RISK-UE
AN ADVANCED APPROACH TO EARTHQUAKE RISK SCENARIOS WITH APPLICATIONS TO DIFFERENT EUROPEAN TOWNS

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An advanced approach to earthquake risk scenarios with applications to different European towns

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Synthesis of the application to Thessaloniki city

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Contents

1. Distinctive Features of Thessaloniki

The city of Thessaloniki is located in the eastern part of Mediterranean in the Northern Greece (Macedonia, Thrace) in a strategic geographical location, constituting a crossroad between Asia, Africa and Europe. It is the second city in population in Greece (1.048.151 people) after Athens and an important administrative, economic, industrial, academic and cultural centre at national scale. Thessaloniki's activities expand in Europe, Balkan and east Mediterranean countries with a very active International Trade Fair (photo 1.2) that vitalizes the commercial and economical corporation not only between different towns in Greece but with other countries abroad.

The urban area of Thessaloniki (Area of the city = 13130Ha, 1991) consists of 17 districts with the more important the municipality of Thessaloniki (Density: 216 people/ Ha), which includes the historical center of Thessaloniki, the old town, the International Trade Fair, the two University campus.

Fig. 1.1 The region of C. Macedonia (Greece)-Thessaloniki

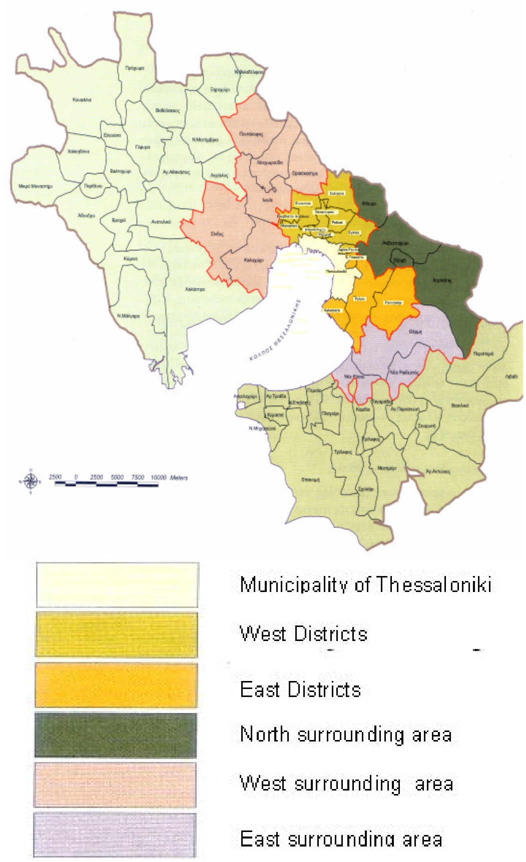


Fig. 1.2 Urban area of Thessaloniki

Photo 1 Satellite photo of Thessaloniki (1987)

Touristic activity is an important component of economical growth of the city as it concentrates a big number of visitors (from Greece and abroad) during the year and especially during the summer months. Thessaloniki is also well known for its active scientific community as a result of the two Universities (Aristotle and Macedonia), the

Technical Institute (A.T.E.I), the National Center for Technology and Development, the Institute of Engineering Seismology and Earthquake Engineering and other research centers. Many conferences, exhibitions and other national and international meetings are being held every year.

The city has a long history that can be divided in the following five main historical periods:

- Hellénistique (Macedonian) period, since the foundation of the city till its occupation by the Romans (315-168 BC)
- Roman period, till the Byzantine's foundation (325 AC)
- Byzantine period, till the occupation of the city by Turks (1430 AC)
- Turkish period, till liberation in 1912
- Greek period, after 1912.

The long history of the city through the centuries left a significant cultural heritage with numerous important monuments harmonized with the modern urban environment (photo 1.3, 1.4, 1.5, 1.6, 1.7).

Photo 1.2 Aerial photo of the International Trade Fair

Photo 1.3 Aerial photo of Thessaloniki's historical center

Photo 1.4 White Tower in the sea-frond of Thessaloniki

Photo 1.5 Arch of Galerios and Rotonda (in the historical center of Thessaloniki).

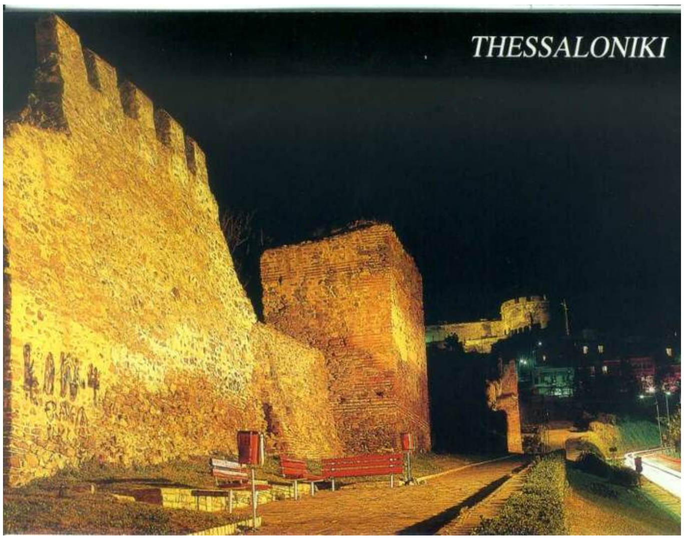


Photo 1.6 Byzantines walls of Thessaloniki.

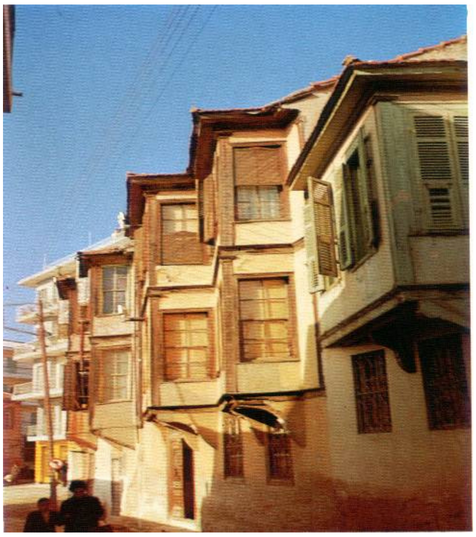


Photo 1.7 An outlook of Old City.

Thessaloniki was stroked from several earthquakes as its urban area is located on the Axios-Vardar seismogenic zone, which is adjacent to Servomacedonian massif, one of the most seismotectonically active regions in Europe. During the centuries, many people in the city died from earthquakes (Papazachos and Papazachou, 1997).

The latest major earthquake occurred in Thessaloniki in June 1978 with an epicenter located at a distance of about 25km NE of the city, a focal depth of about 8 km and a magnitude of M=6.5. The recorded PGA in one station located in the basement of an eight-story building at the shore line of the city was rather low (~0.15g) most probably due to the presence of non linear site effects. Based on the type, extend and intensity of damages it may be concluded that the maximum ground acceleration on stiff soils should be of the order of 0.30g. The earthquake caused a nine-story R/C building collapse, (37 deaths), few partial collapses and extended damage to buildings. The public repair cost of the particular residences was of the order of 250 million US dollars (1978). The total economic damage was certainly very high.

Photo 1.8 Apartment building in Ippodromiou Sq, Thessaloniki. View taken from Nikiforou Foka Str, 30 hours after the collapse.

Photo 1.9 Saint Constantine's church in Thessaloniki. Front view of the church; the left hand side steeple fell down after the main shock (PGA~0.19g).

Photo 1.10 Liquefaction sand boils in Scholari village (30km north-east from Thessaloniki in the epicenter area of 1978 earthquake).

2. Earthquake hazard assessment

Seismicity, Tectonics

The city of Thessaloniki is located on the Axios-Vardar seismogenic zone, which is adjacent to the Servomacedonian massif, one of the most seismotectonically active regions in Europe (Papazachos et al., 1979). There were identified two seismic periods with intense seismic activity in Servomakedonian zone during the present century. The first one started in the region of Volvi- Langada lakes with a main shock of Mo= 6.6 (Assiros 1902) and continued in Bulgaria (1903- 1905) to the north, with the main shock of Mo= 7.6 (Kresna 1904) and in the Athos peninsula to the southeast with the main shock of Mo= 7.4 (1905). The second period started in Yugoslavia with a main shock of Mo= 6.6 (Valandovo 1931) and continued southeastward (1932-1933) with the main shock of Mo= 6.9 (Ierissos 1932) and with other shocks some of which had their epicenters in the region of Volvi-Langada lakes (Comninakis, Papazachos, 1986). Fig.2.1 illustrates the epicentres of large earthquakes in the area surrounding Thessaloniki.

According to the present and past seismicity, a seismic zonation of Greece (fig.2.2) and consequently of the region of Thessaloniki was developed (Papazachos and Papazachou, 1989; Papazachos and Papazachou, 1997; Papaioannou and Papazachos, 2000). The parameters of each zone were derived from the data of previous earthquakes after completeness analysis (Papaioannou and Papazachos, 2000). The seismic zones, surrounding and affecting Thessaloniki, are six (zone 33, 34, 35, 36, 56, 64). The resulting seismotectonic zonation for Greece and surrounding area is shown in Fig.2.2.

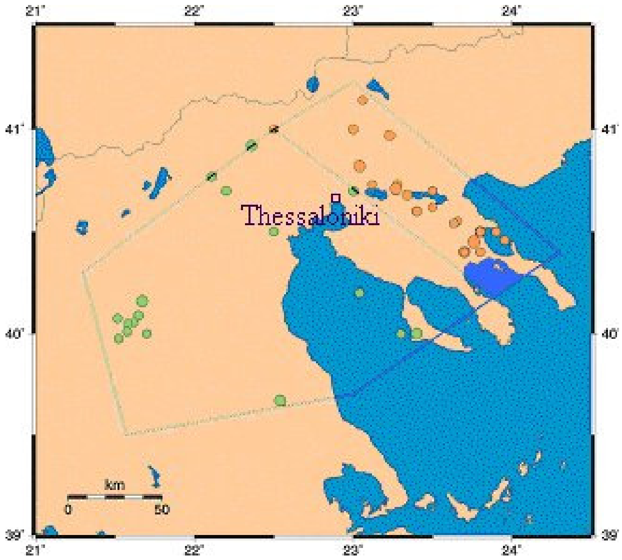


Fig. 2.1 Epicentres of large earthquakes in the area surrounding Thessaloniki (1901-2000)

Fig. 2.2 Seismogenic sources of shallow earthquakes in Greece and surrounding area

From geological and seismotectonic point of view, Servomacedonian zone, where Thessaloniki is located, is considered as a Tertiary structure. Probably represents a reactivated tectonic line, related to an old (Jurassic) subduction of the Vardar Ocean beneath the Servomacedonian continental margin. Many active faults exist, which have given birth to some of the greatest earthquakes of the northern Greece. Since the Miocene the area of Central Macedonia, has been intensely faulted, forming many tectonic grabens and depressions such as the Axios basin, the Anthemountas and Mygdonian grabens etc. These depressions are the result of a continuous extensional deformation, which was mostly associated with pure normal to oblique-normal faults trending mainly NW- SE (sinistral component), ENVE- WSW (dextral component) and E-W strikes (Pavlides S, Soulakellis N, 1990, Pavlides et al 1996, Voidomatis et al 1990). In addition, some long N-S trending faults complete the general fracture pattern. Most of the above mentioned faults (fig. 2.3) have been active at least since the Miocene, while some of them (mainly the E-W trending faults) are associated with the present seismic activity or have a verified activity since the Quaternary. The active belt is characterized by an intense shallow seismic activity with earthquakes having magnitudes up to about 7.6.

Geology

From geological point of view, Thessaloniki presents interesting features (fig.2.4), as it comprises regions with various geological formations composed by a large variety of soil materials (S. Pavlides, N. Soulakellis, 1990). The whole urban area is situated on three (3) main large-scale geology structures, oriented in NW-SE direction. The first formation includes the metamorphic substratum consisting of gneiss, epigneiss, and green schists, which are surficial near the city at the N-NE border of the urban area. These crystalline rocks constitute the bedrock basement beneath the city reaching a depth of 150-300m near the coastline in W-WS direction. The second formation is composed by alluvial deposits mainly of the Neogene period. In this geological structure the red silty clay, series are dominant, covering the bedrock basement beneath the city. Finally, recent deposits of Holocene clays-sands-pebbles compose the third surface formation.

Fig. 2.3 Seismotectonic map of Greece with Seismologeological data
Scale 1: 500.000 I.G.M.E 1989

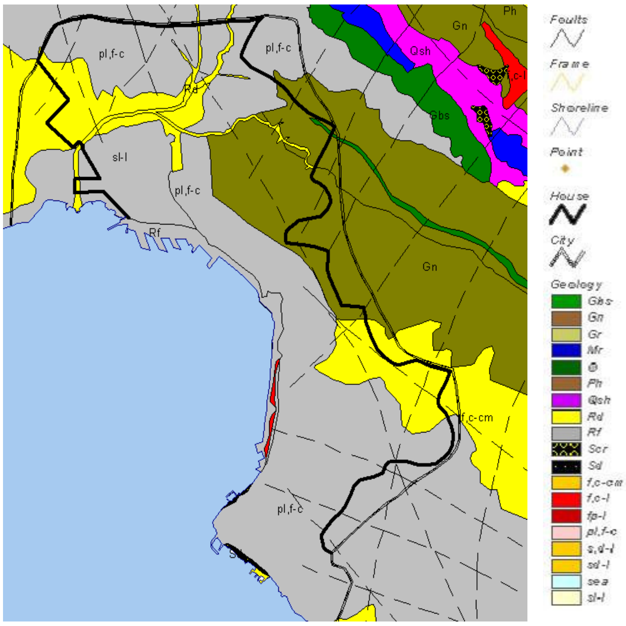


Fig. 2.4 Geological map of Thessaloniki

Geotechnical Zonation of the Thessaloniki Urban Area

Reliable modeling and evaluation of site effects is the key problem in seismic microzonation especially in high seismicity areas, with complex geology and highly heterogeneous soils. Hence, a detailed model of the surface geology and geotechnical characteristics, properly oriented for site effect studies, generated for the city of Thessaloniki. The resulted geotechnical map (Anastasiadis et al., 2001) based on data provided by geotechnical investigations (boreholes, CPT's, water wells), geophysical surveys (cross holes, down holes, surface seismics), microtremors measurements, classical geotechnical and special soil dynamic tests (resonant column, cyclic triaxial), (Pitilakis et al. 1992, Pitilakis and Anastasiadis, 1998, Raptakis et al. 1994a, Raptakis et al. 1994b, Raptakis 1995). The geotechnical map (fig. 2.5) together with thematic GIS maps (fig.2.6) describe the spatial distribution and the thickness of each soil formation and nine (9) different soil formations are needed to fully describe the subsoil conditions in the city (Table 2.1). These maps resulted from the synthesis of all available data and depict the thickness of the A and C soil formations, the depth of the stiff clayey formations (E and F) and the depth of the rock basement (formation G) with respect to the regions where they are predominant. The variation of the thickness and the depth shows a certain irregularity of the subsoil structure beneath the urban area of the city.

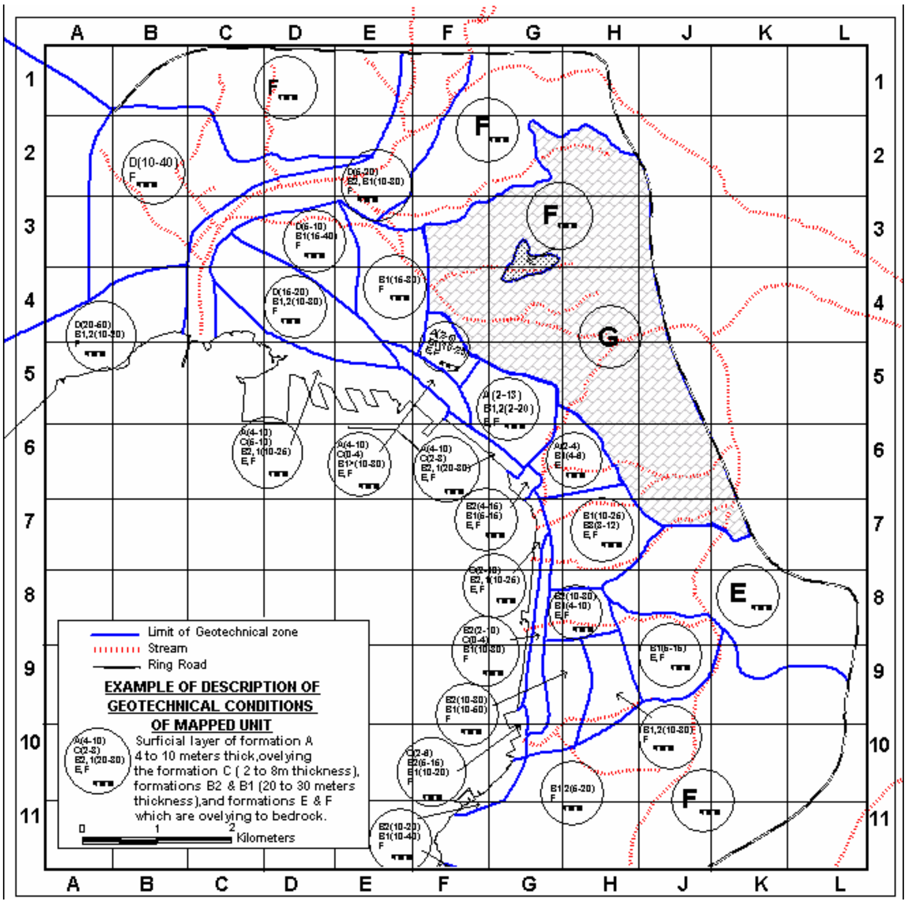
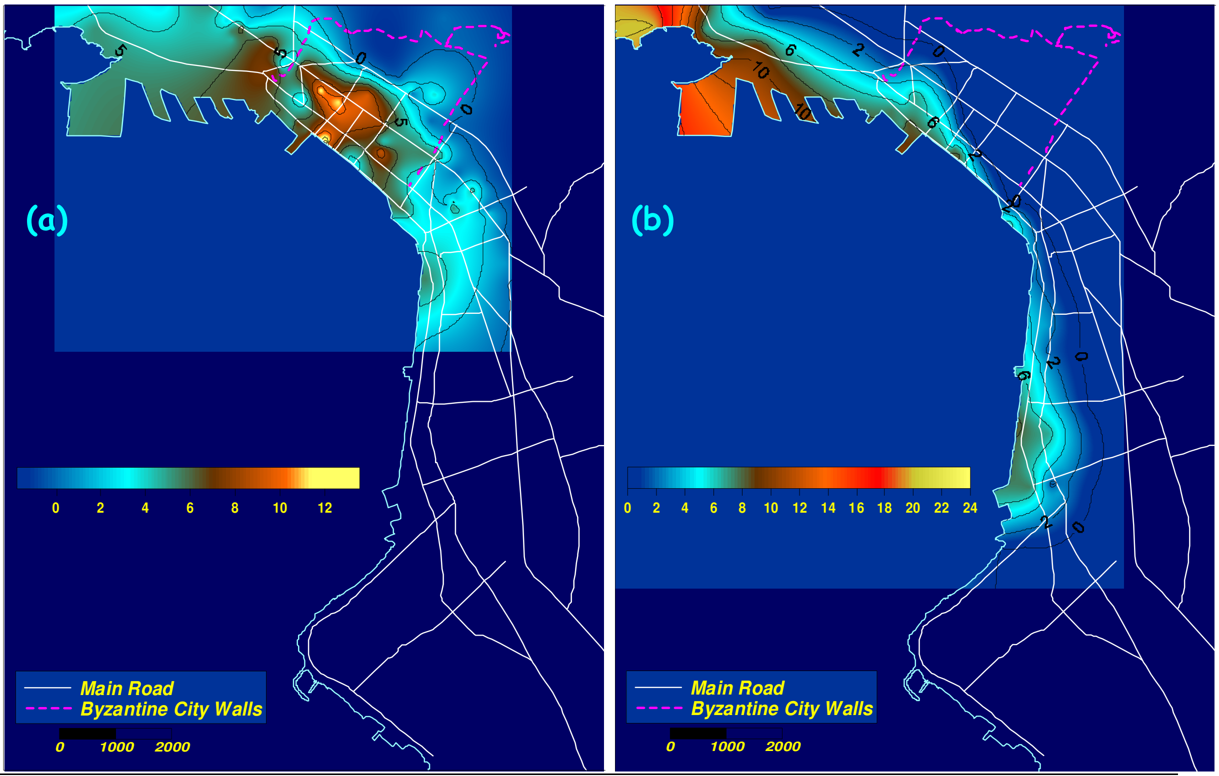


Fig. 2.5 Detailed geotechnical zonation of Thessaloniki with nine main soil formations (A, B, C, D, E, F, G) and respective ground layering [Anastasiadis et. al., 2001].

Table 2.1 Dynamic properties of the main soil formations of Thessaloniki urban area. The values in brackets specify the mean values of V_S velocities and quality factors Q_S.

Formation		Description	V_S (m/s)	V_P (m/s)	Q_S
(1)		(2)	(5)	(6)	(7)
A	*Surficial*	Artificial Fills, demolition materials & debris parts	200-350 (250)	400-1700	8-20 (15)
B1	*Surficial*	Very Stiff sandy-silty clays to clayey sands, low plasticity	300-400 (350)	1900	15-20 (20)
B2	*Surficial*	Soft sandy-silty clays to clayey sands, low to medium plasticity	200-300 (250)	1800	20-25 (20)
B3	*Surficial*	Stiff to hard high plasticity clays	300-400 (350)	1800	20-40 (30)
C	*Surficial*	Very soft buy mud and silty sands	120-220 (180)	1800	20-25 (25)
D	*Surficial*	Alluvium deposits, sandy-silty clays to clayey sands-silts, low strength and high compressibility	150-250 (200)	1800	15-25 (20)
E	*Subbase*	Stiff to hard sandy-silty clays to clayey sands	350-700 (600)	2000	6-30 (30)
F	*Subbase*	Very stiff to hard low to medium plasticity clays to sandy clays,overconsolidated with rubbles and thin layers of gravels	700-850 (750)	3200	50-60 (60)
G		GreenSchists & Gneiss	1750-2200 (2000)	4500	180-200 (200)



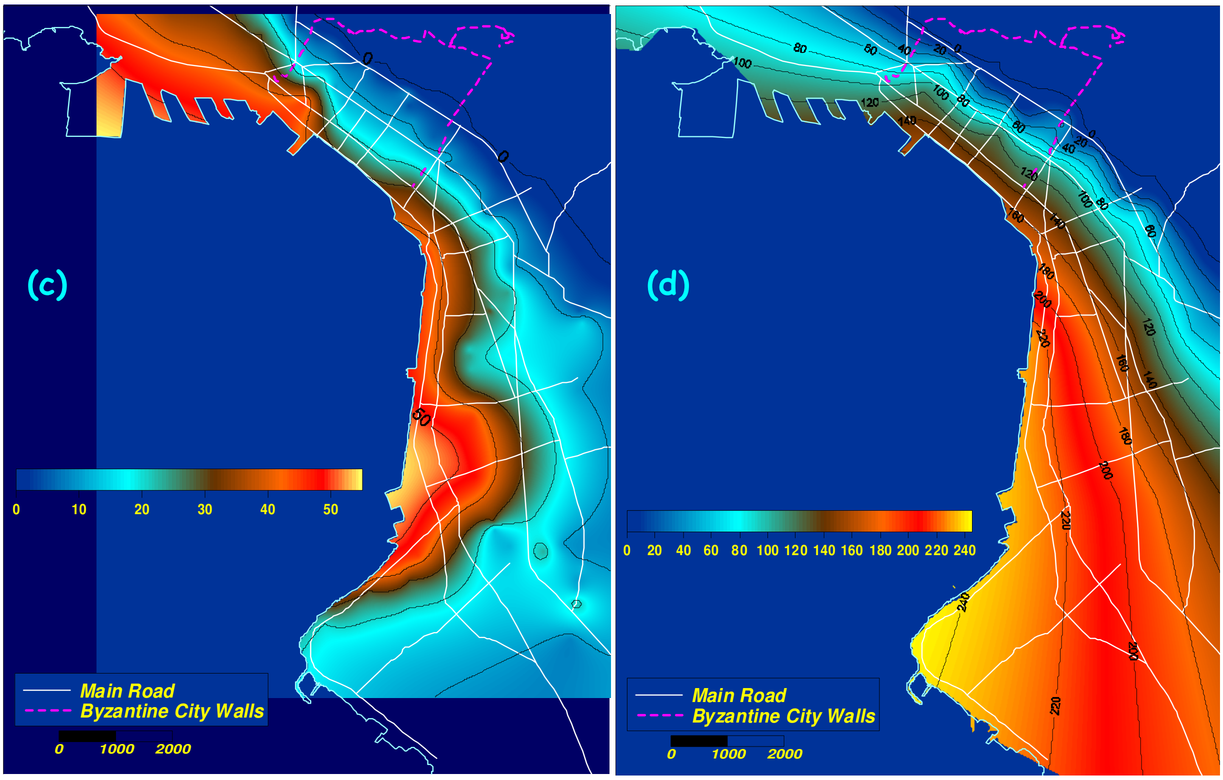


Fig. 2.6 Geotechnical thematic maps for the main soil formations (A, C, E and F and G). a) thickness of formation A(artificial fills); b) thickness of formation C (sandy-silty & organic soils), c) top surface of stiff clayey formations E-F; d) top surface of the formation G (bedrock).

Among the goals of the present geotechnical zonation was the mapping of the thickness and the lateral variations of the artificial or hazardous fills, at the historical part of the city, which contain structural members of ancient buried buildings. Their influence on the seismic behaviour of modern structures founded on this debris is practically unpredictable. Moreover, further attention is focused on the mapping of old and recent described streams and torrent traces indicating the existence of artificial fills and large variety of soil conditions. These features are well correlated with damage distribution and high intensity values after the 1978, (M=6.5) earthquake (fig. 2.7).

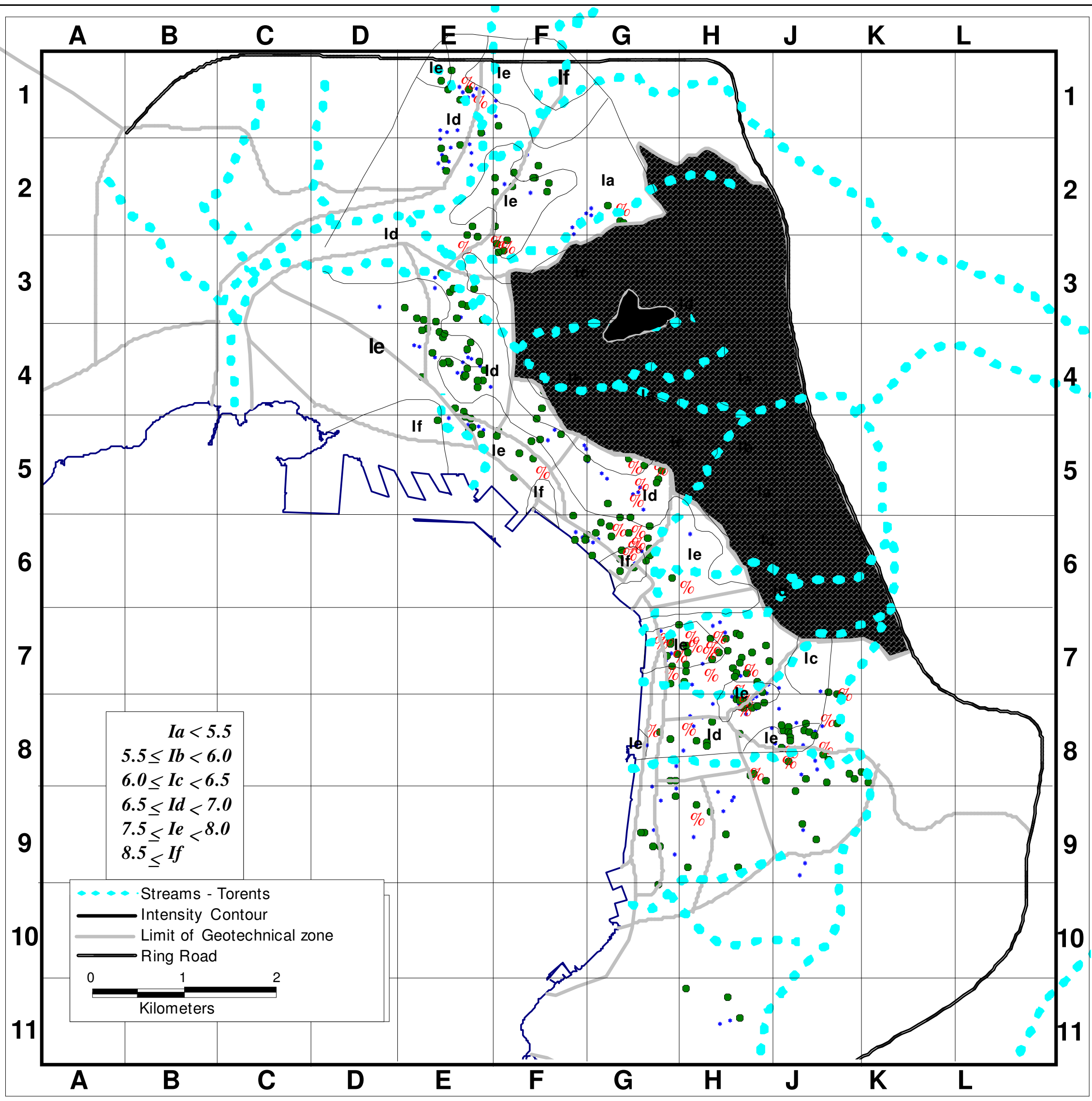


Fig. 2.7 Distribution of damages (symbols) and intensities (thick black lines) after the 1978, (M=6.5) earthquake with respect to the geotechnical zonation (gray lines) and stream-torrent traces (cyan line) The level of damage is indicating with different circles: i) small damages which do not affect the strength of the buildings (open circles); ii) many damages of the structural frame, directly restorable (solid circles); iii) extended damages of the structural frame, not directly restorable. Damages of buildings, which not related to the frame of the structure, are not included. Intensity contours, with Ia-If levels, denote the limits of the intensities for each zone. (Anastasiadis et al 2001).

Degradation curves of shear modulus G/Go-γ and damping ratio Ds-γ, determined for all nine-soil formations from an extended laboratory including resonant column and cyclic triaxial tests [Pitilakis et al., 1992; Pitilakis and Anastasiadis, 1998; Anastasiadis, 1994] are depicted in Fig.2.8.

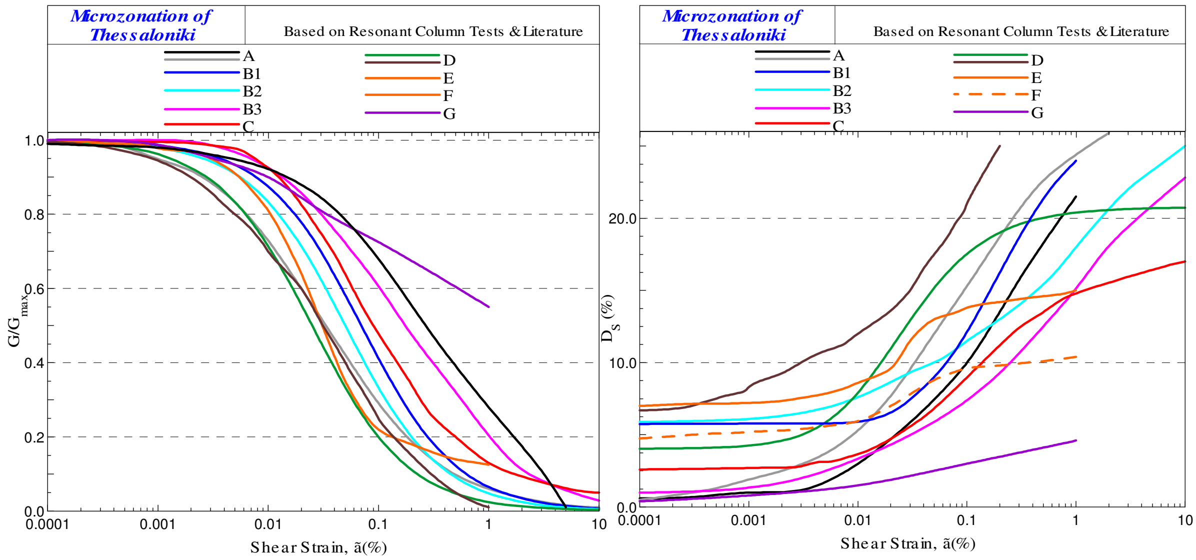


Fig. 2.8 Average degradation curves of shear modulus G/Go-γ and damping ratio Ds-γ of the main soil formations of Thessaloniki urban area.

Taking into account the detailed geotechnical zonation, a simplified classification of soil categories according to the Vs,30 (Table2.2) was followed. The application of Vs,30 lead to a simplified geotechnical map (fig.2.9) of the city of Thessaloniki which was used for the probabilistic seismic hazard evaluation..

Table 2.2 Classification of soil conditions according to Ambrasey's (96) classification.

