Seismotectonics and Seismic Hazard Assessment of the Sari quadrangle in Iran

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Abstract

This research is a part of the Iranian Seismic Hazard Assessment Program. The Sari Province is located in the north of Iran with several active faults. Seismic Risk map of this area were made by using the Seismic data of the past and seismo-tectonic studies. Seismic parameters such as β and λ and also return period of Magnitude earthquakes estimated. This research improved the integration of the geological input in seismic hazard assessment. We applied several attenuation models and deterministic and probabilistic approaches throughout the Sari quadrangle. The maps of the area include the maximum acceleration (g) on the base rock. The return Periods of those maps are 200, 475, 2475, 5000 and 10000 years respectively. Finally, the seismic hazard zonation map has been presented for Sari quadrangle and classified to four zones with low, moderate, high and very high seismic zones. The Design Response Spectra with several return periods presented for these zones.

KEYWORDS: Seismic Hazard, Zonation, Spectra

1. INTODUCTION

For safety of important structures against earthquake hazard into the Sari quadrangle located at north of Iran seismic zonation study has been done. The first we investigated detail seismicity and seismotectonic of its area. Then peak ground acceleration and values spectra for dynamic analysis of structures into the area have been calculated by seismic hazard investigations. These parameters have a very important role in decreasing of economic and life risk against earthquake.
The area with coordinate of 36°- 37°N and 52.5°- 54°E is located at the north of Iran but in the central Iran seismotectonic province (CISP). Then, the seismicity of this quadrangle is following of seismicity characteristics of CISP.

2. SEISMOTECTONICS

Alborz mountains (north of Iran) are considered as mountains without root that its uplift is due to thrusting of allochthonous masses over each other in a compressional tectonic regime. The depth of Moho in Alborz mountains is less than 35km [Dehghani and Makris, 1983]. So, Alborz mountains can be considered as thin-skinned orogen or thin and thick skinned orogen [Berberian, 1981]. If this matter is correct, surface faults can not be respond for seismicity of Alborz. Geological- tectonic investigations in the Alborz mountains obviously show that these mountains have been formed by thrusting of folded rocks over each other [Stocklin 1968, Berberian 1983]. This matter is reason for height of Alborz. The focal mechanism of Alborz's earthquake, [Mckenzie, 1972] indicate strike-slip mechanism with some reverse component. For causative faults that have a dip about 40° toward north or south [Berberian, 1983]. The focal mechanism of the Rudbar- Tarom earthquake (June 20, 1990, M_w=7.3) shows a left- lateral strike slip. Although reverse faults and folding have been had an important role in formation of Alborz folded and thrust active mountains but occurrence of the Rudbar- Tarom earthquake indicates that the Alborz belt in the Rudbar-Tarom area is affected by left- lateral shear.

Sari quadrangle area is comprised from four parallel mountain ranges and valleys with a northwest-southeast trend. From view point of morphology, following units can be distinguished from northeast to southwest:

1- The Alborz Mountain with east- west trend and with maximum 5678 m high (Damavand) is located in the north of Iran. This mountain series is northern part of Central Iran provinces.
2- The south of Alborz mountain series is located Central Iran desert and Zanjan - Tabriz compressive depression (Ghorash and Ghasemi, 2003).
3- The south Caspian Basin, is an intracontinental basin and located between the Kope Dogh mountains and Kura depression.

2.1. Major and most active faults

All of the faults into the area have been investigated and their characteristics with attention to previous studies have been presented. Quaternary faults in the Sari quadrangle area are categorized into three groups:

1- Major and most seismogenic faults (more than 10km long and active)
2- Medium faults (2 to 10km long)
3- Minor faults (less than 2km long)

Major and seismogenic faults (Map No.1) have cut quaternary deposits in the Sari quadrangle. Because of their low age and much length we considered those seismogenic faults.

The Khazar, North Alborz, Damghan and Astaneh faults are the most active faults in this area.

2.1.1 Khazar fault

The Khazar fault is the bounded between Alborz mountains and Khazar depression. The length of this fault is about 454 km. Maximum displacement occurred in the middle of this fault (south of Gorgan). In this area the Gorgan formation (Paleozoic age) located near and over the Quaternary deposit. The eastern and middle part of Khazar fa**ult** is corresponding parallel with F-479 and F-5 magnetic lineaments (Yousefi and Freidberg, 1978) respectively. Figure 1 shows the geological structure of Khazar and related fold in its hanging-wall near the Behshahr city (Ghasemi, 2002).

