Seismic Vulnerability and Risk Assessment of the Building Stock of Attica (Greece) and Correlation to the Actual Repair Cost

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SUMMARY:
A comprehensive research is presented for the seismic vulnerability and risk assessment in the urban area struck by the 7-9-1999 Parnitha's earthquake in Greece. The building stock consists of typical building types of Southern Europe and refers to 750085 buildings which are situated in 122 regions of Attica according to the 2000 year census. The evaluation of loss due to building damage in a certain region requires an assessment of both seismic hazard and the vulnerability of the building stock. Four different damage scenarios are applied based on the National Technical Chamber of Greece and also on recently developed DPMs derived from Parnitha's (Athens) damage database. A pilot methodology is developed for the seismic loss assessment in monetary terms. The statistically derived actual repair cost after the 1999 Parnitha's earthquake is compared with the results of the economic loss estimation for the risk assessment prioritizing the criteria for seismic rehabilitation of existing buildings.

Keywords: seismic vulnerability, seismic risk, risk assessment, damage scenario, repair cost

1. INTRODUCTION

Reliable earthquake loss estimation (in monetary terms) for buildings struck by an earthquake is of growing importance both for the planning of appropriate and cost effective earthquake mitigation measures, and also for the definition of insurance purposes and criteria for prioritizing seismic strengthening (rehabilitation) programmes for existing buildings. The devastating impacts of seismic events during the last decades in areas with densely concentrated population and buildings pointed out that these environments are highly exposed to human and economic losses. The evaluation of loss due to building damage in an area struck by an earthquake depends both on seismic hazard and the vulnerability of the building inventory in the certain region. Seismic vulnerability relationships attempt to predict for several building classes the degree and the extent of damage at different levels of seismic demand. Based on a quantitative assessment of seismic vulnerability, the probability of damage to given building types caused by earthquakes of various intensities can be predicted (Dolce *et al.*, 2003).

The first step for the development of any earthquake scenario is the assessment of damage in structures. Several methodologies and relations exist attempting to express damage indices in economic loss. The correlation of structural damage to economic loss (Kappos *et al.* 1998, Karabinis *et al.* 2006a, 2006b, Eleftheriadou *et al.* 2006) is indispensable for the estimation of seismic risk. Many seismic risk assessments and vulnerability studies (Baltzopoulou *et al.* 2008, Dolce *et al.* 2003 & 2006, D' Ayala *et al.* 1997, Eleftheriadou 2009, Eleftheriadou *et al.* 2011a, 2011b, 2012a, 2012b, Faccioli *et al.* 1999, Kappos *et al.* 2002, 2007, Karabinis *et al.* 2006c, 2007, Lagomarsino *et al.* 2006, Rossetto *et al.* 2003, Rotta *et al.* 2006) have been carried out, and their results constitute important tools in the mitigation of losses due to future seismic events, e.g. allowing disaster management plans to be drawn up. The National Technical Chamber of Greece (NTCG) with the cooperation of Greek Universities provided in 1996 funding for carrying out the «National Programme for Earthquake

Management of Existing Buildings» (NPEMEB). The project has been conducted by several regional sections of the NTCG and involved applications in selected Greek cities (Xanthi, 2005 & 2007, Tripoli, 2004, Corfu 2005), with significant results (NTCG, 2006).

