7th International Conference on Seismology & Earthquake Engineering
18-21 May 2015

THE EFFECT OF SOURCE DISTANCE IN DETERMINATION OF SITE-SPECIFIC HAZARD SPECTRUM

Mohammad Reza SOGHRAT
PhD student, International institute of earthquake engineering and
seismology (IIEES), Tehran, Iran
m.soghrat@iiees.ac.ir

Mansour ZIYAEIFAR
Associate Professor, International institute of earthquake engineering and seismology (IIEES), Tehran, Iran
mansour@iiees.ac.ir

Keywords: Short Return Period, PSHA, Gmpes, Seismicity Zones

ABSTRACT

Some elements of the completed structures that supply strength, stiffness and stability may not be existed at the special phases of the construction procedure. Incomplete structures must have enough structural integrity in various stages of construction to ensure stability and resistance against the seismic loads. Stability of the partially completed structures and the probability of progressive collapse should be considered in seismic design. For seismic design during construction, it seems that we should use reduced seismic load compared to design spectrum (with return period, Tr,of 475 years). To achieve this goal, we should estimate the site-specific spectrum. In this study, we use the probabilistic seismic hazard analysis (PSHA) to determine the uniform hazard spectrum by focusing on short return periods.In short return periods, the low intensity measures of the earthquakes will be important. The measures may be originated from large distant orsmall near earthquakes. Ground Motion Prediction Equations (GMPEs) are an important parameter in PSHA. We select a GMPE which can cover the distance up to 400 km.It is clear that the radius of imaginary circlearound the desired site may be an effective factorin evaluation of seismic hazard (especially in spectrum with short return period) which it is generally considered about 150 km.

In this study; we consider three different radii around the site (100, 200, 400 km) to control the sensitivity of result to the radius parameter.It should be noted that two sites (Tehran; very high seismic zone and Arak; moderate seismic zone) in Iran are chosen to analyze. It is shown that the controlling scenarios in spectrum with short return periods for Tehran site are nearer than Arak. Also, it can be concluded that in lower seismicity zones, considered radius larger than 200 km has significant effect on spectrum with short return periods that are important in during construction structure.

INTRODUCTION

Lack of some important elements which supply strength, stiffness and stability in structures can cause the failure during construction against lateral loads. Therefore, stability of the partially completed structures should be considered in seismic design. For temporary or during construction structures, it seems unreasonably conservative to use design spectrum with return period of 475 years (Design Basis Earthquake; DBE). As an alternative approach, it is better to apply the reduced seismic load due to shorter exposure periods for during construction structures.To achieve this goal, we should estimate the site-specific spectrum in short return periods.

Various studies have been done on seismic hazard analysis with the classic approach of Cornell (1968). From the previous studies,itis observed that researchers consider different radii around the site to assess seismic hazard analysis. For example, Kijko et al. (2002) considereda 300 km radius around the interest site while Irsyam et al. (2008) assume the radius of 500 km.According to previous studies, it can be said that in seismic hazard analysis, the focus is on long return periods while in during construction structures the short return periods spectraare needed. Moreover, few studies have been done on the partially completed structures under seismic load. Ratay (2004) provides a comprehensive study on temporary structures which they clarified the differences between common and temporary structures.Theyshowed that the structures with low exposure time needs the reduced seismic load than the permanent structures. Mohammadi and ZamaniHeydari (2008) presented consideration of lateral loads for temporary structures. They reviewed available studies on seismic and wind loads for temporary structures. In some design codes, it is recommended to use a factor less than one to represent the reduced exposure periodor explained to use design spectrum in shorter return periods.Eurocode 8-2 introduces a factor to convert the peak ground acceleration in reference return period to the interest value.The literature review reveals that a limited number of in-depth studies have been done on partially completed structures and their required spectrum to resist on seismic lateral load.

In summary, it can be said that the most practical output of seismic hazard analysis is the response spectrum. The spectrum is used by engineers to design the structure to withstand the sesimic load in its expected life period. The expected life for a structure depends on some factors such as socio-economic factors. During constructionstructures should be controlled in various steps to resist on seismic load. Because the service life of a during construction or temporary structure is shorter than the common structures, designing the structure with available spectrum (Tr=475 or 2475 years) will not be economically reasonable. So, it is better to use a reduced design load proportional to the service life of the structure. To achieve this, we need to develop special spectrum for short return period. It is tried to distinguish the differences ofspectrum characteristics in long and short return periods.

