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Hazard-Consistent Magnitude and Distance in Iran

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This study deals with the deaggregation of probabilistic seismic hazard of Iran. To this, the relative contributions of earthquake parameters to the total hazard are computed by probabilistic seismic hazard analysis (PSHA) deaggregation. Afterwards, the representative values of earthquake magnitude and distance are obtained for all meshes of Iran and they are plotted as hazard-consistent magnitude and distance, respectively. In the deaggregation analysis for major cities with over one million populations, the values of the strong-motion parameter are recalculated using representative values of magnitude and distance of high contributed seismic sources for PGA, PGV and in each period. New seismic parameters will be matching closely with the distance and magnitude values as obtained by the PSHA approach.

1. Introduction

Probabilistic seismic hazard analysis is a technique for estimation of seismic hazard at a site under the known seismic sources. The relative contributions of the various sources to the total seismic hazard are determined as a function of their occurrence rates and their ground-motion potential. As probabilistic seismic hazard analysis is known as realistic and comprehensive method, it is useful to display the relative contributions to the hazard from the different values of the hazard components, like magnitude and distance of the seismic source to site. The results, which are obtained separately for each seismic source and combined for all the seismic sources in the region, are called the deaggregation of the probabilistic hazard analysis as shown by Bazzurro and Cornell[1]. In this study, the results of probabilistic seismic hazard analysis, which had been done previously by covering all Iran, is used for the deaggregation analysis. Some aspects of deaggregation of seismic hazard for Iran are studied considering the seismic design.

2. PSHA and Deaggregation

Probabilistic seismic hazard analysis (PSHA) considers a probability of occurrence in a certain period of lifetime of structures. The probability of exceeding a particular value y^* in a time period T, of a ground motion parameter, Y, is obtained by the following relations:

$$P\left[Y_T \geq y^*\right] = 1 - e^{-\lambda_{y^*} T} \quad (1)$$

where λ_{y^*} is the total average exceedance rate for the region of the study.

The main formulas for probabilistic seismic hazard analysis can be written using probability of parameters as acceleration, moment magnitude, M, and source to site distance, R, as follow[2].

$$\lambda_{y^*} = \sum_{i=1}^{N_S} \sum_{j=1}^{N_M} \sum_{k=1}^{N_R} \nu_i \cdot P\left[Y > y^* \mid m_j, r_k\right] \cdot P\left[M = m_j\right] \cdot P\left[R = r_k\right] \quad (2)$$

where N_S, N_M and N_R are respectively number of seismic sources, magnitude and distance divisions, and ν_i is the mean rate of exceedance of threshold magnitude, M_{min}, for a seismic source i.

The probabilistic hazard analysis procedure computes the mean annual rate of exceedance at a particular site based on the aggregated risk from many different magnitudes occurring at different distances. Therefore there is not any representor magnitude or distance to be associated with the result of PSHA.

It is useful to estimate the most likely earthquake magnitude or source-site distance. These quantities may be used, for example to select existing ground motion records (recorded in earthquakes of similar magnitude at similar source-site distance) for response analyses[2]. Adding to this, the mean annual rate of exceedance should be expressed as a function of magnitude or distance. Eq.(3) shows the mean annual rate of exceedance as a function of magnitude:

$$\lambda_{y^*} = P\left[M = m_j\right] \sum_{i=1}^{N_S} \sum_{j=1}^{N_M} \sum_{k=1}^{N_R} \nu_i \cdot P\left[Y > y^* \mid m_j, r_k\right] \cdot P\left[R = r_k\right] \quad (3)$$

The mean annual rate of exceedance as a function of source-site distance can be expressed similarly by Eq.(4):

$$\lambda_{y^*} = P\left[R = r_k\right] \sum_{i=1}^{N_S} \sum_{j=1}^{N_M} \sum_{k=1}^{N_R} \nu_i \cdot P\left[Y > y^* \mid m_j, r_k\right] \cdot P\left[M = m_j\right] \quad (4)$$

It is possible to compute the mean annual rate of exceedance as functions of both earthquake magnitude and source-site distance as expressed by Eq.(5):

$$\lambda_{y^*} = P\left[M = m_j\right] P\left[R = r_k\right] \sum_{i=1}^{N_S} \sum_{j=1}^{N_M} \sum_{k=1}^{N_R} \nu_i \cdot P\left[Y > y^* \mid m_j, r_k\right] \quad (5)$$

In this study contribution level of seismic sources for some major cities of Iran has been shown in ranges of magnitude and distances. These quantities can interpret distribution of high contributed areas for desired site.

