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A STATISTICAL EVALUATION OF DAMAGE TO BUILDINGS IN THE THESSALONIKI, GREECE EARTHQUAKE OF JUNE 20, 1978

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SUMMARY

The June 20, 1978 earthquake in Thessaloniki, Greece caused several damages to the buildings of the city. After the repair procedure was completed, a General Purpose Data Base was organized, concerning the buildings of the eastern part of the city. Several statistical analyses were carried out using this Data Base. In this paper results are presented and conclusions are drawn about the quantitative effect of the buildings structural characteristics on their damage pattern and repair cost and about the correlation between existing microzonation maps and damage distribution. The post-earthquake usability classification system of the buildings which was used in the city is also discussed.

INTRODUCTION

The earthquake of June 20, 1978 The main shock of the seismic sequence in the region of Thessaloniki, Northern Greece during the summer of 1978 occured on June 20. The earthquake had an epicenter located at a distance of about 25 km NE of the city, a focal depth of about 8 km, a magnitude of M = 6.5, a maximum ground acceleration of 0.15 g and a predominant period of about 0.45 sec. (Ref. 1). From the social and economical point of view the earthquake caused a multistorey R/C building collapse, (39 deaths), a few partial collapses and extended damage to buildings.

The research area The research covered the eastern part of the city (almost 50 % of the total constructed area, sampling density 1:2 of the blocks, 5740 buildings).

The soil conditions Across the seaside the soil profile consists of sediments (∿5 m), of brown clay (∿5 m) and of brown and red clay with sand and gravel (∿150m). The bedrock surface depth varies from 160 m on the seaside to about 1 m at the upper part of the city. No soil instability or geological problem (settlements, liquefaction, faulting) was reported after the earthquake in the research area.

The buildings Although the city is very old, most of the buildings are relativily new. This renovation of the city is due to the fire of 1917 at the center of the city and to the gradual growth of the population, especially after the Second World War (1981 : 800.000 inhabitants). In the research area 75.7 % of the buildings were constructed after 1950. The most frequent (64.6 % of the total) load carrying system is that of the R/C dual system, used for buildings up to 10 stories high. For low-rise buildings (1-4 stories) in many cases masonry bearing walls were used (31.0 %). In a few cases (4.4 %, 1-5 stories) a mixed structural system consisting of R/C frames and masonry bearing walls was used. Masonry infills is the rule for the partitionings. In Fig. 1 construction activities versus time are shown.

The construction codes The main codes used for the construction of buildings were the Code for R/C Structures (1954), the Recommendations for Aseismic Design (1954) and the Code for Aseismic Design (1959).

The usability classification system The post earthquake usability classification system, used for the city and the villages affected by the earthquake, was based on the damage inspection of each particular building by a team of two civil engineers. They used a not detailed inspection form, easy to fill, and they posted a self-adhesive coloured card. Each colour corresponded to a specified level of damage:

- green : No reduction in seismic capacity. Immediately usable. Entry unlimited.
- yellow : Reduced seismic capacity. Usage not permitted before repair and/or strengthening.
  Limited entry is permitted.
- red : Unsafe. Sudden collapse is probable. Usage or entry is prohibited.

OBJECTIVE OF THE RESEARCH

The objective of the research presented here is a General Purpose Data Base organization, concerning the buildings of the eastern part of Thessaloniki. Using this Data Base the following were examined: the quantitative effect of the buildings structural characteristics on their damage pattern and repair cost, the correlation between existing microzonation maps and damage distribution and the effectiveness of the post-earthquake buildings usability classification system.

DATA BASE ORGANIZATION

At first a data collection form was prepared in a format suitable for transfer to computers for analyses of the relevant parameters. The design of the data collection form had to take into consideration the limited time disposed by the part-time working staff for this programme. As a guide, the post-earthquake damage inspection form proposed by UNIDO (Ref. 2), was used, properly shortened and oriented to the objective of the research. It finally included the following five groups of data.

(a). Building identification: Street, number of building, number of block, nearest police department.
(b). Configuration parameters: Type of structure, type of structural system, number of stories, basements and appentages, usage of the building, position of the building in the block, plan configuration, levels of the slabs of the adjacent buildings, first floor stiffness relative to others, stiffness eccentricities in plan, existance of short columns, volume of the building.
(c). Construction period: Year of construction.
(d). Usability classification: The colour of the card posted on the building by the post-earthquake inspection team (green, yellow, red).
(e). Repair and strengthening data: Cost of repair or reconstruction of the non-structural elements and the incorporated installations, cost of repair or strengthening or reconstruction of the structural elements, type of damage of structural and nonstructural elements.

