PROBABILISTIC SEISMIC HAZARD ANALYSIS IN TEHRAN AND ADJACENT AREA

BY

NOUSHIN NARAGHI ARAGHI

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LIST OF SYMBOLS

M_{min}	Minimum Magnitude
M_{max}	Maximum Magnitude
a	a-value
b	b-value
M_w	Moment magnitude
$M_{w(\max)}$	Maximum moment magnitude
m_b	Body wave magnitude
M_l	Richter magnitude
M_N	Nuttli magnitude
M_s	Surface wave magnitude
M_c	Magnitude of completeness
L	Fault Length
λ	Mean seismic activity rate
M_{max}^{obs}	Largest observed magnitude
RP	Return period

LIST OF ABBREVIATION

ASCE	American Society for Civil Engineers
BHRC	Building and Housing Research Center
CL	Construction Level
DBL	Design Basis Level
DSHA	Deterministic Seismic Hazard Analysis
FMD	Frequency Magnitude Distribution
GMPE	Ground Motion Prediction Equations
GOR	General Orthogonal Regression
IBC 2006	International Building Code
IIEES	International Institute of Earthquake Engineering and Seismology
IRSC	Iranian Seismological Center
ISC	International Seismological Center
ISR	Inverted Standard Least-Squares Regression
MCDL	Maximum Credible Design level
MDL	Maximum Design Level
NEIC	National Earthquake Information Center
NGA	New Generation Attenuation
OR	Orthogonal Regression
PGA	Peak Ground Acceleration
PGD	Peak Ground Displacement
PGV	Peak Ground Velocity
PHA	Peak Horizontal Acceleration
PSHA	Probabilistic Seismic Hazard Analysis
SA	Spectral Acceleration
SR	Standard Least-Squares Regression

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PENILAIAN KEBARANGKALIAN BENCANA SEISMOS DI TEHRAN DAN KAWASAN BERHAMPIRAN

ABSTRAK

Dalam kajian ini, analisis kebarangkalian Bencana Seismos (PSHA) telah dilakukan di Tehran dan di kawasan sekitarnya. Penilaian Kebarangkalian Bahaya Seismos (PSHA) merupakan prosedur yang sering digunakan secara meluas dalam penilaian bencana seismos. PSHA memaparkan kebarangkalian semulajadi bencana seismos dengan mengintegrasikan semua sumbangan magnitud gempa bumi yang berkemungkinan serta lokasi dalam bentuk yang konsisten. Katalog gempa bumi yang seragam adalah penting dalam penilaian bencana seismos. Dalam kajian ini, sebuah katalog gempa bumi Tehran dan kawasan sempadannya telah dikumpulkan dengan mengabungkan bank data antarabangsa dan tempatan. Pempiawaian katalog dalam perihal magnitud telah dicapai dengan mengubah kesemua jenis magnitud kepada magnitud momen dengan menggunakan kaedah regresi ortogon. Dalam katalog baru yang disatukan, semua kejutan lanjuran dan kejutan depan telah dikesan dan dibuang dari katalog. Kawasan kajian ini dibahagikan kepada dua kawasan seismos berasaskan kepada rejim seismotektonik. Sumber seismos telah didefinisikan sebagai sumber sesaran dan sumber kawasan. Parameter keseismosan dan magnitud kelengkapan minimum telah dihitung berasingan bagi sesar-sesar dan setiap zon seismos dalam kawasan tersebut. Empat hubungan pengecilan dan tiga hubungan pengecilan NGA baharu telah dipilih dan diambil kira dalam kajian ini. Puncak pecutan bumi (PGA) tidak mencukupi untuk mereka bentuk kod bangunan moden maka PGA dengan nilai pecutan spectrum telah dianggarkan dan digunakan dalam tempoh masa 0.2 dan 1.0 s.

Analisis bencana seismos telah dilakukan pada beberapa titik terpilih dan peta bencana bagi puncak pecutan bumi mendatar dan pecutan spektrum (T=0.2 saat dan T=1.0 saat) bagi jangka pulangan yang berbeza (475, 975 dan 2475 tahun) telah dihasilkan dan dibandingkan dengan hasil yang sedia ada dalam literatur.

Peta dalam kajian ini menunjukkan tahap anggaran yang lebih tinggi puncak pecutan bumi dan respon pecutan spektrum yang dijangka dalam pelbagai tempoh pulangan daripada yang dihasilkan dalam kajian sebelum ini. Model baru itu dijangka menghasilkan pengubahsuaian besar untuk kod bangunan.

PROBABILISTIC SEISMIC HAZARD ANALYSIS IN TEHRAN AND ADJACENT AREA

ABSTRACT

In the current study, probabilistic seismic hazard assessment (PSHA) for Tehran and adjacent area has been performed. Probabilistic seismic hazard analysis (PSHA) is the most widely used procedure for seismic hazard assessment. PSHA displays the probabilistic nature of seismic hazard by integrating the contributions of all possible magnitude earthquakes and locations in a consistent manner. A uniform earthquake catalogue is an essential tool in any seismic hazard analysis. In this study, an earthquake catalogue of Tehran and adjacent areas was compiled by merging international and local databanks. The standardization of the catalogue in terms of magnitude was achieved by the conversion of all types of magnitude into moment magnitude by using the orthogonal regression technique. In the newly compiled catalogue, all aftershocks and foreshocks were detected and eliminated from the catalogue. The study area is divided into two seismic regions based on their seismotectonic regime. The seismic sources have been defined as fault sources and area sources. The seismicity parameters and minimum magnitude of completeness were calculated separately for the faults and each seismic zone in the area. Four attenuation relationships and three new generation attenuation relations (NGA) have been selected and considered for this study. Peak ground acceleration (PGA) is not sufficient to design for the modern building codes, so PGA along with spectral acceleration values have been estimated and used in period of 0.2 s and 1.0 s.

Seismic hazard analysis was performed in selected points and the hazard maps for horizontal peak ground acceleration and spectral acceleration (T=0.2 sec and T=1.0

sec) for different return periods (475, 975, and 2475 years) have been produced and compared with those available in literature.