3. Previous PSHA for Iran

Authors presented recent seismic hazard of Iran by probabilistic approach[3]. Recent earthquakes catalogue of Iran until 2010 was gathered and recurrence law of seismic zones of Iran were obtained. Seismic zone map was referred to the map shown by Tavakoli[4]. These quantities were used to get seismicity of two types of seismic source; active faults[5] and floating earthquakes. Attenuation relations for Iran major zones, which were already published by authors[6] and is able to evaluate characteristics of seismic major zone and fault mechanism, were used for the analysis. Prediction of ground motion for two levels of hazards, 10% and 2% exceedance probabilities of occurrence per 50 years lifetime of general buildings was calculated in terms of peak ground acceleration (PGA), peak ground velocity (PGV), and spectral acceleration (SA) in each period on the rock site, in meshes whose dimensions were 0.1 latitudes and 0.1 longitudes. Evaluated probability considers seismicity in 100 km from the site. 10 % exceedance probability of occurrence per 50 years lifetime is used in the current practice of seismic design in Iran[7]. Current study deals with deaggregation of PSHA.

4. Hazards-Consistent Magnitude and Distance in Iran

The deaggregation can be imagined as a physical interpretation of the results from PSHA and can be used for taking certain engineering decisions. Then it is desirable to have a representative earthquake which is compatible with the results of the PSHA method[8]. This could be achieved through the de-aggregation of the probabilistic seismic hazard, as described in the follow [9].

Considering the Y as ground motion parameter and y as the probability of exceeding a particular value, the deaggregation of PSHA for finding the relative contribution of the earthquakes of type (i, j), to the probability of $Y > y$ is:

$$f(M_j, R_i \mid Y > y) = \frac{1.0 - \exp\left\{-q(y_p \mid M_j, R_i)\nu T\right\}}{1.0 - \exp\left\{-\sum_{i=1}^{I}\sum_{j=1}^{J} q(y_p \mid M_j, R_i)\nu T\right\}} \quad (6)$$

Parameter ν is average rate of occurrence of earthquake per year and T is time interval in year. The numerator in Eq. (6) represents the probability of $Y > y$ due to earthquakes of type i, j, and the denominator represents the probability of $Y > y$ due to all the expected earthquakes. The representative values of earthquake magnitude and distance can be obtained from this distribution as:

$$\overline{M} = \sum_{i=1}^{I}\sum_{j=1}^{J} M_j \cdot f(M_j, R_i \mid Y > y) \quad (7)$$

$$\overline{R} = \sum_{i=1}^{I}\sum_{j=1}^{J} R_i \cdot f(M_j, R_i \mid Y > y) \quad (8)$$

The value of the strong-motion parameter Y with probability of exceedance y, as it was obtained using these values of magnitude and distance, will be matching closely with the value y as obtained by the PSHA approach. $\overline{M}$ and $\overline{R}$ may thus be termed as hazard-consistent magnitude and distance, respectively as shown by Ishikawa and Kameda[10] and Kameda[11].

In the following, hazard-consistent magnitude and distance for Iran meshes are calculated and presented in Figures 1 to 8 for PGA, SA at periods 0.1 s and 1.0 s, respectively. Analysis for PGA has been presented for two levels of hazard as level 1 and 2 which refer to 10% and 2% probability of occurrence in

