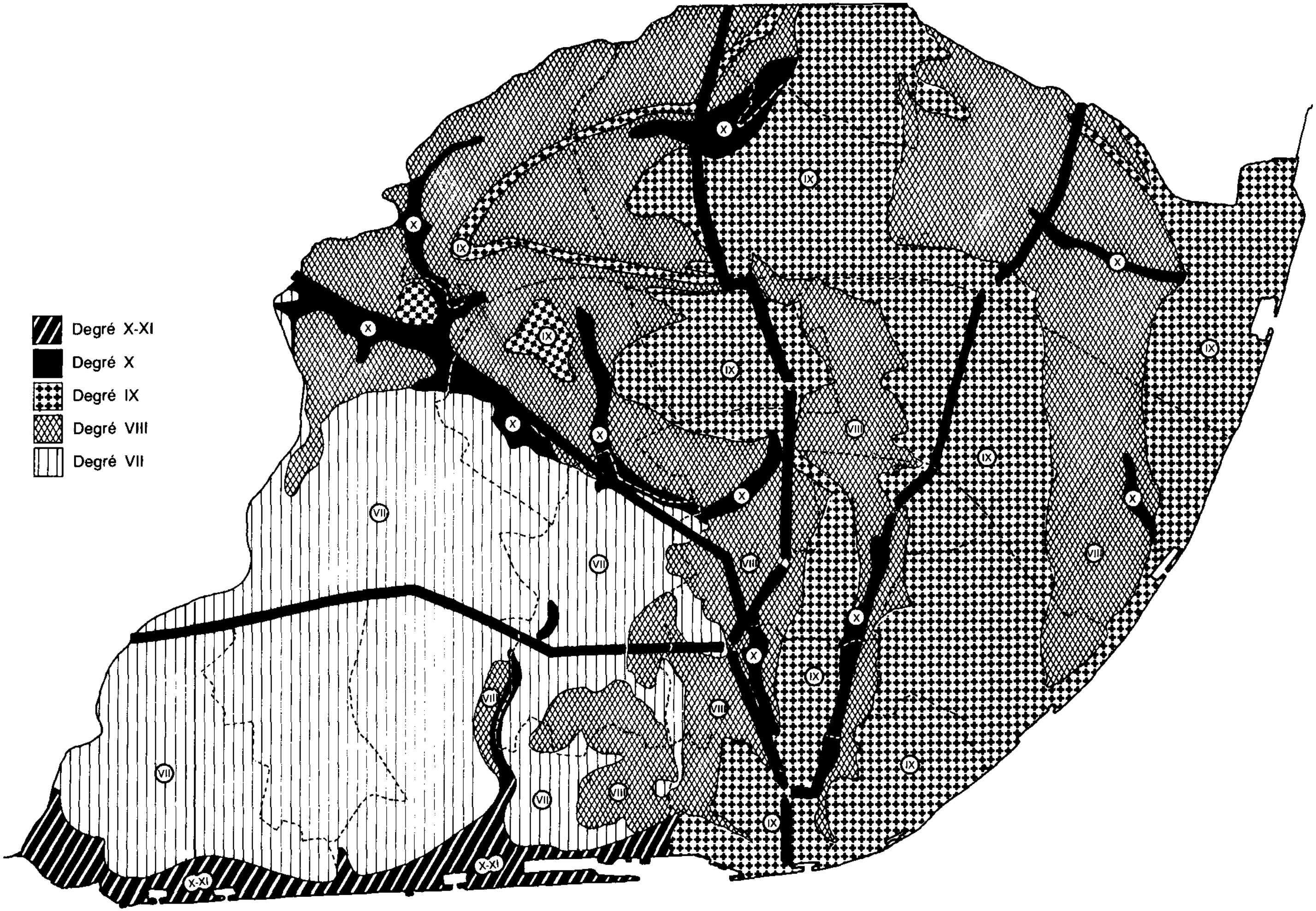


Fig. 6. Distribution des intensités sismiques à Lisbonne (échelle Mercalli modifiée). Scénario Gorringe le plus défavorable.

5. SEISMIC ENERGY PROPAGATION AND STRUCTURAL MODELS

In order to understand the mechanism of vibratory transmission energy along the town and to distinguish common behavior among different sites, a campaign of recording the ground motion, originated at a point-source within the town limits, was carried out for different locations.

This study which emphasizes the area of Lisbon, is part of a more general project aiming a determining the crustal properties for Portugal and neighbouring regions and it was lanched to profit from the explosions used for the construction of a harbour.

The day-time explosions, blasted with two hours windows in a Tagus River bed with charges 18 to 36 Kg, were located in front Alcantara, ALC, 100 to 250 m away from the bank and at 30 m depth, Figure 7. A total of 45 were used in this analysis.

The explosions were recorded by eight mobile stations placed along 12 radial profiles, around the point of explosion, P.E. in both banks of Tagus River, covering approximately an area of 80 km^2. The stations located 800 m from each other were moved from one profile to the next after recording 3 or 4 explosions. Figure 7 presents also the locations of sites with the records used in this study and the identification of profiles and sectors.

