The Role of Soil and Site Conditions in the Vulnerability and Risk Assessment of Lifelines and Infrastructures. The Case of Thessaloniki (Greece).

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THE ROLE OF SOIL AND SITE CONDITIONS IN THE VULNERABILITY AND RISK ASSESSMENT OF LIFELINES AND INFRASTRUCTURES. THE CASE OF THESSALONIKI (GREECE)

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ABSTRACT

Soil conditions and site effects play an important role in the vulnerability assessment of lifelines and infrastructures under strong seismic excitation. Due to the spatial extent of these networks, they are subjected to non-uniform and incoherent ground motion as a result of the variability of soil and geological conditions; consequently their vulnerability assessment depends entirely on the variability of soil conditions and ground motion, known as site effects, for a given seismic scenario. Fragility functions for the exposed elements at risk, composing the different lifelines and infrastructure systems, play an equally important role. The paper presents some selected results of a recent application of a comprehensive methodology assessing the vulnerability of several lifeline systems in Thessaloniki in Greece. The work is part of a large research program, aiming to the development of a general methodology for the assessment of the seismic risk for the building stock, lifeline systems and infrastructures at urban scale. Key factors of the methodology are the inventory, the typology, the specific characteristics and the importance (global value) of the elements at risk, the development of seismic scenarios (seismic hazard) and the geotechnical characterization, with the detailed site response analysis. The methodology and the role of soil and site conditions are highlighted with representative examples of the application in Thessaloniki.

INTRODUCTION

Modern societies are relied on complex networks of lifelines, utilities and infrastructures. They are the basic installations and facilities on which the continuance and growth of a community depends. The uncertainties due to the spatial variability of the networks, the incomplete inventory data, the lack of well-validated damage data from past strong earthquakes and the uniform definition of damage states makes the vulnerability assessment of each particular component and of the network as a whole, a very difficult task.

Herein, a methodology for the seismic risk analysis of infrastructures is presented based on a detailed site response analysis with an application to Thessaloniki's Metropolitan area. The significant role of a well-documented study of the seismicity, surface geology, topography, local soil conditions and characteristics, is reflecting in the reliable estimation of the ground motion.

Furthermore, adequate loss scenarios are generated taking into consideration the individual characteristics of the elements at risk, the typology and the vulnerability, as well as the seismic hazard, geotechnical characterization and site response of the main soil formations for different seismic scenarios. Moreover, taking into account the functional and social vulnerability of lifeline elements through a global value analysis, lifeline networks can be analyzed as an integrated part of the selected seismic risk scenario and as a part of the urban system, considering human, material and immaterial assets. Thus, a prioritization of pre-earthquake retrofitting actions and quantification of the overall importance of different complex and coupled lifeline systems could be performed. Representative examples are given for different steps of the risk analysis.

The work reported in the paper is part of the national research project SRM-LIFE (2003-2007) in which several partners from University, public authorities, local municipalities and organizations managing/owning lifelines were participated.

METHODOLOGY

The general framework of the methodology developed for the vulnerability assessment and seismic risk management of utility networks (potable water, waste-water, gas, electric power, telecommunication, fire-fighting), transportation systems (roadway, railway, airport, port) and critical facilities is illustrated in Fig. 1. Loss estimates including direct and indirect losses, depend on the existing inventory and typology classification of the elements at risk, the vulnerability models and the existing interactions between lifeline components. Inventory is an essential step to identify, characterize and classify all types of lifeline elements according to their specific typology and their distinctive geometric, structural and functional features. Geographical information systems (GIS) offer the perfect platform to implement any inventory inquires. Within this context, earthquake damage is directly related to structural properties of lifeline elements. Typology is thus a fundamental descriptor of a system, derived from the inventory of each element at risk. The level of seismic input motion is defined on the basis of site specific ground response analysis for several probabilities of exceedance. Selection of input motion parameters (i.e. spectral values) estimated from seismic codes prescriptions is a wrong procedure for reasons that are explained throughout this paper. The vulnerability assessment deals mainly with the quantification of damage of each element at risk, using appropriate fragility functions. Furthermore, a "global value analysis" of the elements at risk is proposed, taking into account different criteria such as the functional relations between them and the urban activities and relations of lifelines with the surrounding urban or rural environment. "Global value analysis" aims to the definition of lifeline's importance and role in the urban environment in three periods of urban functioning (normal, crisis, recovery) in respect to the occurrence of an earthquake event. Combining the vulnerability assessment with the importance of different elements in pre and post seismic periods, a rigorous disaster management process including mitigation, preparedness, response and recovery actions could be assigned. An important step for the implementation of an "efficient mitigation strategy" includes a simplified or a more advanced reliability analysis of the damaged and the undamaged system in order to estimate the level of the remaining serviceability of the system which is closely connected with the functionality of the community.

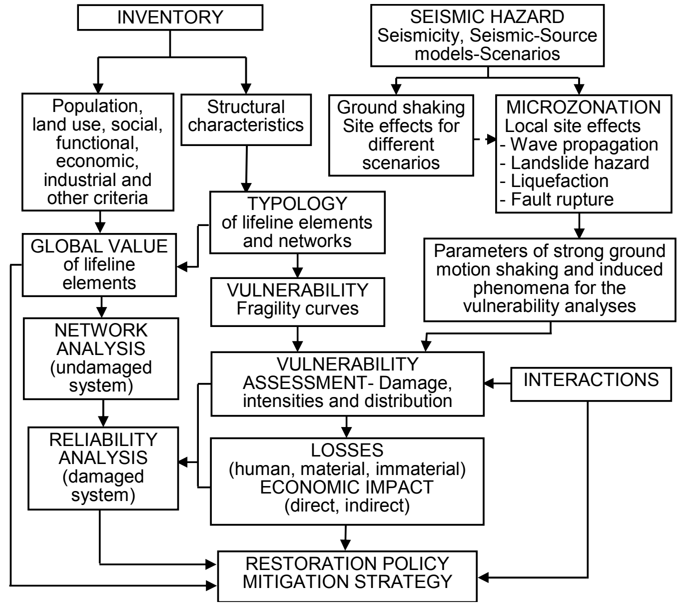

Fig. 1. Flowchart of the methodology (Pitilakis et al. 2005).