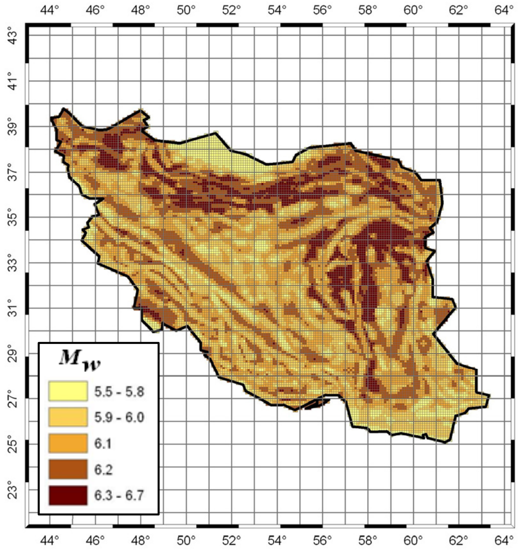

Fig. 1 Hazard-consistent magnitude for PGA (475 years)

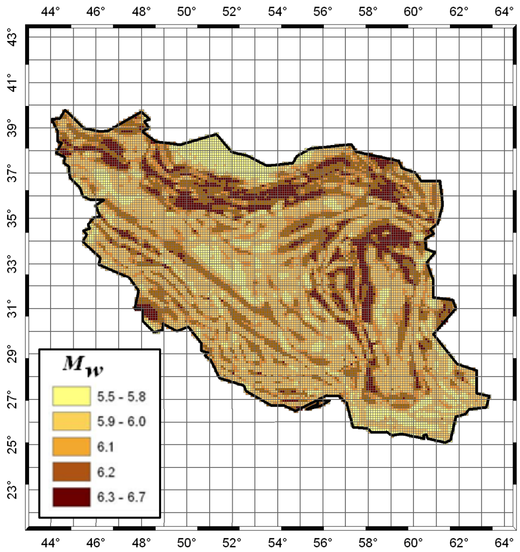

Fig. 2 Hazard-consistent magnitude for PGA (2,475 years)

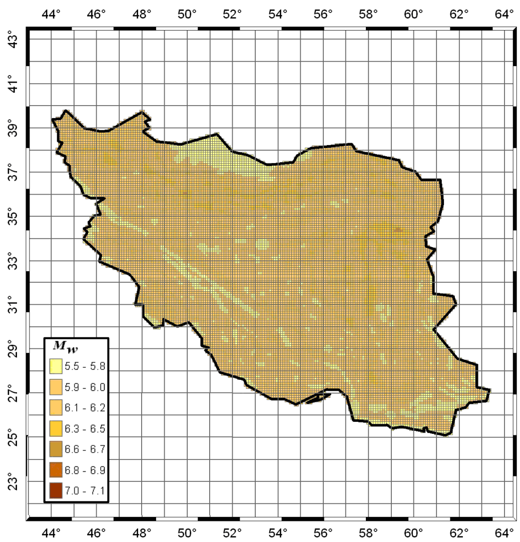

Fig. 3 Hazard-consistent magnitude for SA at period 0.1s (475 years)

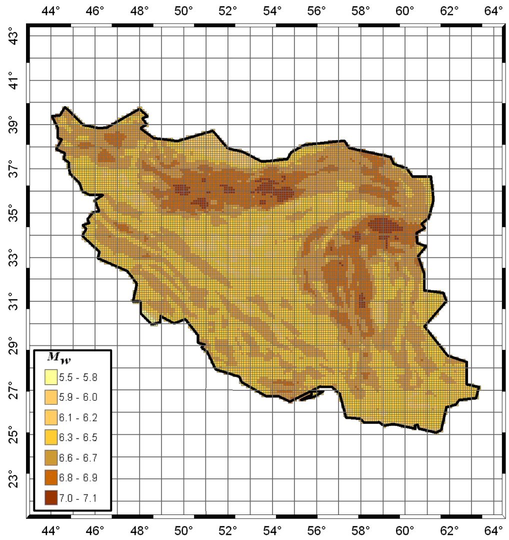

Fig. 4 Hazard-consistent magnitude for SA at period 1.0 s (475 years)