Maps in this study show higher estimate levels of peak ground acceleration and response spectral accelerations expected in various return periods than those produced in the earlier researches. The new model is therefore expected to result in considerable modifications to the building code.

CHAPTER 1

INTRODUCTION

1.1 General background

Vulnerability due to earthquake in many places of the world is seemed to be increasing. The number of victims and damages particularly in the developing countries could be addressed increasing because of over population, poor construction works and lack of useful building codes.

Iran is among the most seismically active places on the world. Over the last number of years, many people died and encountered social and economic problems. Iran has been host to a long series of large damaging earthquakes. There have been roughly 126000 deaths attributed to 14 of magnitude of 7 and 51 earthquakes of 6 to 6.9 that have occurred in Iran since 1900. During this period nine cities were destroyed. Review of historical seismic data shows that every part of the country has been hit by major earthquakes.

For example, during the 1990 Rudbar earthquake (moment magnitude =7.3) in northwest Iran, more than 40000 people lost their lives, more than 50000 became homeless, nearly 100000 buildings were destroyed, three cities and 700 villages were demolished. In December 2003 an earthquake measuring moment magnitude of 6.6 devastated the city of Bam, 1,000 kilometer southeast of Tehran 31,000 people were killed.

Report on these seismic events demonstrates nearly all part of the region is being suffered and has gone under experiences of the severe economic process and social damages by major earthquakes.

Hence, it is important for the scientists and engineers to reduce such destructions through scientific research and development. A useful map is used as an aid for the sustainable development and can explain seismic hazard through the understanding and uses of seismogenic faults, ground motions, existing building codes or any relevant associated parameters (Gholipoor et al., 2008).

1.2 Natural hazards

Any undesirable event in any system is hazard. Natural hazard indicates the occurrence of a natural risky event in a in a defined space and time. Natural hazards tend to be harmful and often create damage to the physical as well as social on short time and long-term basis because of their effects, thus hazards are the consequence of instant changes within long-term behavior caused by minute. These hazards are highly relevant to geomorphology while they are important parts of the Earth's surface dynamics (Alcantara-Ayala, 2002).

Rapid changes due to Earth system processes could rearrange the planet's surface in a moment with consequences for both natural systems and people's welfare and livelihoods (Young and Leon, 2009). Cities are definitely more vulnerable to disasters because of the density of buildings, population, and infrastructure. Unfortunately, many urban as well as rural dwellers live near the coasts or active seismic faults and are subject to natural hazards like hurricanes, landslides or earthquakes (Montoya and Masser, 2005).

1.3 Earthquake hazards

Earthquakes tend to be the most harmful associated with natural hazards. Earthquake happens because of unexpected instant movement of the ground as a result of release of elastic energy in a matter in couple of seconds. Earthquakes happen sudden and affect large area so the impact of the event is harmful. They could lead to huge loss of life and property and disturb important services including sewerage systems, communication, power, water supply transportation and many others.

Earthquakes demolish cities, towns and villages and destabilize the economy and social structure of the region. Earthquakes lead to huge damage in lifelines, structures and other facilities for prepared and less prepared regions in spite of awareness and mitigation attempts. Consequently, it is essential to create plans that could set priorities for prevention, reduction, and compensation for regions. Government and public awareness could play fundamental role in reducing human and financial losses due to earthquakes if decision makers know what could be done in advance to reduce hazards (Momani, 2011).

Seismic hazard assessment research is actually important for identification of the zones with various hazards that will help doing additional risk studies, land use planning and updating construction codes.

The energy released by an earthquake sets many processes into action, and may have both short-term and long-term consequences. Some of the hazards make effect immediately, and others may not appear for days, weeks, or months after the event. Earthquakes are associated with a wide variety of specific hazards, including primary effects such as ground motion, ground breaks (or faulting), mass wasting and liquefaction.

Secondary and tertiary hazards are indirect effects, caused by events initiated by the earthquake. These may include explosions, tsunamis and fires caused by interruption of pipelines utilities (Kusky and Kushy, 2008).

1.4 Seismic hazards and risks of study area

Seismic hazard analysis is the evaluation of the maximum amplitude of some ground motion parameter (peak ground acceleration, peak ground velocity, relative displacement, etc.) expected to occur once at a certain site or area within a particular time span. This time span is referred to the return period, which is the reciprocal of the annual probability of occurrence of certain amplitude (Thenhaus and Campbell, 2003).

Seismic hazard is often displayed on a ground motion hazard map, which illustrates the regional differences in expected ground motion amplitude (typically PGA) at a constant return period.

The growth of population, high buildings and big cities lead to the increase in damages caused by seismic hazards. Throughout the twentieth century, huge earthquakes have caused about 90 % of direct deaths because of buildings collapsing (Lantada et al., 2009). Consequently, happening of great earthquakes and their effects in different areas during the last couple of years informs us about the necessity of hazard assessment (Mohanty and Walling, 2008). The probabilistic earthquake hazard analysis aim to estimate the likelihood function of the study area for any specified level of ground motion due to the cause of earthquakes from potential seismic sources (Hamouda, 2011). Iran situated on the Alp-Himalayan belt one of the seismic zones in the world where critical earthquakes have always been happening(Ghobadi and Fereidooni, 2012).

The Iranian plateau is famous because of recent volcanic, active faults and high surface elevation alongside the Alpied earthquake belt. Extremely high density of active and recent faults could be observed in Iranian Plateau according to the tectonic studies.

Tectonics information, the historical earthquakes data, fault activity, geology and seismic source models are used for seismic hazard map based on probabilistic seismic hazard. These maps explain the earthquake hazard of study area in the forms of iso-acceleration contour lines, and include the probabilistic estimates of Peak Ground Acceleration for different return periods.

The basis for all seismic hazard assessment is the investigation of seismicity or the occurrence of earthquake in space and time (Scawthorn and Chen, 2002; Tavakoli and Ghafory-Ashtiany, 1999).

