Probabilistic Methods and Study Earthquakes Aided by Geoinformatics

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Abstract
Evaluation of the earthquakes risk and mitigation strategy is one of the crucial and concerned matters for a country where disasters may occur such as Bam earthquake in Iran. Tectonic and structural geologic study using the modern space-based remote sensing and integrates to the spatial data in Geographic Information System (GIS) environment has become more popular among the scientists and researchers. Fault rupture and associated surface deformation, damage due to ground shaking can be observed using remote sensing. The recognition of fault displacements using remote sensing techniques for study in Esfahan has brought more care for rehabilitation and vulnerability. The compiled seismocity map with field checks and lab analysis for buildings beside remote sensing and GIS techniques shows that Esfahan probably has potential to the earthquakes and causes damages in the buildings. This study reveals that some of the infrastructures in Esfahan should be rehabilitated and increases the resistance against future earthquakes, especially for those historical buildings, bridges which goes back to 400 years.

1. General and Background

Emergency situations in urban areas require: 1) excellent coordination between different relief /rescue groups; 2) appropriate information (especially geo-referenced information); and 3) intelligence in communicating orders and information to different participants. Natural disasters like cyclone, flood, drought, landslide, earthquake etc. have devastating effect on life and property. Earthquakes are short-lived, menacing and the most feared natural hazards because of their sudden impact and devastation in a matter of few seconds inflicting immense losses of life and property. The maximum economical casualties that caused by natural disaster are between1900-2005 and occurred in Asia and Pacific. During the last 55 year Asian Pacific has tolerated around 588 billion US Dollar. Around 33 people of economical casualties belong to earthquake (www.unescap.org). According to UN report in 2005 Iran are listed Among 15 countries in the world that faced with natural disasters and some of the Iran neighboring countries in Asia such as Armenia, Turkey, Afghanistan, India, Russian Federation and Georgia faced with Natural Disaster. Crustal deformation is in fact a direct manifestation of the process that leads to earthquakes. Though areas prone to seismic hazards are fairly well known, there has been very little advance in our ability to predict when, where, or with what magnitude will the next earthquake strike. Since we are not in a position to predict an earthquake, we must at least try to find out the scientific causes that can lead to such catastrophic earthquakes. For this, study of neo tectonics and geology of a particular region is very important. Geoinformatics is a recently emerging technology, which can play a vital role in mitigation of natural disasters. Geoinformatics is a conglomerate of measuring, mapping, geodesy, satellite positioning, photogrammetry, computer systems and computer graphics, remote sensing, geographic information systems (GIS) and environmental visualization. The earth observation satellites provide comprehensive, synoptic and multi-temporal coverage of large areas for a wide range of scales, from entire continents to details of a few meters in real time and at frequent intervals and thus have become valuable for continuous monitoring of earth and its atmosphere (Maiti, 2001). Remote sensing and GIS based change detection technique is used to assess earthquake induced damages to houses and other structures accurately and speedily as this technique is cost effective, unbiased, and free from subjectivity, time saving and provides quantitative damage assessment (Saraf et al., 2002).

In this research, the earthquake hazard analysis of Naghsh-e-Jahan Square is being evaluated using combination of geoinformatics technology and survey data with the help of laboratory analysis. According to the latest regional seismicity data using epicenters deterministic and probabilistic methods the focus has also been emerged to understand the behavior of the buildings against future earthquakes.

2. Study Area

The study area is located in the central of Iran. Esfahan is historical city of Iran and goes to about more than 600 years back. It is about 360 km south east of Tehran and easy reachable with road. The coordinates of the study area covers the longitude 51°35′00″ E to 51°45′00″ E and latitude 32° 30′ 00″ N to 32° 56′ 00″ N (Figure.1). The Naghsh-e-Jahan square has been selected for compelling collection data in the study area.

3. Tectonic Seismicity and Geostrcutural

Geologically the study area belongs to Sanandaj-Sirjan Zone which consists of igneous-metamorphic rocks, volcanic and sedimentary from Precambrian to Recent in age. Generally earthquakes of this region are classified in to two periods:

1- Historical seismicity, prior to 1900.
2- Instrumental seismicity, after 1900.

Among other natural disasters, earthquake has been considered as a devastating and fatal occurrence effects of which could have been missed by the authorities, historians and writers in the past. The first recorded earthquake in Iran dates back to the forth century BC, where the ancient city of Ray was completely demolished. Since Iranian national records are based on historical documentations, proving their being decisive does not seem to be a difficult task.

