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Seismic Risk Assessment of Buildings in the Extended Urban Region of Athens and Comparison with the Repair Cost

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Abstract

A complete research of seismic risk assessment is presented herein focused on the existing buildings of the extended urban region of Athens in Greece. The seismic risk assessment is fulfilled by discriminating the current study in two approaches, probable and actual, conducting afterwards between them a comparison analysis. In the first part, a pilot methodology is developed for the seismic loss assessment in monetary terms regarding the buildings damages, consistent with the National Programme for Earthquake Management of Existing Buildings (NPEMEB). The building stock consists of typical building types of Southern Europe and refers to 750,085 buildings (18.80% of buildings in Greece) situated in the entire region of Athens according to the results of the 2000-1 statistical census. A wider research of seismic risk assessment could include direct losses of infrastructures and indirect economic losses. The evaluation of loss due to building damage in a certain region requires an assessment of both seismic hazard and vulnerability of the building stock in the study area. Four different existing damage scenarios are applied for the vulnerability assessment. The results of the seismic risk assessment for the four different aspects of the estimated damage and the different soil conditions are presented in a map of the study region. The existing vulnerability curves corresponding to defined types of buildings have been derived from the National Technical Chamber of Greece and also from recently developed DPMs. The last DPMs were obtained in a previous research (Eleftheriadou, 2009) from the process of a created damage database after the 7th of September 1999 Parnitha's earthquake and comprised 180,945 buildings which developed damage of varying degree, type and extent. In the second part of the research, the seismic risk is evaluated from the available data regarding the mean statistical repair/strengthening or replacement cost for the total number of damaged structures (180,427 buildings) after the same (1999 Parnitha's) seismic event. Data regarding the compatible (budget approved

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according to the ministry's provisions) repair cost has been collected. The structural losses in monetary terms for the 180,427 buildings damaged structures are evaluated equal to 2450.0 M€, 1887.8 M€ and 2118.9 M€ based on the previously mentioned statistical seismic risk data. The statistically derived repair cost for Attica is compared with the results of the economic loss estimation for buildings using the aforementioned risk assessment methodology. From the analysis results, the seismic scenario based on the recently developed DPMs (Eleftheriadou, 2009) presented the better correlation (2627.77 M€) with the total statistically evaluated repair cost (2450.02 M€). 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 comparison of the estimated economic loss with the statistical repair cost calibrates the reliability of the commonly used risk assessment method and serves in the improvement of seismic security prioritizing the criteria for seismic rehabilitation programmes of existing buildings.

Keywords

Seismic Vulnerability, Seismic Risk, Damage Scenario, Economic Loss, Repair Cost

1. Introduction

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. In risk analysis the probability of losses is calculated over a specified period of time due to all the possible future seismic events, whereas in a seismic scenario the impact of a given earthquake is investigated and quantified. 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 for insurance purposes, and also for the definition of criteria for prioritizing seismic strengthening (rehabilitation) programmes for existing buildings. Decisions regarding the seismic rehabilitation of existing buildings require both engineering and economic studies and consideration of social priorities. Pre- and post-earthquake upgrading of a city's existing building stock is one of the most conflictual and difficult issues of public policy decisions.

The interest in earthquake management by governments and policies is obvious considering the numerous projects financed for this purpose. After the socio-economic impact of the earthquakes in Turkey (Izmit on 17th-8-1999 & Düzce on 12th-11-1999), and Greece (Athens on 7th-9-1999), the European Commission funded in 1999 the RISK-UE project: "*An advanced approach to earthquake risk scenarios with application to different European towns*", aiming at the assessment of seismic risk in European urban centres. Seven research centres from European countries (France, Italy, Romania, Spain, Greece, FYROM, and Bulgaria) were involved in the project. Shortly before RISK-UE, another international project, RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters) aimed to develop earthquake damage scenarios in urban areas of nine case-study cities all over the world. The ENSeRVES project (European Network on Seismic Risk, Vulnerability and Earthquake Scenarios) in 1997 gathered together teams of scientists of different categories (seismologists, geologists, engineers, architects, etc.) involving 11 international institutions working on earthquake engineering and seismology. Along similar lines, the National Technical Chamber of Greece (NTCG) with the cooperation of Greek universities provided in 1996 funding to the Earthquake Planning and Protection Organization (EPPO) for carrying out the "National Programme for Earthquake Management of Existing Buildings" [1]. 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.

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. Loss is defined as the human and financial consequences of damage, including injuries or deaths or the costs of repair. A wider research of seismic risk assessment could include direct economic losses (**Figure 1**) of infrastructures (water networks, sewerage, roads, bridges, etc.) and indirect losses (human losses, business interruption). The seismic vulnerability of a building can be defined as its proneness to be damaged by an earthquake. Seismic vulnerability relationships attempt to predict for several building classes the mean degree and the extent of damage at given levels of seismic demand. Vulnerability analysis reveals the damageability of the structure(s) under varying intensity or magnitudes of ground motion. Multiple damage states are typically considered in the analysis [4].

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 [5].

It is important to clarify the distinction between risk and vulnerability. Risk combines the expected losses from all levels of hazard severity, also taking their occurrence probability into account, while vulnerability of an element is usually expressed for a given hazard severity level. Components of seismic risk assessment and loss estimation are 1) Hazard analysis; 2) Local site effects (microzonation); 3) Exposure information (structural inventory); 4) Vulnerability analysis; 5) Estimation of risk and loss. Since the standard definition of risk is a probability or likelihood of loss, between zero and one, it may be more appropriate to express risk as *Risk* = *Hazard* × *Vulnerability* while loss depends on the value of the exposure at risk, given by *Loss* = *Hazard* × *Vulnerability* × *Exposure*. Thus, while seismic hazard is a product of natural processes, seismic risk and loss are dependent on the vulnerability and social exposure in terms of the built environment, human population, and value of operations.

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 is indispensable for the estimation of seismic risk [6]-[8]. Many seismic risk assessments and vulnerability studies [9]-[19] 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 research includes a study for the seismic vulnerability and risk assessment in the extended region of Athens (Greece) struck by the 7th-9-1999 Parnitha's earthquake. The building stock in the study area consists of typical building types, representative of the materials, seismic codes and construction techniques of Southern Europe. The building exposure refers to 750,085 buildings which are situated in 122 regions of Attica according to the results of the 2000 statistical census (one year after the seismic event), information obtained from the National Statistics Service of Greece (NSSG). For the evaluation of seismic hazard, 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 PGA which is evaluated using simple expressions from the estimated in earlier research macroseismic intensities, and a_o is the PGA by which each municipality of Attica is characterized according to the hazard map of the 2003 Seismic Code [20]. 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 had been derived from the application of the specific project in several Greek cities, have been used for the needs of this study. The vulnerability assessment is based on four different existing damage scenarios. The three of them have been proposed by NTCG in 2006 and the vulner-

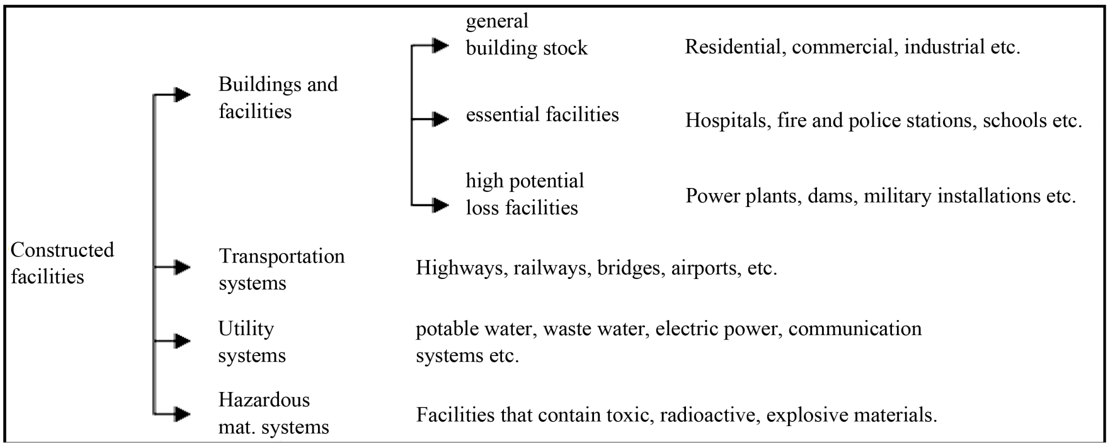


Figure 1. A structural inventory classification system [2] [3].

ability 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. The forth damage scenario is based on relatively recently developed Damage Probability Matrices-DPMs [21] applying the empirical seismic method for the vulnerability analysis on a large set of observational data comprising 180,945 buildings which developed damage of varying degree, type and extent after the 7th of September 1999 Parnitha's earthquake. The empirical vulnerability assessment is generally based on the distribution of damage reported in post-earthquake surveys and treats these data according to statistical procedures. It includes the real response of the exposed building stock, taking into account all the structural characteristics, topography, site and soil conditions of Greece. Survey data can rarely provide a complete set of data. The difficulty focuses on the lack of a sufficiently large set of reliable empirical data, due to the limited number of damaging earthquakes at a small distance from densely populated areas, covering a wide range of ground motions [19] [20].

