UNIVERSITI PUTRA MALAYSIA

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM IN SEISMIC HAZARD ASSESSMENT FOR THE CENTRAL ALBORZ, IRAN

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By

SEYED RAMZAN MOUSAVI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

February 2013

DEDICATION

To my lovely wife, Khadijeh Afzali who has supported me throughout this study

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Associate Prof. Saeid Pirasteh, PhD
Faculty : Institute of Advanced Technology

The assessment of the seismic hazard of the Central Alborz in Northern Iran, expressed in terms of strong ground-motion which is demonstrated using Geographical Information System (GIS) techniques. The inability of a single hazard study to meet the needs of users and to handle the uncertainties of such analyses, demands a more user friendly procedure. GIS technology provides facilities for seismic hazard assessment which permits users to see the geographical distribution of calculated effects from different viewpoints. GIS is a powerful tool which is potentially very useful in seismic hazard analysis, seismic risk assessment and seismic zonation studies. This study applied GIS and spatial modeling using different data sets such as Digital elevation models (DEM), topographic maps, century earthquake data, and geological maps to help establish the seismic hazard assessment and analyze the tectonic history of the Alborz area. A period of historic seismicity encompassing more than 2,000 years has been collected and used as the earthquake catalogue data for this study. GIS programs are used in this research to collect, manipulate, generate and analyze various data input to seismic hazard analysis. GIS based methodology is introduced to combine available information on seismicity, tectonics and strong ground-motion. The external computer programs applied in this work are linked to the GIS, adding flexibility and analytical capabilities to the seismic hazard procedure. The traditional probabilistic approach is modified to account for detailed regional variation of seismicity parameters. Seismic hazard computer program is examined whether it is able to perform hazard analysis interactively within the GIS environment to yield acceptable results. The methodology is flexible as regards the way input data for seismic source boundaries, regional focal depth, faulting orientation, and seismogenic parameters are implemented. The procedure is capable of handling further potential site-dependent and site-specific hazard analysis.

In the proposed approach, GIS raster –based data models are used in order to model geographical features in a cell-based system. The cell- based source model proposed in this study provides a framework for implementing many geographically referenced seismotectonic factors in to seismic hazard modeling. Using GIS methods in this study,

seismic source zones are delineated based on the relationship of the observed earthquakes with the tectonic manifestations of the geological units. Maps with seismic interpretation are produced as a tool to delineate seismic source areas, to study the completeness of the earthquake catalogue, to determine the seismic activity, and to define recurrence parameters for the source areas. Various maps representing different aspects of seismic hazard are calculated and presented in this study. Probabilistic seismic Intensity maps and probabilistic ground acceleration maps are calculated based on different assumptions regarding seismicity parameters, source to- site distance, and alternative seismic source zones. Subsequently, the uniform hazard spectra are calculated in some major cities of Central Alborz, and the effects of uncertainties in the calculated ground motion are studied.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

