

Risk Analysis IV 2004, WIT Press, Southampton, pp.12-22

Seismic Hazard Simulation And Risk Reduction Training Algorithm For The City Of Patras-Greece

G-A. Tselentis, A. Serpetsidaki, F. Gkika, E.Sokos, L. Danciu & P.
Paraskevopoulos

Seismological Laboratory, University of Patras, Greece.

Abstract

A software package with a friendly user interface has been developed for training engineers, geoscientists and city officials in all the subjects of seismic risk assessment and its reduction. As a pilot city we selected the city of Patras which is a representative middle size S. European city consisting of a great variety of old and new buildings, very complicated geology and very high seismic risk. The algorithm permits the trainee to experiment with the various components of seismic risk, starting from the selection of seismic sources, to the effect of local geology and vulnerability of buildings. It can provide for each scenario earthquake and ARCVIEW based GIS system detailed strong motion acceleration scenarios, distribution of intensities and effects on buildings. A very detailed data base containing all the geological conditions and building details of the city has been constructed and linked to this tool and can also provide site specific design spectra to any construction site of the city.

Keywords: Seismic Risk, Seismic Scenario, Vulnerability

1. Introduction

It has been estimated that within 50 years, more than a third of the world's population will live in seismically and volcanically active zones (Rundle [5]). Thus, an urgent need for the development of methodologies for reducing the seismic risk in modern cities arises.

The existing historical data on earthquakes are insufficient for predicting seismic events at any particular location, although rich data on their occurrence and magnitudes may exist on an aggregated (say regional) level. Potential damages in a particular location may be unlike anything that has been experienced in the past.

In recent years, it has become clear that strategies for seismic risk mitigation might usefully be based on catastrophic modelling and seismic scenarios. A central aspect of this new approach is simulating the performance of buildings and bridge systems, (broadly defined to include the foundations, soil, and non-structural components), during and after an earthquake to assess impacts in terms of direct loss, functional loss and casualty loss.

The development of information technology (IT) in the last two decades provides a wide support for the seismic risk management and mitigation activities. The advances in computing systems, software and communication technologies have brought new development in the seismic risk mitigation approaches, especially in risk management and information support and training (e.g. Koike [2]).

2. Description

Although Greece is a country that has suffered a lot from earthquakes in the past, there has not been any significant effort towards emergency planning, specialized risk reduction training and decision support. Decision makers in Greek cities need a concrete evaluation of the possible impact of future major seismic events. The present project is a combination of IT and state of the art seismic hazard assessment methodologies in order to provide to the authorities of a typical Greek city a tool for creating earthquake scenarios at pre and post earthquake level.

Experts of various disciplines, including seismologists, engineers, planners, geologists and computer scientists, cooperated together in an actual multidisciplinary process to develop this useful tool.

2.1 Objectives

The principal objective of this work was to show that a successful earthquake mitigation program can be implemented in each earthquake prone city, based on the following steps:

- identify, analyze and map seismic hazard in the city, related to seismic source zone, peak ground acceleration and its secondary effects such as liquefaction, landslide and fires.

- Identify the vulnerability of the city towards earthquake related to the physical infrastructures condition, exposure of the city, social and economic conditions.
- Disseminate the lesson learned through a collaborative network of disaster mitigation advocates in various parts such as city authorities, engineers and various agencies on a national and regional level.

3. Seismic hazard assessment

The principal stage of any seismic risk mitigation attempt is a realistic assessment of hazard in such a way that its output may be used to assess expected level of damage to buildings or to urban and regional systems using the following well known approach:

$$Risk = Hazard * Vulnerability \quad (1)$$

Many methodologies have been proposed in the literature to identify the various parameters of seismic hazard, among those, two models are widely used in the engineering related community: the probabilistic and the deterministic approaches. The first provides a fairly reliable forecast of what can be called “standard seismic input”, that is the probability that an earthquake of given intensity will be exceeded in a given time interval, using data stored in earthquake catalogues and relying on propagation models.

On the contrary the second evaluates the ground motion in a given area starting from a hypothetical source with a given strength, according to a propagation law. To set the parameters and the propagation law a sort of geostructural model of the area must have been previously prepared.

3.1 Seismic sources

One of the most important parameters for assessing the seismic hazard of a city is the identification of all possible earthquake sources (faults) that have significant potential for future earthquakes. During this step we try to identify the causative fault and to estimate the extent of fault rupture. It is important to estimate fault rupture lengths and their locations since ground motion patterns will depend on the distance to the fault rupture plane.

