International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

2010 - Fifth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

28 May 2010, 2:00 pm - 3:30 pm

Uniform Seismic Hazard Spectra of Sanandaj, Iran

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ABSTRACT

This paper presents uniform seismic hazard spectra of Sanandaj city of Iran. Sanandaj is the administrative center of Kurdistan province, in which more than 500,000 people live in. A collected catalogue, containing both historical and instrumental events and covering the period from the 10th century BC to the year 2006, is used. Then seismic sources and The seismotectonic model of the considered region have been modeled within the radius of 200 km and recurrence relationship is established. After elimination of the aftershocks and foreshocks, the main earthquakes were taken into consideration to calculate the seismic parameters. For this purpose the method proposed by Kijko [2000] was employed considering uncertainty in magnitude and incomplete earthquake catalogue. Sanandaj and its vicinity has been meshed as an 8(vertical lines)* 10(horizontal lines) and the calculations were performed using Ambraseys and et al. [1996] attenuation relationship. These calculations have been performed by the Poisson distribution of four hazard levels. Seismic hazard assessment is then carried out for each grid point using SEISRISK III [1987]. The evaluation of the probabilistic occurrence of earthquake for the specific area is shown by horizontal spectral acceleration maps with the probability of 2% and 10% occurrences in 50 years.

INTRODUCTION

Many disasters have been occurred in Iran due to the occurrence of earthquakes, causing large economic and life losses. Sanandaj is the administrative centre of Kurdistan province in Iran, in which more than 500,000 people live in. The city has fundamental installations and attractive places for tourists and its many other potentialities for development can make it one of the significant centers of the country. Any strong earthquake may then make considerable damages in there. So, the importance of such studies is apparent.

The recent study, done by authors, Probabilistic Seismic Hazard Assessment of the Sanandaj, Iran, showed that the maximum and minimum values of PGA for the return periods of 75, 225, 475, 2475 years are (0.114, 0.074) (0.157, 0.101), (0.189, 0.121) and (0.266, 0.170), respectively [Ghorati Amiri, G., Andisheh, K., and Razavyan Amrei. A. 2009].

The existence of active faults in the vicinity and the occurrence of severe earthquakes in the past show that the region has high seismicity and severe earthquakes are probable in the future. Fig. 1 represents the faults of the region.

The studied region encircles Sanandaj city with the radius of 200 km.

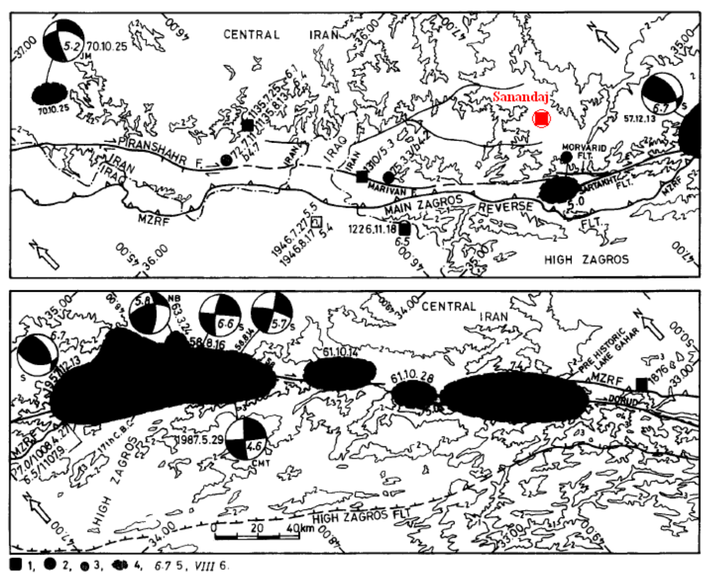

Fig.1. Map of region faults (Berberian M. 1999)

GEOLOGIC BACKGROUND

Based on geological and geotectonical references, Sanandaj is situated in the zone of Sanandaj-Sirjan band [as an independent region of the central Iran] and also located near to the zone of high Zagros.