DATABASE AND PROCESSING

In this study to assess seismic hazard analysis, two sites are selected; Tehran and Arak. Tehran, capital of Iran, is a densely populated metropolitan with more than 10 million residents. Arak city, the center of Markazi province, is one of the main industrial cities of Iran that includes several infrastructures such as power plants. Tehran and Arak cities are located in very high and moderate seismic zones according to Iranian Code of Practice for Seismic Resistant Design of Buildings (code 2800), respectively. The major active faults (Hessami et al., 2003) around the cities are shown in Figure 1.

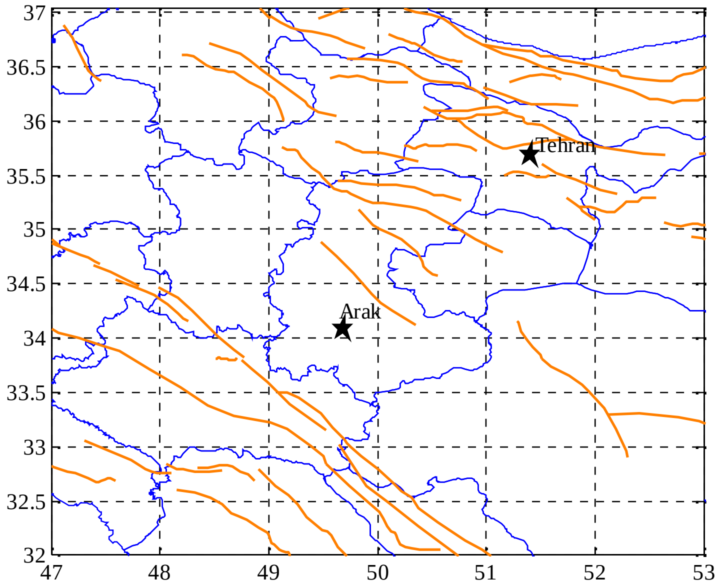

Figure 1. The active faults around the Tehran and Arak sites (Hessami et al., 2003)

In this study, the catalog is contained by only the instrumental events. To provide the catalogs, threedifferent radiiaround two sites are considered; 100, 200 and 400 km. So, the effect of theradius changes on spectrum with different return periods can be observed. The distribution of earthquakes in each radius around the sites is plotted inFigure 2. It should be noted that in each graph in the figure, the boundary of the circle with a100 km radius is also shown.

