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SEISMIC HAZARD ASSESSMENT OF SANANDAJ CITY OF IRAN BASED ON PSHA

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ABSTRACT

This paper presents a probabilistic seismic hazard assessment of a Sanandaj city of Iran. Sanandaj is the administrative centre of Kurdistan province, in which more than 500,000 people live in. Many destructive earthquakes such as Rudbar-Manjil(1990), Bam(2003) happened in Iran that caused many casualties and damages. Two maps have been prepared to indicate the earthquake hazard of Sanandaj city and its vicinity in the form of iso-acceleration contour lines. They display the probabilistic estimate of Peak Ground Acceleration (PGA) over bedrock for the return periods of 475 and 950 years. A collected catalogue, containing both historical and instrumental events and covering the period from the 10th century AD to 2006 is then used, seismic sources are modeled and recurrence relationship is established. For this purpose the method proposed by Kijko [2000] was employed considering uncertainty in magnitude and incomplete earthquake catalogue. The calculations were performed using the logic tree method and three weighted attenuation relationships; Ramazi [1999], 0.40, Ambraseys &Bommer [1991], 0.35, and Sarma & Srbulov [1996], 0.25. Seismic hazard assessment is then carried out for 8×10 grid points using SEISRISK III. Finally, two seismic hazard maps of the studied area based on Peak Ground Acceleration (PGA) over bedrock for 10% probability of being exceeded in two life cycles of 50 and 100 years are presented. The results showed that the PGA ranges from 0.115(g) to 0.177(g) for a return period of 475 years and from 0.135(g) to 0.206(g) for a return period of 950 years. Since occurrence of large earthquake close to cities in Iran is probable, risk of future earthquakes will be very significant.

Keywords: Sanandaj; Iran; seismicity Parameters; seismic hazard assessment

INTRODUCTION

Iran is one of the most seismic countries of the world. It is situated over the Himalayan- Alpine seismic belt and is one of those countries which have lost many human lives and a lot of money due to occurrence of earthquakes. In this country, a destructive earthquake occurs every several years due to being situated over a seismic zone. Economical, cultural, societal, and political importance of a large city like Sanandaj makes it prone that severe earthquakes in this region will affect the whole country. Therefore, the evaluation of the severity of the occurrence of earthquakes is indeed very necessary.
The existence of the active thrusts and active faults like Morvarid, Sartakht, Piranshahr, Dinevar, and Zagros mountain front fault, and the occurrence of severe past earthquakes, all indicate that probability of occurrence of severe earthquakes is very high.

The occurrence of destructive earthquakes like the ones that occurred in the 956 AD (with magnitude of Ms =5.3), in 958 AD (magnitude of Ms =6.4), in 1008 AD (magnitude of Ms =7.0), in 1087 AD (magnitude of Ms =5.9), and in 1107 (magnitude of Ms =6.5), in 1130 AD (magnitude of Ms =6.8), in

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1135 AD (magnitude of Ms =6.4), in 1150 AD (magnitude of Ms =5.9), in 1226 AD (magnitude of Ms =6.5), in 1310 AD (magnitude of Ms =5.3), in 1430 AD (magnitude of Ms =5.9), in 1872 AD (magnitude of Ms =6.1), in 1880 AD (magnitude of Ms =5.6), all show seismic hazard that threatens the studied region [Ambraseys and Melville, 1982].

Iranian Code of Practice for Seismic Resistant Design of Buildings [2005], suggests the value of A=0.3g (the design basis acceleration over bedrock with return period of 475 years) for the entire region. The importance of Sanandaj city demands a more comprehensive study to evaluate the A factor. Availability of newer and more complementing data and new scientific research, demands the necessity of performing hazard analysis for updating the corresponding results for an important region like Sanandaj.

Considering the importance of Sanandaj city and the fact that a comprehensive seismic hazard (PGA over bedrock) study has not been performed for different parts of this region, this paper introduces new research done in this concern using the latest and updated.