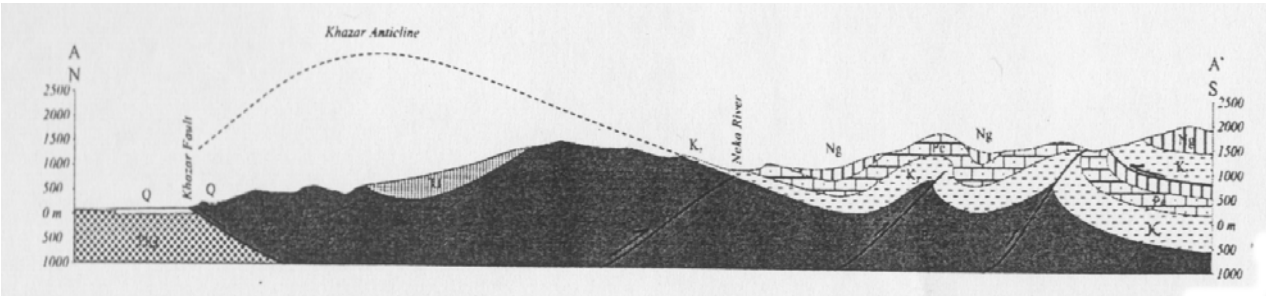


Figure 1 geological structure of the Khazar fault and related fold in its hanging-wall **near** the Behshahr city

The Gonbad Kavos earthquake (874) with Ms6.0 and 1436, 1470 and 1489 earthquakes located along this fault and many people dead. The source of 1809 Amol earthquake with M6.5 is Khazar fault. During the earthquake many villages destroyed and happened liquefactions along the valleys. The 1944 Gorgan earthquake with M5.2 and I=VII was depend of reactivated of this fault (Gorelikov, 1960, Tchalenko, 1975b) during the quake 60% of Gorgan city destroyed. The 1952 (mb4.7), 1970 (mb5, Tchalenko, 1975b), 1971 (mb5.2) and 1999 with mb5.3 earthquakes were happened along this fault.

2.1.2 North Alborz Fault

The North Alborz fault, with a length of about 427 km and thrust mechanism, makes the southern boundary of Khazar Neogene deposits. The western termination of the fault is bounded by the Lahijan fault. The dip of North Alborz fault is towards south, and its most stragraphic displacement can be seen in Zarem Rud region. In this locality Triassic Rocks are thrusted over the Neogene deposits.

Tilting of the Quaternary deposits in the east, and several small and large landslides, indicate that the fault is active. The 1127 Farim-Chahardangeh (Ms6.8, I=VIII-IX), 1301 (Ms6.7), 1687 (Ms6.5), 1805 (Ms6.7), 1825 (Ms6.7), 1935 (Ms6.7) and 1999 (M4.8) earthquakes, could be related to the reactivation of North