The current research presents a comprehensive study for the seismic vulnerability and risk assessment in the urban area struck by the 7-9-1999 Parnitha's earthquake in Greece. The building stock consists of typical building types of Southern Europe and refers to 750085 buildings which are situated in 122 regions of Attica according to the results of the year 2000 census (National Statistics Agency of Greece –NSAG). The evaluation of loss due to building damage in a certain region requires an assessment of both seismic hazard and the vulnerability of the building stock in the area. For this purpose, data specific to the characteristics of the earthquake that struck the area has been used. The seismic demand is characterized by the ratio, a_g/a_o, where a_g is the regional Peak Ground Acceleration (PGA) which is evaluated using simple expressions from the estimated in earlier research macroseismic intensities, and a_o is the PGA by which each region (municipality) of Attica is characterized according to the hazard map of the 2003 Greek Seismic Code. A pilot methodology is developed for the seismic loss assessment in monetary terms, consistent with the National Programme for Earthquake Management of Existing Buildings (NPEMEB). Useful results, which have been derived from the application of the specific project in several Greek towns, have also been used for the needs of this study. The vulnerability assessment is based on three different existing damage scenarios proposed by NTCG in 2006 and also one on relatively recently developed Damage Probability Matrices - DPMs (Eleftheriadou 2009, Eleftheriadou & Karabinis 2011a, 2012b). The vulnerability curves have been derived from a hybrid approach, which combines statistical data with appropriately processed results from nonlinear dynamic or static analyses, that permit extrapolation of statistical data to PGA's and/or spectral displacements for which no data are available. Also the aforementioned 4th damage scenario (DPMs) has been obtained from the empirical seismic method of vulnerability analysis based on processing of a large set of observational data. The DPMs are based on a damage database which has been created after the elaboration of the results from post - earthquake surveys carried out after the 7th of September 1999 Parnitha's earthquake and comprises 180945 buildings which developed damage of varying degree, type and extent. Information regarding the actual repair cost after the 1999 Parnitha's earthquake has been used in order to conduct correlation analysis with the estimated losses. The statistically derived repair cost for the area is compared with the results of the economic loss estimation obtained using the pre - described procedure for the risk assessment. The comparison of the estimated economic loss with the actual repair cost calibrates the reliability of the commonly used method for the risk assessment and serves in the improvement of seismic security and prioritizing the criteria for seismic rehabilitation programmes of existing buildings.

2. BUILDING STOCK

A classification system to characterize the earthquake - exposed building stock and describe its damage is a necessary step in development of seismic vulnerability and risk models. The only complete set of data (covering the entire city) is able to be provided by the National Statistics Agency of Greece based on the year 2000 census of buildings. In the present research, the seismic risk assessment of the study area struck by the 7-9-1999 Parnitha's earthquake refers to 750085 buildings which are located in 122 regions of Attica. The above information has been derived from NSAG. According to the same source, the building exposure in Attica represents the 18.80% (750085/3990970) of the total number of the entire building stock in Greece. A full set of data collected from NSAG regarding: a) The total number of buildings of the study area (Attica), b) The number of buildings categorized according to the construction materials (reinforced concrete, masonry of bricks or cinder blocks, metal or wood or stone or other), c) The number of buildings categorized according to the construction materials combined with the year of construction (Seismic Code), d) The number of buildings categorized according to the construction materials and the year of construction combined with the height (one floor; two floors; three-to-five floors; more than five floors). Useful information are gathered about the building exposure of Attica, which represents a reliable sample of Greece and generally South Europe, after elaborating the initial data collected from NSAG. The

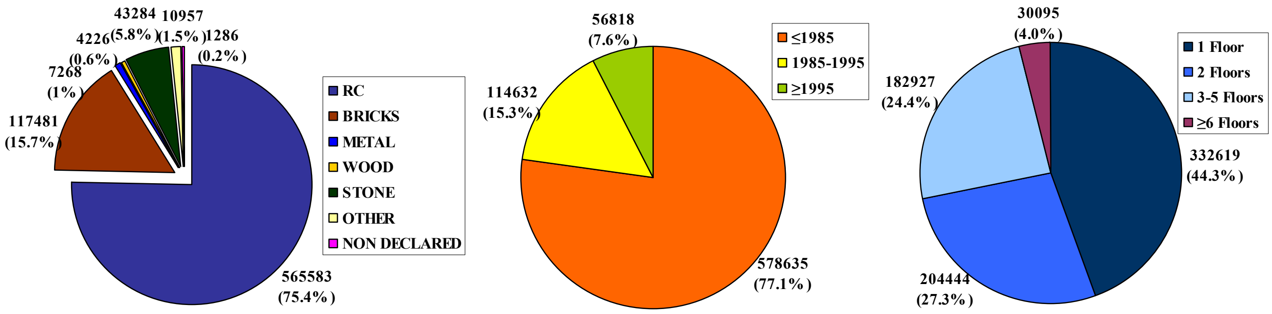

Figure 2.1. Analysis results of the building stock including 750085 buildings

analysis results of the building stock (750085 buildings) regarding construction materials, period of construction correlated to the seismic code and number of floors is presented in Fig. 2.1.