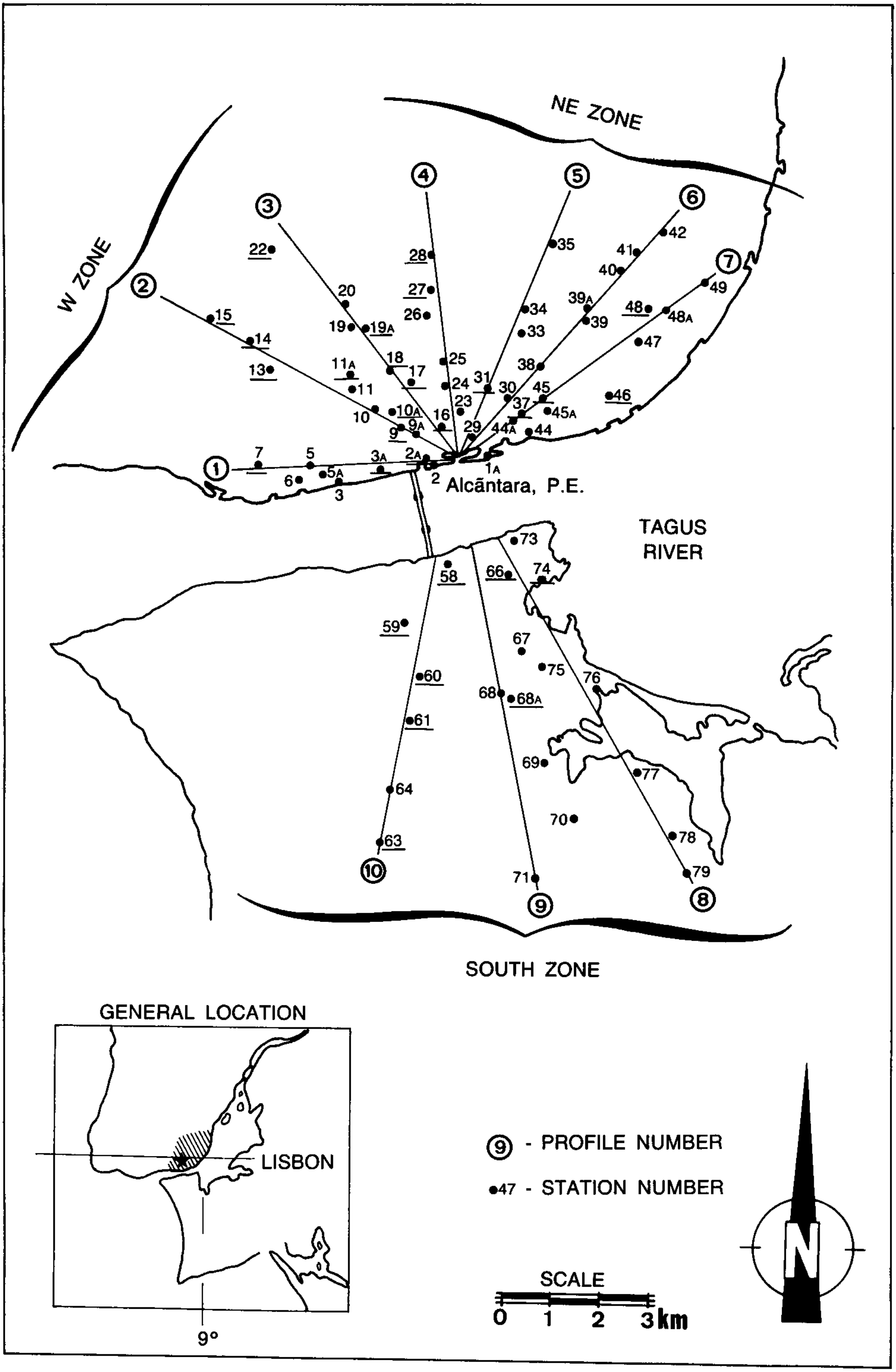
5.1.

The vibratory signal, picked up by three-component geophones equiped with velocity transducers and time signal, was recorded in analogic form in a magnetic tape using carriers in audio-frequency range. The instrument gains were set in such a way to produce the highest signal-to-noise ratio without saturation. The record at the point of explosion, set to determine the time of explosion, contains only the vertical component of motion. Input signals, subjected to an analogic low pass 50Hz Butterworth filter, with 48 dB per oct., were digitized to 12 bit words at the selected clock controlled sample rate of 200Hz, in single component, and stored continuously in a floppy disk.

Time signals were subjected to an automatic detection technique capable of locating the most probable time for the initialization of digitation. The records were then filtered for given frequencies windows using recursive digital Butterworth filters avoiding phase distorsions.

5.2.

In order to build an adequate model for the whole area of the Lisbon region, it was considered, according to the field performance, that grouping the profiles into three zones — West, Northeast and South —, the adjustment could be improved. In fact, geological and historical seismicity knowledge, largely justify this strategy, Ref. 16, 18, 19.


NE ZONE
W ZONE
SOUTH ZONE
TAGUS RIVER
Alcântara, P.E.
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
1A
2
2A
3
3A
5
5A
6
7
9
9A
10
10A
11
11A
13
14
15
16
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45A
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47
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48A
49
58
59
60
61
63
64
66
67
68
68A
69
70
71
73
74
75
76
77
78
79
GENERAL LOCATION
LISBON
9°
⑨ - PROFILE NUMBER
●47 - STATION NUMBER
SCALE
0 1 2 3 km
N

Fig. 7.

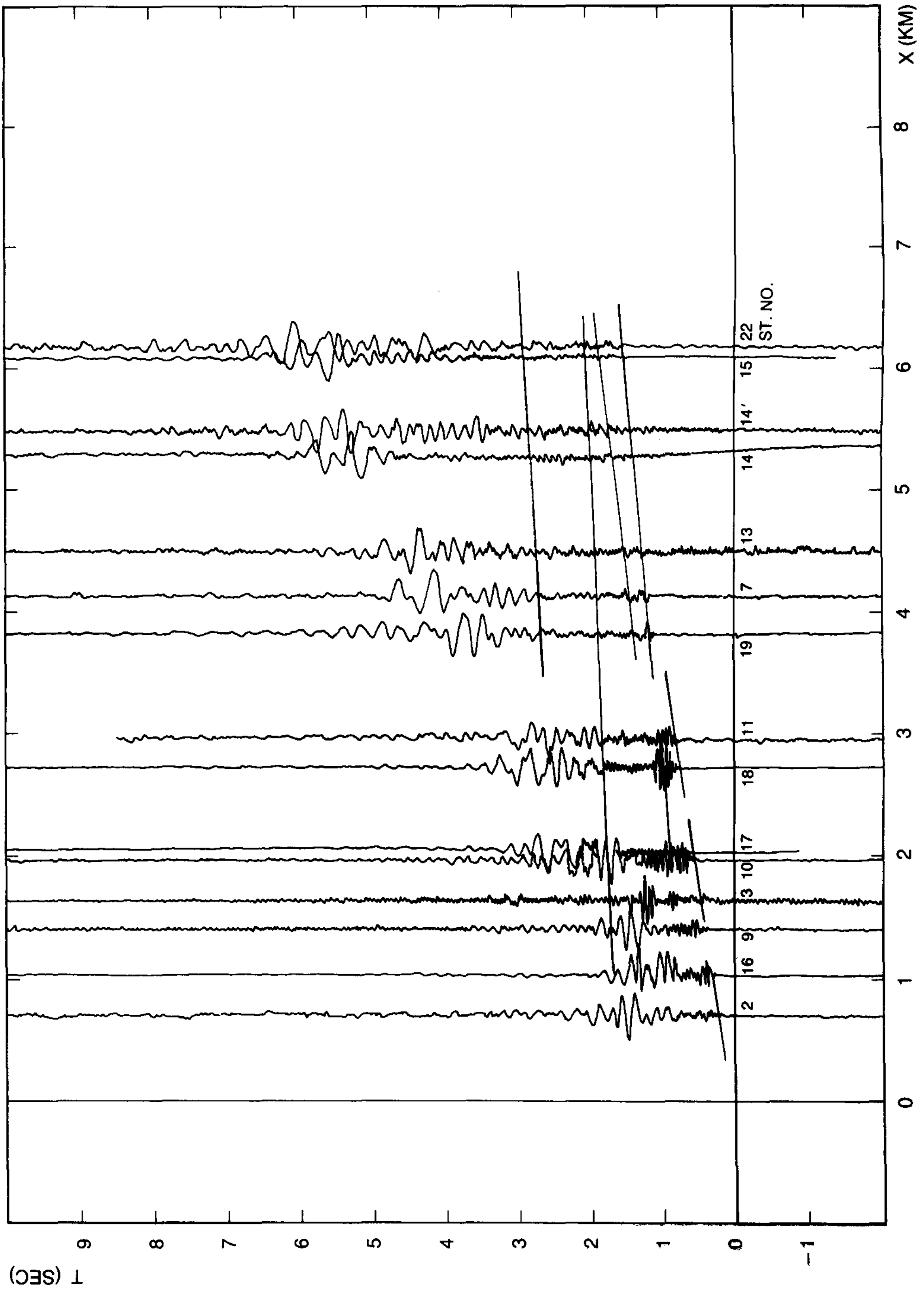

X (KM)
8
7
6
5
4
3
2
1
0
ST. NO.
22
15
14'
14
13
7
19
11
18
17
10
3
9
16
2
T (SEC)
9
8
7
6
5
4
3
2
1
0
−1

Fig. 8.

