SEISIMPACT-THES: A SYSTEM FOR THE EVALUATION OF SEISMIC IMPACT IN THE BUILT ENVIRONMENT OF THE PREFECTURE OF THESSALONIKI

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ABSTRACT

One of the scopes of the SEISIMPACT-THES project is to organize into digital form and evaluate the records of reported damage, connected to the occurrence of the 1978 Thessaloniki earthquake (Mw=6.5). For the exploitation of these data, an advanced Information System is under development that will include:

- A properly designed database
- A Geographic Information System that will contain all the necessary data (after digitization and corrections) enriched with more recent data, as well as topographic, geological and geophysical data of the region (metropolitan area of Thessaloniki)
- A model system of accessing the above via the web and mobile devices

The basic data for the implementation of the project are derived from the archives of the Agency for the Relief of Seismic Catastrophes in Northern Greece (YASBE). The data are included in the forms of inspection of buildings carried out in Thessaloniki shortly afterwards the 1978 earthquake. It is estimated that there are roughly 63,000 building inspection forms in the region of Thessaloniki.

The exploitation of this rich database with the description on damage of buildings will result into a complete electronic database properly standardized so that it can be linked to the geographic data of a complete Geographic Information System. The database structure will allow multiple queries and processes to study in depth the behavior of buildings in Thessaloniki, and its correlation with other geological, geophysical, geotechnical factors.
I INTRODUCTION

The development of databases for the registration of multiple information on the buildings that suffered damage due to earthquakes constitutes a methodology that is used with increasing frequency in the last few years. The information included in these databases basically concerns the type of damage recorded for each building and is connected to their structural characteristics. At the same time, a large quantity of related information (e.g. spatial, geographical, economical, demographical etc.) is recorded. All these data can be utilized by many categories of potential users, such as scientists, engineers, professionals, public employees, but also institutions of the private as well as the public domain.

Geographical Information Systems (GIS) are the main tool for the management of data stored in the above mentioned databases. In some cases, new software packages based on the Expert Systems technology have been developed for the management, modification or extension of these data. All efforts contribute to the creation of a framework of procedures aiming to the solution of problems created after serious seismic incidents in the population, but also in the study and growth of action plans and strategies for the relief of population and the effective confrontation of similar natural phenomena in the future. Usually, on the basis of seismic data analysis and the type of buildings, several scenarios are being studied about the ways earthquakes affect the built environment. The development of such simulation models - but also forecast models for the estimation of emergency situations and their satisfactory confrontation - is associated to the type of structures and their quality in the particular geographical area under investigation. Therefore, it is obvious that the models developed with the help of GIS spatial analysis tools may assist the authorities in decision-making for emergency management, a task with direct social and economic impact.

Different techniques and systems have been used for the recording and management of damage information in buildings. Among them:

- The Federal Emergency Management Agency (FEMA) and the Defense Threat Reduction Agency (DTRA) in U.S.A. have developed the "Consequences Assessment Tool Set" (CATS), a software tool for the better planning of meters of confrontation of natural or anthropogenic emergencies of various forms, among which of course and the earthquakes (Swiatek & Kaul 1998). With regard to earthquakes, CATS deals with the damage in buildings, infrastructure and the probability of existence of victims.
- The Federal Emergency Management Agency (FEMA) and the National Earthquake Hazards Reduction Program (NEHRP) in U.S.A. have developed the HAZUS (HAZards United States) system for the reduction of seismic danger in the country. The particular system has been developed so that it can be used by state institutions, at local and national level, for an estimate of seismic danger, the more effective antiseismic planning and the organization of practical measures of confrontation of seismic destructions (Bouhafs et al., 1998). It also uses mathematical relations and information with regard to the epicenter and the size of likely future earthquakes, the vulnerability of existing building infrastructure, the local geology, as well as demographic elements, aiming to the calculation of the impact of future earthquakes (Bausch et al., 1999).
- A system based on the technology of GIS and ArcView software contains a database of expected ground movements during various scenarios of earthquakes in correlation to already observed damage data from more than 62000 buildings in the region of Los Angeles (O'Rourke et al., 2000).
- The Extremum system has been developed by the Russian State Federal System of Seismological Observations and Earthquake Prediction (FSSN) and EMERCOM. It can manage and analyze spatial and descriptive data that include seismic risk and the estimate of the vulnerability of structures (Milutinovic 2000).
- Another system based on the technology of GIS has been developed by the Institute of Architecture and City Planning in Japan. The system contains a digital map of the city of Nishinomiya showing the location of building and a database with damage data in buildings after an earthquake that occurred in 1995 (Murao and Yamazaki 1999, Umemura et al., 2002).
Greece has suffered many times from big earthquakes that caused human victims as well as big damage to public and private infrastructure. However, the 1978 earthquake in Thessaloniki (Mw= 6.5) enhanced the beginning of a more systematic confrontation of the impact of such phenomena. This happened because it was the first time that a powerful earthquake affected a big modern city of roughly one million of residents. Thessaloniki presented the formal characteristics of Greek urban built environment: buildings with 4 to 8 storey, large population in numbers and density, mixed land use, traffic problems and lack of effective planning of management of natural catastrophes.

The scope of the SEISIMPACT-THES System is to organize into digital form and evaluate the records of reported damage in buildings connected to the occurrence of the 1978 Thessaloniki earthquake. SEISIMPACT-THES is a project financed by the General Secretariat of Research and Technology (Ministry of Development) in the framework of EPAN project. For the exploitation of these data, an advanced Information System is under development. This system will include a properly designed database, a Geographic Information System that will contain all the necessary data (after digitization and corrections) enriched with more recent data, as well as topographic, geological and geophysical data of the region (metropolitan area of Thessaloniki). It will also include a model system of accessing the above via the web and mobile devices (it is more thoroughly described in Koutoupes et al. 2004).

The participants collaborating in the completion of the project are:

- The Laboratory of Geodesy, Division of Geotechnical Engineering of the Department of Civil Engineering, Aristotle University of Thessaloniki.
- The Department of Geodesy and Surveying, Aristotle University of Thessaloniki.
- The Department of Geophysics, Aristotle University of Thessaloniki.
- The Institute of Engineering Seismology & Earthquake Engineering (ITSAK).
- Hellas On Line (HOL) S.A., a private company working with Internet Information Services.
- AgilTech S.A. (subcontractor of HOL S.A.) for software systems design and development.

The above participants have also valued from the cooperation with engineers employed by The Agency for the Relief of Seismic Catastrophes in Northern Greece (YASBE), which provided the core data, as the basic data for the implementation of the. As mentioned earlier, the data are included in the forms of inspection of buildings carried out in Thessaloniki shortly after the 1978 earthquake. It is estimated that there are roughly 63,000 building inspection forms in the region of Thessaloniki.

2 INSPECTION FORMS FOR EARTHQUAKE DAMAGED BUILDINGS AND THE SEISIMPACT-THES DATABASE

One of the fundamental duties of emergency management agencies is the inspection of public and private structures and buildings after a strong earthquake. In this way, safe use of buildings can be ensured and damage can be recorded for scientific and statistical evaluation. This procedure has been followed in all major earthquakes in Greece, starting from Thessaloniki in 1978 up to the most recent strong earthquake of Athens in 1999, but also in moderate earthquakes (Dandoulaki et al. 1998).

This subject is really very important: From one side, inspection after the earthquake helps in reducing the probability of casualties from aftershocks, a fact that gives the character of urgent and imposes the need for quick actions. The evaluation of the condition of buildings will then give the likely number of citizens that should be accommodated in settlements and will appease the other citizens with regard to their residences. On the other hand, the inspections must record in an equitable way the observed damage so that they can be used for statistical and mainly for scientific reasons.