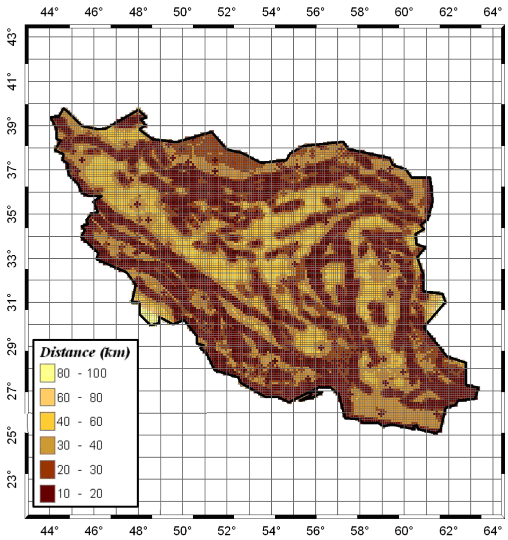

Fig. 5 Hazard-consistent distance in km for PGA (475 years)

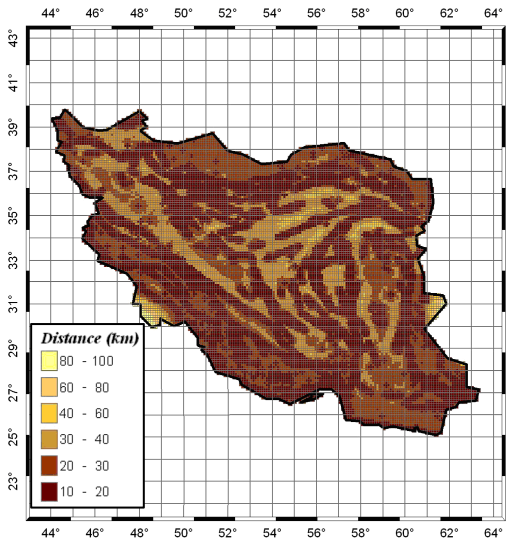

Fig. 6 Hazard-consistent distance in km for PGA (2,475 years)

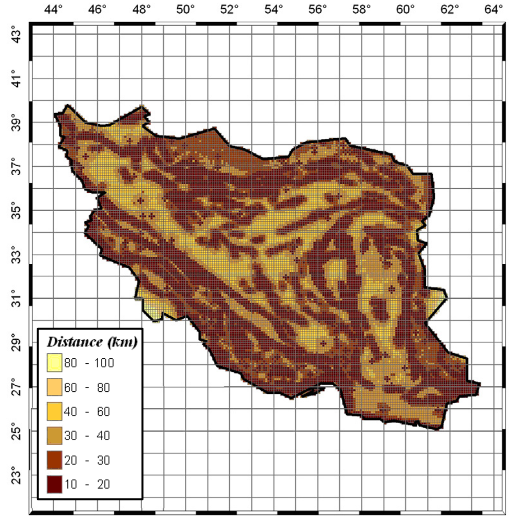

Fig. 7 Hazard-consistent distance in km for SA at period 0.1 s (475 years)

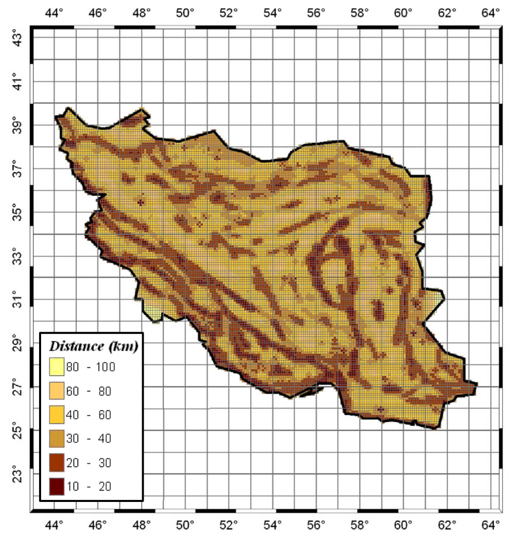

Fig. 8 Hazard-consistent distance in km for SA at period 1.0 s (475 years)

50 years, corresponding to return periods 475 and 2,475 years. Figures 1 and 2 show hazard-consistent magnitude for PGA in two levels of hazards. Results depend on distribution of seismic sources around the desired site and their earthquake potential, and it varies from M_w 5.5 to 6.7. Comparison of hazard-consistent magnitude for two levels of hazards shows that as the hazard level increases $\overline{M}$ also decreases.