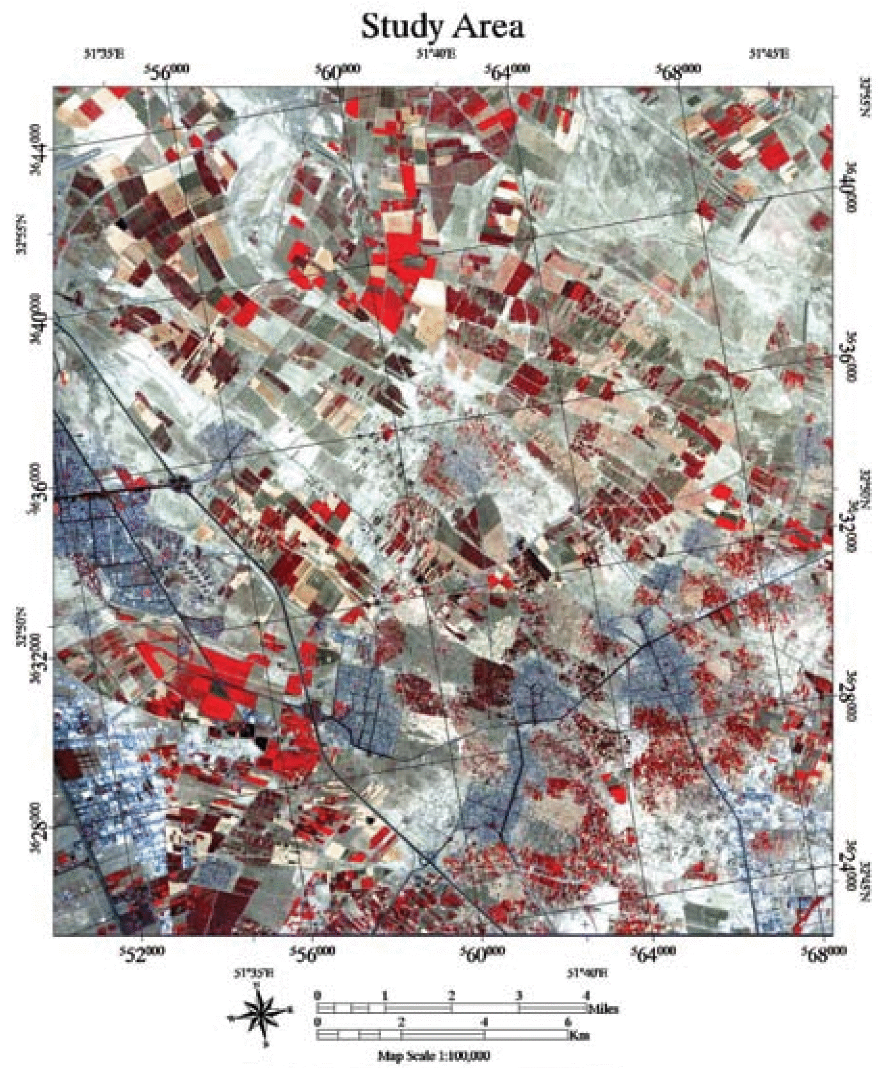

Figure 1: ASTER Satellite Image 3-2-1 FCC

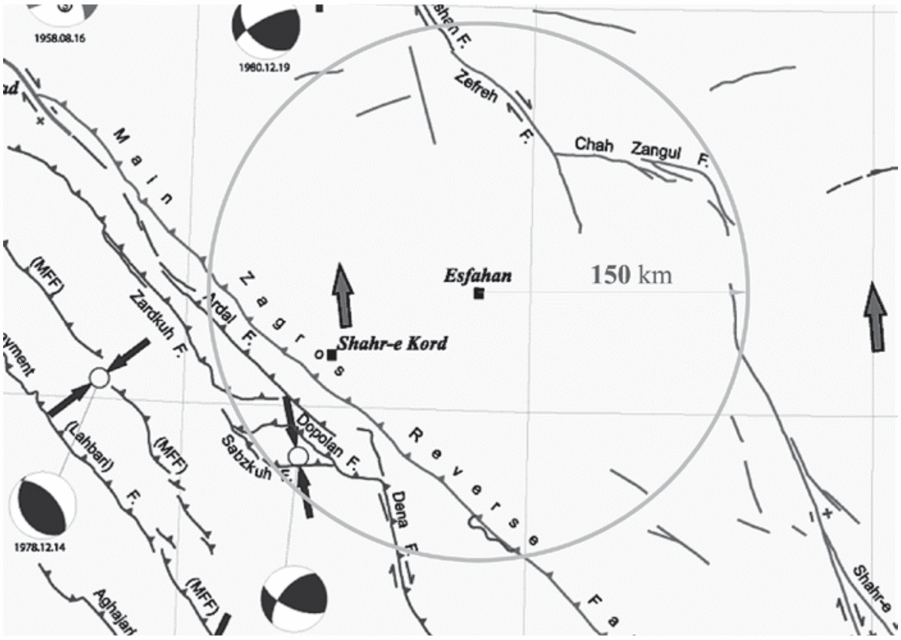

Figure 2: The historical and instrumental layout in the region with 150km radius

The magnitude of historical seismicity is determined based on the damages they have caused in a given area. Many researchers like Berberian (1995), Gupta et al., (1995) and Gupta 2002 have been through restless studies regarding historical seismicity the results of which have become seismic data. Among all these reports the list provided by Amberasay and et al., (1996) about historical seismicity in Iran contains more uniformity when compared to the similar works. The seismic activities in Iran are limited to Zagros highland's regions in comparison with center and east of Iran. In the recent years, many studies have been conducted on the characteristics of earthquake in Iran (Berberian, 1976, Berberian, 1995, Barzangi, 1989 and Ali and Pirasteh, 2004). Some of the major faults around Esfahan city (within 150km Radius) are recognized by using digital image processing techniques and on screen image interpretation. The key elements for detecting the lineaments features were sharp and linearity in drainages and vegetation cover. The other image elements such as tone and association have been used for interpretation. However, the faults that are detected in this study are a) main Zargos belt, b) Ardal, c) Zardkoh, d) Dopolan, e) Sabzkoh, f) Dena, h) Kashan, i) Zafre, j) Chah Zangol and k) Kolaghazi.The active faults of Iran and the location of the region illustrates in Figure 2. The parameters of the seismicity are geospatially considered. They are: fundamental faults; patterns and hazard which their analyses are based on the existing data from International Institute of Earthquake Engineering and Seismology (IIEES). Further in this study satellite image interpretation and GIS techniques are used to generate update maps such as structural map. The seismicity cataloging is used in seismologic engineering and analysis. Based on the zonation of the region under this study the related seismicity parameters for deterministic and probabilistic analysis are: maximization of magnitude seismicity, annual occurrence rate and the β parameters has been assessed through the common procedures.

3.1. Structural Recognition