SEISMIC SCENARIOS – SITE SPECIFIC GROUND RESPONSE ANALYSIS

Seismic hazard for the vulnerability analysis and risk assessment of lifelines, utilities and infrastructures, should be specified according to the precise needs for the particular lifeline components and networks, as well as the most adequate models used to describe vulnerability and fragility relationships. Moreover due to the spatial extent of lifeline systems, spatial variability of ground motion considering the local soil conditions is of great importance (Pitilakis et al. 2005).

Specific geotechnical-surface geology information is required, and adequate studies should be performed to estimate the necessary ground shaking parameters, in terms of seismic scenarios with different mean return periods. These studies are conventionally referred as "microzonation studies". In Thessaloniki, a detailed microzonation study has been conducted for three different mean return periods of approximately Tm=100, 475 and 1000 years. The study is based on the results of a probabilistic seismic hazard analysis using recent data regarding the seismicity, the corresponding seismic zones and the seismic faults in the greater area (RISKUE, 2001-2004, SRMLIFE, 2003-2007). A detailed model of the surface geology and geotechnical characteristics, for site effect studies, was generated for the city of Thessaloniki. The resulted geotechnical map (Anastasiadis et al. 2001) was based on numerous data provided by geotechnical investigations, geophysical surveys, microtremors measurements, classical geotechnical and special soil dynamic tests (Pitilakis et al. 1992, Pitilakis and Anastasiadis 1998, Raptakis et al. 1994a, Raptakis et al. 1994b, Raptakis 1995, Apostolidis et al. 2004). The dynamic properties of the main soil formations have been defined from an extended laboratory testing including resonant column and cyclic triaxial tests (Pitilakis et al. 1992, Pitilakis and Anastasiadis 1998, Anastasiadis 1994).

Site effects are calculated performing a great number of 1D linear equivalent response analyses, and few 2D analysis in selected cross sections, in order to take into account the influence of geotechnical characteristics and dynamic properties of the main soil formations, on expected seismic ground motion. The analysis is conducted for five different scaled real accelerograms (for bed rock motions), which were selected according to the seismic hazard study, for three scenarios (mean recurrence period of 100, 475 and 1000 years) (Papaioannou 2004).

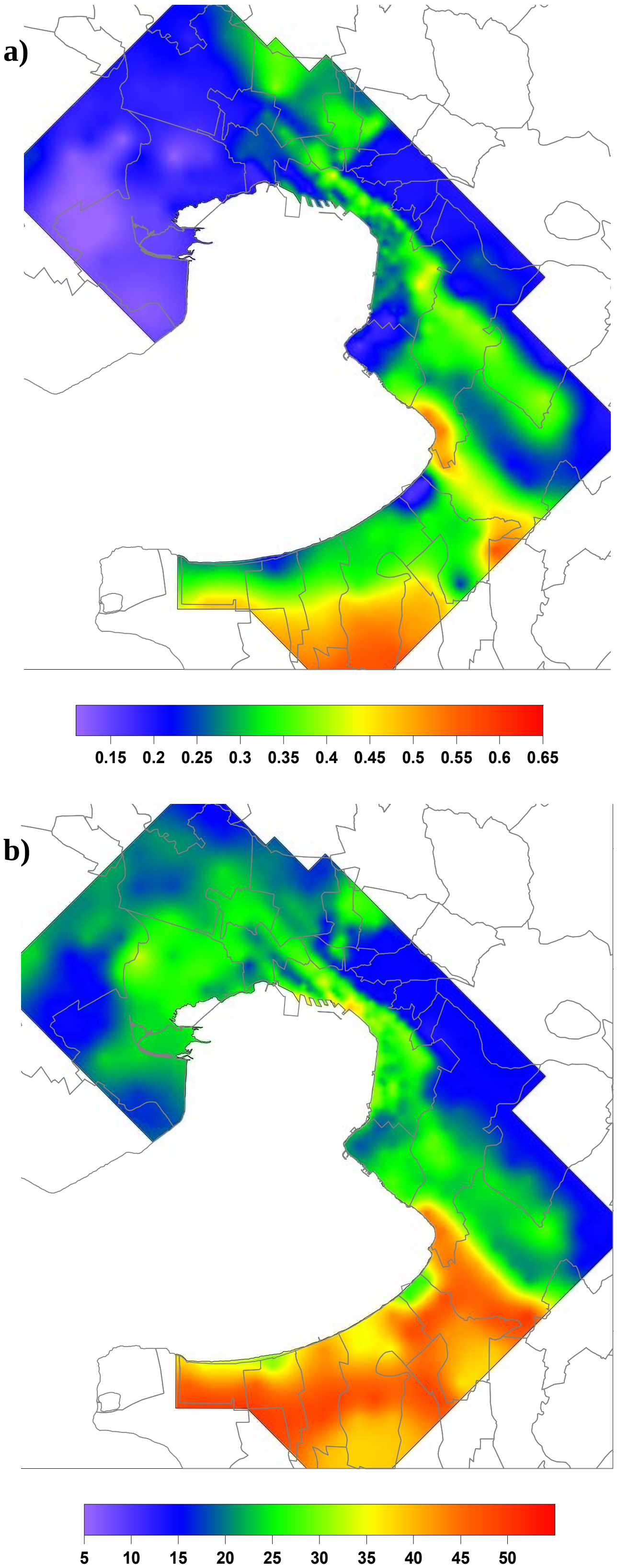

Fig. 2. Distribution of mean peak ground acceleration (PGA: g's) (a) and mean peak ground velocity (PGV: cm/s) (b) obtained by 1D (EQL) analytical approach for the 475 years seismic scenario.