Classification	$V_{s,30}$ (m/sec)
Rock	> 750
Stiff Soil	360- 750
Soft Soil	< 360

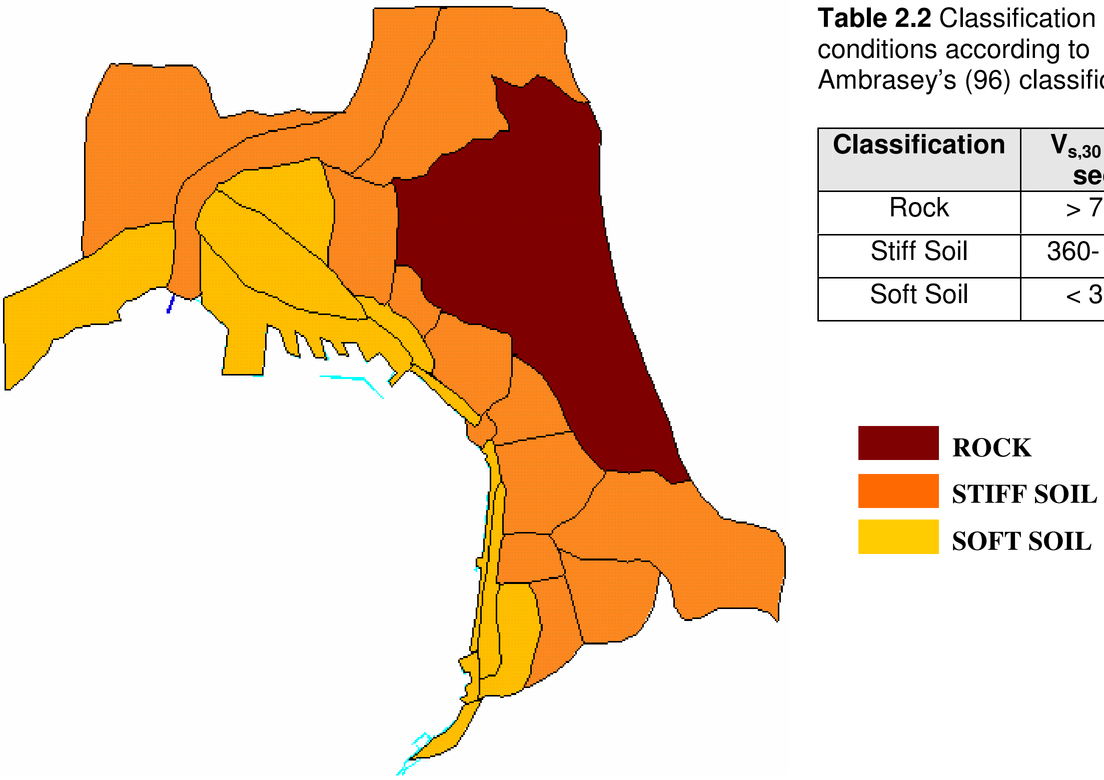


Fig.2.9 Simplified geotechnical map of the city of Thessaloniki

Seismic Hazard

According to WP02 methodology (Faccioli and Pessina, 2003), for the seismic hazard evaluation both deterministic scenario (maximum probable/ historical earthquake or maximum credible earthquake compatible under the known tectonic framework) and probabilistic approach will be used. A more advanced approach premises a detailed Microzonation study. However, in Thessaloniki, five seismic hazard scenarios were developed: two deterministic scenarios and three probabilistic scenarios (Alexoudi et al., 2002).

The selected deterministic scenarios correspond to the historical earthquake–Assiros, 1902 and to Thessaloniki 1978 earthquake (fig.2.10). For the deterministic scenarios, 4maps/ 2per scenario were produced for EMS98 intensity (Ambrasey's mean value & Ambrasey's mean value+std), 20 maps/ 10per scenario for PSA in terms of spectral ordinates (SA(T) = 0.0, 0.3, 0.6, 1.0, 1.6sec) using Ambraseys et al., 1996 relationship for mean value & for mean value+std), 4 maps/ 2 per scenario for PGV and 4/ 2per scenario for PGD (Bommer et al., 2000 relationships for mean value & for mean value+std). Figures 2.11, 2.12 illustrate some results obtained using the deterministic scenarios.

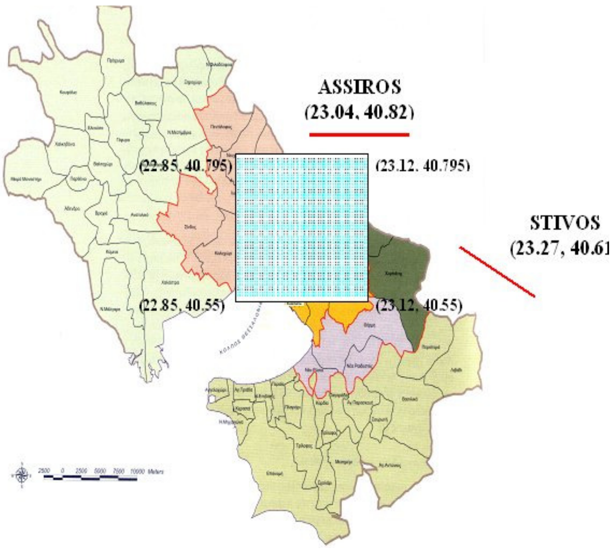


Fig.2.10 Assiros and Stivos faults location in respect to the selected grid.

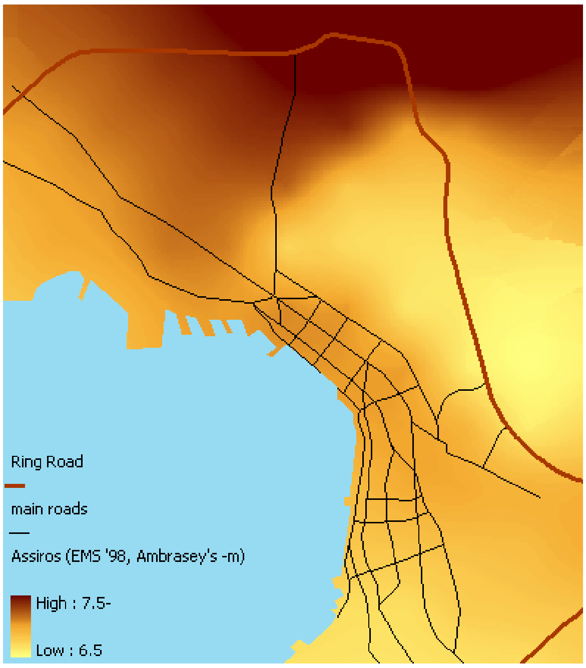


Fig. 2.11 EMS98 intensity map based on ASSIROS deterministic scenario (T=0sec) (Ambrasey's 96 -mean value)

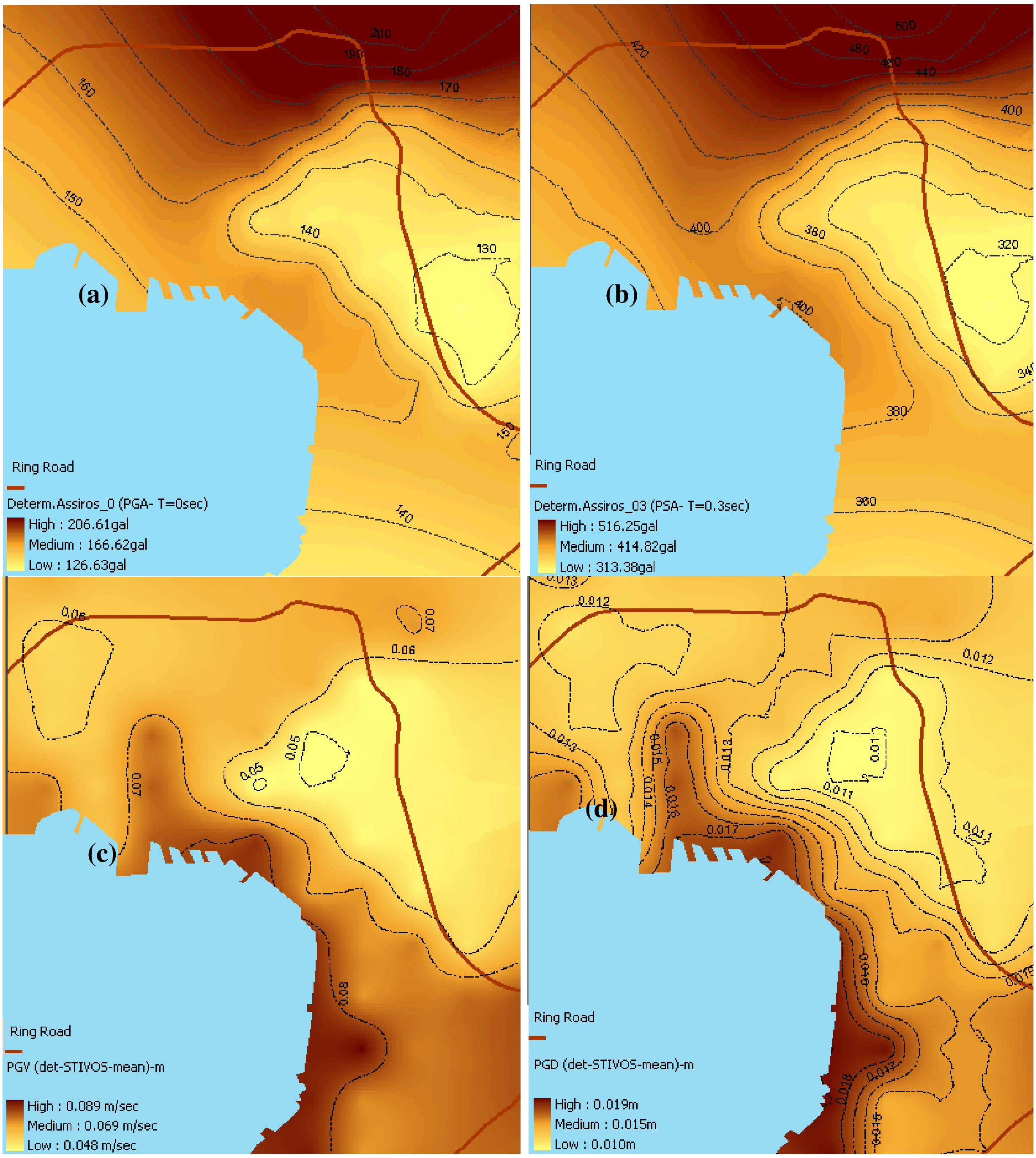


Fig. 2.12 Deterministic scenarios: Distribution of mean a) PGA (gal) values - Assiros earthquake, b) PSA values in terms of spectral ordinates (T=0.3sec) -Assiros earthquake, c) PGV (m/sec) values - Thessaloniki '78 earthquake d) PGD (m) values –Thessaloniki '78 earthquake.

Three probabilistic scenarios where developed (recurrence period of 475years) due to complex seismotectonic environment. One for uniform distribution of the seismicity in two seismic source zones (SSZ) and two where the seismicity is concentrated in two seismic fault zones describing the complex seismotectonics of the area. Maps where produced for the spectral values according to WP02 handbook for PSA for the three seismic scenarios. Characteristic maps are given in figure 2.13.

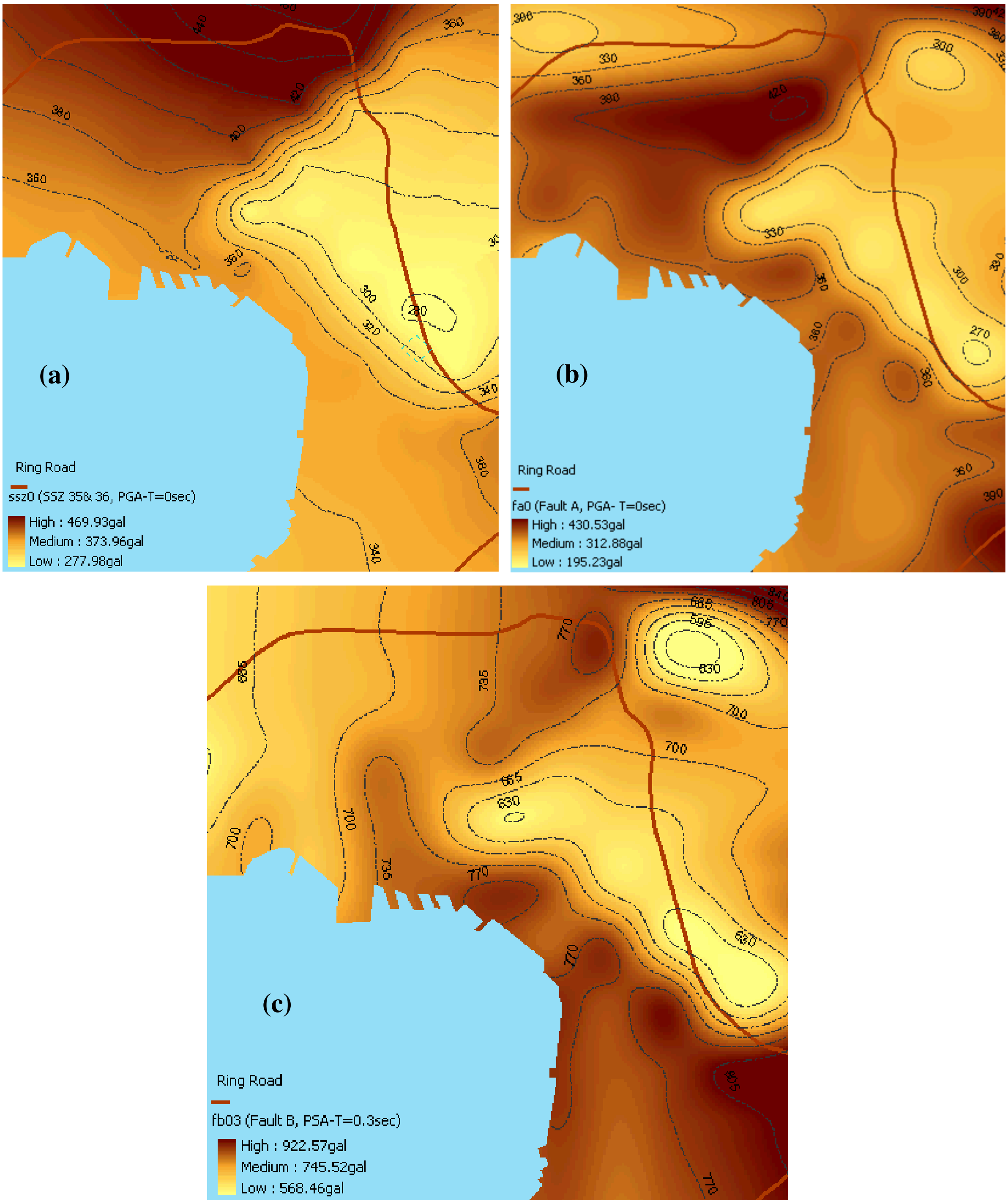


Fig 2.13 Probabilistic approach: a) PGA (gal) values for SSZ b) PGA (gal) values for fault geometry A; c) PSA values (gal) for fault geometry B -T=0.3sec.

Site Response Analysis

Site effects are calculated performing a great number of 1D linear equivalent response analyses (Schnabel et al., 1972) in order to take into account the influence of geotechnical characteristics and dynamic properties of the main soil formations on expected seismic motion.

The geotechnical thematic GIS maps describing the spatial distribution and the thickness of each soil formation, combined with detailed 2D cross sections were used to develop adequate 1D soil profiles at 301 sites in a quadratic grid of 500m x 500m or 250m x 250m. For the seismic response analyses, five different real accelerograms were selected to satisfy the following criteria: a) originated from earthquakes that have similar seismotectonic environment to that of the area under study, b) recorded at rock outcrop sites, c) at different epicentral distances to account for waveforms from near, intermediate and far field conditions and d) to cover the response spectra provided by the Greek seismic code and Eurocode 8 for soil type A. The recorded input motions were scaled properly according to the seismic hazard results for 475 years return period, (SSZ case) to 0.24-0.26g, (Fig. 2.14).

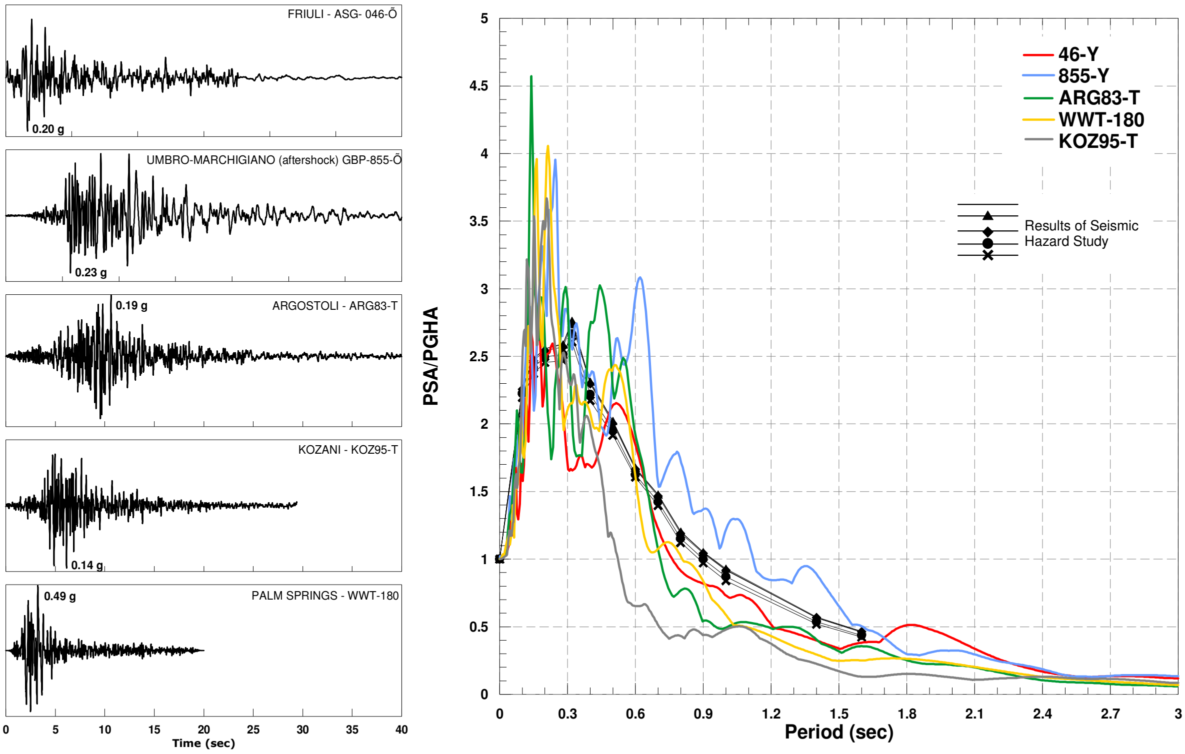


Fig. 2.14 Acceleration time histories (left) and of normalized acceleration response spectra (right) compared with mean probabilistic values of the seismic hazard analyses of the five input motions used in the 1D response analysis study

On the basis of the earthquake scenario with 10% probability of exceedence in 50 years, according to the results of seismic hazard study, the characteristics of the calculated seismic motions at the free surface, in terms of maximum amplification ratio and peak parameters (PGA, PGV, PGD) for the city of Thessaloniki, directly organized through GIS environment are presented in Figures 2.15 to 2.19.

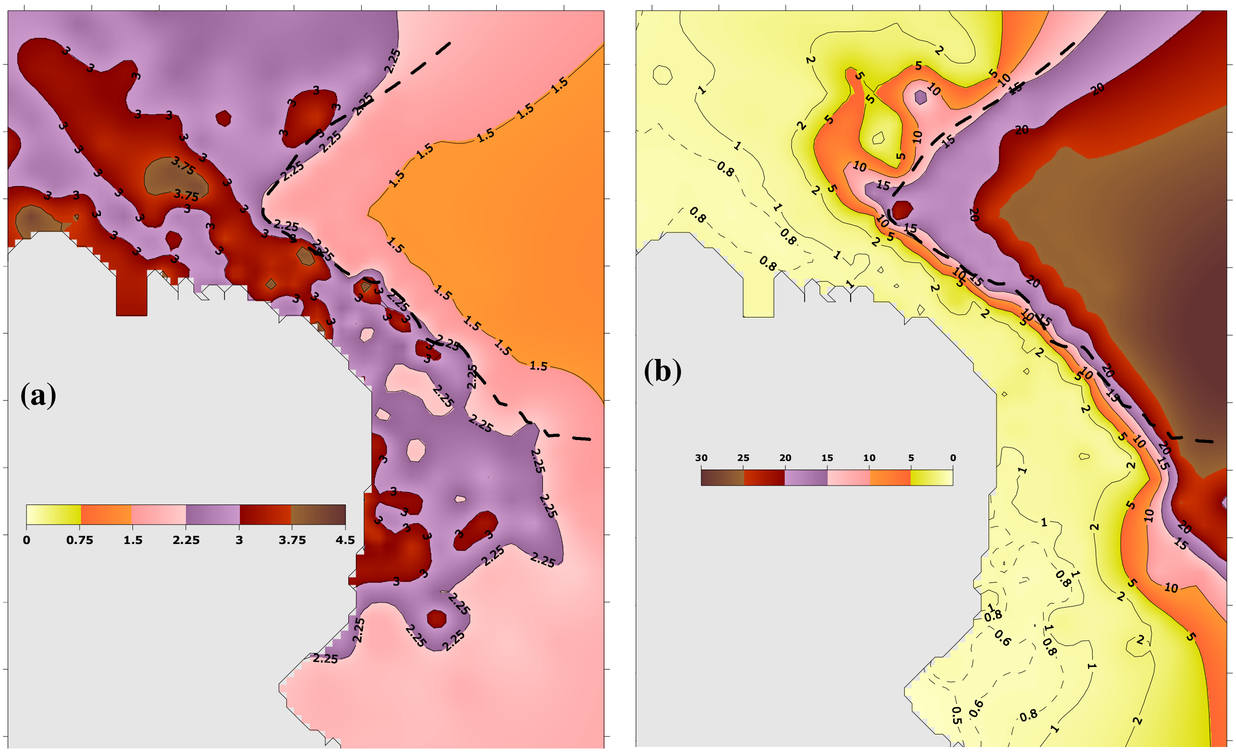


Fig. 2.15 Distribution of (a) mean amplification ratio at resonant frequency (b) in the city of Thessaloniki obtained by 1D analytical approach.

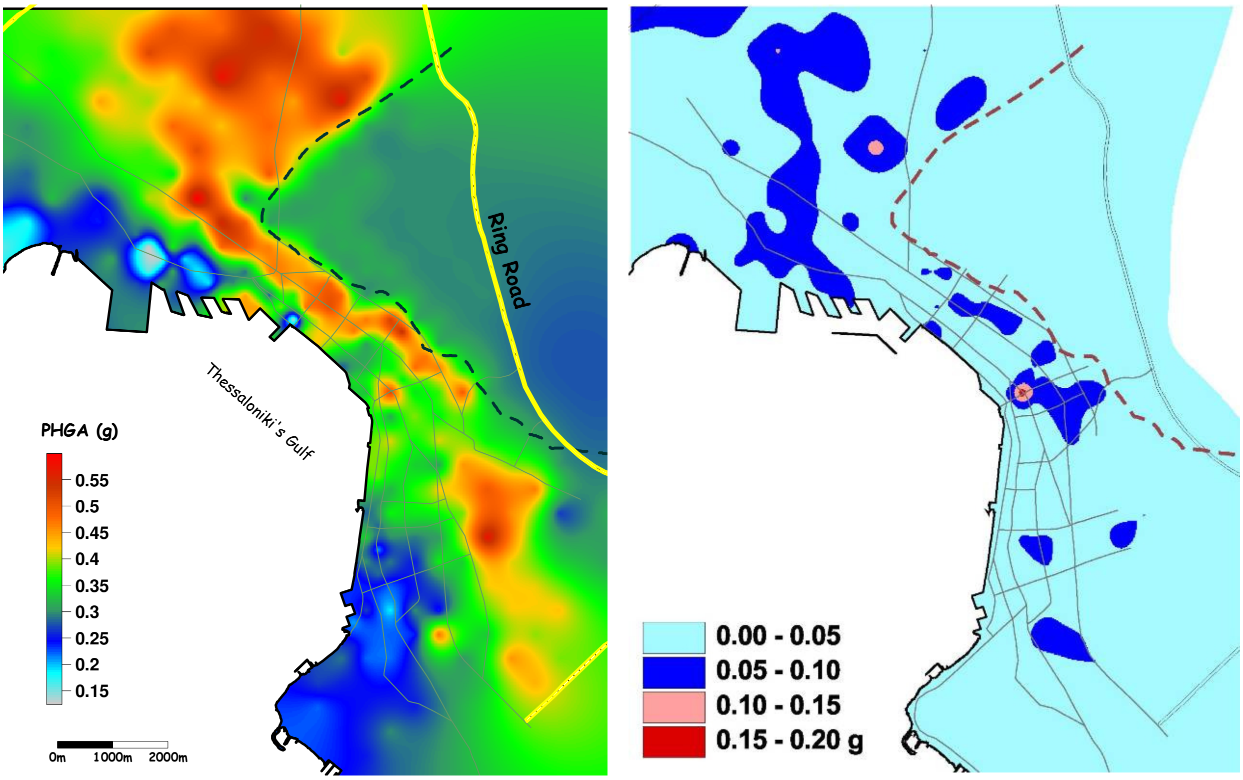
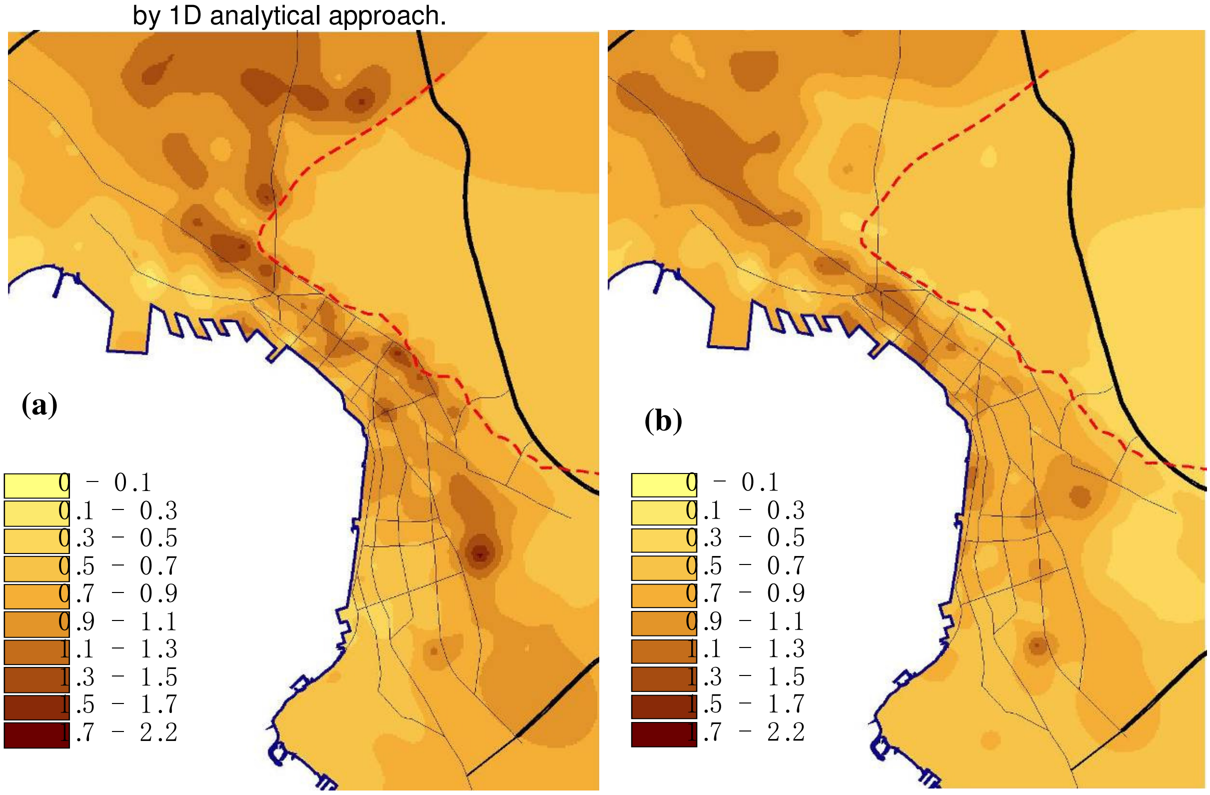


Fig. 2.16 Distribution of mean peak horizontal acceleration (left) and standard deviation (right) obtained by 1D analytical approach.



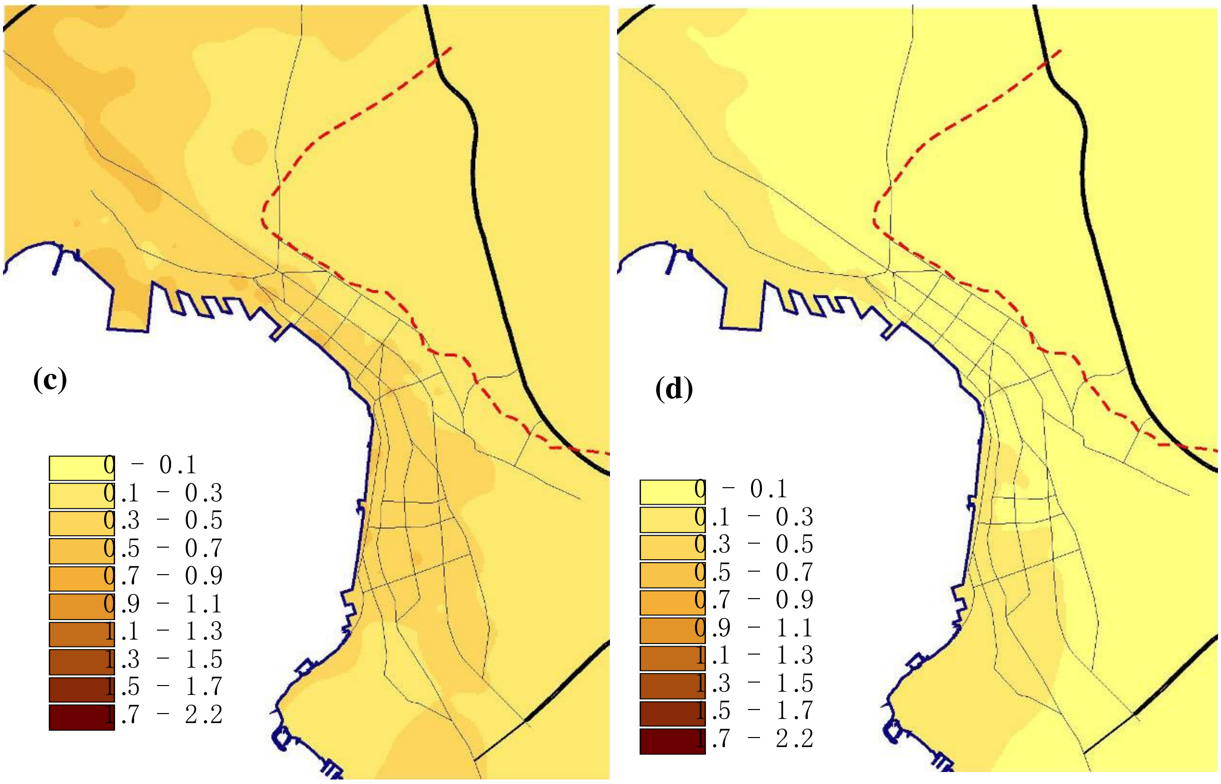


Fig. 2.17 Distribution of mean peak acceleration in g's at (a) T=0.3 sec, (b) T=0.6 sec, (c) T=1.0 sec and (d) T=2.0 sec, obtained by 1D analytical approach.

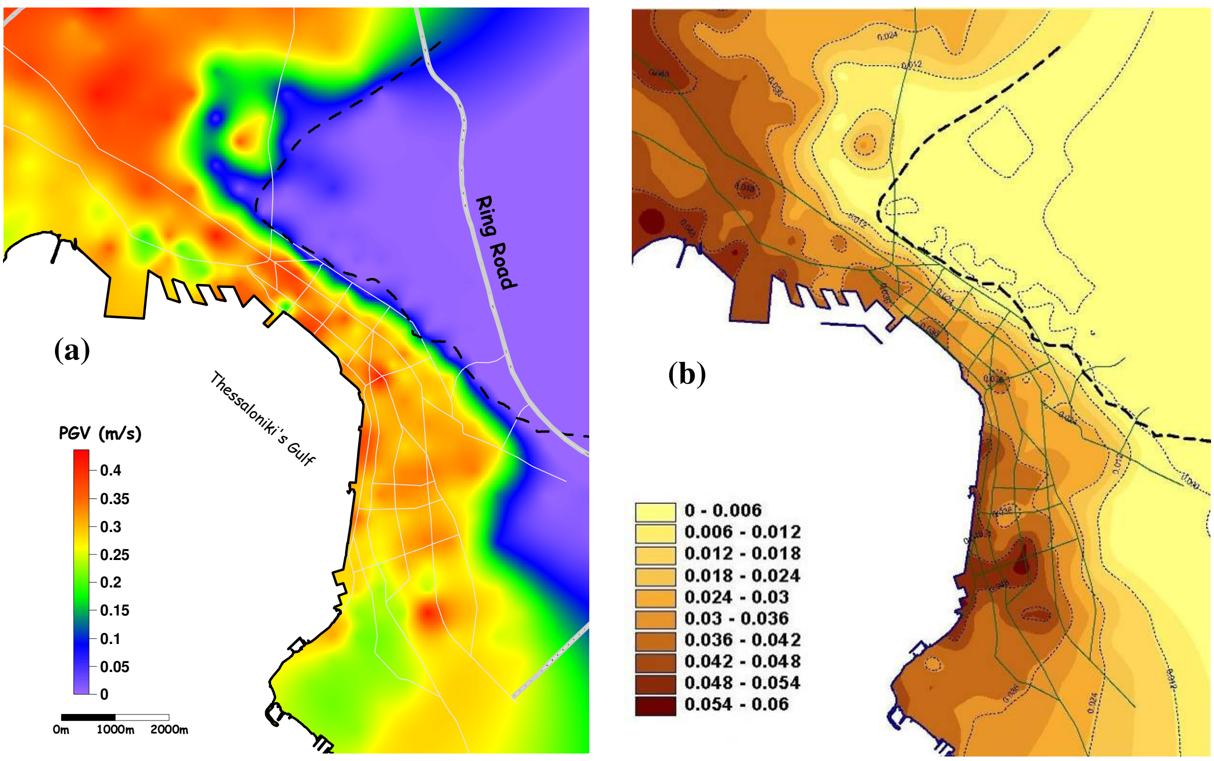


Fig. 2.18 Distribution of mean (a) PGV (m/s) values and (b) PGD (m) values in the city of Thessaloniki obtained by 1D analytical approach.