Information regarding the compatible (budget approved according to the ministry's provisions) 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 compatible 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 Exposure

The development of seismic vulnerability and risk models needs a classification system to characterize the earthquake-exposed building stock and describe its damage. A complete set of data (*i.e*. covering the entire city) is able to be provided only by the National Statistics Service of Greece (NSSG). The current research is focused on the seismic risk assessment of Attica area struck by the 7th-9-1999 Parnitha's earthquake and refers to 750,085 buildings which are located in 122 regions. The above information has been derived from NSSG according to the information of 2000-1 census of buildings, conducting just a year after the occurrence of the earthquake. According to the same source, the building exposure in Attica represents the 18.8% (/3990970) of total population of the entire building stock in Greece (total number of buildings). A full set of data collected from NSSG regarding: 1) The total number of buildings of the study area (Attica); 2) The number of buildings categorized according to the construction materials (reinforced concrete, masonry, metal or wood or stone or other); 3) The number of buildings categorized according to the construction materials combined with the year of construction (Seismic Code); 4) The number of buildings categorized according to the construction materials and the period of construction combined with the height (number of floors). The classification system should also take into account the building types of the existing vulnerability models. The level of seismic design and construction detailing, could generally be discriminated in four subclasses, as follows: a) *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; b) *Low Seismic Code* (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); c) *Moderate Seismic Code* (the 1st Greek Seismic Code of 1959 plus the 1985 Supplement Clauses: year of construction between 1985-1995): R/C buildings with medium level of seismic design (corresponding approximately to post-1980 codes in S. Europe) and reasonable seismic detailing of R/C members; d) *High Seismic Code* (new Greek generation of RC and seismic codes similar to Eurocodes: year of construction after 1995): R/C buildings with adequate level of seismic design according to the new generation of seismic codes and ductile seismic detailing of R/C members including sufficient descriptions for detailing and anchorage. Useful information about the building exposure of Attica, which represents a reliable sample of Greece and generally South Europe, after elaborating the initial data collected from NSSG. The analysis results are presented in **Tables 1-3** including the building stock regarding construction materials, period of construction connected to the seismic codes and number of floors.

Information that was missing for the needs of the research was derived from previous studies (Xanthi, 2005; 2007; Tripoli, 2004; Corfu, 2005) of the National Programme for Earthquake Management of Existing Buildings. Thus, buildings of Attica with 3 to 5 floors are distributed as follows: 1) RC buildings designed and constructed

Table 1. Construction system materials.

Structural System	Reinforced Concrete	Bricks/Cinder Blocks	Metal	Wood	Stone	Other	Non Declared	Total
Number of Buildings	565,583	117,481	7268	4226	43,284	10,957	1286	750,085
Percentage (%)	75.4	15.6	1.0	0.6	5.8	1.4	0.2	100.00

Table 2. Period of construction.

Period of Construction (Seismic Code, SC)	All Buildings		RC Buildings		Other: Masonry, Metal, Wood, Stone, Other, Non Declared	
	Number of Buildings	Percentage (%)	Number of Buildings	Percentage (%)	Number of Buildings	Percentage (%)
Earlier than 1985	578,635	77.1	420,096	74.3	158,539	85.9
1985-1995	114,632	15.3	98,208	17.3	16,424	8.9
After 1995	56,818	7.6	47,279	8.4	9539	5.2
Total	750,085	100.00	565,583	100.00	184,502	100.00

Table 3. Number of floors.

Number of Floors	All Buildings		RC Buildings		Other: Masonry, Metal, Wood, Stone, Other, Non Declared	
	Number of Buildings	Percentage (%)	Number of Buildings	Percentage (%)	Number of Buildings	Percentage (%)
1 Floor	332,619	44.3	180,669	31.9	151,950	82.36
2 Floors	204,444	27.3	177,350	31.4	27,094	14.68
3 - 5 Floors	182,927	24.4	177,622	31.4	5305	2.88
≤6 Floors	30,095	4.0	29,942	5.3	153	0.08
Total	750,085	100.00	565,583	100.00	184,502	100.00

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: a) 24.9% buildings designed and constructed earlier than 1985; b) 57.9% buildings designed and constructed between the period 1985 - 1995; and c) 59.7% buildings after 1995. Finally, the distribution of the mean constructed area per floor based on the previous studies has occurred: a) 150 m^2 for buildings of RC structural system designed and constructed earlier than 1985; b) 133 m^2 for RC buildings designed and constructed between the period 1985 - 1995; c) 180 m^2 for buildings of reinforced concrete structural system after 1995; and d) 74 m^2 for masonry buildings.

3. Seismic Vulnerability Assessment

Four different damage scenarios according to existing vulnerability curves are considered for the seismic risk assessment. These vulnerability models (in form of curves or DPMs) 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 [21] on the recently developed Damage Probability Matrices (5 structural building types and 1 damage scenario) [12]. The three damage scenarios of NTCG are based on the researches of city of Volos by Kappos *et al.* [22] (2002), by ITSAK-AUTH (2004) [23] and ARISTION project [17]. The NTCG vulnerability curves have been derived from a hybrid approach [14] [22], 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 damage database (which has been created in the RC laboratory of DUTh [21]) after the elaboration of the results from post-earthquake surveys carried out after the 7th of September 1999 Parnitha's earthquake. The database comprises 180,945 buildings which developed damage of varying degree, type and extent [24]. 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 [25] [26]. 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 [27]. 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 very wide and reliable statistical sample for buildings. In the collected data, there was no information about the repair costs or the physical description of damage.

The Median Damage Factors (%) for the four different damage scenarios MDFij (%): $i = 7$, $j = 3$ (categorized in 7 structural types with 3 damage scenarios: $j = 1$ Volos, $j = 2$ ITSAK-AUTH and $j = 3$ ARISTION, [1]-MDFi4 (%), $i = 5$, $j = 4$ (categorized in 5 structural types with 1 damage scenario) [12] [20] [21]) and the seismic demand characterized by the ratio, $a_g / a_o = 1$ for several building types are presented in **Table 4**. A comparison analysis for a specific building type (**Figure 2**) is conducted according to the existing vulnerability curves.

4. Estimation of Seismic Demand in the Study Area

Parnitha's near field earthquake $[M = 5.9]$ on the 7th of September, 1999 occurred at a small epicentral distance (18 km) from the historical centre of the city of Athens in Greece, a densely populated area and it is considered the biggest recent natural disaster in Greece regarding the monetary loss. The parameter that characterizes the seismic input, in National Technical Chamber of Greece [1] models, has been the ratio a_g / a_o, where a_g is the regional PGA which has been evaluated from the estimated in earlier research macroseismic intensities and a_o is the unique value is the PGA that characterizes each municipality of Attica according to the hazard map of the 2003 Seismic Code [12] [20].

The examined building stock (750,085 buildings) refers to 122 regions of Attica. Among them, 80 belong in seismic zone I according to the Greek Seismic Code with equivalent ground acceleration $a_o = 0.16 \times 981\ \text{cm/sec}^2 = 156.96\ \text{cm/sec}^2$ and 42 are classified in seismic zone II with $a_o = 0.24 \times 981\ \text{cm/sec}^2 = 235.4\ \text{cm/sec}^2$. The intensity values that were estimated vary from III to IX regarding the 122 regions according to: 1) the Geodynamic Institute of the National Observatory of Athens; 2) a research programme; and 3) isoseismal maps. The majority of the regions belong to weak intensity level and only a few municipalities are found in the area encircled by high intensity isoseismals. The assumption that each municipality has a certain level of seismic severity was necessary for the development of Damage Probability Matrices (DPMs). PGA's and the corresponding ratios a_g / a_o have been evaluated, as they are presented in **Table 5**. It is important to mention that, beyond the above procedure, an additional loss scenario for the numerical value of

Table 4. Median damage factors-MDF (%).