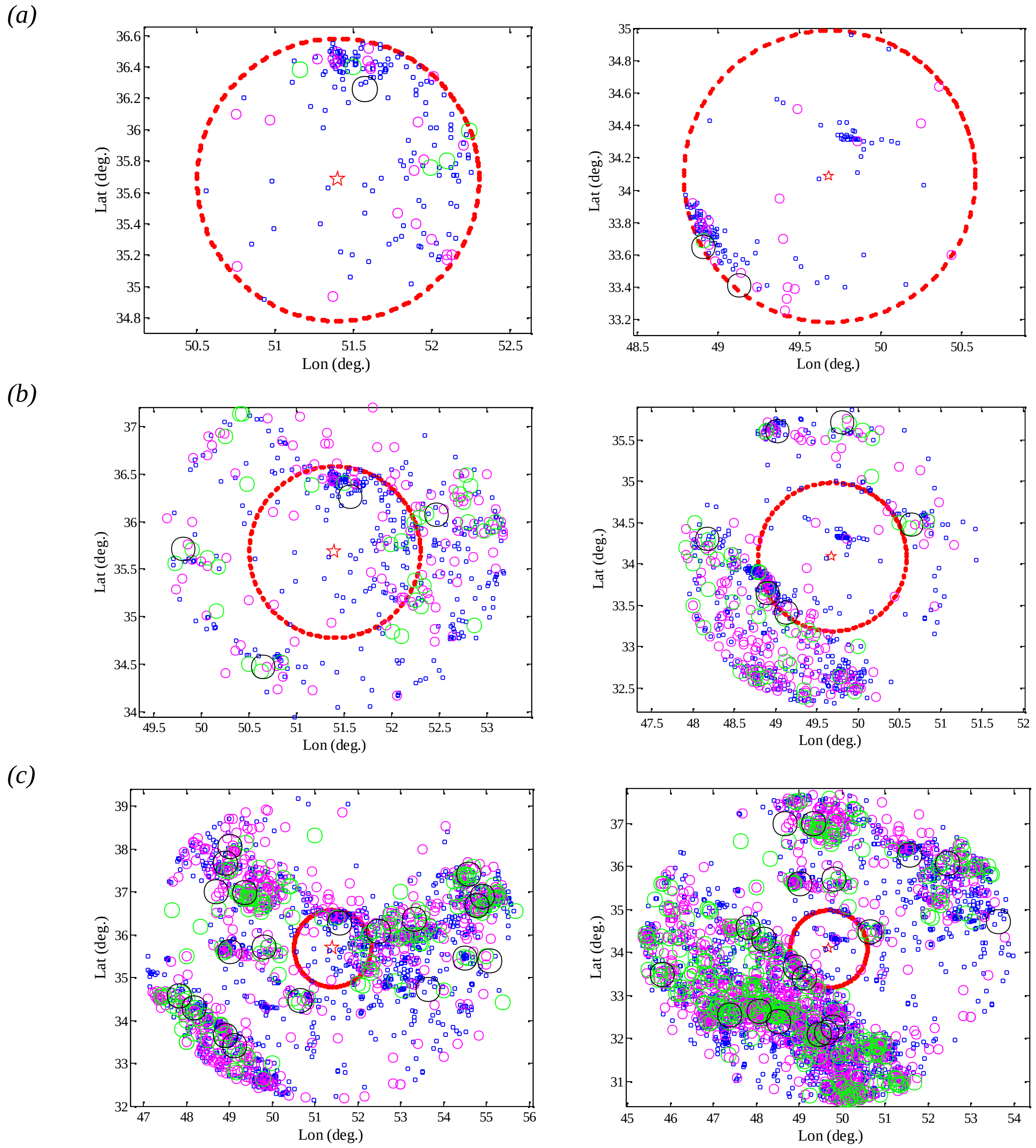

Figure 2.The distribution of events in Tehran (left column) and Arak (right column) sites with considered radii of 100 km (a), 200 km (b) and 400 km (c)

Circle signs in Figure 2 are in four sizes which the size of them are attributed to the size of earthquakes. For example, smallest circle belongs to the earthquakes with magnitude less than 4 and the largest one is for eventsgreater than 6. Also, the number of events in corresponding radii is shown in Table 1.

Table 1. Number of events in each radius for Tehran site

No. of events at	**Considered radius around the sites**		
	100km	**200km**	**400 km**
Tehran site	215	638	2039
Arak site	221	900	3694

The details of major earthquakes greater than 6.5 around Tehran and Arak sites with a 400 km radius are shown in Table 2andTable 3. It should be noted that the earthquake events are reported in different magnitude scales: body-wave magnitude (mb), surface wave magnitude (Ms), local magnitude (ML) and moment magnitude (Mw), which were derived by different analytical methods. For seismic hazard analysis, the catalog has to be consistent in magnitude scale. Mw is the most widely used and reliable magnitude for describing the size of an earthquake as it does not saturate. Various empirical relations are available to convert different magnitude scales to Mw which some of them are listed in Table 4.

Table 2. List of Major Earthquakes (Mw ≥ 6.5) around the Tehran site since 1900

No.	Date	Time	Lon.	Lat.	Mw	Depth	D2S*	Region
1	01/23/1909	02:48:00	49.13	33.41	7	-	357.15	Lorestan, Dorud
2	07/22/1927	03:55:00	53.64	34.72	7.2	-	271.08	Semnan, South-East of Semnan
3	04/11/1935	23:14:00	53.32	36.36	7.1	-	226.34	Mazandaran, South of Neka
4	02/12/1953	08:15:00	55.08	35.39	7.2	10	410.43	Semnan, South-East of Shahrud
5	07/02/1957	00:42:00	52.47	36.07	7.3	-	126.50	Mazandaran, South-East of Amol
6	12/13/1957	01:45:00	47.82	34.58	6.5	-	416.48	Kermanshah, West of Kangavar
7	08/16/1958	19:13:00	48.17	34.3	6.5	-	390.64	Hamedan, North-West of Nahavand
8	09/01/1962	19:20:00	49.81	35.71	6.9	-	176.80	Ghazvin, West of Buinzara
9	11/04/1978	15:22:20	48.91	37.67	6.4	26	354.17	Gilan, South of Hashtpar
10	05/04/1980	18:35:19	49.02	38.05	6.6	20	373.18	Caspian Sea, North-East of Hashtpar
11	06/20/1990	21:00:10	49.35	36.99	7.2	18	270.30	Gilan, South of Shaft
12	06/22/2002	02:58:23	49.02	35.6	6.5	11	264.76	Hamedan, North of Razan

* Means of D2S is the distance between epicenters of earthquake to the studied site.