According to geological studies, Sanandaj-Sirjan zone is the most active tectonic zone in Iran. The zone is influenced by the Mesozoic tectonic occurrences and severe foldings, faultings and Magmatism have been caused. But Cenozoic era appears as erosion without folding in the zone. In fact severe faulting and relative erosion caused in Mesozoic tectonic occurrences in Sanandaj-Sirjan zone have saved it from getting buried under Cenozoic deposits. Only so me shale and sandstone appearances are seen in small areas in west and east of Khomein located in the low parts of Sanandaj-Sirjan band. These are the youngest deposits of this zone. Besides, driving the oceanic crust of the high Zagros under the south active edge of central Iran (Sanandaj-Sirjan belt) has caused a Magmatic belt during Mesozoic and possibly tertiary. The Arabian plateau movement towards north and the subduction of its oceanic crust has closed the Alps Ocean of the high Zagros and finally has caused the collision of the central Iran and the Arabian plateau[Berberian, M., et. al, 1981]. On the basis of the available information the thickest part of the crust is situated along Sanandaj-Sirjan (south west of the continental side of central Iran during Mesozoic) and also in the north east part of this zone (the continental side of Paleozoic and near Kopeh Dagh belt). The studied region is situated in the collided area of Iran, Arabia and Caucasus and is involved in motions which are caused by the transaction of these areas. Hence, it has unique seismotectonic specifications [Hesami, K., et. al, 2001; Berberian, M., 1981].

MODEL OF SEISMOTECHTONIC OF SANANDAJ CITY

Based on seismotectonic, the studied region contains the seismotectonic units of Maraghe-Sirjan (including two tectonic zones: Sanandaj-Sirjan and Oroumiye-Dokhtar in the middle of Zagros and central Iran), the high Zagros, the driven folded thrust of Zagros and Central Alborz.

Based on the performed studies, the studied region, a part of Zagros, is situated in the collided part of Iran, Arabia and Caucasus and mainly has got involved in vertical strike-slip and transitional motions. Structural elements of studied region consist of faults with north-west; south-east direction and reverse strike-slip reverse mechanism. Vertical component along these structures is mainly reversed (compressive) [Harvard Seismology education, 2007; Hesami, K., et. al, 2001; Berberian, M., 1981]. Release rate analysis of seismic moment of earthquakes in the studied region shows that main part of energy releases along the strike-slip moving faults. But this is incompatible with the expected shortening of the region. So, this is the fact that increases the probability of moderate and severe earthquakes [Tchalenko, J. S., et. al, 1974]. Most of the past earthquakes in the region were those have small depth and in many cases the bedrock is involved in deformations. The mean Moho depth is about 50 km and the depth of the seismic stratum has been assessed 8-12 km. [Maggi, A., et. al, 2002], According to focal mechanism of past earthquakes and tectonic evidences, the mechanisms of the reverse faults are predominant in the studied region but the effect of the reverse strike-slip faults can't be ignored. Groups of young faults of Zagros as reverse strike-slip faults are most active faults of the region which encircle its young and principal deformations.

Fig.2 displays the centroid depth determined from body wave modeling. These vary from 4 to 20 km, with typical uncertainties being ± 4 km.

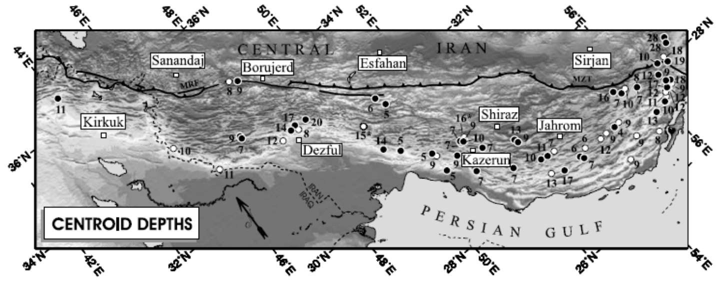

Fig.2. Earthquake centroid depths determined from body wave modeling. Numbers are depth in km. block circles are those determined from long period P and SH waves. Open circles are those determined from P waves alone. The two depths marked with stars (15 and 16*) are earthquakes whose depths were estimated from SH wave alone (Talebian M. and Jackson J. 2004).*