The classification system should also take into account the building types of the existing vulnerability models. The level of seismic design and detailing in Greece, could generally be discriminated in four subclasses, as follows: 1) *Without Seismic Code* (or pre - seismic code: year of construction before 1959): RC buildings with practical very low level of seismic design or no seismic design, and poor quality of detailing; 2) *The 1st Greek Seismic Code of 1959 (year of construction 1959-1985)*: RC buildings with low level of seismic design (corresponding approximately to pre – 1980 codes in Southern Europe); 3) *The 1st Greek Seismic Code of 1959 with the 1985 Supplement Clauses (construction between 1985-1995)*: RC buildings with medium level of seismic design (corresponding approximately to post - 1980 codes in S. Europe) and reasonable seismic detailing of RC members; 4) *New Greek Seismic Code (construction after 1995)*: RC buildings with adequate level of seismic design according to the new generation of seismic codes (similar to Eurocode 8) and ductile seismic detailing of RC members including sufficient descriptions for detailing and anchorage.

Information derived from the application of the National Programme for Earthquake Management of Existing Buildings in several Greek towns has been used for the needs of this study (NTCG, 2006). Based on the results of the previous studies, buildings of Attica with 3 to 5 floors are distributed as follows: 1) RC buildings designed and constructed earlier than 1985: 47.0% with 3 floors, 38.6% with 4 floors and 14.4% with 5 floors 2) RC buildings designed and constructed between 1985 ÷ 1995: 39.1% with 3 floors, 27.6% with 4 floors and 33.3% with 5 floors, 3) RC buildings designed and constructed after 1995: 54.5% with 3 floors, 25.5% with 4 floors and 20.0% with 5 floors, 4) masonry buildings are considered with 3 floors. In the category of six and more floors all buildings are considered having six floors. As far as RC buildings of Attica with ground floor without infill panels (*pilotis*) are regarded: 1) 24.9% buildings designed and constructed earlier than 1985, 2) 57.9% buildings designed and constructed between the period 1985 ÷ 1995 and 3) 59.7% buildings after 1995. Finally, the distribution of the mean constructed area per floor based on the previous studies has occurred: 1) 150 m^2 for buildings of RC structural system designed and constructed earlier than 1985, 1) 133 m^2 for RC buildings designed and constructed between the period 1985 ÷ 1995, 3) 180 m^2 for buildings of reinforced concrete structural system after 1995 and 4) 74 m^2 for masonry buildings.

3. SEISMIC VULNERABILITY ANALYSIS

The evaluation of loss due to building damage in an area struck by an earthquake depends both on vulnerability of the building stock and the seismic hazard in the studied area. Four different damage scenarios according to existing vulnerability curves are considered for the seismic risk assessment. These vulnerability models regarding typical structural types have been proposed by National Technical Chamber of Greece in 2006 (7 structural building types in 3 different damage scenarios) and also by Eleftheriadou (2009) on the recently developed Damage Probability Matrices (5 structural building types and 1 damage scenario) (Eleftheriadou & Karabinis 2011a, 2012b). The Median