Table 3. List of Major Earthquakes (Mw ≥ 6.5) around the Arak site since 1900

No.	Date	Time	Lon.	Lat.	Mw	Depth	D2S*	Region
1	01/23/1909	02:48:00	49.13	33.41	7	-	97.33	Lorestan, Dorud
2	07/15/1917	17:58:00	45.82	33.48	6.6	-	434.97	Iraq, North-West of Mehran
3	07/22/1927	03:55:00	53.64	34.72	7.2	-	445.30	Semnan, South-East of Semnan
4	07/15/1929	07:44:00	49.48	32.08	6.6	-	224.29	Khoozestan, North-East of MasjedSoleyman
5	06/09/1951	11:22:07	49.8	32.26	6.5	53	203.52	Khoozestan, North of Izeh
6	07/02/1957	00:42:00	52.47	36.07	7.3	-	380.10	Mazandaran, South-East of Amol
7	12/13/1957	01:45:00	47.82	34.58	6.5	-	214.47	Kermanshah, West of Kangavar
8	08/16/1958	19:13:00	48.17	34.3	6.5	-	170.09	Hamedan, North-West of Nahavand
9	09/01/1962	19:20:00	49.81	35.71	6.9	-	180.98	Ghazvin, West of Buinzara
10	06/20/1990	21:00:10	49.35	36.99	7.2	18	324.89	Gilan, South of Shaft
11	06/22/2002	02:58:23	49.02	35.6	6.5	11	183.74	Hamedan, North of Razan

In the present study, a new set of relations was developed for the studied area using the new collected earthquake data. We develop relationships between the different magnitude scales and thus converted mb and Ms to the standard Mw. The obtained relations from regression analysis are given by:

$$Mw=0.6552Ms+2.1,\ R^2=0.8182 \qquad \text{for } 3.9\leq Ms \leq 7.7 \tag{1}$$

$$Mw=1.1081mb-0.428,\ R^2=0.7466 \qquad \text{for } 4.5\leq mb\leq 6.7 \tag{2}$$

After comparing models to each other, based on the agreement between our model and other relations, we decided using the Erdik et al. (2012) to convert the ML to Mw. Also, the model that suggested by Kolathayar&Sitharam (2012) are used to convert mb and Ms to Mw in out of range of developed relations. Thus, a consistent catalog with a unified magnitude scale is obtained for the entire studied area.

Table 4. The candidate models to convert different scales to moment magnitude

Reference	Relation	Range
Scordilis (2006)	$M_W=0.67M_S+2.07$ $M_W=0.99M_S+0.08$ $Mw = 0.85\ mb + 1.03$	$3.0\leq M_S<6.2$ $6.2\leq M_S\leq 8.2$ $3.5 \leq m_b \leq 6.2$
Erdik et al. (2012)	$M_W=0.66M_S+2.11$ $M_W=0.93M_S+0.45$ $Mw = 0.87mb + 0.83$ $Mw = 1.013ML + 0.05$	$2.8\leq M_S<6.1$ $6.2\leq M_S<8.2$ $3.5 \leq m_b \leq 6.0$ $4.0 \leq ML\leq 8.3$
Kolathayar&Sitharam (2012)	$M_W=0.707M_S+1.87$ $Mw = 1.14mb - 0.7$	$3.7\leq M_S<8.8$ $4 \leq m_b \leq 7.0$
Pailoplee et al. (2010)	$M_W=0.028M_S^2+0.3364M_S+3.2574$ $M_W=0.0167\ mb^2+0.8438\ mb+0.9071$ $mb=0.63M_L+1.64$	$M_S \leq 7.6$ $mb\leq 6.8$ $M_L\leq 6.8$

It should be noted that declustering has been done on the databases. Declustering is the separation of the dependent events (i.e., foreshocks, aftershocks) from the back-ground seismicity. For seismicity rate studies

(Wiemer and Wyss, 1994, 1997) and hazard-related studies (Frankel, 1995)declustering is often considered necessary to achieve better results. In this study, we applied the proposed model of Gardner and Knopoff (1974) to decluster the earthquake events. This model assumes that the time and spatial distribution of foreshocks and aftershocks are dependent on the magnitude of the main event.