APLIKASI SISTEM MAKLUMAT GEOGRAFI DALAM PENILAIAN BAHAYA SEISMIK BAGI CENTRAL ALBORZ, IRAN

Oleh

SEYED RAMZAN MOUSAVI

Februari 2013

Pengerusi : Prof. Madya Saeid Pirasteh, PhD
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Penilaian bahaya seismik daripada Alborz Pusat di Utara Iran, dinyatakan dari segi kuat tanah-usul yang ditunjukkan menggunakan teknik Sistem Maklumat Geografi (GIS). Ketidakmampuan kajian bahaya tunggal untuk memenuhi keperluan pengguna dan menangani ketidakpastian analisis tersebut, menuntut prosedur yang lebih mesra pengguna. teknologi GIS menyediakan kemudahan untuk penilaian bahaya seismik yang membenarkan pengguna untuk melihat taburan geografi kesan dikira dari sudut pandangan yang berbeza. GIS adalah alat yang berkuasa yang berpotensi sangat berguna dalam analisis bahaya seismik, penilaian risiko seismik dan kajian penzonan seismik. Kajian ini digunakan GIS dan model spatial menggunakan set data yang berbeza seperti model ketinggian digital (DEM), peta topografi, data gempa bumi abad, dan peta geologi untuk membantu mewujudkan penilaian bahaya seismik dan menganalisis sejarah tektonik kawasan Alborz itu. Tempoh seismicity bersejarah yang merangkumi lebih daripada 2,000 tahun yang telah dikumpulkan dan digunakan sebagai data katalog gempa bumi untuk kajian ini. program GIS digunakan dalam kajian ini untuk mengumpul, memanipulasi, menjana dan menganalisis pelbagai input data untuk analisis bahaya seismik. metodologi berasaskan GIS diperkenalkan untuk menggabungkan maklumat yang ada pada seismicity, tektonik dan kuat tanah gerakan. Program-program komputer luaran digunakan dalam kerja-kerja ini dikaitkan dengan GIS itu, sambil menambah fleksibiliti dan keupayaan analitikal dengan tatacara bahaya seismik. Pendekatan kebarangkalian tradisional diubahsuai untuk mengambil kira perubahan serantau terperinci bagi parameter seismicity. program komputer bahaya seismik diperiksa sama ada ia mampu untuk melaksanakan analisis bahaya secara interaktif dalam persekitaran GIS untuk menghasilkan keputusan yang boleh diterima. kaedah ini adalah fleksibel berkenaan dengan data input laluan kepada sempadan sumber seismik, kedalaman fokus serantau, orientasi faulting, dan parameter seismogenic dilaksanakan. Prosedur ini adalah mampu mengendalikan potensi laman web yang bergantung dan khusus tapak analisis bahaya selanjutnya.

Dalam pendekatan yang dicadangkan, GIS raster berasaskan model data yang digunakan untuk model ciri-ciri geografi dalam sistem berasaskan sel. Model sumber sel-berdasarkan dicadangkan dalam kajian ini menyediakan rangka kerja untuk melaksanakan banyak faktor seismotektonik geografi dirujuk dalam pemodelan bahaya seismik. Dengan menggunakan kaedah GIS dalam kajian ini, zon sumber seismik diasingkan berdasarkan hubungan gempa bumi diperhatikan dengan manifestasi tektonik unit geologi. Peta dengan tafsiran seismik yang dihasilkan sebagai alat untuk menggambarkan kawasan sumber seismik, untuk mengkaji kesempurnaan katalog gempa bumi, untuk menentukan aktiviti seismik, dan untuk menentukan parameter berulang bagi kawasan sumber. Pelbagai peta yang mewakili pelbagai aspek bahaya seismik dikira dan dibentangkan dalam kajian ini. Kebarangkalian peta Intensity seismik dan tanah kebarangkalian peta pecutan dikira berdasarkan andaian yang berbeza mengenai parameter seismicity, sumber jarak tapak kepada-, dan alternatif zon sumber seismik. Selepas itu, bahaya spektrum seragam dikira dalam beberapa bandar utama di Central Alborz, dan kesan daripada ketidaktentuan dalam pergerakan tanah yang dikira dikaji.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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LIST OF ABBREVIATIONS

GIS	Geographic Information System
RS	Remote sensing
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DEM	Digital elevation models
ETM+	Enhanced Thematic Mapper Plus
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984 datum
PGA	Peak Ground Acceleration
PSHA	probabilistic seismic hazard assessment
MM	Maximum Magnitude
SPM	Slip-Predictable Model
TPM	Time-Predictable Model
RDBMS	Relational Data Base Management Systems
CLI	Command Line Interface
GUI	Graphical User Interface
AML	Arc/Info Macro Language
VNIR	visible to near infrared
SWIR	short-wave infrared
TIR	thermal-infrared
DN	digital number
3D	Three Dimensional
EOSAMI	Earth Observing System
RGB	red, green, and blue
PCA	Principal component analysis

CHAPTER 1

INTROUCTION

1.1 Background

An earthquake is a seismic hazard that occurs inside the Earth's crust as a result of sudden release of energy, creating seismic waves. It is one of major natural hazard that each year causes damage to both life and social and economic infrastructures in many parts of the world. According to official report of USGS (2015)[1] more than 2,309,716 people have been killed by earthquakes during the period from 1900 to 2012 in tectonically regions. (Storchak *et al*., 2013) shown earthquakes occur near or and over active faults areas (Figure 1.1).