Damage Factors (%) for the four damage scenarios and the seismic demand characterized by the ratio, $a_g/a_o=1$ for several building types are presented in Table 3.1. The three damage scenarios of NTCG are based on the researches of city of Volos by Kappos *et al.* (2002), by ITSAK-AUTH (2004) and Panagopoulos *et al.* (2006). The NTCG vulnerability curves have been derived from a hybrid approach (Kappos *et al.* 1998, 2007), which combines statistical data with appropriately processed (utilising repair cost models) results from nonlinear dynamic or static analyses, that permit extrapolation of statistical data to PGA's and/or spectral displacements for which no data are available. On the other hand, the pre - mentioned DPMs have been obtained from the empirical (or statistical) seismic method of vulnerability analysis based on processing of a large set of observational data. The DPMs are based on a damage database which has been created after the elaboration of the results from post - earthquake surveys carried out after the 7th of September 1999 Parnitha's earthquake and represents one of the larger existing database. The database comprises 180945 buildings which developed damage of varying degree, type and extent. Comparing the total number of damaged buildings to the total number of buildings in the affected area it is concluded that the dataset addresses the 24% of the total number of buildings in the studied area, which is a wide and reliable statistical sample. In the collected data, there was no information about the repair costs or the physical description of damage. The damage calibration of the damage dataset was initially based on instructions provided by Earthquake Planning and Protection Organization of Greece (EPPO) and referred to the qualitative characterization for the recording of damage in post - earthquake surveys in Greece. The building label - damage calibration is based on instructions provided by EPPO (1984 & 1997) using the method of Rapid Visual Screening (R.V.S.) during the conduct of post - earthquake surveys in Greece. The last is based on a macroscopic inspection of the building in order to define whether the building's seismic resistance is adequate against future expected seismic forces, as follows: a) *Green*: building without or with slight damage and original seismic capacity has not been decreased, the building is immediately usable and entry is unlimited. b) *Yellow*: building with moderate damage and with decreased seismic capacity that should be repaired. Usage is restricted. c) *Red*: building with very heavy damage or partial collapse. Buildings in this category are unsafe and entry is prohibited. Decision for demolition is to be made on the basis of more thorough inspection. d) *Collapse (black)*: building that has collapsed or is under demolition. In a recently proposed damage scale a measurable calibration of seismic damage has been presented according to the physical description and, as well, in terms of structural and economic damage index and has been correlated with the pre - mentioned qualitative description provided by EPPO and FEMA (Eleftheriadou & Karabinis 2008, 2010).

4. ESTIMATED GROUND MOTION IN THE STUDIED AREA

The earthquake on the 7th of September 1999, with moderate to strong magnitude [M = 5.9], according to the Institute of Geodynamics of the National Observatory of Athens (NOA), occurred at a small epicentral distance (18 km) from the historical centre of the city of Athens in Greece, a densely populated area.

Table 3.1: Median Damage Factors – MDF (%)

Srtuctural Types (ST)	Design Seismic Code Period (SeismicCode)	MDF_{i1} (%)	MDF_{i2} (%)	MDF_{i3} (%)	MDF_{i4} (%)
RC with infills in ground floor (*normal*)	Earlier than 1985	6.00	5.20	7.90	4.56
RC without infills in ground floor (*pilotis*)		7.20	6.24	9.48	
RC with infills in ground floor (*normal*)	1986 - 1995	2.50	2.00	3.33	2.26
RC without infills in ground floor (*pilotis*)		3.00	2.40	4.00	
RC with infills in ground floor (*normal*)	After 1995	1.10	1.30	3.33	1.42
RC without infills in ground floor (*pilotis*)		1.10	1.30	3.33	
Masonry of bricks	All periods	19.40	12.50	15.90	10.56
Structural system of stone, wood, metal or other					9.99

The correlation between macroseismic intensity (I) and peak ground acceleration PGA could make attainable a comparison between the vulnerability models proposed by EPPO. The parameter that characterizes the seismic input, in EPPO models, has been the ratio a_g/a_o, where a_g is the evaluated PGA from the macroseismic intensity and a_o is the unique value that characterizes each municipality in the Greek hazard map (NTCG, 2006). In the current research, the seismic demand has also been characterized by the ratio a_g/a_o, where a_g is the regional PGA which had been evaluated in earlier research, using simple expressions, from the estimated macroseismic intensities (Eleftheriadou & Karabinis 2012b). Moreover, a_o is the PGA by which each municipality of Attica is characterized according to the hazard map of the 2003 Seismic Code. The estimated values of the macroseismic intensity were also consistent with the real records, which described the ground seismic motion, obtained near most NOA stations. Macroseismic Intensities (I) in Modified Mercalli Scale (MMI) and PGA's have been correlated using the empirical relationship for the area studied of Eq. (4.1).

$$\ln(PGA) = 0.74 * I + 0.03 \tag{4.1}$$

This is a recently proposed relationship, which was derived from the statistical processing of a large number of strong ground motions in Greece (Koliopoulos *et al.* 1998). The pre-mentioned equation has been selected in the present paper among others because its validity has been examined in Athens earthquake. The relationship between seismic intensities I and PGAs, according to Eq. (4.1), has been calibrated for intensities up to IX. Therefore, its validity for stronger seismic intensities is limited.

