MASSIVE PROJECT

MAPPING SEISMIC VULNERABILITY AND RISK OF CITIES

Funded by DG ECHO

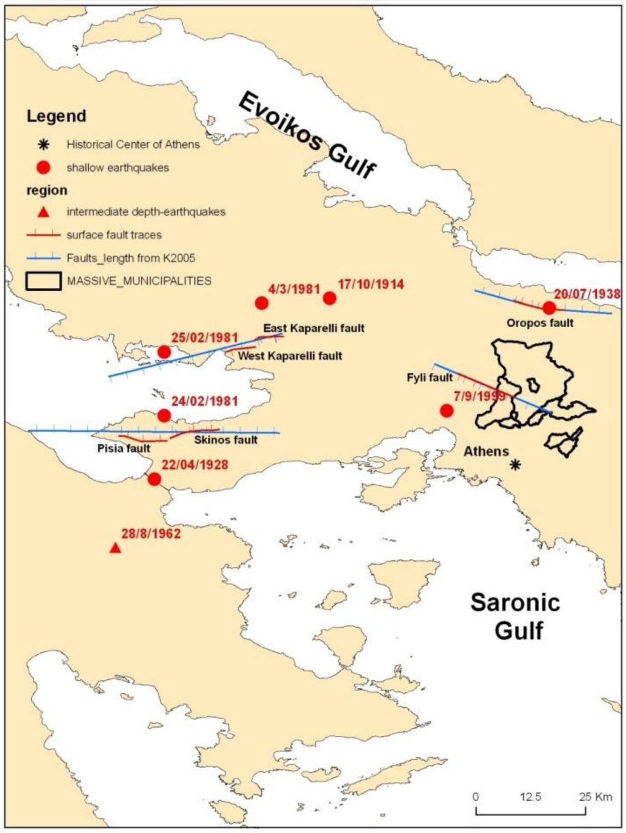
Layman's Report – December 2011

Test Areas

The Greek Pilot Area

Description:

The Greek pilot area refers to the mostly urbanized municipalities of the western part of the Metropolitan area of Athens, capital city of Greece.



Seismicity:

The surrounding areas of Athens city are also of high seismicity, given that strong, destructive earthquakes occurred in Thiva (1914), in Oropos (1938) and in the Alkyonides at the East of the Gulf of Corinth (1981)

Major Seismic Event:

The most severe earthquake event was the Athens earthquake which occurred on September 7, 1999. This was a moderate (Mw=5.9) normal faulting earthquake with its epicenter located at the northwestern part of the study area.

The aftermath of the Athens 1999 Earthquake:

About 100 buildings collapsed causing 143 deaths, while another 800 people were injured. Search and rescue operations were conducted in more than 25 different locations. About 13,000 buildings were damaged beyond repair. During the first days after the shock about 100,000 people rendered homeless. More than 50 municipalities were affected, while the tangible loss caused is roughly estimated equal to about $3b US, value at year of 2000. From the point of view of economic loss it is the worst natural disaster reported in the modern history of Greece.

MASSIVE OVERVIEW

The focus of MASSIVE project was to provide Civil Protection authorities with accurate and up-to-date maps of seismic hazard, urban vulnerability, and building damages risk at census block scale, together with state-of-the-art uncontrolled population evacuation models for two European pilot sites heavily struck by earthquakes, Western Athens (GR) and Abruzzo Region (IT).

OBJECTIVES

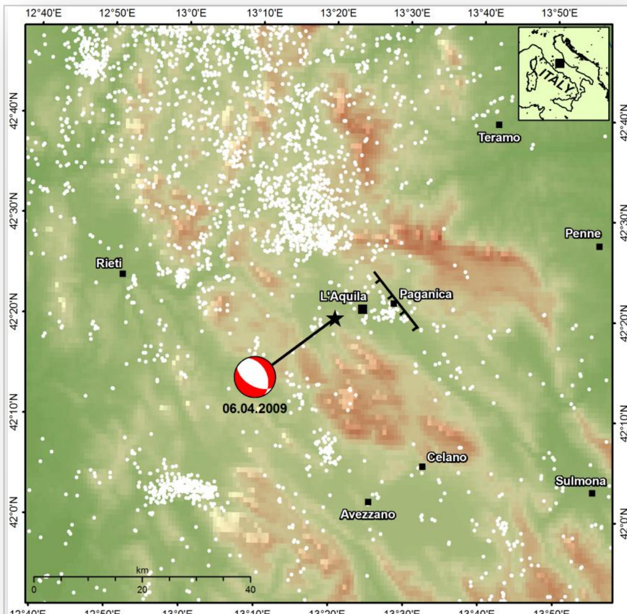
- To recognize and estimate seismic hazard in certain urban areas
- To analyze and deliver information in the form of maps at census block level representing the buildings vulnerability by making reliable assumptions on buildings construction endurance according to the specific anti-seismic regulations applied in the past years
- To assess the vulnerability of the building stock, taking into account the structural characteristics of buildings
- To evaluate damages of buildings based on hazard and vulnerability assessments at local scale
- To develop a model to identify city areas where population is likely to get trapped in case of uncontrolled population evacuation
- To integrate all relevant tools into a GIS interface to be delivered to end-users (e.g. Civil Protection)
- To generate hazard and risk maps for Athens and L'Aquila based on several earthquake scenarios.

Test Areas

The Italian Pilot Area

Description:

The Italian pilot site refers to the region of Abruzzo in central Italy. The demonstration area of MASSIVE project is located around L'Aquila municipality where the population is mainly concentrated. The site covers an area of about 160 km^2.