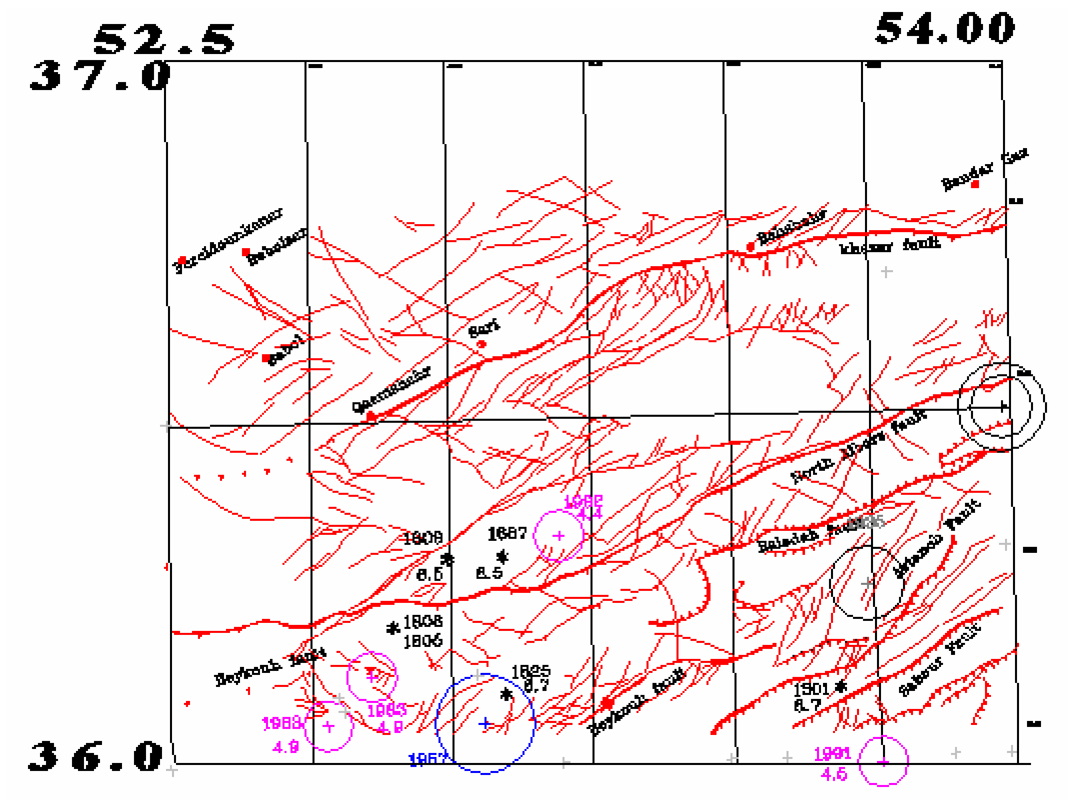
2.1.3. Alborz fault.

Damghan fault

This fault is with a reverse mechanism is located in a distance of 10 km north of Damghan city. This fault with a length of more than 100 km cuts the Quaternary deposits of the northern Damghan. Probably the 22 December 856 (Ms7.9, I=X) Komes and 9 Jan. 1982 (Ms4.2) earthquakes, might be the result of Damghan fault reactivation (Berberian, 1983).

2.1.4. Astaneh fault

The Astaneh fault with a length of more than 75 km has a mainly left-lateral strik-slip mechanism. It is highly probable that 22 Dec. 956 (M7.9) Komes earthquake.



Map No.1, seismotectonic map of Sari quadrangle area

3. SEISMIC PARAMETERS

Seismic parameters estimated based on happening earthquakes in the Sari quadrangle area. Iranian seismic data collected and printed by Ambraseys, N. N. and Melville, C. P. (1982) and Mahdavian et. al, (1994). Because there is error to estimate earthquakes location, the study has been done on the basis of number of events that recorded within the area with radius of 100 km from center of Sari quadrangle. This area is a little bigger than of Sari quadrangle.

Seismic parameters were estimated in different ways. We consider the results obtained as followings:

3.1. The Gutenberg-Richter Relationship:

Relation of Gutenberg-Richter has been calculated with respect R=100, with number 1, and 150 km with number 2 the following results are:
In an area covering 100 km:

$$LogNc = 3.6932 - 0.555Ms \qquad (Ms \geq 4.3).with....r = 0.99 \tag{1}$$

In an area covering 150 km

$$LogNc = 4.71531 - 0.56394Ms \quad with \quad r = 0.9923 \tag{2}$$

3.2. Double truncated Gutenberg- Richter

The assumption of the Poisson occurrence of earthquakes with mean rate λ and doubly truncated Gutenberg- Richter magnitude is distribution, implies that earthquakes of magnitudes greater than M (m>M) can be represented by a Poisson process with the mean rate of occurrence. The distribution of its function is expressed as follow (No. 3):

$$G(m \mid T) = \Pr(M \leq m) = \exp[-\lambda T \frac{\exp(-\beta M_{max}) - \exp(-\beta m)}{\exp(-\beta M_{max}) - \exp(-\beta_{min})}] \tag{3}$$

In this relation λ and β are seismic parameters and M is the maximum Magnitude.
The best method and software program which is suggested for analysis of earthquakes in Iran is kijko & Sellevol method which was introduced in 1992. In this method the last software which presented by kijko and Graham (1999) is used the obtained results are as follows (table No.1):

Table 1, Seismic parameters of two areas

Area under study	Seismicity Parameter		Area under study	Seismicity Parameter	
	β	λm4.3		β	λm4.3
Area 100 km	2.13±0.1	0.503	Central.Iran	1.73±0.08	1.82
Area 150 km	1.97±0.09	0.75	Alborz	1.18±0.2	0.257