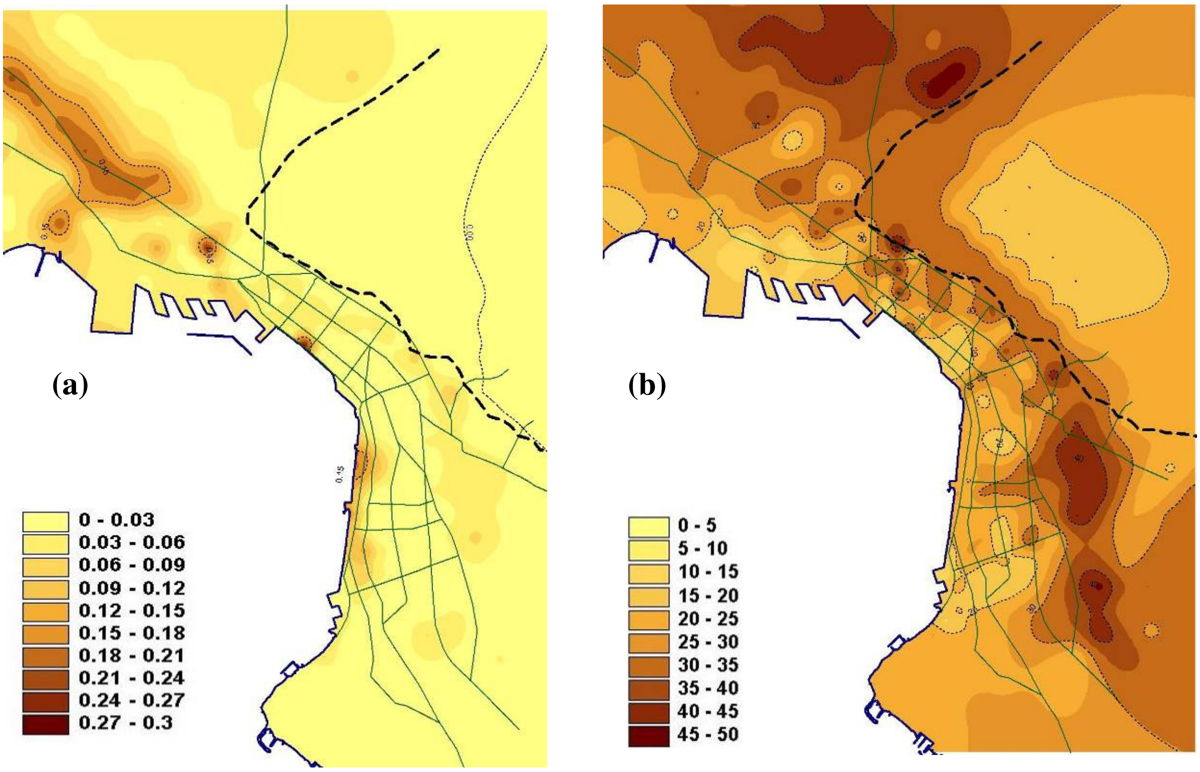


Fig. 2.19 *(a)* Mean shear strain (%) and (b) Mean shear stress (kPa) at z=-3.0m

The mean values for the five seismic motions of maximum amplification ratio (fig.2.15.a) reflects the variation of the impedance contrast between the surface soil formations and the underneath green-schists bedrock. The spatial distribution of mean PHGA values (fig. 2.16) exhibits relatively high values, ranging from 0.45g to 0.6g, at the N-SE part of the city where the subsoil consists of very stiff, having small thickness, clayey formations and the mean Vs velocity of the 1D profile ranges from 500 to 600 m/s. At the central part of the city along the coastline, the mean PGA values are ranging from 0.25-0.40 g due to the effect of non-linear phenomena in the surface soft soil deposits. The calculated standard deviation values of PHGA (Fig.2.16.b) are small (<0.05g) at the greater area, while larger values are mainly attributed to the coincidence of predominant period of input motion and predominant period of soil profile and are consolidated at few points.

The mean values of PGA at periods T=0.3, 0.6, 1.0 and 2.0 sec obtained from 1D-EQL for all the design seismic motions are depicted in figure 2.16. Spectral acceleration at T=0.3sec, reach the highest value (~1.2 g) in a large part of the city, where mean Vs range from 500 to 550 m/s. At period T=1.0 sec mean spectral acceleration are ranging from 0.26g- 0.3g in stiff soil sites and 0.3g to 0.5g in the rest part of the city. At periods of T=2.0 sec mean PGA values have lower values ranging from 0.15g to 0.08g, fact directly related to the spectral content of the input motions.

In addition, the variation of average ground velocity and displacement (PGV, PGD) computed at the surface, and the spatial variation of mean shear strain and stress at depth of 3m, are presented in figures 2.18 and 2.19, respectively. The mean values of peak ground velocity (PGV) and displacement (PGD) are uniformly distributed along the city ranging from 0.125 to 0.25 m/s and 0.02 to 0.04m, respectively.

Finally, the main results of the present deterministic approach are compared with the corresponding results coming from the probabilistic case in order to illustrate the effects of local site conditions at three sites located at different soil conditions (A, B and C) according to EC8 (H19, I20 and K22 respectively – see Figure 2.20).

Results in terms of response spectra (PSA, PSV and PSD) are presented in Figure 2.21. In Figure 2.21 the calculated values are compared with the response spectra provided by EC8. The differences, especially in cases of A and C soil classes, reflect the effects of induced ground shaking intensity and non-linear behavior on the surface amplification under 1D wave propagation.

The elaboration of all results stemming from site classification and theoretical computations led to the definition of seismic zones and the corresponding mean response spectra, (Fig.2.22, 2.23) of the city of Thessaloniki.

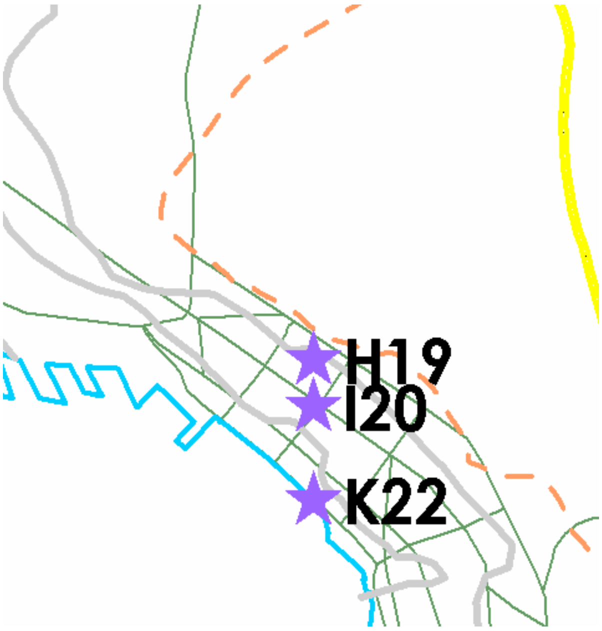


Fig 2.20. Map of Thessaloniki and location of three sites at different soil conditions at central part of the city (H19: 'rock-like' conditions, I20: 'stiff to very stiff' soils, K22: 'loose to soft' soil conditions).

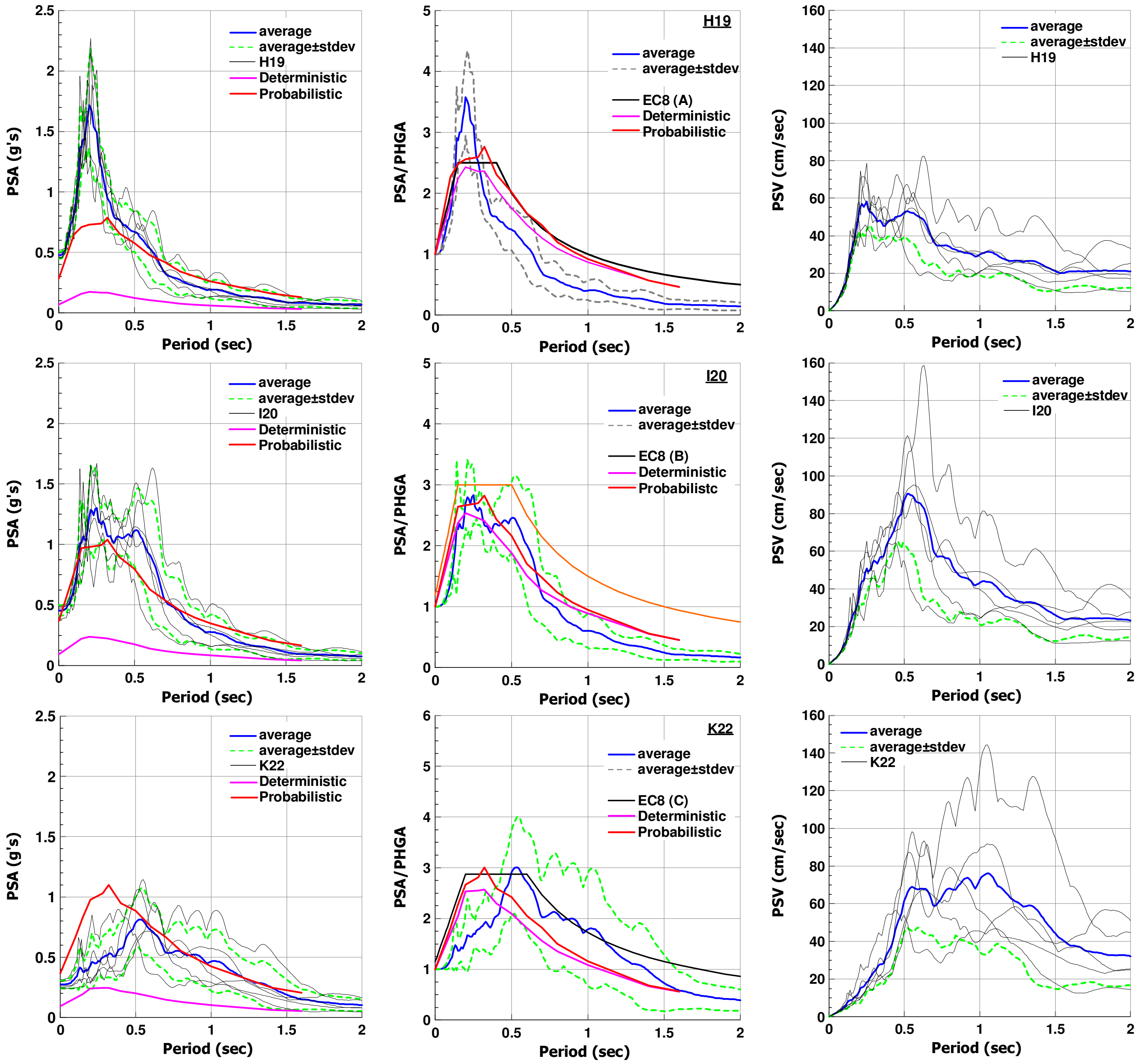


Fig. 2.21 Results from 1D theoretical analyses in terms of PSA, PSV response spectra and normalized response spectra are compared with results from Seismic Hazard assessment study (Deterministic Scenario: Thessaloniki 1978, M=6.5, Probabilistic Scenario: T=475 years recurrence period).

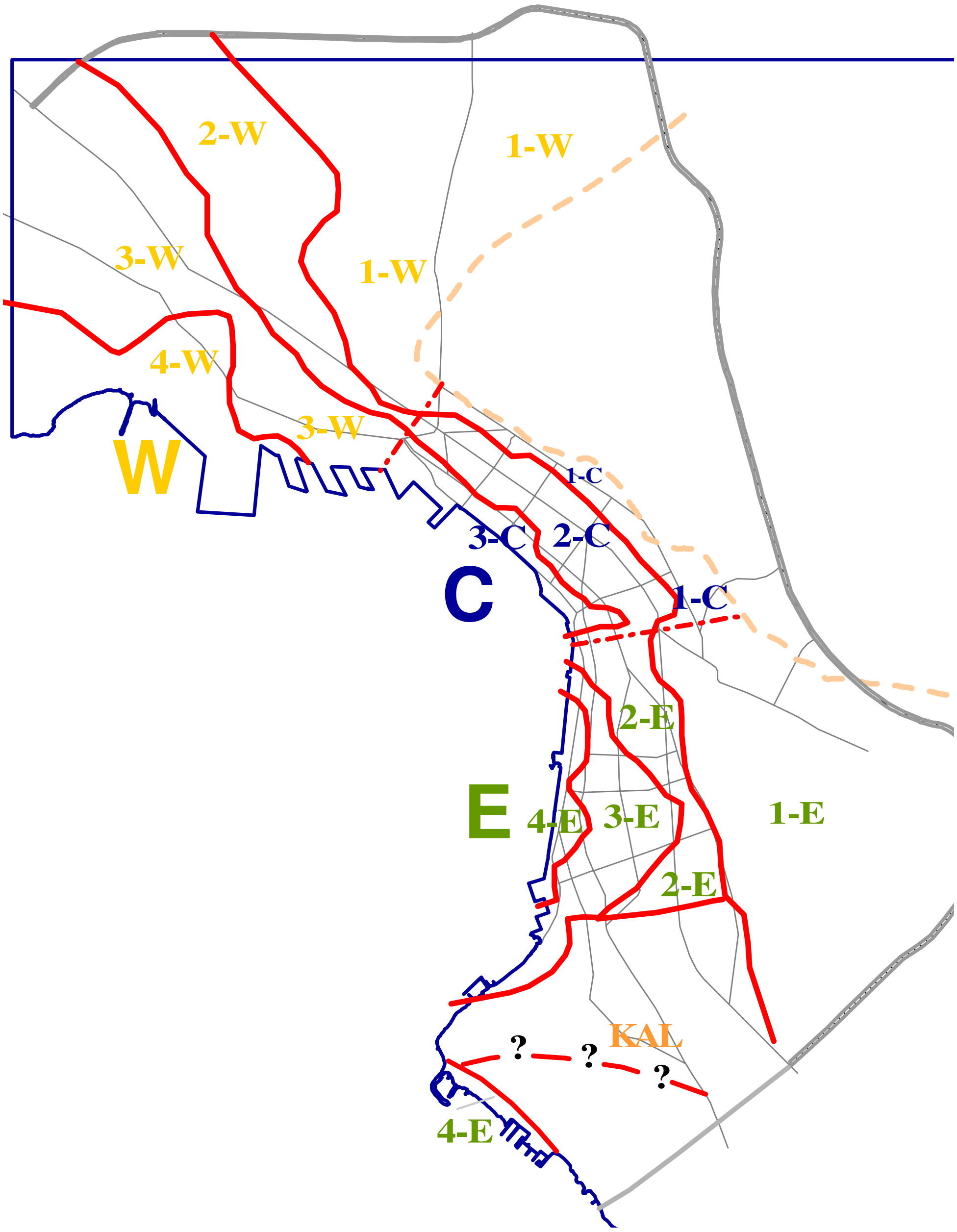
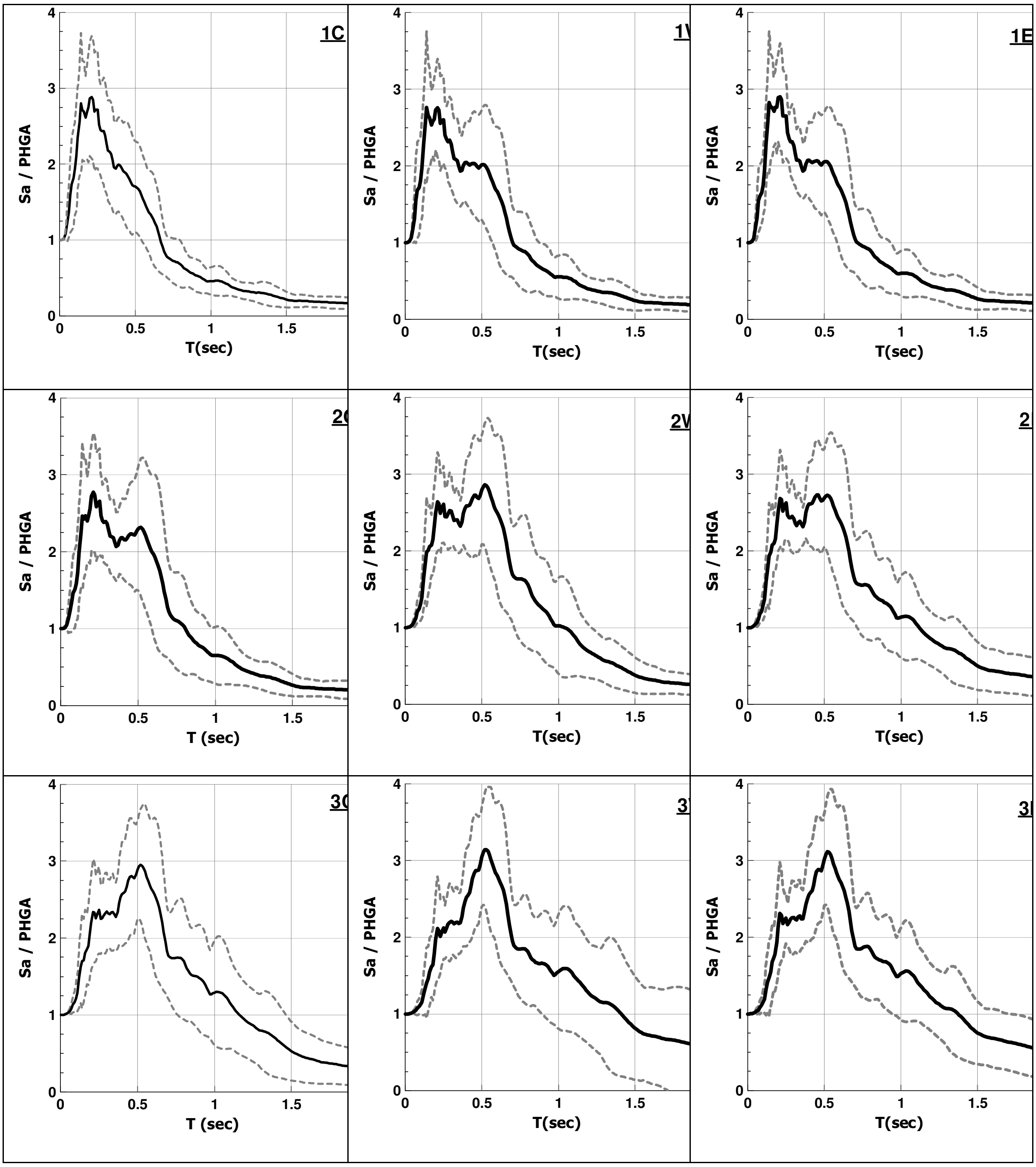


Fig. 2.22 Seismic zonation of Thessaloniki based on 1D theoretical analyses


1C
1V
1E
2C
2V
2
3C
3
3
Sa / PHGA
T(sec)
T (sec)
0
0.5
1
1.5
2
3
4

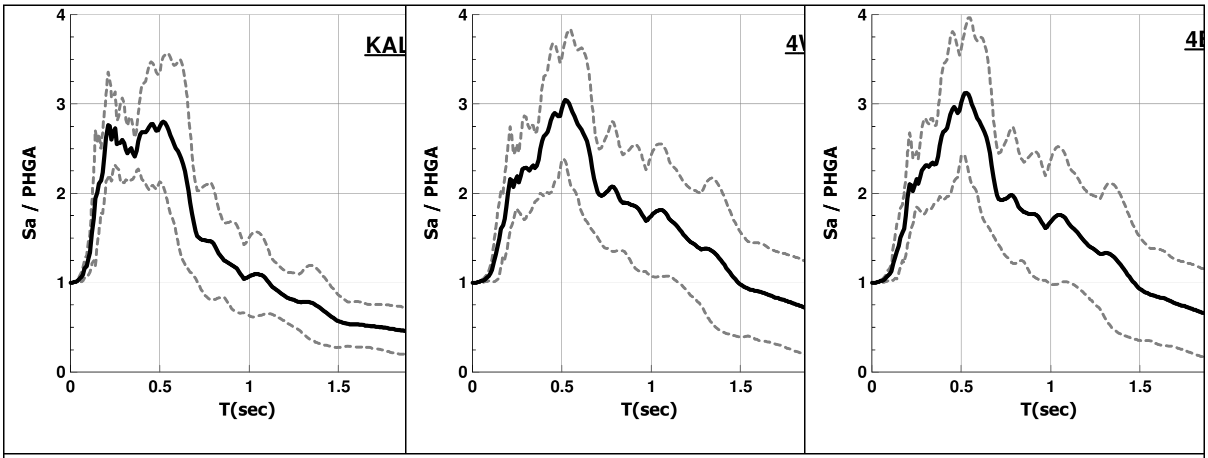


Fig. 2.23 Seismic zonation of Thessaloniki: Normalized response acceleration spectra foe zone.

Liquefaction risk

The evaluation of permanent ground displacement due to liquefaction phenomena was performed in a narrow area to the coastal zone of the central Thessaloniki, where loose and saturated deposits appear, taking into account the aforementioned presented distribution of PGA values.

The assessment of the liquefaction potential performed at 37 soil profiles along the major part of the coastal zone of the city using the results of 1D site response analyses, stress-based methodologies, data from SPT test together with recent recommendations (Seed et al. 2003). Additionally, the probabilistic relationship proposed by Liao et al., 1988, was applied for a rough estimation of the possibility of liquefaction at the sites examined. Figure 2.24 shows the probability for liquefaction in the risk area. Ishihara and Yoshimine, 1992, approach was applied for the estimation of the post-liquefaction volumetric strain and subsequent permanent ground settlement. Conclusively, a range of 0.0 to 0.22 m of ground settlement was estimated (fig.2.25). Moreover, the potential permanent horizontal ground displacement due to liquefaction was assessed, using the recently revised empirical equations proposed by Youd et al., 2002. The MLR model for sloping ground conditions was used, ignoring the presence of waterfront structures. Using the proposed maximum values, estimates of ground deformation ranging between 0 and 0.14 m were made (fig. 2.25).

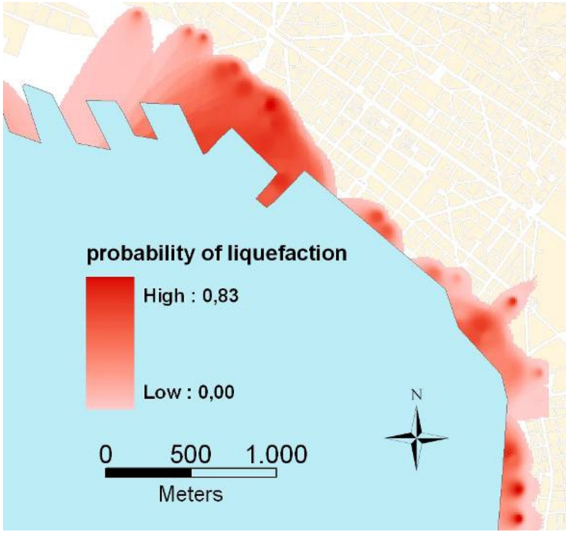


Fig. 2.24 Probability for liquefaction in the coastal zone of the city.

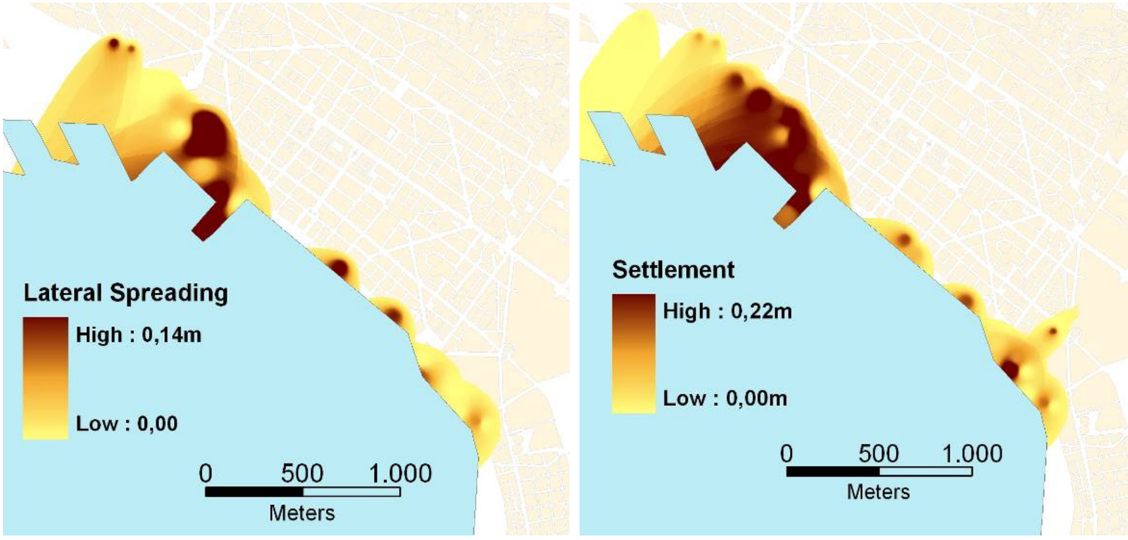


Fig. 2.25 Estimated lateral spreading (left) and settlement (right) due to liquefaction.

3. Urban system exposure

A conventional seismic risk analysis is limited to the evaluation of the direct impacts of isolated elements in human, material, or financial terms, based on the seismic hazard and the physical vulnerability of the elements. An integrated seismic risk study of an urban area must consider all exposed elements at risk such as human, material (buildings, lifelines, architectural patrimony, natural resources, etc.), or immaterial (culture, social fabric, heritage, image), but also the functional relations between the elements, urban activities (production, consumption, exchanges), the relations of the city with its surrounding environment, etc. This kind of study, referring as "urban system exposure", requires to consider the city as an open system connected with its regional, national and international environment, and to approach it as an integrated part of the seismic risk scenario. The goal is to identify the main issues of the city through ranking of the value of the exposed elements, based on various factors that describe the importance and role of each element in the urban system. The methodology that is developed in WP03 of the RISK-UE project (Masure and Lutoff, 2002) is applied in the city of Thessaloniki for the three main periods of urban functioning: the development period or *normal* period, the *crisis* period related to seismic aggression and the *recovery* period after the disaster.

A basic characteristic of the organization of city planning in Thessaloniki is the high population density as a result of high building ratio and, thus, the high residential density. We are dealing with values that exceed the accepted standards set by city planning legislation both in Greece and the European Union. Their negative range becomes particularly evident when correlated with the very few free spaces left in the urban environment and the inefficiency of technical infrastructure (roads network and city transport). In view of this, the high-density section of the urban region of Thessaloniki, consisting of the central borough of Thessaloniki and the newer north-western boroughs, is characterized as an area of high seismic risk. The problem of the lack of institutionalized specifications in the domain of urban development, expansion and planning, especially in large urban centres, became fully evident in the large earthquake of June 1978 in Thessaloniki. All the characteristics of the urban region already mentioned should raise serious concern, since the feeling of insecurity in the case or a great earthquake still prevails.

In the frame of the application in this research project, the central part of the city, inside the Byzantine walls, was studied. This area includes the historical center, many roman and byzantine monuments and a variety of buildings with neoclassic, art nouveau and eclecticism architecture. The central business district (CBD) of Thessaloniki prevails over any other operational concentration at this part of the city and is characterized from the domination of the tertiary sector, particularly business offices and retail trade. In order to evaluate and classify, through a global-value analysis, the urban components such as residential, commercial and building stock areas, it was necessary to divide the urban fabric of the study area in 20 homogeneous units (fig. 3.1), mainly based on the primary land use. Each unit is assigned to the following six categories and subcategories:

- Areas where the residence dominates
- Areas where the residence dominates, with particular central uses as well.

  Subcategories: areas with parallel domination of central tertiary sector uses (apart from residence), areas with parallel domination of central trade uses (apart from residence), areas with parallel domination of small industry (apart from residence),

- Areas where central uses dominate
  Subcategories: areas where central uses of the tertiary sector dominate, areas where central trade uses dominate

The application of the urban system exposure methodology in Thessaloniki is performed in four subsequent steps:

<u>1st step</u>
Firstly, the elements at risk are divided in “areas”, “groups”, “point” and “linear” elements. In order to define the *areas* of risk, the overall area is divided in zones according to the land use (residential and trade zone). The *groups* of risk are referring to a grouping of urban elements such as the building stock. The *point* elements at risk concern cultural, monumental, educational, administrative, medical care, and emergency buildings, hotels, city symbols etc. The *linear* elements concern the lifeline components that are studied separately in this research project (WP06) following the methodology of WP03.

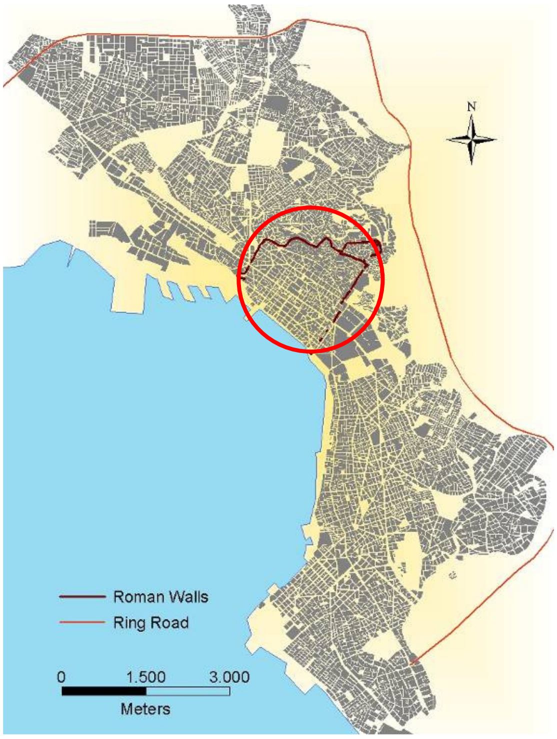
<u>2nd step</u>
The analysis of each element is based on the following urban *components*: *population, activity, urban space, functions* and *identity* of the city. Each component is characterized by an urban *indicator* such as *residents, workers, housing, business-trade, building, social, decision and radiance*.

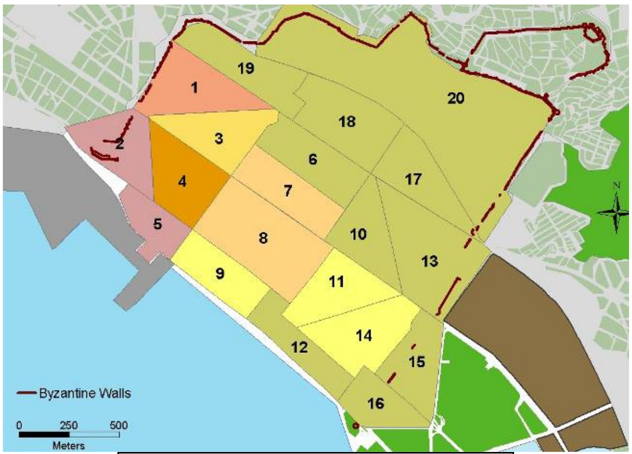
<u>3rd step</u>
The *measuring units* of each indicator are identified, based on appropriate quantitative or qualitative criteria. The main measuring units for the residential, trade and building stock areas are the population density (inhabitants/Ha), the trade density (workers/Ha), the housing area density (sq.m./Ha), the trade area density (trade sq.m./Ha), the influence scale, the structure coefficient, the market price and the building area density (built sq.m./Ha). Few examples of measuring units for the point elements are the concentration of visitors for churches, the number of beds for hospitals, the intervention capability for fire stations or the symbolic weight for monuments. The measuring units are transcribed to a *relative value scale* depending on available data. The threshold values are defined based on a statistical analysis in case of quantitative data or a qualitative analysis otherwise. As an example the relative values for the population density are assigned as 1 for >1500 inhabitants/Ha; 0.75 for >1000 inhabitants/Ha; 0.50 for >500 inhabitants/Ha; 0.2 for <500 inhabitants/Ha. The value scale for the symbolic weight is defined as 1.0 for major, external recognition; 0.5 for important, local recognition; 0.3 for low, inner recognition.

<u>4th step</u>
According to the considered period (normal, crisis, or recovery), the relevant indicators are selected for each element at risk. The indicators per period for the residential, trade and building stock elements are showing in Tables 3.1, 3.2. The global value is calculated for each element and for each period, while individual graphs with the distribution of the global value are produced, in order to define the threshold values for the assessment of the main, important and secondary issues for each period.

Finally, various thematic maps in GIS format were created, presenting the spatial distribution of the importance of the study elements at risk. Examples with the definition of main, important and secondary issues for areas of risk are given in fig. 3.2, 3.3 and for point elements such as hospitals and churches are presented in fig. 3.4, 3.5.