Some results are summarized in Figure 8, where the « record sections » composed of the vertical component, Z, of velocity measurement are displayed. By « record sections » we mean the arrangements of seismograms made taking into account the stations located within angular sectors less than 60° corresponding the three above mentioned zones. The motion for these record sections was band-pass filtered (0.1-30Hz) for the above three zones and also for the whole set.

The identification of patterns of wave propagation was performed filtering the initial record in a low (0.1-5Hz) and a high (8-30Hz) band pass for the Z-component and for each one of the three zones.

5.3.

The structure of the intermediate deep crust shows an unusually large variation according to the model of previous studies concerning the area of the Lower Tagus River Valley, Mendes Victor *et al.*, 1980. That model obtained from seismic experiments, is consistent with the Bouguer anomaly distribution. The model exhibits variations in both the Moho and the intercrustal reflector ; nevertheless the crustal structure under the sedimentary cover can be described by the simple approach presented in Figure 9. We used this simple model as a first iteration to obtain local shallow models for the three above refered zones. The inversion techniques make use of the Herglotz-Wiechert algorithm, H.W., the Ray-tracing technique, Ref. 20, and synthetic seismograms.

Energy from blasts was not enough to attain the Moho and the identification of an intercrustal reflector at 17 km depth was impossible.

The crustal model for the Northeast Zone, Figure 10 is entirely similar to the West Zone with the following differences :

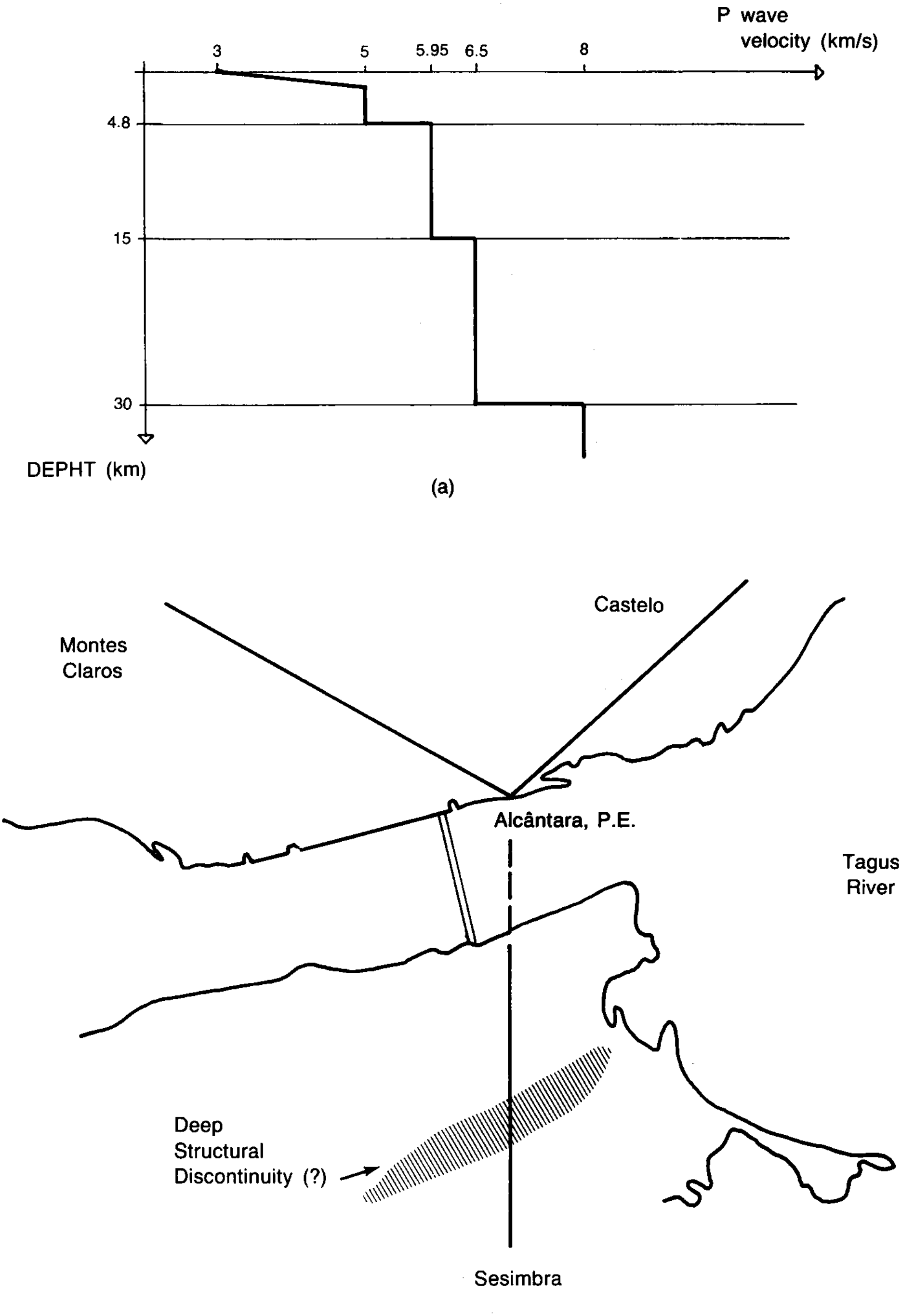
1. the outer 700 m should have slower layers, specially the first 100 m with a constant V = 1.8 km/s ;
2. the reflector at 1.75 km depth was moved to 1.60 km.

The South Zone is composed by stations scattered in a sector of about 60°, the closer one due to the presence of the River, at 2 km from the P.E. and the farthest at 8 km. They are not evently spaced, forming three main groups.

The record section is characterized by the presence of two main apparent discontinuities in first arrivals, at distances to the P.E. respectively of approximately 3 km and 5.5 km.

Model studies for this zone were conducted under two main lines which are based on the assumption of two different tectonic interpretations :

— Model 1 considers that the upper crust in this zone is similar to the zones in the northern River bank. Slight surface layer corrections were introduced for the benefit of the trial.


P wave velocity (km/s)
3
5
5.95
6.5
8
4.8
15
30
DEPHT (km)
Castelo
Montes Claros
Alcântara, P.E.
Tagus River
Deep Structural Discontinuity (?)
Sesimbra

(a)

(b)

Fig. 9.