Knowledge of rupture length is critical for large earthquakes that generate long or multiple segment ruptures. Smaller events may be modelled as point sources with little or no linear rupture length. One of the more important tasks associated with this step is identification of the causative fault. In Western Greece, where fault systems are complex, it may be difficult to initially determine the causative fault. This identification is further complicated by the presence of faults that do not break the surface or blind thrust faults.

During this stage of the project we investigated all the existing information describing the tectonics of the region, (maps, published and unpublished reports, historical data etc.) and tried to recognize all possible faults that might affect the city of Patras. In addition we digitised the existing geological and neotectonic maps and correlated them with historical and recent seismicity as well as with microearthquake seismicity, which resulted from a 10 years operation of the University of Patras microearthquake network operating in the region

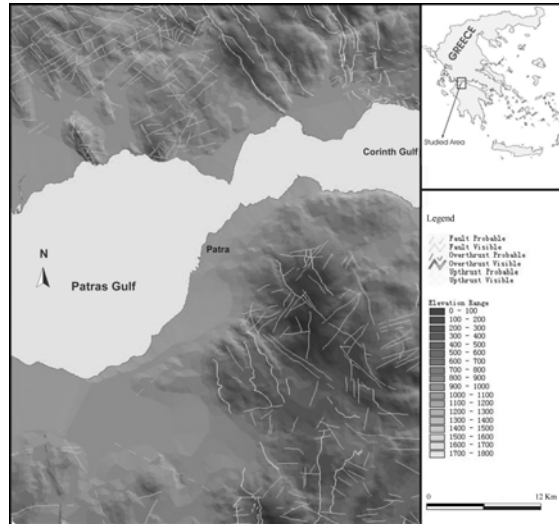


Figure 1: Three-dimensional topography map with superimposed faults.

We ended up with a GIS Arcinfo-based platform containing all the Geological, topographic, neotectonic and seismic information with all possible faults identified and coded as 1) active, 2) probably active, 3) inactive, 4) probable fault (Fig.1,2).

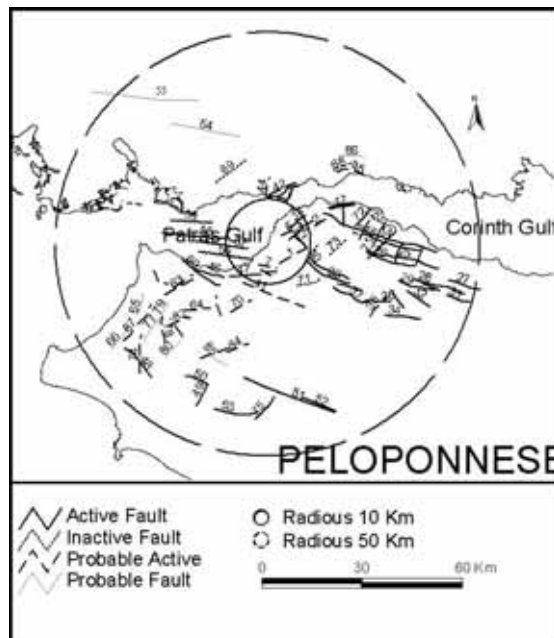


Figure 2: All potentially dangerous faults have been entered in the GIS base.

FAULTS			
ID:	1	AREA:	South of Perivola, Elekistra
LENGTH (km):	3	SLIP (m):	250
DIP DIRECTION:	NNW		
MAXIMUM SLIP (m):	360		
WIDTH (m):	5500		
STRATIGRAPHIC AGE:	700		
SLIP RATE (mm/yr):	0,51		
RUPTURE AREA (m ²):	4,40E+07		
MAGNITUDE (M):	5,6	MAGNITUDE (M*):	
Coseismic Average Slip u (m x 1/10):	2,2		
Recurrence Interval R:	430		
Distance from Patras (km):	8,38		
Acceleration (g):	0,17		
Characterization:	Probably Active - Normal		
Data Source:	Neotectonic Map of Patras		

Figure 3: A fault database containing all relevant to each fault information is linked to the GIS module.