SEISMOTECTONIC STRUCTURE OF SANANDAJ CITY OF IRAN

Active faults and volcanic high surface elevations along Himalayan-Alpine earthquake belt characterize the Iranian plateau. According to the earthquake data of Iran, most activities are concentrated along Zagros fold thrust belt in comparison to the central and eastern parts of Iran. Thus several regions are vulnerable to destructive earthquakes. The seismotectonic conditions of the studied region are influenced by the condition of the Iranian tectonic plate in the Middle East. In order to understand the seismotectonic role of the corresponding region, the conditions of the tectonic plate of Iran are briefly discussed.

Several studies have been done on the seismotectonic structure of Iran in the past. Tavakoli [1996] proposed a new model of seismotectonic provinces using a modified and updated catalogue of large and catastrophic Iranian earthquakes. The most significant & primary faults in the vicinity of the region include Morvarid, Sartakht, Piranshahr, Dinevar, Sahneh, Nahavand, Garoun, and Zagros mountain front fault & Main Zagros revers, Shahu, Ravansar, High Zagros, and Takht-e Soleyman. The locations of these faults can also be seen in Figure 1 within the Sanandaj city region.

SEISMICITY OF SANANDAJ CITY OF IRAN

The earthquakes occurred in Sanandaj city can be classified in 2 groups: (1) The historical earthquakes (the earthquakes occurred before 1900), and (2) The instrumentally recorded earthquakes (the earthquakes after1900).

Researchers like Berberian [1973], Nabavi [1978], Ambraseys and Melville [1982] have performed some investigations in historical earthquakes and have reported seismic data. From all reports, the list of Iranian historical earthquakes, reported by Ambraseys and Melville [1982], was more homogenous compared to other seismic lists. Since the nearest places to the studied region which documents of historical earthquakes of them are available are Gudin hill, and Dinevar city, so, they are considered in the studies on the historical earthquakes of the region.

The important buildings located in Gudin hill were destroyed suddenly between 1600 B.C. and 1650 B.C. All evidences showed that the earthquake was very severe. Dinevar city was destroyed two times by severe earthquakes in the history that one of them was the largest historical earthquake occurred in 11^{th} century AD., its magnitude was estimated to be (M_S =7.0). Dinevar city was destroyed completely and it had many casualties. [Ambraseys and Melville, 1982].

In general, 29 earthquakes with magnitudes greater than M_S =5.3 were reported over the time span of