According to Figures 3 and 4, hazard-consistent magnitude, $\overline{M}$ increases when period becomes longer from 0.1 s to 1.0 s. This means higher magnitudes have higher contribution level in a long period. As the same with hazard-consistent magnitude, hazard-consistent distance, $\overline{D}$ also decreases with increasing of hazard level and it increases with growing the period. On the other hand far areas have higher contribution levels in long periods than nearer areas. This is affected by the attenuation relation characteristics. The ground motion in a short period attenuates rather than in a long period and it does not provoke effectively in far area.

5. Deaggregation of Probabilistic Ground Motions for Major Cities of Iran

In this study deaggregation of PSH for 6 cities of Iran having population with over one million has been conducted. These cities are listed in Table 1 which shows location and population of them based on the last population census in 2006. In the following deaggregation of seismic hazard for cities of Mashhad and Tabriz is studied.

Table 1 Staticties of over one million populated cities of Iran

Row	City	Population (million)	Capital of prefecture	Latitude	Longitude
1	Tehran	7.7	Tehran	35.77	51.45
2	Mashhad	2.4	Khorasan razavi	36.29	59.60
3	Esfahan	1.6	Esfahan	32.65	51.68
4	Tabriz	1.4	Azarbayjane sharghi	38.08	46.29
5	Karaj	1.4	Alborz	35.83	51.01
6	Shiraz	1.2	Fars	29.60	52.53

5.1 Deagregation of PSHA in Mashhad

Mashhad is located in the east of Iran. Seismic activity of this city is lower than Tehran. It is the second populated city of Iran and an industrial city. Figure 9 shows active faults around Mashhad. Numbers depicted in Figure 9 is the faults used in PSHA. Faults 169, 170 and 171 are running within 20km from the city.

Figure 10 shows the joint distribution of *M* and *R* for PGA for 475 years return period. The major contribution comes from small magnitudes at close distance. For return period of 2,475 years, the contribution of moderate earthquakes with magnitude M_w 5.5-6.0 are the topmost contributed earthquakes for this city as shown in Figure 11.

In the next step, the contribution level of seismic sources are examined using SA probabilistic seismic hazard from 0.05 s to 2.0 s. Distribution of the contribution level and seismic sources are shown with highest 4 seismic sources in Figures 12 and 13 for 475 and 2,475 years return periods, respectively. Based on this figures, Fault 169 has the highest contribution level up to period 2.0 s for two hazard levels. However, as the period of SA becomes longer, the contribution of F169 decreases and the others increase.

Using the highest contributed seismic source (Fault 169) the ground motion is revaluated and is shown for spectral acceleration at two level of hazard, in Figures 14 and 15. Comparison of disaggregated hazard with seismic design code of Iran [7] indicates that seismic design code of Iran is over estimated for Mashhad for return period of 475 years. Deaggregation of PSHA gives almost same values with PSHA for level 1 and lower values than PSHA for level 2 of hazard.

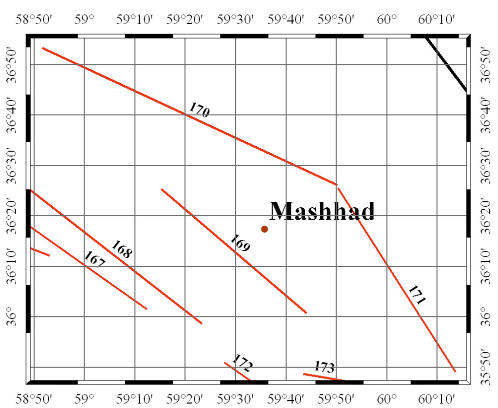

Fig. 9 Active faults around Mashhad

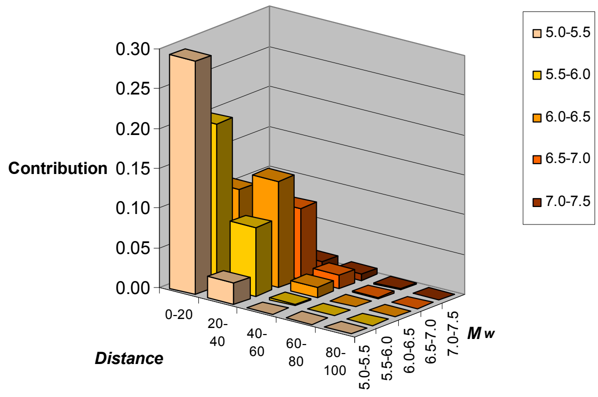

Fig. 10 Deaggregated seismic hazard for Mashhad (475 years)