Structural Types (ST)			Design Seismic Code Period (Seismic Code)	MDFi1 (%)	MDFi2 (%)	MDFi3 (%)	MDFi4 (%)
RC with infills in ground floor (normal)	1	1	Earlier than 1985	6.00	5.20	7.90	4.56
RC without infills in ground floor (pilotis)	4			7.20	6.24	9.48	
RC with infills in ground floor (normal)	2	2	1986-1995	2.50	2.00	3.33	2.26
RC without infills in ground floor (pilotis)	5			3.00	2.40	4.00	
RC with infills in ground floor (normal)	3	3	After 1995	1.10	1.30	3.33	1.42
RC without infills in ground floor (pilotis)	6			1.10	1.30	3.33	
Masonry of bricks	7	4	All periods	19.40	12.50	15.90	10.56
Structural system of stone, wood, metal or other		5					9.99

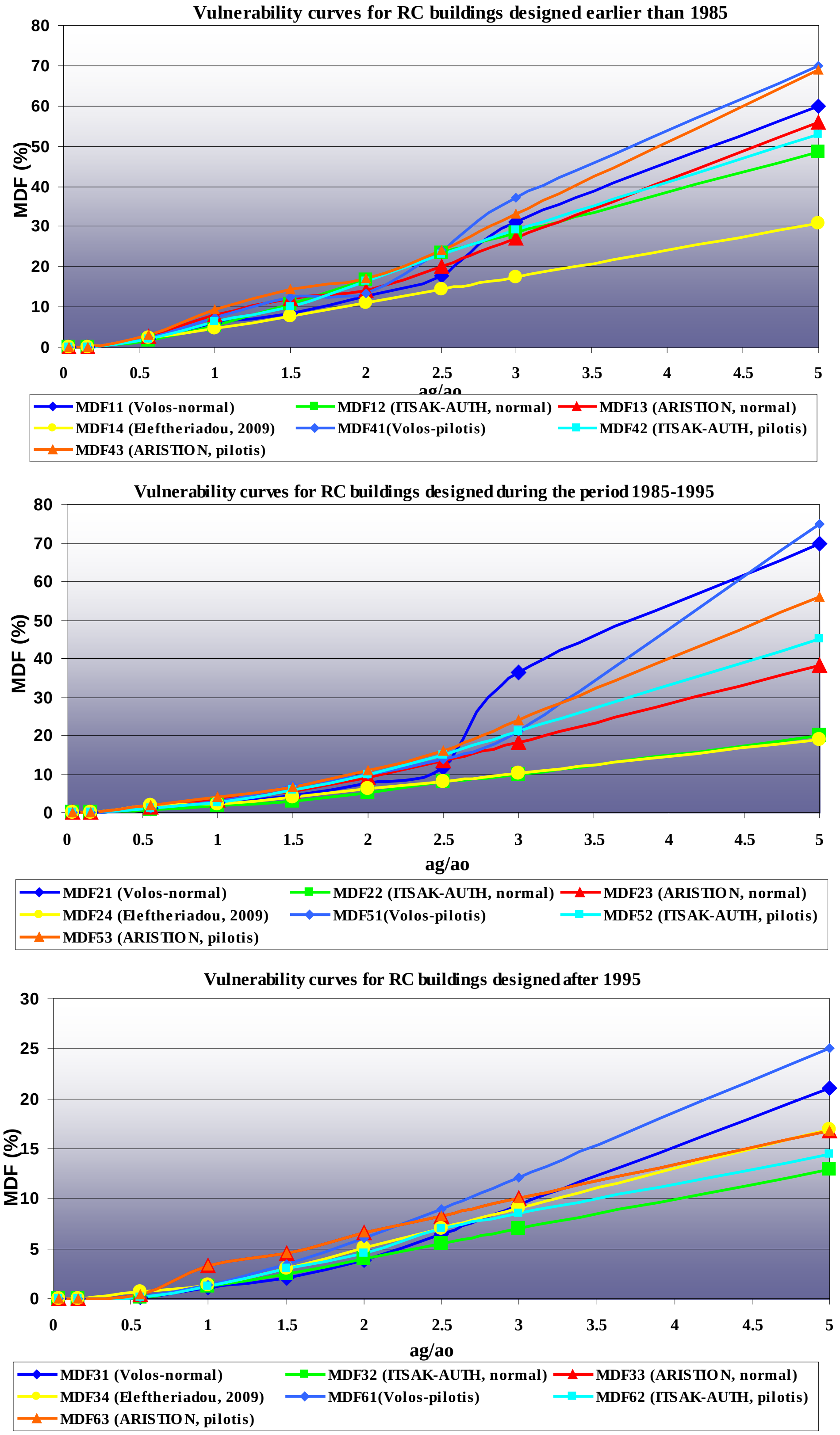


Figure 2. Median Damage Factors-MDF (%) for the RC buildings without infill panels in ground floor (pilotis) designed after 1995.

Table 5. Attica regions (122) with: macroseismic intensities (I), a_g the evaluated PGA from the macroseismic intensity with the application of Equation (1), a_o the unique value that characterizes each municipality in the Greek hazard map (Seismic Code 2003).

Number of Studied Municipalities	Macroseismic Intensity I	a_g (cm/sec^2)	a_o (cm/sec^2)	a_g/a_o
1 - 3	IX	804.32	235.44	3.42
4 - 5	VIII	383.75	156.96	2.44
6 - 13	VIII	383.75	235.44	1.63
14 - 31	VII	183.09	156.96	1.17
32	VII+	265.07	235.44	1.13
33 - 36	VI+	126.47	156.96	0.81
37 - 40	VII	183.09	235.44	0.78
41 - 50	VI	87.36	156.96	0.56
51 - 65	V+	60.34	156.96	0.38
66 - 69	VI	87.36	235.44	0.37
70 - 98	V	41.68	156.96	0.27
99 - 109	V+	60.34	235.44	0.26
110 - 118	V	41.68	235.44	0.18
119 - 120	IV	19.89	156.96	0.13
121	IV	19.89	235.44	0.08
122	III	9.49	235.44	0.04

Estimated macroseismic intensity values according to the Modified Mercalli Scale: 1) Geodynamic Institute of the National Observatory of Athens [28] (Kalogeras and Stavrakakis, 2001); 2) Research programme referring to the meizoseismal area [29] (Gazetas and collaborators, 2001); 3) Isoseismal intensity maps ([30] Schenková *et al.* 2007, [31] Hutchings, *et al.*, 2007).

the ratio $a_g/a_o = 1$ has also been examined.

According to the National Technical Chamber of Greece [1], for buildings designed and constructed according the 1st Seismic Code of 1959 standing up to 1985 or the 1st Seismic Code of 1959 plus the 1985 Supplement Clauses (1985-1995), with different from today's design seismic code, a relative coefficient $a'_o = 1.75 \times \varepsilon$ has been used in order to take into consideration the change in the applied codes. For those buildings that belong in regions, that the design-year seismic zone identification and PGA (a'_o) differs from today's (Seismic Code 2003) seismic zone and seismic design acceleration (a_o), a relative coefficient S (>1) is used in order to take into account the change by overestimating the Median Damage Factor $(\text{MDF} * S)$. A coefficient factor S of Median Damage Factor has been estimated according to NPEMEB expressions (Equation (1) and Equation (2)). **Table 6** presents the modified design PGAs in several seismic hazard zones according to different Greek seismic codes (SC) and the evaluated modification damage factor S.

$$S = 1.35 * \left(\frac{a_o}{a'_o}\right) - 0.35, \quad \text{for} \quad \frac{a_o}{a'_o} \le 2.25 \tag{1}$$

$$S = 1.97 * \left(\frac{a_o}{a'_o}\right) - 1.74, \quad \text{for} \quad \frac{a_o}{a'_o} \succ 2.25 \tag{2}$$

Summarizing, 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 applied methodology for seismic risk estimation. An alternative scenario for $S = 1$ has also been examined. Moreover, two different scenarios for seismic demand expressed by the ratio a_g/a_o have been examined taking into account the evaluated factor S and for $S = 1$, as it has been already discussed. The results of the seismic risk assessment are presented in a map of the study region. Note that in the cases that the coefficient factor S has been taken into account by multiplying with for the Median Damage Factor $(\text{MDF}_{ij} \times S_i)$ resulted in exaggerated values (over

Table 6. Modification of design PGAs in different Greek seismic codes (SC) and the evaluated factor S.