The distribution of main active faults in Iran has been evaluated by Berberian in 1976. In this study the emphasis has been given on integration of field survey, geospatial data and remotely sensed data. It would recognize and further analyze the structural features within GIS environment to develop digital thematic maps. The characteristics of recognized faults are summarized as follows:

a. Main Zagros Reverse Fault (MZRF): The Zagros fault with (N 130◦ E) elongation enters Iraq through Marivan (North-western border of Iran Iraq) and enters Iran in the Sardasht region the crosses the Turkish boarder. MZRF is 1350km long. The trend of MZRF begins from Turkish boarder in the NW and ends in Bandar Abbas (SW), Iran. The fault is of pressurized- thrust type. Falcon in 1974 has called it Zagros Thrust, while Berberian (1976) called it Main Zagros Reverse Fault (MZRF) because of its verity in sections with different types of dips.

b. Ardal Fault: This is a thrust fault, 100km long running NE-SW. The tectonic and geomorphic evidences show that this fault is considered to be an active and quake generating.

c. Zardkuh Fault: The Quaternary thrust fault is one of fundamental group of high elevation faults on Zagros belt which is bent towards W-SE. The geospatial analysis in GIS environment indicates that the fault is about 130km long.

d. Dopolan Fault: Another wide angle thrust fault that recognized on the image is Dopolan Fault and is running toward W-SE. It is about 110km long. This fault joins Dena fault eastwards and Sabzkoh fault westwards.

e. Sabzkuh Fault: The integration of ground truth data and satellite image shows that it is thrust fault running similar to Dopolan fault with 120km length, bent on both ends.

*f. Dena Fault:*This fault is about 130km long with almost NS pattern which joins Shalamzar and main Zagros faults in the north, and in the south to Kazeroon fault. This is a rectified strike-slip-fault with a reverse constituent.

g. Kashan Fault: This fault is 80km long with almost NS pattern which joins Zafre fault in the east and it is of the rectified strike-slip kind.

h. Zafreh Fault: This fault is located in North of Esfahan, it begins from the NW; end of Kashan fault and joins the east; end of Chah Zangool fault which continues northwards on the eastern side of the Esfahan province. This fault is 150 km long. It is a rectified strike- slip fault.

i. Chah Zangool: This fault is 150 km long, beginning west eastwards and changes in the middle and continues north southwards. This fault is a rectified- strike kind and it joins Zafre fault in the east and where the end towards south seismicity joins the continuation of Dehshir fault.