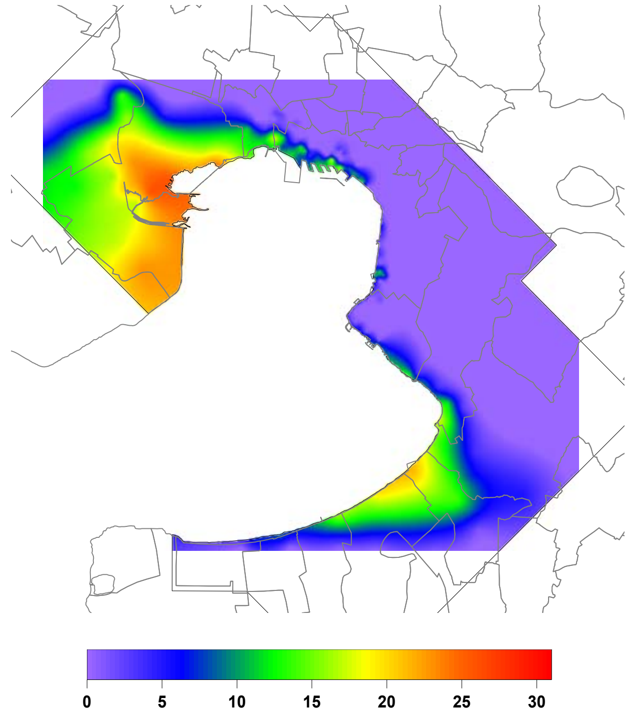

Fig. 3. Distribution of the mean values of "peak" permanent ground settlements due to liquefaction - Δv(cm) for the 475 years seismic scenario.

Advanced seismic risk analysis study requires maps with the spatial distribution of strong motion parameters (e.g. PGA, PGV, PGD) in the study area. As an example, the characteristics of the calculated seismic ground motions at the free surface, in terms of peak acceleration (PGA) and velocity (PGV) are presented in Fig. 2 for the earthquake scenario with 10% probability of exceedance in 50 years (mean return period of 475 years). Similar maps have been generated for all seismic scenarios, and for several other ground motion parameters (i.e. ground strains, response spectra, etc).

Finally, in order to account for the liquefaction-induced phenomena, the evaluation of permanent ground horizontal and vertical displacements, (lateral spreading and settlements), has been performed for the three scenarios using empirical and analytical procedures (Seed et al. 2003, Youd et al. 2001, EC8, Ishihara and Yoshimine 1992, Elgamal et al. 2001). Figure 3 illustrates the spatial distribution of permanent ground settlements for the 475 years scenario.

PGA values are varying from 0.15g to 0.55g while, if the whole analysis was based on the Hellenic seismic code, the design PGA should be equal only to 0.16g! Site effects play a crucial role and, with respect to the spatial variability and typology of various assets, their spatial variability may change completely the intensity and spatial variability of damages and losses. The simple use of seismic code soil classification schemes, and associated design acceleration values, is completely inadequate for a "high technology" vulnerability analysis and risk assessment.

VULNERABILITY ASSESSMENT AND LOSS SCENARIOS

A fundamental requirement for assessing the seismic performance of a system is the ability to quantify correctly the damages related to the level of seismic hazard intensity, and of course the typology of each component and system. In general, vulnerability functions, are deterministic, statistical or probabilistic relationships between the component's damage state, functionality, economic losses etc, and an appropriate measure of the intensity of the earthquake hazard. Besides the great inherent uncertainties, the key assumption in the vulnerability assessment of lifeline and utility systems, is that structures having similar structural characteristics, being in similar geotechnical conditions, are expected to perform in the same way for a given seismic loading (source and path effects are excluded). Thus, the respective fragility functions should be defined on the basis of the typological characteristics of the elements at risk, taking also into consideration specific construction practices and distinctive features affecting their seismic behavior.

In Thessaloniki, the assessment of potential earthquake losses is performed for utility systems (potable water, fire-fighting, waste-water, gas, telecommunication, electric power) and transportation systems (roadways, railways, airport, port), as well as for other critical facilities (hospitals, schools), based on the results from the detailed microzonation study, for the three selected scenarios with mean return periods Tm=100, 475 and 1000 years. Thus, these loss scenarios are constructed on the basis of site specific seismic hazard analysis using available inventory data and adequate fragility curves. In the following some representative examples of vulnerability assessment are given for water, road and port systems.

Potable water system

Thessaloniki's principle potable water system is comprised of about 1351 km of pipes. The current inventory database includes several attributes such as location, diameter, material, age, operating area, supplied tank, type, depth, length, joint type and history of failures, where these data are available. The vulnerability assessment of potable water pipes is based on the estimation of the expected Repair Rate per pipe km (RR/km). Expected damages (leaks and/or breaks) caused by wave propagation are estimated using O' Rourke and Ayala (1993) fragility relation proposed by HAZUS (NIBS 2004), where the seismic loading is described in terms of peak ground velocity (PGV). The expected damages due to ground failure, expressed in terms of ground settlements, are assessed based on the Honegger and Eguchi (1992) fragility relation. Prior to their application in Thessaloniki, these empirical vulnerability functions have been validated with well documented data, from recent earthquakes in Lefkas-Greece, 2003, and in Düzce-Turkey, 1999 (Alexoudi 2005). Appropriate fragility curves for tanks and pumping stations are also selected from HAZUS (NIBS 2004), after adequate elaboration of the structural characteristics of the exposed elements and Greek practice. Figure 4 presents the spatial distribution and the intensity of the estimated damages for the 475 years scenario. The number, the intensity and the location of the damages are related to the spatial distribution of seismic ground motion for the specific scenario, and the individual characteristics of the examined elements.

About 1.4% of the potable water system of Thessaloniki is anticipated to experience leaks and about 4.1% breaks for the 475 years scenario. A total number of 79 leaks and 224 breaks are expected in the principle water pipeline network. Two (2) of the total forty-three (43) water tanks, are estimated to have moderate or extensive damages for the above scenario. A significant number of water pumping stations, about 82%, is expected to present small to moderate damages. The rest 18% of the pumping stations will experience extensive failures that can lead to malfunction, and in some cases even in loss of water serviceability in major areas of the city. It must be mentioned that the majority of the anticipated damages in water pipes across the coastline are attributed to the occurrence of liquefaction induced phenomena (settlements). For the pumping stations and tanks, damages are attributed to the specific ground motion characteristics related to local soil conditions.