Seismicity:

This area was hit by strong earthquake events in the past (1461, 1762 and 2009),

Major Seismic Event:

The most severe earthquake event was the one occurred at 3:32 local time on 6 April 2009, and was rated 5.8 on the Richter scale and 6.3 on the moment magnitude scale. Its epicentre was near L'Aquila, the capital of Abruzzo, which together with surrounding villages suffered most damages. There have been several thousand foreshocks and aftershocks since December 2008 (white dots on map), more than thirty of which had a Richter magnitude greater than 3.5.
The area interested by seismicity is about 30 km long and strikes in the NW-SE direction, parallel to the Apennine mountain axis.

The aftermath of L'Aquila 2009 Earthquake:

308 people are known to have died, 1,000 injured, 40,000 homeless and 10,000 buildings damaged or destroyed in the L'Aquila area. The earthquake has been felt throughout central Italy.

- To provide support to the Civil Protection towards integrating the project outcome and developed IT tools in the daily practice for improving preparedness and risk prevention planning.
- To initiate co-operation with countries with similar problems
- To enhance public awareness
- To promote the project idea and outcome in two information days in Greece and Italy with the involvement of the interested parties (crisis managers, civil protection and regional authority officers), and prepare relevant scientific publications for refereed journals and international conferences.
- To support project dissemination through the development of a dedicated Web site.

Damages in L'Aquila city center after the 6th April 2009 earthquake event.

Key Concepts

Vulnerability I

Description: The term vulnerability refers to the probability of damage due to the occurrence of a hazardous event. Seismic vulnerability is a measure of the impact of earthquake effects on buildings and people. The concept of vulnerability introduced here refers to the building construction year.

Methodology:

Building vulnerability is dependent on the period of construction taking into consideration which version of the anti-seismic code was applied. The vulnerability of a block depends on the number of buildings (parameters *a*, *b*, *c*) built at certain time intervals defined by the revisions of the code. To express this in a quantitative way the coefficient Σ was considered:

ATHENS	L' AQUILA
$\Sigma = (a + 0.5b + 0.3c) / (a+b+c)$	$\Sigma = (a + 0.5b) / (a + b)$

Hazard

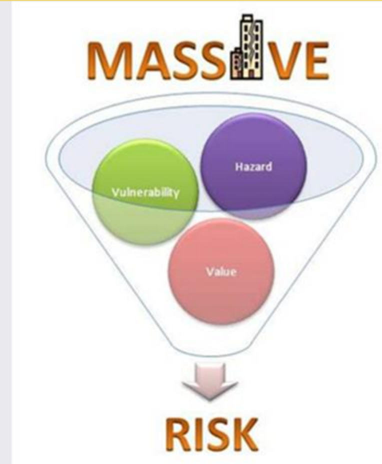
Description: Seismic hazard analysis aims to quantitatively estimate ground shaking hazard at a particular site. Seismic hazard may be approached either deterministically by analysing geology and geotechnical engineering or stochastically by estimating the probability of not exceeding a certain value of the strength of seismic ground motion (e.g. ground acceleration) in a particular time interval. The most appropriate expression of the strong ground motion was considered the **Peak Ground Acceleration, PGA**. For a particular site PGA is dependent on the earthquake magnitude, the distance from the epicentre of the earthquake, the local site conditions and the pattern of seismic energy radiation from the seismic source, i.e. the type of seismic fault activated. Empirical attenuation laws of the PGA are in extensive use for the estimation of its expected values in a target area.

Methodology: Seismic hazard depends on three main parameters:

- the seismic sources that produce the hazard,
- the ground motion that is attenuated away from the earthquake epicentre, and
- the local soil conditions defined from a geological map.

WHAT IS RISK?

R = H * VA * VU



Seismic risk is the potential or probability of a loss due to the occurrence of an earthquake. The seismic risk, ***R***, is the convolution of three main elements: ***R = H * VA * VU***, where ***H*** is the earthquake hazard, which depends on the seismicity and the geology of the region, ***VA*** are the assets at risk, if available, i.e. the economic value that is threatened by the earthquake, and ***VU*** is the vulnerability of the assets to the effects of the earthquake

L'Aquila city center is currently held up entirely by scaffolding (10/2011)

The following empirical attenuation laws of PGA have been applied:

ATHENS

$$\log PGA = 0.86 + 0.45M - 1.27 \log (d^2 + h^2)^{1/2} + 0.10F + 0.06S \ (\pm 0.286)$$

and

$$\log PGA = 1.07 + 0.45M - 1.35 \log (d + 6) + 0.09F + 0.06S \ (\pm 0.286)$$

where M=earthquake magnitude, d=epicentral distance (in km), h=hypocentral distance (km), F is a factor for the type of the seismic fault, and S is a factor taking the value of 0 for hard rock, 1 for semi-hard rock or 2 for soft soil. Top equation is used for near-field conditions (short epicentral distances, d <30 km) of shallow earthquakes (h < 50 km), as well as for intermediate-depth earthquakes where the hypocentral depth is considerable (h > 50 km), while bottom equation is used for far-field estimations (long distances, d>30 km) [source: Skarlatoudis et al., 2003]

L' AQUILA

$$\log PGA = -1.562 + 0.306\,M - \log (d^2 + 5.82)^{1/2} + 0.169\,S$$

Here d=is the closest distance to the surface projection of the fault rupture (in km), which for practical reasons was taken as equal to the epicentral distance (in km), and S is a variable taking the value of 1 for shallow and deep alluvium sites or 0 otherwise. Practically, for soft soils S=1 and for hard soil S=0. This equation is applicable for 4.5 ≤ M ≤ 6.8 and d ≤ 100 km [source: Sabetta and Publiese, 1987]

Risk

Description: The quantitative calculation of **risk** can be expressed as building **damages**. Various expressions of damage have been computed:

- Normalized Damage,
- Relative Damage, and
- Macroseismic intensity.