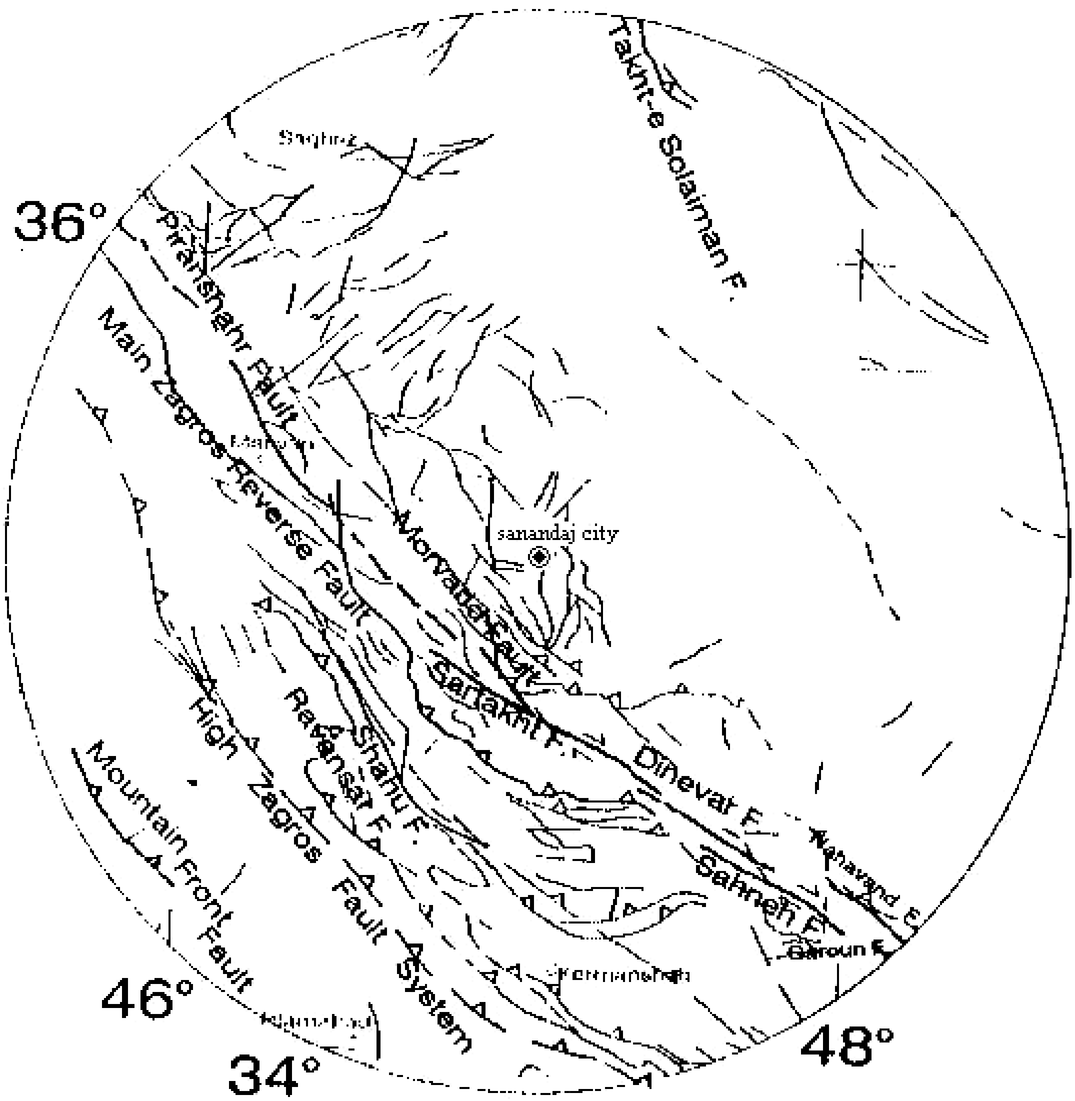

Figure 1. Active faults of Sanandaj region (Berberian et al., 1983)

the studied catalogue, the maximum of which occurred in 1957 with magnitude of M_S = 7.35. The epicenter of this earthquake was South of Sahneh. 211 villages in the area were destroyed and 1130 of people died. The earthquake, that was named Farsineh earthquake, was strongly felt in the studied region and several aftershocks occurred afterwards.

SEISMICITY PARAMETERS OF SANANDAJ CITY OF IRAN

The seismic assessment is based on data on the earthquakes occurred in the concerned region and utilization of probabilistic methods. The earthquake catalogue in a radius of 200 km has been gathered and processed, assuming the earthquakes follow a Poisson distribution. A final collective catalogue was prepared by eliminating aftershocks, foreshocks, and incorrectly reported events from data. The method that was used for the elimination of foreshocks and aftershocks is the variable windowing method in time and space domains [Gardner and Knopoff, 1974]. The data sources for the compilation of the catalogue used are mentioned in appendix A.

In some records of the final collective catalogue M_S magnitude values were not mentioned and just m_b magnitude is reported. In order to complete the catalogue, M_S values are calculated using the relationship (Equation 1) presented by Iranian Committee of Large Dams, IRCOLD [1994].

$$M_S = 1.2m_b - 1.29 \quad (1)$$

Seismicity Parameters Calculated by Kijko [2000]

The seismic parameters, recurrence intervals, and the probability of the occurrence of earthquakes were calculated using the Kijko method [2000].

The values of seismicity parameters β and λ resulting from this method are 2.3 and 0.97, respectively. The maximum expected magnitude for the region based on this method is 7.7 $\pm$ 0.46.

The annual average occurrence rate of earthquake versus magnitude for earthquakes with magnitude greater than M_S = 4.0 in the extent of 200 km is shown in Figure. 2 based on these investigations and the performed calculations with Kijko [2000] method.