The building stock (750085 buildings) refers to 122 regions of Attica. Among them, 80 belong in seismic hazard zone I with equivalent ground acceleration for seismic design $a_o=0.16\times981cm/sec^2=156.96$ cm/sec^2 and 42 are situated in seismic hazard zone II with value $a_o=0.24\times981cm/sec^2=235.44$ cm/sec^2. The seismic intensity values that are estimated in the 122 regions in the database vary from III to IX (in MMI scale). The majority of the regions belong to weak intensity regions and only a few are found in the area encircled by high intensity isoseismals. The assumption that each region (municipality) has a certain level of seismic severity was necessary for the development of DPMs. Moreover, the current research provides the advantage of satisfying the need of homogeneity in the presented large amount of damage data, all derived from the post - earthquake surveys of the same seismic event, covering a wide range of ground motions in several regions with similarities in the building stock and the soil conditions. PGA's and the corresponding ratios a_g/a_o have been evaluated with the application of Eq. 4.1. It is important to mention that, beyond the above procedure, an additional loss scenario for the numerical value of the ratio a_g/a_o = 1 has also been examined. For buildings designed and constructed between the years 1959-1985 according to the 1st Greek Seismic Code (of 1959) or the 1st Greek Seismic Code with the 1985 Supplement Clauses (between the years 1985-1995) an equivalent factor $a_o'=1.75\times\varepsilon$ (ε is the design PGA, corresponding to earlier Seismic Code) has been used in order to take into consideration the change in the applied codes (NTCG 2006). For those buildings that belong in regions, that the design - year seismic zone identification differs from today's seismic zone, a relative coefficient S (>1) is used in order to account for the change by overestimating the Median Damage Factor (MDF*S). The coefficient factor S has been estimated according to Eq. 4.2 and 4.3 for those buildings that had been constructed with different (a_o') from today's (Greek Seismic Code 2003) seismic design acceleration (a_o).

$$S = 1.35 * \left(\frac{a_o}{a_{o'}}\right) - 0.35 \qquad \text{for } \frac{a_o}{a_{o'}} \leq 2.25 \tag{4.2}$$

$$S = 1.97 * \left(\frac{a_o}{a_{o'}}\right) - 1.74 \qquad \text{for } \frac{a_o}{a_{o'}} \succ 2.25 \tag{4.3}$$

An alternative scenario for S=1 has also been examined. Two different scenarios for soil conditions (a=good soil conditions-smaller PGAs and b=medium soil conditions-bigger PGAs) and four damage scenarios have been applied in the described methodology for the estimation of seismic risk.

5. METHODOLOGY OF SEISMIC RISK ASSESSMENT

A pilot methodology is presented herein for the seismic loss assessment in monetary terms in Attica according to the NPEMEB (NTCG, 2006). The seismic loss factor (in monetary terms) is calculated according to the economic Mean Damage Factor % (MDF_i) for each building type (i) by evaluating the mean ratio of repair/strengthening or replacement cost (Rc) to the replacement cost (C_{RB}) of the building with the application of Eq. (5.1). Therefore the replacement cost of each building is evaluated by the total area and the compatible replacement cost per unit area (€/m^2).

$$MDF_i = \left(\frac{\frac{Rc_1}{C_{RB1}} + \frac{Rc_2}{C_{RB2}} + \ldots + \frac{Rc_n}{C_{RBn}}}{n}\right) \quad (5.1)$$

$$C_{RB} = A * c$$

n: total number of buildings belonging to the building type i,
Rc: repair/strengthening or replacement cost of the building (€),
C_{RB}: replacement cost of the building (€),
A: total area of the building (m^2),
c: compatible replacement cost per unit area (€/m^2).