Furthermore, a fault database was constructed and linked to the GIS platform containing all the relevant to each fault information such as maximum possible earthquake magnitude, fault length, fault slip, recurrence interval etc (Fig.2,3). The seismic hazard assessment module which was constructed allows also the use of various seismic attenuation formulas, for soil or hard rock, already published for Greece and the user can select various combination of these attenuation rules to obtain a mean result.

3.2 Probabilistic hazard analysis

The model for the occurrence of ground motions at a specific site in excess of a specified level is assumed to be that of a Poisson process. This follows if the occurrence of earthquakes is a Poisson process, and if the probability that any one event will produce site ground motions in excess of a specified level is independent of the occurrence of other events. The probability that a ground motion level z is exceeded at a site in unit time is thus expressed as:

$$P(Z > z) = 1 - e^{-v(z)} \quad (2)$$

Where $v(z)$ is the mean number of events per unit time in which Z exceeds z . With N seismic sources, and seismicity model parameters S_n for each source n , the mean number of events pr. unit time in which ground motion level z is exceeded can be written as:

$$v(z) = \sum_{n=1}^N v_n(z|S_n) \quad (3)$$

where

$$v_n(z|S_n) = \sum_{i,j} \lambda_n(M_i|S_n) P_n(r_j|M_iS_n) G_n(z|r_jM_iS_n) \quad (4)$$

$\lambda_n(M_i|S_n)$ is the mean number of events per unit time of magnitude M_i ($M_i \in [M_{min}, M_{max}]$) in the source n with seismicity parameters S_n . $P_n(r_j|M_iS_n)$ is the probability that a significant site-source distance is r_j , ($r_j \in [r_{min}, r_{max}]$) given an event of magnitude M_i in source n with seismicity parameters S_n . $G_n(z|r_jM_iS_n)$ is the probability that the ground motion level z will be exceeded, given an event of magnitude M_i at distance r in source n with seismicity parameters S_n . The three functions $\lambda_n(M_i|S_n)$, $P_n(r_j|M_iS_n)$ and $G_n(z|r_jM_iS_n)$ model the inherent stochastic uncertainty in the frequency of occurrence and location of earthquakes, and in the attenuation of seismic waves.

Given that the mean number of events per unit time for which Z exceeds z is expressed for example as $1/T_R$, where T_R is the return period (inverse of annual exceedance probability), then the number of events in a time period T (e.g. the life time of a certain construction) for which Z exceeds z is given by T/T_R and the probability for Z exceeding z during that life time T is given by:

$$P(Z > z) = 1 - e^{-T/T_R} \quad (5)$$

For a lifetime T of 50 years and a return period T_R of 475 years (annual probability of exceedance 0.211×10^{-2}) the probability for Z exceeding z becomes 0.1, corresponding to 90% probability that this size ground motion is not exceeded in 50 years. With several seismic sources, described through particular model parameters, the mean number of events per unit time in which the ground motion level is exceeded can be expressed specifically, involving functions that model the inherent stochastic uncertainty in the frequency and location of earthquakes, and in the attenuation of the seismic waves.

Besides this natural uncertainty, there is also an element of uncertainty associated with the variability of model parameters. This source of uncertainty is accounted for by regarding these parameters as random variables, whose discrete values are assigned weights reflecting their likelihood.

The algorithm outputs directly the Probabilistic Seismic Hazard Analysis (PSHA) in contour maps of acceleration (in g) that has a 90% probability of not being exceeded in various returning periods for the seismic basement of the region of Patras. The hazard calculations are been performed using the SeisRiskIII algorithm by Bender [1]. A typical result for a return period of the next 50 years is depicted in (Fig.4).

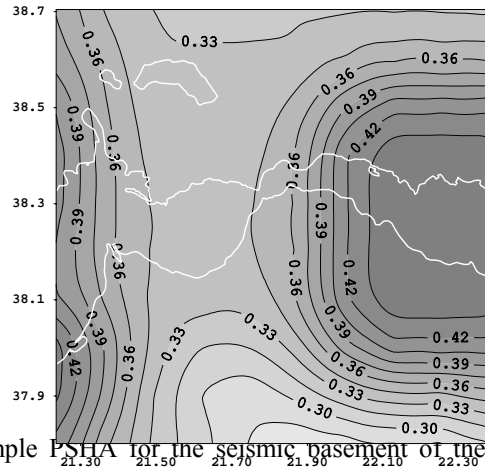


Figure 4: Sample PSHA for the seismic basement of the region for 50 years return period.