The groups (a), (b), (c) were filled in the field by teams of two engineers while groups (d), (e) were filled in the office. For the latter, the files of the Ministry of Public Works were used. Additional informations (i.e. maps, photos) were used whenever possible. For the 5740 buildings covered by the programme, 9 part-time engineers for 18 months were needed.

After the data collection procedure was completed, the data were transferred to a computer and suitable programs were prepared for the analyses.

It must be pointed out that other significant parameters (i.e. quality of materials and workmanship) were not examined because of the data collection time limitation or the high degree of subjective judgment involved.

RESULTS AND CONCLUSIONS

Correlation between structural characteristics and damage Table 1 shows the influence of the structural characteristics on the variation of the percentage of the damaged buildings. In all cases, the buildings with normal structural layout were less affected by the earthquake. Higher reduction corresponds (in an order of minor significance) to buildings which were low-rise, stiff, had normal plan configuration, no appentages, normal stiffness distribution in elevation and were free in the block. Short columns, stiffness eccentricities in plan and basements did not affect the damage percentage (Fig. 2). It can be concluded that, although some exceptions exist, standard provisions of current seismic codes concerning normal structural layout proved to be effective in seismic hazard reduction. An almost linear reduction of the percentage of the damaged buildings versus construction period was found (Fig. 3). The Code for Aseismic Design (1959) had no significant effect on the hazard reduction. Local maxima correspond to peaks in building construction activity.

Correlation between microzonation maps and damage distribution To examine the damage distribution in the research area, the map shown in Fig. 4 was drawn. In this map, zones of relatively low, moderate and high cost of repair are shown. In the same map, zones of predominant frequencies and site amplification factors (after Sherif, 1973) (Ref. 1) are also drawn. The correlation between damage and microzonation maps is not bad, although damage concentration zones, not traced by the latter, appeared in some cases. It appears that the characteristics of the buildings, not affecting the microzonation maps, have equally affected the damage distribution. In any case, more research is needed in the direction of the city microzonation.

Cost of repair Table 2 shows the cost of repair per unit volume. It is significant to observe that the cost ratio between R/C, mixed type and masonry structures is almost 1 : 5 : 10. Significant part of the repair cost (44.7 %) corresponds to infills (se also Ref. 3). The total economic losses reached 1.57 % of the constuction cost.

Effectiveness of the post-earthquake usability classification system Table 3 shows the percentage of the buildings, which eventually needed some kind of repair, in regard with the colour of the card of the post-earthquake classifacation. It is apparent that the system of classification used, although simple, was quite successful.

Damage elements of R/C structures Table 4 shows the number and the percentage of the buildings having damages to the specified structural elements. It appears that the nonstructural damage is the rule.

ACKNOWLEDGMENTS

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Table 1 Influence of structural characteristics on the damage