The results of this study combined with the outcome of the vulnerability assessment of the exposed elements at risk such as current buildings, monumental and historical buildings, lifelines and essential structures and their subcomponents, will contribute to the development of an efficient mitigation strategy and a well-organized emergency planning of the city. Therefore, based on the classification of the importance and the role of the above elements in normal, crisis and recovery periods and the expected physical damages, it could be possible to define prioritization policies for appropriate pre-earthquake retrofitting or restoration actions. In that way, focus will be given on the decrease of the necessary recovery period to the most possible extent, in order to provide to the related city activities the optimum feasible operation level. The role of the local actors (city planners, risk managers, lifeline owners and others) is essential in order to validate the results and to develop earthquake crisis management strategies.





Land Use
Residential
Residential & Trade
Residential, Trade & Tertiary sector
Tertiary sector
Residential and Small industry
Tertiary Sector and Trade
Residential and Mixed Residential and Small industry
Port
University

Fig. 3.1 The area where the "urban system exposure" methodology is applied and the division in homogeneous units.

Table 3.1 Indicators per period for the building stock element.

Element	Component	Indicator	Measuring Units	Normal	Crisis	Recovery
Building Stock	Urban Space	Building	Structure coefficient	✓	-	-
			Market price	✓		✓
	Functions	All	Built Area Density (sq.m /Ha)	✓	-	✓
	Identity	Radiance	Influence Scale	✓	-	✓

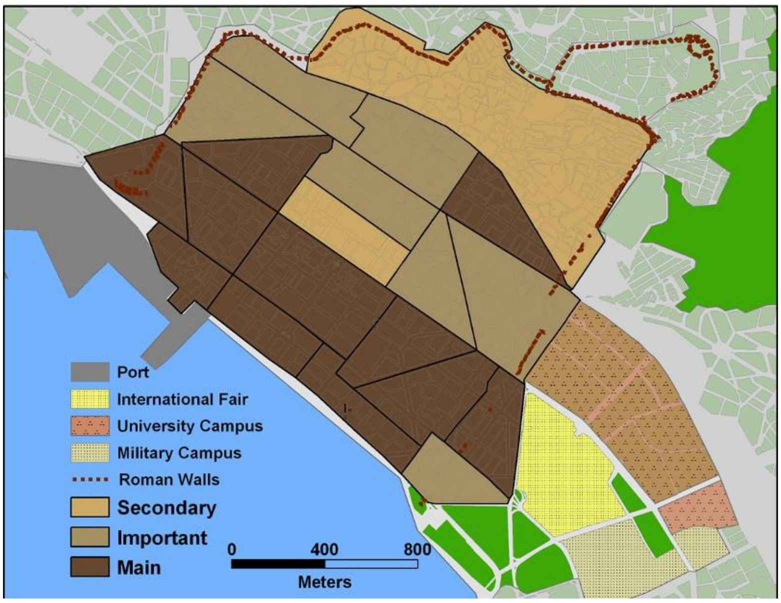


Fig. 3.2 Main, important and secondary issues of building stock area in terms of urban units for the central area of Thessaloniki in normal period.

Table 3.2 Indicators per period for the residential and trade zone elements

Element	Component	Indicator	Measuring Units	Normal	Crisis	Recovery
Residential zone	Population	Residents	Inhabitants /Ha	✓	✓	-
	Functions	Housing	Housing Area Density (sq.m /Ha)	✓	-	✓
	Identity	Radiance	Influence Scale	✓	-	✓
Trade zone	Population	Workers	Workers /Ha	✓	✓	-
	Activities	Business-Trade	Trade Area Density (sq.m /Ha)	✓	-	✓
	Identity	Radiance	Influence Scale	✓	-	✓

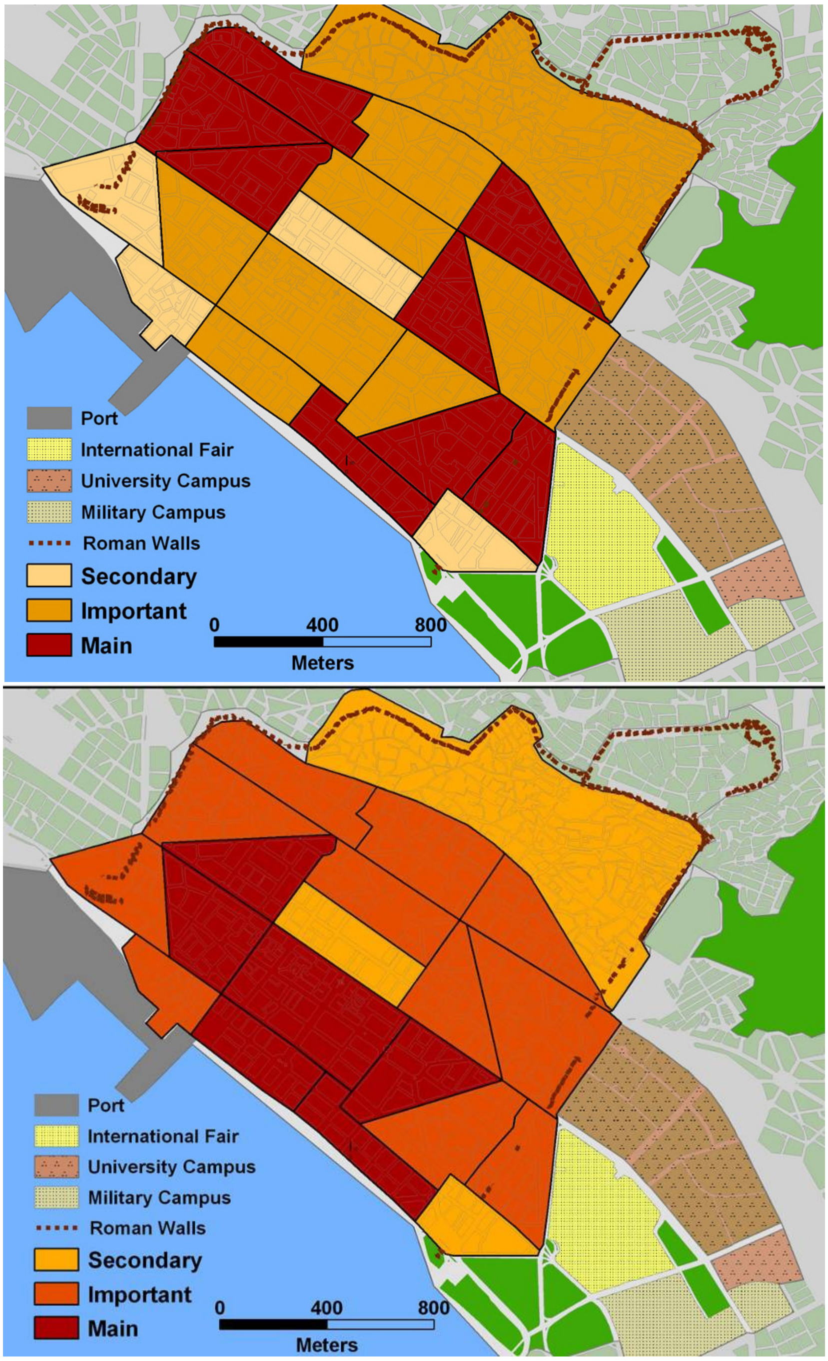
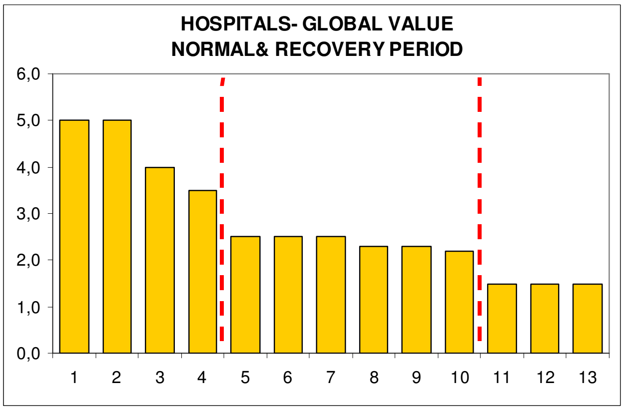


Fig. 3.3 Main, important and secondary issues of residential (up) and trade (down) land use in terms of urban units for the central area of Thessaloniki in crisis period.

Component	Measuring Unit	N	C	R
Population	Number of workers	✓	✓	✓
	Number of patients/ year	✓	✓	✓
Function	Number of beds	✓	✓	✓
Urban Space	Built sq. meters	✓	-	✓
Identity	Influence Scale	✓	-	✓



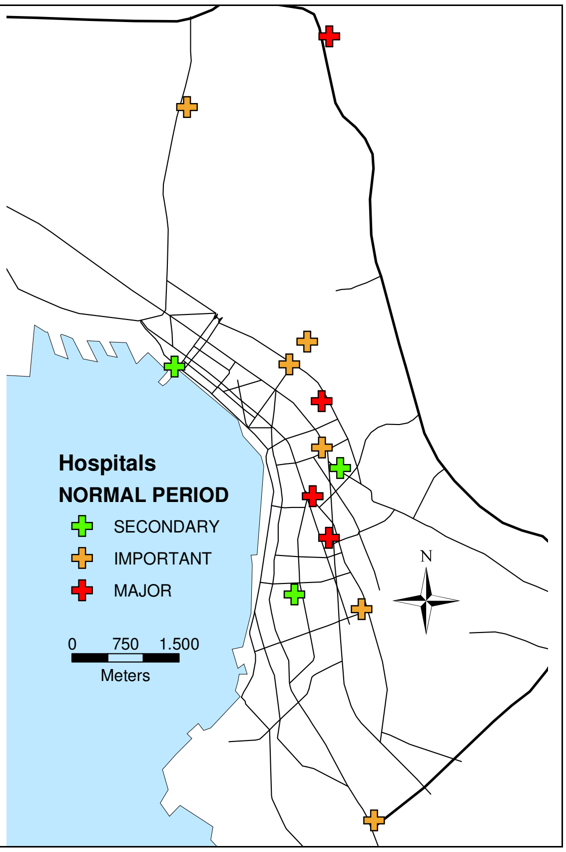
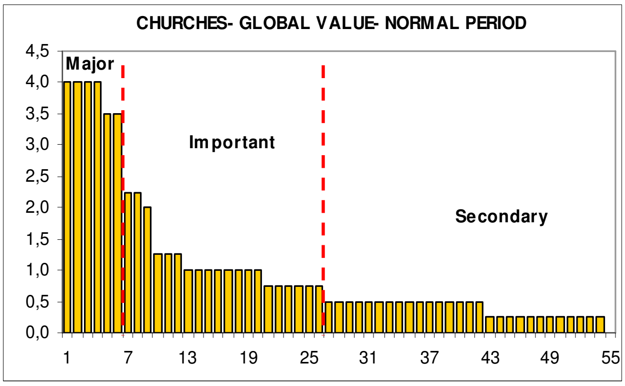


Fig. 3.4 Example of application of the urban system exposure methodology to public hospitals.

Component	Measuring Unit	N	C	R
Population	Visitors	✓	✓	-
Activities	Frequentation	✓	-	✓
Identity	Influence Scale/Image	✓	-	✓
	Symbolic or Cultural Importance	✓	-	-



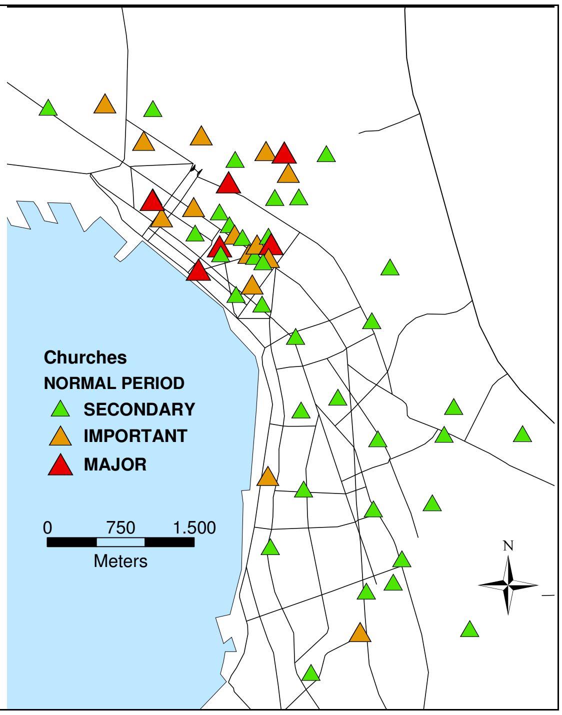


Fig. 3.5 Example of application of the urban system exposure methodology to churches for normal period.

4. Vulnerability assessment of current buildings

Inventory of buildings

It is well known that inventory collection is the most demanding of tasks for risk scenario development, unless extensive information on this is already available. In line with other RISK-UE partners, it was the goal of the AUTh Structural group to present all available data in a GIS format. The only complete set of data (i.e. covering the entire city) is the one collected by the Statistics Agency of Greece (ESYE) based on the 2000-1 Census of Buildings. This data has been long requested and was supposed to be made available to the AUTh group in early 2003. Unfortunately, as to the date of writing this report (Mar. 2004) processing of the census data has not been completed by ESYE (the official ESYE position was that it was not feasible for them to release data for selected regions only, but rather the entire data-set would be released in "one go"). In view of this, and given the time frame of the project, the AUTh team decided to carry out the vulnerability analysis (for the purposes of the risk scenarios) on the basis of the 1991 Census data for the Municipality of Thessaloniki in combination with a reevaluation of available data and introduction into the GIS platform of the city, and in-situ work on an appropriate sample of building blocks. The 1991 data is less reliable than the 2001 one, not only because it is older (changes in the building stock in the centre of the city are not significant, while the opposite occurs in the suburbs), but because the characterization of the building system is made in terms of the material used as exterior cladding and not that of the structural (load-bearing) system, and data on area and/or volume of building are not included. In addition to the aforementioned drawbacks, it is not even possible to establish a one-to-one correspondence between, say, number of storeys and structural system!

Based on data collection work carried out within another (nationally funded) programme, all hospital buildings (a total of 330[1]) in the major area, as well as a percentage of secondary school buildings in the centre of Thessaloniki (a total of 170), were added to the ArcView database set up within RISK-UE. The entire GIS database showing the locations of hospital buildings (red dots) and school buildings (green dots) is shown in Fig. 4.1.

In view of the situation regarding the inventory, it was finally decided to proceed as follows:

- Carry out a global analysis of the building stock in the municipality of Thessaloniki, based on a combination of the 1991 ESYE data and those from a previous project (Penelis et al. 1986) wherein detailed data were collected for a total of 5740 buildings (75% of which were situated in the municipality of Thessaloniki) struck by the 1978 earthquake
- Carry out a "block-by-block" analysis of a selected part of the city (where most of the damage from the 1978 earthquake occurred) based on an *update* of the detailed data concerning the buildings struck by the 1978 earthquake using a new in-situ collection of data for a number of blocks (50); this in-situ work was carried out by the members of the AUTh Structural Group, and covered an appropriately selected (>10%) sample of the 470 blocks covered by the 1984-86 survey that belong to the municipality of Thessaloniki.

[1] All buildings in a hospital complex were included, even minor ones; parts of the same building separated by construction joints (or separation gaps) were treated as independent buildings.

This pragmatic approach is deemed to lead to a reasonable global loss scenario for the entire municipality, as well as to a detailed scenario for a large part of the city centre (covering about 40% of the municipality, presented in a GIS format in Fig. 4.2), where most of the damage expected by the scenario earthquake will occur.

The final composition of each building block (in terms of structural typologies, as defined in the RISK-UE BTM), resulting from the application of the aforementioned procedure, was introduced in the general GIS platform (ARCView© 3.3) used for developing all the WP14 scenarios; this composition of blocks is shown in Figures 4.3 and 4.4.

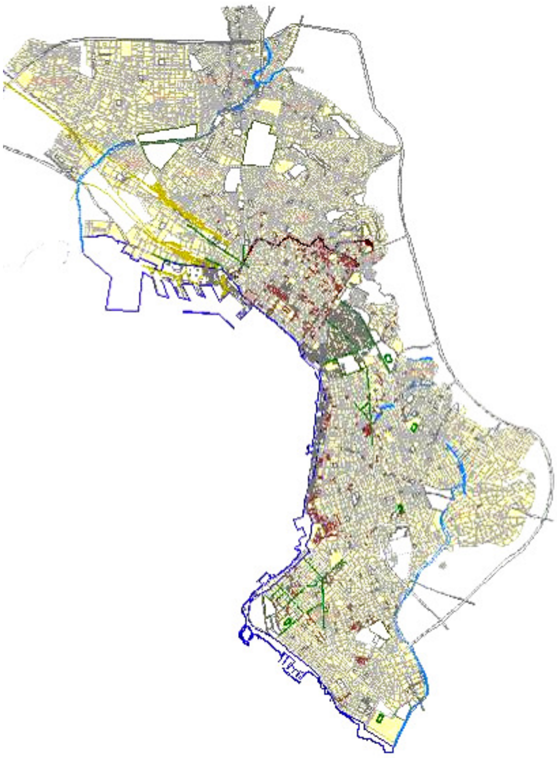


Fig. 4.1 Global GIS map indicating hospital buildings (red dots) and school buildings (green dots).

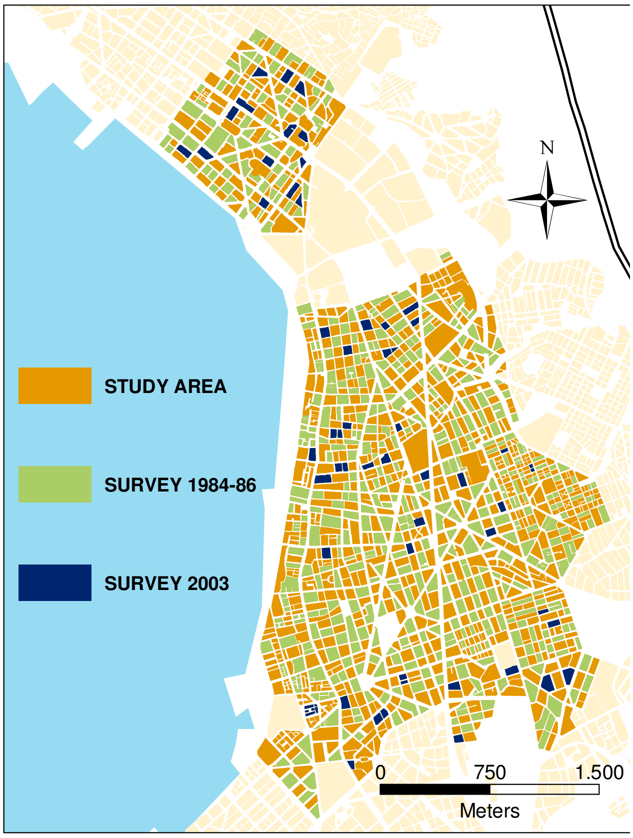


Fig. 4.2 Study area including "block-by-block" analysis of 1984-86 and 2003.

Fig. 4.3 gives the geographical distribution of the main typologies of buildings, i.e. R/C buildings designed to 'old' (pre-1984) and 'new' (post-1985) seismic codes, and URM buildings. It is clear that the prevailing typology in the area (as well as in the entire municipality) is R/C buildings designed to old codes (these include also pre-1959, or 'pre-code' buildings whose performance was found to be very similar to that of 'low-code' buildings, as discussed in previous RISK-UE reports, e.g. Kappos et al. 2004, as well as in the 1989 study by Penelis et al.). It is noted that the intermediate area (lying between the two surveyed ones) not covered by the surveys (Fig. 4.2, 4.3) mainly includes the University Campus, whose buildings are of generally similar typology as the rest i.e. prevalence of 'low-code' R/C buildings.

The composition of buildings (including all the BTM categories) for the entire municipality, estimated assuming that the composition of the surveyed area is representative of that of the entire municipality (which, to the writers' best knowledge is actually the case) is shown in Fig. 4.4. The total number of buildings in the surveyed area is 5047 (one out of two buildings was surveyed in 1984), the total in the municipality is about 19000.

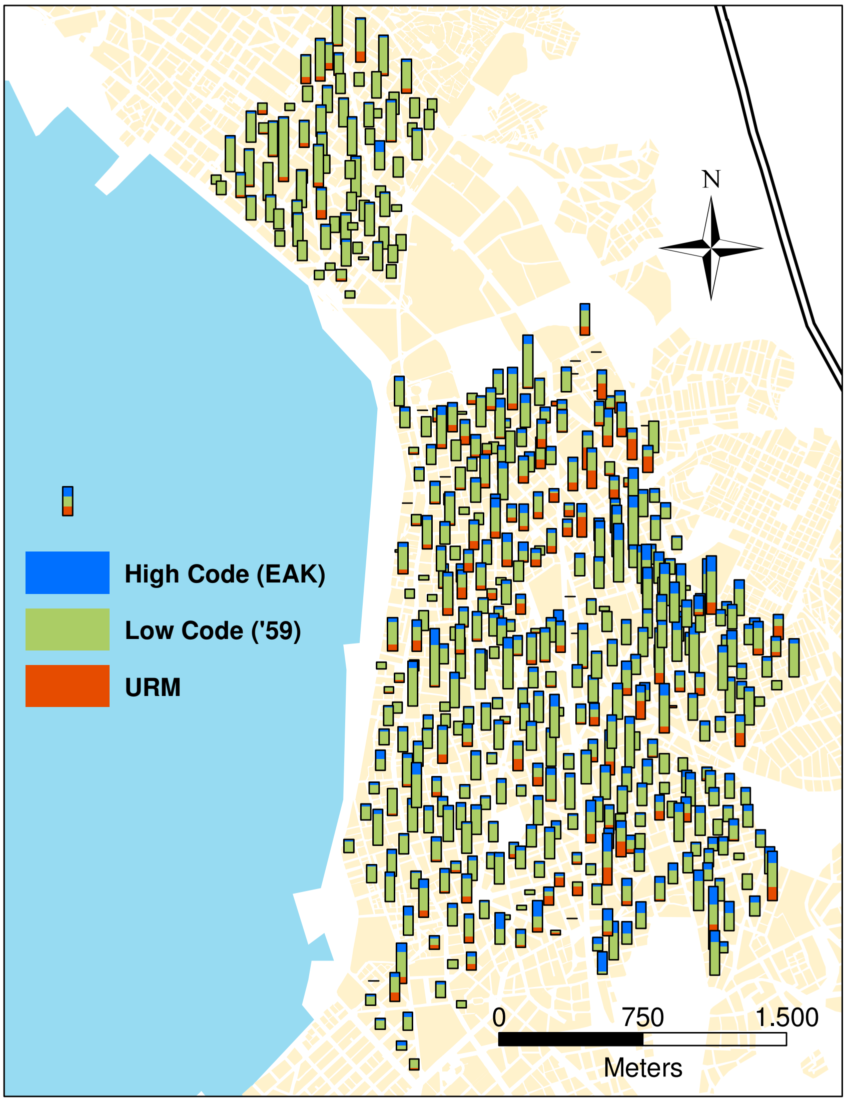


Fig. 4.3 General composition of building blocks.

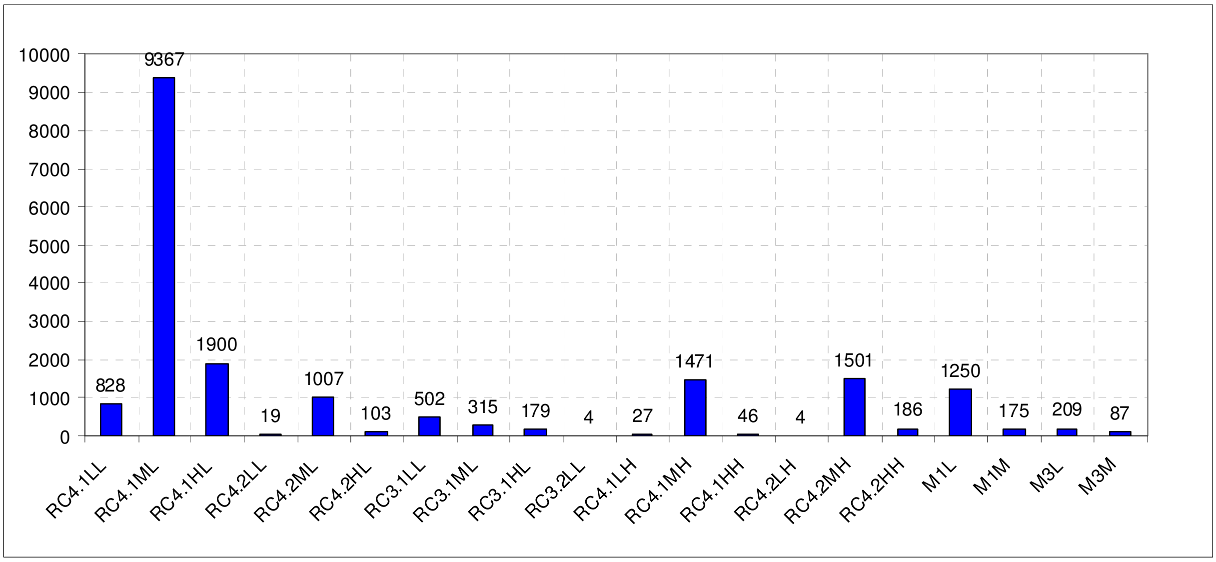


Fig. 4.4 Building type distribution (Municipality of Thessaloniki).

Methodology for building damage assessment

With regard to the vulnerability (fragility) curves to be used for constructing the scenario, more detail was given in previous WP04 reports, as well as in conference papers. Capacity curves, as well as fragility curves (in terms of PGA for the Level I approach) for R/C structures are given for all typologies present in Greece (RC1, RC3.1, RC3.2, RC4.1, RC4.2, RC4.3) in the RISK-UE report by Kappos et al. (2004). Two example curves are given in Fig. 4.5 and 4.6; they refer to medium-rise infilled frame buildings (a very common typology in S. Europe), designed to “Low” and “High” seismic codes, RC3.1ML and RC3.1MH, respectively. The significant effect of seismic design level on the vulnerability is obvious from the curves; it is worth pointing out that the effect of seismic design was much less pronounced in the case of dual buildings (RC4 typologies), as found by Kappos et al. (2004) and as verified from observation of past earthquake damage.

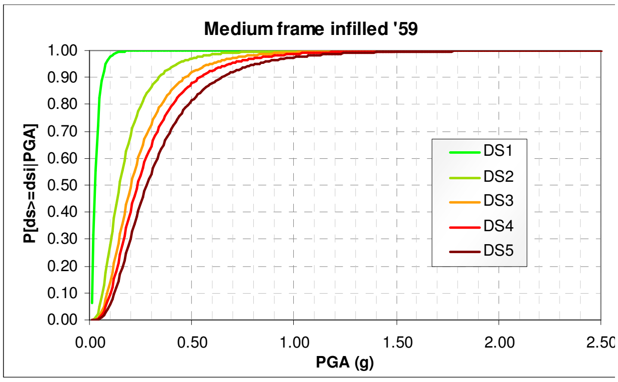


Fig. 4.5 PGA Fragility Curves for RC3.1ML

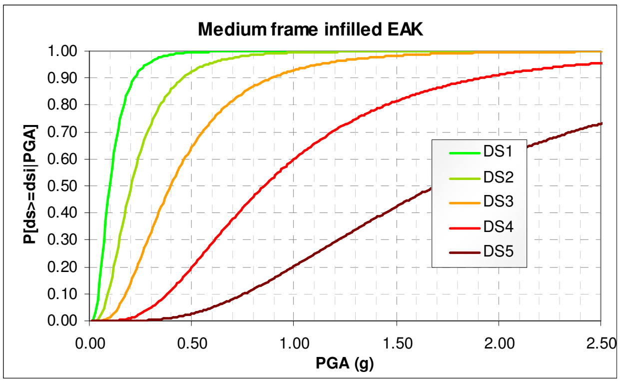


Fig. 4.6 PGA Fragility Curves for RC3.1MH

The aforementioned fragility curves (in terms of PGA) were also used to derive the fragility curves, in terms of S_d this time, necessary for the Level II approach. The procedure adopted was to transform the median PGA values to corresponding median S_d values, using the average spectrum of the Microzonation study (fig. 4.7) and the fundamental period of the typical building for all typologies (assuming the equal displacement rule).

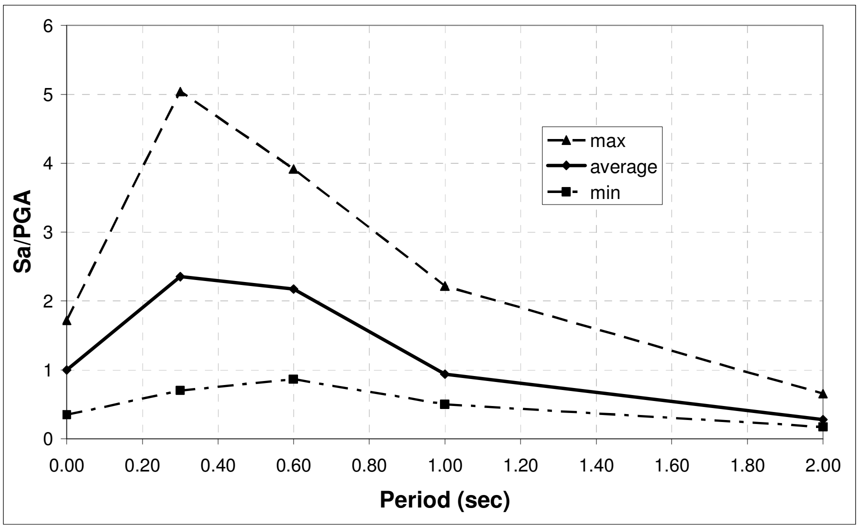


Fig. 4.7 Normalized maximum, minimum and average spectra of the Microzonation study.

The Level II fragility curves (in terms of S_d) assume 4 damage states (instead of 5, used in the Level I case). Nevertheless, since the S_d fragility curves were derived from the corresponding PGA curves and given that a separation between DS4 and DS5 would be necessary for the estimation of the casualties, an extra DS5 fragility curve was derived in terms of S_d as well. Two example curves are given in Fig. 4.8 and 4.9.

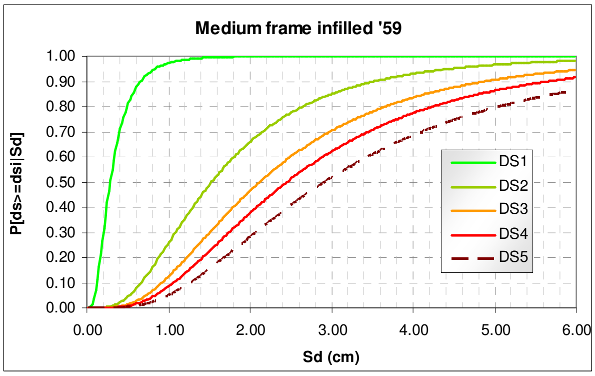


Fig. 4.8 S_d Fragility Curves for RC3.1ML

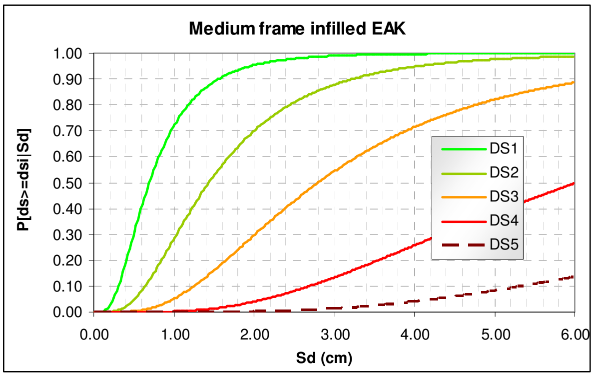


Fig. 4.9 S_d Fragility Curves for RC3.1MH

It should be emphasized herein that curves used for the Thessaloniki buildings are indeed specific to Greece and Thessaloniki in particular, since they have been developed using a combination of analysis and statistical data, the so-called 'hybrid' approach (Kappos 2001), both of which are drawn from Greek practice; in fact a large part of the statistical data used is from the 1978 Thessaloniki earthquake.

Capacity curves, as well as fragility curves (in terms of both PGA and S_d) for masonry structures are given for all typologies common in Greece (low-rise stone masonry and brick masonry) in recent papers by the AUTh group (Penelis et al. 2002). The fragility curves given in these publications were based on the 5 (DS0 to DS4) damage states used in Hazus, as well as the RISK-UE 'level II' approach (see WP04 Handbook, Milutinovic &

Trendafiloski 2003). In order to better suit the needs of WP7 and obtain a more complete scenario, it was decided to use 6 damage states (DS0 to DS5) in the present study, mainly along the lines of the 'level I' approach. The damage states used are given in Table 4.1 for R/C and URM structures, both in descriptive terms and as loss indices (repair cost/replacement cost); consistent with the approach also adopted by the IZIIS group (see Milutinovic & Trendafiloski 2003), loss indices are somewhat higher for URM than for R/C, for the same damage state.

Table 4.1 Damage Grading and Loss Indices for R/C and URM structures

Damage State	Damage state label	Range of loss index-R/C	Central index (%)	Range of loss index - URM	Central index (%)
DS0	None	0	0	0	0
DS1	Slight	0-1	0.5	0-4	2
DS2	Moderate	1-10	5	4-20	12
DS3	Substantial to heavy	10-30	20	20-40	30
DS4	Very heavy	30-60	45	40-70	55
DS5	Collapse	60-100	80	70-100	85

Due to the increase in the number of damage states, the previously developed fragility curves for URM buildings (Penelis et al. 2002) have been revised to conform to the definitions of Table 4.1, and were recast in terms of PGA (rather than I and S_d). The curves for two common typologies are shown in Fig. 4.10 and 4.11; it seen that (as anticipated) the vulnerability is higher than for R/C buildings (even 'low-code' ones) and that the curves for various damage states are often quite closely spaced.