Seismic design acceleration ε (SC 1959) or a'_o (SC 1995)	$a'_o = 1.75 \cdot \varepsilon$	a_o/a'_o ($a_o = 0.16 \cdot g$, SC 2003)	S	a_o/a'_o ($a_o = 0.24 \cdot g$, SC 2003)	S
Zone I, Soil $a, \varepsilon = 0.04$	0.070	2.286	2.763	3.429	5.014
Zone I, Soil $b, \varepsilon = 0.06$	0.105	1.524	1.707	2.286	2.763
Zone II, Soil $a, \varepsilon = 0.06$	0.105	1.524	1.707	2.286	2.763
Zone II, Soil $b, \varepsilon = 0.08$	0.140	1.143	1.193	1.714	1.964
Zone III, Soil $a, \varepsilon = 0.08$	0.140	-	-	1.714	1.964
Zone III, Soil $b, \varepsilon = 0.12$	0.210	-	-	1.143	1.193
SC 1995 (1995-2003) $a'_o = 0.12$	0.120	1.333	1.450	-	-
SC 1995 (1995-2003) $a'_o = 0.16$	0.160	1.000	1.000	1.500	1.675

100%) the upper limit of the vulnerability curve (MDF for $a_g/a_o = 5$) has been adopted. These cases referred in meizoseismal areas with a_g/a_o values equal to 1.63, 2.44, 3.42 regarding the most vulnerable buildings.

5. Applied Methodology of Seismic Risk Analysis

A pilot methodology is presented herein for the seismic loss assessment in monetary terms in Attica according to the National Programme for Earthquake Management of Existing Buildings [1] [32]. The building stock of Attica (750,085 buildings) collected from NSSG has been categorized in 7 structural types for the 3 damage scenarios of NTCG and in 5 structural types for the 4th damage scenario (**Table 4**).

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 Equation (3). Therefore the replacement cost of each building is evaluated by the total area and the compatible replacement cost per unit area (€/m^2).

$$\mathrm{MDF}_i = \left(\frac{\dfrac{Rc_1}{C_{RB1}} + \dfrac{Rc_2}{C_{RB2}} + \cdots + \dfrac{Rc_n}{C_{RBn}}}{n} \right) \tag{3}$$

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

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 Equation (4) and Equation (5). The mean value R_m of the pre-mentioned indices is evaluated for the three damage scenarios derived from the NTCG vulnerability models (Equation (6)) and it is compared to the numerical value R_4 based on the recently developed DPMs after the Parnitha's earthquake.

$$R_j = \sum A_i * \mathrm{MDF}_{ij} * S_i \quad \left(\text{in m}^2,\ j = 1,2,3,\ i = 7\right) \tag{4}$$

$$R_4 = \sum A_i * \mathrm{MDF}_{i4} * S_i \quad \left(\text{in m}^2,\ j = 4,\ i = 5\right) \tag{5}$$

$$R_m = \frac{\left(R_1 + R_2 + R_3\right)}{3} \quad \left(\text{in m}^2\right) \tag{6}$$

The normalized seismic risk ratio r_4 (%) regarding the total number of buildings of entire Attica is estimated from the mean value R_4 divided to the total area of the buildings situated in Attica, as it is presented in Equation (7). The seismic risk ratio regarding the total number of buildings in Greece, V_4 $(‰)$, is estimated according to Equation (8) from the numerical value R_4 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 3,990,970 buildings with 6,635,860 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_4 (€) of the buildings derived from the application of Equation (9).

$$r_4 = \left[\frac{R_4\left(\text{m}^2\right)}{\sum_{\text{ATTICA}} A_i\left(\text{m}^2\right)}\right](\%) \tag{7}$$

$$V_4 = \left[\frac{R_4\ \left(\text{m}^2\right)}{\sum_{\text{GREECE}} A_i = A_c = 663586000\ \left(\text{m}^2\right)}\right](‰) \tag{8}$$

$$Rc_4 = r_4 * C_{RB} = r_4 * \sum A_i * c = R_4 * c \tag{9}$$

It is important to clarify that the estimated monetary loss does not include indirect loss (casualties, injuries, interruption of jobs etc.).

Information regarding the compatible repair cost after the 1999 Athens earthquake has also been collected. 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 with the compatible cost calibrates the reliability of the commonly used method for the risk assessment and would serve in subsequent earthquake loss estimation studies. The reliable seismic risk management is of crucial importance for the improvement of seismic security and sets the criteria for prioritizing seismic rehabilitation programmes for existing buildings.

6. Estimation of Seismic Risk for Different Damage Scenarios in Athens Extended Urban Region

The application of the aforementioned methodology requires the distribution of Attica building stock (750,085 buildings) selected from the National Statistics Service of Greece according to the statistical census 2000 in distinct severity levels of seismic input, expressed by the ratio a_g/a_o, as it has been already explained (**Figure 3**). 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 (**Figure 4**).

The results of seismic risk assessment are presented in **Table 7** and **Figure 5** for the entire examined area of attica including 750,085 buildings, equivalent to 222,748,853 m^2, for all different damage scenarios that have been above explained. In **Figure 6** is presented the distribution of Attica buildings categorized in structural types according to number of buildings, total area and the estimated seismic risk R_4 for soil type *b*.

Note that, the inclusion of the coefficient parameter S overestimates significantly the seismic losses. Moreover, the results of the 1st (Volos) and 2nd (ITSAK-AUTH) damage scenarios are close, the 3rd (ARISTION) differs overestimating seismic risk while the 4th [21] 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. **Figure 7** presents all regions of Attica categorized in the severity levels of the seismic input expressed in a_g/a_o as they have been estimated from Parnitha's earthquake and the hazard seismic zones (SC 2003). The estimated seismic risk based on the above methodology is also demonstrated in the same figure.

7. Statistical Repair/Strengthening Cost

The statistically derived compatible repair/strengthening or replacement cost has been calculated for the affected area and afterwards it is compared with the results of the economic loss estimation obtained from the application of the pre-described methodology for the risk assessment. 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 analytical estimation of the statistical repair cost needed the discrimination of damaged buildings from

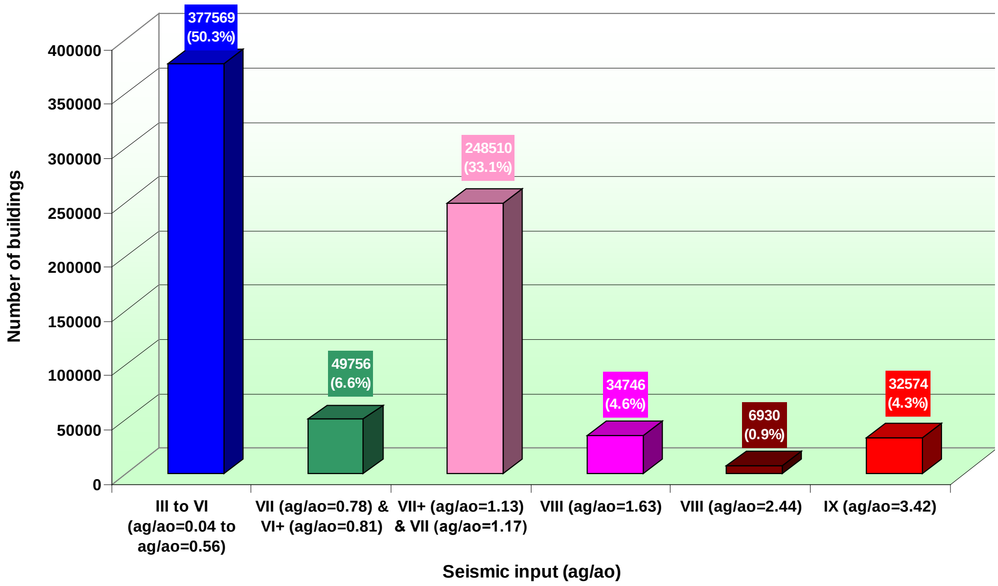


Figure 3. Distribution of 750,085 Attica buildings according to the seismic input $\left(a_g/a_o\right)$.