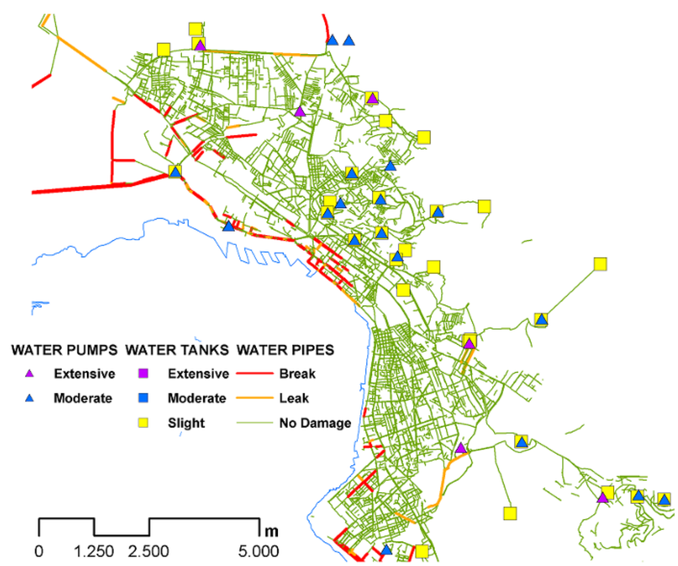

Fig. 4. Vulnerability assessment and damage distribution of Thessaloniki's water system (Tm=475 years)

Roadway system

The inventory for the roadway network in the metropolitan area of Thessaloniki includes about 600 km of road-lines and 80 bridges. The roadway system is rather insufficient, especially in the centre, where the densely built up area creates a complex network, with narrow streets and inadequate parking areas. Roads are classified in freeways, major and secondary arterials, primary and secondary collectives, based on their geometry and functional role in the network. The majority of bridges are in the ring road and the main exits of the city. Their classification is based on the number of spans (single or multiple), the design seismic code level (low or upgraded), the pier type (single or multiple columns) and the span continuity (continuous or simple support). The vulnerability analysis of the network includes the estimation of direct losses such as bridge and road damage due to ground shaking or ground failure, and indirect such as street blockades, due to debris of collapsed buildings.

The expected level of damages for bridges is assessed based on the fragility curves that are provided in HAZUS (NIBS 2004), for the input earthquake hazard scenario and the estimated mean spectral acceleration at T=1.0sec. The estimated damage state for each bridge for the 475 years seismic scenario, is presented in Fig. 5. The majority of bridges will respond in a satisfactory way, but there are still few bridges, which are expected to sustain serious damage for the specific seismic hazard scenario. This is due to the higher vulnerability of these bridges (single column, simple support bridges and inadequate seismic design), and the higher values of the expected surface spectral acceleration. The latter is attributed to the local soil conditions and the proximity of the seismic source (ex. southeast part). For instance, in the west part of the city, deep soft alluvium deposits of sandy-silty clays to clayey sands-silts, with low strength and high compressibility, (category C and D in EC8), present stronger amplification at longer periods.

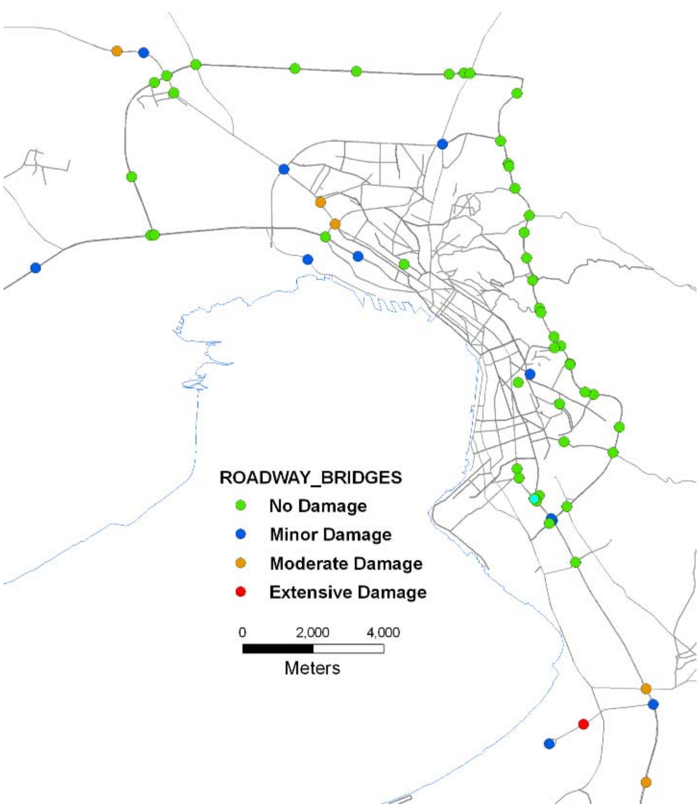

Fig. 5. Distribution of expected damages to roadway bridges of Thessaloniki for the 475 years seismic scenario.

For the functionality of roads just after the earthquake a correlation between the building's height (i.e. number of storeys) and the width of the induced debris is used, in order to estimate the impact of collapsed buildings. The spatial distribution of the collapsed or heavily damaged buildings is again depending on their typology and the site conditions. A Gaussian distribution describes the variation of the debris width, which is a function of the building collapse angle (ϕ) and the building volume reduction (kv) (Fig. 6). This model is used in order to estimate the exceedance probability of certain road function levels (100% open, 50% open, 0% closed or one lane open). The collapse probability of buildings is estimated based on appropriate fragility models which have been developed for the building types commonly presented in Thessaloniki, as a function of the peak ground acceleration (Kappos et al. 2006, Penelis et al. 2002).

Past experience in Greece reveals that a percentage of collapses ranging between 10 and 20% can have such form and amount of debris, which can result to road closure. The probability of closure due to building collapse is calculated based on the combination of the aforementioned probabilities for each road segment (node to node). Figure 7 illustrates the probability of closure for the main roads in the central city due to building collapses for the scenario with a mean return period 1000 years. The reduction of the road width depends on the distance from the buildings, the width of the road and the induced debris width, while the closure probabilities depends on the concentration of the most vulnerable building type, the length of the road segment and the discrete collapse probabilities related to the local site conditions.