Earthquake Data

In this paper a list of earthquakes containing both historical and instrumental events and covering the period from the 17th century BC to 2006 is used. According to the available information of the historical earthquakes, the oldest earthquake of the studied region is Goudin earthquake that has been occurred about 1600-1650 BC [Berberian, M., et. al, 2001]. The nearest historical city to Sanandaj was Dinvar, that has been destroyed twice by earthquake. The most severe historical earthquake with the magnitude of Ms7 has been occurred in this city, that made the city completely destroyed and more than 16000 people lost their lives. [Ambraseys, N. N., et. al, 1982]. The most severe earthquake of the region has occurred in the south of Sahneh with the magnitude of mb7.2 [Moinfar, A., et. al, 1994] and is known as Farsineh earthquake. According to official reports 1130 people died and 211 villages were destroyed.

Since all magnitudes reported for historical earthquakes are in the form of surface wave, *Ms*, also instrumental earthquakes are based on surface wave, *Ms*, or volumetric wave (m_b). Then, the magnitude of the surface wave, *Ms*, is used for all data. Using the relationship presented by Iranian Committee of Large Dams [IRCOLD, 1994], the magnitude of m_b is converted into *Ms*.
In seismic hazard analysis of a region it is assumed that occurred earthquakes are location and time independents. Regarding the mentioned limitations, foreshocks and aftershocks that are related to principal earthquakes should be eliminated from the data base. In this study Gardner and Knopoff [Gardner, J.K., et. al, 1974] method is used to eliminate aftershocks and foreshocks. Fig.3 shows distribution of peak magnitude of historical & instrumental earthquakes in a 200 Km radius of Sanandaj city after elimination foreshocks and aftershocks.

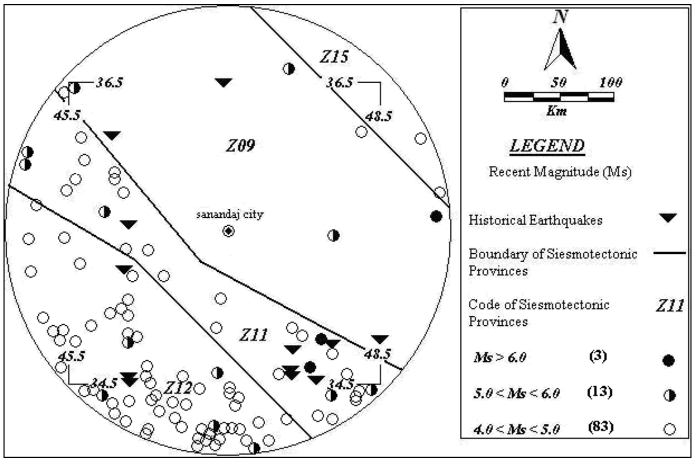

Fig.3. The distribution of magnitude of historical & instrumental earthquakes in a 200 Km radius of Sanandaj city[Ghorati Amiri, G., Andisheh, K., and Razavyan Amrei. A. 2009]

ASSESSMENT OF EARTHQUAKE HAZARD PARAMETERS

Earthquake hazard parameters such as, maximum expected magnitude, *Mmax*, the rate of earthquake occurrence with different magnitudes (activity rate), λ, and b have been evaluated using maximum likelihood method [Kijko, A., and Sellevoll, M.A., 1992]. Besides, the return period and the occurrence probability of each magnitude have also been calculated by the Kijko [Kijko, A., 2000] software. Calculation results of the seismic hazard parameters for each of three time periods are represented in Table 1 for comparison [Ghorati Amiri, G., Andisheh, K., and Razavyan Amrei. A. 2009].