Methodology: A quantitative expression of earthquake risk, R, for a region is the convolution of seismic hazard (PGA) and building vulnerability. In many cases, especially in metropolitan cities, the hazard might be low but the risk is high due to the high average density of buildings. This recognition was verified with the earthquake of 7 September 1999 in Athens which was of moderate physical size but caused the most costly impact ever reported from earthquakes in Greece.

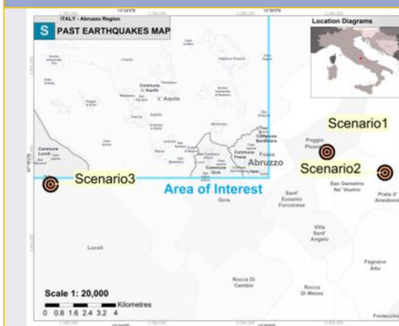
Considering the Damage expected in subarea A as a function of Hazard (**H**) and Vulnerability (**VU**), then $D(A) = H * VU$

Moreover, the macroseismic intensity *I* has also been implemented as an independent calculation of a parameter strongly related to Damages. Macroseismic intensity is expressed in the 12-grade Mercalli-Sieberg scale. This has been implemented using empirical relations between the PGA and the macroseismic intensity I, as follows:

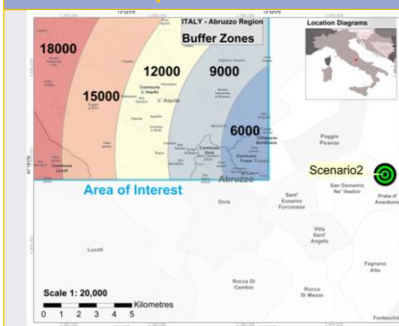
ATHENS	L' AQUILA
$\log PGA = 0.33I + 0.07$	$I = 1.68 (\pm 0.22) + 2.58 (\pm 0.14) \log PGA$
[Koliopoulos et al., 1998]	[Sabetta and Publiese, 1987]

Data Layers-L'Aquila

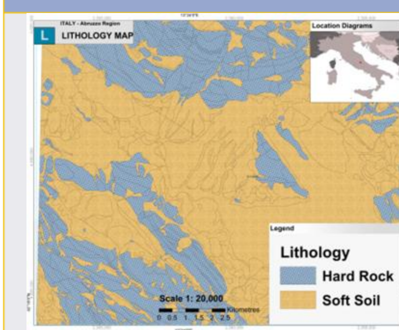
Census Blocks



Earthquake Scenarios



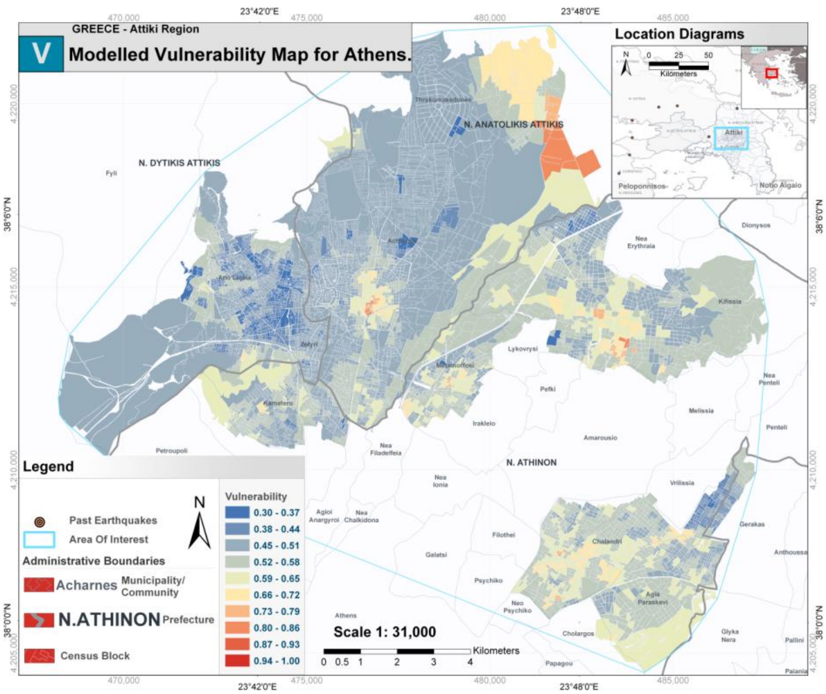
3000Km Zonal Areas



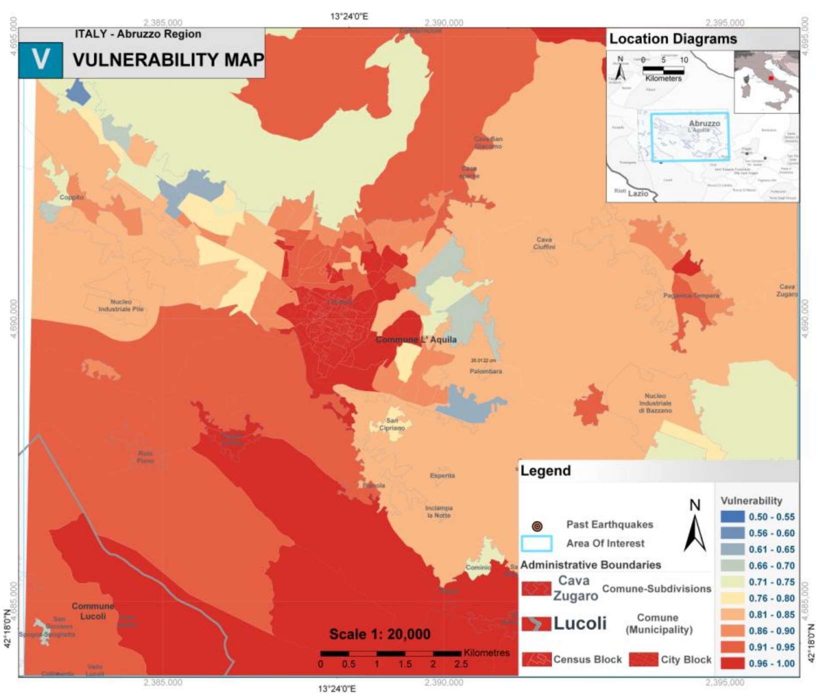
Lithography

Results – Vulnerability I

Vulnerability - Athens



Vulnerability L'Aquila



PARTNERSHIP

National Observatory of Athens, Institute for Space Applications and Remote Sensing (NOA/ISARS)