4. Methodology

Methodology of the study consists of three main steps: a) Field data and laboratory analysis and b) remote sensing and GIS techniques and c) integration of two last steps in GIS environment and d) using different probabilistic methods. Beside this, several field checks are attempted to collect surface data. It was done by using Global Position System (GPS). The data were used in laboratory for analyzing the hazard risk. In this study also ASTER image was selected to extract linear structural features using ENVI 4.2 software. The satellite image was geometrically corrected with help of digital topography map in scale 1:25000, and FCC was made. Different enhancement techniques were carried out to highlight the lineaments and the faults. Using image elements and field survey, faults have been recognized and digitally digitized on the image. The buffer technique in Arcview environment was applied for all the faults. The same buffer technique is also applied for 150 km from Esfahan city (Figure 2) on the basis of statistic historical earthquakes in Esfahan, Iran. In order to determine resistance of the building against future earthquakes, digital schumize hammer, share tester for masonry walls, canin and covermeter are used for 100 masonry type houses. Digital topography map of Emam Square area, Esfahan, Iran in scale 1:2000 was introduced to GIS environment. Using 3D model extension of Arcview software the 3D model was created (Figure 3). Data collected for all buildings are also introduced to Arcview environment for analysis and to define non engineering and engineering buildings. Basically, in this method we classify buildings from non-engineering to engineering buildings (Figure 3). The concept for classification of the building is given on the basis of properties of the material used in building against earthquake about 5 Richters. The 5 Richters earthquakes also assumed on the basis of the statistic historical data recorded by Iranian geophysics organization. The data of 475 years has been collected and statistically used in Microsoft Excel to understand the cycle period of the earthquakes. This data has been used for different probabilistic methods such as Ambreasys & Simpson's spectra hazard analysis to evaluate risk analysis of the earthquakes.

5. Results and Discussions

Using geospatial techniques and integration with laboratory analysis beside deterministic and probabilistic methods, the engineering and non engineering building could be enhanced for rehabilitation. Those building which are in the non engineering class should be considered for rehabilitation and use further techniques and materials to increase the resistance against future earthquakes. This study shows that most of the houses are to be considered for rehabilitation otherwise in the future earthquakes more than 5 to 6 magnitude; a disaster may occur. Thus this is alarming news for the government to protect the life of the people in future, if the infrastructure of the city does not become more strengthen than the present time.

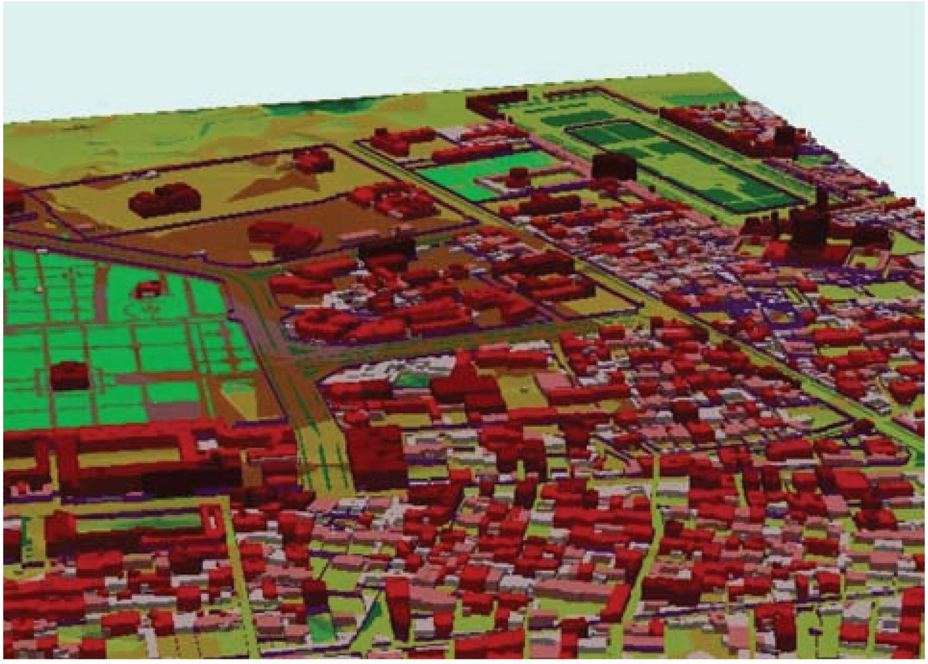

Figure 3: Showing Non-engineering building in Naghsh-e-Jahan Square, Esfahan Iran