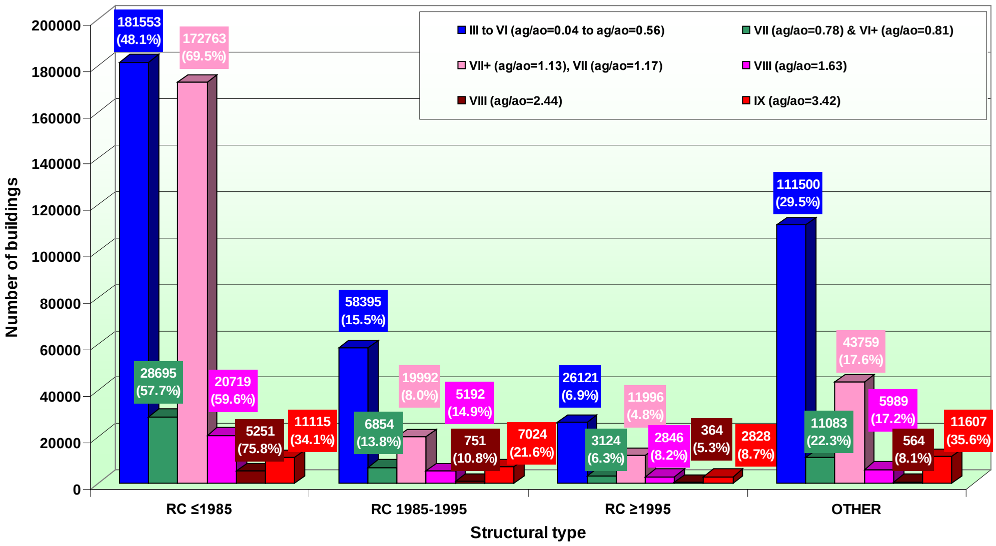
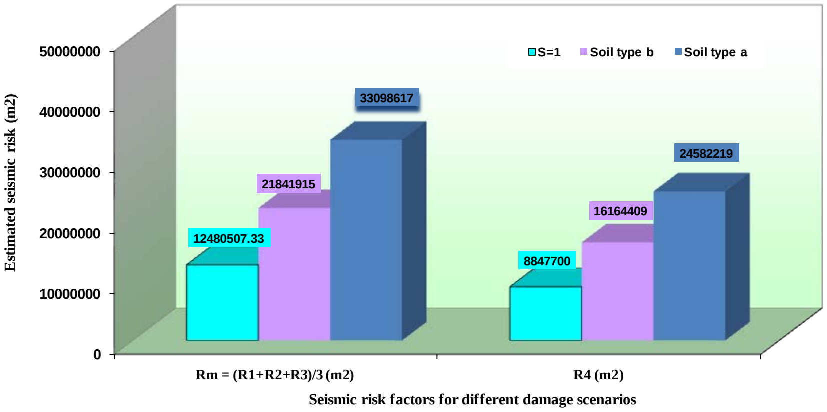


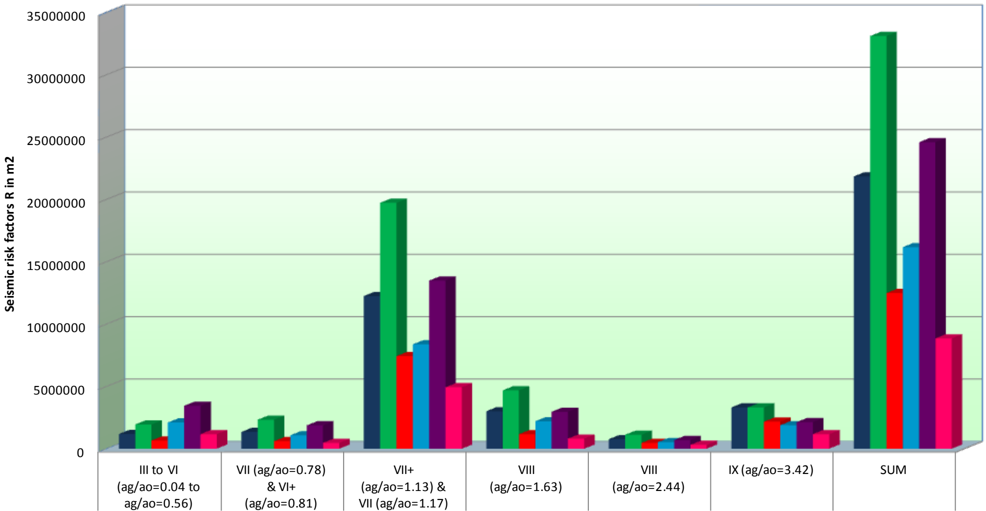
Figure 4. Distribution of 750,085 Attica buildings categorized in structural types according to the seismic input.

Table 7. Seismic risk assessment for different damage scenarios.

Estimated seismic risk loss factors for entire Attica (750,085 buildings, 1,599,315 floors, 222,748,853 m^2 area) according to Parnitha's eathquake (7th-9-1999) and the hazard map of Greek Seismic Code 2003					
Attica (122 regions)	a_g	Modification damage factor S	R_m = (m^2)	R_4 (m^2)	r_4 (%)
750,085 buildings according to statistical census 2000-1	a_g estimated from 7th-9-1999 Athens earthquake	S for soil type a	33,098,617	24,582,219	11.0%
		S for soil type b	21,841,915	16,164,409	7.3%
		S = 1	12,480,507	8,847,700	4.0%
	a_g according to Seismic Code (a_g/a_o = 1)	S for soil type a	43,309,677	29,569,852	13.3%
		S for soil type b	26,535,299	18,141,327	8.1%
		S = 1	14,110,820	9,654,192	4.3%

Total area of Attica buildings (750085) according to structural types 222748853 m^2





	III to VI (ag/ao=0.04 to ag/ao=0.56)	VII (ag/ao=0.78) & VI+ (ag/ao=0.81)	VII+ (ag/ao=1.13) & VII (ag/ao=1.17)	VIII (ag/ao=1.63)	VIII (ag/ao=2.44)	IX (ag/ao=3.42)	SUM
■ Rm Soil type b	1179095	1339469	12246723	3004659	763859	3308111	21841916
■ Rm Soil type a	1940038	2326060	19724153	4679750	1120505	3308111	33098617
■ Rm S=1	657226	605605	7425329	1162175	463257	2166915	12480507
■ R4 Soil type b	2103889	1071503	8369945	2202607	529670	1886795	16164409
■ R4 Soil type a	3441460	1870488	13482140	2961399	698481	2128252	24582219
■ R4 S=1	1164199	467603	4929723	808107	310499	1167571	8847700

Total area of Attica buildings (750085) according to structural types 222748853 m^2.

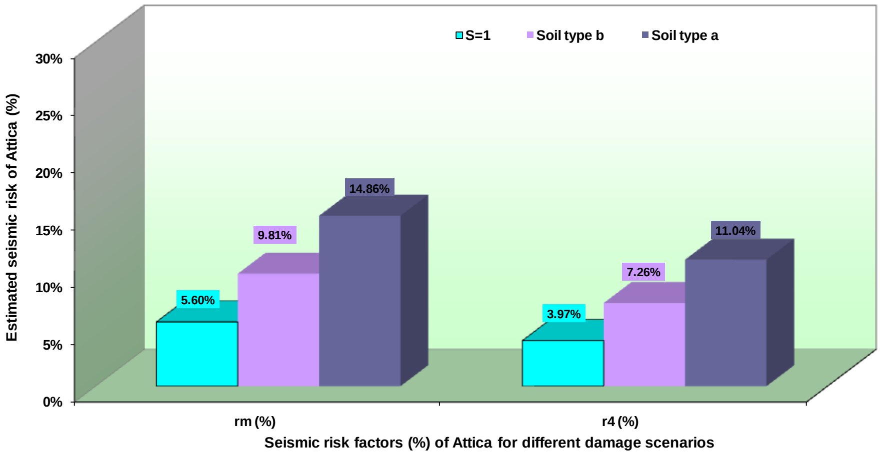


Figure 5. Estimated seismic risk for different damage scenarios.