The obtained results of seismic parameters in these areas (R= 100 and 150 km) showing that return period of an earthquake with the magnitude of Ms 5.6 and Ms 5.9 is 50 years and earthquakes with M6 and M6.3 are 100 year in the area with radius 100 and 150 km respectively. The return period of an earthquake with the magnitude of Ms6.7 is 500 year in the area with R=100 km. The Maximum magnitude is estimated Ms7.4.
According to these parameters the return period of the earthquakes in these two areas is not considerably different. The research area located in the central Iran province and its parameters are estimated β =1.73 and λm4 = 2.16 and the maximum magnitude is Ms7.6.

4. SEISMIC ZONATION

The strong ground motion parameters presented by standard code or by some national institutes are usually determined conservatively. This study is to calculate ground motion parameters in given area. Deterministic and probabilistic methods are applied to Seismic Hazard Analysis (SHA).
Base on the seismotectonic map No.1, the active faults and area are modeled such as line and area sources.
The probabilistic method was done according to the Cornell method represented in 1968 and relations of Bender and Perkins (1987). In this study the applied attenuation relationships introduced by Cmpbell &

Bozorgnia (2003) and Ambraseys N, and Douglas (2003) has been used and presented for seismotectonic active zone with shallow earthquakes of the world such as Iran. The average of these two relationships has been considered in final calculations.

The maximum horizontal and vertical accelerations calculated and discussed in the mentioned area, with approximate geographical distance of one to one minute, for return periods 200, 475, 2475, 5000 and 10000 years. For each point the acceleration parameter has been calculated without standard deviation (SD=0) of formula and with standard deviation. The average value of two above relationships is calculated and the related curves were drawn.

Figures 2 to 3 represents some of these results for horizontal curves (with SD) for return periods 475 and 2475 years.

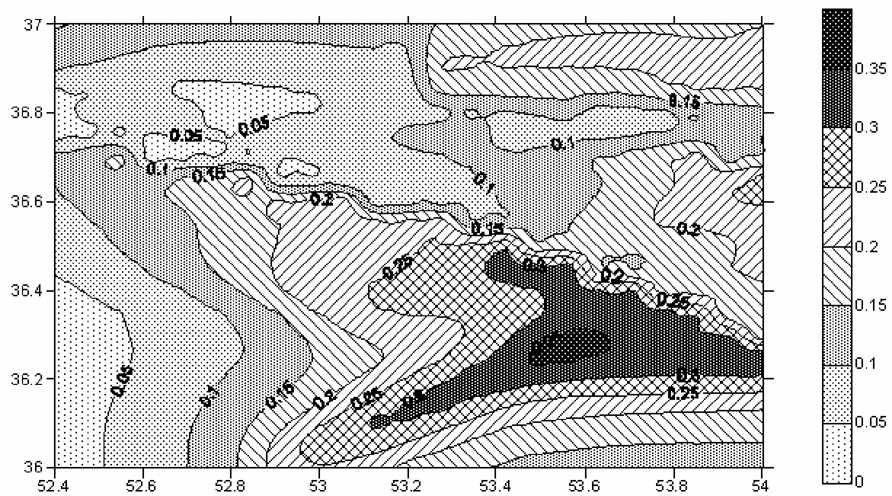


Figure 2: Seismic zonation map of Sari quadrangle, based on Horizontal PGA for return period 475 year

Sari quadrangle area divided based on the acceleration map with return period of 475 year and rules of designing buildings code of Iran (Standard 2800, 2005), including four areas has been shown as follow:

The area with maximum amount of acceleration with more than 0.35g is considered with very high seismic zone.

The area with maximum amount of acceleration is between 0.30g to 0.35 g considered high seismic zone.

The area with maximum amount of acceleration is between 0.20g to 0.30g considered moderate seismic zone.

The area with maximum amount of acceleration is less than 0.20g considered low seismic zone.