After the Thessaloniki earthquake, a situation of chaos was created due to the panic, the destructions, the lack of information and the innumerable calls on help, but also on control of static
condition and damage of buildings (fig.1). By that time, there was no specific procedure for the inspection of buildings and infrastructure. However, after the first period of embarrassment, the state agencies reacted. Forms were drafted, printed and distributed during the first days after the earthquake. The buildings were inspected by two member teams of engineers in order to be classified in three categories with regard to their damage and usability (Green: Usable – no serious damage, Yellow: Temporarily unusable - with damage, usable after the repairs, Red: Unusable, dangerous) (fig.2).

The result of this procedure was the creation of an enormous database from the inspection forms that contained classification of buildings, but also certain additional information on types of damage, structure and size of building etc. After the completion of the inspections (in approximately two months for the first and second degree inspection), roughly 63000 buildings in the region of Thessaloniki were inspected (corresponding to roughly 250000 apartments, offices and shops). All data were kept in the archives of the newly established Agency for the Relief of Seismic Catastrophes in Northern Greece. Table 1 shows an overview of the number of inspections and the results (Doukas 2003).

Figure 1. Building collapse in Thessaloniki after the 1978 earthquake

Figure 2. Post-earthquake building safety classification (Green: Usable - Yellow: Temporarily unusable - Red: Unusable, dangerous)

The data of the inspection forms of the Thessaloniki 1978 earthquake have been used to some extend for scientific research in the past (Papacharisis 1980, Penelis et al., 1988).
In 1984, one year after the establishment of the Earthquake Planning and Protection Organization of Greece, the inspection form was re-designed to assist the standardized import of information, prevent errors and shorten the time needed to fill it in. These inspection forms were used after a number of devastating earthquakes in Greece undergoing revisions, improvements and additions.

<table>
<thead>
<tr>
<th>Post-earthquake building safety classification in the area of Thessaloniki</th>
<th>Number of buildings</th>
<th>Number of apartments, shops, offices</th>
</tr>
</thead>
<tbody>
<tr>
<td>GREEN (Usable – no serious damage)</td>
<td>46441</td>
<td>184082</td>
</tr>
<tr>
<td>YELLOW (Temporarily unusable - with damage, usable after the repairs)</td>
<td>12823</td>
<td>61270</td>
</tr>
<tr>
<td>RED (Unusable, dangerous)</td>
<td>3648</td>
<td>4648</td>
</tr>
<tr>
<td>TOTAL</td>
<td>62912</td>
<td>250000</td>
</tr>
</tbody>
</table>

The structure of the main database of the SEISIMPACT-THES project was based on the design of three paper inspection forms used for post- or pre-seismic control of buildings:
- Inspection forms used after the Thessaloniki 1978 earthquake, being the main source of information.
- Inspection forms used after the Athens 1999 earthquake.
- Forms for pre-seismic control of buildings according to a proposal by the Earthquake Planning and Protection Organization of Greece (Karabinis et al., 2002).

The design of the SEISIMPACT-THES database was flexible enough to allow the input of inspection data from existing files related to a past earthquake occurrence anywhere in Greece along with the Thessaloniki data. It can also be used and store data from pre-seismic inspections of buildings. User-friendly entry tools in Microsoft Excel and Microsoft Access have been developed for the quick and reliable input of inspection details in the database (fig. 3).

Figure 3. An example of a page of the Microsoft Access entry tool (in Greek)
The fields of the SEISIMPACT-THES database are organized into the following groups:

- Location (address: street name and number) of building and relevant information
- Geometric characteristics of the building
- Main use of building
- Structural type
- Inspection results - damage
- Estimation of Structural Capacity
- Capacity Curve - Vulnerability Curve
- Cost of repair
- Characterization of soil properties

Table 2 shows an example of the structure of the SEISIMPACT-THES main database concerning the observed damage of a particular building.