GROUND-MOTION MODELS

Based on different studies on the seismotectonic characteristics of Iran, it was shown that all of the Iranian plateau earthquakes are shallow intra-plate events.Also, a general similarity is reported between the shallow intra-plate events from different regions, including Turkey and California (Chen and Atkinson 2002). Therefore, we can use three categories of GMPEs; ground motion models obtained specially for the region of Iran (Category 1); ground motion models calculated for the Middle East and Europe region (Category 2); global ground motion models developed by the “Next Generation of Ground Motion Attenuation Models” (NGA) project (Category 3).

The selection of GMPEs is important in this study because they should cover distances up to 400 km and be valid for magnitudes greater than 3. The model that proposed by Boore et al. (2014) is selected in this study according to category 3. This model is valid for earthquakes with Mw 3.0 up to 8.5, distances from 0 to 400 km and site classes having Vs30 in the ranges from 150 m/s to 1500 m/s.The model is developed for PGA and spectral periods (T) of 0.01-10 s.The model considered regional variability in source, path and site effects, but does not attend to directivity effects. The proposed model by Boore et al. (2014) in a general form is given by the following equation:

$$\ln Y = F_E + F_P + F_s \tag{3}$$

where$\ln Y$ is the natural logarithm of ground motion predicted; F_E, F_P and $F_s$indicate the effects of source, path and site condition, respectively (For more details about the GMPE, it can be referred to Boore et al., 2014).Generally, it is recommended to use different ground-motion prediction models in probabilistic seismic hazard analysis (Bommer et al., 2005) to reduce the uncertainty. Because in this study our aim is focusing on the effect of different radii around a site in short return periods; it seems that using a GMPE is enough and appropriate.

SEISMIC HAZARD ANALYSIS

There are two ways to determine the earthquake ground motion parameters: use of local or international codes and conducting seismic hazard evaluation. Seismic hazard evaluation can be performed in two methods; deterministic and probabilistic. The most of codes considered the design earthquake spectrum for a 475 or 2475 years return period. So, if other return periods are needed, we should estimate these values by probabilistic seismic hazard analysis. The PSHA methodology was introduced by Cornell (1968) and McGuire (1976). This approach has been used widely to determine the characteristics of ground motion for engineering design (Bommer, 2002).

The hazard maps can be obtained in a desired region by simultaneously hazard analysis for various sites in the selected regions and creating iso-maps for specified ground motion levels corresponding to given return periods.

In simple terms, the following steps should be performed to assess the seismic hazard;

- Consider a circular area around the given site. One of the aims of this study is to determine the sensitivity of the results to the selected radius around the site.
- Collect the earthquakes with known magnitude and convert different magnitude scales to moment magnitude. Declustering the events is also needed.
- Determine seismic sources based on the geophysical, geological and seismological data. Sources can be defined as a point, linear or area zones.
- Calculate the Gutenberg and Richter (G-R) recurrence parameters.
- Select the appropriate GMPE.It should consider our constraints (for example, small magnitudes and far distances).
- Compute the Probability Density Functions (PDF)of distance and magnitude and probability of exceeding any intensity measure.

- Obtain the resultswhich can be site-specific spectrum in different return periods.

The obtained uniform hazard spectrum (UHS) for Tehran and Arak sites in three return periods (10, 100 and 475 years) are plotted in Figure 3.