— Model 2 considers a lateral discontinuity in depth at a distance of approximately 4.5 to 6 km from the P.E. as sketched in Figure 9 — According to the geological interpretation, Ref. 16, and to previous models established in the upper section of the Lower Tagus River, Ref. 16, a vertical discontinuity is believed to be present in the zone clarifying the geological process of setting the sedimentary Tagus basin.

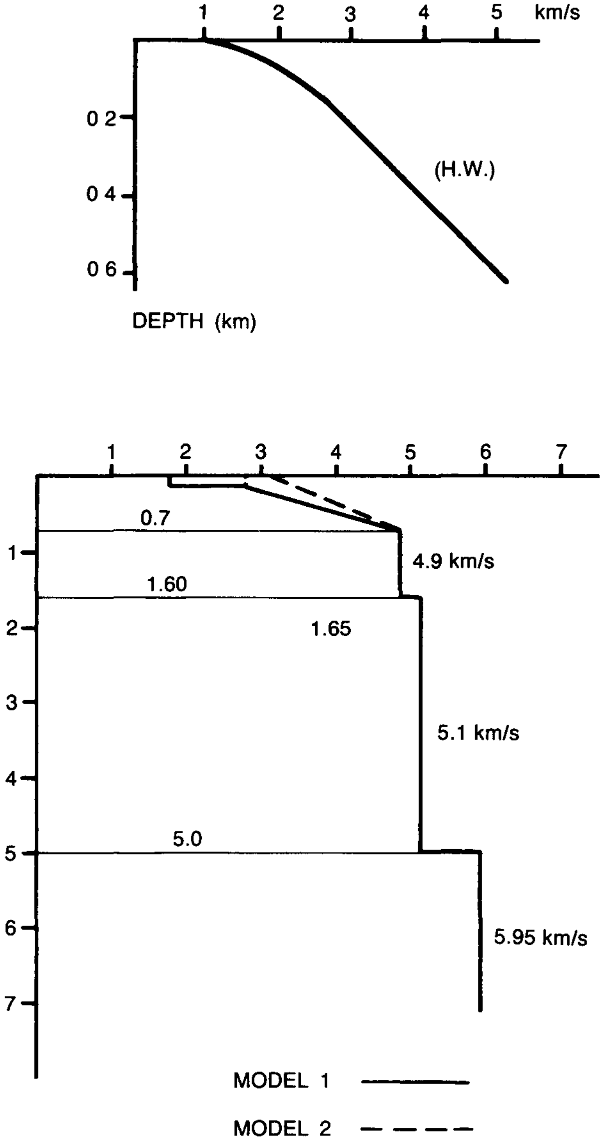


Fig. 10.

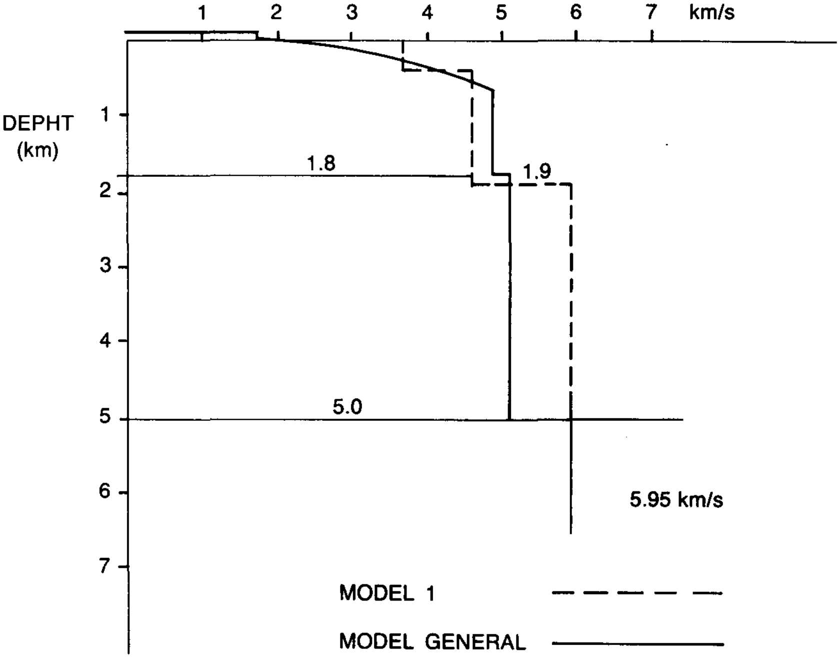


Fig. 11.

The velocity profile for Model 1 is presented in Figure 11 together with the general model of Figure 9. In this zone, topographic elevations were taken into account by adding a constant 100 m above the sea level with a velocity of 1.6 km/s. As it can be seen in the figure, the main difference to the general model is the extension of the deep layer with V = 5.95 km/s from 5.0 km to 1.9 km depth, creating a larger velocity contrast at this last interface.

For the South Zone Model 2, Fig. 12, was developed, Ref. 19, in order to study the hypothetic vertical discontinuity. Ray-tracing techniques were used in a very detailed way as to investigate the reflected, refracted and head wave energy at the different interfaces identified :

1. Interfaces *17* and *19* are invisible for reflected and head waves.
2. Energy from interface *19* is only received at emergent angles between 56 ° and 50 °.

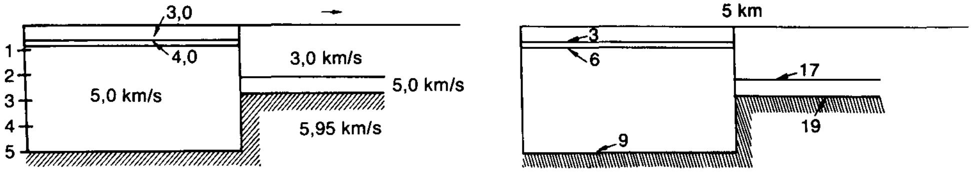


Fig. 12. Model 2 for the South Zone : velocity profile and identification for reflectors.

3. The discontinuity with an horizontal decrease of velocity causes a deflection of reflected and refracted waves with effect at 8 km and a convergence of rays in a very limited extension.

With the available records it is impossible to solve the controversy between Model 1 and Model 2 as they both constitute necessary conditions. We need a higher density of stations to be able to set the sufficient conditions.

The experiment conducted in the metropolitan area of Lisbon, taking advantage of low charge explosions in the Tagus river bed was conclusive enough about the upper part of the crust up to 6 km.

Using different techniques of interpretation it was possible to propose very plausible models and evaluate reasonably the effect of propagation in order to adjust the travel times in the best way. The limitations of the process constraint very much the windows of the reasoning towards more accurate models, nevertheless those ones could very well serve as a basis for the simulation of the surface structure, such as those we are interested in.

5.4.

According to the seismograms obtained through the mobile stations, Fig. 7, and using the spectral analysis (Barrodale and Erickson, Ref. 14) the frequency of maximum power pics have been calculated. The distribution of the values have two major modes in the range of $f_c = 2{,}9 \pm 0.5$Hz and $f_c = 6{,}3 \pm 0{,}4$ Hz, whose correlations with the geological local conditions are difficult to obtain without further and distinct considerations (Fig. 13).