National Observatory of Athens, Institute of Geodynamics (NOA/GI)

National Technical University of Athens

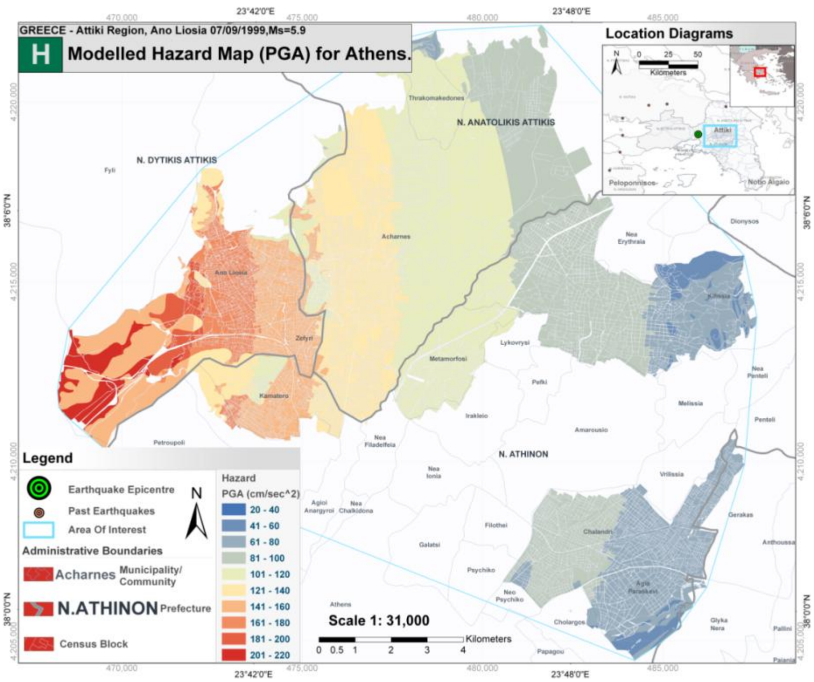
Planetek Italia

GEOAPIKONISIS SA.

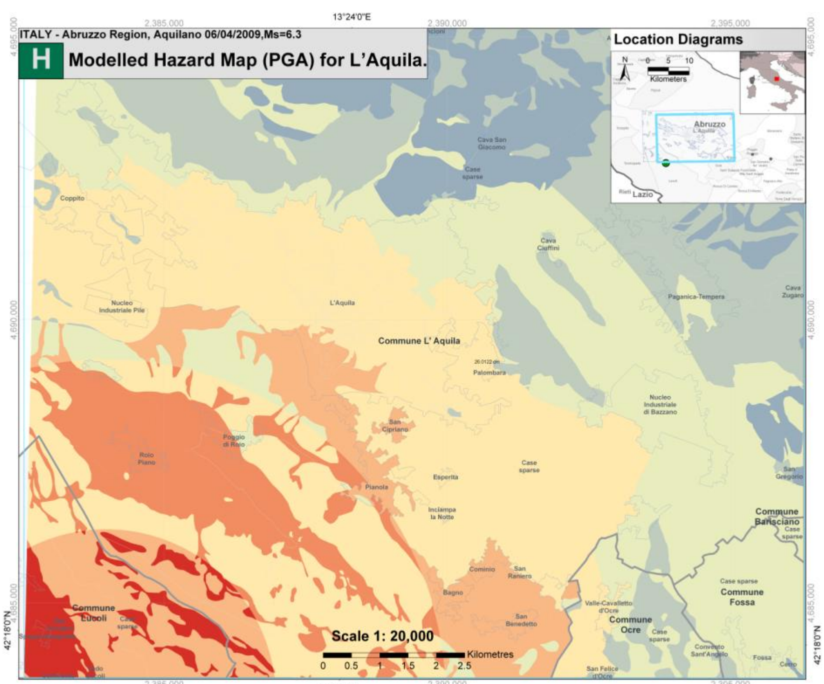
Aristotle University of Thessaloniki (AUTh) & Institute of Engineering Seismology and Earthquake Engineering (ITSAK)