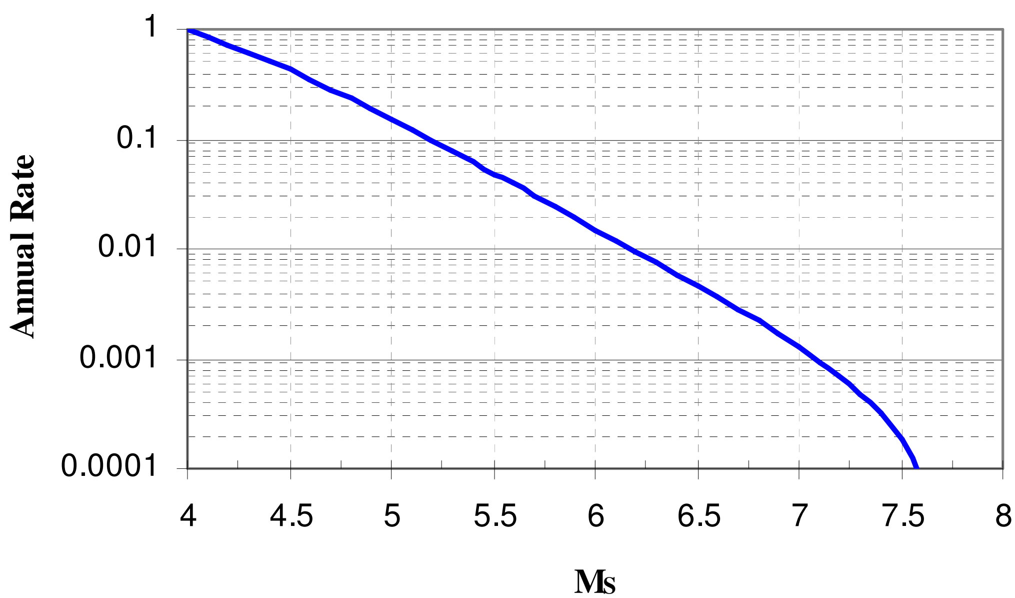

Figure 2. Annual rates estimated by Kijko method

Seismicity Parameters Calculated by Tavakoli [1996] for Iran

Tavakoli [1996] has divided Iran into 20 seismotectonic provinces and earthquake hazard parameters have been evaluated for each seismotectonic province. In this study, maximum likelihood method was applied. Suggested values for seismicity parameters for Sanandaj city and vicinity (Provinces No. 9) are shown in Table 1. In addition, these parameters were used in this paper through the logic tree method. Distribution of the strong earthquakes and the provinces 9, 11, 12 and 15 are shown in Figure. 3.

TABLE 1. SEISMICITY PARAMETERS FOR SEISMOTECTONIC PROVINCE OF SANANDAJ [TAVAKOLI, 1996]

Province No.	Span of time	Beta	M max	Lambda(Ms=4.5)
9	1922-1995	1.94±0.16	7.3±0.3	0.27