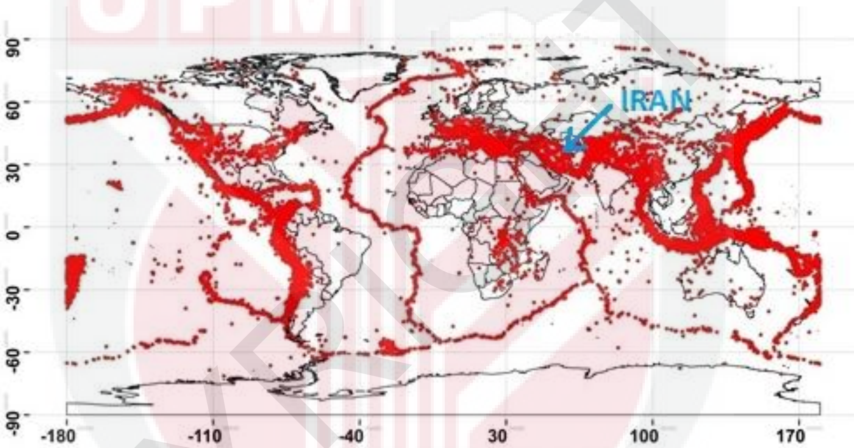

Figure 1.1: Frequency and distribution of earthquakes in the world (Red points = Epicenters) 1900-2012, (Storchak *et al*., 2013).

Iran as a developing country is located in an active tectonically and seismically region over Alp - Himalayan Belt Mountain ranges that always is affected by earthquakes. The Central Alborz mountain is the most tectonically structure and seismic area. From all natural disasters, earthquakes are reasonable to be the most destroyers that could strike the Central Alborz northern Iran. It is noteworthy that more than twenty million live in the area. There are important infrastructures such as network North-south transportation, Oil and Gas pipes line network. In addition, this area has high potential to develop tourism planning. Therefore, it is necessary to study seismic activity emphasis on seismic hazard assessment to generate seismic hazard map for planners and engineers.

1. http://earthquake.usgs.gov/earthquakes/world/world_deaths.php

The Alborz mountain range is frequently reminded of this by occurrences of disastrous earthquakes such as the Manjil earthquake of 20 June 1990 (Ms=7.7), the Ardebil earthquake of 28 February 1997 (Ms=6.1), and the Baladeh earthquake of 28 May 2004 (Ms=6.2) (Tatar, Jackson, Hatzfeld, & Bergman, 2007). The damage and losses associated with recent large earthquakes in Alborz, confirm the importance of regional earthquake hazard assessment for estimating the consequences of earthquakes. Damage to the built environment reported during recent earthquakes in Alborz show surprising examples of the vulnerability of buildings and other structures to earthquake. The large number of fatalities during these earthquakes is mainly due to the collapse of the built environment. The large part of this damage was due to the ruin of older buildings, especially in villages, which had been built with any seismic standard. Damages from these earthquakes emphasized the need for reliable estimates of seismic hazard to be available to local and national decision makers and engineers (Abbassi & Farbod, 2009). The assessment of seismic hazard on a regional and national scale is important steps in the prevention procedure and the preliminary step toward the modification of building construction codes. The impact of a future possible large earthquake on the capital city of Tehran and several major cities of the Central Alborz area may have disastrous social, economic and political effects on the country. This, in turn, demands microzonation of the city based on tectonic, geological and site conditions. According to the above mentioned, Hazard assessment is important step in alleviating of the potentially disastrous economic and social impacts of natural disasters. Seismic hazard requires the knowledge of possible epicenter locations, occurrence and strength. The process of seismic hazard assessment consists usually of four steps. The first step is the characterization of the seismic sources. The second step is the estimation of earthquake recurrence from seismic catalogues. The third step is the estimation of ground motion attenuation from macroseismic data (e.g. intensity maps from bigger earthquakes). The last step is finally the calculation of probability of the exceedance for events of certain magnitudes for a certain time period. All these steps can be done when a seismic catalogue and necessary geologic information are available (Abrahamson & Bommer, 2005; Cornell, 1968; Scawthorn & Chen, 2002)