<table>
<thead>
<tr>
<th>Field code</th>
<th>Description</th>
<th>Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>A5.1</td>
<td>Safety classification of building</td>
<td>K1=Green</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K2=Yellow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K3=Red</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K4=Collapsed</td>
</tr>
<tr>
<td>A5.1a</td>
<td>Valid only for part of building</td>
<td>K1=Yes, K2=No</td>
</tr>
<tr>
<td>A5.2a</td>
<td>Damage to plaster</td>
<td>K1=Yes, K2=No</td>
</tr>
<tr>
<td>A5.2b</td>
<td>Damage to brickwork</td>
<td>K1=Yes, K2=No</td>
</tr>
<tr>
<td>A5.2c</td>
<td>Damage to slates</td>
<td>K1=Yes, K2=No</td>
</tr>
<tr>
<td>A5.2d</td>
<td>Damage to beams</td>
<td>K1=Yes, K2=No</td>
</tr>
<tr>
<td>A5.2e</td>
<td>Damage to pillars</td>
<td>K1=Yes, K2=No</td>
</tr>
<tr>
<td>A5.2f</td>
<td>Damage to concrete walls</td>
<td>K1=Yes, K2=No</td>
</tr>
<tr>
<td>A5.2h</td>
<td>Damage to roof</td>
<td>K1=Yes, K2=No</td>
</tr>
<tr>
<td>A5.3</td>
<td>Number of unusable households</td>
<td></td>
</tr>
<tr>
<td>A5.4</td>
<td>Access to certain parts of building denied</td>
<td>K1=Yes, K2=No</td>
</tr>
<tr>
<td>A5.5.</td>
<td>Disconnection of facility networks</td>
<td>K1=Electricity,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K2=Water, K3=Gas</td>
</tr>
<tr>
<td>A5.6</td>
<td>Is propping necessary?</td>
<td>K1=Yes, K2=No</td>
</tr>
<tr>
<td>A5.7</td>
<td>Elements that must be urgently pulled down</td>
<td>Short description</td>
</tr>
</tbody>
</table>

3 THE SEISIMPACT-THES GEOGRAPHIC INFORMATION SYSTEM

On the basis of the above-mentioned information, a Geographic Information System is being developed using ESRI’s ArcGIS and ArcIMS software. The ultimate purpose is to provide support for making decisions based on spatial and descriptive data. GIS will be also invaluable for collecting, maintaining and using geographic information, as well as for producing both standardized and customized cartographic products (Savvaidis and Ifadis 2000).

The SEISIMPACT-THES GIS system is based on a detailed digital map of the greater Thessaloniki area. The map displays city blocks and roads as well as different municipality boundaries. Addresses of buildings whose damage has been stored in the database described in the previous paragraph are being linked to their geographical location on the map through an address-matching procedure (fig. 4). Additional layers of information include seismological and geotechnical data, such as historical and instrumental seismicity, maximum values of peak ground acceleration (PGA map) using empirical relations, values of maximum spectral acceleration in discrete periods (PSA map) depending on the target scenario earthquakes considered, tectonic lines, site effects – expressed as mean values of shear – wave velocity if available.
Spatial analysis based on the combined use of geographic and descriptive data may result into an evaluation of the reliability of the buildings. Spatial queries will involve several types of question:

- Safety classification (red – yellow – green) of a specific building (or buildings in a region)
- Damage a specific building had suffered (or buildings in a region)
- Locations (buildings) at which a specific type of damage had occurred.

The application is intended to be accessible by authorized users over the Internet, instantly providing information about recorded damage as well as related geographical information. The GIS user would point with the cursor to a location on the map displayed or type in the address of a building, and retrieve information about the damage or other characteristics of the selected data layers related to that location. Also, the user would have the ability to find locations that meet certain criteria, such as “close to a road”, “on a specified geologic formation or soil type”, “more than one type of damage”, and so on. The selected locations could either be highlighted on screen, or shown on a new view. On both cases, interactive visualization will play an important role.