The considered region in this research is the area including mega city of Tehran and adjacent area covers a square limited by 34.35˚N to 37.10˚N and 49.80˚E to 53.10˚E. It covers the northern central Iranian depression in the south and the central part of the Alborz mountain in the north (Figure1.1).

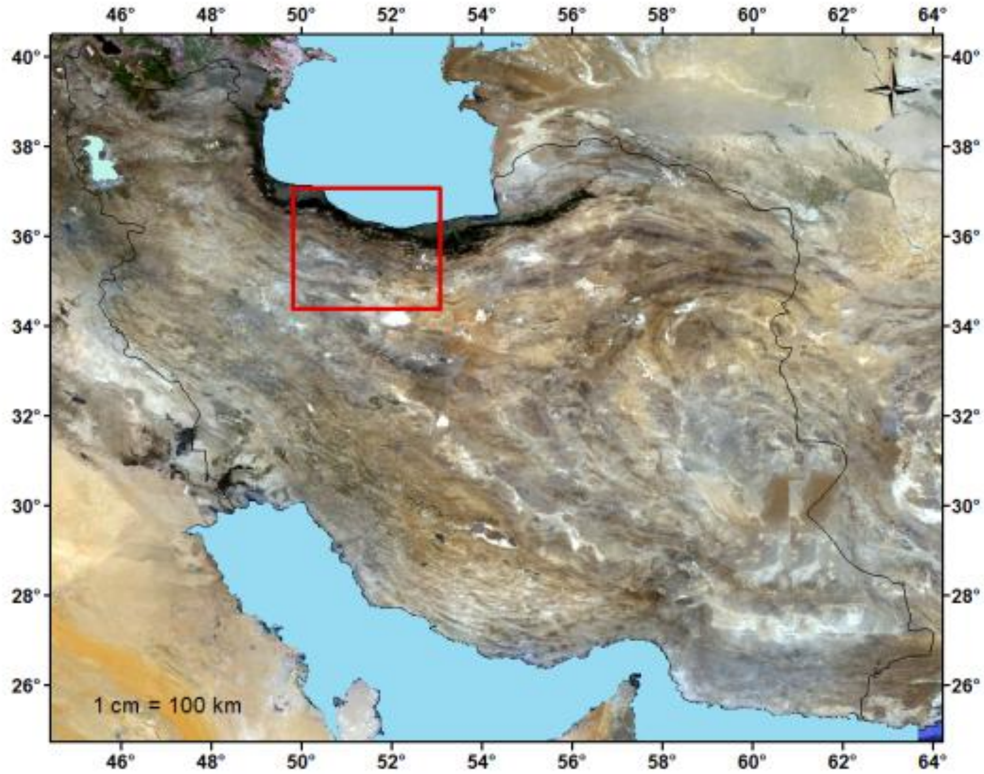

Figure 1.1 Map of Iran. Study area is inside the box

1.5 Tectonic Framework

The tectonic framework physically links the geologic, geodetic and seismological data on earthquake sources and constrains geodetic models of crustal deformation. Plate tectonic processes cause earthquake events and crustal deformation. These processes have been going on for hundreds or millions of years (Gholipoor et al., 2008).

Four major tectonic plates (Arabia, Eurasia, India and Africa) are responsible for seismicity and tectonics in the Middle East and adjacent area (Figure 1.2). The active deformation of the Iranian plateau, as a tectonically active part of Alpine-Himalayan tectonic belt is effected by the Arabian–Eurasian convergence and it makes regions with different seismotectonic features.

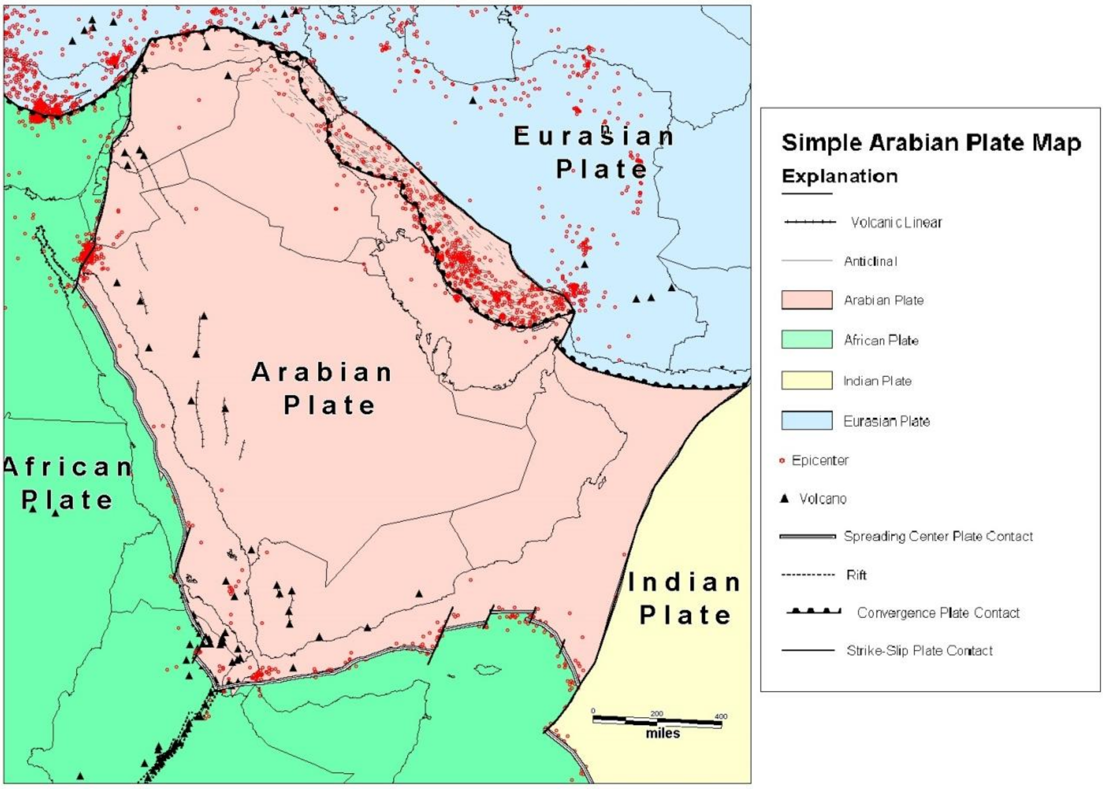

Figure 1.2 Seismotectonics of the Middle East and vicinity (Walter, 2002).