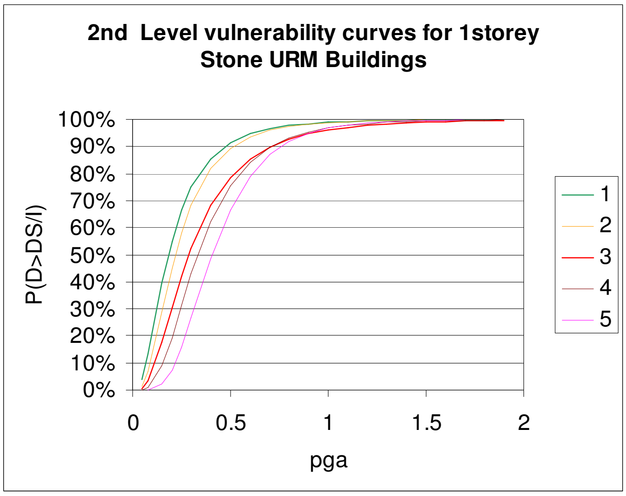


Fig. 4.10 Fragility curves for single-storey stone masonry buildings

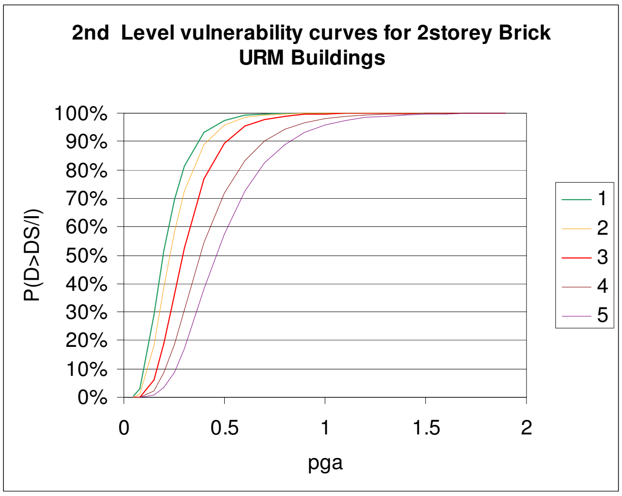


Fig. 4.11 Fragility curves for two-storey brick masonry buildings

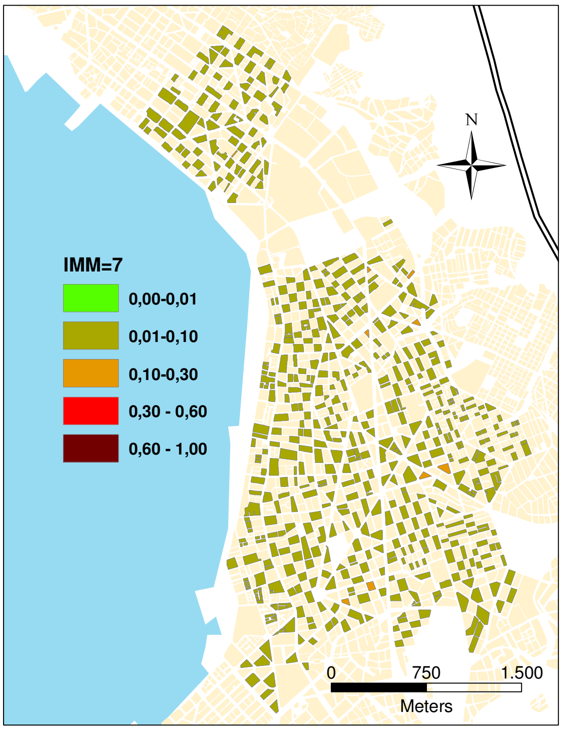
Scenario for current buildings

Two approaches for the estimation of the damage of current buildings were considered.

- **Level I**: The fragility curves in terms of PGA were used in combination with the mean PGA value of each building block obtained by the Microzonation study

- **Level II**: The fragility curves in terms of S_d were used where the S_d was calculated using the Capacity Spectrum Method taking into account the Capacity Curves of each building typology and the pseudoaccelleration spectrum of each building block obtained by the Microzonation study. In the case that the Capacity Spectrum Method results in no solution (S_d>D_u) for a building typology, the assumption that S_d=max{D_u, S_d(pr[D5]=0.50)} was made in order to obtain the necessary S_d value.

The (idealized) distribution of damage in the area considered, when subjected to uniform intensities (I=7 and I=9) is shown in Fig. 4.12; the damage levels were estimated using the aforementioned (level I) fragility curves for each building type (intensity and PGA were correlated using the Koliopoulos et al. 1998 empirical relationship, see also Kappos et al. 2004), and the index plotted is a weighted one $\Sigma(MDF_i \cdot V_i)/V_{tot}$, where volume V_i of each building type is used to weigh the mean damage factor (central index in table 4.1) for this type. These maps were derived using the Level I approach (PGA fragility curves) and give a good picture of the most vulnerable parts of the city, regardless of the scenario earthquake (and local amplifications due to particular soil conditions), and they are a useful tool in emergency planning, keeping in mind that even an 'accurate' scenario earthquake is just one possible description of the seismic risk in the considered area (i.e. vulnerable buildings not heavily struck by a specific scenario earthquake, might be heavily damaged by a different scenario earthquake not considered due to lack of time or lack of data at the time of the study).



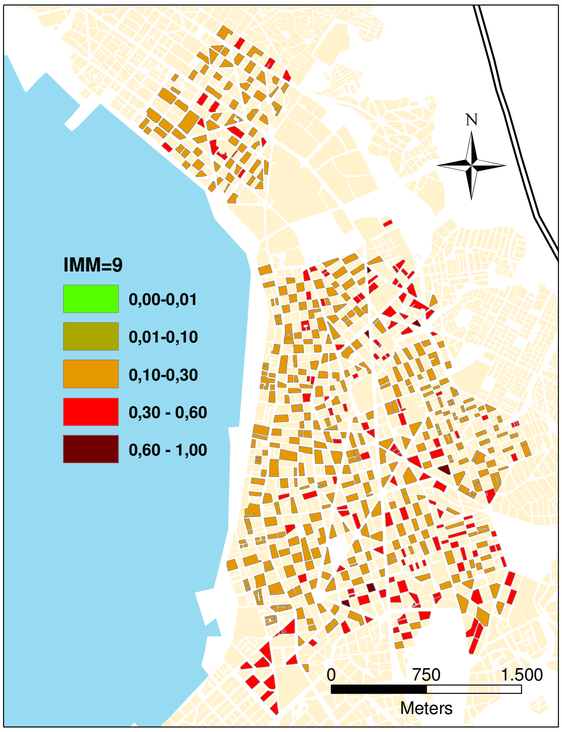
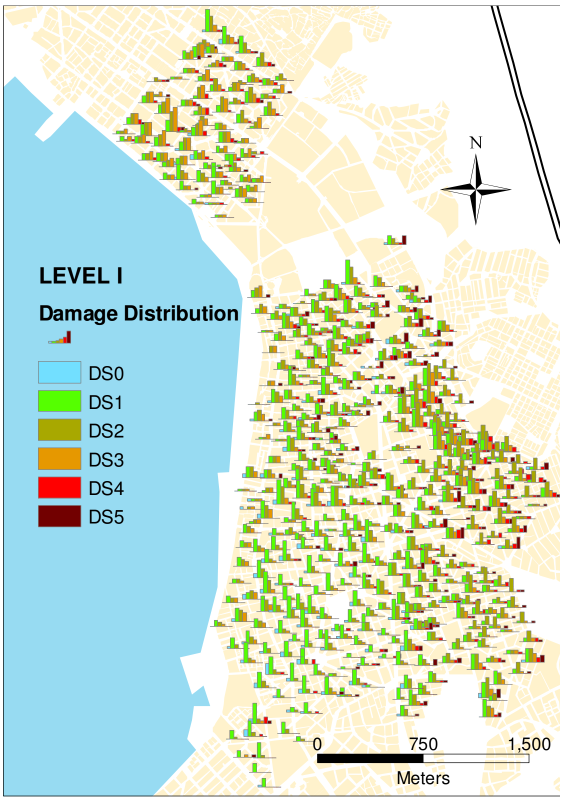


Fig. 4.12 Expected damage distribution for intensities 7 and 9 (assumed to be uniform in the studied area).

The remainder of the maps and related material given herein refer to the particular earthquake scenario developed as described in the WP02.



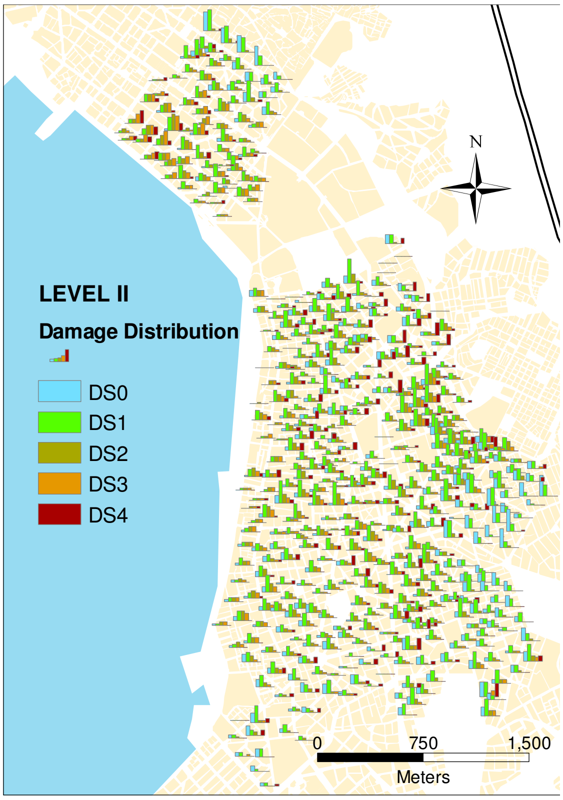


Fig. 4.13 Number of buildings suffering damage states DS0 to DS5 in each building block (scenario earthquake)

The map of Fig. 4.13 shows the number of buildings suffering damage states DS0 to DS5 (or DS0 to DS4), based on the PGA or the S_d in each building block and the afore-mentioned fragility curves for each building type. More specifically, after calculating the discrete probabilities of each damage state for each type present in a building block, the number of buildings suffering each damage state is calculated accordingly; for example, if in a block there are 4 buildings of a particular typology, and the discrete probabilities (derived by subtracting the values determined from the intersection points of the fragility curves and the vertical line corresponding to the given PGA, see also WP04 HB) for DS0 to DS5 are, say, 6, 17, 53, 21, 2, and 1 (%), respectively, two buildings will suffer DS2, one will suffer DS3 and one DS1 (no buildings in the DS0, DS4 and DS5 categories). It is pointed out that this is only one of the possible ways of estimating the number of buildings suffering each damage state; it is the most reasonable one (to the writers' opinion), but its potential drawback is that in (hypothetical) cases of very uniform distribution of PGA (or any other measure of earthquake intensity) in the studied area, damage states associated with very low probability (e.g. DS4 and DS5 in the previous example) might never appear on the map of DS distribution. As seen in Fig. 4.13, a non-zero number of buildings exists for all damage states, including even DS5 (collapse), for the considered scenario.

A clearer picture of the total number of buildings in each BTM category that suffer each damage state can be obtained from Fig. 4.14, 4.15 which refers to the entire municipality (subject to the already discussed assumption regarding the composition of building blocks); note particularly that the number of buildings in each category is very different (hence it is given with numbers inside of each portion of histogram). It is seen that the most heavily damaged typologies are low-rise, 'low-code' R/C buildings with infilled frame systems (RC3.1LL, RC3.1HL and RC3.2LL) and masonry buildings; the latter was anticipated, whereas the particularly high vulnerability of low-rise old R/C buildings is not a surprise either, but part of the problem might be their location with respect to the specific considered scenario (high PGA values in the western part of the studied area, see Fig. 4.13), i.e. not only their own (absolute) vulnerability (compare Fig. 4.12). It is also seen that the Level I approach results in a relatively different damage distribution than the Level II for each building typology, e.g. M1M & M3M buildings are heavily damaged (DS4) for the Level II approach, while for the Level I most of them are slightly damaged (DS1) or not damaged at all (DS0). These were usually the cases where the Capacity Spectrum Method resulted in no solution (S_d>D_u) and a high probability (at least 50%) was assumed for DS5.

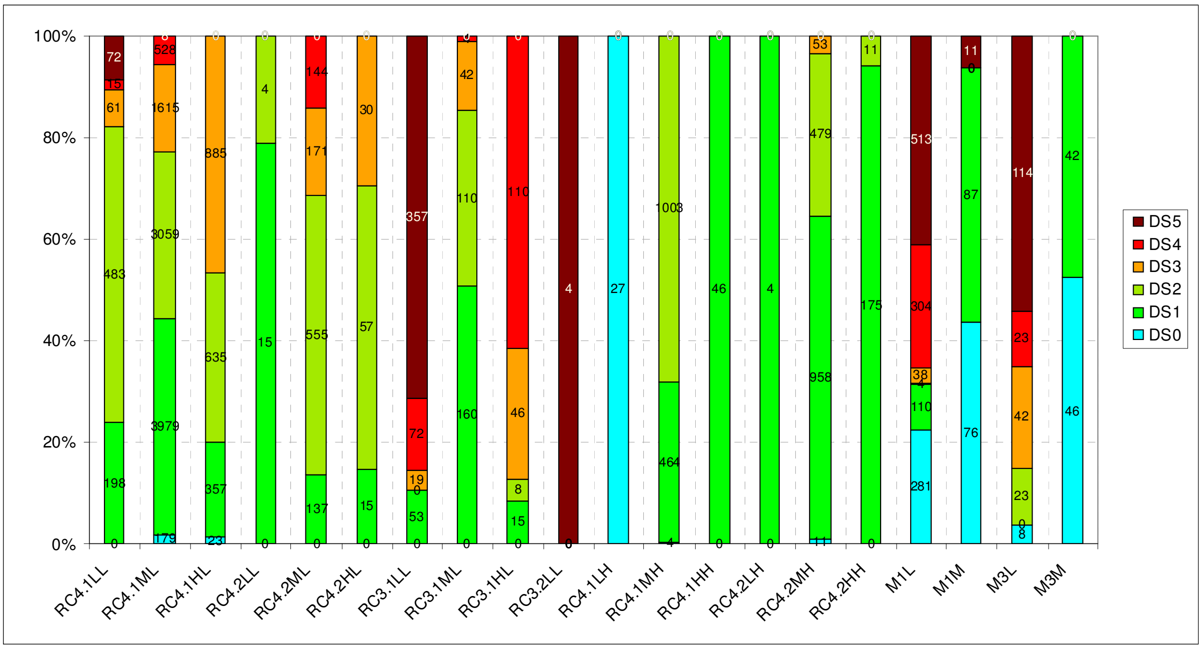


Fig. 4.14 Level I damage distribution (% of buildings) for all building types (Municipality of Thessaloniki)

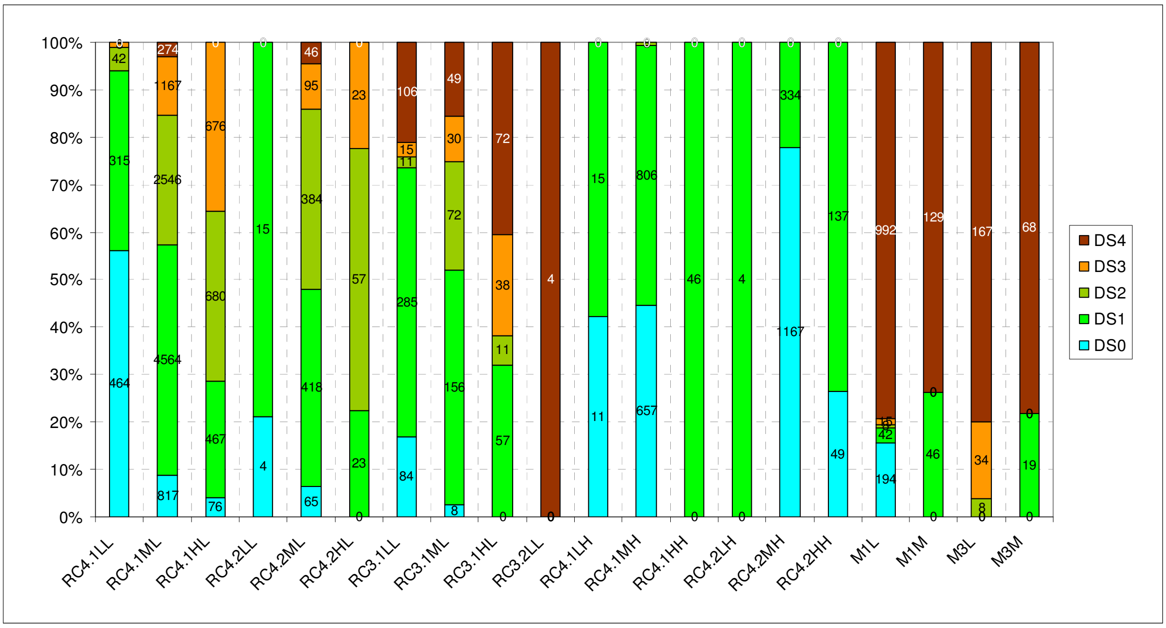


Fig. 4.15 Level II damage distribution (% of buildings) for all building types (Municipality of Thessaloniki)

The total number of buildings that suffer a particular damage state is given in Table 4.2 (referring, again, to the entire municipality). The figures shown confirm that the city is rather vulnerable to the considered earthquake, as about 12% for the Level I or 10% for the Level II approach of the buildings will suffer very heavy damage or collapse. It is worth recalling here that in the 1978 earthquake (the strongest that hit the city in the 20th century) there was only one collapse of multistorey R/C building (and at that time all R/C buildings were 'low-code' or 'pre-code' ones) and heavy damage was observed mainly in masonry buildings; moreover, the percentage of 'green' buildings (roughly corresponding to DS0 and DS1 in the present study) was 74%, almost twice the figure indicated in Tables 4.2 and 4.3 for the Level I approach, while for the Level II the convergence seems to be better.

Table 4.2 Total number of buildings in each damage state.

Level I	Damage State	DS0	DS1	DS2	DS3	DS4	DS5
	Number of buildings	654	6813	6430	3002	1201	1079
	Percentage (%)	3.41%	35.53%	33.52%	15.65%	6.26%	5.63%
Level II	Damage State	DS0	DS1	DS2	DS3	DS4	
	Number of buildings	3595	7748	3827	2101	1908	
	Percentage (%)	18.74%	40.40%	19.95%	10.96%	9.95%	

A picture of the expected distribution of post-earthquake tagging of buildings using the familiar Green, Yellow, and Red tag scheme is shown in Fig. 4.16; the total number and percentage of buildings in each category are summarized in table 4.3. The correspondence between tag colour and DS was assumed as follows:

- Green: DS0 & DS1
- Yellow: DS2 & DS3
- Red: DS4 & DS5 (or DS4 for the Level II approach)

Based on experience from past earthquakes it might well be argued that at least part of (or the entire) DS3 should go to the red tag category.

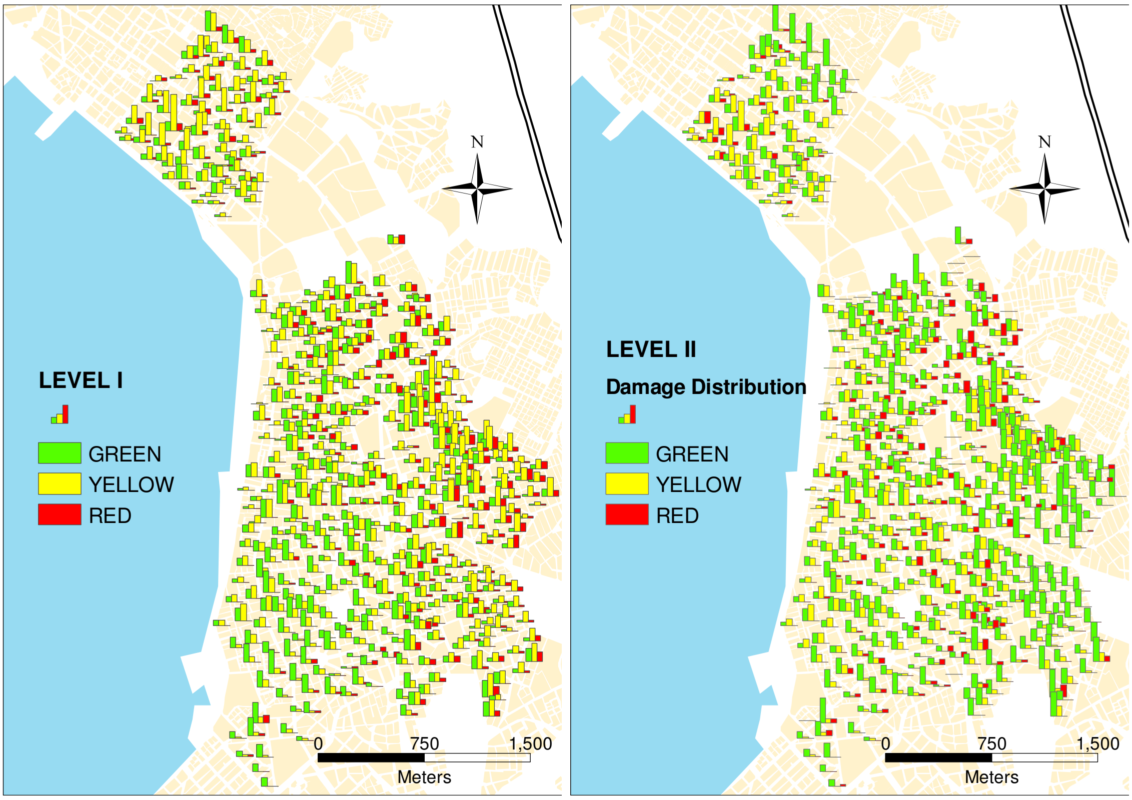


Fig. 4.16 Predicted tagging of buildings.

Table 4.3 Total number of buildings in each damage label.

Level I	Damage Label	Green	Yellow	Red
	Number of buildings	7467	9432	2280
	Percentage (%)	38.93%	49.18%	11.89%
Level II	Damage Label	Green	Yellow	Red
	Number of buildings	11343	5928	1908
	Percentage (%)	59.14%	30.91%	9.95%

Given the limitations of the procedure for assigning each individual building within a block to a discrete damage state, it is important to map also the damage index for each block, this time as a weighted one $\Sigma(MDF_i \cdot V_i)/V_{tot}$, as discussed previously; this map is given in Fig. 4.17 and it puts the damage distribution 'into scale' in the sense that the degree of damage is now associated with the volume of the buildings (e.g. a collapsed single-storey masonry building has a smaller influence on the index than a 9-storey R/C building suffering “substantial to heavy” damage, i.e. DS3). Other implications of the correlation between damage state and the size of the buildings at risk are discussed within WP07.

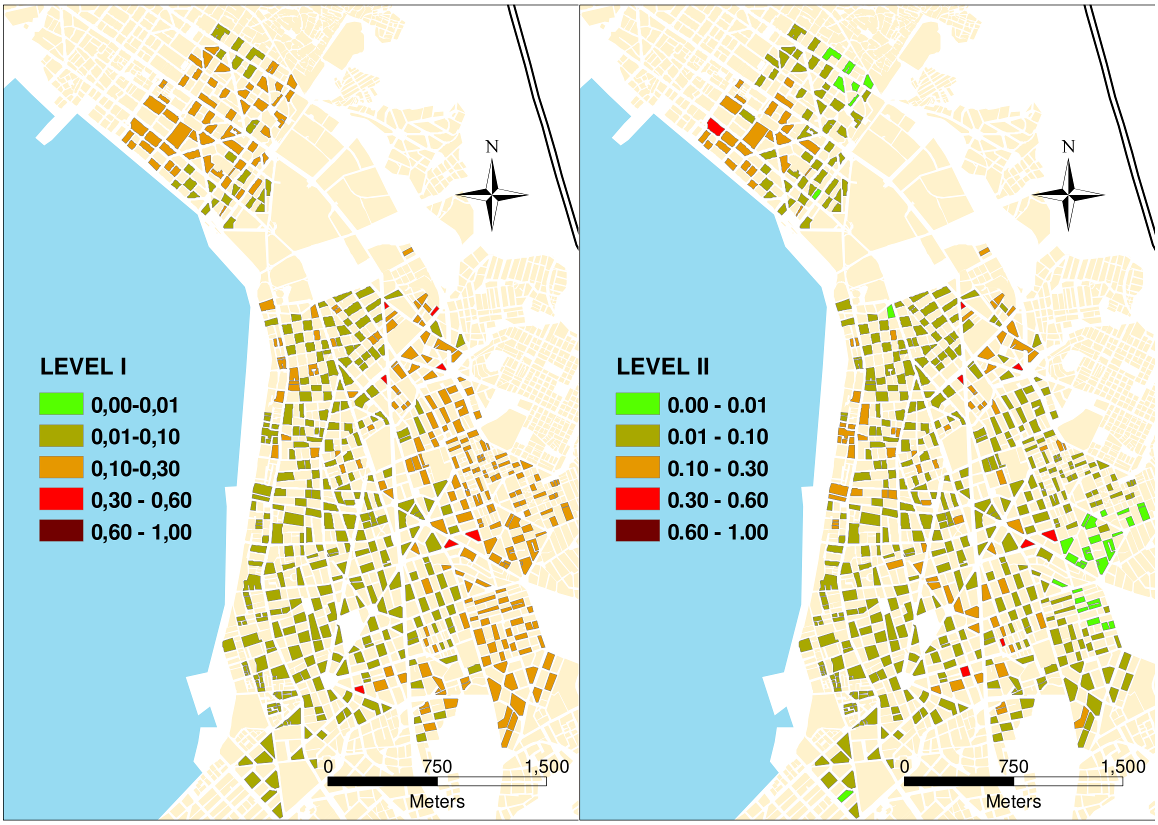


Fig. 4.17 expected distribution of damage due to the scenario earthquake

Last but not least, the economic loss predicted for the scenario earthquake is of particular importance, in several ways (earthquake protection and emergency planning, earthquake insurance). The fragility models developed by the AUTh group (Kappos et al. 2004, Penelis et al. 2002) originate from repair cost considerations; hence it was relatively straightforward to use them for economic loss assessment purposes. The map of Fig. 4.18 shows the estimated total cost of repair required in each building block, derived using the loss indices of Table 4.1 and assuming an average replacement cost of €700 /m^2, i.e. calculating $\Sigma[(V_i \cdot MDF_i] \cdot 700$ in each block. The distribution of cost is, of course, consistent with (and conditional on) the distribution of the degree of damage (Fig. 4.17). A very heavy cost of over 460 million € for the Level I or 330million € for the Level II approach is predicted for the area studied (the figure should be multiplied by about 4 for the entire municipality), again an indication of the severity of the estimated scenario earthquake.

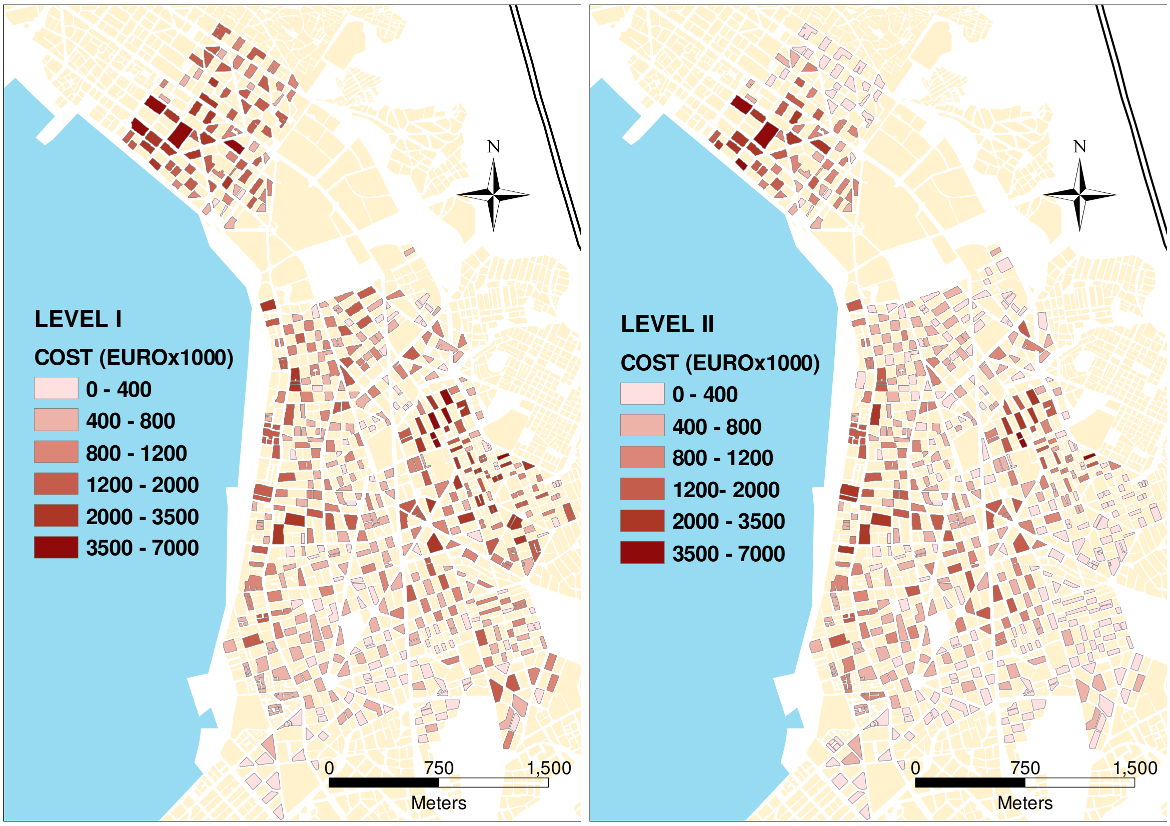


Fig. 4.18 Repair cost (in 10^3€) distribution.

In closing the WP04 scenarios, a couple of notes of caution appear in order:

- As already discussed, all the evidence provided by the present study clearly points to the fact that the scenario earthquake estimated within WP02 is an event significantly stronger than the historical (1978) earthquake whose consequences for the city are known. It is certainly beyond the scope of the WP04 work (but falls well within the broader scope of RISK-UE) to discuss whether some assumptions or methods have led to a certain degree of overestimation of the 475 yr. earthquake for the city.
- The vulnerability assessment of current buildings was estimated using both Level I and Level II approach. The Level I approach (cast into PGA terms) has a number of advantages, but also ignores, to an extent that depends on the spectral characteristics of the motions considered for deriving the fragility curves and their relationship to the characteristics of the scenario motions, the possibly lower damageability of motions with high PGA and spectra peaking over a very narrow band and/or with very short duration (both these characteristics are more or less typical in strong motions recorded in Greece). The Level II approach takes into account the spectral characteristics of the motion but further research is needed in several points such as the case where the Capacity Spectrum Method does not result in a solution, the equal displacement rule assumption etc.
- Both Level I and Level II approaches resulted in similar results (in fact the Level II approach resulted in a little lower predictions of the damage degree). However, it has to be emphasized that the Level I and the Level II fragility curves are not completely independent since the first were used to derive the second, as mentioned above.

5. Vulnerability assessment of historical and monumental buildings

Inventory of monuments

The historical background of monuments in Greece, including issues such as the definition of a monument, the legal framework governing protection and maintenance of monuments, and existing guidelines for retrofitting of monuments are summarized in a RISK-UE report by the AUTh group (Kappos and Stylianidis, 2002), and will not be repeated herein.

The most impressive monuments situated in Thessaloniki are the Byzantine ones, especially the churches, but other monuments, including some notable roman and several contemporary (post-1830) ones, also exist. Five case studies concerning churches and other important monuments of Thessaloniki, namely:

- The Rotunda (Roman - Christian domed structure), see Fig. 5.1
- Achiropiitos (Early Christian basilica)
- St. Panteleimon (13th - 14th century crossed compound four - pillar Church), see Fig. 5.2
- The Rotunda Minaret (16th century ottoman minaret)
- Yahudi (Pazar) Hamam (Turkish bath of 17th century)

have been presented in some detail in another RISK-UE report by the AUTh group (Stylianidis et al. 2002). The report first presents historical data for each monument, then the morphology of the structural system is briefly discussed. Finally, the pathology of the load bearing system (including damage from previous earthquakes) is described, with emphasis on the causes of damage, especially those which are due to static and seismic loads and to soil conditions. Again, due to space limitations, this detailed information will not be repeated herein.

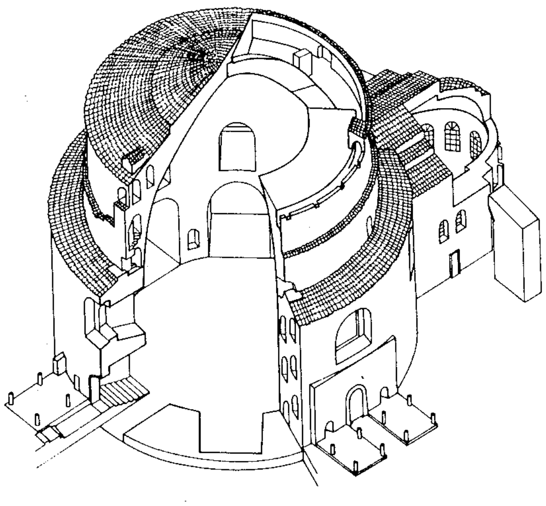


Fig. 5.1 The Rotunda: Cutaway isometric view from the southwest.