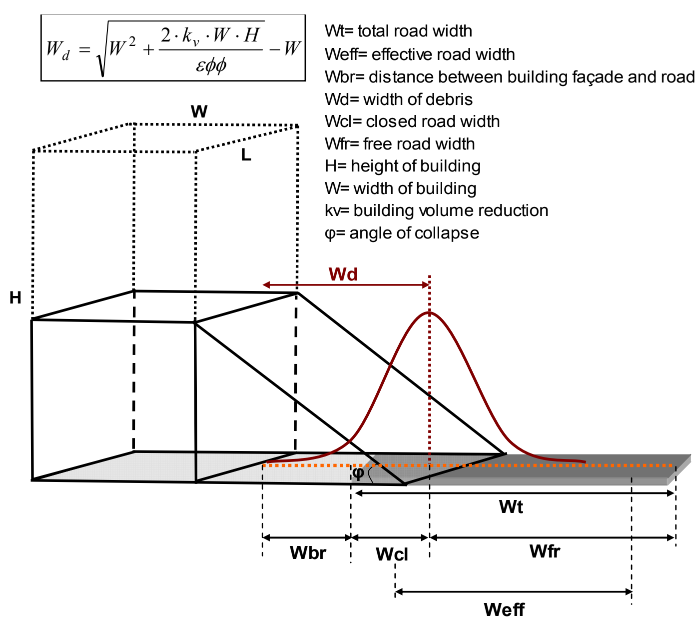

Fig. 6. Estimation of debris width and road closure.

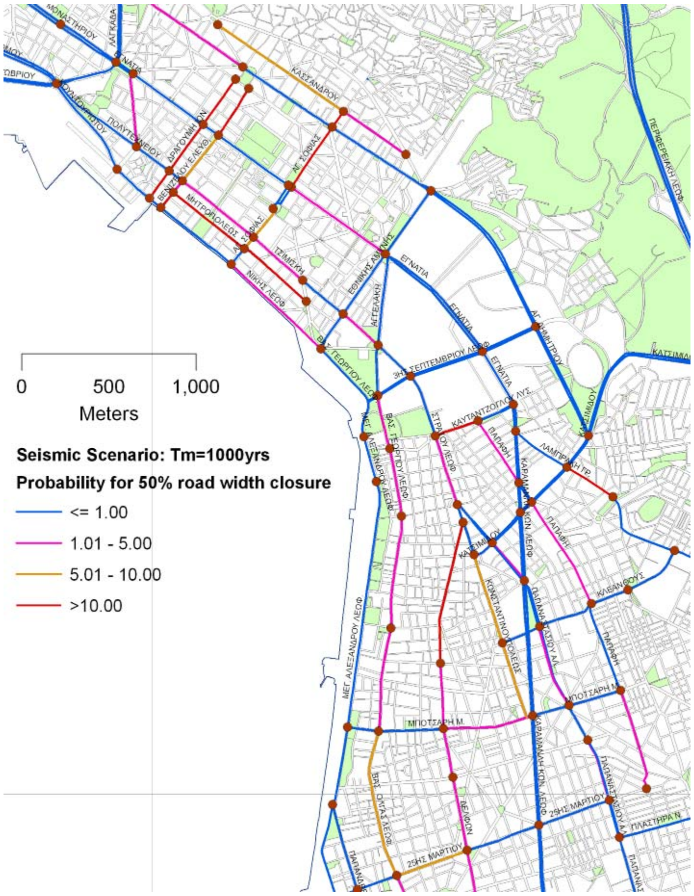

Fig. 7. Sample map with probabilities for 50% road width closure of the main road network due to building collapses for the 1000 years seismic scenario.

Port system

The Port of Thessaloniki 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 6,500m length. In collaboration with the port authority (Thessaloniki Port Authority, THPA), various data was collected and implemented in GIS format for the construction, typological and functional characteristics of the considered elements at risk, including cargo and handling equipment, waterfront structures, electric power (transmission and distribution lines, substations), potable and waste water (pipelines), telecommunication (lines and stations), railway (tracks) and roadway (roads and bridge) systems as well as buildings and critical facilities. The presence of all the above utilities and infrastructures in a limited area enables the complete application of the methodology for the seismic risk assessment of lifelines-infrastructures and the specification of possible weak or critical points for the operation of the whole system.

Loss assessment for a given seismic scenario refers to direct damages and indirect effects due to loss of functionality of lifeline components, networks and infrastructures inside port facilities. Indirect damages can be particularly important in complex systems such as port facilities. A representative example is the Port of Kobe (Japan) that suffered severe damage during the 1995 Great Hanshin earthquake; the port was essentially shut down and required over two years to fully repair. Indirect financial losses were profound due to the "permanent" loss of the diverted traffic during the reconstruction phase (Chang 2000).

Loss estimations are performed for the port facilities utility networks, transportation systems and buildings of Thessaloniki's Port based on the results of the site specific (microzonation) study for the three seismic scenarios (Tm= 100, 475 and 1000 years). The soil conditions are quite poor dominated by soft – loose alluvial deposits at great depth. In each particular system, adequate fragility curves and/or vulnerability relationships were used, based on the specific features and typology of the considered elements at risk. The type, extent and spatial distribution of induced earthquake damage were specified and illustrated in GIS thematic maps. In the following, some examples of the vulnerability assessment and estimated direct damages of port facilities (waterfront structures, cargo and handling equipment), potable water system, electric power system and building structures of Thessaloniki's port are provided for selected seismic scenarios.

Waterfront structures, cargo and handling equipment. The inventory developed for the waterfront structures includes several attributes such as name, location, operational depth (m), year of construction, equipment, material, type, foundation type, maintenance, damages in previous earthquakes and length (m). Empirical vulnerability functions for gravity waterfront structures (HAZUS, NIBS 2004), have been validated prior to their application, using data from recent European earthquakes (i.e. Lefkas, 2003, Kakderi et al. 2006). Ground shaking parameters and permanent ground displacement due to liquefaction are the input parameters describing the intensity of seismic hazard. For cranes and cargo handling equipment the available inventory data include their type, capacity (t), working range (m), year of construction, source, location, anchorage, type of cargo and energy, alternative energy sources, maintenance and damages in previous earthquakes.