Furthermore, the stored data and the spatial analysis results will be employed for a better understanding of the role of site effects in the amplification of the ground motion and studying of nonlinear phenomena. A microtremors study in the city of Thessaloniki is planned to be done as well as geophysical measurements in specific sites for which geotechnical data are not available. A rich database of waveforms from the weak and strong motion from earthquakes that occurred in the broader area has already been available to the SEISIMPACT-THES research group. These data come from the accelerograph network and the telemetry seismological network operated by two of the participants. All these data put together will give the opportunity to do a detailed study of site – effects, to test synthetic models against the original observations, and refine their parameters. Thus, amplification – reduction curves can be estimated for practical engineering analysis.
The next main target is to see what the past can teach us about the future by simulating the expected ground motions from a number of possible scenarios of earthquake occurrence from the rupture of nearby faults. Thessaloniki is not vulnerable to an earthquake which will have the same focus as the 1978 one in the sense that the return period of the rupture form the same fault is large. But the city is vulnerable from the rupture of other faults that are clearly observed on the geologic maps, seen in the topography, in satellite photographs, and detected from offshore geophysical prospecting. To estimate the parameters of the expected ground motion in terms of acceleration, velocity and displacement, the good knowledge of the focal mechanism of the expected events, their parameters, and the previous experience collected over the years will be utilized (Benetatos and Kiratzi, 2004; Roumelioti et al., 2003a, b; 2004a, b). As a result of this approach, a clear view of the Fourier spectra of key parameters of strong ground motion from future modeled events near the metropolitan city of Thessaloniki will be identified. In this way when the epicenter of the earthquake is in the broader area of Thessaloniki there will be an immediate presentation of the predicted damage. Finally, a number of scenario regarding earthquakes affecting the built environment of the Prefecture of Thessaloniki will be produced and tested on the basis of the information stored in the SEISIMPACT-THES database and GIS concerning the real damage the buildings had suffered in Thessaloniki (Kiratzi et al., 2004).

4 CONCLUSIONS

The project implementation is expected to result in benefits for the state, the scientific institutions and the companies participating in the project as well as for citizens. The exploitation of the rich database with the description of damage of the 1978 earthquake will result to a complete electronic file of inspections properly standardized so that it can be linked to the geographic data of the Geographic Information System. The database structure will allow multiple queries and processes, to study in depth the behavior of buildings in Thessaloniki, and its correlation with other geological, geophysical, geotechnical factors.

The public organizations concerned with the relief of earthquake impact will have the possibility to retrieve important information regarding the static behavior of buildings as well as the expected damage according to several scenario earthquakes. A new market of services will be created with benefits for the while range of involved parties (Public Services, engineers, notaries, lawyers, seismologists, individuals).

The participating institutions can use the above-mentioned data for further research and contribute to knowledge regarding consequences of seismic phenomena to various sectors of the social, economical and technical activity.

Therefore, the benefits for the scientific community can be summarized to the following:

- A detailed evaluation of the observed damage in the buildings of Thessaloniki taking into account the spatial distribution of different types of damage with the help of the GIS system.
- Improvement – Development of methodology for the effects of local conditions using microtremors.
- Improvement – Development of methodology for determination of geophysical ground properties by deployment of special networks
- Comprehension of the consequences of various seismic scenarios to the built environment of Thessaloniki.
- Strong motion simulation in various locations of Thessaloniki from a future strong earthquake.
- Evaluation of the reliability of methodologies based on the earthquake of 1978.

Benefits for companies are summarized as follows:

- Know-how increase through their collaboration with scientific institutions of the project on post-seismic inspection data management and generally issues of managing and processing geographically distributed information.
- Gain important experience through the implementation of a complex information system that interconnects a specialized database, a GIS and a Web application.
• Ability of know-how development in mobile applications for mobile computers (PDAs) and in location-based applications.
• Opportunity for commercial exploitation of an innovative system, both by providing a service over Internet, and reselling a stand-alone application software package.

Finally, even the individual citizen will be able to make very quick retrievals of specified information in many combinations and with different criteria, e.g. to easily locate areas with specific characteristics such as distribution / concentration of buildings characterized as green, yellow or red, buildings with particular damage (in relation to their spatial distribution, year built, number of floors) etc.

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