The early Quaternary tectonic history and the pre-Quaternary geological record are very important in understanding the present continental deformation during earthquakes. Iranian seismic activity is directly related to reactivation of the existing faults and it is separated into three categories:

i. The Zagros active fold-thrust belt, where shortening along longitudinal high angle reverse basement faults spread over the entire belt, is absorbed by ductile layers of the top sedimentary cover (usually no earthquake rupture is observed at the surface).

ii. The Central Iranian plateau, where the earthquakes are accompanied by surface faulting along mountain-bordering reverse faults.

iii. The Makran accretionary flysch wedge where the oceanic crust of the Oman Gulf is subducting underneath the southeastern Central Iran.

Tectonic shows movements during the late Neogene-early Quaternary and the mechanism of the recent active fault motions explains that the Iranian plateau is a broad zone of compression deformation. The plateau is a quite weak belt affected by several collisional orogenic movements and is being compressed between two blocks (Arabia and Eurasia), since 65 Million years. The compressional motion between these blocks resulted in a continuous thickening and shortening of the continental crust by reverse faulting and folding in a NE-SW direction. Situation of the Iranian plateau between two impinging zones of the Arabian plate in the west and the Indian plate in the east has provided a unique constrained convergent zone along the Alpine-Himalayan belt (Copley and Jackson, 2006).

1.6 Geology of the Study area

Systematic geological studies in Iran started in late 1960s with the establishment of the Geological Survey of Iran. The tectonic and structural setting of Iran in the Alpine–Himalayan orogenic belt, and the structural evolution of Iran, has been the focus of many studies. Using Stocklin and Nabavi (1973) was the first to publish a tectonic map of Iran. The authors divided Iran into 10 structural zones (units) based on certain geological features: Makran, the Lut Block, Eastern Iran, Kope Dagh, the Alborz mountains, the Central Iran Block, the Urumieh-Dokhtar zone, the Sanandaj-Sirjan zone, the Zagros fold belt, and the Khuzestan plain. The boundaries of these units are usually marked by faults or in some cases (mainly tectonic) depressions. This structural division remained a reference for Iranian geologists for almost three decades (Figure 1.3).

New observations and findings require a revision to this structural scheme. Following this structural division by Stocklin and Nabavi, some other structural divisions were presented that are cited in following section related to Central Iran. These newer structural schemes are mostly derived and inspired by the very first structural division presented by Stocklin(1968). In recent years, new interpretations and models have been offered regarding the geological setting of Iran (Nabavi, 1976; Eftekharnezhad, 1980; Nogol-e-Sadat, 1993; Alavi, 1996; Aghanabati, 2004).

Northern region of Tehran province is a part of Alborz mountains while southern Tehran is located in central Iran plain so Tehran province belongs to Alborz and central Iran structural zones. The boundary between these zones matches on northern Tehran thrust fault. The oldest stratigraphic units of Tehran province include a late Precambrian to mid Triassic platform sequence which emprise several geologic formations and sedimentary unconformities indicating land-forming movements during late Precambrian to mid Triassic time. These units outcrop specially on upriver regions of Karaj River.