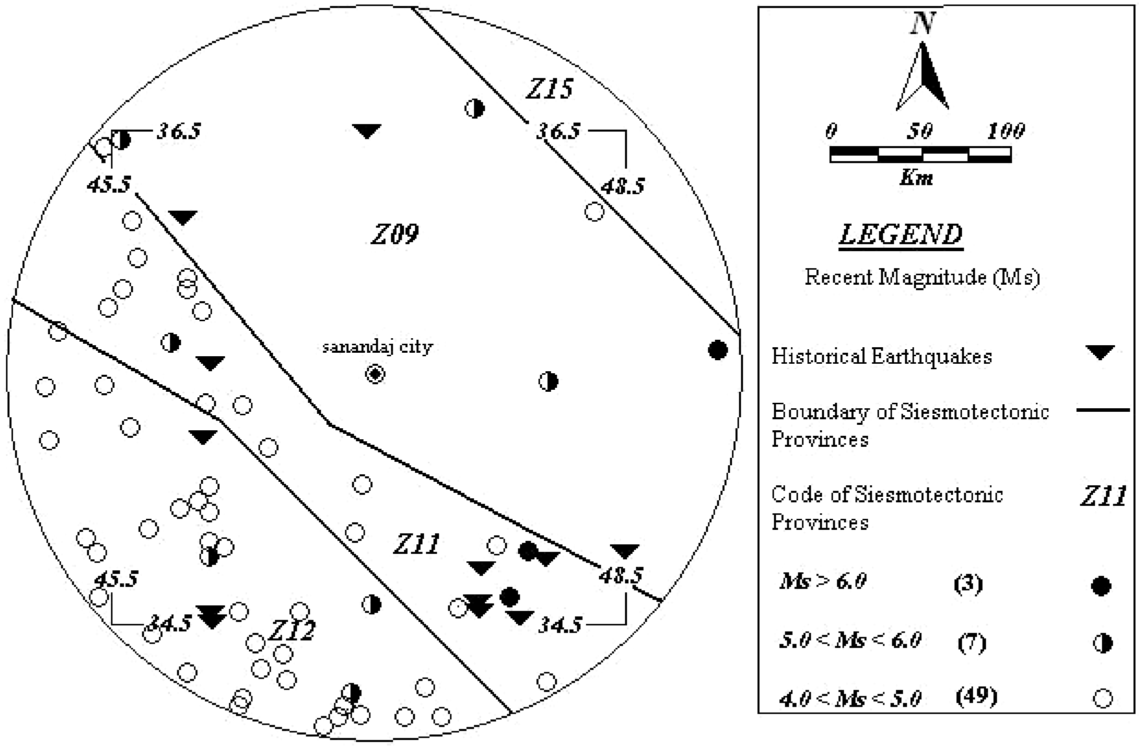

Figure 3. the distribution of the strong earthquakes and the provinces 9, 11, 12 and 15

SEISMIC HAZARD ASSESSMENT

In order to evaluate Peak Ground Horizontal Acceleration (PGHA) for the return period of 475 and 950 years; probabilistic seismic hazard analysis method has been used. In this method, seismicity parameters (β, λ) are given to the seismic sources based on the seismicity investigations, then based on earthquake magnitude, distance to epicenter or hypocenter from site and application of an appropriate attenuation relationship, Peak Ground Horizontal Acceleration (PGHA) at the corresponding site is evaluated.

The relationship between the maximum expected magnitude and fault length depends on the understanding of the seismotectonic and geotectonic behavior of the concerned area. Therefore, Nowroozi [1985] relationship was used to express the relationship between fault rupture and the earthquake magnitude (Equation 2):

$$M_S = 1.259 + 1.244 \log L \quad (2)$$

Where Ms is surface wave magnitude and L is rupture length in meter.

Attenuation Relationship

Selection of appropriate attenuation relationship is very important in validity and reliability of the analysis results. Therefore, there are some important notes that must be paid attention for the selection of attenuation relationship. The most important ones are source specifications, magnitude, fault rupture type, distance to the seismogenic sources, geology and topology of site.

Based on the mentioned remarks, in this research three attenuation relationships; Ramazi [1999], Ambraseys & Bommer [1991] and Sarma & Srbulov [1996], were employed.

Ramazi relationship is derived specially for Iran and it can be considered to be more accurate to be used in this study than other ones, so it has given the highest weight. Ambraseys & Bommer and Sarma & Srbulov relationships are for the Middle East and worldwide consecutively and can be weighted the same. But, better to give a higher weight to Ambraseys & Bommer relation. So, in this study 0.4, 0.35 and 0.25 are various weights of the attenuation relationships and the standard deviation (sigma) of the three attenuation relations is used in calculations.

Logic Tree

Logic tree is a popular tool used to compensate for the uncertainty in PSHA. Logic tree reflects uncertainty by allowing the analyst to assign each parameter a range of values, along with an assessment of the probabilities that each of these is the correct value [Rabinowitz et al., 1998]. Figure 4 shows the logic tree that considered the uncertainty in attenuation relationships and seismicity parameters. Each branch is weighted by the product of the weight assigned to it. Seismic hazard can then be assessed at each end node.