Figure 8 presents the results of the vulnerability assessment (estimated worst probable damage state, i.e. exceeding probability >50%) for the waterfront structures and cargo handling equipment for the 475 years scenario. The majority of the waterfront structures (63%) is expected to remain practically undamaged for the referred seismic scenario, while the rest 37% will have only minor to slight damages. The damage states have been considered according to HAZUS (NIBS 2004). However, moderate level damages are expected for 42 out of the 49 elements of cargo handling equipment due to their sensibility in differential ground settlements. In both cases the anticipated damages are attributed mainly to the occurrence of liquefaction induced phenomena.

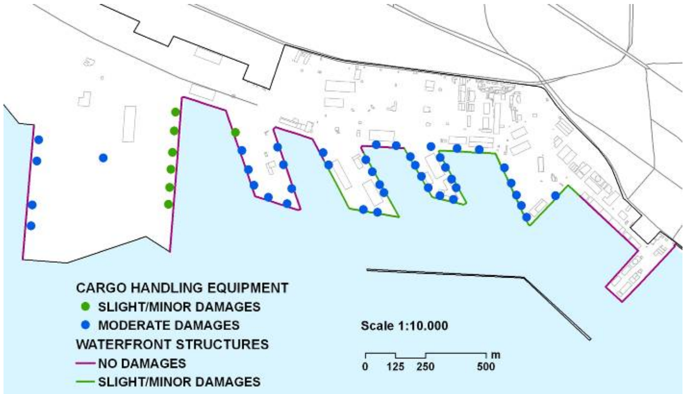

Fig.8. Distribution of damages to waterfront structures and cargo handling equipment of Thessaloniki's Port (Tm=475 years).

Utilities: Water and electric power supply systems. Figure 9 presents the spatial distribution and the intensity of estimated damages for the water supply network within the port area for the 1000 years scenario. Their number, intensity and location are related to the spatial distribution of seismic ground motion (velocity and strains), for the specific scenario as well as the individual characteristics of the examined elements. Also in this particular case, the occurrence of liquefaction induced phenomena is the determinant factor of the pipelines' anticipated seismic performance, in all three seismic scenarios.

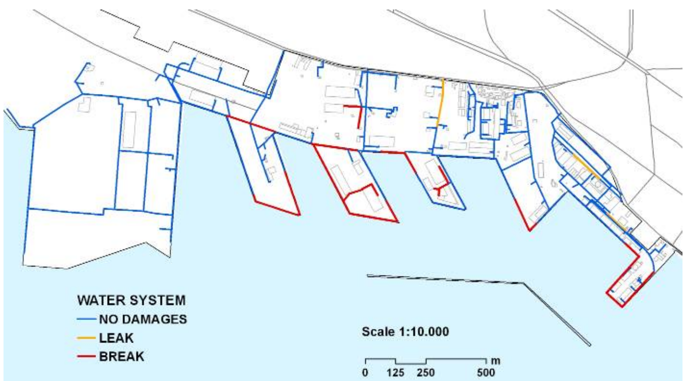

Fig.9. Distribution of damages to water pipelines of Thessaloniki's Port (Tm=1000 years).

The electric power system of Thessaloniki's port includes transmission and distribution lines (13.6Km length), electric power generators for serving the critical facilities in case of loss of power supply and open and closed type substations. The current inventory database for the substations includes several typological and functional attributes, such as name, power of transformers, voltage, service area, equipment anchorage, loop connection, functional control form another substation, type of transformers, number of transformers, type of substation and supply type. Inside the port facilities are located 17 electric power substations; 13 elements cover the power demand of the port facilities and 4 substations serve external needs but are located inside the port territory; they all are medium voltage (20kV-400V) substations with un-anchored components. For the electric lines, the inventory includes attributes such as length, voltage, type, depth, age, material, and foundation type.

Given the fact that the available fragility curves for electric power substations refer to higher voltage elements, with different designing and functional characteristics, they cannot be directly applied herein. Thus a preliminary estimation of induced seismic damage for the three scenarios has been performed using the vulnerability functions proposed by HAZUS (NIBS, 2004) for low voltage (115kv) substations with non-anchored components (conservative approach considering the increase of the damage possibility for higher voltage elements). Fragility curves that are provided by HAZUS (NIBS 2004) were also used for the vulnerability assessment of the electric lines, using the spatial distribution of peak ground acceleration (PGA) values for the three seismic scenarios. Figure 10 presents the spatial distribution and the intensity of estimated damages for the electric power system for the 1000 years scenario. The majority of the elements estimated to sustain moderate to extensive damages.

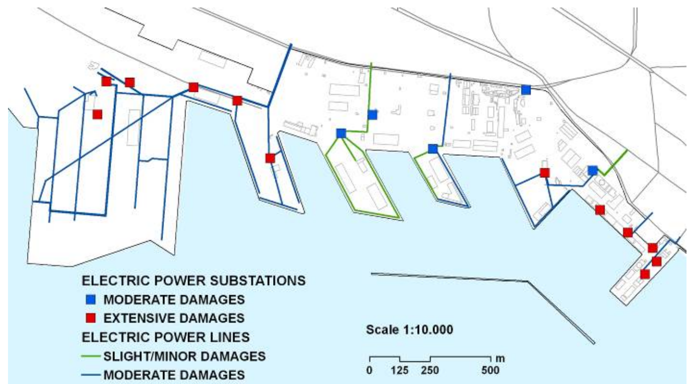

Fig.10. Distribution of damages to electric power system of Thessaloniki's Port (Tm=1000 years).

Buildings: Buildings in a port system include administration and control buildings, traffic control buildings, passenger terminals, offices, security and maintenance buildings, sheds and warehouses and other critical facilities. Furthermore, buildings within lifelines systems and infrastructures are also considered (e.g. pumping stations, engine-houses, electric power substations, etc). Thessaloniki's port includes 88 elements of this type. Their typology was defined based on the construction material, structural type, height and seismic design code level.