The seismic loss factors, and therefore the estimation of seismic risk, are calculated for every structural type regarding the entire studied area of Attica. The seismic risk loss factors for the four damage scenarios R_1, R_2, R_3 and R_4 are defined according to the Eq. (5.2) and (5.3). The mean value R_m of the pre - mentioned indices is evaluated using the Eq. (5.4):

$$R_j = \sum A_i * MDF_{ij} * S_i \qquad \text{(in } m^2\text{, j=1,2,3, i=7)} \quad (5.2)$$

$$R_4 = \sum A_i * MDF_{i4} * S_i \qquad \text{(in } m^2\text{, j=4, i=5)} \quad (5.3)$$

$$R_m = \frac{(R_1 + R_2 + R_3 + R_4)}{4} \qquad \text{(in } m^2\text{)} \quad (5.4)$$

The normalized seismic risk ratio r_m (%) regarding the total number of buildings of entire Attica is estimated from the mean value R_m divided to the total area of the buildings situated in Attica, as it is presented in Eq. (5.5). The seismic risk ratio regarding the total number of buildings in Greece, V_m (‰), is estimated according to Eq. (5.6) from the mean value R_m divided to the total area of the building stock (A_c), respectively. It is considered that the building exposure of Greece (year 2000) refers to 3990970 buildings with 6635860 floors and estimated mean area per floor 100 m^2. Finally, the seismic loss estimation (in monetary terms) is estimated from the replacement cost Rc_m (€) of the buildings derived from the application of Eq. (5.7).

$$r_m = \left[\frac{R_m(m^2)}{\sum_{ATTICA} A_i(m^2)}\right](\%) \quad (5.5)$$

$$V_m = \left[\frac{R_m(m^2)}{\sum_{GREECE} A_i = A_c = 663586000(m^2)}\right] (‰) \quad (5.6)$$

$$Rc_m = r_m * C_{RB} = r_m * \sum A_i * c = R_m * c \quad (5.7)$$

6. PREDICTED SEISMIC LOSS

The application of the aforementioned methodology requires the distribution of Attica building stock (750085 buildings) in distinct severity levels of seismic input. Beyond that, the classification of buildings in structural types together with the total area regarding the building category in each level of ground motion constitutes an essential step for seismic risk assessment. The results of seismic risk assessment are presented in Table 6.1 and Fig. 6.1 for the entire examined area of Attica including 750085 buildings for all different damage scenarios that have been above explained. Note that, the inclusion of the coefficient parameter S overestimates significantly the seismic losses. Moreover, the results of the 1st and 2nd damage scenarios are close, the 3rd differs overestimating seismic risk while the 4th scenario presents the lower values due to the fact that the vulnerability models have been derived from the actual response of the exposed building stock to the referring earthquake.

7. STATISTICAL REPAIR COST

The statistically derived repair/strengthening or replacement cost has been calculated (Table 7.1) for the affected area (regarding 178578 damaged buildings) and afterwards it is compared with the results of the economic loss estimation obtained using the pre - described procedure for the risk assessment. The analytical estimation of the statistical repair cost needed the discrimination of damaged buildings from Parnitha's earthquake in groups per damage level. It is important to clarify that the estimated monetary loss does not include indirect losses (casualties, injuries, loss of machines/furniture, stop of functions, etc.). The statistical repair cost was based on two previous researches in the region of (1) Aharnes (Karabinis *et al.* 2006a) and (2) Ano Liosia (in similar form) (Kappos *et al.* 2007), the epicentral area where heavy damages were recorded. The total statistical cost evaluated in Table 7.1 has derived from the mean repair cost per square meter and the mean constructed area per building for each damage category (Table 7.2), provided by the Departments for Seismic Restoration in the above mentioned researches. The statistical repair cost, as well as the statistical area, per damage level for each of the previous studies and the mean value of them, is presented in Table 7.2. It has resulted that the mean statistical compatible replacement cost has risen in 297÷361 €/m^2. The last values have been adopted for the evaluation of the equivalent replacement area R (m^2) from the total repair cost per discrete damage levels.