As we would expect the PSHA computed peak ground acceleration for the city of Patras is rather high ($\sim 0.3g$) which is in good agreement with the high seismicity of the area. Moreover using the above procedure we were able to compute the contribution of each seismic source to the total seismic hazard for various frequencies of ground motion. From the above analysis we found out that the most threaten seismic source for the city of Patras, in a broad frequency band is the Patraikos – Corinthiakos zone. Only at long periods ($> 2\text{sec}$) of ground motion the contribution of the seismic sources located in central Ionian ,about 100Km to the West, (which historically can generate earthquakes of magnitude of the order of 7) start to be significant. This result indicates that these zones should be taken into consideration during the stage work of strong ground motion synthesis and finally in the scenarios that will be computed.

3.3 Assessment of seismic motions at the surface

Since we are interested in estimating surface ground motions at this point, a conversion methodology between seismic basement ground motions and surface motions is needed. For this purpose, we have chosen to use two computing methodologies. Two dimensional finite element method is applied to estimate the city of Patras basin amplification effect up to 1Km depth for periods longer than 3 sec. One dimensional multi-reflection method is also applied to estimate the local amplification effect at shallow layers for periods shorter than 3 sec.

In order to account for variations in local ground conditions from firm alluvium (seismic basement), extensive geophysical surveys, site soil classifications and local geotechnical investigations have been carried out.

4. Damage assessment

The estimation of damage and casualties follows basic damage equations. In general, the following equation is used:

$$\text{Damage} = E[\text{Damage}|\text{Intensity}] \quad (6)$$

where $E[]$ represents the expected or mean value of damage given a particular Intensity level. That is, once the intensity is known for a particular site, the appropriate damage algorithm is selected and damage is estimated based on the observed intensity. Equation (6) is generally referred to as a damage function or algorithm. The development of these damage algorithms have been assessed throughout a detailed study depicted below.

The objectives of this stage were first, to evaluate the interdependence between ground motion integral parameters (Arias Intensity, Characteristic Intensity Cumulative Absolute Velocity) and diverse damage indices and to estimate the suitable acceleration threshold for CAV calculation; second, the overall structural damage (OSDI), the maximum inter-storey drift (ISD) and the maximum floor acceleration (MFA) are the damage indices used to relate the structural and non-structural damage. Non-linear dynamic analysis is carried out for 3 different reinforced concrete plane frame designed according with Euro code 8 and 2. The data used for this study consist on 205 earthquake records for Greece.

Ground motion integral parameters (GMIPs) are characterized by a single numerical value, thus all the existing damage in the structural or non-structural elements should be reflected by a single numerical value. Having in mind this, most widely used index, *overall structural damage index (OSDI)* (Park [3]) has been selected to characterize the structural damage;

$$OSDI = \frac{\sum_{i=1}^n DI \cdot E_i}{\sum_{i=1}^n E_i} \quad (7)$$

where:

DI local damage index after Park & Ang; E_i total absorbed energy of the *i*-th member under cycling loading of the structure. Interstorey drift (ISD) is the maximum relative displacement between two storey normalized to the storey height and is correlate well with observed architectural, mechanical, electrical and plumbing.

Damage classifications are necessary to characterize structural and non-structural damage during ground motion excitation. Table 1 presents the criteria for damage classification used for Patras. The outcome of dynamic non-linear dynamic analysis of the structures for all examined accelerograms has been the calculation of the final OSDI for each seismic excitation. An OSDI equal 0.0 denotes that the structures remain in the elastic region during the excitation.

Table 1: Damage classification limits

	DAMAGE			
	Low	Medium	Large	Total
<i>OSDI</i>	0.3	$0.3 < OSDI < 0.6$	$0.6 < OSDI < 0.8$	> 0.8
Architectural	0.5	$0.5 < ISD < 1.2$	$1.2 < ISD < 1.7$	> 1.7
<i>MFA</i> [g]	0.2	$0.2 < MFA < 0.8$	$0.8 < MFA < 1.25$	> 1.25

To measure the strength of the suspected relationship between damage indices and the ground motion parameters (GMIPs) two simple coefficients have been estimated: *Pearson product-moment correlation coefficient* (r) and *The Spearman Rank Correlation Coefficient* ([4]). To visualize the correlation among damage indices computed for three RC frame structures and seismic parameters, matrix plots like the one below (Fig.5) were made for all the indices.