6. BUILDINGS STOCK EVALUATION

The behavior of existing buildings during earthquakes is very difficult to predict and depends upon a great number of parameters. Buildings of different types, ages, number of stories and material properties exist in the metropolitan area of Lisbon. Furthermore, buildings in Lisbon are laterally supported by each other with discontinuities in height and in plan. The existence of a first floor transition to accomodate wide open spaces is very common. They may be located in a flat zone or at a steep street and may be in a good or bad structural condition due to lack of repairing.

The buildings are classified into 5 different categories according to their main structural properties (n° of stories, type of construction, configuration in plan and height and conservation) and their basic cost value is attributed according to location, business and utility.

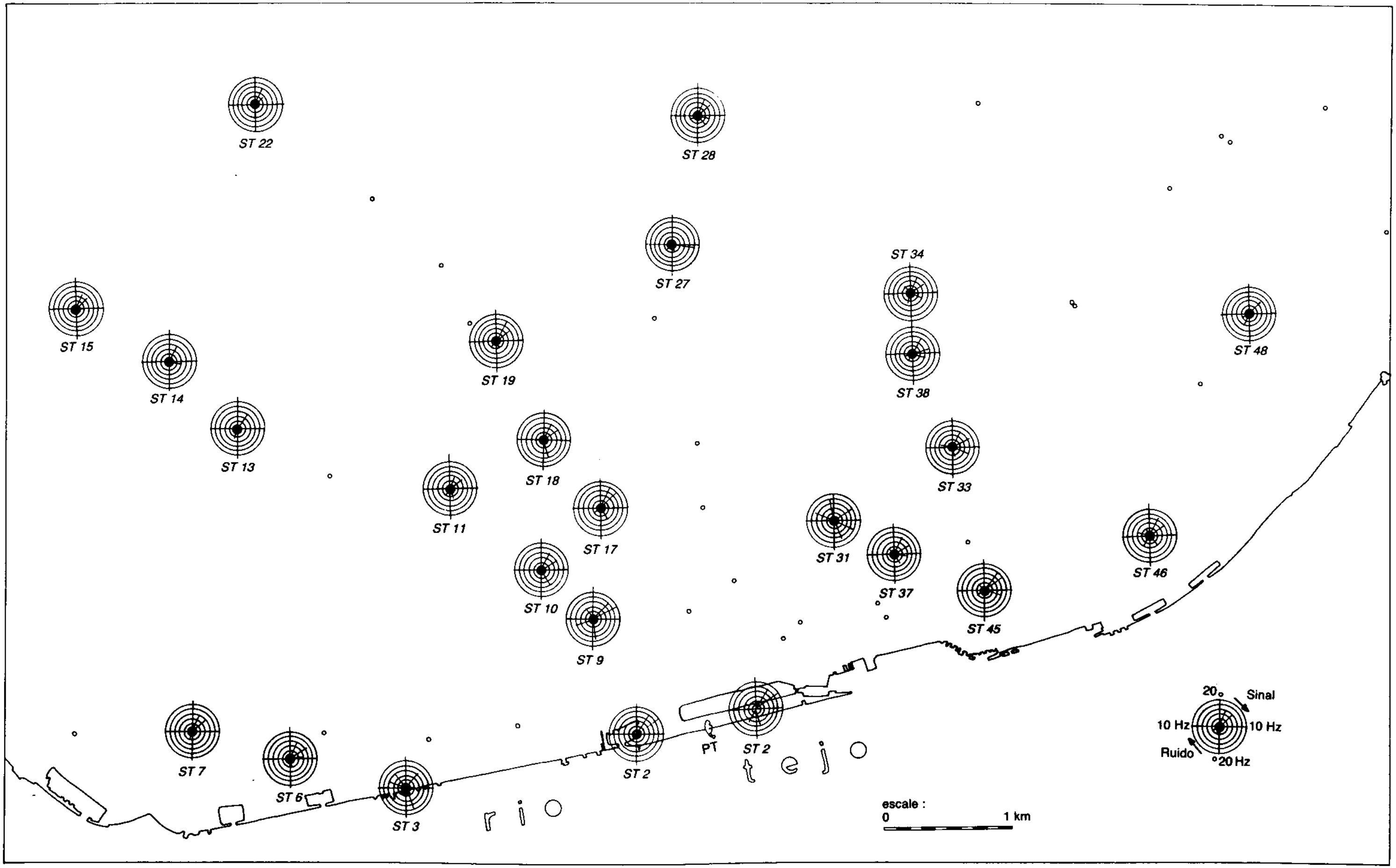

ST 22
ST 28
ST 27
ST 34
ST 15
ST 48
ST 19
ST 38
ST 14
ST 13
ST 18
ST 33
ST 11
ST 17
ST 31
ST 37
ST 46
ST 10
ST 45
ST 9
20
Sinal
10 Hz
10 Hz
Ruido
20 Hz
ST 7
ST 6
ST 3
ST 2
PT
ST 2
rio tejo
escale :
0
1 km

Fig. 13.

Typification of buildings in Lisbon

BUILDING CATEGORY

A — Masonry stone buildings prior to 1880, in bad shape. (Freq > 2.5 Hz) ;

B — Masonry stone buildings prior to 1880 with horizontal ties and in good shape. (Freq > 2.5 Hz) ;

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

D — Dual Structures with masonry resistant walls + RC slabs or RC moment resistant frames heavily infilled with non-resistant brick walls. (Freq > 2.5 Hz) ;

E — Modern RC buildings designed for same lateral load. (Freq. < 2.0 Hz).

With the objective of characterizing structurally the construction of Lisbon, a survey was initiated. About 30 parameters (Table II) among which are the ones above referred, are considered in this enquiring. A small sample of enquires which are made from the outside of the building by teams of experts will be subjected to confirmation of actual structure. The buildings selected will be analysed according to the present knowledge of earthquake engineering and vulnerability curves derived. In some cases additional testing such as measurement of frequencies of vibrations might be used. Important, dangerous or special structures whose knowledge and behavior is essential to disaster preparedness are always studied in detail.

The survey will be completed and a general formulation to assess building vulnerability will be determined but by now, a pilot study for a small area of the town is under way and results briefly referred in the following sections.

We selected for this study a small zone of the Lisbon area, corresponding to about 1/15 of the total stock of buildings in the town, a representative sample of the existing building types. The distribution of Mercali Modified Intensities VIII, IX and X, which are upper bound scenarios for the Gorringe bank source constitutes the seismic input of our analysis.

In order to make an application of methodology referred to special teams have been prepared for the benefit of the necessary homogeneity. The results of this inquiry have been synthetized using adequate formats as it is showed in the Tables III and IV.

The considerations of the first phase as contained in the Table V, enable the computation of some preliminary estimations for three different zones of the town of Lisbon.

TABLE II. — ENQUIRE FOR EVALUATION OF BUILDING STOCK IN THE TOWN OF LISBON. TYPICAL OPTIONS.