Geographic information system (GIS) is a knowledge and new technology, science and art that has used in many fields and disciplines particularly in earth sciences. Many scientists have used GIS in soil sciences (Bahadur, 2009; Fu, Chen, & McCool, 2006; Pradhan, Chaudhari, Adinarayana, & Buchroithner, 2012), Geomorphology (Bai *et al*., 2010; Conforti, Aucelli, Robustelli, & Scarciglia, 2011; Gustavsson, Kolstrup, & Seijmonsbergen, 2006), Climatology(Dobesch, Dumolard, & Dyras, 2013; Dyras *et al*., 2005; Hartwig, Pierre, & Lzabela, 2007), Urban planning (Baz, Geymen, & Er, 2009; Maantay & Ziegler, 2006; Phua & Minowa, 2005), Hydrology (Chen, Hill, & Urbano, 2009; Fernandez & Lutz, 2010; Hammouri & El-Naqa, 2007), and Earthquakes (Fernandez & Lutz, 2010; Hammouri & El-Naqa, 2007; Hashemi & Alesheikh, 2011; Hassanzadeh, Nedović-Budić, Razavi, Norouzzadeh, & Hodhodkian, 2013; Kienzle *et al*., 2006; Mhaske & Choudhury, 2010; Miles & Ho, 1999; Pal *et al*., 2008). Among many advanced developments that have been recently made in information processing and analytical technology, GIS can greatly aid engineers in the preparation of input data, modifying assumptions and implementing new methodologies.

The geographic variation of natural catastrophes and their impacts are due to several factors involving a number of different disciplines, ranging from Earth sciences to engineering. The significant demand for natural hazard models for public policy decisions making, disaster response and the insurance industry, to name a few, makes clear the need for reliable and flexible hazard and risk estimation tools. So, GIS as a good tool has high contribution with seismic activity and data for assessment of seismic hazard in study area.

Seismic risk addresses the probability of adverse consequences of economic or social effects of earthquakes. The real impact of an earthquake on an area depends on the geographical distribution of the hazard incurred by the earthquake, the geographical distribution of the built environment and its vulnerability to the earthquake hazard. Seismic risk assessment provides the basis for a range of pre- and post-catastrophe planning used by such disciplines as disaster mitigation, code development, land and town planning, emergency and post-earthquake response teams and not least the insurance industry. In order to develop an earthquake risk model, it is required to know not only the nature of earthquake hazard in the region but also the response of the environment to that hazard. The response of a region to seismic hazard depends on different factors such as population density, built environment inventory, site conditions, etc. The general definition for seismic risk calculation can be given as (Huabin & Kyoji, 2007; RJS Spence, Coburn, Pomonis, & Sakai, 1992; H. Wang, Wang, Wang, Sassa, & Chen, 2008):

$$Risk(i , j)= Seismic\ Hazard(j) * Vulnerability\ (i , j) * Value\ (i) \qquad (1\text{-}1)$$

which describes the probability of loss to building i as a result of estimated level of hazard j. This translation from hazard to risk is expressed through a vulnerability function which relates damages to hazard for different type of buildings. The basic aspect of a seismic risk analysis is a seismic hazard analysis which describes the probability of occurrence of a seismic-related phenomenon for a specified exposure time. The vulnerability of a structure reflects its ability to respond to seismic shaking, and it is measured by the damage which the structure suffers as a result of seismic shaking. Consequently the evaluation of vulnerability of a structure corresponds to the information available from damage incurred due to seismic events and results obtained from structural analyses. In order to predict the economic impact of an earthquake, a relatively complete and reliable inventory of built environment is required. The exposure data describes the built environment such as ages, construction type, height, value and other information representing the structural behavior and damage induced by earthquake. Seismic hazard expresses the distribution of future earthquake-related phenomena in size, time and space. The damage to man-made structures as a result of an earthquake is due to one or a combination of the effects such as earthquake strong ground-shaking, Fire following earthquake, fault rupture, landslide and soil liquefaction.