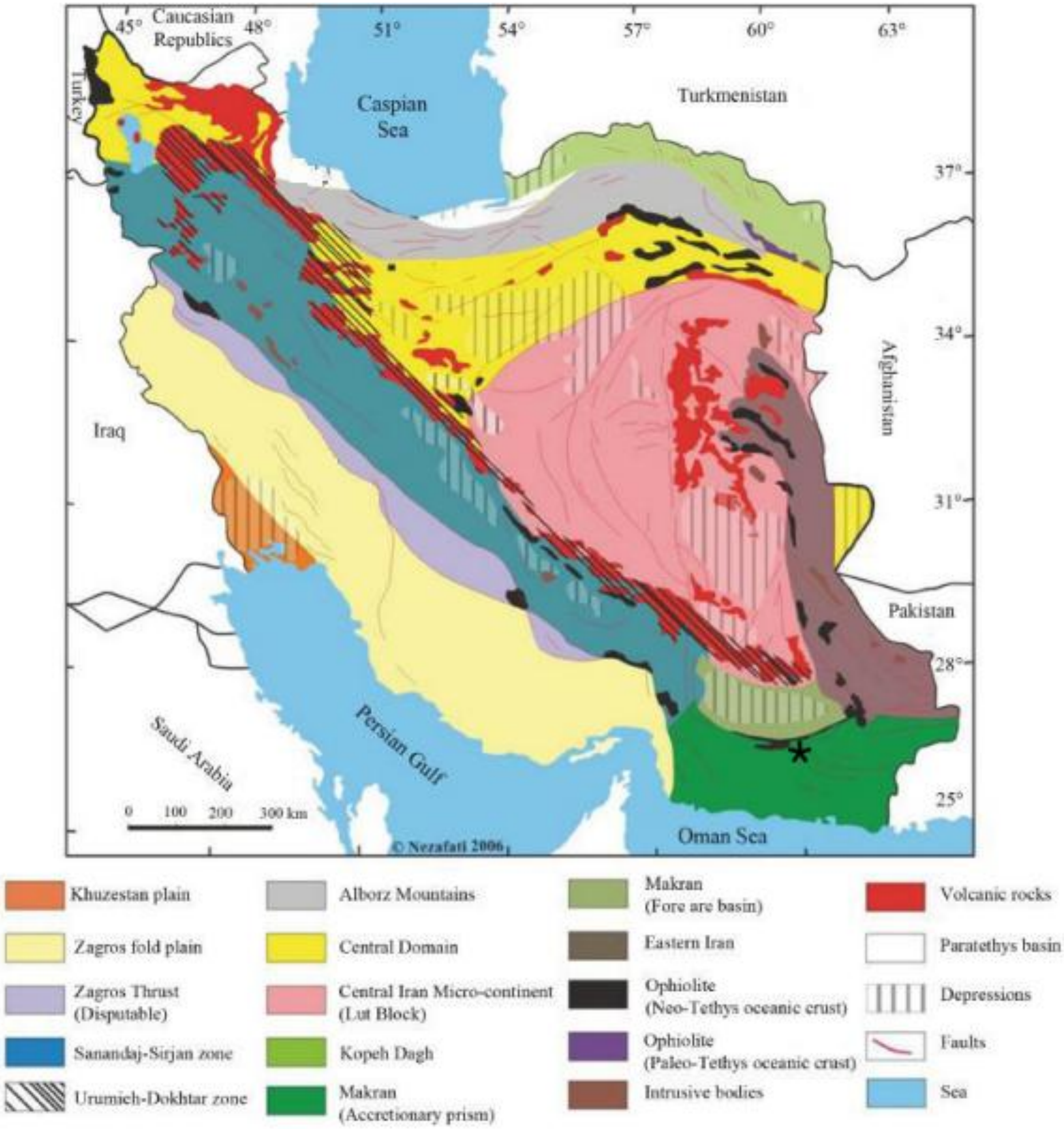

Figure 1.3 Structural zones of Iran (Stocklin, 1968)

1.7 Problem statement

People have been experiencing numerous catastrophic earthquakes all around the world. As there are no reliable means to predict the timing of these earthquakes, engineers focus on preventing significant earthquake loss by designing earthquake-resistant new structures and seismically mitigating existing structures based on proper seismic hazard analysis.

Major earthquakes in Iran have motivated Iranian scientists to map and study the seismic hazard and enhance existing building codes. The study of earthquake hazard plays an important role in the sustainable development countries like Iran, where earthquakes have occurred repeatedly.

Most researchers have concluded their seismic hazard analyses by reporting the PGA value of Iran. This value will be very useful once the analysis of structures becomes based on local Building codes for Iran. However, the analysis of a structure based on International Building Code (IBC) 2003 or IBC 2006 is not possible using PGA alone; instead, spectral acceleration values are required for a return period of 2500 years.

Within the scope of the literature review done for this study, it was established that only Gholipour et al. (2008), Hamzeloo et al. (2012) and Abdi et al. (2013) had applied estimation of spectral acceleration along with peak ground acceleration. In this study, we perform a seismic hazard analysis of Tehran and the surrounding areas and suggest spectral acceleration values in line with ASCE (American Society for Civil Engineers) and IBC 2006 (International Building Code of 2006) and improve the results by considering fault slip rates along with fault activity rate and using new generation attenuation relations .

Improve the accuracy and quality of existing data is a knowledge gap to be filled in this study. However, establishment of a local relation for converting magnitudes instead of global relations is also considered in this study, Hence, a new but a simple relation is developed for this study.

1.8 Objective of thesis

The general approach to seismic hazard evaluation is usually directed towards reducing the uncertainties at various stages of the research process by collecting a sufficient amount of reliable and relevant data. In this study, the available geophysical, geological, seismological and geodetic characteristics of the project area are evaluated. The database should be sufficient to determine the strong ground motion at the project area.

In summary the objectives of this research are:

i. To develop and update earthquake data to compile a comprehensive earthquake catalogue of the region and standardize the event catalogue in terms of magnitude to generate a uniform catalogue with moment magnitudes.

ii. To develop and validate data for faults and produce the existing fault mechanism and an effective fault map for the region for developing a comprehensive seismicity of the study area and calculating seismic parameters using available earthquake catalogues.

iii. To investigate the New Generation Attenuation (NGA) functions using the Iranian recorded ground motions to verify its applicability for use in the hazard analysis of the research for the study area and produce Peak Ground

Acceleration (PGA) and Spectral acceleration(SA) for the entire study area in different return periods.

iv. To develop new seismic hazard maps for the study area.

1.9 Significances and novelties of the study

The uniqueness and novelties of this study are as follows:

i. The study adopted a novel approach of homogenizing the earthquake magnitudes for this area.

ii. The study will be the first to build seismic hazard map of the area based on combination of new generation attenuation and the old attenuation relations considering the fault slip rate along with the activity rate to generate new hazard maps based on International building codes.

iii. The study improved the accuracy and quality of existing data.

1.10 Thesis Organization

Generally, the content of this thesis is as organized in five chapters. The components of each chapter are briefly discussed as follows:

Chapter1 presents the introduction of the study. This chapter is discussed under background of study area, problem statement, research objectives and location of the study area.

Chapter 2 is devoted to review the early studies using the two approaches of seismic hazard analysis (Deterministic and Probabilistic) However, only study on probabilistic seismic hazard is to be highlighted.

Chapter 3 deals with the methodologies adopted for the study and discuss compilation of the earthquake catalogue, by merging information from different international and local sources and conversion all magnitudes into moment magnitude. Processing of the data, which includes removing of duplicate events, homogenizing, declustering, and calculating magnitude of completeness has been carried out. The next part of this chapter summarizes geological and seismotectonic setting of the study area and includes the study of the active faults in this area and calculates maximum moment magnitude related to each fault. The last part of this chapter describes seismicity assessments, calculates seismic hazard parameters separately for each seismotectonic zone and deals with the selection of ground-motion prediction equations and explains Four ground motion equations and three new generation attenuation relations appropriate for this region. The final part of this chapter proposes model for seismic hazard assessment and illustrates the outline of the seismic hazard assessment methodology applied in the current study by using the EZ-FRISK.

Chapter 4 allows showing the results of probabilistic seismic hazard analysis in terms of maps and tables for PGA and spectral acceleration in different return periods along with comprehensive discussions.