The vulnerability analysis of R/C buildings is performed based on fragility curves (in terms of PGA) that have been developed using a hybrid technique combining analytical results and statistical data (Kappos et al. 2006). Six damage states (DS) are defined, the names of which have been slightly modified in order to be compatible with other lifeline elements damage definitions: no damage (DS0), minor (DS1), slight (DS2), moderate (DS3), extensive (DS4) and complete (DS5).

Moreover, fragility curves (in terms of both PGA and Sd) for masonry structures that were developed for all typologies common in Greece were used in the present application (Penelis et al. 2002). Vulnerability assessment for the three seismic scenarios has been performed, using a reduction factor of 0.7 for the conversion of peak to effective values of ground acceleration. The distribution of estimated damages for the port building for the 475 years scenario is illustrated in Fig. 11. 27%, 64% and 9% are estimated to sustain minor, slight and complete damages respectively.

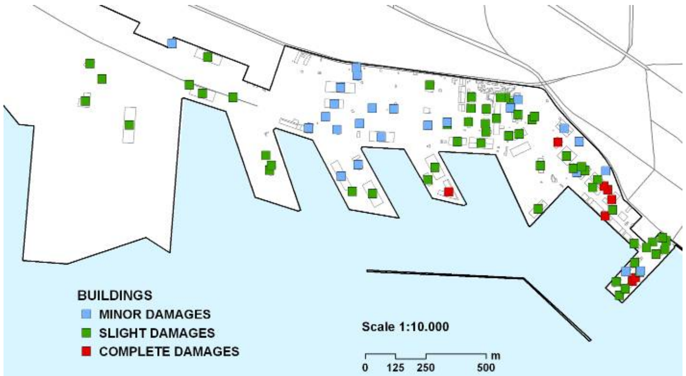

Fig.11. Distribution of damages to building structures of Thessaloniki's port (Tm=475 years).

GLOBAL VALUE ANALYSIS

The aim of the global value analysis is to identify the main issues and relative importance of each lifeline network, through appropriate ranking of the value of the exposed elements, based on various factors that describe the role of each element in the urban system. In that way, the global value of each element at risk, depends not only on its direct specific value or content (physical and human), but also upon its indirect/immaterial value, that is represented by the usefulness and relative role in the whole urban system, at a specific time. Three periods are identified in respect to the occurrence of an earthquake event: normal, crisis and recovery. "Global value" evaluation in different periods could be a powerful tool for the prioritization of pre-earthquake actions and quantification of the overall importance of different complex and coupled lifeline systems. Several criteria for this are used, such as operational attributes, land use, population influenced, human losses, economic and social weight under normal, crisis and recovery circumstances, identity/ radiance, environmental impact and other. Appropriate qualitative or quantitative indicators can then be defined for each period, while relevant measuring units are used for their evaluation and the identification of "main", "important" and "secondary" elements and system's weak points. An example of the indicators used for the classification of the importance of Thessaloniki's port cargo handling equipment is provided in Table 1. Cargo handling operation during crisis and after that, is crucial for the successful recovery reaction and resilience following a major earthquake event. Other elements at risk have different indicators depending on their relative importance in the crisis management process. Representative GIS maps illustrating the definition of main, important and secondary elements at risk can also be constructed (Figs. 12, 13).

Table 1. Indicators used for the global value analysis and classification of importance of cargo handling equipment seismic of Thessaloniki port.

Cargo handling equipment			Period		
Components	Indicators	Description	Normal	Crisis	Recovery
Operation	1.Capacity	Lifting capacity in tons.	•	•	•
Operation	2.Location	Location / dock-pier located	•	•	•
Operation	3.Cargo capacity	Type of cargo that can be handled (conventional, containers)	•	•	•
Operation	4.Redundancy	Alternative equipment to cover the activity.	-	•	•

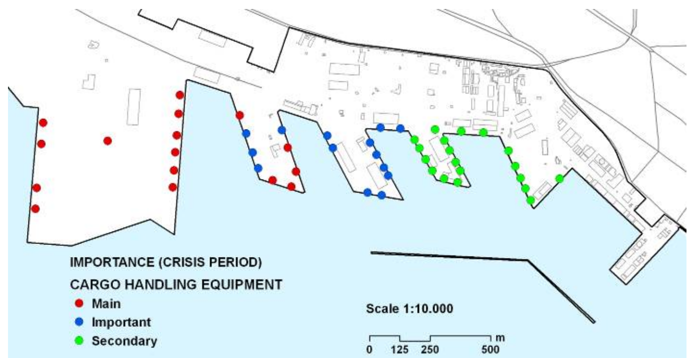

Fig.12. Classification of the importance of cargo handling equipment of Thessaloniki's port during the crisis period.

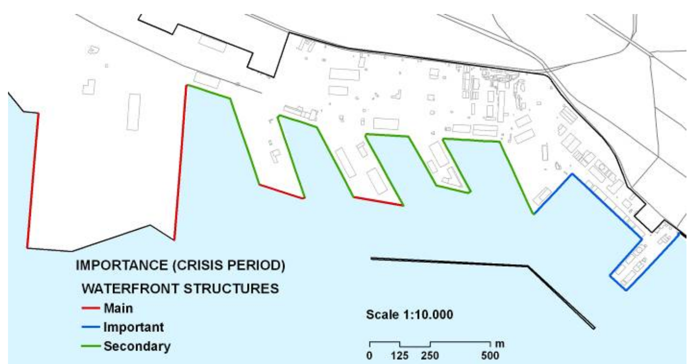

Fig.13. Classification of the importance of waterfront structures of Thessaloniki's port during the crisis period.

SEISMIC RISK MANAGEMENT

The pre-earthquake mitigation plans must be based on appropriate prioritization criteria that combine engineering techniques, economic analysis tools and decision-making or political aspects. The identification of “main”, “important” and “secondary” element at risk in “normal” period provides a prioritization according to the importance of the activities, the social and economical values and the daily demand for serviceability.