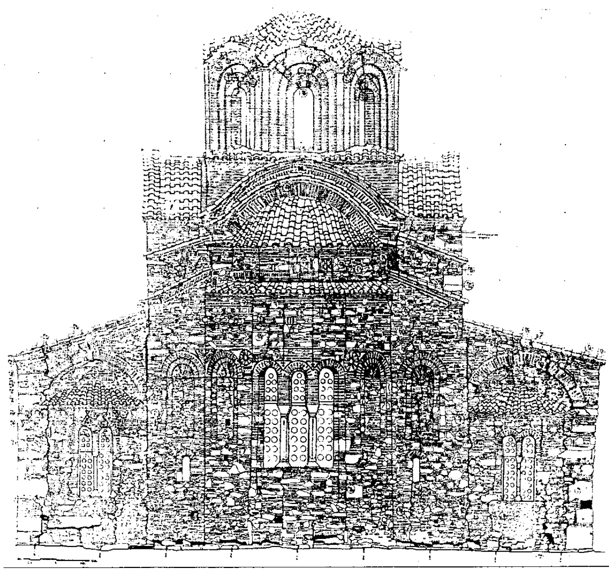
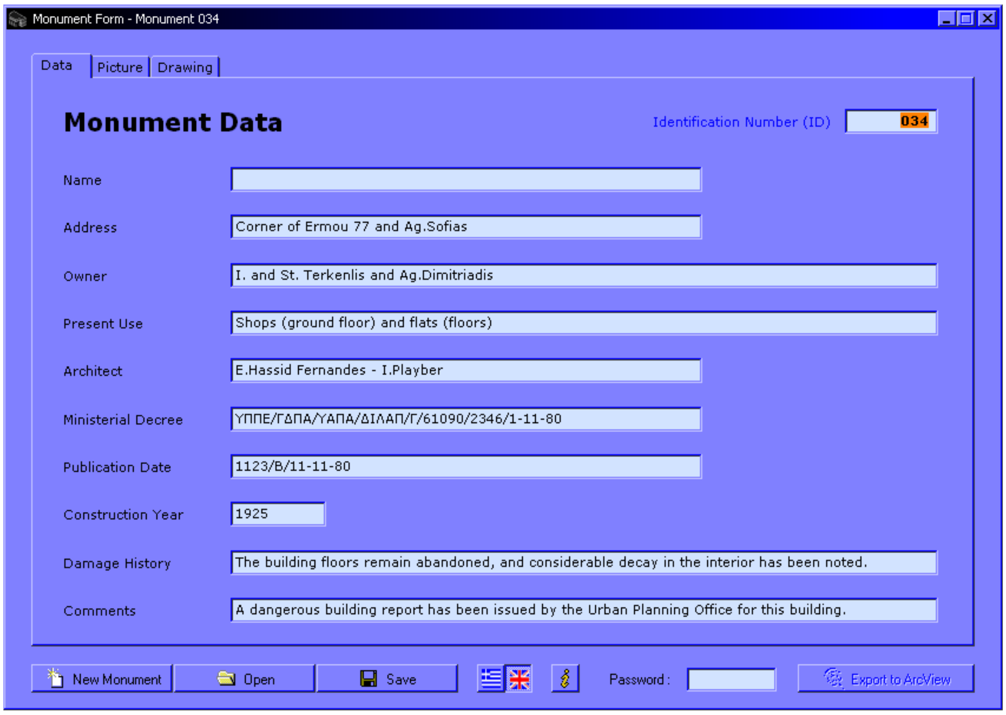


Fig. 5.2 The St. Panteleimon Byzantine Church: Elevation from the east.

All major roman and byzantine monuments in Thessaloniki, as well as all contemporary monuments (even relatively minor ones) have been introduced in a GIS map of the city. The ARCView© (3.2) database of Thessaloniki monuments which is set up in both English and Greek, currently includes a total of over 340 monuments; an example is shown in figures 5.3 and 5.4, while Fig. 5.5 shows the main part of the GIS map of Thessaloniki showing the positions of monuments included in the database set up within the RISK-UE programme.

Information included in the database was used to develop the scenario for monuments using the methodology suggested by Lagomarsino et al. (2003) within WP05, as described in the next section.


Monument Form - Monument 034
Data | Picture | Drawing

Monument Data

Identification Number (ID): 034

Name	
Address	Corner of Ermou 77 and Ag.Sofias
Owner	I. and St. Terkenlis and Ag.Dimitriadis
Present Use	Shops (ground floor) and flats (floors)
Architect	E.Hassid Fernandes - I.Playber
Ministerial Decree	ΥΠΠΕ/ΓΔΠΑ/ΥΑΠΑ/ΔΙΛΑΠ/Γ/61090/2346/1-11-80
Publication Date	1123/B/11-11-80
Construction Year	1925
Damage History	The building floors remain abandoned, and considerable decay in the interior has been noted.
Comments	A dangerous building report has been issued by the Urban Planning Office for this building.

New Monument | Open | Save | Password : | Export to ArcView

Fig. 5.3 Electronic form for data collection (data concern a contemporary monument).

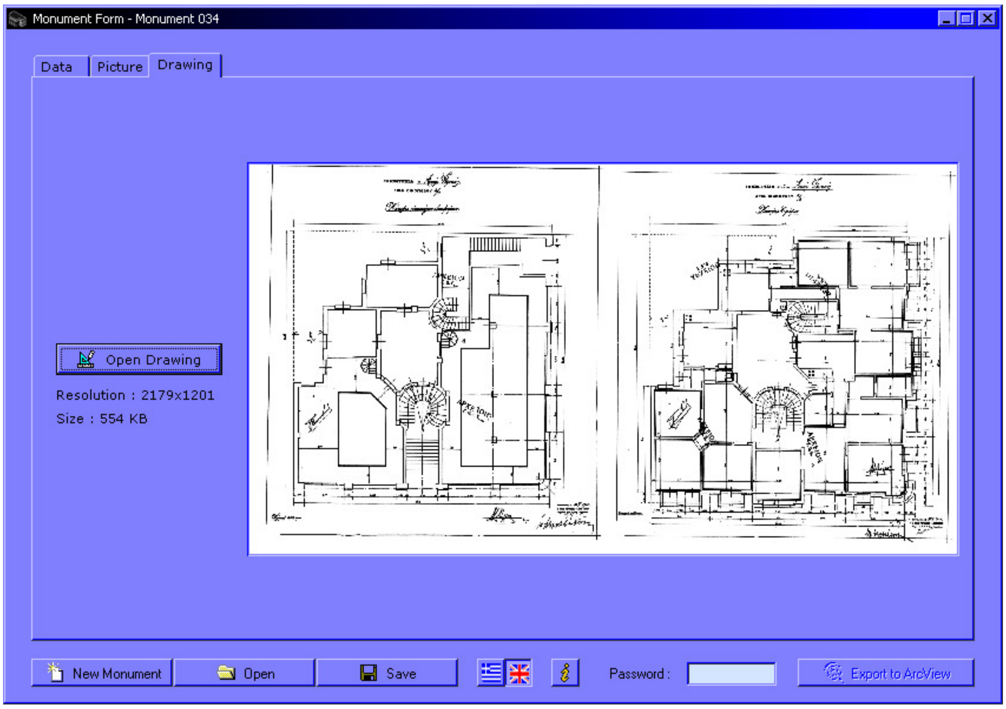


Fig. 5.4 Typical example of construction drawings (plans) for building whose main form is shown in Fig. 5.3.

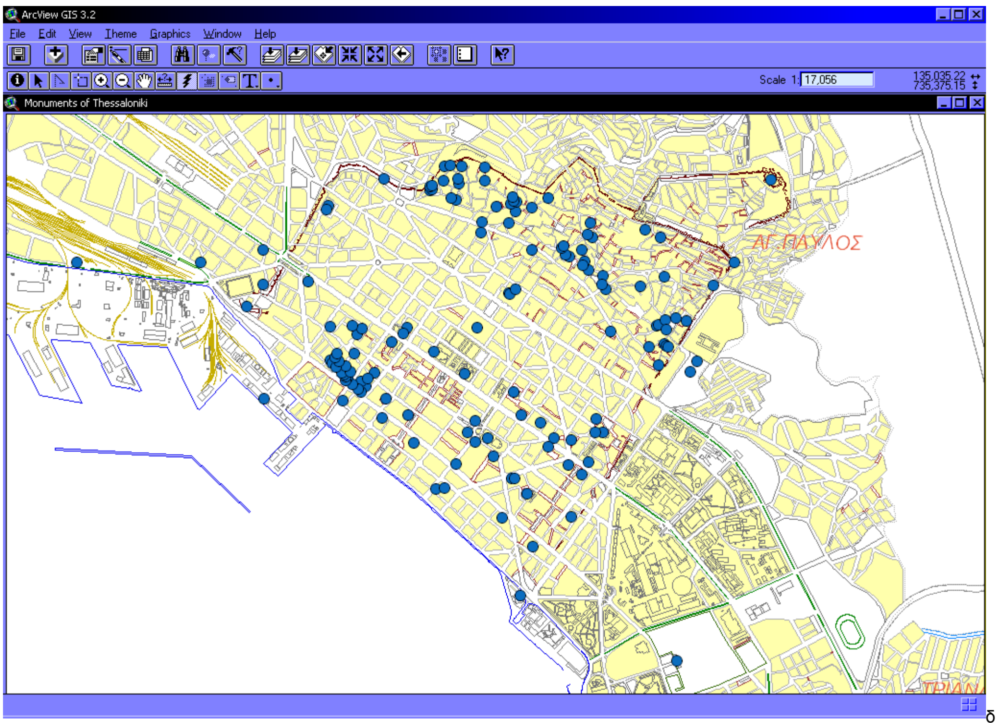


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Fig. 5.5 Part of the GIS map of Thessaloniki showing the locations of monuments included in the RISK-UE database.

Scenario for monuments

The damage scenario for the monuments has different aims than the general scenario since its aim is the estimation of the 'cultural damage' that Thessaloniki will sustain when subjected to the design earthquake. Therefore of the 340 buildings of the 'monuments' database this part of the scenario focuses on the 47 most important ones, for the following two reasons:

(a) The "monuments" database includes all the buildings that have been listed by the Ministry of Culture, many of which are residential masonry buildings of the early 20th century and therefore are not of the same importance as the exquisite monuments of the Roman and Byzantine period of Thessaloniki. These buildings have been already included in the damage scenario of WP04 as URM buildings and therefore there is no real point for their inclusion in this scenario which aims to assess the possible cultural damage of the city.

(b) For several monumental buildings of low importance the available data was not adequate to assess the vulnerability index (as defined in the WP05 methodology), hence it was not possible to include them in the scenario.

All the above led to addressing a smaller, yet more concise, database which includes all the monuments – landmarks of Thessaloniki.

The damage scenario for the monuments is based on the combination of two parameters

- the *peak ground accelerations* (PGA's) estimated for each building block of Thessaloniki with 10% probability of exceedance in 50 years (475 return period), which are shown graphically in fig 5.6.
- the estimated *vulnerability index* of each monumental building, which has been assessed using the methodology described in the WP05 Handbook. The methodology is based on a survey form including several weighted parameters such as type of building, quality of construction, existence of specific vulnerable elements etc., which are combined to derive a final index.

Examples of estimation of the vulnerability index for monumental buildings (in the sense discussed earlier in this section) in Thessaloniki is shown in table 5.1.

Table 5.1 Assessment of the vulnerability index for monumental buildings.

NAME	TYPOLOGY	AGE	KIND OF USE	FREQUENCY	CROWD	MAINTENANCE	DAMAGE LEVEL	Arch TRAN	REC. INTER	MAS QUAL	SITE	PLAN REG.	POSITION	I_v
The Customs	Palaces - Vilas	1910	Offices in the main building and warehouses in the rest buildings	Daily	yes	good	severe	no	yes	yes	flat ground	yes	isolated	0.576
Ioniki and Laiki Bank	Palaces - Vilas	1929	Bank	Daily	yes	medium	nihil	no	no	yes	flat ground	yes	corner	0.656
Vlatadon Monastery	Monasteries	1351	0	occasional	yes	good	medium	no	yes	yes	ridge	yes	isolated	0.676
The Rotunda	Churches	300	0	Occasional	yes	good	severe	yes	yes	good	flat ground	central	isolated	0.97
The Church of Achiropiitos	Churches	500	church	daily	yes	good	severe	no	yes	good	sloping	three	isolated	0.99

The Church of St.Panteleimon	Churches	1300	church	Daily	yes	good	severe	no	yes	good	flat ground	one	isolated	0.95
The Church of Ayia Sophia	Churches	800	church	daily	yes	good	light	no	yes	good	flat ground	three	isolated	0.99
The Church of Ayios Nikolaos Orphanos	Churches	1400	church	daily	yes	medium				good	flat ground	three	isolated	0.95
The Church of Hosios David	Churches	600	church	daily	yes	good	severe	no	yes	good	flat ground	one	isolated	0.89
The Rotunda Minaret	Minaret	300	0	Occasional	yes	good	severe	no	yes	good	flat ground	circular	isolated	0.736
The White Tower	tower	0	Museum	daily	yes	good	light	no	yes	good	slopping	circular	isolated	0.796
Galerios Arch (Kamara)	arch	0	0	Daily	yes	good	light	yes	yes	good	flat ground	not meaningful	isolated	0.456

The combination of the above is performed using the expression:

$$\mu D = 2.5 \cdot \left[1 + \tanh\left(\frac{I + 3.4375 \cdot i_v - 8.9125}{3} \right) \right]$$

where,

μD: Mean damage grade varying from 0 – 5

I: EMS98 intensity which is linked to pga using the following expression: Ln(pga)=0.03+0.74I

iv: The vulnerability index of each monumental building

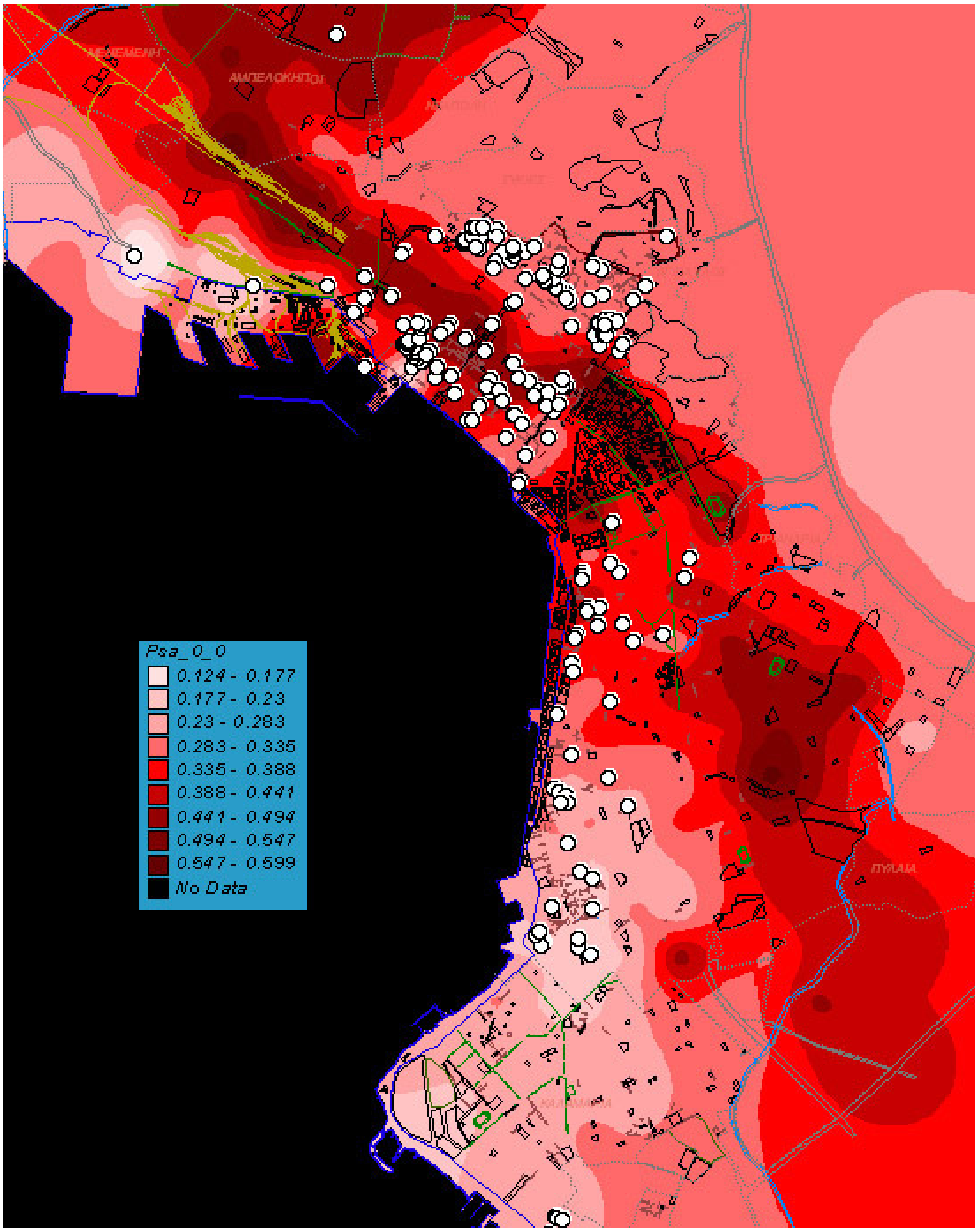


Fig. 5.6 Part of the GIS map of Thessaloniki showing the locations of monuments included in the RISK-UE database combined with the expected PGA's.

In figure 5.7 the damage grade for each monument is plotted on the GIS map using an appropriate color and size scale. This data has also been summarized in a tabular format in table 5.2

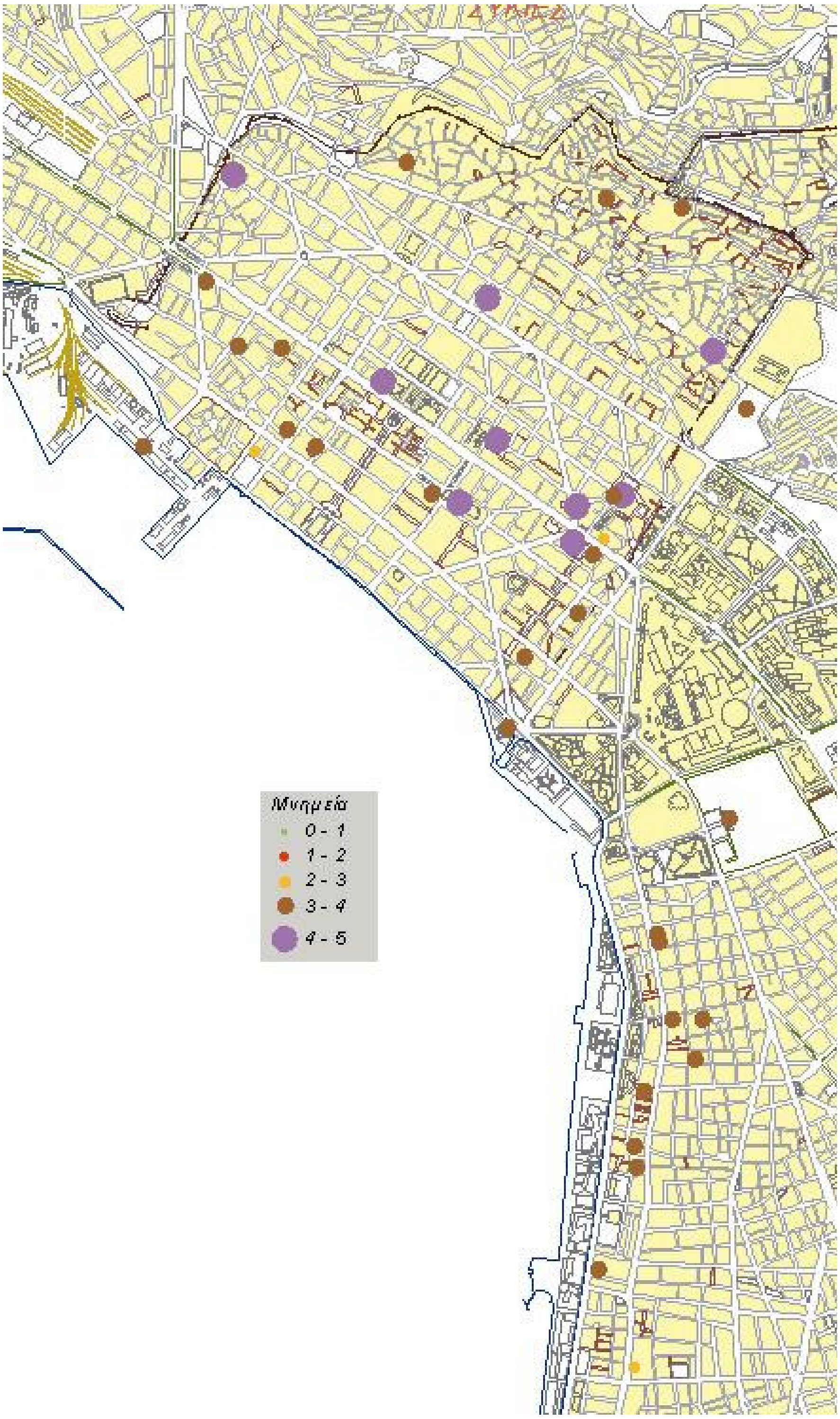


Fig. 5.7 Part of the GIS map of Thessaloniki showing the locations of monuments actually graded for the RISKUE project and the resulting damage grade (0 – 5).

Table 5.2 Results of the earthquake scenario for monumental buildings.

RANGE	NUM	PER
0 -1	0	0%
1-2	0	0%
2-3	5	11%
3-4	32	70%
4-5	9	20%

It is interesting to check the final prediction of the scenario in the case of the few monuments of the previous section (the ones described in more detail in the RISK-UE Report by Stylianidis et al. 2002):

Table. 5.3 Results of the earthquake scenario for selected monumental buildings

Monument	PGA	Iv	Damage grade
Rotunda	0.45	0.97	4.25
Rotunda minaret	0.45	0.736	3.84
Acheropiitos	0.438	0.99	4.27
Agios Panteleimon	0.423	0.95	4.19

From the results of the scenario (Tables 5.2, 5.3) it is obvious that the majority of monuments will suffer a damage grade of 3-4 while a significant number will sustain damage of 4-5 (near collapse). This prediction is, of course, related to the severity of the scenario earthquake, and all comments made in this respect in the WP04 section are also pertinent herein. In particular one should point out that the level of damage predicted here for the major monuments of Thessaloniki does not appear to be consistent with their (long) 'seismic history' (i.e. exposure to past earthquakes). As discussed in connection with the general (WP04) scenario, this apparent over-prediction of damage should be either due to overestimation of hazard, or of the vulnerability (this is perhaps more true in the case of monuments where the WP05 rating method applied has not been calibrated against local data), or, indeed, a combination thereof.

6. Vulnerability assessment of lifelines and essential structures

Lifelines in Thessaloniki play an important role, as in all modern urbanized areas, while their functionality is vital, especially during an earthquake crisis. In many cases the lifeline components are old and not seismically designed, thus the vulnerability assessment is essential. The main problem for the vulnerability assessment of lifelines in Thessaloniki is the lack of reliable and integrated data for all the elements at risk. Security restriction and other financial considerations often restrain the easy availability of data.

The vulnerability assessment of lifeline systems in Thessaloniki was performed according to methodology developed in WP06 of this project (see Monge et al, 2003). The application is presented in the following order:

- Brief description of the network, together with the basic features of the inventory and the typology.
- Application of the urban system exposure methodology and classification of the importance of each element at risk, according to WP03 and WP06.
- Input seismic hazard scenario for the damage estimation, according to WP02.
- Application of the fragility model and distribution of the expected damages, according to WP06.
- Restoration progress and mitigation priorities (not in every system), according to WP06 and the combination of the above results.

Transportation Systems

Transportation networks in the greater area of Thessaloniki provide services to the increased needs for work, trade, touristic, social and other daily or occasional transports. Thessaloniki constitutes a transportation nodal point at a supranational, national and regional level due to the convergence of the transport infrastructure (roads, rail, sea and air networks). In the present report the roadway and port systems are studied.

Roadway network

The roadway network in the region of the central Macedonia can be distinguished into the following levels: the interregional/ international (PAThE, Egnatia), the inter-prefecture level, and the local level. During the RISKUE project the internal roadway network of the urban area of the city was digitized and studied.

The *roads* are categorized in freeways, major and secondary arterials, primary and secondary collectives, based on their geometry and functional role in the network. Fig. 6.1 presents the percentage of each class according to the length, while fig. 6.2a illustrates the road network of the city. The four main exits of the city and the ring road are characterized as freeways. Thessaloniki is extended along the seaside and consequently the road system follows this fact being parallel and perpendicular to the sea. The roadway network of the urban area is rather insufficient, especially in the center, where the densely built up area creates a complex network, with narrow streets and inadequate parking areas.

Following the methodology developed in WP03 and WP06, roads were classified in 3 periods based on their functional class, the access to critical facilities (ex. hospitals), the access to residential and commercial land use areas and the symbolic weight. The classification of urban units per period, referred to the residential and trade land use, was utilized in order to give relative values to the roads that cross the central part of the city. In figures 6.2a and 6.2b are given two examples of the classification of roadway elements based on the relative values of the functional class and the access to critical facilities.

As the critical factor for the vulnerability assessment of roads is the ground failure, the estimated permanent ground displacements due to liquefaction (lateral spreading and settlement) were used in order to assess the direct damages (fig. 2.24). Roads are expected to experience slight damages due to permanent ground displacement in a limited prone to liquefaction area as it is estimated based on the proposed in WP06 fragility model (fig. 6.3).

The majority of roadway *bridges* and viaducts mainly belong to the ring road and the main exits of the city as it shown in figure 6.4. A database in GIS format was produced for bridges based on the available information, which is including as minimum information the location, material, structural type, year built and geometry of the bridge. The inventory shows that the majority of bridges were designed after 1986, when the upgraded seismic code was introduced.

Similarly to roads, bridges were classified based on the global value, resulting from indicators such as the functional class of the road on/under the bridge, the strategic importance of the bridge and the number of spans. Fig. 6.4 illustrates an example of the hierarchy of importance for the normal period.

The input earthquake hazard scenario for the seismic risk assessment of bridges was obtained from the application of the WP02 methodology to Thessaloniki and is referred to the mean peak acceleration at T=1.0sec (fig. 2.17c). In fig. 6.5 is presented the worst probable damage state as it was estimated based on the appropriate fragility model, together with an example in fig. 6.6.

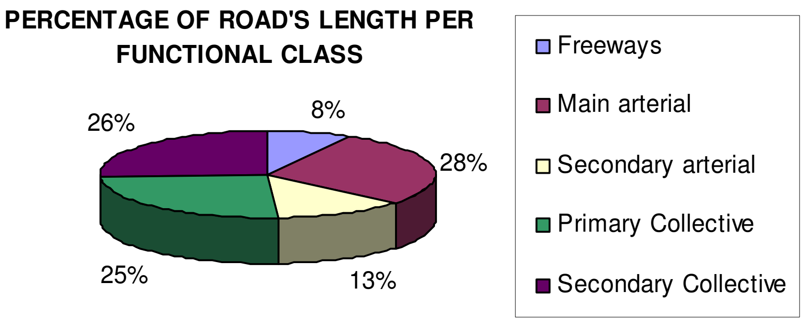
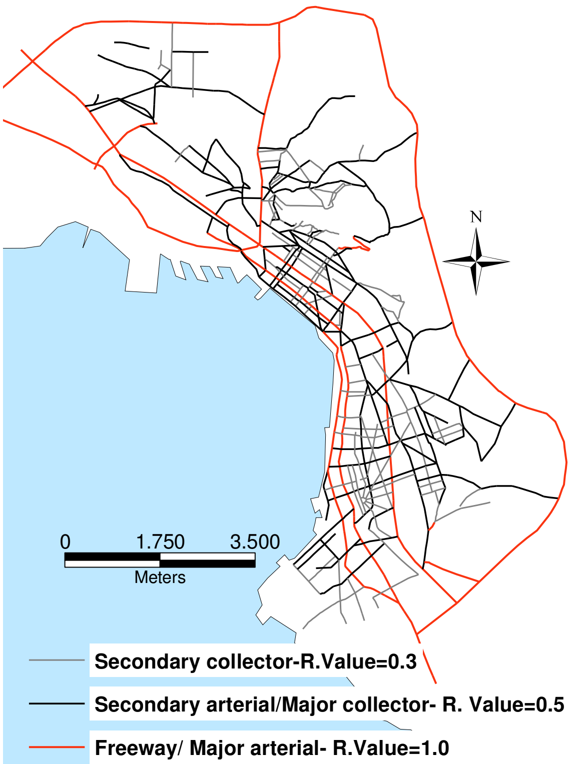


Fig. 6.1 Functional classes of roads. (Source: Organization of Thessaloniki)



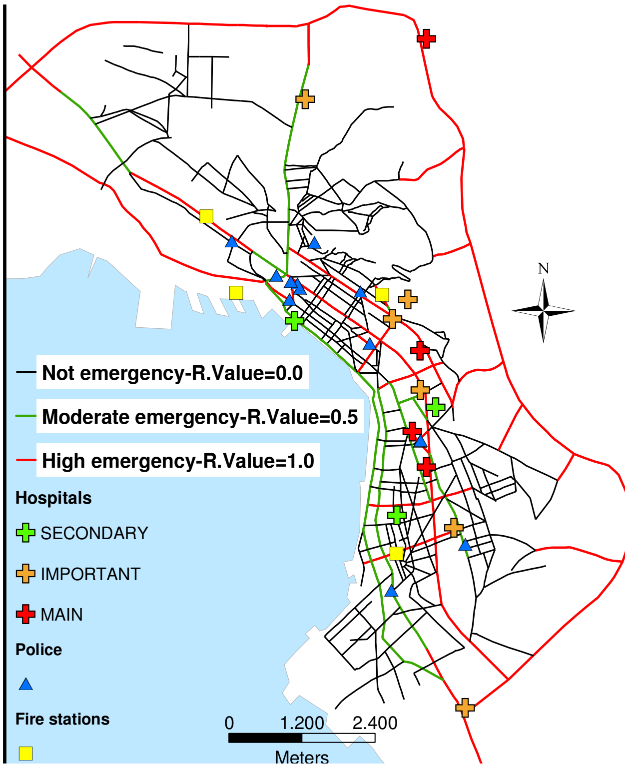


Fig. 6.2 Classification of roads according to the functional class (left) and the emergency access to critical facilities (right) based on the relative values.

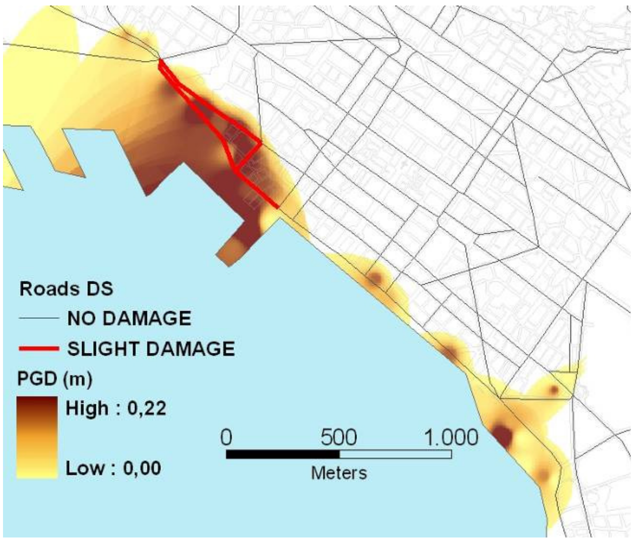


Fig. 6.3 Damages in roads caused by permanent ground displacement.

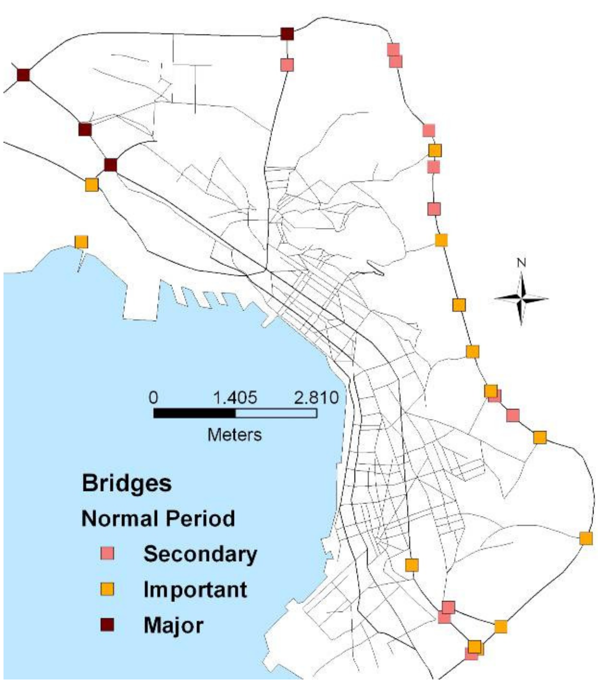


Fig. 6.4 Classification of bridges for normal period based on the global value.