Results - Hazard

Hazard Athens – Earthquake Ano Liosia 07/09/1999 Ms=5.9

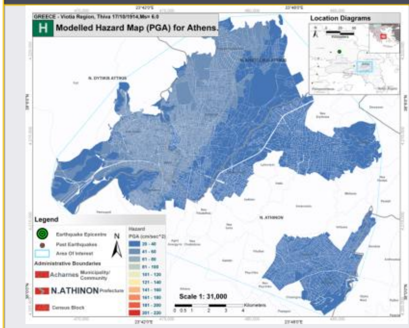


Hazard L'Aquila – Earthquake Aquillano 06/04/2009 Ms=6.3

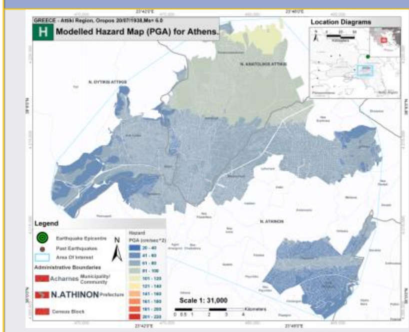


HAZARD SCENARIOS

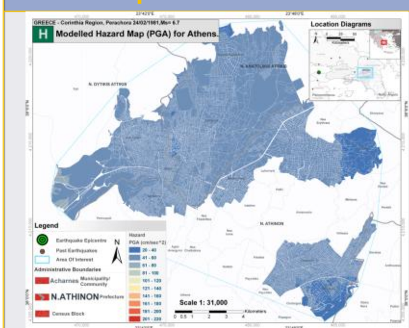
Athens



Thiva 1914 Ms=6.0

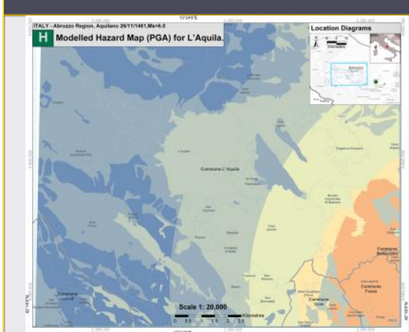


Oropos 1938 Ms=6.0



Perachora 1981 Ms=6.7

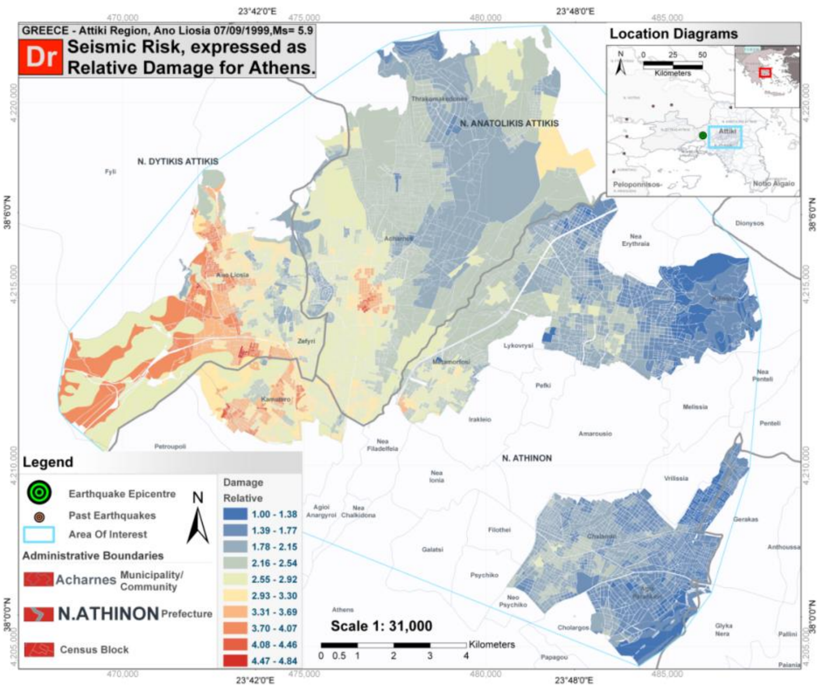
L'Aquila



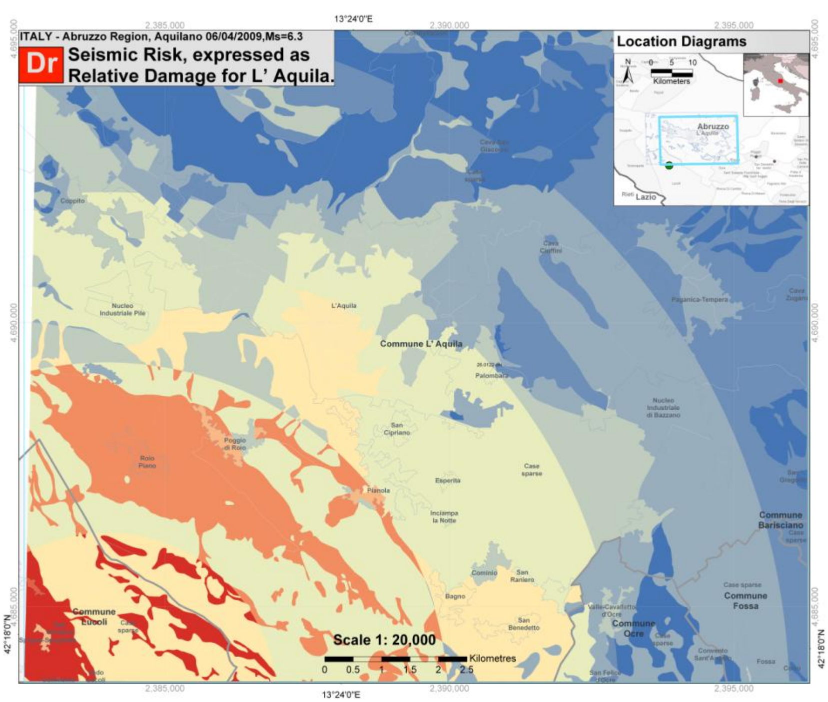
Aquilano 1461 Ms=6.0

Results -Risk

Rel. Damage Athens –Ano Liosia 07/09/1999 Ms=5.9

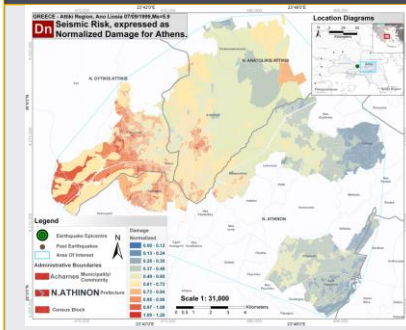


Rel. Damage L'Aquila – Aquillano 06/04/2009 Ms=6.3

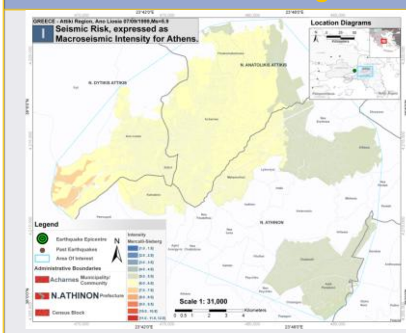


RISK EXPRESSIONS

Athens

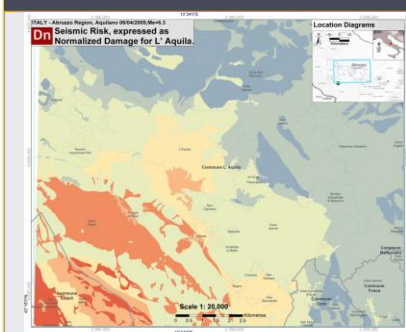


Normalized Damage

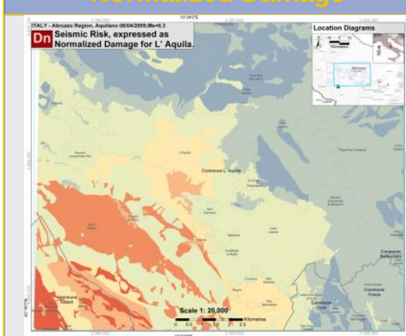


Intensity

L'Aquila



Normalized Damage



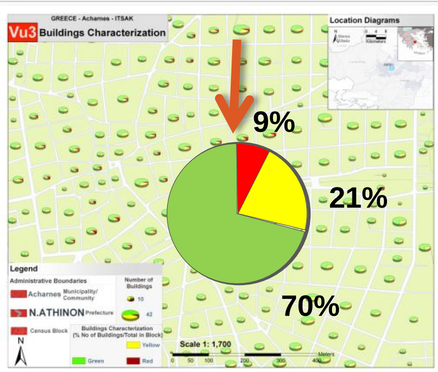
Intensity

Vulnerability II

Methodology Description: Within the framework of the MASSIVE project, researchers from the Aristotle University of Thessaloniki (AUTh) and the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) were invited to develop an alternative methodology for the vulnerability assessment of the building stock, taking into account the structural characteristics of buildings and apply it to the cities of Athens and L'Aquila. The methodology for vulnerability and loss assessment of the building stock was based on a 'hybrid' approach, combining statistical data from actual earthquakes with the results of inelastic analyses of representative structures resulting in the derivation of **fragility curves** for representative building typologies.

Results

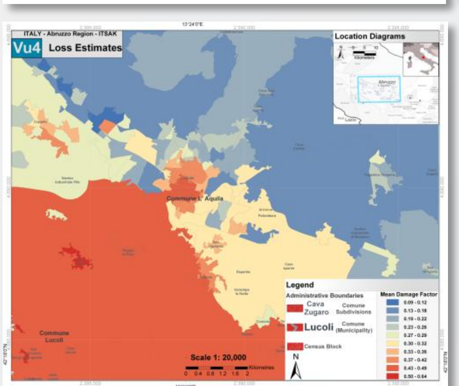