			Buildings		Damaged	
			Number	%	Number	%
1		Type of structural system				
	a.	Reinforced concrete	3707	64.6	848	22.9
	b.	Masonry	1782	31.0	403	22.6
	c.	Mixed (Masonry + R/C frames)	251	4.4	44	17.5
2		Basements				
	a.	Yes	2903	78.3	688	23.7
	b.	No	804	21.7	160	19.9
3		Appentages				
	a.	None	1416	38.2	235	16.6
	b.	One	1386	37.4	350	25.3
	c.	Two	589	15.9	167	28.4
	d.	More than two	316	8.5	96	30.4
4		Usage of the first floor				
	a.	Parking (pilotis)	127	3.4	32	25.2
	b.	Stores	1119	30.2	271	24.2
	c.	Mezzanines	370	10.0	110	29.7
	d.	Residential	1306	35.2	227	17.4
	e.	Mixed (Residential + stores)	785	21.2	208	26.5
5		Usage of the building				
	a.	Residential and office	3646	98.4	833	22.8
	b.	Other (industry, education, etc.)	61	1.6	15	24.6
6		Short columns				
	a.	Yes	1476	39.8	325	22.0
	b.	No	2231	60.2	523	23.4
7		Number of stories				
	a.	1 - 3	669	18.0	68	10.2
	b.	4 - 6	2126	57.4	463	21.8
	c.	7 - 10	912	24.6	317	34.8
8		Position of the building in the block				
	a.	Middle	889	24.0	231	26.0
	b.	Corner (one adjacent building)	422	11.4	117	27.7
	c.	Corner (two adjacent buildings)	1495	40.3	318	21.3
	d.	Free	901	24.3	182	20.2
9		Cross section				
	a.	Square	1368	36.9	275	20.1
	b.	Rectangular	1683	45.4	378	22.5
	c.	Non-convex	294	7.9	96	32.7
	d.	Irregular	362	9.8	99	27.3
10		Staircases				
	a.	R/C shear wall cores	3313	89.4	764	23.1
	b.	Masonry	216	5.8	74	34.3
	c.	No staircases (one storey building)	178	4.8	10	5.6
11		Position of staircases shear wall cores				
	a.	Center	1613	48.7	355	22.0
	b.	Middle	540	16.3	127	23.5
	c.	Corner	1160	35.0	282	24.3
12		Slab levels of adjacent buildings				
	a.	Same levels	1267	34.2	244	19.3
	b.	One different level	1151	31.0	305	26.5
	c.	Two different levels	388	10.5	117	30.2
	d.	Free	901	24.3	182	20.2

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Table 2 Repair cost per unit volume (In drachmas 1978, 1 $ = 36 drachmas-1978)

Type of structural system	Nonstructural elements (drach/m^3)	Structural elements (drach/m^3)	Total Cost (drach/m^3)	Economic losses (% of the construction cost)
Rein. con.	12.87	17.07	29.94	1.00
Mixed	78.55	65.49	144.04	4.81
Masonry	132.00	155.68	287.68	9.59
Total	21.05	26.09	47.14	1.57

Table 3 Effectiveness of the post-earthquake usability classification system

Post-earthquake classification	Buildings finally repaired (%)
Green	11.6
Yellow	45.2
Red	81.9

Table 4 Typical damages of R/C buildings

Structural elements	Number of buildings	% of the damaged	% of the total
Total	3707		
Damaged	846		22.9
Nonstructural	815	96.3	22.0
Beams	276	32.6	7.4
Columns	196	23.2	5.3
Shear walls	242	28.6	6.5
Foundations	17	2.0	0.5

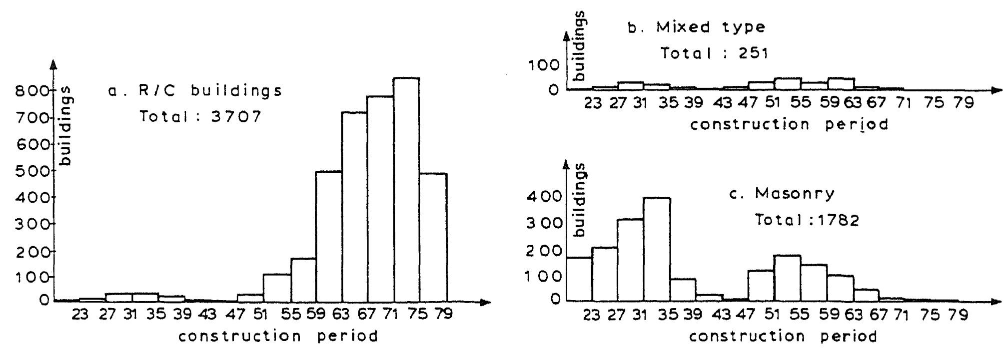


Fig. 1 Building construction activity versus time

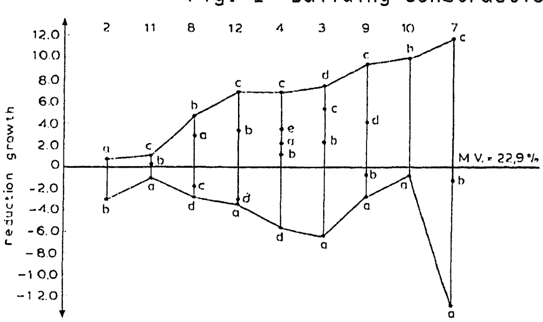


Fig. 2 Divergence from the mean value in regard with the parameters investigated (Symbols in table 1)