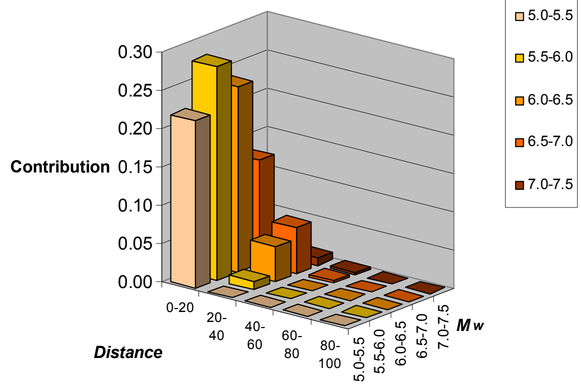

Fig. 11 Deaggregated seismic hazard for Mashhad (2,475 years)

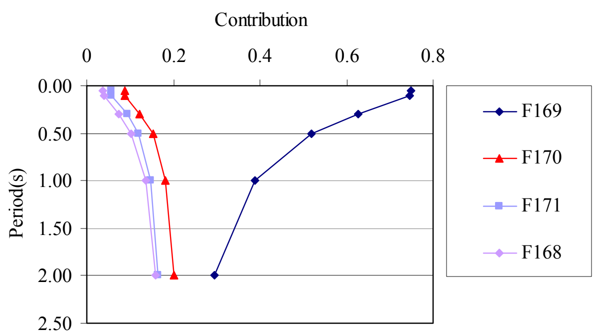

Fig. 12 Distribution of the contribution level and seismic sources for Mashhad for 10% per 50 years (475 years)

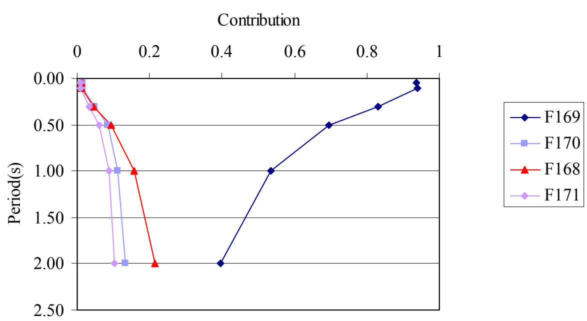

Fig. 13 Distribution of the contribution level and seismic sources for Mashhad for 2% per 50 years (2,475 years)

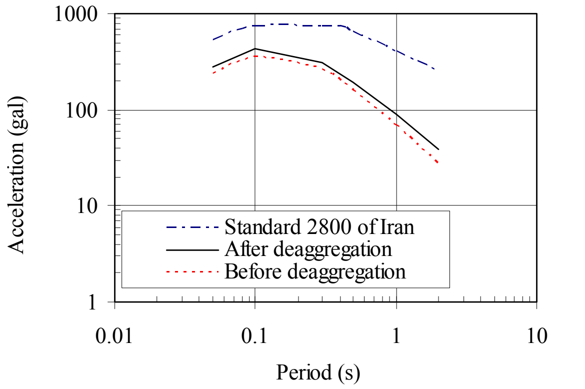

Fig. 14 Revaluated spectral acceleration for Mashhad for 10% per 50 years (475 years)

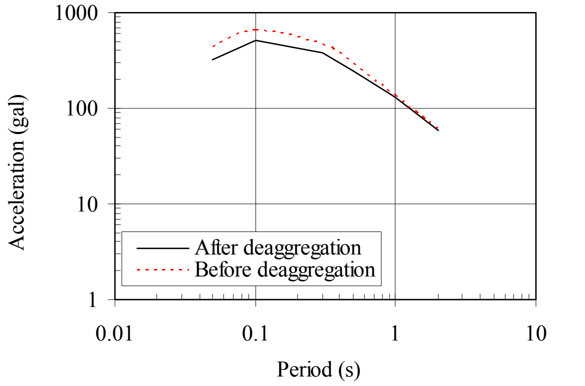

Fig. 15 Revaluated spectral acceleration for Mashhad for 2% per 50 years (2,475 years)

5.2 Deagregation of PSHA in Tabriz

Tabriz is located in a mountain area at west of Iran. This city has experienced strong earthquakes in its history. Active faults around Tabriz are shown in Figure 16. Fault 220 runs very near the city.