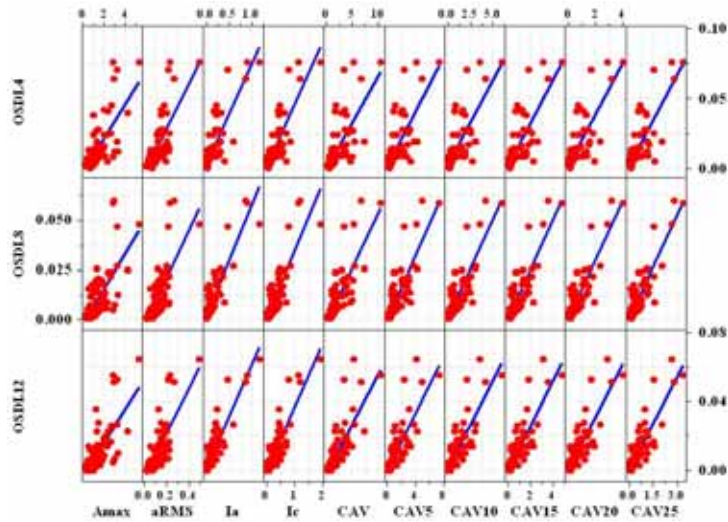


Figure 5: Matrix of least-square regression plot Maximum Floor Acceleration (three RC frame structures) versus Ground Motion Integer Parameters.

5. Earthquake Scenario generator

After having evaluated the surface expected seismic motions for a particular time period or for the activation of a particular fault a section of the city can be selected and the most probable damages can be assessed. To achieve this, a detailed building inventory has been compiled and linked to the city's GIS.

The whole system has great flexibility and a friendly user interface allowing testing various seismic scenario hypotheses and can be effectively used as a

training tool. A general structure of the developed algorithm (ASPIS) is depicted in Fig.6.

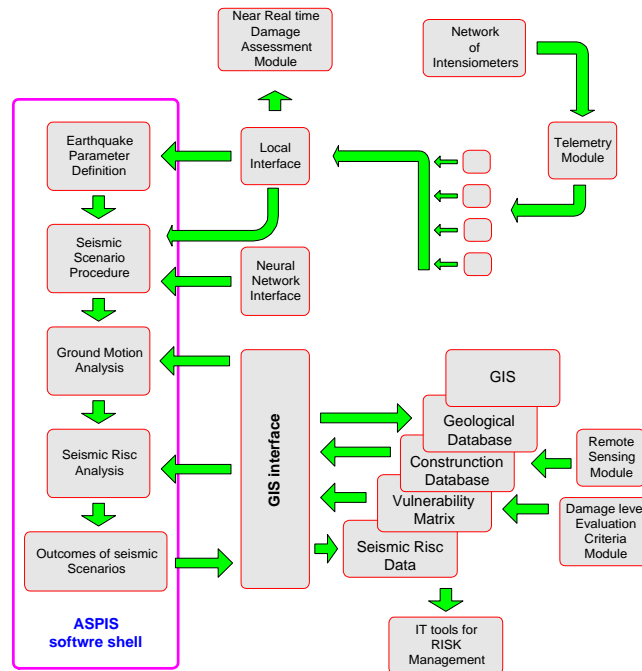


Figure 6: General structure of the developed risk assessment algorithm ASPIS.

ACKNOWLEDGEMENTS

This work has been partially financed by EC contracts SHIELDS:NNE5-1999-381 & AEGIS IST-2000-26450.

References

- [1] Bender, B.K. & Perkins, D.M., SEISRISKIII: A computer program for seismic hazard estimation, U.S. Geological Survey Bulletin 1772, pp. 1 48, 1987.
- [2] Koike, T., Imai, T. & Kaneko, T., Liquefaction Hazard Mapping of regional area by using GIS, *Proceedings 11th WCEE*, Acapulco, Mexico, 1996.
- [3] Park Y.J., Ang A., Mechanistic Seismic Damage Model for Reinforced Concrete, *Journal of Structural Engineering ASCE*, pp. 722 739, 1985.
- [4] Spiegel M.R., Theory and problems of statistics, London, Mc Graw Hill, 1992.
- [5] Rundle, J.B., Turcotte, D.L. & Klein, W., (eds), *Reduction and Predictability of natural disasters*, Addison Westley, Volume XXV Reading, MA, 1996.