Finally, Chapter 5 makes conclusions of the current research and contains the outcome of the hazard assessment and including recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Seismic hazard is related to any physical phenomena associated with an earthquake (ground motion, ground failure, liquefaction, and tsunami) and their effects on land, man-made structures and economic systems that have the potential to produce a loss (Kijko, 2011a). Seismic hazard analysis is a critical part of the development of design ground motions (Zhao, 2005).

There are two approaches for the seismic hazard analysis, Deterministic Seismic Hazard Analysis (DSHA) and Probabilistic Seismic Hazard Analysis (PSHA). Both probabilistic and deterministic methods have a role in seismic hazard and risk analysis performed for decision-making purposes. These two methods can complement another to provide additional insights to the seismic hazard or risk problem. One method will have priority over the other depending on how quantitative are the decisions to be made, Seismic environment and scope of the project.

Deterministic against probabilistic approaches have differences, advantages, and disadvantages that often make the use of one advantageous over the other. Probabilistic methods can be viewed as inclusive of all deterministic events with a finite probability of occurrence (McGuire, 2001).

2.2 Deterministic seismic hazard analysis (DSHA)

Deterministic seismic hazard analysis involves the quantitative estimation of ground-shaking hazards at a particular site (Kramer, 1996). In deterministic approach, earthquake magnitude is the magnitude of the largest earthquake capable of occurring on each seismic source (the maximum creditable earthquake). Faults and other tectonic features near the site are identified. A suitable attenuation equation is used to determine the ground motion at the site (Bhatti et al., 2011).

The shortest distance is selected as the source to site distance parameter for the seismic source zone. After the earthquake magnitude and distance are selected, the peak horizontal acceleration (PHA) is estimated (Reiter, 1990). The controlling earthquake is one that produces the highest PHA and the hazard in the site is formally defined in terms of ground motions produced at the site by the controlling earthquake (Reiter, 1990).

DSHA provides a framework for evaluation of worst-case ground motions. However, it provides no information about the likelihood of occurrence of the controlling earthquake. The frequency of earthquakes and resulting ground motions are not clearly considered in DSHA. The uncertainties and scientific judgment in DSHA may not be explicitly recognized and quantified. Figure 2.1 shows the steps in this approach.

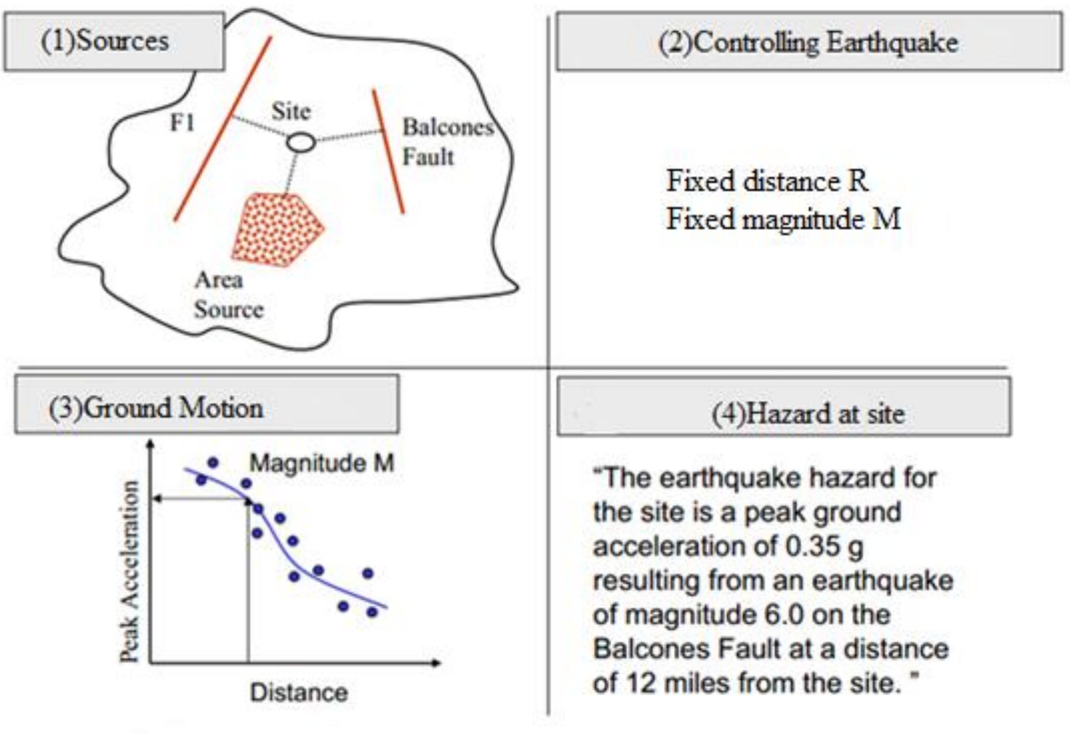

Figure 2.1 Steps in Deterministic Seismic Hazard Analysis.

2.3 Probabilistic seismic hazard analysis (PSHA)

The concept of probabilistic seismic hazard has allowed uncertainties in the size, location and rate of recurrence of the earthquake events. PSHA provides a framework which uncertainties can be identified, quantified and combined in a rational manner to provide a more complete picture of the seismic hazard (Kramer, 1996).