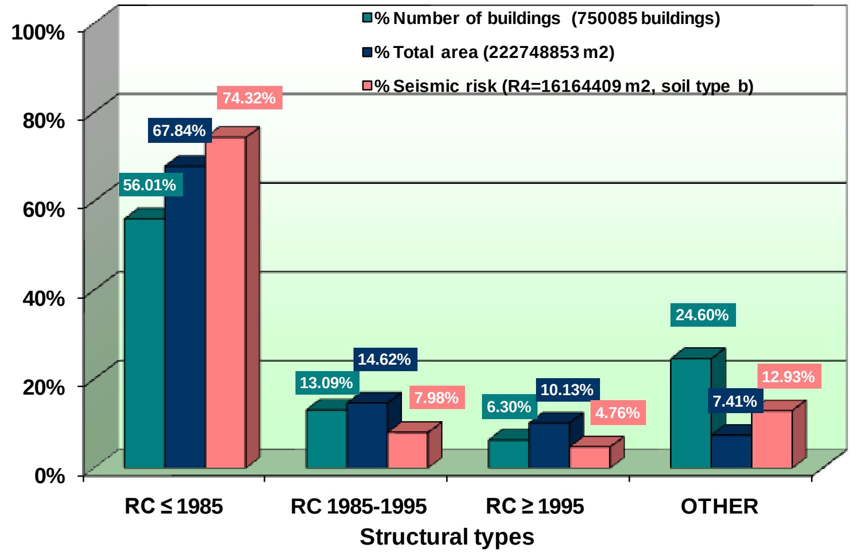
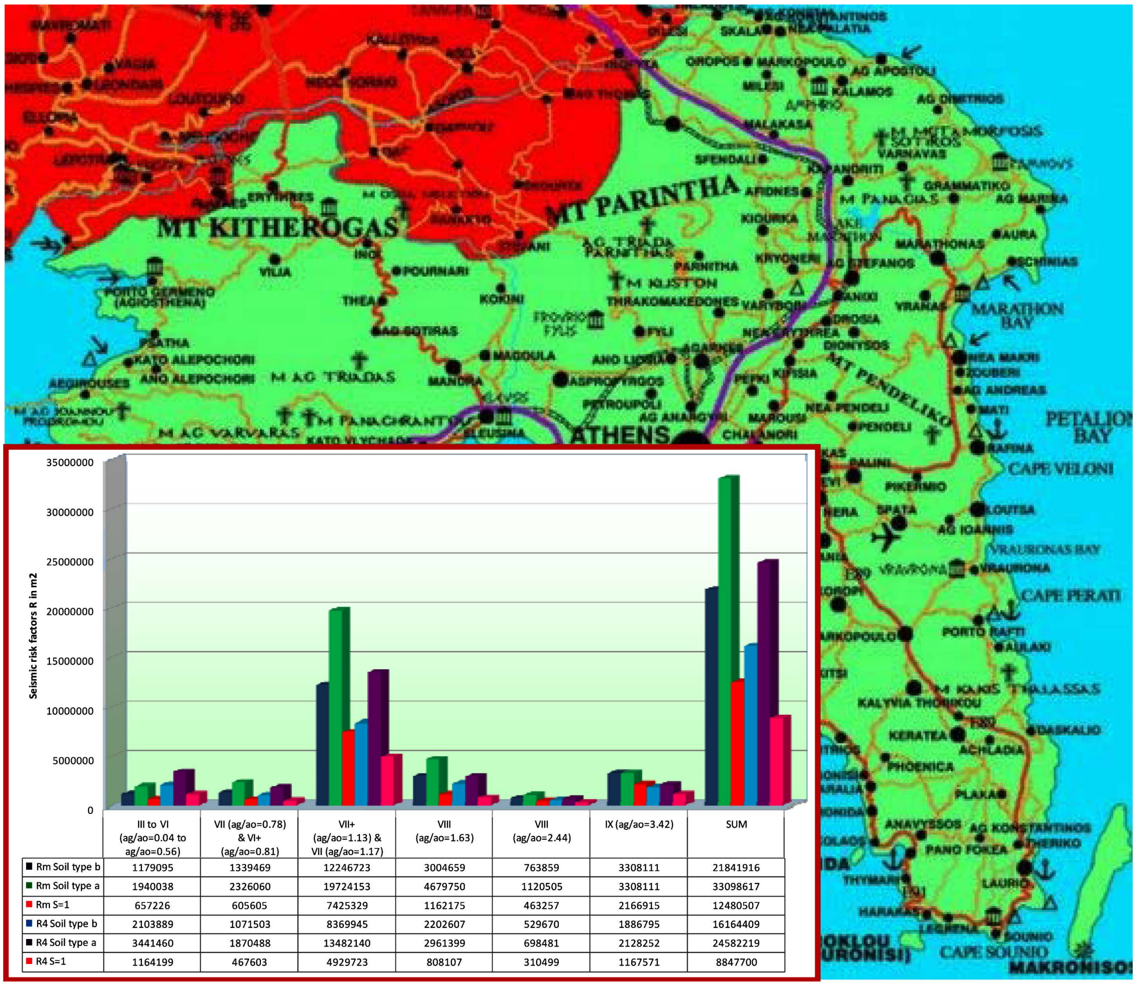


Figure 6. Distribution of Attica buildings categorized in structural types according to number of buildings, total area and the estimated seismic risk R_4.



	III to VI (ag/ao=0.04 to ag/ao=0.56)	VII (ag/ao=0.78) & VI+ (ag/ao=0.81)	VII+ (ag/ao=1.13) & VII (ag/ao=1.17)	VIII (ag/ao=1.63)	VIII (ag/ao=2.44)	IX (ag/ao=3.42)	SUM
■ Rm Soil type b	1179095	1339469	12246723	3004659	763859	3308111	21841916
■ Rm Soil type a	1940038	2326060	19724153	4679750	1120505	3308111	33098617
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■ R4 S=1	1164199	467603	4929723	808107	310499	1167571	8847700

Figure 7. Seismic input in Attica in a_g/a_o of Parnitha's earthquake and the estimated seismic risk.

Parnitha's earthquake in groups per damage level. Damage data include 178,578 buildings (**Table 8**) of the created database and represents the largest existing database in Greece [12] [21]. Moreover, it derived from the same seismic event (7th-9-1999 Parnitha's earthquake) with the one used for the simulation of ground motion in the methodology for the predicted losses.

The statistical compatible repair cost was based on two previous researches regarding damaged buildings after the 7th-9-1999 Parnitha's earthquake in the region of 1) Aharnes [6] and 2) Ano Liosia (in similar form) [7] belonging in the epicentral area where heavy damages were recorded. In addition, the mean values of the above researches are also examined (**Table 12**). The total statistical compatible repair cost of the 178,578 buildings has been evaluated from the mean repair cost per square meter and the mean constructed area per building for each damage category, provided by the Departments for Seismic Restoration in the above mentioned researches, as it is presented in **Tables 9-11**.

Table 8. Damage data categorized in structural types according to the damage level and seismic input [12].