Table 1: The result values of the calculated seismic hazard parameters in different time periods by Kijko method [Ghorati Amiri, G., Andisheh, K., and Razavyan Amrei. A. 2009]

Catalogue	Parameter	Value	Data Contribution to the Parameters (%)		
			Period#1	Period#2	Period#3
20th Century Earthquakes Data	Beta	2.03		23.4	76.6
	Lambda(for Ms=4)	1.08		17.2	82.8
Historical Earthquakes Data	Beta	2.27	100		
	Lambda(for Ms=4)	0.42	100		
Historical and 20th Century Data	Beta	2.22	53.6	17.7	28.7
	Lambda(for Ms=4)	0.92	10.8	15.3	73.9

STRONG GROUND MOTION PARAMETERS IN THE REGION OF SANANDAJ CITY

Different parameters are involved in ground motion. The peak horizontal ground acceleration and respond spectrum are two index parameters representing the nature of the strong ground motion. In this paper is in order to assess the parameters of the ground motion, the acceleration uniform hazard spectra is calculated by probabilistic seismic hazard analysis.

The steps for seismic hazard assessment to provide acceleration uniform hazard spectra can be summarized as follows:
Step 1: Identification of seismic sources. Step 2: Establishment of recurrence relationship, magnitude distribution and average rate of occurrence. Step 3: selection of attenuation ground motion. Step 4: computation of site hazard curve. Step 5: repeat previous steps numerous times using different coefficients corresponding to each discrete frequency.

Seismic Hazard Assessment of Sanandaj City

In this paper in order to evaluation of seismic hazard, the model of linear sources is used and it is also assumed that the seismic power of all the active faults in the region is equal, and the occurrence relationship of Gutenberg and Richter and Poisson model are used as the function of the probability prediction of the earthquake occurrence in the future. Nowroozi [Nowroozi, A., 1985] relationship was used to express the relationship between fault rupture and the earthquake magnitude. Attenuation relationships are one of the most important elements in the seismic hazard analysis which represent the relationship between spectral acceleration, the distance from the surface epicenter of the earthquake and the magnitude. In this study, after assessing different spectral attenuation relationships to select proper relationship, Ambraseys and et al. [1996] attenuation relationship was selected. Because there was no valid report about soil type of different regions of Sanadaj city, spectral acceleration was computed for all three soil type represented in the used attenuation relationship. In this Research the structure of Sanandaj city and its vicinity is subdivided into a grid of 8×10, total of 80 sites, with eight vertical and ten horizontal lines that the distance between every two subsequent vertical lines is 1.66 km and the distance between every two subsequent horizontal lines is 1.82 km. Probabilistic seismic hazard analysis is then carried out for each site by SEISRISK III [Bender, B., et. al, 1987], based on 10%, and 2% probability of being exceeded during life cycles of 50 years or the return periods of 475 and 2475 years respectively, and eight period including 0.1sec, 0.2sec, 0.3sec, 0.5sec, 0.75sec, 1sec, 1.5sec, and 2sec

Uniform Hazard Spectra

In order to provide uniform hazard spectra, spectral acceleration is computed for all 80 identified sites based on probabilistic seismic hazard assessment for a specific hazard level, a specific soil type represented in attenuation relationship, and a specific period. The maximum, average, and minimum values of spectral accelerations correspond to the represented period is then identification. Using a different period and same hazard level and same soil type, spectral acceleration is computed for all 80 identified sites, and the maximum, average, and minimum values of spectral accelerations is identified among the computed spectral accelerations. This process is continued and the maximum, average, and minimum values of spectral accelerations correspond to all different periods is computed, and maximum, average, and minimum uniform hazard spectra is provided using them. The provided uniform hazard spectra shows spectral acceleration (SA) versus period (T) for the specific hazard level and the specific soil type. The uniform hazard spectra are calculated for all different soil types and all different hazard levels. Figures 4 to 9 show maximum, average, and minimum values of uniform hazard spectra, calculated for Sanandaj city, for the return period of 475 and 2475 years, and for three soil type including rock, stiff soil, and soft soil site.