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)	Use (18)	Structural type (20)
1. Exact date of construction	1. Housing	1. Wood
2. Before 1755	2. Industry	2. Masonry walls + wooden slabs
3. 1755-1850	3. Business	3. Masonry walls + metallic supports
4. 1850-1890	4. Offices	4. Masonry walls + concrete slabs
5. 1890-1920	5. Warehouse	5. Masonry walls + concrete slabs + first floor with mom frame
6. 1920-1940	6. Hybrid : Housing + offices	6. R.C. mom resisting frame + infilled brick walls
7. 1940-1958	7. Hybrid : Industry or business + Housing	7. R.C. mom resisting frame
8. After 1958	8. For demolition	8. Other

TABLE III

Geograpic area	286 ha
No. of blocks	185
No. of buildings	3 280
Total no. of stories	15 692
Total no. of dwellings	22 264
Average no. of stories	4.32
Predominant epochs	1980-1920 – 36 % 1940-1950 – 23 %
Average area per buildings	280 m^2
Average area per dwelling	112 m^2
Predominant uses	housing – 42 % mixed : housing + offices – 46 %
Predominant structural type	masonry + wooden slabs – 58 % reinf. conc. mom frame + infilled brick walls – 19 %
Average state of conservation	average – 55 % bad – 20 %
INDICES	
Occupation : *Land covered* Geographic area	0,32
Use : *Construction area* Geographic area	1.56
Refurbishment of building stock : *new construction* old construction	40 %

TABLE IV

LINE — Variable V8 (construction period)
ROW — Variable V9 (no stories above ground)

(%)

0 %	Before 1755 2.	1755-1850 3.	1870-1930 5.	1930-1940 6.	1940-1958 7.	After 1958 8.	TOTAL
1.	28.6	7.3	6.4	3.6	3.5	7.6	5.6
2.	33.3	8.0	29.8	9.7	2.9	3.0	14.4
3.	19.0	28.5	16.4	17.2	5.3	3.7	12.4
4.	19.0	30.7	19.7	38.0	25.1	9.9	23.2
5.	.0	20.4	22.1	21.4	17.8	13.0	19.3
6.	.0	5.1	4.8	7.4	25.3	26.6	13.6
7.	.0	.0	.8	.7	13.2	17.8	6.4
8.	.0	.0	.1	.7	5.7	9.7	3.1
9.	.0	.0	.1	1.0	.8	5.0	1.2
10.	.0	.0	.0	.0	.1	2.4	.4
11.	.0	.0	.0	.3	.1	.7	.2
13.	.0	.0	.0	.2	.1	.2	.1
15.	.0	.0	.0	.0	.0	.2	.0
19.	.0	.0	.0	.0	.0	.2	.0
TOTAL (No. buildings)	21	137	1196	611	768	538	3271

TABLE V

CATEGORIES		A	B	C + D	E_1	E_2
S. JORGE DE ARROIS		1.0 %	6.5 %	59.5 %	13.8 %	19.2 %
S. JOÃO DE DEUS		—	0.7 %	46.0 %	40.2 %	13.1 %
ALTO DE PINA		—	0.3 %	54.0 %	35.6 %	10.2 %
TOTAL	%	0.6 %	4.2 %	55.2 %	23.5 %	16.5 %
	N° STORIES	(1-4)	(2-6)	(2-7)	(2-7)	(2-11)
Expert opinion	%	5 %	—	47 %	28 %	20 %
	N° STORIES	(2-5)		(3-6)	(4-7)	(5-12)

TABLE VI
SUMMARY OF BUILDING DAMAGE PRODUCED IN 13 PAST EARTHQUAKES

EARTHQUAKE	MMI	DEATH	INJURED/DEATH		DAMAGE			
			Severe injured	Total	Monum.	Masonry	R Conc. n< 5	R Conc. n > 5
CARACAS	VI-VIII	$136/10^6$	0.6	6	Mean	Mean	Low	1.43% collapse (VIII) Mean
FRIULI	VIII-IX	1% localy 4.5%			"	"		
MONTENEGRO	IX		1.7	12		27% 0.25 g causes 50% collapse		2% collapses
MANÁGUA	VIII-IX	2.2%		5		severe	moderate	
IMPERIAL COUNTY	VII	0	-	-		slight		few
AGADIR	IX	33%				severe		moderate
ROMÉNIA	VII-VIII	0.12%		5		large		15% of damaged buildings collapse large
EL ASNAM	IX	4%						brittle failure
GUATEMALA	VII-IX	0.4%		5	moderate	large		few
SUL ITÁLIA	VII X	$74/10^6$		2.5				2 buildings collapsed
AÇORES 1980	VII-VIII	0.1%			large	large		few
LISBOA 28/2/1969	VI	-	-	-	no	slight		-
GRÉCIA 1981	VIII				large	moderate		

American Statistics of death
(dwelling.-Calif)

VII	$10/10^6$	$20/10^6$
VIII	$150/10^6$	$300/10^6$
IX	$500/10^6$	$1000/10^6$

$$\frac{\text{Injured}}{\text{death}} = 4:1$$

7. VULNERABILITY

Vulnerability curves were subjectively assigned to each category based on type of construction, natural period of vibration (n° of stories plus type) and on statistics obtained from 13 recent earthquakes (Table VI). Some statistics show that, without further developed studies, the percentage of victims and injuries varies tremendously, it is difficult to correlate with building damage.

The statistics of the damages observed in Lisbon after the occurrence of the last earthquakes specially taking into account the age of the building, have been used for the assumption of the vulnerability as follows :

TABLE VII

INTENSITY	BUILDINGS				
M.M.	A	B	C	D	E
VII	1 %	0,05 %	0,5 %	0,05 %	0,1 %
VIII	5 %	0,1 %	1 %	0,1 %	0,5 %
IX	10 %	1 %	5 %	1 %	0,8 %
X	50 %	10 %	10 %	2 %	1 %

For reasons of applicability of this study, the metropolitan area of Lisbon (county) was divided into 23 units showing some kind of homogeneity in building and population morphology. Each one of these unit areas is considered as having uniform characteristics.

8. SPACE-TIME POPULATION DISTRIBUTION

The same 23 units just mentioned have been taken by specialists searching for an adequate pattern of the space-time evolution of the Lisbon population.

The figure 14 showing how Lisbon expanded since 1147 was a guidance for the division established above.

The time evolution of the population concerned is displayed on figure 15 where the periods 0-7,30 ; 7,30-9,30 ; 9,30-18 ; 18 -20 and 20-24 hours have been considered.

Simultaneously the location of important buildings, hospitals, schools, industries and commercial complexes has been used to clarify the social-economic value of each unit.

In the figure 16 we have just considered, in thousands, the population of the same Lisbon units, the dashed ones were considered for the model example.