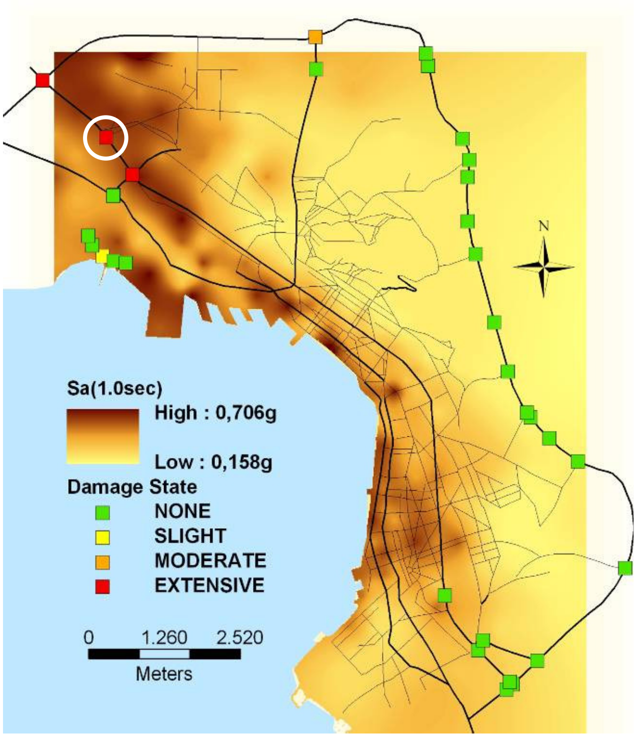


Fig. 6.5 GIS map showing the worst probable damage state for bridges.

Prestressed Concrete - Single Column - Simple Support	
Year built	1981
Angle of skew	30
Number of spans	11
Maximum span length (m)	30,5
Total bridge length (m)	250

$Sa_{(1.0sec)}$	0.5g
K_{skew}	0.931
K_{3D}	1.025

Probability >=ds (%)			
Slight	Moderate	Extensive	Complete
87.3	74.5	59.5	31.1

Fig. 6.6 Example of damage evaluation of bridge.

Port system

The port of Thessaloniki is the nodal point for the transport of goods coming from inland as it is located in a very sensitive, in terms of geography area. It is the first export and transport harbor of Greece and is European Union's closest port to the countries of Southeast Europe as well as to the countries of the Black Sea and East Mediterranean. It covers an area of 1,500,000 m^2 and trades approximately 15,000,000 tons of cargo annually, having a capacity of 200,000 containers and 6 piers with 6,200m length. In collaboration with the port authority (Thessaloniki Port Authority, THPA), various data was collected and implemented in GIS format for the considered elements at risk, including cargo & handling equipment, waterfront structures, electric power (transmission & distribution lines, substations), potable and waste water (pipelines), railway (tracks) and roadway system (roads & bridge). The presence of all the above utilities in a limited area enables the complete application of the methodology for the seismic risk assessment of lifelines and the specification of possible weak points.

The indicators for the classification of the importance of each element according to the methodology of WP03 and WP06 were defined based on the available data from the inventory, which are describing the role of any particular element in each period. For instance, the cranes were classified based on the lifting capacity (tons), the draught of the dock where the crane is located, the capability for container handling and the frequency of use (high, moderate, low). Representative GIS maps illustrating the definition of main, important and secondary elements at risk are shown in fig. 6.7, 6.8.

The input seismic hazard scenario has been evaluated using the average values of PGA plus 1 standard deviation, as it was derived from the 1D-EQL analyses for the 5 design input motions at outcropping conditions in the frame of the Microzonation study (see section 2 of this report). Additionally, based on the soil profiles that were used for the 1D analyses, an estimation of the liquefaction susceptibility was made, while the settlements due to liquefaction were calculated for these locations according to the procedure described earlier in this report.

Following the methodology of WP06, the vulnerability of the considered elements at risk was assessed, while the distribution of the expected damages was appointed and illustrated in GIS maps (fig.6.9, 6.10). The derived results were consistent to the considered extreme scenario, although a diversification of results (estimated damage states) was observed, according to the input parameter (PGA, PGV, PGD). However, it should be mentioned that the port is a complicated system of lifelines and infrastructures, thus a complete seismic risk assessment requires a detailed data base and an advanced methodology that would take into account the synergies between the different elements.

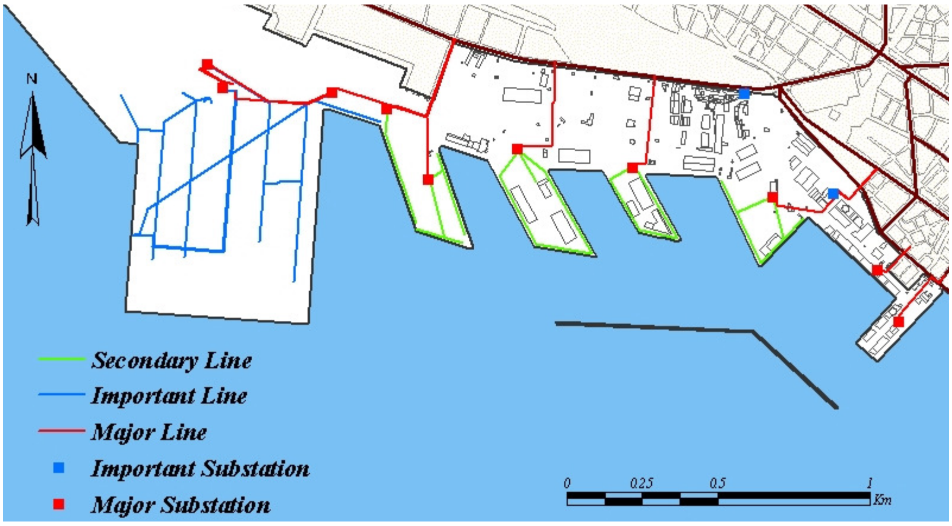


Fig. 6.7 Classification of importance for electric power system in the normal period.

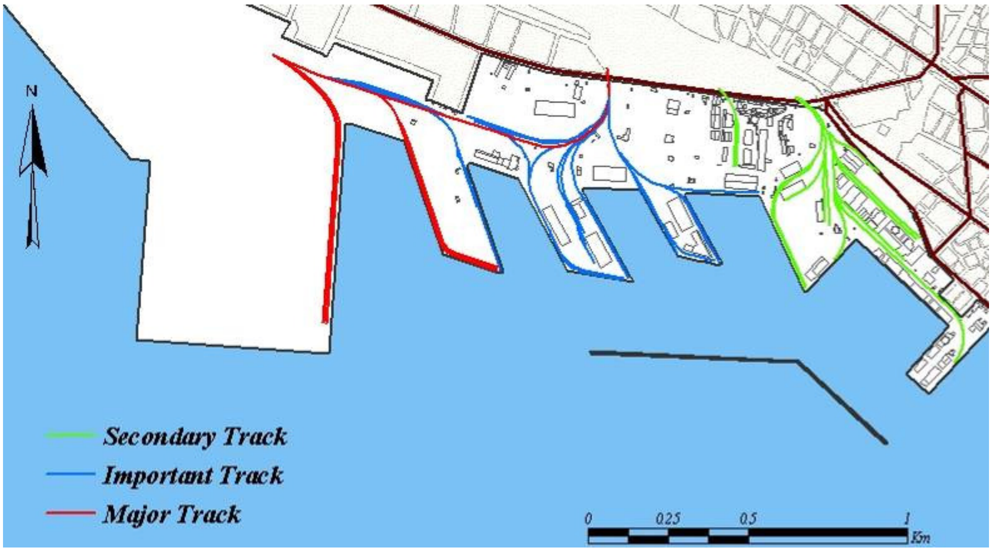


Fig. 6.8 Classification of importance for railway tracks in the restoration period.

Fig. 6.9 Vulnerability assessment of cranes based on PGA.

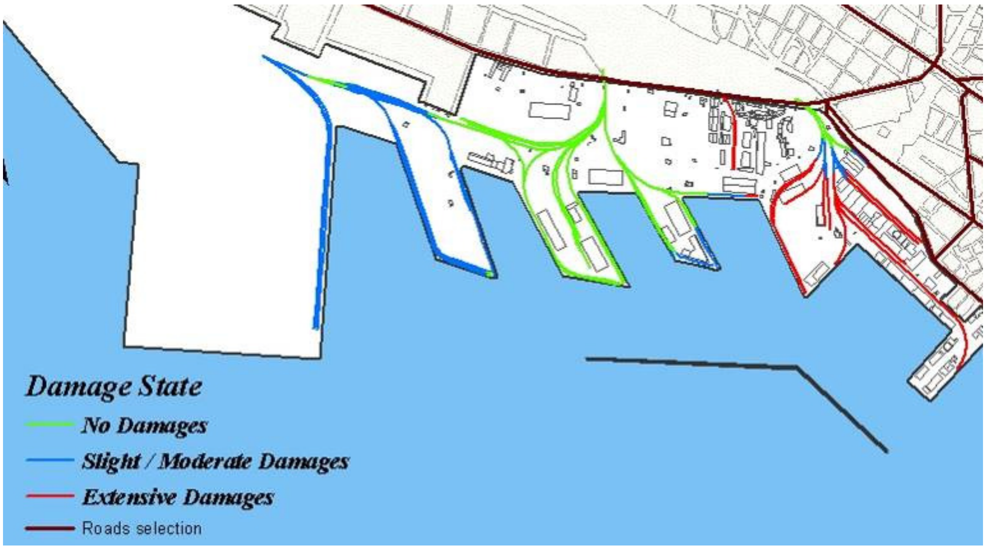


Fig. 6.10 Vulnerability assessment of railway tracks based on PGD.

Utility Networks

The utility networks of Thessaloniki that were studied during this project include gas, potable water, and waste water and telecommunication systems.

Gas system

Thessaloniki's gas system, transmission and distribution, includes: City gate stations, M/R stations 19/4 bar, steel pipes with pressure of 19bar and PE pipes with pressure of 4bar. Nowadays, the gas network is in progress and it has 90km of steel pipes for the constant supply (19bar), 2-City gate stations and 210km of PE pipes (4bar).

In the framework of RISK-UE project about 67,20km of pipes were digitized from paper maps referring to the central part of the city. About 58% of the digitized pipes are steel, while the rest are PEAD pipes. The length of pipes with diameters 63mm is 16,15km, 125mm is 11,30km, 150mm is 37.134km, 200mm is 244,91km. The digitized gas system is presented together with the seismic input motion as derived from WP02 application (fig. 6.11). The input seismic hazard scenario is based on the Microzonation study of the city (10% exceedance in 50 years) and more precisely in terms of peak ground velocity for ground shaking and permanent ground displacement for liquefaction.

The classification of importance in the three periods was evaluated according to WP03 methodology, based on three indicators for gas pipes (function, emergency and radiance) and four for M/R stations (function, emergency, alternative solution and radiance). The results of the classification are presenting in GIS maps in fig. 6.12 for normal and crisis period. Similar results were obtained for restoration period as well.

The damage level of the gas network depend on seismic hazard scenarios, the individual characteristics of the components (inventory) and the selected fragility model as it is provided in WP06 handbook (for wave propagation: Isoyama 1998, relation and for permanent ground displacement ALA, 2001). Table 6.1 presents the predicted Repair Rate/km for the seismic scenario anticipated, using the relations proposed by RISK-UE. In the same table a comparison is made between RISK-UE and HAZUS'99 fragility relations (wave propagation: O'Rourke and Ayala, 1993 and permanent ground displacement: Honneger and Equchi, 1992). The results are illustrated in GIS maps in fig. 6.13.

Table 6.1 Estimated Repair Rate/km for the gas system in Thessaloniki.

Cause of damage	*Isoyama, 1998 & ALA, 2001*		*HAZUS'99*	
	RR/ km	*Number of repairs*	*RR/ km*	*Number of repairs*
Wave propagation	0.069	5	0.050	3
PGD	0.189	13	0.015	1
Total		18		4

The restoration process is based mainly on the extent of damage, manpower, expertise, company organization and interaction between other lifeline systems. Assuming that the total number of available workers of the Gas company for the study area, at the time of earthquake is 30 persons and all breaks and leaks are concentrated to small pipes<500mm, then the time needed to restore the full functionality of gas system is given in Table 6.2. The prioritization of restoration actions, based on the combination of vulnerability and classification of gas system isn't very essential for the specific scenario, as the level of damage is limited and the time for full recovery is quite short.

Table 6.2 Restoration time for the gas system in Thessaloniki.

Methodology	*Estimated damage state*	*Restoration process*
HAZUS'99	4 breaks and 1 leak	6 hours
RISK-UE	10 breaks and 3 leaks	1day

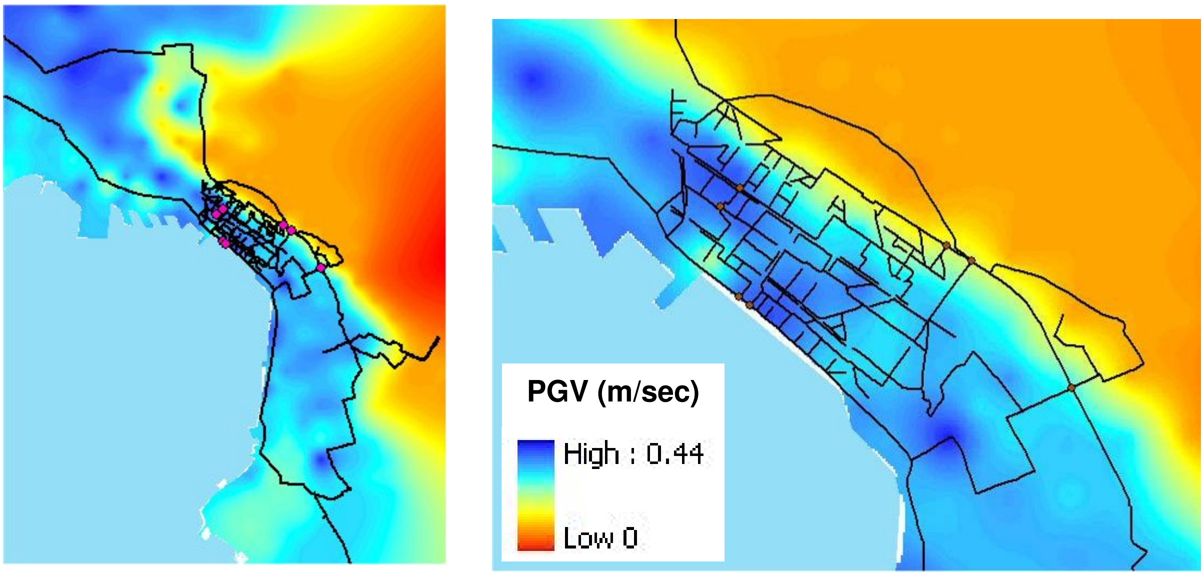


Fig. 6.11 Gas system and overlay PGV (m/sec) map.

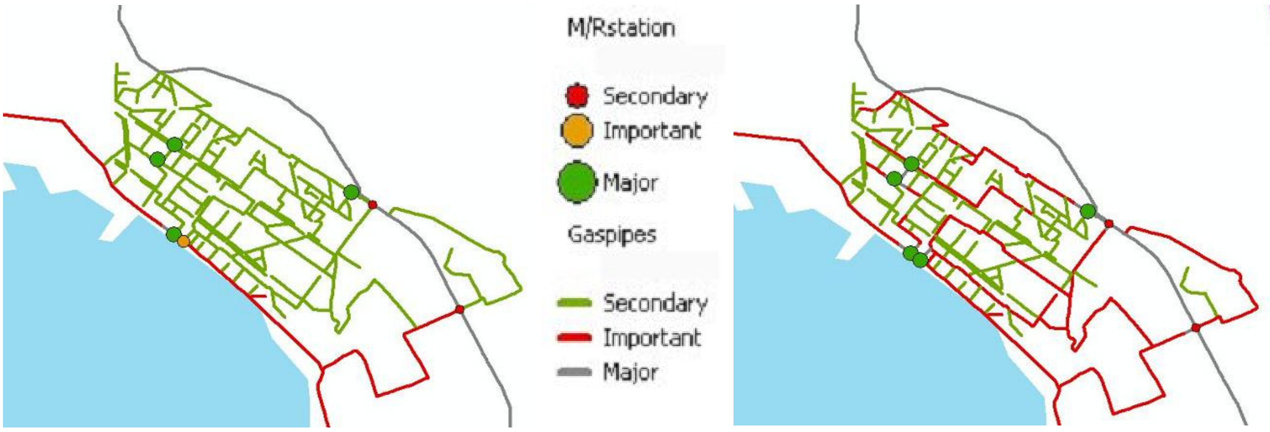


Fig. 6.12 GIS maps illustrating the classification of importance of gas network in normal (left) and crisis (right) periods, based on the estimated global value.

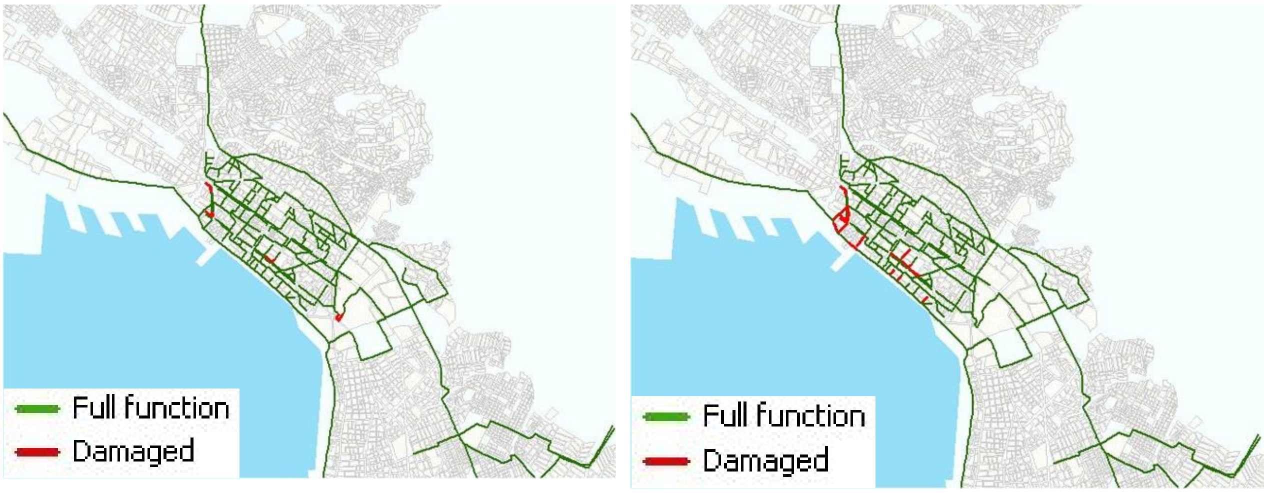


Fig. 6.13 Vulnerability of gas system according to RISK-UE (left) and HAZUS 99 (right).

Telecommunication system

Telecommunication system is divided into public telecommunication system (permanent) and cellular network (wireless). In the frame of RISK-UE project public telecommunication network was studied for Thessaloniki. It consists of nodes (Central offices) and telecommunication cable network.

Three different types of nodes exist in Thessaloniki:

a. Telecommunication nodes/ Central offices (International Centers, Long- distance centers, Urban or Primary Centers, Secondary Centers or End office Center)
b. Data nodes (low speed- HellasPac, high speed- ATM)
c. Digital connectors (basic nodes- DXC, Secondary subscribers- AN)

and,

four different types of telecommunication cable network:

1. Network that connects customers with nodes (Main, Distribution, Digital cooper and Fiber optic network).
2. Network that connects nodes with nodes inside the city.
3. Network that connects nodes with nodes outside the city.
4. Wireless network (transmission towers and antennas).

Inside the city, telecommunication system is supported by 11 first priority central offices (CO) (includes international, long-distance and urban centers), which were identified during RISK-UE project. Two different types of telecommunication cable network in Thessaloniki were also mapped in GIS ("Network that connect nodes with nodes inside the city" and "Network that connect customers with nodes" the part that refers to Fiber optic network). The digitized telecommunication network is presenting in fig. 6.14 beside with the classification of importance according to WP03.

Following the methodology developed in WP03, five indicators were selected for Central Offices (according to telecommunication equipment, function type, communication capability, intervention capability and radiance) for the three main periods (normal, crisis, recovery). Similarly, telecommunication cable network was classified into main, important and secondary issues based on three indicators (function, emergency, radiance). In figure 6.14 it is illustrated the hierarchy of importance of the telecommunication elements for the normal and crisis periods. It can be noticed, that during the earthquake the larger part of telecommunication cable network is crucial and especially the fiber optic network. In normal and restoration periods the service of customers plays the important role in CO classification, while in crisis period the "emergency" capabilities of CO are the primary target.

The estimation of the vulnerability of telecommunication system is mainly based on the performance of Central Offices. The expected damages were estimated based on the methodology of WP06 and are illustrated in fig. 6.15.

Telecommunication network is expected to function without any major problems due to redundancy of the system, although some moderate damages in Central Offices are expected. The restoration progress is given in table 6.3. Figure 6.16 depicts the progress of restoration activities in GIS map (3days). Similar pictures are given for the first day and 1 week after.

Table 6.3 Restoration progress of Central Offices for the telecommunication system in Thessaloniki.

Restoration progress			
Functionality level of Central Offices	1st day	3rd day	7th day
	7/11 CO→ 50%	7/11 CO→ 98%	Full recovery
	4/11 CO → 90%	4/11 CO → 100%	

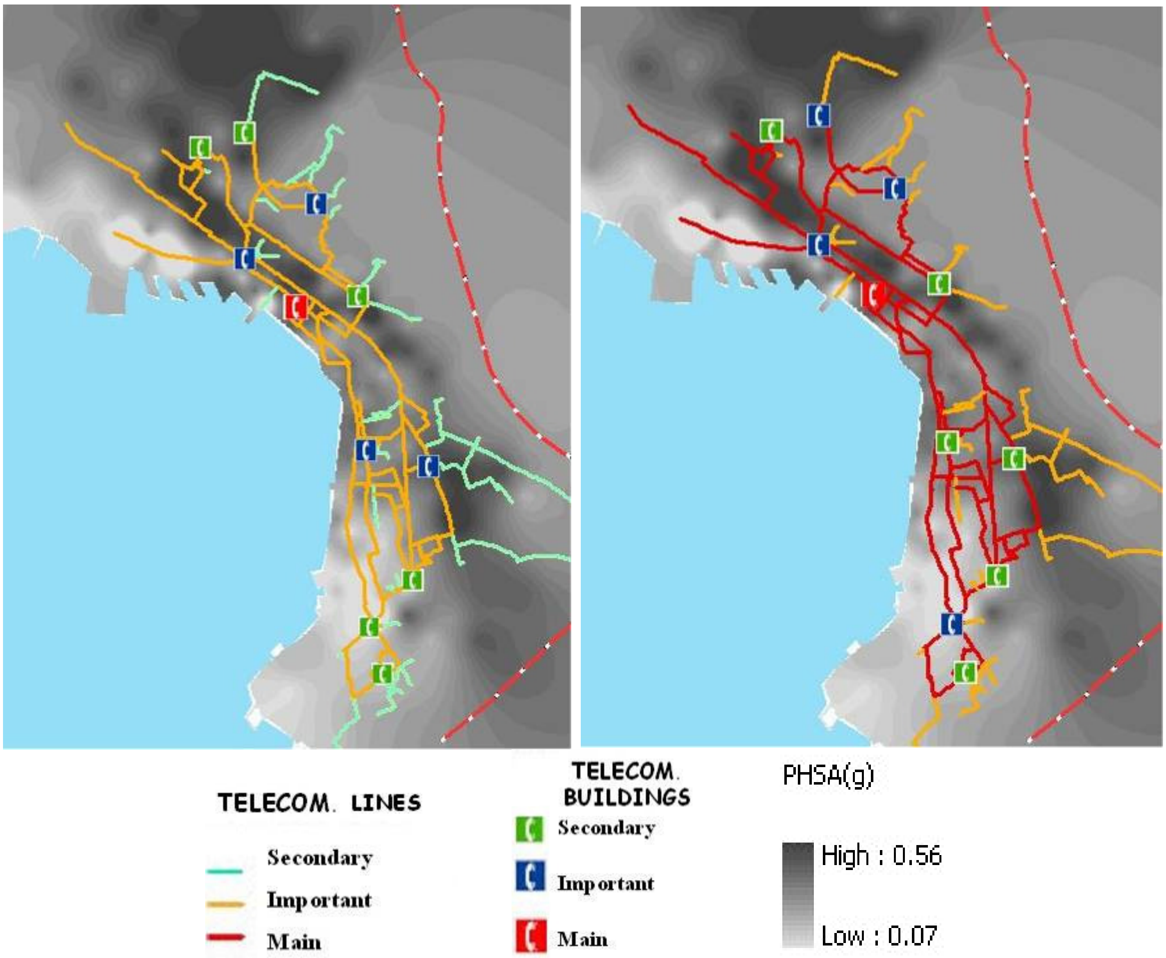


Fig. 6.14 Classification of the telecommunication system for normal (left) and crisis (right) periods.

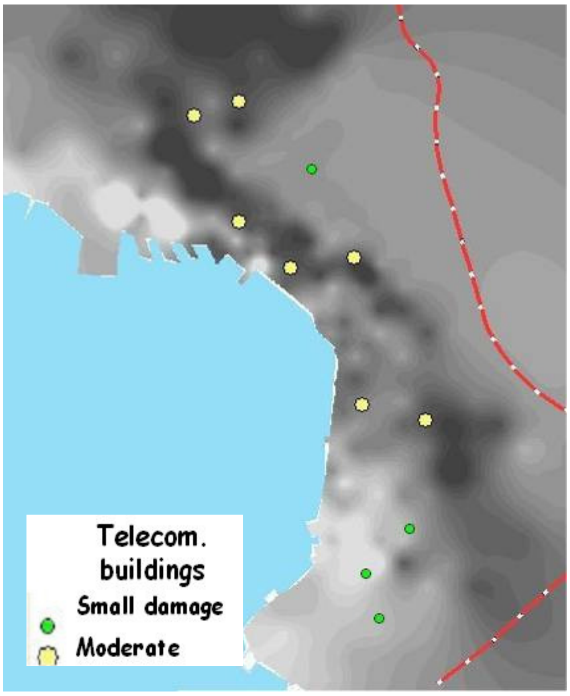


Fig. 6.15 Vulnerability assessment of Thessaloniki's CO's.

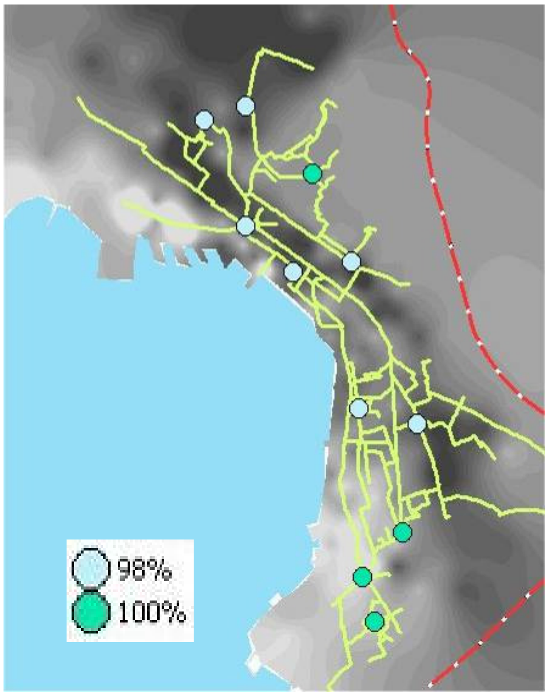


Fig. 6.16 Restoration progress (3day).

Potable water system

The water connections in urban area of Thessaloniki are about 420.000 (99% common customers), while the served population is 1.000.000people. The needs for water consumption are about 250.000m^3/day. About 300km is the transmission system, 71km is pressure pipes and 1.284km is the length of the distribution system. The pressure in the internal network varies between 2-5bar. The water is stored inside the town in 12 tanks and in the urban area that includes the industrial zone in other 8 tanks.

In the frame of RISK-UE project about 1351 km of pipes were digitized from paper maps (fig. 6.17). It is worth mentioning that important information such as material, diameters and ages of water pipes is missing in many cases. It can be noticed that about 42.5% of pipes have unknown diameter and large areas have pipes of unknown construction date and materials (fig. 6.17).

Following the methodology developed in WP03, three elements at risk of water system (pipes, tanks and pumping stations) were analyzed. Four indicators were selected for pipes (function, emergency-existence of SCADA, connection with fire-fighting system, radiance), four for tanks (function, emergency, alternative solution, radiance) and four for pumping stations (function, emergency, intervention capability, radiance) for the three periods (normal, crisis, recovery). In fig. 6.18 is presented an example of the classification of the water system in normal period.

In order to accomplish a reliable approximation of the existing network, logical assumptions based on engineering judgment were made with the cooperation of Water Company experts. Based on the methodology proposed in WP06 handbook, ALA 2001 relationships were used in order to calculate the vulnerability of water pipes. As more than

60% of pipe materials in Thessaloniki are asbestos-cement (AC), and the average age of water network is 50 years, ALA 2001 relation gives realistic results. The potable water system is exposed in transient motion (wave propagation) and permanent ground displacements along the coastal area due to liquefaction (see WP02) -lateral spreading and ground settlements. Table 6.4 presents the predicted Repair Rate/km for the seismic scenario anticipated (10% exceedance in 50years) using RISK-UE methodology (WP02, WP06). Figure 6.19 illustrates the estimated damages, while fig. 6.20 specifies the location of breaks and leaks.

Table 6.4 Estimated Repair Ratio/km for the water system in Thessaloniki.

ALA, 2001	*RR/ km*	*Number of repairs*	*Leaks*	*Breaks*
Wave propagation	0.051	68	54	14
PGD	0.054	73	15	58
Total		**141**	**69**	**72**

According to RISK-UE methodology, for the case of water system of Thessaloniki, it is expected to have 69 breaks and 72 leaks. Taking into account the total length of the water system (1351.198km) and the number of breaks, the average Repair Ratio is calculated as $RR_{average}$/km = 72/ 1351.20= 0.053. A rough estimation of water system serviceability just after the earthquake, according to different approaches, is given in table 6.5.

Table 6. 5 Serviceability of water system in Thessaloniki

Post- earthquake system performance	*Serviceability index (%)*
Isoyama & Katayama (upper limit)	85%
Isoyama & Katayama (lower limit)	55%
AWSS (average)	65%
NIBS	80%

Assuming that the total number of available workers in the time of earthquake for Water Company is 40 for the study area, then six (6) days are needed to restore the functionality of water system. The necessity to provide service just after earthquake to critical facilities and minimize the economical loss for Water Company and urban community require the well-organized post-earthquake actions. The restoration policy should be based on the combination of urban system exposure in crisis period and on the vulnerability of water system. Seismic retrofit priorities were identified for the digitized network (Table 6.6). Figure 6.21 presents the retrofit priorities for water pipes combining the results derived from the application of WP06 and WP03.

Table 6. 6 Risk analysis matrix showing seismic retrofit priorities.

Urban Risk/ Seismic Risk	Issues		
	Main	Important	Secondary
Breaks	1st priority	1st priority	2nd priority
Leaks	2nd priority	3rd priority	3rd priority

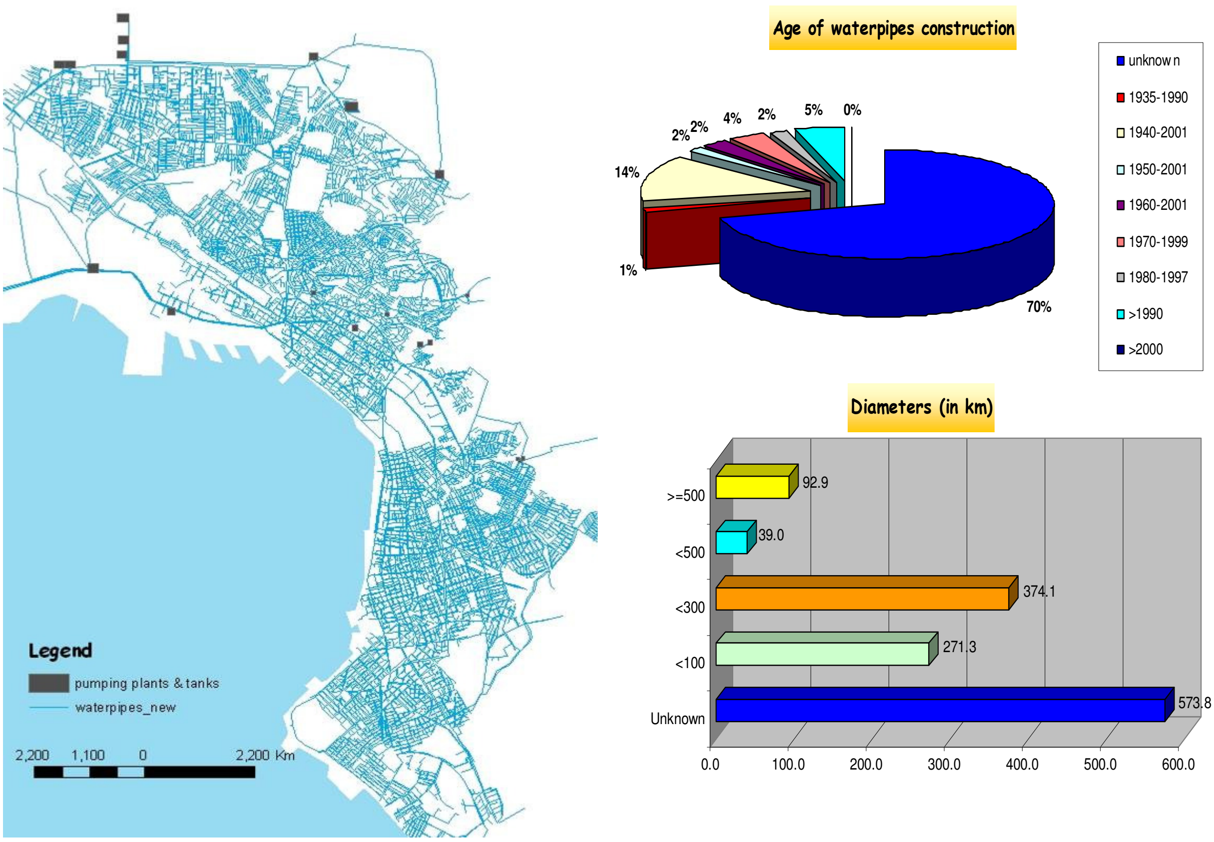


Fig. 6.17 GIS map with the digitized water system in Thessaloniki.