The recurrence rate and the seriousness of each of these seismic-related hazards depend on the geological and geomorphologic conditions of the sites and their geographical locations relative to the earthquake source (Tosun *et al*., 2007). The most common and widely spread damage caused by earthquakes are due to strong ground-shaking. The strong ground motion can propagate to considerable distance from the earthquake source and affects a relatively large area. It is directly related to the dynamic forces acting on the structures, which are generally responsible for highly destructive damage induced by earthquakes. Structural failures and building collapses are the predominant type of damage caused by earthquakes which results directly from ground-motions (Bi & Hao, 2012; Boore, 1983; Boore & Atkinson, 2008; Kurahashi & Irikura, 2011; Seed & Idriss, 1982; Takewaki, Murakami, Fujita, Yoshitomi, & Tsuji, 2011; Toro, Abrahamson, & Schneider, 1997). On the other hand, the geotechnical seismic hazard in the form of soil failure such as landslide and liquefaction are triggered by the ground-motion, and therefore, are directly related to the ground-motion. Hence, destruction of buildings due to landslides and soil liquefaction also can be considered as a result of ground-shaking. Secondary earthquake-related hazard such as fire following earthquakes and flooding are also indirect effects of strong ground-motion. In the literature the term "seismic hazard" mostly refers to the probability of occurrence of ground-motion, although there are other hazardous and destructive earthquake-related phenomena. However, in this thesis seismic hazard refers to strong ground-motion.

Nowadays, we need seismic hazard assessment for many regions because there are numerous applications for probabilistic seismic hazard assessment using new technology specaily GIS becuase GIS methode can help to reduce time and cost with high accuracy and also other possiblities such as:

• Evaluating the seismic safety of the built environment.

• Clarify the seismic design level for individual structures and building codes.

• Post-earthquake and emergency planning.

• Making decision whether an existing building should be retrofitted.

• Providing guidelines for site selection of new facilities.

• Providing a tool for the insurance industry to estimate the probable losses to the total insured value.

1.2 Statement of the Problem

Seismic hazard has a very special place in Central Alborz mountain in north Iran. In this region, earthquakes are the most important natural hazards in terms of population affected, frequency, area extent, and social economic damage. According to Ministry of Roads and Urban development (2008), earthquake prone areas cover 29% of land area in the country, and 25% of the population (20 million) is affected by earthquakes. To record and capture of earthquake data, Iranian government has established about 108 Seismograph Stations as 20 Seismograph networks for real time seismic monitoring in Iran. Different seismic models include physical and conceptual models also have been used to seismic hazard assessment and seismic simulation. Thus, currently, seismic data are collected real time to meet more effective seismic hazard monitoring and natural hazard management are received near real time. Nevertheless, earthquakes occur repeatedly as short and long period times in various parts of the country, destroying property and killing people each year (Abbassi & Farbod, 2009). The current method of seismic hazard assessment in Iran is based on a relationship between magnitude and focal depth and ignored other seismic hazard causes factors.

Exception of magnitude and focal depth factors as the main reason, earthquake is affected by several factors such as lithology, fault, soil moisture, geology, distance of faults. The effects of these factors are well known separately, but combination of them and interaction effects are less. To seismic hazard mitigation and reduce the losses, authorities and the general public should know these factors and role of each one in effects of earthquakes. This issue has not been done yet in details for study area. The second problem is related to the deficiency of available seismic hazard models to use and definition of these factors. Since earthquakes are inherently uncertain, nonlinear and complex, it is impossible to seismic hazard assessment using available seismic models by using all incorporate factors in seismic activity region. To dissolve these problems, this study is tried to change and develop a seismic hazard assessment model using various seismic hazard causative factors and their influence on seismic activity in study area.

