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.

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.

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).
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 km².

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.
Key Concepts

Vulnerability

**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, and c) built at certain time intervals defined by the revisions of the code. To express this in a quantitative way the coefficient $\Sigma$ was considered:

<table>
<thead>
<tr>
<th>ATHENS</th>
<th>L’ AQUILA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Sigma = (a + 0.5b + 0.3c) / (a+b+c)$</td>
<td>$\Sigma = (a + 0.5b) / (a + b)$</td>
</tr>
</tbody>
</table>

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.
The following empirical attenuation laws of PGA have been applied:

**ATHENS**

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

and

\[
\log \text{PGA} = 1.07 + 0.45M - 1.35 \log (d + 6) + 0.09F + 0.06S (\pm 0.286)
\]

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**

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

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 \(4.5 \leq M \leq 6.8\) and \(d \leq 100\) km [source: Sabetta and Publiese, 1987]

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**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

\[
D(A) = H \times VU
\]

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**

\[
\log \text{PGA} = 0.33I + 0.07
\]

[Koliopoulos et al., 1998]

**L’ AQUILA**

\[
I = 1.68 (\pm 0.22) + 2.58 (\pm 0.14) \log \text{PGA}
\]

[Sabeta and Publiese, 1987]
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

[Modelled Hazard Map (PGA) for Athens]

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

[Modelled Hazard Map (PGA) for L’Aquila]
Results - Risk

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

Rel. Damage L’Aquila – Aquillano 06/04/2009 Ms=6.3
**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
   
<table>
<thead>
<tr>
<th>Damage State</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0</td>
<td>None</td>
</tr>
<tr>
<td>DS1</td>
<td>Negligible to slight</td>
</tr>
<tr>
<td>DS2</td>
<td>Moderate</td>
</tr>
<tr>
<td>DS3</td>
<td>Substantial to heavy</td>
</tr>
<tr>
<td>DS4</td>
<td>Very heavy</td>
</tr>
<tr>
<td>DS5</td>
<td>Destruction</td>
</tr>
</tbody>
</table>

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).
**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**

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.
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:
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.

The Italian Information Day

The Italian Information Day was held at Regione Abruzzo premises in L’Aquila city on 18 October 2011.
The authors acknowledge the financial support of the Civil Protection Financial Instrument of the European Community. 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.