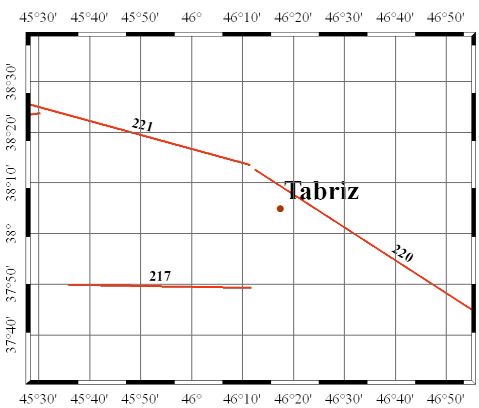

Fig. 16 Active faults around Tabriz

Figure 17 illustrates the joint distribution of moment magnitude and distance for PGA in the return period of 475 years. Base on this figure, the major contribution comes from small magnitudes at close distance (Faults 220). Figure 18 shows the distribution for 2,475 years return period and it signifies on higher contributions with larger *M*.

Distributions of the contribution level and seismic sources are shown in terms of spectral acceleration with highest 4 seismic sources in Figures 19 and 20 for 475 and 2,475 years return periods, respectively. Based on this figures, Fault 220 has the highest contribution in all periods. It is remarkable that the floating earthquakes contribute secondary in the both of seismic hazard levels. Seismic source due to unspecified source should be paid attention to the design in this city.

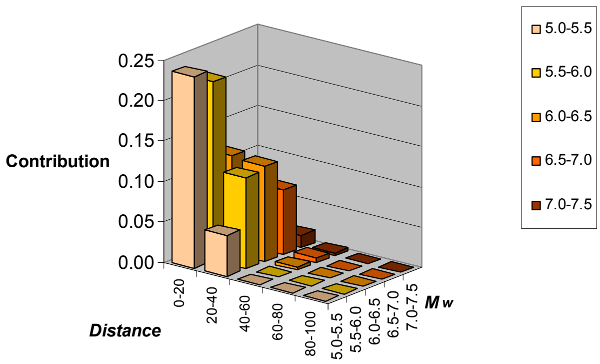

Fig. 17 Deaggregated seismic hazard for Tabriz (475 years)

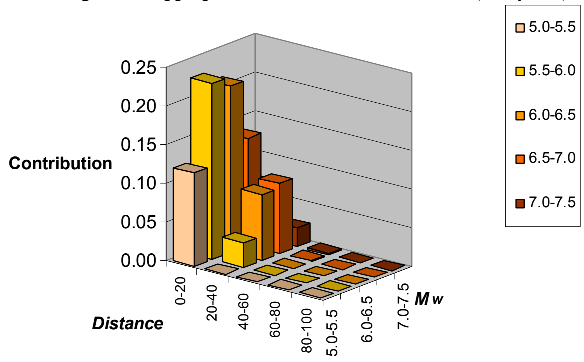

Fig. 18 Deaggregated seismic hazard for Tabriz (2,475 years)

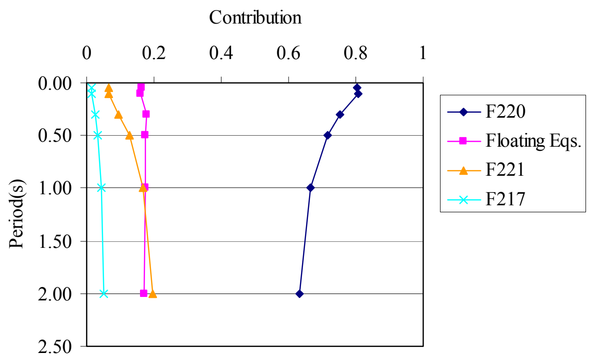

Fig. 19 Distribution of the contribution level and seismic sources for Tabriz for 10% per 50 years (475 years)