		Macroseismic Intensity					
Damage Level	Structural Type	V, V+	VI, VI+	VII, VII+	VIII	IX	
Light	RC1-MIX1	7030	5380	53,929	9413	5826	81,578
	RC2-MIX2	385	571	3488	1719	2747	8910
	RC3-MIX3	165	78	1267	818	1322	3650
	MAS	1366	1189	8463	2056	2157	15,231
	OTH	164	245	1672	229	1008	3318
Moderate	RC1-MIX1	2147	2213	21,059	4916	5784	36,119
	RC2-MIX2	107	230	1428	577	1994	4336
	RC3-MIX3	8	41	264	202	702	1217
	MAS	1074	988	6337	1340	1825	11,564
	OTH	255	277	2339	322	770	3963
Extensive	RC1-MIX1	107	125	878	271	563	1944
	RC2-MIX2	2	3	176	27	191	399
	RC3-MIX3	1	3	13	3	66	86
	MAS	90	134	766	184	536	1710
	OTH	70	68	785	140	785	1848
Collapse	RC1-MIX1	18	29	478	210	348	1083
	RC2-MIX2	2	1	29	16	66	114
	RC3-MIX3	0	0	3	10	18	31
	MAS	12	34	415	157	119	737
	OTH	10	25	334	109	262	740
TOTAL		13,013	11,634	104,123	22,719	27,089	**178,578**
NSSG		284,164	104,764	277,137	41,676	32,574	**740,315**

Table 9. Statistical repair costs per damage level 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)	112,687	247	33	918.51	3.09
Moderate (Yellow)	57,199	285	62	1010.71	3.41
Extensive (Red)	5987	190	297	337.85	1.14
Collapse	2705	190	297	152.64	0.51
Total	178,578			2419.71	8.15

Table 10. Statistical repair costs per damage level based on Ano Liosia 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)	112,687	148	35	583.72	1.62
Moderate (Yellow)	57,199	177	92	931.43	2.58
Extensive (Red)	5987	113	361	244.23	0.68
Collapse	2705	113	361	110.35	0.31
Total	178,578			1869.72	5.18

Table 11. Statistical repair costs per damage level based on Aharnes & Ano Liosia 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)	112,687	159	35	627.10	2.06
Moderate (Yellow)	57,199	266	66	1004.19	3.29
Extensive (Red)	5987	175	305	319.56	1.05
Collapse	2705	175	305	144.38	0.47
Total	178,578	0	0	2095.22	6.87

Table 12. Statistical repair costs and constructed area regarding discrete damage levels.

Damage level	Studies (1) + (2)	Number of buildings	Area (m^2)	Total repair cost (M€)	Mean repair cost (€/m^2)	Mean area (m^2/building)
Light (Green)	(1)	51	12,610	0.414	33	247
	(2)	403	59,547	2.114	35	148
	(1) + (2)	454	72,157	2.528	35	159
Moderate (Yellow)	(1)	1586	452,658	28.190	62	285
	(2)	350	61,871	5.717	92	177
	(1) + (2)	1936	514,529	33.907	66	266
Extensive (Red)	(1)	919	174,906	51.904	297	190
	(2)	230	25,974	9.379	361	113
	(1) + (2)	1149	200,880	61.284	305	175
Total	(1)	2556	640,174	80.509		
	(2)	983	147,392	17.210		
	(1) + (2)	3539	787,566	97.719		

According to research (1) of Aharnes the damage data included 2556 buildings with 640,174 (m^2) total area and total repair cost 80.50 (M€). Among these buildings: 1) 51 developed minor (green) damages with 12,610 (m^2) total area and 0.41 (M€) approved total repair cost; 2) 1586 developed moderate (yellow) damages with 452,658 (m^2) total area and approved total repair cost 28.19 (M€); 3) 919 developed extensive (red) damages with 174,906 (m^2) total area and 51.90 (M€) approved total repair cost. According to research (2) of Ano Liosia the damage data included 983 buildings with total area repair 147,392 (m^2) and total repair cost 17.21 (M€). Among these buildings: a) 403 developed minor (green) damages with 59,547 (m^2) total area and approved total repair cost 2.11 (M€); b) 350 developed moderate (yellow) damages with 61,871 (m^2) total area and approved total repair cost 5.726 (M€); c) 230 developed extensive (red) damages with 25,974 (m^2) total area and approved total repair cost 9.38 (M€).

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 9**). According to the statistical data of Ano

Liosia the total compatible repair cost has been evaluated equal to 1869.72 M€ with equivalent replacement area 5.18 km^2 (**Table 10**). 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€ (**Table 11**) with equivalent replacement area of buildings 6.87 km^2.

The statistical costs for each damage category are presented in **Table 12**. It has resulted that the mean statistical compatible replacement cost has risen in 297 €/m^2, 361 €/m^2 or 305 €/m^2, taking into consideration the two researches and the mean value, respectively. The last values have been adopted for the evaluation of the equivalent replacement area R (m^2) from the total repair/strengthening cost per discrete damage levels in **Tables 9-11**. The evaluation and distribution of the statistical repair cost per intensity and damage level is presented in **Table 13** for the 178,578 damaged buildings based on the statistical data of the two researches.

Note that the approved budget by the National Agency for the Relief of Earthquake Victims for repair/replacement cost was based on a compatible work invoice. One third (1/3) of the approved budget was national assistance and the rest (2/3) was provided as without interest loan in earthquake victims. The upper limits that were set by the National Agency for the Relief of Earthquake Victims for the replacement and repair cost for habitat use regarding a building with area up to 120 m^2 were 382 €/m^2 and 191 €/m^2, respectively. The mean actual replacement cost in the same period was 528 €/m^2 according to estimations of the National Technical Chamber of Greece. Thus the reduction of the compatible to the actual cost could be attained by multiplying the first with the values of 1.78 (528/297 €/m^2), 1.46 (528/361 €/m^2) and 1.73 (528/305 €/m^2), regarding the 1) Aharnes research, 2) Ano Liosia and both (1 + 2) researches, respectively.

Finally, the created damage database referred in 180,945 buildings. Among them the 180,427 had the characterization of damage and the 178,578 were also able to be discriminated in structural types. Following the same assumptions an additional assessment of the compatible and the actual repair cost was fulfilled by multiplying with the values of 1.78, 1.46 and 1.73, as it is presented in **Tables 14-16**, regarding the Aharnes research, Ano Liosia and both (1 + 2) researches, respectively.

8. Comparison of Predicted with the Statistical Economic Losses

The results of seismic risk assessment are presented in **Table 17** for the entire examined area of Attica including 750,085 buildings for four different damage scenarios along with the estimated compatible cost in monetary loss based on the above mentioned. Conducting a comparison analysis between the predicted with the statistical

Table 13. Evaluation of statistical repair costs per intensity level and discrete damage levels regarding 178,578 damaged buildings.

Damage level	Total repair cost (M€) V, V+	Total repair cost (M€) VI, VI+	Total repair cost (M€) VII, VII+	Total repair cost (M€) VIII	Total repair cost (M€) IX	TOTAL (M€)
Light (Green)	50.70	41.53	382.98	79.218	72.679	627.104
Moderate (Yellow)	63.04	65.82	551.73	129.159	194.433	1004.185
Extensive (Red)	14.41	17.77	139.74	33.359	114.276	319.556
Collapse	2.24	4.75	67.20	26.794	43.394	144.379
TOTAL	130.39	129.87	1141.65	268.53	424.782	2095.224
	6.22%	6.20%	54.49%	12.82%	20.27%	100.00%

Table 14. Statistical repair costs per damage level 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)	Actual repair cost (M€)
Light (Green)	114,755	247	33	935.37	3.15	1664.96
Moderate (Yellow)	56,533	285	62	998.94	3.36	1778.11
Extensive (Red)	6423	190	297	362.45	1.22	645.16
Collapse	2716	190	297	153.26	0.52	272.81
Total	180,427			2450.02	8.25	4361.04

Table 15. Statistical repair costs per damage level based Ano Liosia 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)	Actual repair cost (M€)
Light (Green)	114,755	148	35	594.43	1.65	867.87
Moderate (Yellow)	56,533	177	92	920.58	2.55	1344.05
Extensive (Red)	6423	113	361	262.01	0.73	382.54
Collapse	2716	113	361	110.79	0.31	161.76
Total	180,427			1887.82	5.23	2756.22

Table 16. Statistical repair costs per damage level based on Aharnes & Ano Liosia 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)	Actual repair cost (M€)
Light (Green)	114,755	159	35	638.61	2.09	1104.80
Moderate (Yellow)	56,533	266	66	992.49	3.25	1717.01
Extensive (Red)	6423	175	305	342.83	1.12	593.09
Collapse	2716	175	305	144.97	0.48	250.79
Total	180,427			2118.90	6.95	3665.70

Table 17. Comparison of predicted with the statistical economic losses.