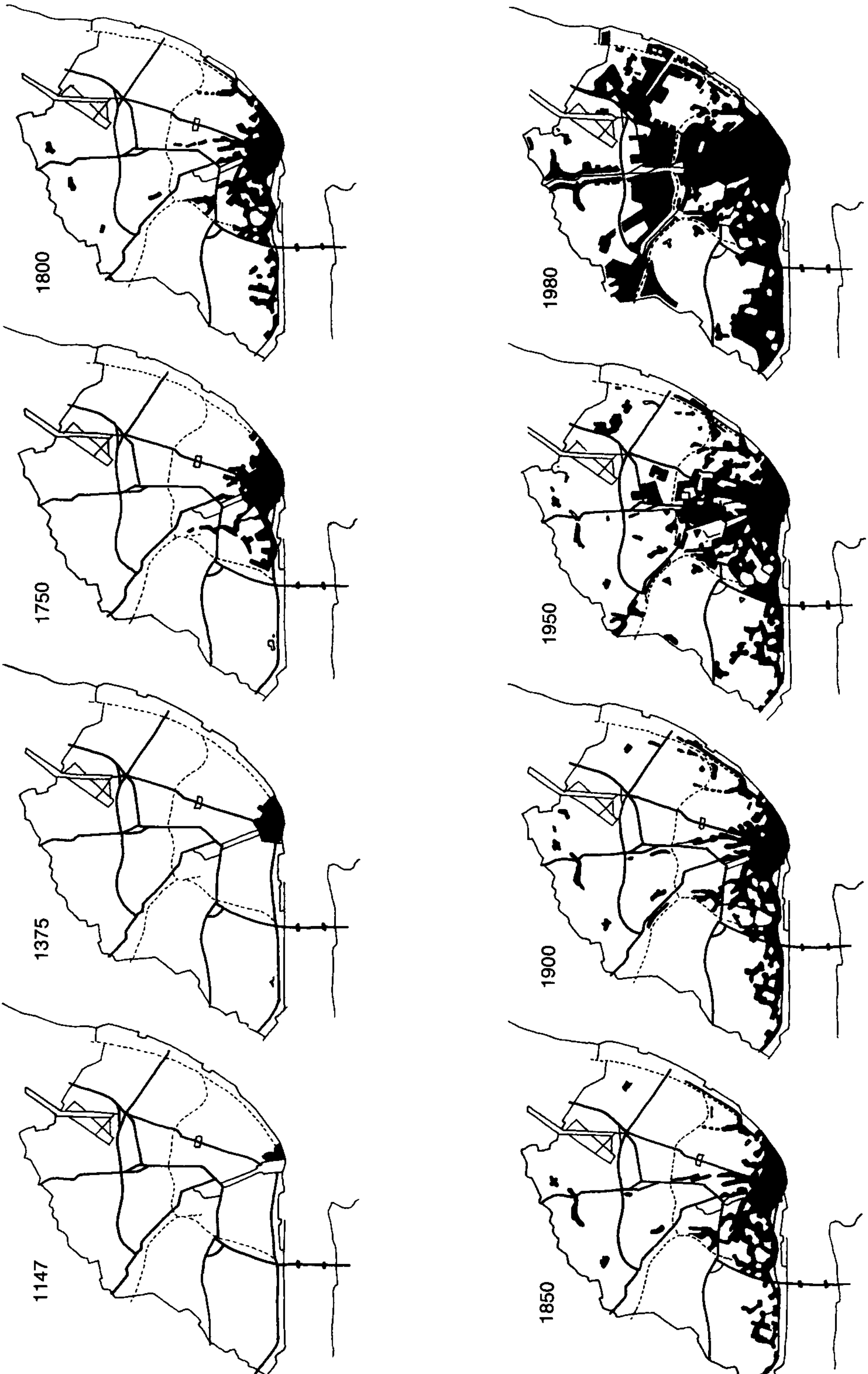


Fig. 14.

9. THE SEISMIC IMPACT MODEL

The mathematical model to analyse the seismic impact is developed along the following :

a. Lisbon is divided into 23 unit areas (j = 1, 23) ;
b. 5 classes of buildings (i = 1,5) with n_i stories ;
c. 4 seismic source of earthquake generation-scenarios (k = 1,4) each one associated with a certain probability distribution of occurrence ($F_k(.)$;
d. 6 classes of intensity due to microzonation reasons (l = 1,6) ;
e. 5 periods during the day (m = 1,5).

If :

$S_{j,k,l}$ (w) is the response or power spectrum in unit j, soil l, due to source k ;

$V_{i,j,k,l}$ (w) is the mean vulnerability for $S_{j,k,l}$ (w) in buildings of class i with n_i stories and plant area api

$P_{j,m}$ is the n° of persons in unit j during the period m ;

$N_{i,j}$ is the n° of buildings of class i in unity j ;

$C_{i,j}$ is the value of construction per m² as a function of class i and location j (more correctly, $C_{i,j}$ depends on others factors such as utilization and social and economical functions) :

A_j is the area of unit area j : $a_{l,j}$ is the area of class of intensity l in unit j.

The following functions can be obtained for unit j and source k (Ref. 11) :

$$\text{ILF (Individual Loss Function) } i,j,k = C_{i,j}\, a_p n_i N_{i,j} \underset{e}{\Sigma_l}\, V_{i,j,k,l}\, \frac{a_{l,i}}{A_j}$$

$$\text{GLF (Global Loss Function) } j,k \underset{e}{=} \Sigma\, ILF_{i,j,k}$$

$$\text{AP (Affected Population) } j,k,m = \sum_{i}\sum_{l} V^{p}{}_{i,j,k,l}\, \frac{a_{l,j}}{A_j} N_{j,j} P_{m,j}$$

Where $V^{p}{}_{i,j,k,l}$ is taken as percentage of population affected as a function of vulnerability $V_{i,j,k,l}$ (for instance if $V_{ijkl} > 50\,\%$, $V_{ijkl}P_l \sim 1$). To compare different damage in different units the Density of Losses (DL) and the Density of Population Affected (DPA) are more appropriate.

$$DLj,k = GLF_{j,k} \,/\, \underset{e}{\Sigma_i} C_{i,j}\, a_{ni}\, N_{ij}\ ;\ DPA_{j,k} = AP_{j,k,m} \,/\, P_{m,j}$$

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

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

To illustrate the model, an application was made for 3 unit areas under seismic scenario of Gorringe (Table VIII) : the first two, Alcântara and Olivais are representative, respectively, of old and new construction areas ; Baixa is an area with fluctuations of population of order 1 : 8 along the day.