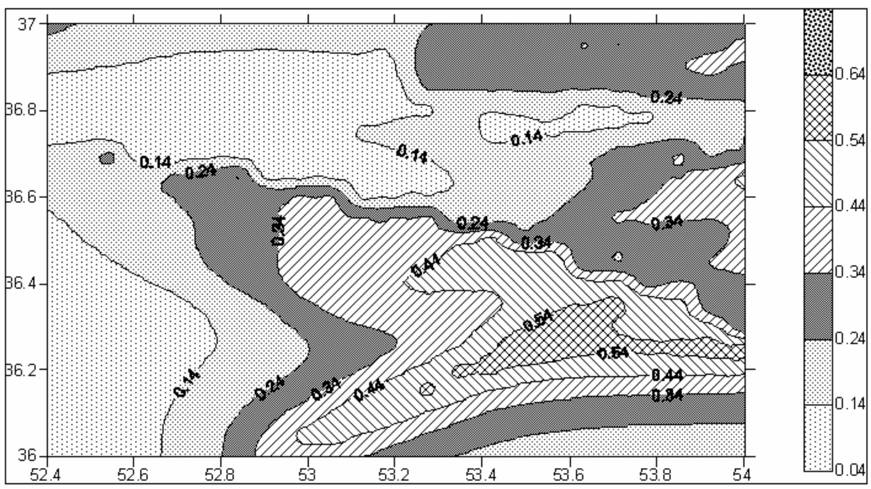


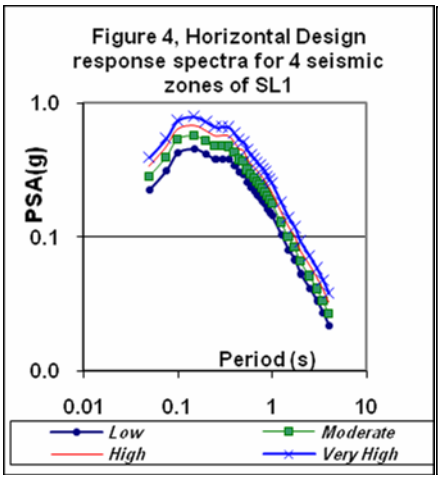
Figure 3: Seismic zonation map of Sari quadrangle, based on Horizontal PGA for return period 2475 year

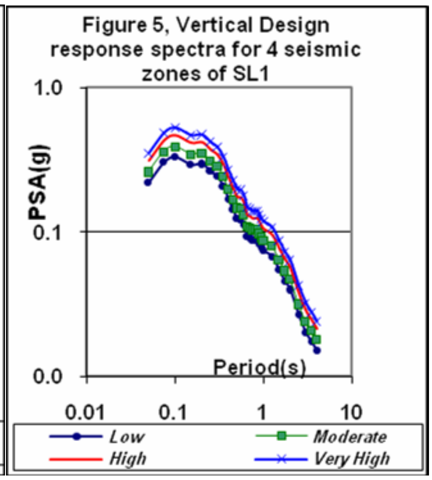
5. DSIGN SPECTRA

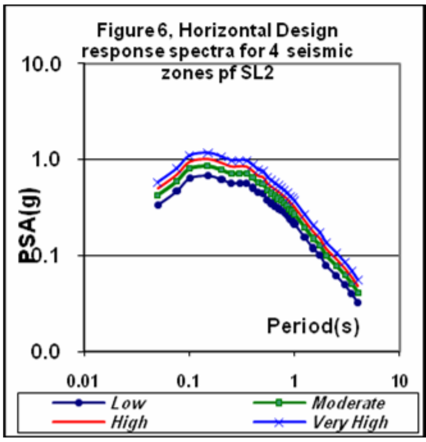
To evaluate design spectra for each level of acceleration in the Sari quadrangle the probabilistic and statistical methods are applied.
Using the data described in the above for SHA computed equal probability response spectra (EPRS) corresponding to additive probabilities in the range 10^{-4} to 10^{-2} per years. The resulting spectra for the mean horizontal and the vertical components by Campbell and Bozorgnia (2003) Response Spectra models are calculated without standard deviation (SD=0) of formula and with standard deviation for points selected of each seismic zone.
Acceleration time history from available data selected and applied statistical method to its data. Selection criteria include earthquake magnitude, distance range, site conditions and focal mechanism [Kimball, 1983]. The purpose of these criteria is to render the accelerogram suite as site-specific as possible as discussed in Kimball (1983).
Acceleration data is selected from recorded earthquakes in different parts of Iran and certain country with the same conditions.
The specifications considered to select the acceleration time histories according to the above results an earthquake with Ms 6.7 has a return period of 475 year with maximum magnitude Ms 7.4, for Sari quadrangle area. This magnitude (Ms 7.4) has an approximate return Period of 2000 to 2500 year for the mentioned area. Thus, the selected target magnitude is about Ms6.7. It is suggested that the range of magnitude of selected data is between Ms6.2 to Ms7.4.
Table No.2 shows list of the selected accelerograms. Acceleration time histories scaled based on peak values of acceleration and those response spectra for 5% damping calculated. The mean response spectra for horizontal and vertical components were computed separately and called coefficient of response spectra for this study. As mentioned above the ground motion parameters (PGA) of each seismic zone with return periods 475 (Fig. 4 &5) and 2475 (Fig. 6 &7) year selected and multiplied by coefficient of response spectra for horizontal and vertical components. These response spectra compared with results of response spectra estimated based on probability methods. There was a good enveloping between the results of both methods. The response spectra estimated by statistical method suggested for Design Response Spectra of SL1 and SL2 for each seismic zone and for horizontal and vertical components.