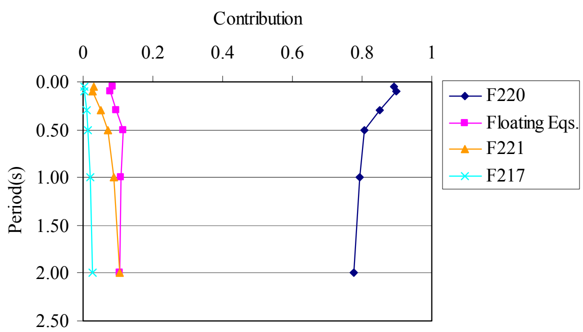

Fig. 20 Distribution of the contribution level and seismic sources for Tabriz for 2% per 50 years (2,475 years)

Spectral accelerations are revaluated based on Fault 220, as shown in Figures 21 and 22. Deaggregation of PSHA for Tabriz gives same values with PSHA for level 1 and lower values than PSHA for level 2 of seismic hazard. Comparison of disaggregated hazard with seismic design code of Iran shows that seismic design code of Iran for Tabriz is overestimated for return period of 475 years.

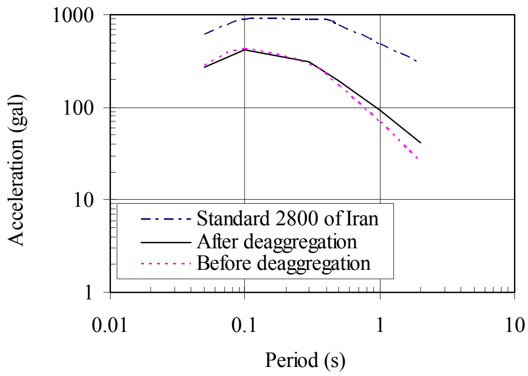

Fig. 21 Revaluated spectral acceleration for Tabriz for 10% per 50 years (475 years)

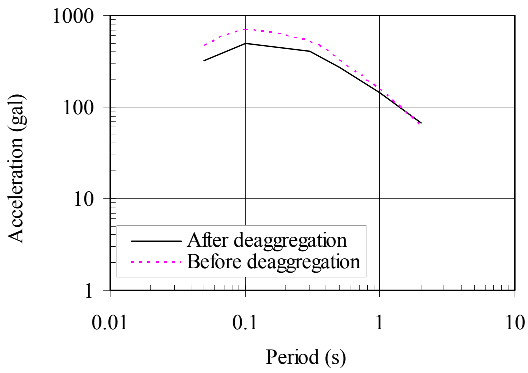

Fig. 22 Revaluated spectral acceleration for Tabriz for 2% per 50 years (475 years)

Results of current study come from general investigation of seismic hazard for Iran with precision of 0.1 latitudes and 0.1 longitudes. Applicability of attenuation relation used for this study is for areas far from 10 km of active faults. Obviously results of analysis will increase in areas near active faults even up to two times of presented ground motion which should be studied in a specific investigation.

6. Conclusions

In this study deaggregation of probabilistic seismic hazard of Iran was studied. First, the representative values of earthquake magnitude and distance for all meshes of Iran were plotted. Hazard-consistent magnitude and distance for PGA (in two levels of hazard) and SA in short period and long period were drawn. Comparison of hazard-consistent magnitude and distance for PGA in two levels of hazards showed that as hazard level increases, $\overline{M}$ and $\overline{D}$ decreases. However hazard-consistent magnitude and distance increase when period becomes longer.

Afterward, deaggregation of probabilistic ground motions for some major cities of Iran with over one million population was explained. Deagregation of PSHA for these cities was done based on the high contributed seismic sources around. Then spectral accelerations for two levels of seismic hazards were revaluated. In the most cases, deaggregation of hazard led to lower values than result from PSHA for level 2 of hazard. Design spectra were compared with deaggregated results and spectra of standard 2800 of Iran for level 1 of hazard. In all cases using of standard 2800 of Iran led to higher value of acceleration.

Result of deaggregation can be used for taking certain engineering decisions especially for infrastructures which have longer predominant periods or in level two of hazard analysis for all structures.

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