Based on the statistical data of Aharnes the total compatible repair cost has been evaluated equal to 2419.71 M€ with equivalent replacement area of buildings 8.15 km^2 (Table 7.1). According to the statistical data of Ano Liosia the total compatible repair cost has been evaluated equal to 1869.72 M€

Table 6.1: Seismic risk assessment for different damage scenarios

Estimated seismic risk loss factors for entire Attica (750085 buildings, 1599315 roofs, 222748853 m^2 area) according to Parnitha's eathquake (7-9-1999) and the hazard map of Greek Seismic Code 2003								
Attica (122 regions)	**a_g**	**Modification damage factor S**	**Mean seismic risk factors of the 4 damage scenarios**					
			R_1 (m^2)	**R_2 (m^2)**	**R_3 (m^2)**	**R_4 (m^2)**	**R_m (m^2)**	**r_m (%)**
750085 buildings (1599315 floors) according to statistical census 2000-1. Total estimated area 222748853 m^2.	**a_g estimated from 7-9-1999 Parnitha's earthquake**	**S for soil type a**	31814508	29152994	38328349	24582219	30969517	13.9%
		S for soil type b	20877604	19588973	25059169	16164409	20422538	9.2%
		S=1	12100875	11112617	14228030	8847700	11572306	5.2%
	a_g according to Greek Seismic Code 2003 (a_g/a_o=1)	**S for soil type a**	41682533	35219636	53026863	29569852	39874721	17.9%
		S for soil type b	26212726	21304874	32088296	18141327	24436806	11.0%
		S=1	13879624	11332975	17119862	9654192	12996663	5.8%