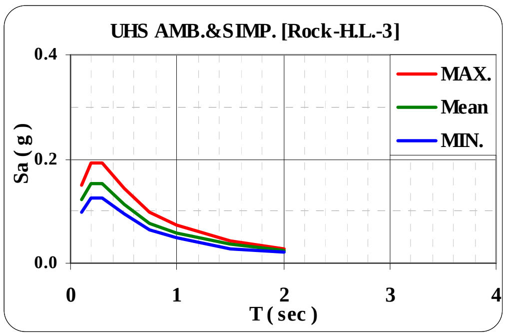

Fig.4. Uniform Hazard Spectra for 475-year return period with rock soil site

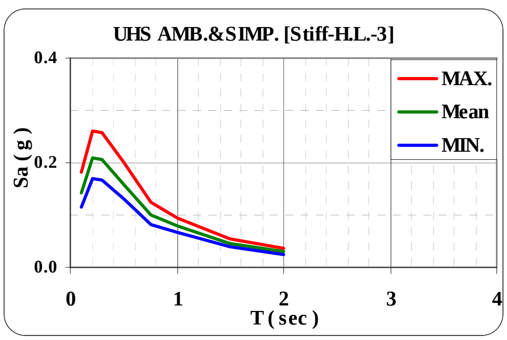

Fig.5. Uniform Hazard Spectra for 475-year return period with stiff soil site

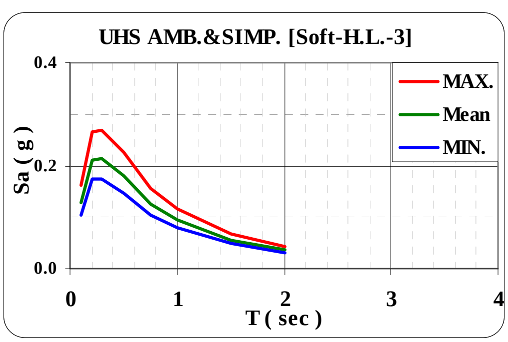

Fig.6 .Uniform Hazard Spectra for 475-year return period with soft soil site

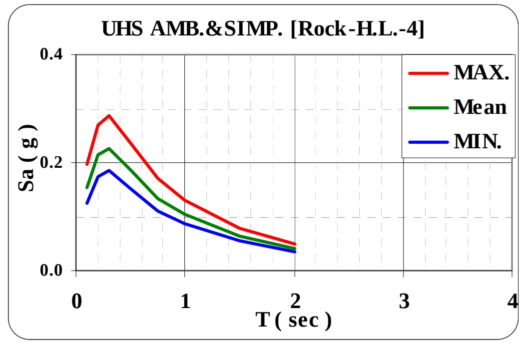

Fig.7. Uniform Hazard Spectra for 2475-year return period with rock soil site

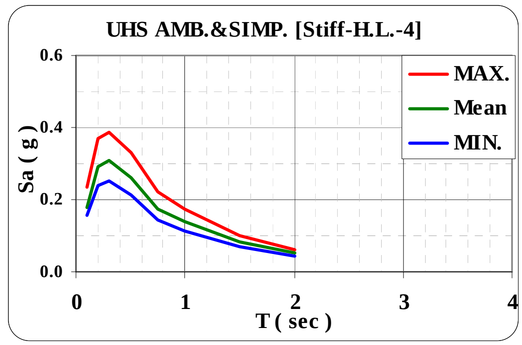

Fig.8. Uniform Hazard Spectra for 2475-year return period with stiff soil site

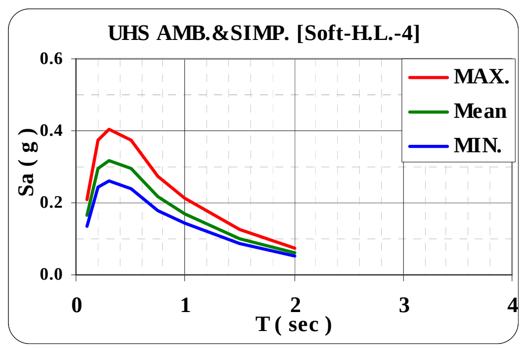

Fig.9. Uniform Hazard Spectra for 2475-year return period with soft soil site

CONCLUSIONS

The results show maximum, average, and minimum values of uniform hazard spectra for the return period of 475 and 2475 years, in rock, stiff soil, and soft soil sites. The comparison of the calculated values of acceleration spectral in this study in the return period of 475 years with the proposed spectral acceleration of the Iranian Code of Practice for Seismic Resistant Design of Buildings [BHRC, 2005] (A*B) shows that the proposed values of spectral acceleration of the 2800 manual are conservative.

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