In probabilistic approach, site ground motions are estimated for selected values of the probability of exceedance in a specified return period. PSHA can be implemented by a four step procedure developed by Reiter, 1990 (Figure2.2):

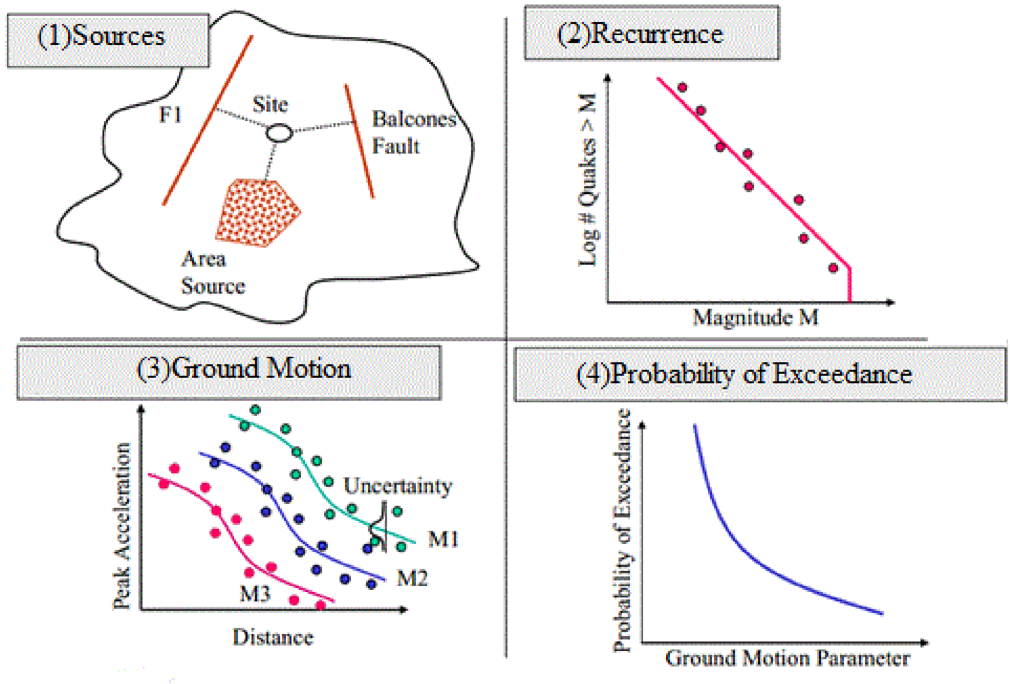

Figure 2.2 Steps in Probabilistic Seismic Hazard Analysis.

1. The first step of PSHA consists of the identification and parameterization of the seismic sources (known also as source zones, earthquake sources or seismic zones) that may affect the site of interest. These may be represented as area, fault, or point sources. Area sources are often used when one cannot identify a specific fault. In classic PSHA, a uniform distribution of seismicity is assigned to each earthquake source, implying that earthquakes are equally likely to occur at any point within the source zone. Seismic source models can be interpreted as a list of potential scenarios, each with an associated magnitude, location and seismic activity rate (Field, 2005).

2. The next step consists of the specification of temporal and magnitude distributions of seismicity for each source. The classic, Cornell-McGuire approach, assumes that earthquake occurrence in time follows the Poisson process. The most often used model of earthquake magnitude recurrence is the frequency-magnitude Gutenberg-Richter relationship (Gutenberg and Richter, 1942) .

$$LogN = a - bM \tag{2.1}$$

Where N is the number of earthquakes with a magnitude of M and a and b (b-value of Gutenberg and Richter) are constant parameters. It is assumed that earthquake magnitude belongs to the domain between M_{min} and M_{max}, where M_{min} is the level of completeness of earthquake catalogue and M_{max} is the upper limit of earthquake magnitude for a given seismic source. The parameter a is the measure of the level of seismicity, while b describes the ratio between the number of small and large events.

The seismicity of each seismic source is described by four parameters: the (annual) rate of seismicity λ, the lower and upper limits of earthquake magnitude M_{min} and M_{max} and the $b-value$ of the Gutenberg-Richter relationship.

3. Calculation of ground motion prediction equations and their uncertainty. Ground motion prediction equations are used to predict ground motion at the site. The parameters of interest include peak ground acceleration, peak ground velocity, peak ground displacement, spectral acceleration, intensity, strong ground motion duration, etc. Most ground motion prediction equations available today are empirical and depend on the earthquake magnitude, source-to-site distance, type of faulting and local site conditions (Campbell, 2003; Douglas, 2003; 2004). The choice of an appropriate ground motion prediction equation is crucial since it is a major contributor to uncertainty in the estimated PSHA.

4. Integration of uncertainties in earthquake location, earthquake magnitude and ground motion prediction equation into probability that the ground motion parameter of interest will be exceeded at the specified site during the specified time interval. The ultimate result of a PSHA is a seismic hazard curve (McGuire, 2004).

The discussion by seismologists about the pros and cons of deterministic and probabilistic seismic hazard analysis has a long history. Using these approaches depends on the design level. There are four design levels for structures:

i. Maximum Credible Design level(MCDL)
ii. Maximum Design Level(MDL)
iii. Design Basis Level(DBL)
iv. Construction Level(CL)

MCDL is used for structures with return period of 10000 years(useful life of structure) so infrastructures such as nuclear power plants or dams in most countries is still largely based on deterministic seismic hazard analysis.

MDL is considered for return period between 1000 to 5000 years. DBL and CL are used for 475 and 50 year return period respectively (ICSRDB, 2005).

Structures such as normal buildings, hospitals and schools are based on probabilistic seismic hazard assessment (Klugel, 2008).

PSHA accounts for some points that DSHA does not consider them. Activity rates (Number of earthquakes per year) vary from fault to fault in PSHA. In PSHA hazard increases from multiple faults but in DSHA the hazard for multiple faults is same as single fault (Figure 2.3).

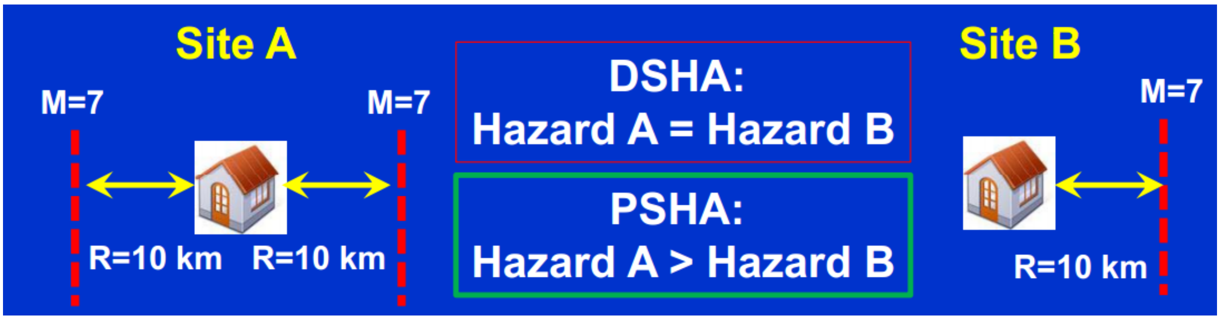

Figure 2.3 Comparison Multiple faults in PSHA and DSHA.