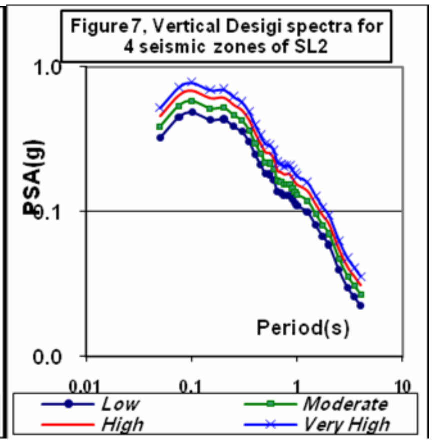
Table No2: Selected acceleration time histories to estimate design response spectra

Earthquake name	Station Name	Date of event	Magnitude
Baladeh-Iran	Pol (3330-1)	May. 28, 2004	6.4
Ardebil-Iran	Azr (1933-2)	Feb. 28, 1997	6.2
Changuleh-Iran	Razan (2756-1)	June. 22, 2002	6.5
Zarand-Iran	Shirin rud Dam (3697-1)	Feb. 22, 2005	6.5
Manjil-Iran	Abbar (Abbar)	June. 20, 1990	7.4
Tabas-Iran	Deyhuk (1082-1)	Sep. 16, 1978	7.3
Friuli	Tolmezzo (FRTO)	May. 6, 1976	6.5
Changuleh-Iran	Shirin Sou (2781)	June. 22, 2002	6.5
Spitak, Armenia	Gukasiiyan (SPIT)	Dec. 7, 1988	6.8
Imperila Valley, USA	Compuertas (IVCOM)	Oct. 15, 1979	6.7
San Fernando USA	Santa Felicia Dam (40GFS)	Feb. 9, 1971	6.5
San Fernando, USA	Castaic (SFCA)	Nov. 23, 1980	6.5
Irpinia, Ita.	Sturno (IRS)	Nov. 23, 1980	6.8
San Fernando	Pacoima Dam (40D)	Feb. 09, 1971	6.6
Zarand-Iran	Gha Dam (3689-1)	Feb. 22, 2005	6.5









6. CONCLUSION

Sari quadrangle is located at north of Iran. Several active faults, such as Khazar, North Alborz, Damghan and Astaneh faults are the most active faults in this area. Major and seismogenic faults have cut quaternary deposits in the Sari quadrangle. Because of their low age and much length we considered those seismogenic faults. One of the big earthquake happened in 1975 with Ms7.0 in this region. Then, this quadrangle is one of the seismic active zones in Iran.
Peak ground acceleration and values spectra for dynamic analysis of structures within the area have been calculated by detailed seismicity, seismotectonic and seismic hazard investigation. Sari quadrangle divided into four seismic zones based on the map with return period of 475 year. Ground motions are defined in terms of peak ground acceleration, and response spectra. Two levels of earthquake ground motion will be determined for each zone.
Peak ground accelerations and response spectra associated with the return period 475 year and 2475 year are determined by the probabilistic approach.
The mean response spectra for horizontal and vertical components were computed separately and called coefficient of response spectra for this study. To estimate response spectra, the ground motion parameters (PGA) of each seismic zone with return periods 475 and 2475 year selected and multiplied by coefficient of response spectra.
The response spectra estimated by this method suggested for Design Response Spectra of SL1 and SL2 for each seismic zone and for horizontal and vertical components.

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