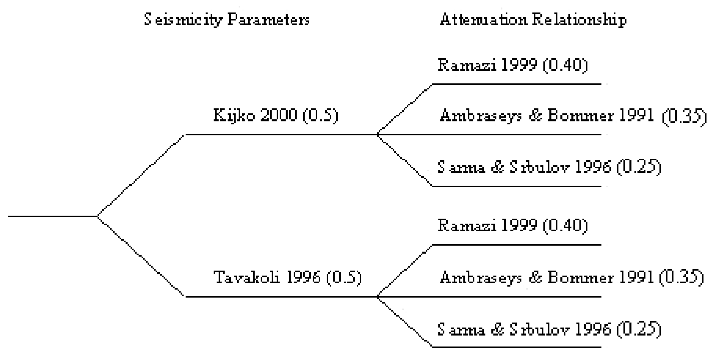

Figure 4. Applied logic tree

Probabilistic Seismic Hazard Analysis

For probabilistic seismic hazard assessment, SEISRISK III [Bender and Perkins, 1987] was used to calculate Peak Ground Acceleration.

In this study, the whole area of interest was subdivided into a grid of 8×10, total of 80 sites, and probabilistic seismic hazard analysis was carried out for each site. The output of program was the anticipated Peak Ground Acceleration in g with 10% probability of being exceeded during life cycles of 50 and 100 years or for the ground motion return periods of 475 and 950 years. In each site, seismic hazard curve is drawn, for example, in Figure 5; a typical curve can be seen. The result of the seismic hazard analysis is graphically shown in Figures 6 and 7.

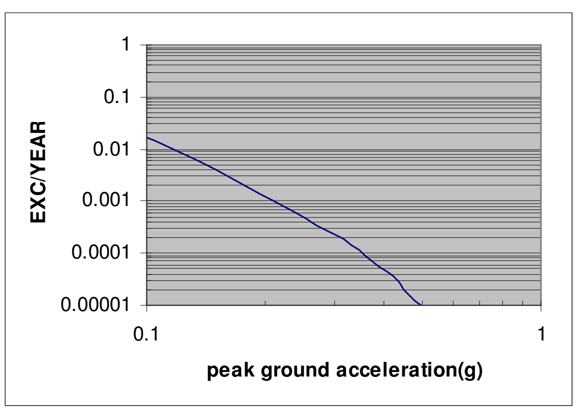

Figure 5. Mean seismic hazard curve for a site

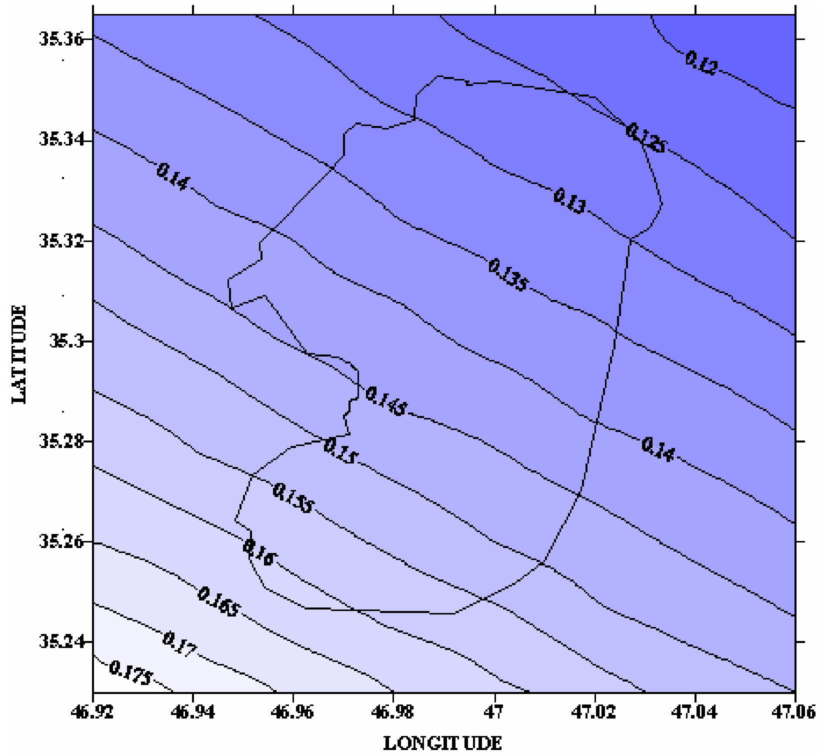

Figure 6. Final seismic zoning map (PGA over bedrock) of Sanandaj city of Iran using logic tree for 475 year return period