1.3 Research Objectives

The main objective of this study is the application of GIS methods based Seismic hazard assessment for the Central Alborz in Iran.

The specific objectives of this study is accomplished by:

- To modify a methodology for developing seismic hazard assessment in a Geographic Information System environment.
- To provide the seismotectonic and probabilistic seismic hazard maps and calculating the uniform hazard spectra for different aspects over the Central Alborz region.
- To apply and examine, the raster based data layers to model spatial variation of seismotectonic Data in probabilistic seismic hazard assessment.

1.4 Scope of Work

The scope of work covered in this study includes:

1. Selecting a complex Geohazards area with the best various data availability.
2. Collecting data including historical earthquake data, satellite digital data, different type of printed maps and constructing geographical information system data.
3. Pre-processing, analysis and splitting historical data.

4. Determination of model inputs that are extremely important.
5. Selecting performance criteria by which the performance of the model will be judged, as they can have significant impact in the GIS environment.
6. Using alternative attenuation relationships calculate the seismic hazard map in terms of PGA and MM Intensity.
7. Using the historical seismicity, known geological faults and tectonic characteristics of the region to delineate the region into seismic source zones.
8. Generating the probabilistic seismic hazard maps to represent different aspects of ground-motion.
9. Calculating the uniform hazard spectra for major cities in the Alborz region.

Distribution of the activity rate along each fault requires information from fault geometry, historical seismicity and long term slip rate. It is also necessary to recognize past activity associated with different segments of the fault. Detailed geological and tectonic investigations were out of the scope of this study. The tectonics review in this work was to help the seismic source delineation and the maximum magnitude estimation. Detailed geological information regarding fault segmentation, maximum magnitude earthquakes and time-dependent behaviour of active faults are required for more realistic seismic hazard assessment. The seismicity database used in this study is a combination of historical and instrumental data which are uncertain with respect to earthquake size, completeness and location accuracy.

1.5 Outline of Thesis

This thesis describes the application and development of a GIS-Based earthquake hazard assessment methodology and seismotectonic characteristics of the Central Alborz region are characterised and probabilistic seismic hazard maps and uniform hazard spectra are calculated for this region.

In Chapter 2, literature review discussed on the seismic hazard methodology with emphasis on the probabilistic approach. Significant advances that have been made in computer technology in the last few years regarding analytical speed and storage media, allow the seismic hazard and loss estimation to be done in a fast and flexible approach which was not possible previously. Among these, GIS provides facilities to combine data on seismic activity, seismic sources, local geotechnical and soil conditions, ground-motion characteristics and exposure data.

The GIS-based methodology of seismic hazard assessment is discussed in Chapter 3, where modifications have been made to consider the uncertainties associated with different components of seismic hazard assessment. The earthquake database employed in this study is presented.

Chapter 4 included the results and discussed the seismicity of the region including historical and recent earthquakes are combined together and their temporal and geographical distribution are presented. Various types of maps representing different aspects of seismic activity are developed and presented in this chapter, which aid in the assessment of the extent of seismic activity in the region. Several alternative attenuation relationships are reviewed in order to be used to calculate the seismic hazard map in terms of PGA and MM Intensity.

The historical seismicity, known geological faults and tectonic characteristics of the region are used to delineate the region into 6 seismic source zones. The completeness of the seismicity within each source is examined before they being used for the determination of seismicity parameters. The spatial distribution of seismicity for different intervals of magnitude is used to weight the activity in each seismic source zone. Seismic hazard analysts are generally faced with decision making with incomplete and uncertain information.

Probabilistic seismic hazard maps representing different aspects of ground-motion are presented in this Chapter. There are always applications in which seismic zoning based on the spectral content of ground-motion is required. The uniform hazard spectra are calculated for major cities in Northern Iran. The probabilistic ground-motion, taking into account the uncertainties associated with seismicity parameters are calculated for Sari city.

Conclusion and recommendations for future work are presented in Chapter 5.

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