The aforementioned approach has been applied to the case studies of Athens and L'Aquila and loss estimates have been derived for both cities using PGA-based seismic scenarios that correspond to the Athens 1999 and the L'Aquila 2009 earthquakes



Results can be obtained:

1. In terms of a 5-scale damage state definition

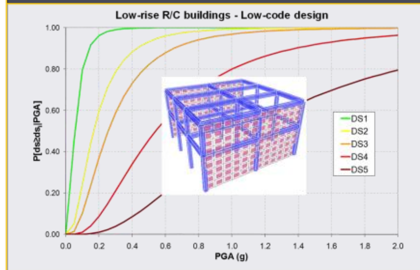
Damage State	Description
DS0	None
DS1	Negligible to slight
DS2	Moderate
DS3	Substantial to heavy
DS4	Very heavy
DS5	Destruction



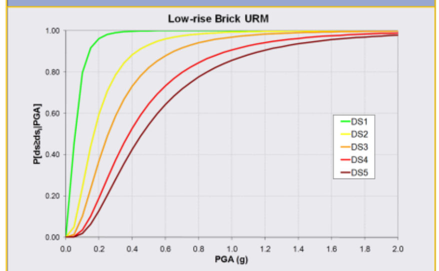
2. In the common Green-Yellow-Red post earthquake tagging approach (Upper Figure)
3. In terms of an appropriate mean damage factor (MDF) that provides a good insight into the most vulnerable parts of the city when projected on a GIS map (Lower Bottom).

FRAGILITY CURVES

Examples

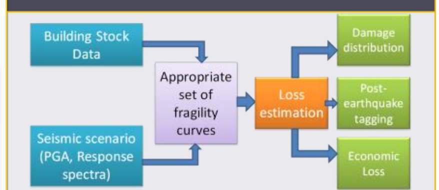


Fragility curves in terms of PGA for low code, low rise with frame system



Fragility curves in terms of PGA for low rise, brick URM buildings (right)

Loss Estimation procedure scheme



Since the building stock data gathered from the 2001 national censuses in Greece and Italy were used, the transferability of the model to other areas of these two countries is straightforward, assuming that the required data is available in the same format. In order to use this model for other case studies, it is essential to verify that data for the building stock are provided in a compatible format and that the building classification adopted herein is able to describe the seismic performance of the existing building typologies; otherwise a new set of fragility curves has to be added.

The overall scheme of the applied procedure is presented above.