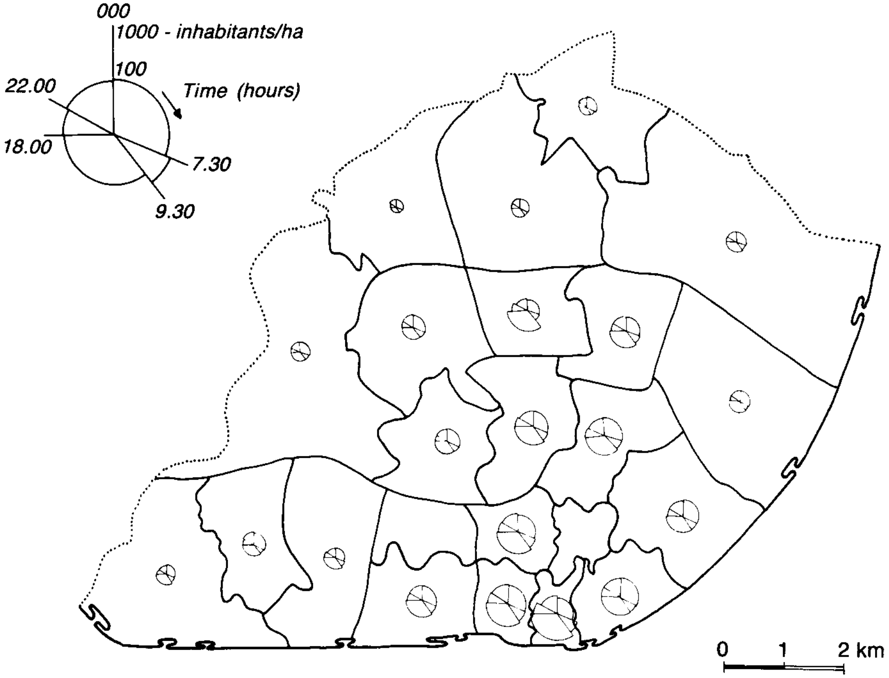

000
1000 - inhabitants/ha
100
22.00
Time (hours)
18.00
7.30
9.30
0
1
2 km

Fig. 15.

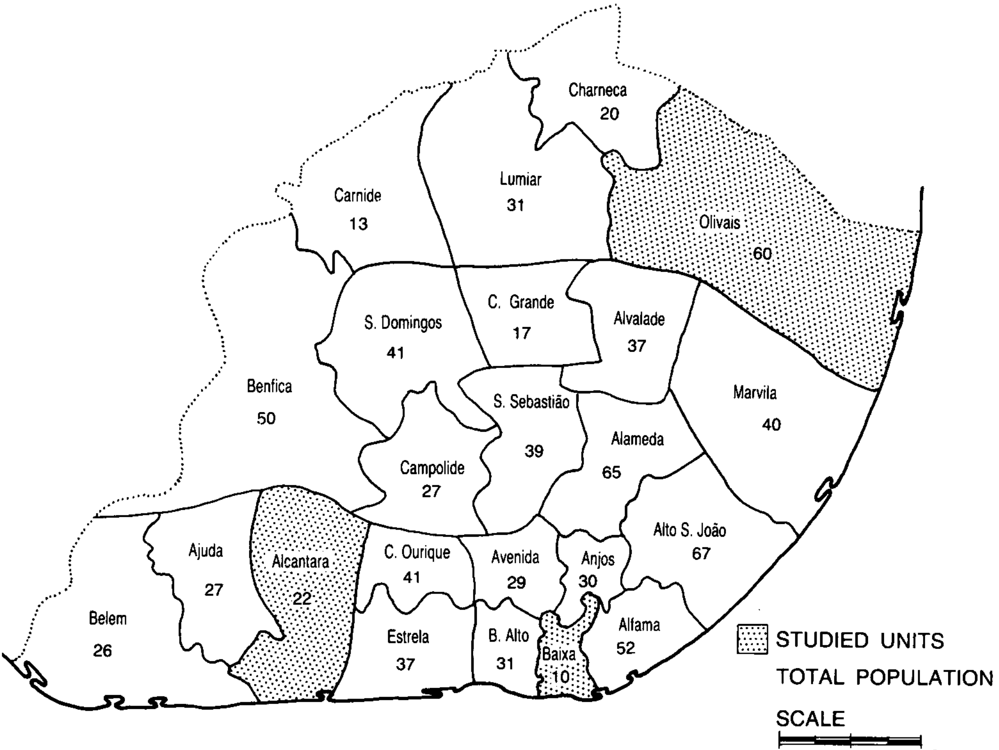

Charneca
20
Carnide
13
Lumiar
31
Olivais
60
S. Domingos
41
C. Grande
17
Alvalade
37
Benfica
50
S. Sebastião
39
Marvila
40
Alameda
65
Campolide
27
Alto S. João
67
Ajuda
27
Alcantara
22
C. Ourique
41
Avenida
29
Anjos
30
Belem
26
Estrela
37
B. Alto
31
Baixa
10
Alfama
52
STUDIED UNITS
TOTAL POPULATION
SCALE
0
1
2 km

Fig. 16.

TABLE VIII

EVALUATION OF SEISMIC IMPACT FOR THREE ZONES OF LISBON

UNIT AREA	BUILDING CATEG.	N_{ij}	n_i	a_i (m^2)	ILF $x10^3$	GLF $x10^3$	AP (inhab)	DL	DPA
ALCÂNTARA	A	108	3	180	29.2	187.0	$v^p > 50\%$ 2835	0.23	$v^p > 50\%$ 0.13
Popul. 22 600	B	-	-		-				
Estimated	C	442	4	150	104.4				
Buildings 774	D	108	4	130	15.6		$v^p > 80\%$ 2712		$v^p > 80\%$ 0.12
C_{ij} = 1.85 units	E	116	6	100	67.0				
OLIVAIS	A	-	-		-	227.1	$v^p > 50\%$ 1125	0.20	$v^p > 50\%$ 0.05
Popul. 60 800	B	-	-		-				
Buildings 1232	C	370	2.5	150	77.9				
	D	-	-	130	-		$v^p > 80\%$ 87		$v^p > 80\%$ 0.004
C_{ij} = 1.25 units	E	862	9	100	149.2				
BAIXA	A	-	-		-	975.7	$v^p > 50\%$ 22154	0.53	$v^p > 50\%$ 0.98
Popul. 12 600	B	274	5	180	956.6				
Buildings 238	C	3	5	150	10.5				
C_{ij} = 7.33	D	3	5	130	6.1		$v^p > 80\%$ 35		$v^p > 80\%$ 0.002
Units	E	3	5	100	2.5				

According to the distribution of intensities shown in Fig. 6 it was possible to establish the non-homogeneous behavior within each unit and evaluate the risk function defined above. For each unit, the ratios of different building categories as well mean n° of stories were estimated by urban experts, (Ref. 12) ; 0-7,30 population distribution ; the mean area per building was assigned to each category according to the evolution of living standards with time ; finally the estimation of C was made taking into consideration the volume of transactions and services related to the 1976 statistics.

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

An analysis of uncertainties in the different tasks of this presentation will also be studied in such a way that final risk estimations (DL and DPA) are associated to confidence limits. It can already be emphasized that the largest uncertainties come from the evaluation of intensities of shaking throughout the town and from vulnerability functions.

To implement the estimation of intensities (microzonation), it is strongly recommended the installation of a network of ground motion instruments that can record microseisms and large earthquakes. Vulnerability functions can only be implemented if detailed analytical studies and observation on real buildings are made.

Luis Alberto MENDES VICTOR
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