2.4 Previous work

Number of studies (Orozova and Suhadolc, 1999; Romeo and Prestininzi, 2000; Krinitzsky, 2002) exist in the literature which have been trying to integrate both probabilistic approach and deterministic approach in a sophisticated engineered framework.

The majority of the publications in the subject of seismic hazard analysis concentrate on the application of the probabilistic approaches at different parts of the world. New challenges in the methodologies used in its development since its formation (Cornell, 1968; Veneziano et al., 1984; Kebede and van Eck, 1996; Theodulidis et al., 1998; Kijko and Graham, 1998; Eck and Stoyanov, 1996; Lindholm and Bungum, 2000; Stirling et al., 2002; Tsapanos, 2003).

Cornell (1968) formulated the theoretical base of ‘deductive’ method developed for seismic hazard analysis and it was called ‘deductive’ because by applying this procedure, the causative sources and ground motions for future earthquakes are deducted. This approach has permitted the incorporation of geological and geophysical evidence to complete the seismic event catalogues. It is still evident that deductive procedures of PSHA are dominant and remain the most commonly used method worldwide.

On the other side, the second category of PSHA has been composed of historic methods (Veneziano et al., 1984). They require input data, such as information about past seismicity and do not require specification of seismogenic zones.

Kebede and van Eck (1997) performed a probabilistic seismic hazard assessment for the Africa based on seismotectonic regionalization. The results have been presented as the regional hazard maps for 0.01 annual probability for intensity and peak ground acceleration and made the hazard curves for six economically significant sites. They have also analyzed the model uncertainties with respect to seismicity in a novel approach by means of a sensitivity analysis quantifying them in the probabilistic seismic hazard analysis.

The purpose of the study by Theodulidis et al. (1998) has been to suggest a probabilistic seismic hazard analysis based on the local attenuation relations for peak ground acceleration and peak ground velocity. This study propose two factors, first the observed spectral acceleration amplification values and second the expected peak ground acceleration for mean return period of 500 years.

Kijko and Graham (1998) have described a new methodology for probabilistic seismic hazard analysis (PSHA) which combines the best features of the deductive and historical procedures and they called this new approach as ‘parametric-historic’ procedure. Part I of their study presents some of the statistical techniques used for the assessment and evaluation of the maximum regional magnitude. In Part II the approach of a probabilistic seismic hazard assessment, which permits the utilization of incomplete earthquake, catalogues and which takes into account uncertainty in the determination of the earthquake magnitude is described. Their technique has provided specifically the estimation of seismic hazard at individual sites, without the psubjective judgment involved in the definition of seismic source zones, in which specific active faults have not been mapped and identified .

Vaneck and Stoyanov (1996) performed a probabilistic seismic hazard analysis (PSHA) for southern Bulgaria which represents a typical case of seismic hazard for a tectonically complex region with large uncertainties in model parameters. They showed that large uncertainties in seismic characteristics have relatively little effect on the PSHA output, especially when compared with the uncertainties associated with the attenuation function. Finally, they claimed that some future improvements could be handled first by the development of more accurate regional attenuation models, second by the addition of some constraints on the seismic zones and last by a better constrain of magnitude-frequency distributions.

Lindholm and Bungum (2000) presented some examples from Norway within a seismological frame by the aid of a probabilistic seismic hazard. They highlighted the subject of how a combined seismicity analysis using both modern network data and historical data can be utilized in order to provide realistic insights into location precision and to establish magnitude homogeneity. In fact their aim has been to improve the reliability of the seismic source models (activity parameters) and to rehabilitate the spatial differentiation of the seismogenic zones. By the objective of this study they demonstrated how a seismic hazard analysis critically depends on proper analysis of the underlying seismological information such as the seismicity catalogue, the attenuation relationships and the magnitude conversions .

On the other hand, Stirling et al. (2002) have presented a new probabilistic seismic approach for probabilistic seismic hazard analysis (PSHA) to be applied in New Zealand. This new challenge added as an important feature in the analysis has been the application of a new methodology which combines the modern method based on the definition of continuous distributions of seismicity parameters with the traditional method based on the definition of large area sources and the associated seismicity parameters for the treatment of the historical seismicity data. Their PSHA has combined the modeled seismicity data with geological data representing the location and the earthquake recurrence behavior of different active faults and then incorporated new attenuation relationships specifically developed for New Zealand to these elements. They stated that the resulting maps have been currently used for the revision of the building code of the country.

Tsapanos (2003) has also developed a site-specific seismic hazard scenario to be applied to the sites located in the main cities of Crete Island in Greece in order to compute the probabilities of exceedance of specific peak ground acceleration (PGA) values and to predict the maximum possible PGA at each site. According to Tsapanos (2003). The methodology allows the use of historical or instrumental data, or a combination of both. The instrumental part of the data can be divided into subcatalogues with each having an individual minimum threshold magnitude for completeness and were published maximum possible magnitudes for each site .

Wiemer et al. (2009) have presented the results of a new generation of probabilistic seismic hazard assessment for Switzerland. This study have replaced the previous intensity-based generation of national hazard maps and was based on a revised moment-magnitude earthquake catalogue for Switzerland. Seismic parameters ($a-value,\ b-\ value$ and $M_{w(\max)}$) were estimated for earthquake catalogues of one-million-year duration .they expected ground motions in units of the 5% damped acceleration response spectrum at frequencies of 0.5–10 Hz for all of