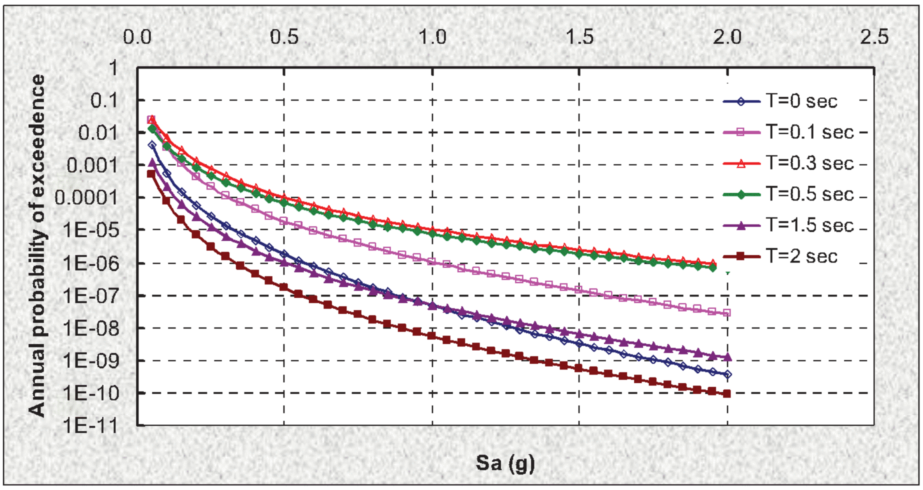

Figure 4: The diagram of hazard analysis curves based on Ambreasys & Simpson's

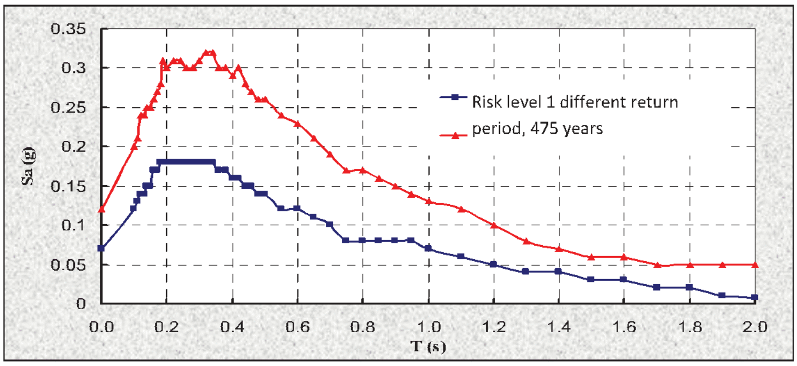

Figure 5: The risk levels of seimicity, 1 and 2, UHS method based on Ambrasys & Simpson relationship (1996)

The investigation related to earthquake and the tectonics of the designated region reveals that based on seismic data, the seismic activities in Iran are limited to high Zagros regions in comparison with center and east of Iran. This study emphasizes that some of the major faults around Esfahan (within 150 km radius) are: the Main Zargos Revers fault, Ardal, Zardkuh, Dopolan, Sabzkoh, Dena, Kashan, Zafre, Chah Zangol and Kolaghazi. This study shows that the risk curves are for specific alternative periods. Figure 4 shows diagram of the site risk based on Ambraseys & Simpson's spectra obtained through spectral attenuation relation. The result of the analysis in relation to risk levels of seismicity 1 and 2 are based on Ambreasys and Simpson's attenuation relation which is illustrated in Figure 5. The volume of spectra is compared with standard 2800. According to the existing rehabilitation instruction for the buildings against seismicity code in case they obtained spectra acceleration of the designed spectra for the site is less than 70% of the same in (standard 2800) accord, the indicated value of the accord will establish the base. The study also illustrates the behavior of the designed spectra of the site through UHS method for two levels of risk (Figure 6). In this study, the deterministic and probabilistic methods integrated with geospatial techniques within remote sensing and GIS environments and further have been applied for the seismicity hazard for Naghsh-e-Jahan Square, Esfahan Iran. It shows that, because of deficiencies and no uniformity of the elements in the catalogue with historical earthquakes, the site parameters are obtained through Kijko's and et al., (1989, 1992) method and are based on probabilistic analysis. This study also shows that the combination of deterministic and probabilistic hazard analysis using Ambraseys & Simpson and Sarma & Srbulov methods is a good method to study the history of the earthquakes and predict the future earthquakes. Using deterministic method based on identified earthquakes in the proximity of the site and also using the obtained fault plans through (IIEES), the study could be able to identify the imposed seismic maxizimation (MPE). Hence, according to the investigations conducted on the site, the following results on the peak ground acceleration have been obtained (Figure 7).