A disaster management plan can enhance the pre-earthquake activities for retrofitting (or strengthening), important and critical components in the urban environment and prepare an efficient organization of public services and local authorities for “crisis” period. For the “recovery” period an efficient management plan must minimize the restoration time, the efforts and the cost. In order to achieve reliable estimates of the required time for recovery, lifeline owing and operating companies, local actors in collaboration should define restoration curves for every component in each lifeline system, with lifelines experts using basically qualitative evaluations.

The method we developed applying the “global value” approach uses the classification of lifeline system components into main, important and secondary, according to their global value. Combining “global value” evaluation and vulnerability assessment, it is possible, using, if necessary, an “expert opinion” as well, to estimate priorities and to account for the economic and social losses, for a specific utility system and a given seismic scenario. Recovery activities could also follow these priorities aiming at efficient seismic risk management procedures.

Table 2 summarizes the application of the proposed methodology in a simple system like the cargo handling equipment of Thessaloniki’s port. Figure 14 illustrates the restoration priorities defined for the same cargo handling equipment during the crisis period, for the 475 years scenario.

Table 2. Risk analysis matrix showing cargo handling equipment seismic retrofit priorities.

Urban Risk/ Seismic hazard	Priorities		
	Main	Important	Secondary
Complete/ Extensive damages	1st priority	1st priority	2nd priority
Moderate damages	1st priority	2nd priority	3rd priority
Slight/ minor damages	1st priority	2nd priority	4th priority

Restoration curves have been defined in collaboration with the port authority, based on available man power, and capabilities, local experience and expertise. Assuming that there are only two available teams that could work together, the time requested for the full recovery of all damaged equipment for the 475 years scenario reaches the 6 years, which of course is completely unacceptable, leading to a an obvious ex-ante policy decision. Figure 15 illustrates the functionality level of cargo handling equipment 90 days after the seismic event, supposing that the restoration process starts immediately after the earthquake.

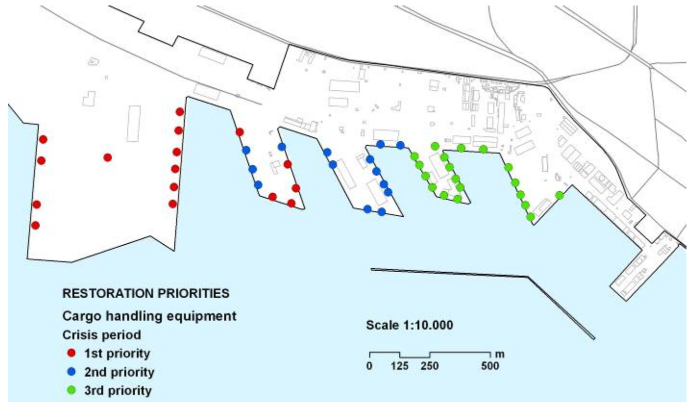

Fig.14. Restoration priorities of cargo handling equipment of Thessaloniki’s Port during the crisis period (Tm=475 years).

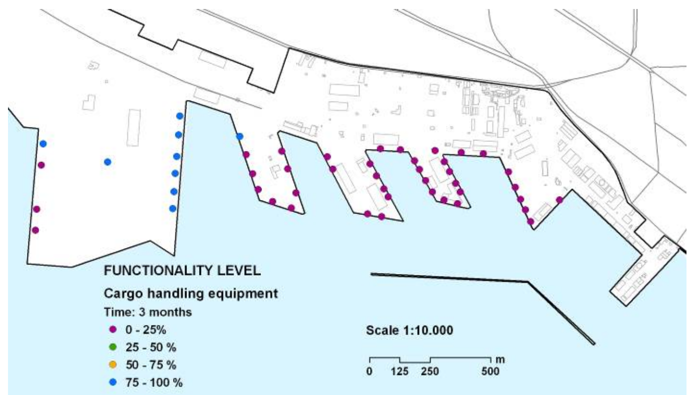

Fig.15. Functionality percentage of cargo handling equipment of Thessaloniki’s port in three months time (90 days) after the seismic event (Tm=475 years).

CONCLUSIONS

A short description and an application of a general methodology for the vulnerability assessment and seismic risk management of lifelines and infrastructures, is presented; the city of Thessaloniki in Greece has been used as test site.

Seismic risk scenarios take into consideration the inventory, the typology and vulnerability characteristics of different elements at risk, as well as the seismic hazard, geotechnical characterization and site response of the main soil formations for different seismic scenarios. Thus, vulnerability and loss estimates for lifelines and infrastructures are evaluated on the basis of site specific seismic hazard analysis using available inventory data and adequate fragility curves. Local site conditions and specific seismic ground response, conventionally referred as "zoning study", plays the key role in the vulnerability analysis and loss assessment.

Herein, a very short presentation of the site characterization and seismic zonation for the city of Thessaloniki is presented. A detailed microzonation study has been conducted for three mean return periods (Tm=100, 475 and 1000 years). Based on these results, examples of the assessment of potential earthquake losses are presented for selected lifeline and utility systems i.e. the water roadway and port system of Thessaloniki. The intensity and spatial variability of the losses are entirely relied on the specific ground response characteristics.

On the basis of a global value analysis (material and immaterial) of lifeline, utility and infrastructure elements, the classification of their importance in different periods is performed. This leads in a prioritization, in a more efficient way, of the pre-earthquake retrofitting actions, and post earthquake restoration efforts. Pre-earthquake mitigation actions could include upgrading of structural performance of lifeline components, improvement of the network performance, organization of redundant systems, implementation of advanced technologies during earthquake emergency (early warning systems, real time damage estimation etc). Furthermore, efficient disaster management plans aiming at the minimization of the restoration time, the efforts and the cost, could be implemented. An example of a global value analysis, determination of priorities and estimation of the recovery time are presented for the cargo handling equipment of Thessaloniki's Port and for the 475 years scenario.

Finally, based on the previous applications, the importance of site-specific seismic response analysis is revealed for the vulnerability assessment and the definition of efficient mitigation strategies and policies for pre and post earthquake actions. The actual vulnerability and the associated risk of any element at risk may be reduced with appropriate mitigation countermeasures. The accurate evaluation of the input motion in terms of ground shaking characteristics, for a given probability of occurrence of a specific magnitude seismic event, always plays the decisive role in the risk assessment.

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