Predicted seismic risk loss factors for entire Attica according to Parnitha's eathquake (7th-9-1999) (750,085 buildings, 1,599,315 floors, 222,748,853 m^2 area)									
Attica (122 regions with 750,085 buildings)	a_g estimated from 7th-9-1999 Parnitha's earthquake	Modification damage factor S	4 damage scenarios		Mean seismic risk factors of the 4 damage scenarios		Predicted repair cost $Rc_4 = R_4$*c based on 1) Aharnes research 297 (€/m^2), 2) Ano Liosia research 361 (€/m^2), and the mean value (1) + (2) 305 (€/m^2)		
			R_m (Km^2)	R_4 (Km^2)	r_4 (%)	V_4 (‰)	$Rc_4^{(1)}$ (M€)	$Rc_4^{(2)}$ (M€)	$Rc_4^{(1)+(2)}$ (M€)
		S for soil type a	33.10	24.58	11.0%	37.0	7300.92	8874.18	7497.58
		S for soil type b	21.84	16.16	7.3%	24.4	4800.83	5835.35	4930.14
		S = 1	12.48	8.85	4.0%	13.3	2627.77	3194.02	2698.55
Statistical economic losses including 180,427 damaged buildings (**Tables 14-16**) based on 1) Aharnes research, 2) Ano Liosia research, and 3) the mean value of (1) + (2)									
	1) Aharnes research		Equivalent replacement area *R* = 8.25 (km^2)				Compatible repair cost 2450.02 (M€)		
	2) Ano Liosia research		Equivalent replacement area *R* = 5.23 (km^2)				Compatible repair cost 1887.82 (M€)		
	3) Aharnes & Ano Liosia		Equivalent replacement area *R* = 6.95 (km^2)				Compatible repair cost 2118.9 (M€)		

compatible cost it is concluded that generally the seismic risk methodology overestimates seismic losses. As expected, the seismic scenario based on the developed DPMs [21] from 7th-9-1999 Athens damage data presented the better correlation (2627.77 M€) with the total statistically evaluated repair cost, especially when the last was based on Aharnes research (2450.02 M€). 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.

9. Conclusions

A complete research of seismic risk assessment is presented regarding the extended urban region of Athens in Greece. The seismic risk assessment is fulfilled by discriminating the current study in two approaches, probable and actual, conducting afterwards between them a comparison analysis. In the first part, a pilot methodology is developed for the seismic loss assessment in monetary terms regarding the buildings damages, consistent with the National Programme for Earthquake Management of Existing Buildings (NPEMEB). The building stock consists of typical building types of Southern Europe and refers to 750,085 buildings (18.80% of buildings in Greece) situated in the entire region of Athens according to the results of the 2000-1 statistical census. A wider research of seismic risk assessment could include direct losses of infrastructures and indirect economic losses. The evaluation of loss due to building damage in a certain region requires an assessment of both seismic hazard and vulnerability of the building stock in the study area. Three different scenarios for soil conditions (a, b and $S = 1$) and four damage scenarios have been applied in the described methodology for the estimation of the seismic risk. The results of the seismic risk assessment for the four different aspects of the estimated damage and the different soil conditions have been presented in a map of the study region. The existing vulnerability curves corresponding to defined types of buildings have been derived from the National Technical Chamber of Greece and also from recently developed DPMs. The last DPMs were obtained in a previous research [21] from the process of a created damage database after the 7th of September 1999 Parnitha's earthquake and comprised 180,945 buildings which developed damage of varying degree, type and extent. The numerical values of the seismic risk factors (**Table 7** & **Table 17**) after the application of the described methodology are estimated as follows:

1) $R_m = 12.48\ \text{Km}^2$, $R_4 = 8.85\ \text{Km}^2$ and $r_4 = 4.0\%$ with predicted repair cost from 2627.77 to 3194.02 M€, for a_g according to the Parnitha's earthquake and $S = 1$.
2) $R_m = 14.11\ \text{Km}^2$, $R_4 = 9.65\ \text{Km}^2$ and $r_4 = 4.3\%$, for $a_g / a_o = 1$ and $S = 1$.
3) $R_m = 33.10\ \text{Km}^2$, $R_4 = 24.58\ \text{Km}^2$ and $r_4 = 11.0\%$ with predicted repair cost from 7300.92 to 8874.18 M€, for a_g according to the Parnitha's earthquake and S for soil type a.
4) $R_m = 21.84\ \text{Km}^2$, $R_4 = 16.16\ \text{Km}^2$ and $r_4 = 7.3\%$ with predicted repair cost from 4800.83 to 5835.35 M€, for a_g according to the Parnitha's earthquake and S for soil type b.
5) $R_m = 43.31\ \text{Km}^2$, $R_4 = 29.57\ \text{Km}^2$ and $r_4 = 13.3\%$, for $a_g / a_o = 1$ and S for soil type a.
6) $R_m = 26.54\ \text{Km}^2$, $R_4 = 18.14\ \text{Km}^2$ and $r_4 = 8.1\%$, for $a_g / a_o = 1$ and S for soil type b.

In the second part of the research, the seismic risk is evaluated from the available data regarding the mean statistical repair/strengthening or replacement cost for the total number of damaged structures (180,427 buildings) after the same (1999 Parnitha's) seismic event. Data regarding the compatible (budget approved according to the ministry's provisions) repair cost has been collected. The structural losses in monetary terms for the 180,427 buildings damaged structures are evaluated equal to 2450.0 M€, 1887.8 M€ and 2118.9 M€ based on the previously mentioned statistical seismic risk data. The statistically derived repair cost for Attica is compared with the results of the economic loss estimation for buildings using the aforementioned risk assessment methodology. Conducting a comparison analysis between the estimated with the compatible repair 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. From the analysis results, the seismic scenario based on the recently developed DPMs [21] presented the better correlation (2627.77 M€) with the total statistically evaluated repair cost (2450.02 M€). 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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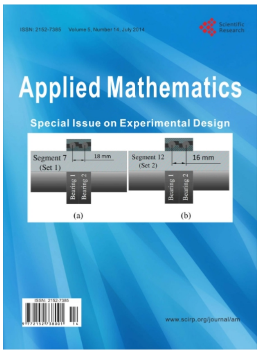
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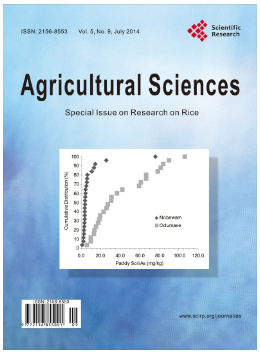
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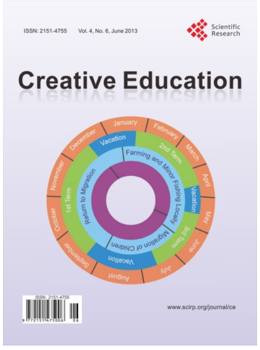
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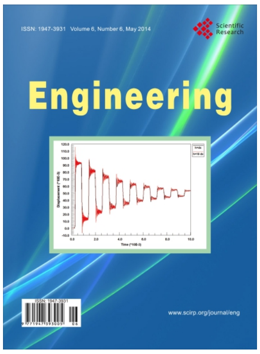
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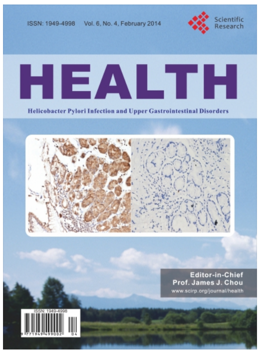
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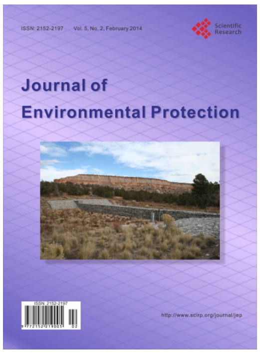
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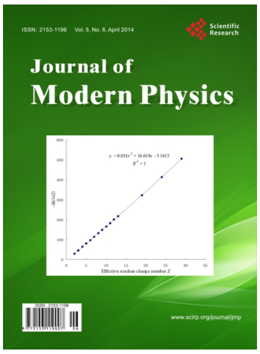
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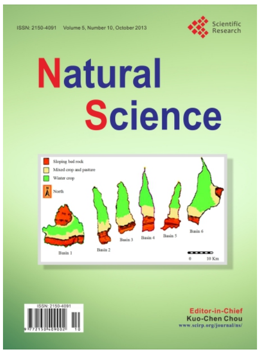
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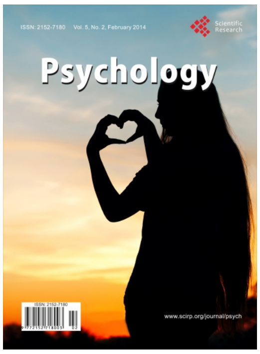
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