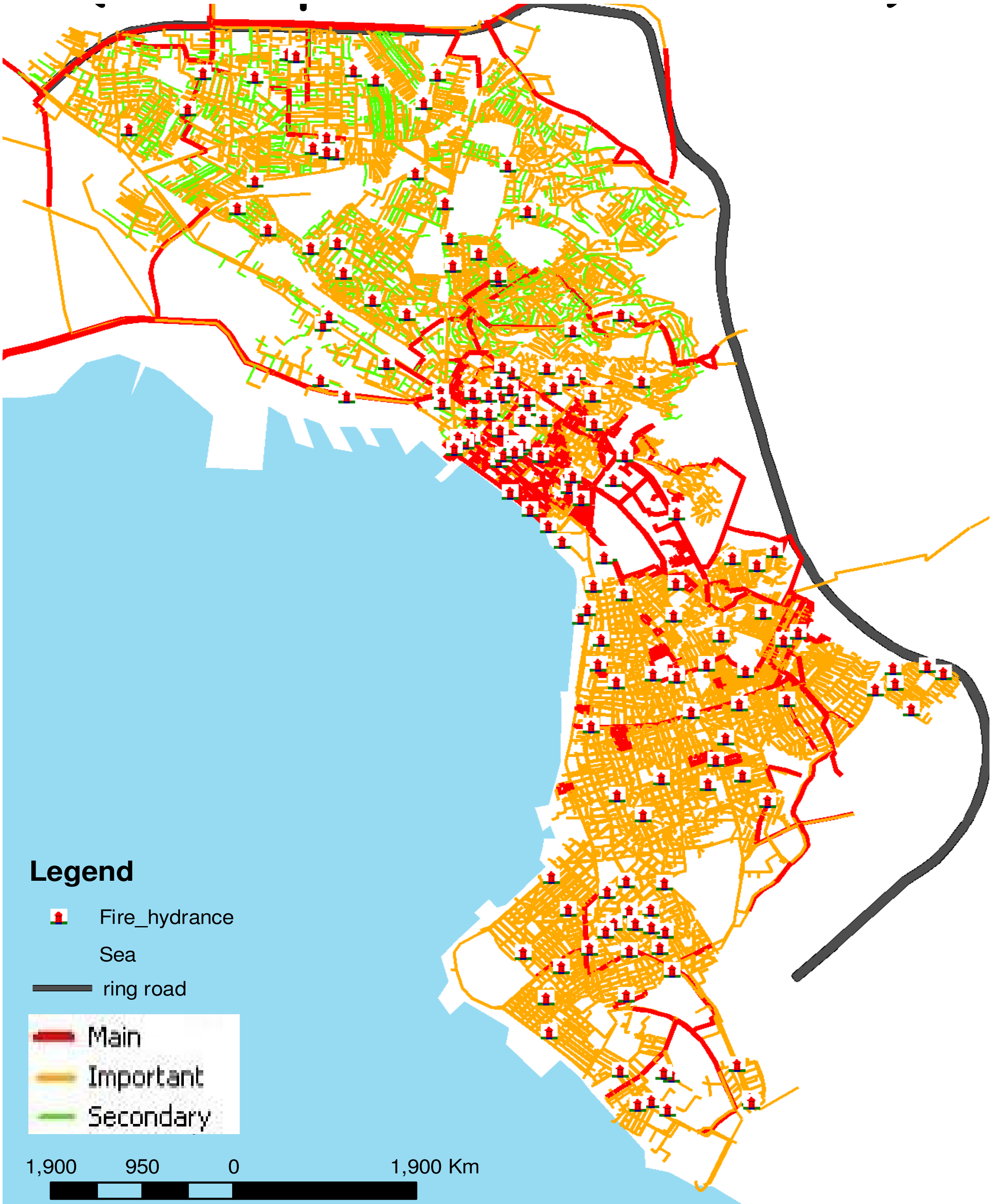


Fig. 6.18 Classification of importance of water system elements in normal period.

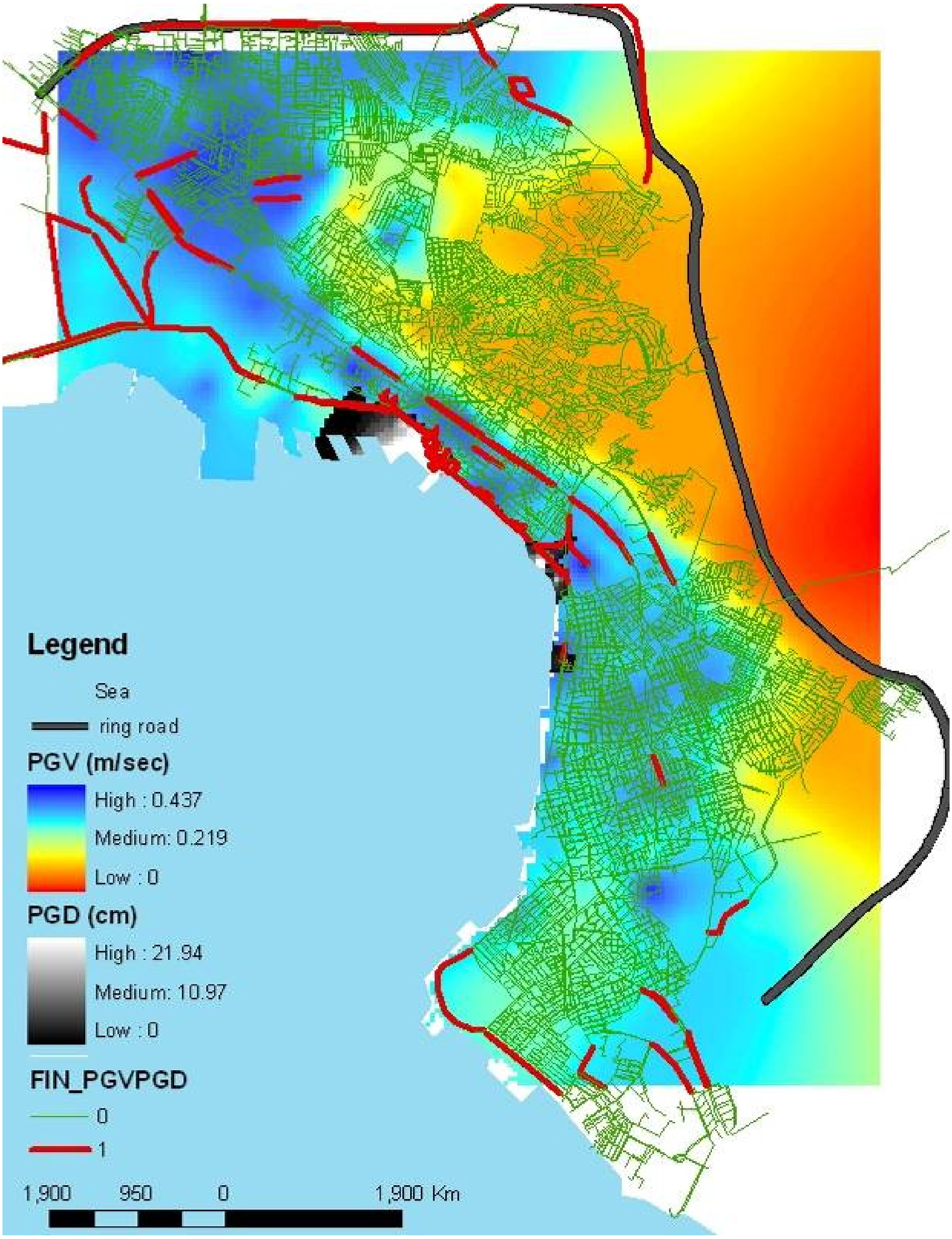


Fig. 6.19 Estimated damages of water pipes due to wave propagation and PGD.

Fig. 6.20 Location of breaks and leaks in the water network of Thessaloniki.

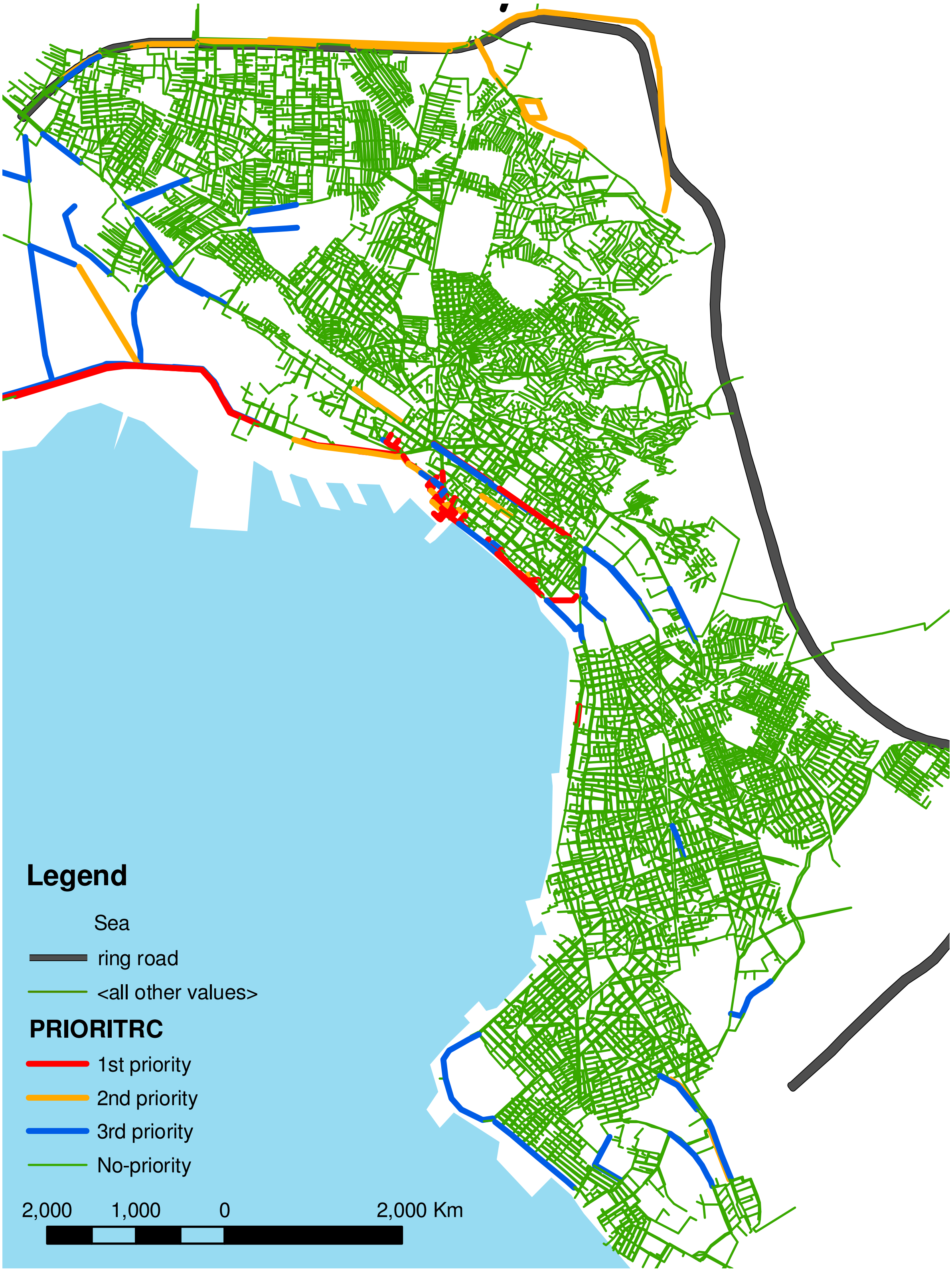


Fig. 6.21 Retrofitting priorities of the water network in Thessaloniki.

Wastewater system

Thessaloniki's waste-water system includes a network of rain-storm water, mixed water and waste disposals. The major part of the system includes gravity pipes with an exception of the pressure pipes that start from the pumping stations in the coastline of Thessaloniki to the Central Sewage Tunnel (CST or KKA). Six pumping stations were constructed in coastal zone of Thessaloniki that boosts the waste-water to CST. In the cross-connection between waste-pressure pipes and CST there are 18 manholes. The waste disposals, depending upon the area of gathering, are leading into two wastewater treatment plants. The waste disposals of central and west districts are gathered in the larger of the two treatment plants with a daily flow of $160{\cdot}10^3$ to $180{\cdot}10^3$ m^3. The rest disposals from the east areas are leaded to the second plant with a rate of 29.000m^3/day. Nowadays, the size of served area is 80km^2 and the waste-water pipes length is about 1.250km.

In the framework of RISK-UE project, the waste-water system in the greater part of urban area of Thessaloniki was digitized from paper maps. More specific, it was made an effort to digitize gravity pipes (storm, mixed and waste-water), pressure pipes and a part of CST (fig. 6.22). It should be noticed that gravity pipes can't be considered as a network due to the inexistence of connection with each other, mainly because of the lack of data (even the location may be unknown). Information like material, diameters and age are missing in many cases as well.

Following the methodology developed in WP03, two elements at risk of waste- water system (pipes and pumping stations) were analyzed in order to classify the importance. Four indicators were selected for pipes (function, emergency-existence of SCADA, environmental pollution and radiance) and four for pumping stations (function, emergency, intervention capability and radiance) for the three periods (normal, crisis and recovery). The identification of urban importance was limited to waste-water pipes in the central part of Thessaloniki municipality where the network had a basic connection, to pressure pipes and to Central Sewage Tunnel. The results are illustrated in the fig. 6.22 below for crisis period. Similar maps were produced for the other two periods in GIS format as well.

Using the methodology proposed in WP06 handbook and the results of Microzonation study of Thessaloniki (WP02) an assessment of the vulnerability of the primary network (CST, pressure pipes) and the secondary gravity pipes in the central part of Thessaloniki was performed. The calculation of restoration process is in progress.

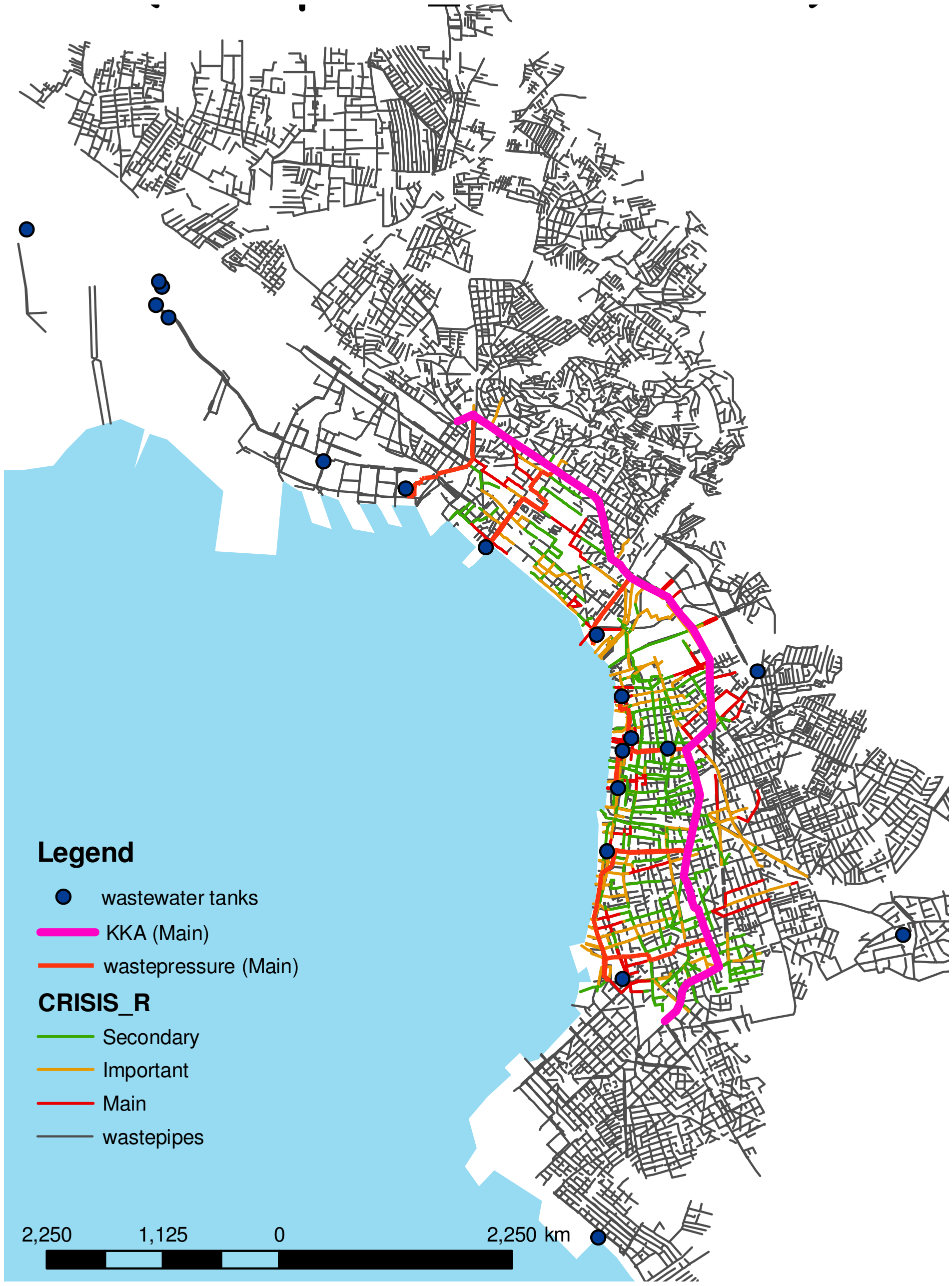


Fig. 6.22 GIS map illustrating the digitized waste- water network in Thessaloniki and the classification for crisis period.

7. Earthquake risk scenarios

According to the methodology of WP07, the debris and casualties are estimated for the selected earthquake scenario and for both level I and II approaches. The estimation is based on the probabilities of damage states for buildings that represent half of the building stock of the study area, as it was previously described in this report. Hence the results are not referred to the entire area of Thessaloniki. Indicative figures and maps are presented below corresponding to the level I approach.

Debris

In the framework of development of the earthquake risk scenario in Thessaloniki, the two different types of debris were estimated based on the empirical approach that is proposed in WP07. In tables 7.1, 7.2 are presented the assumed fractions of weight of the two types of debris for each model building type and each structural damage state. In table 7.3 is presented the expected debris fraction in unit weight of the two types of debris due to structural damage for each model building type. The total amount of expected debris is shown in table 7.4.

Table 7.1 Reinforced concrete and wrecked steel generated from damaged structural elements (in fraction of weight)

Building Typology	*Structural Damage State*			
	Slight	*Moderate*	*Extensive*	*Complete*
Masonry (all)	0	0.02	0.25	1
RC1 (frames bare)	0	0.05	0.33	1
RC3.1, RC3.2 (frames inf, pil)	0	0.04	0.32	1
RC4 (duals)	0.02	0.10	0.35	1

Table 7.2 Brick, wood, and other debris generated from damaged structural elements (in fraction of weight)

Building Typology	*Structural Damage State*			
	Slight	*Moderate*	*Extensive*	*Complete*
Masonry (all)	0.05	0.25	0.55	1
RC1 (frames bare)	0	0	0	1
RC3.1, RC3.2 (frames inf, pil)	0.05	0.25	0.60	1
RC4 (duals bare)	0	0	0	1
RC4.1, RC4.2 (duals inf, pil)	0.05	0.25	0.60	1

Table 7.3 Unit Weight (tons per 1000 m^2) for structural elements as building debris

Building Typology	*Brick, Wood and Other*	*Reinforced Concrete and Steel*
Masonry (all)	380	450
RC1 (frames bare)	0	1055
RC3.1, RC3.2 (frames inf, pil)	215	969
RC4 (duals bare)	0	1206
RC4.1, RC4.2 (duals inf, pil)	215	1119

Table 7.4 Estimated debris of the study area (in tons)

Debris (tons)		
	Reinforced Concrete and Steel	Brick, wood and other
Level I	1.332.670	426.883
Level II	904.054	189.081

The estimation of debris is based on empirical data from USA (HAZUS'99), which certainly may not be adequate for European building typology. The predicted quantity seems to be overestimated.

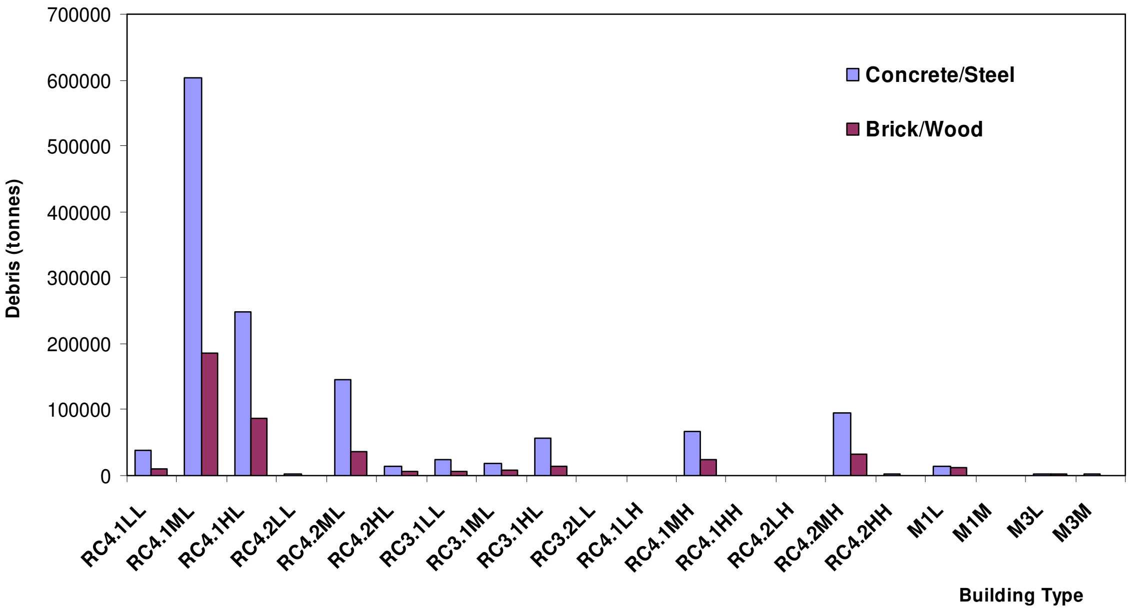


Fig 7.1 Graph showing the distribution of debris per building type.

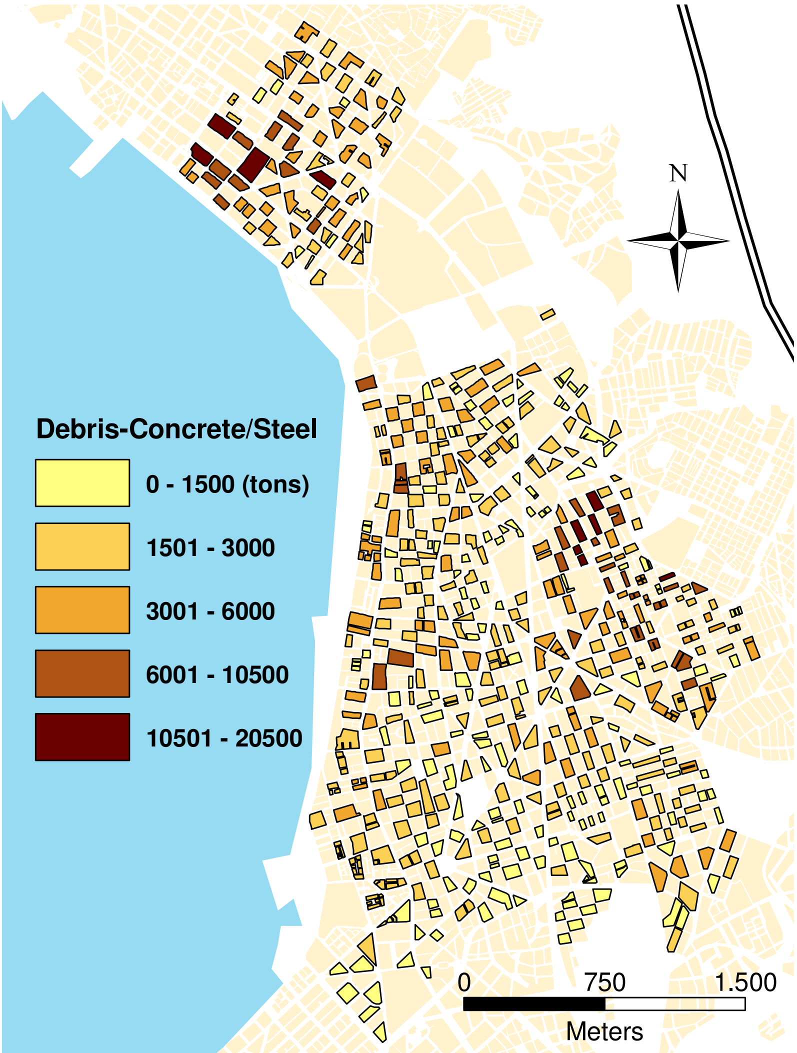


Fig. 7.2 Distribution of debris in tons (reinforced concrete and wrecked steel) for the study area.

Casualties

According to the methodology of WP07, the number of casualties due to collapse of buildings is expressed as: Ks = C x [M1 x M2 x M3 x (M4 + M5 x (1 - M4))]
where,

- *C* is obtained multiplying the floor area of each building type in the study area by the corresponding complete damage state probability,
- *M1* is the occupancy rate (number of people/built m^2) and an average value for the study area of Thessaloniki is assumed to be 0.025. A more detailed application should take into account the range of this rate according to the land use, the built density, the value of land and other urban parameters.
- *M2* is the occupancy at time of earthquake and is considered that the earthquake strikes at 12.00 or 24.00. As the study area has mixed land uses it is assumed that the 80% is referring to residential and the 20% to non-residential buildings. Thus the values of M2 are 0.52 and 0.65 respectively.

- *M3* represents the percentage of occupants trapped by collapse and is assumed to be 0.30.
- *M4* gives the injury distribution at collapse according to Table 7.5.

Table 7.5 Factor M4: injury distribution at collapse.

Triage injury category	*Low strength masonry*	*RC*
Dead or unsavable	0.1	0.4
Life threatening cases needing immediate medical attention	0.2	0.1
Injury requiring hospital treatment	0.3	0.4
Light injury not necessitating hospitalization	0.4	0.1

- *M5* represents the mortality post-collapse and for Thessaloniki is assumed to be 0.45 for masonry and 0.70 for RC buildings. The Greek community is considered to be capable of organizing rescue activities, especially after the experience gained from major earthquakes in the last decades.

The number of human casualties in the study area of Thessaloniki is shown in table 7.6, and in figures 7.3 and 7.4.

Table 7.6 Breakdown of casualties.

	Level I		*Level II*	
Time of earthquake	*12:00*	*24:00*	*12:00*	*24:00*
Dead or unsavable	246	360	216	291
Life threatening cases needing immediate medical attention	216	310	210	287
Injury requiring hospital treatment	261	371	241	323
Light injury not necessitating hospitalization	234	319	237	323

The estimated number of casualties corresponds to approximately 284 (level I) or 308 (level II) collapsed (and non-repairable) buildings as it was derived from the application of the vulnerability assessment methodology of current buildings (WP04) to the study area. However, the proposed in WP07 casualty model may not be the most adequate for European construction practice. The experience from past earthquakes in Greece reveals that the number of death rate is quite low compared to other countries for the same seismic magnitude. Therefore, the estimated casualties in the frame of this project are probably overestimated, due to many reasons partially discussed previously (i.e. seismic hazard assessment, methods for vulnerability analysis etc). However, accepting that the estimated hazard, vulnerability and damage states analysis conducted previously are the best that could be done in practice with the existing know-how, we may consider that the parameters used in the estimation of casualties are probably not very appropriate for Greece, where the seismic design and construction practice seem to be of rather good quality. Further research is needed in order to take into account the special characteristics of European typology and construction practice including pre-seismic and post earthquake organization.

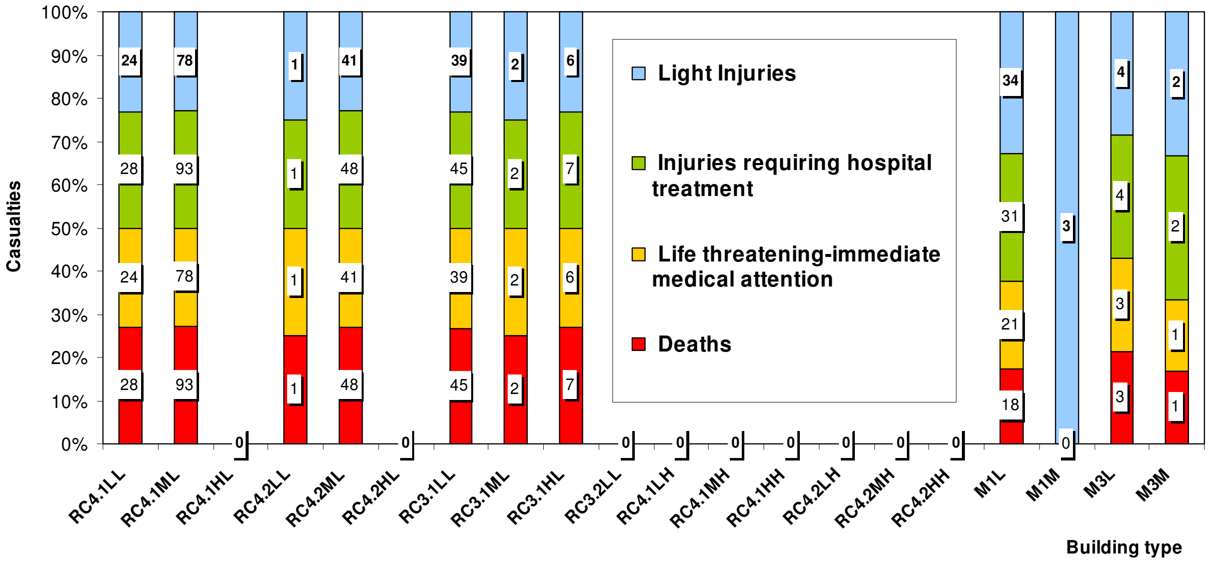


Fig. 7.3 Distribution of casualties per building type (at 12.00h).

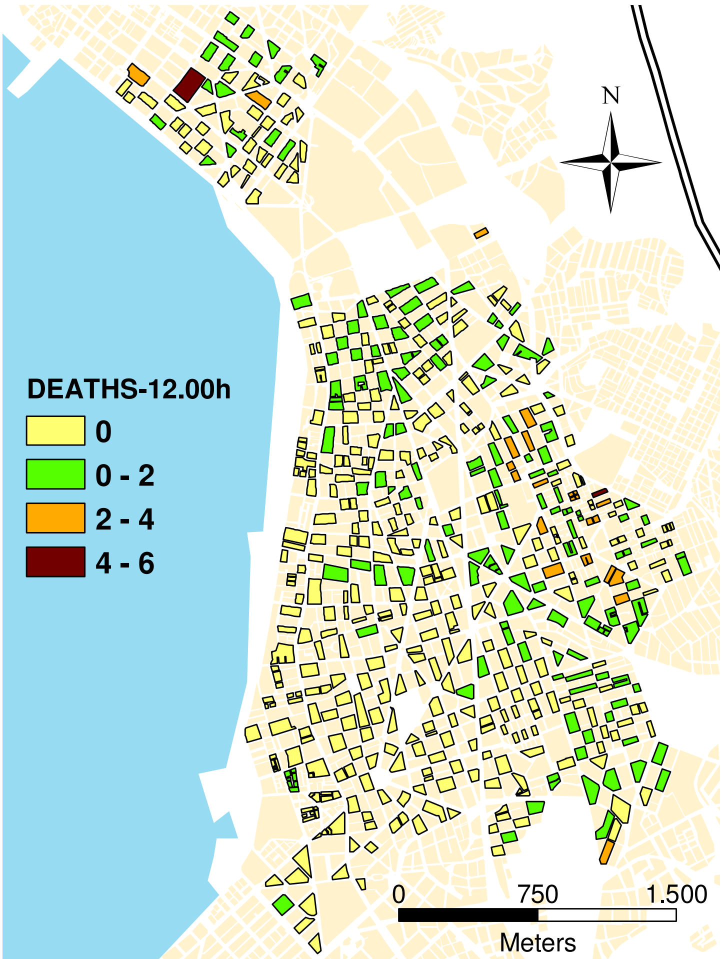


Fig. 7.4 GIS map showing the distribution of death casualties in the study area for the level I approach (at 12.00h).

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