Uncontrolled Evacuation of Population

Methodology Description: The basic idea is that the model can be used to search, based on the road network of a locally defined area and the corresponding population, the most difficult to evacuate areas. The optimization problem is based on a model that computes, for each area, the worst possible scenario as far as the ratio of population to exceed capacity is concerned. Then, that area can be classified as to the degree to which evacuation difficulty exists. By applying the model numerous times across the network and classifying each local area as to evacuation difficulty, a map of evacuation vulnerability can emerge, provided that the model is fed with appropriate information.

Results

(a)

(b)

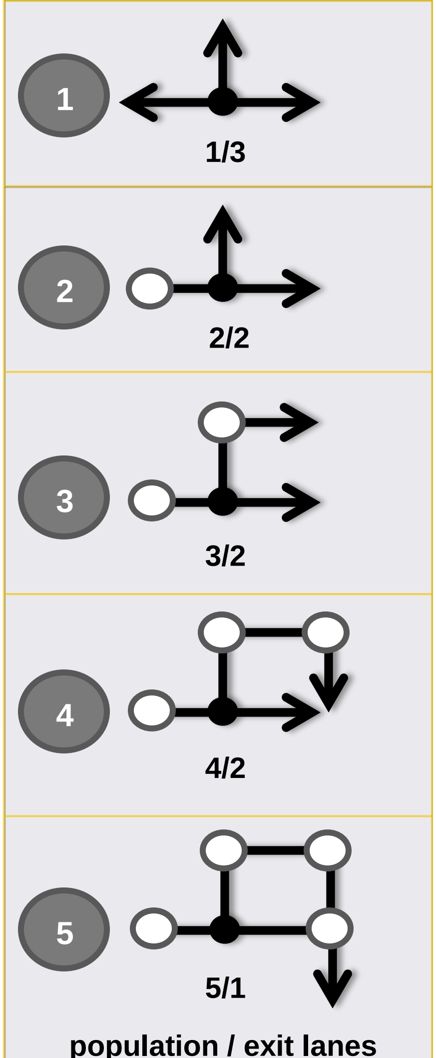
The thematic map unit is the number of people per lane in a road segment's worst-case evacuation. Orange colored segments correspond to Bulk Lane Demand (BLD) value of 300 persons per lane while red to more than 500.

Figure (a) shows the results of producing a complete vulnerability map at neighborhood level for Athens Greece. Clearly, in this case study more in number and spatial extension "hot spots" were identified and the four major evacuation sheds were presented in their satellite view.

Figure (b) shows the results of producing a complete vulnerability map at neighborhood level for L'Aquila Italy.

DEVELOPMENT OF AN UNCONTROLLED EVACUATION MODEL

Critical cluster problem (CCP) : Given a node of interest identify a critical neighborhood of connected nodes and arcs about that anchor node which corresponds to the highest population to exits ratio (after Cova & Church 1997).

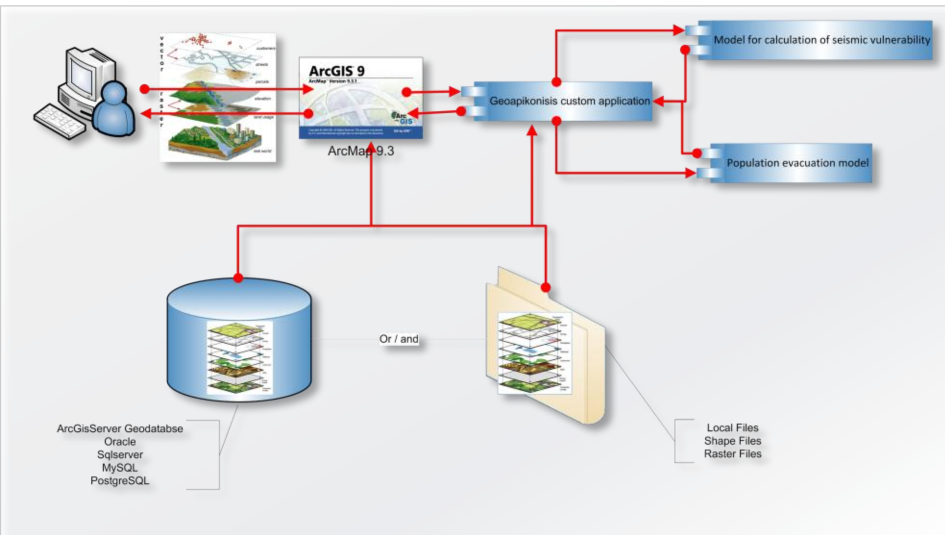


Integrated GIS System

Methodology

Methodology Description: MASSIVE GIS system accommodates a user interface, an adequate environment for the models and applications to run and a database component. The design and implementation of the GIS system assures optimized functionality and robust models handling. The integrated GIS system was designed as a custom Add-in module for the ArcGIS ArcMap GIS software version 9.3.1.

System Configuration



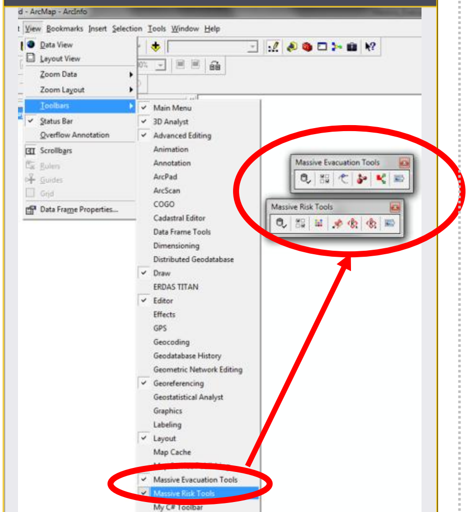
The user Interface of the MASSIVE custom add-in module consists of (i) the MASSIVE Risk toolbar and (ii) the MASSIVE Evacuation toolbar. The great advantage for emergency planning is that within the custom add-in module it is possible to insert new earthquake scenarios, select the area for the model to run, calculate the seismic risk parameters as well as the evacuation risk for each road network. Therefore, the user can create "What if" scenarios for prevention and planning. The final outputs are thematic maps depicting the results of the risk and evacuation models. The user can run multiple risk and evacuation model tasks, referring to one or more earthquake scenarios.