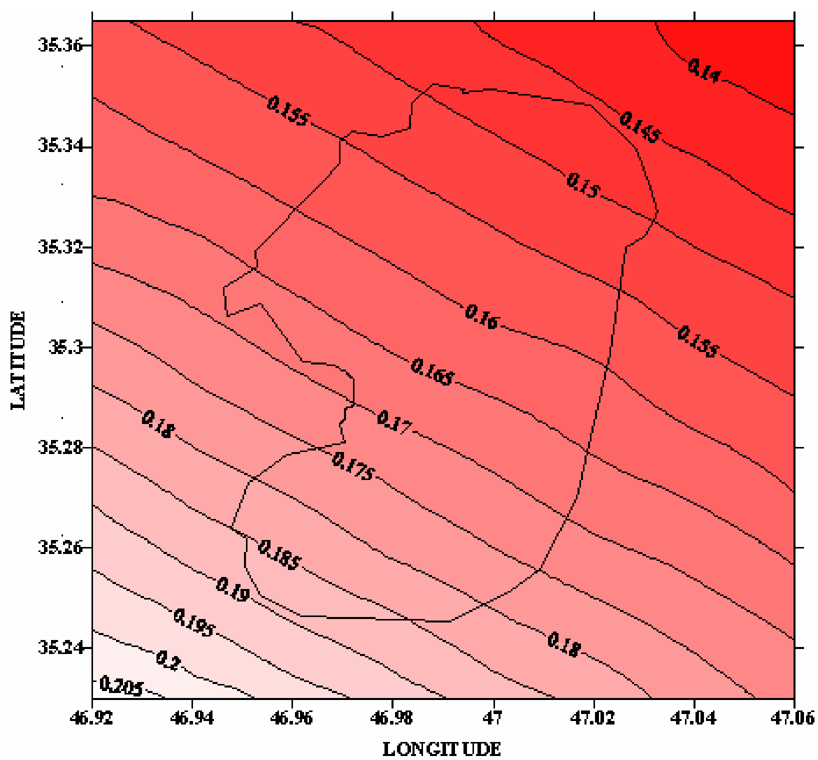

Figure 7. Final seismic zoning map (PGA over bedrock) of Sanandaj city of Iran using logic tree for 950 year return period

CONCLUSION

The significant results of this study can be summarized as: (1) Generation of a preliminary seismic zoning map (PGA over bedrock) that can be used, with caution, as a guide for determining the earthquake design and (2) Utilization of different worldwide attenuation relationships using logic tree method.

The PGA in the interested area ranges from 0.115g to 0.177g for a return period of 475 years and from 0.135g to 0.206g for a return period of 950 years.

The difference between the results of the present study and the design value of the Iranian Code of Practice for Seismic Resistant Design of Buildings [2005] is because the Iranian Code gives the PGA for a large area including many places. It may be the greatest PGA calculated for different parts of that area. But, this study is for limited region with its special conditions, so the PGA obtained is more precise the studied region.

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APPENDIX A

The data sources for the compilation of the catalogue used are as follows:
AMB: Ambraseys, N., Melville, C. P.
BSIC: Bureau Central International de Seismologie, Strasbourg, France
BER, M: Berberian, Geological and Mining Survey of Iran
CCP (BAN): Atlas USSR Earthquake
CGS: US Coast and Geodetic Survey, USA
FS (BAN): Fisher
HFS1: Hagfors, Sweden
ISC: International Seismological Center, UK
MOS: Moscow, USSR
NOW: Nowroozi
NEIC: National Earthquake Information Center, USA
NEIS: National Earthquake Information Service, USA
PT: Publication of Institute of Geophysics- Tehran of University
USGS: United States Geological Survey

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