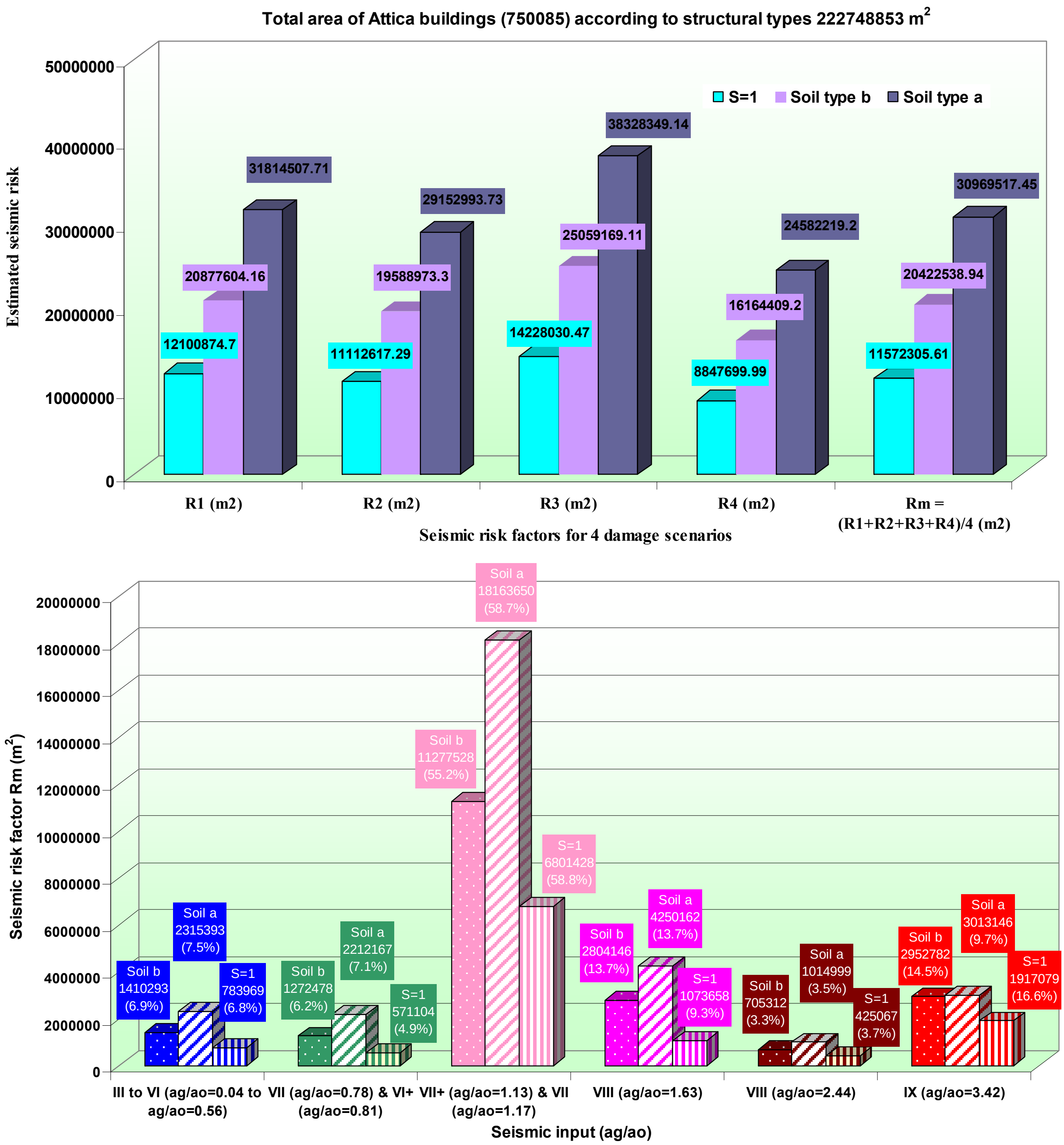

Figure 6.1. Estimated seismic risk for different damage scenarios based on Parnitha's (7-9-1999) earthquake.

with equivalent replacement area 5.18 km^2. Finally, taking the mean values for the repair cost of the two researches including 3539 buildings the total compatible repair cost has been evaluated equal to 2095.22 M€ with equivalent replacement area of buildings 6.87 km^2.

Table 7.1: Statistical repair costs per damage level for 178578 damaged buildings after the 7th-9-1999 Parnitha's earthquake based on Aharnes research

Damage level	Building number	Mean area per building (m^2)	Mean compatible repair cost (€/m^2)	Total repair cost (M€)	Equivalent replacement area R (Km^2)
Light (Green)	112687	247	33	918.51	3.09
Moderate (Yellow)	57199	285	62	1010.71	3.41
Extensive (Red)	5987	190	297	337.85	1.14
Collapse	2705	190	297	152.64	0.51
Total	**178578**			**2419.71**	**8.15**

Table 7.2: Statistical repair costs regarding the damage level of Aharnes and Ano Liosia researches

Damage Level		Building number	Area (m^2)	Total repair cost (M€)	Mean repair cost (€/m^2)	Mean area (m^2/building)
Light (Green)	(1)	51	12 610	0.41	33	247
	(2)	403	59 547	2.11	35	148
	(1)+(2)	454	72 157	2.53	35	159
Moderate (Yellow)	(1)	1 586	452 658	28.19	62	285
	(2)	350	61 871	5.72	92	177
	(1)+(2)	1 936	514 529	33.91	66	266
Extensive (Red)	(1)	919	174 906	51.90	297	190
	(2)	230	25 974	9.38	361	113
	(1)+(2)	1 149	200 880	61.28	305	175
Total	(1)	2556	640 174	80.50		
	(2)	983	147 392	17.21		
	(1)+(2)	3 539	787 566	97.72		

8. CONCLUSIONS

Conducting a comparison analysis between the estimated with the compatible actual cost it is concluded that generally the seismic risk methodology overestimates seismic losses. It should be mentioned, though, that the predicted loss takes into consideration the total building stock and not only the damaged buildings. As expected, the seismic scenario based on the developed DPMs from 7-9-1999 Parnitha's damage data presented the better correlation with the total statistically evaluated actual repair cost, especially when the last was based on Aharnes research. It is important to stress that the inclusion of the coefficient parameter S overestimates significantly the seismic losses. The last result should be taken into consideration in future risk researches. The benefits which arise from the research are connected to individuals, engineers and citizens, and also governments, research centres or organizations related to the earthquake management and protection. The comparison of the estimated economic loss with the actual repair cost calibrates the reliability of the commonly used method for the risk assessment and serves in the improvement of seismic security and prioritizing the criteria for seismic rehabilitation programmes of existing buildings.

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