References:

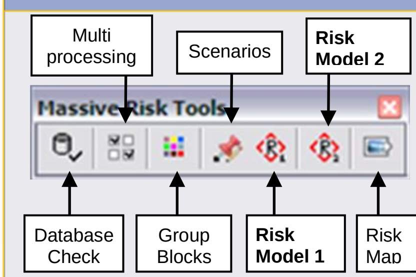
1. Sabetta, F. and Pugliese, A.: 1987, Attenuation of peak horizontal acceleration and velocity from Italian strong-motion records,Bull. Seism. Soc. Am. 77, 1491-1511
2. Cova, T.J., Church, R.L., 1997. Modelling community evacuation vulnerability using GIS, International Journal of Geographical Information Science, 11, 763-784.
3. Koliopoulos, P. K., B. N. Margaris, and N. S. Klims (1998). Duration and energy characteristics of Greek strong motion records, J. Earthq. Eng. 391–417.
4. Skarlatoudis A.A., Papazachos C.B., Margaris B.N., Theodulidis N., Papaioannou Ch., Kalogeras I., Scordilis E.M. and Karakostas V., Empirical peak ground-motion predictive relations for shallow earthquakes in Greece, Bull. Seism. Soc. Am. 93 (2003), pp. 2591–2603.

GIS SYSTEM

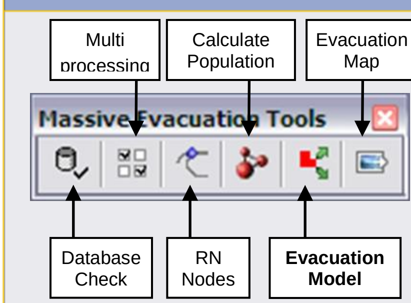
MASSIVE Toolbars



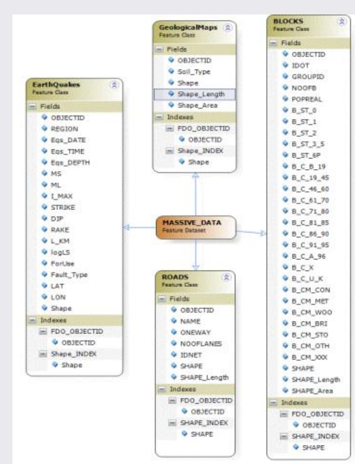
Seismic Risk Tools



Evacuation Tools



Database Schema



Dissemination

Target Groups and organizations

Two dedicated information days (in Greece and Italy) were organized in order to promote the concept and the products (maps, reports, DBs, GIS system) of MASSIVE to the interested authorities.

The main targeted groups and organizations in these info days were: Public authorities on central, regional and local level, Civil Protection officers, Crisis Managers, Assessment and immediate response teams as well as the European Commission representatives.

The Greek Information Day

The Greek Information Day took place on 4 October 2011 at the Cultural Centre "K. Palamas" in the centre of Athens.

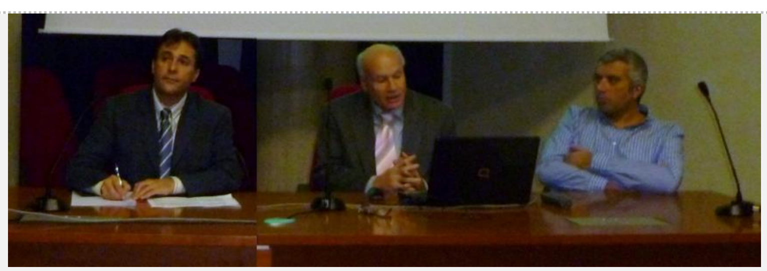
Mr. Bart Materne, EC Project Officer, Dr. Haris Kontoes, Project Coordinator (NOA) and Dr. Iphigenia Keramitsoglou, Project Technical Manager (NOA)

Dr. Gerassimos Papadopoulos, Research Director, NOA

Dr. Christos Karakostas, Research Director, ITSAK

The Italian Information Day

The Italian Information Day was held at Regione Abruzzo premises in L'Aquila city on 18 October 2011.



Dr. Haris Kontoes (NOA), Dr. Gerassimos Papadopoulos (NOA), Prof. Chris Kiranoudis (NTUA)

THE GREEK INFO DAY

Mr. Bart Materne, EC Project Officer, Protection Mechanism, MIC

Greek users attending the information day

THE ITALIAN INFO DAY

Dr. Haris Kontoes, Project Coordinator, NOA, chairing the session

From left: Dr. H. Kontoes (NOA),
Dr. G. Papadopoulos (NOA),
Prof. C. Kiranoudis (NTUA),
Dr. G. Panagopoulos (AUTH),
Dr. I. Keramitsoglou (NOA),
Ms. A.-M. Deflorio (Planetek IT)

MASSIVE Web Site:
http://massive.eu-project-sites.com/

Contact email:
massive@noa.gr

From left to right: Dr. Haris Kontoes, Project Coordinator (NOA), Dr. George Panagopoulos (AUTH), Dr. Iphigenia Keramitsoglou (NOA), Mr. Massimo Zotti (Planetek IT), Ms. Anna-Maria Deflorio (Planetek IT), Prof. Chris Kiranoudis (NTUA), Mr. Themistocles Herekakis (NOA) & Dr. Gerassimos Papadopoulos (NOA), in front of the Italian User Premises-Regione Abruzzo

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The sole responsibility of this publication lies with the authors and the Commission is not responsible for any use that may be made of the information herein.