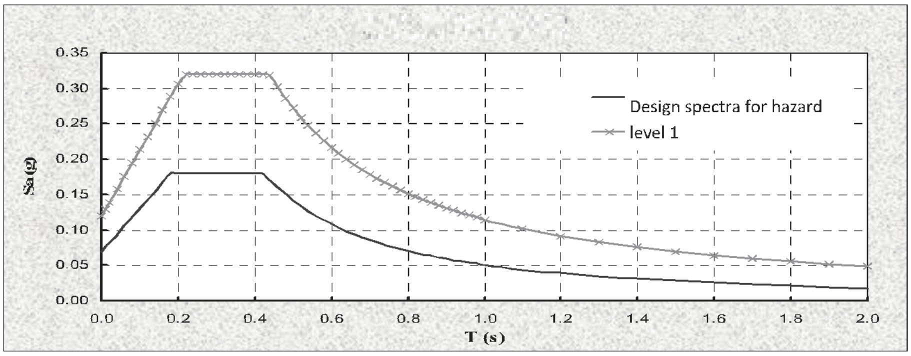

Figure 6: The designed spectra of the site, Emam Square (Naghsh-e-Jahan)

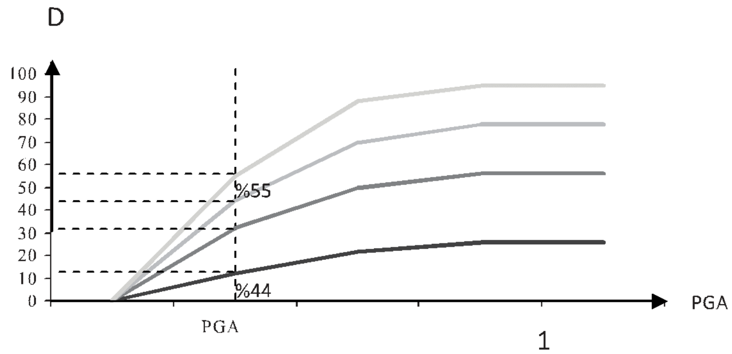

Figure 7: Diagram showing relationship of peak ground acceleration and damage

Table 1: The results of deterministic analysis based on indicator faults in the region

Fault Length (km)	Source to Site Distance(km)	Magnitude $_{Max}$	Ambraseys Bommer (g)	Sarma & Srubolov	Logic tree (g)	Features and Comment
250	90	7.5	0.07	0.08	0.07	MZRF
100	110	7.1	0.04	0.05	0.04	Ardal
150	100	7.3	0.06	0.06	0.05	Zefreh
130	100	7.2	0.05	0.05	0.05	Dena
130	130	7.2	0.04	0.04	0.04	Zardkuh
40	20	6.7	0.17	0.21	0.18	Kolahghazi
110	120	7.1	0.04	0.04	0.04	Dopolan
120	130	7.2	0.04	0.04	0.04	Sabzkuh
85	60	7	0.07	0.09	0.08	Kashan

The obtained spectra velocity is less than 70% of the same in the accord; therefore according to building rehabilitation against earthquake guideline, the standard 2800 should be the base for the seismicity loading for the buildings. However, the study indicates that GIS is a powerful tool for storing and analyzing the data in the field of civil engineering and also earthquakes. Integration of the remote sensing techniques to detect the geostructral features such as lineaments beside urban earthquake study with a concept of spatial data analysis would be more useful when other statistical methods are used.

6. Conclusions

This study shows that Iranian region is facing a numerous hazards and should be more careful against the future natural hazards for planning and sustaining different structures and infrastructures programs. According to the attenuation relations and the shortest distance of each fault in the study area extracted by remote sensing techniques, to the designated site with 30 km focal depth, the maximum earth movement velocity is calculated. The results of deterministic analysis are shown in table 1. The estimation of maximum credible earthquake (MCE) velocity is based on deterministic method equivalent of 0.18 g.

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