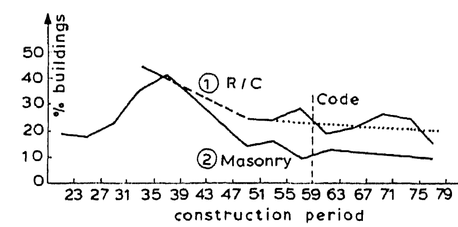
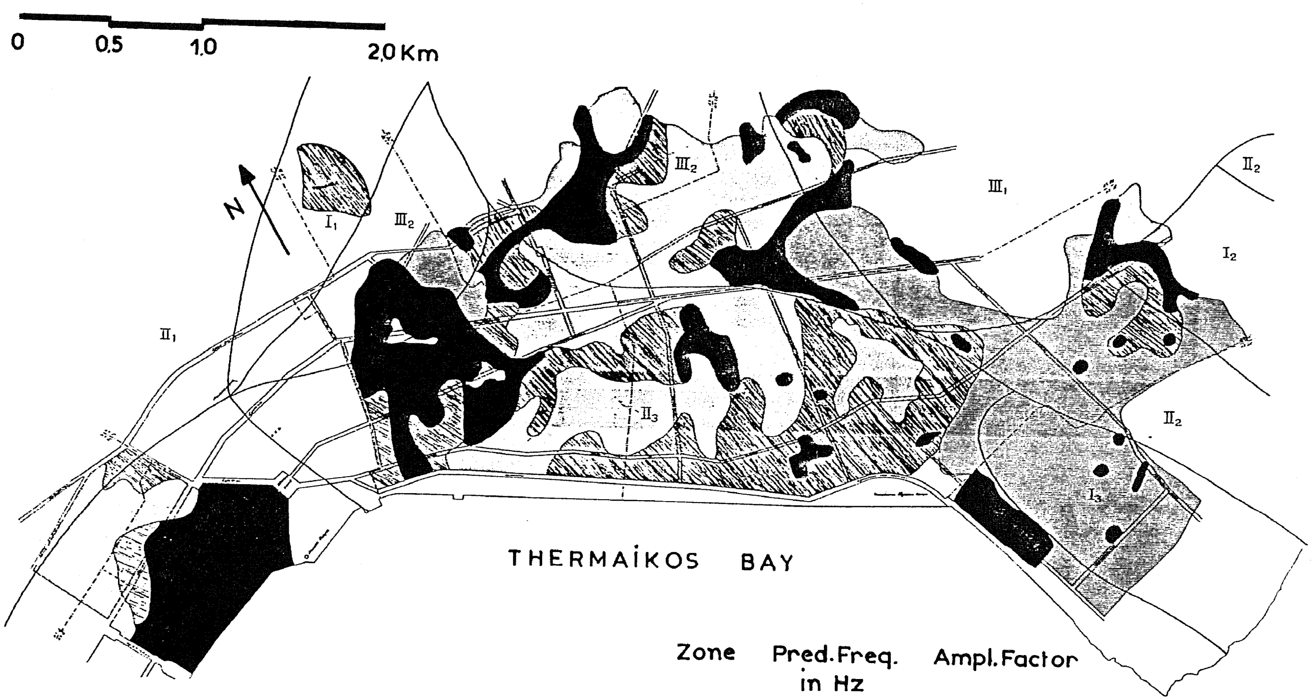


Fig. 3 Percentage of the damaged buildings versus time



LEGEND

COST OF REPAIR
(DRACHM*/M^3)

- 0÷5
- 5÷20
- > 20

*in drachmas 1978
(1$=36 drachmas 1978)

Zone	Pred.Freq. in Hz	Ampl.Factor
I_1	0.5<f<2.5	1.0<A<1.5
I_2	0.5<f<2.5	1.5<A<3.0
I_3	0.5<f<2.5	3.0<A
II_1	2.5<f<5.5	1.0<A<1.5
II_2	2.5<f<5.5	1.5<A<3.0
II_3	2.5<f<5.5	3.0<A
III_1	5.5<f<8.0	1.5<A<3.0
III_2	5.5<f<8.0	3.0<A

Fig. 4 Correlation between microzonation maps and damage distribution