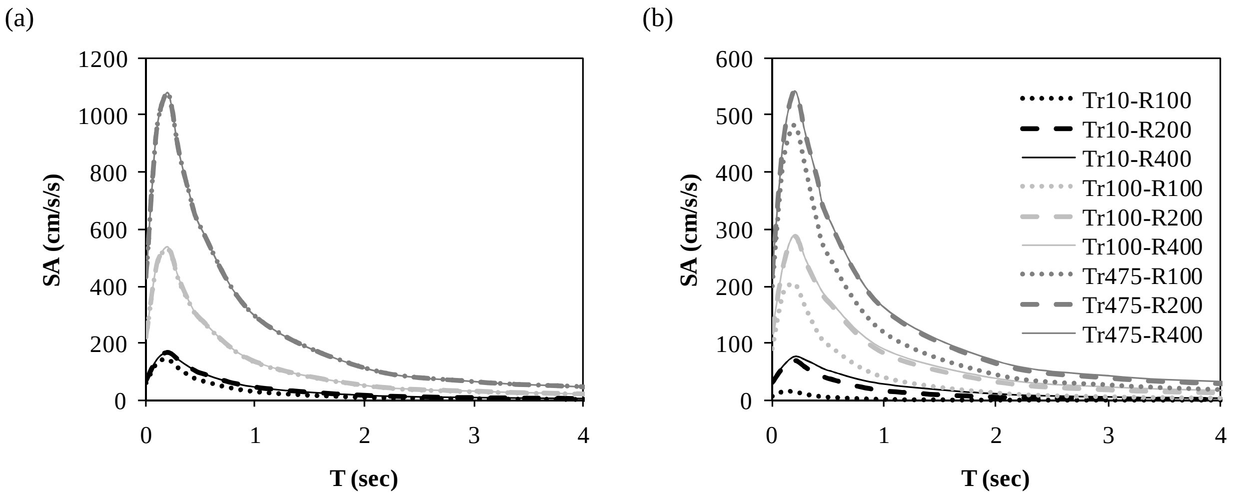

Figure 3. The impact of the radius changes on determination of hazard spectrum in different return periods for Tehran (a) and Arak (b)sites

For Tehran site (Figure 3a), It seems that considered radius larger than 200 km around the site has no significant effect on spectrum, Although, there are differences between Radius of 100 km and 200 km on short return period (10 years). From the Figure 3b it can be concluded that radius larger than 200 km has significant effect on spectrum in short return period unlike in Tehran site.

For a more detailed view, the effect of larger radii as a function of theratio of spectral accelerations in three return periods (10, 100 and 475 years) versus period is plotted in Figure 4. It is shown that for Arak site in short return period, considering larger radii around the site can cause to amplify the spectral amplitudes which are not negligible. For example, the ratio will be about 2 in period of 2 sec for arak site in return period of 10 years when we assume the radius of 400 km instead of 200 km. This amplification is attributed to be effective the large distant earthquakes in this site (moderate seismic zone).Figure 5shows the hazard deaggregation results at return period of 10 years for period of 3 sec in two sites which reveals the importance of considering larger radius around the site for Arak site and other similar regions.

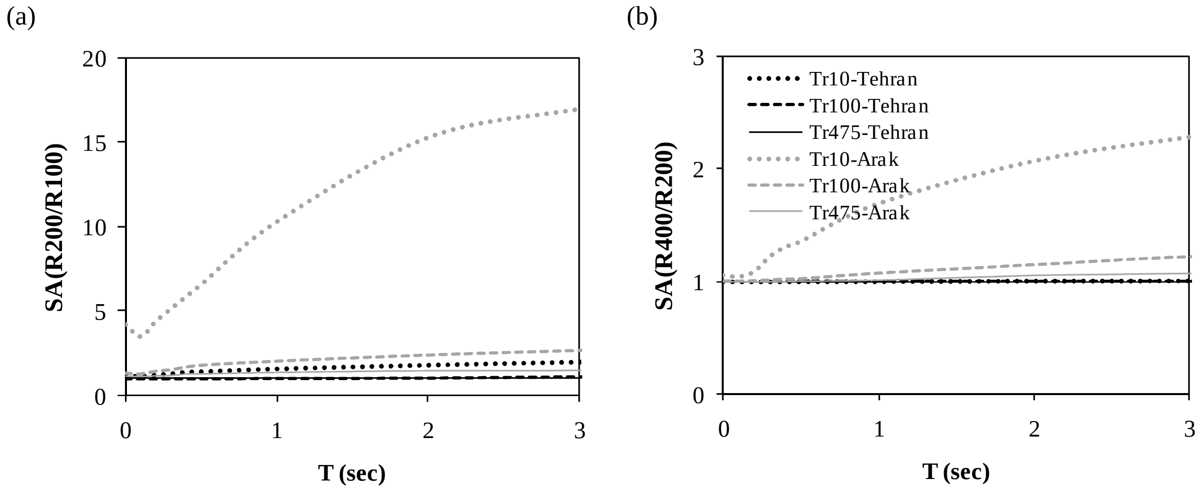

Figure 4. The ratio of spectral accelerations in three return periods; radius of 200 to 100 (a) and radius of 400 to 200 (b)

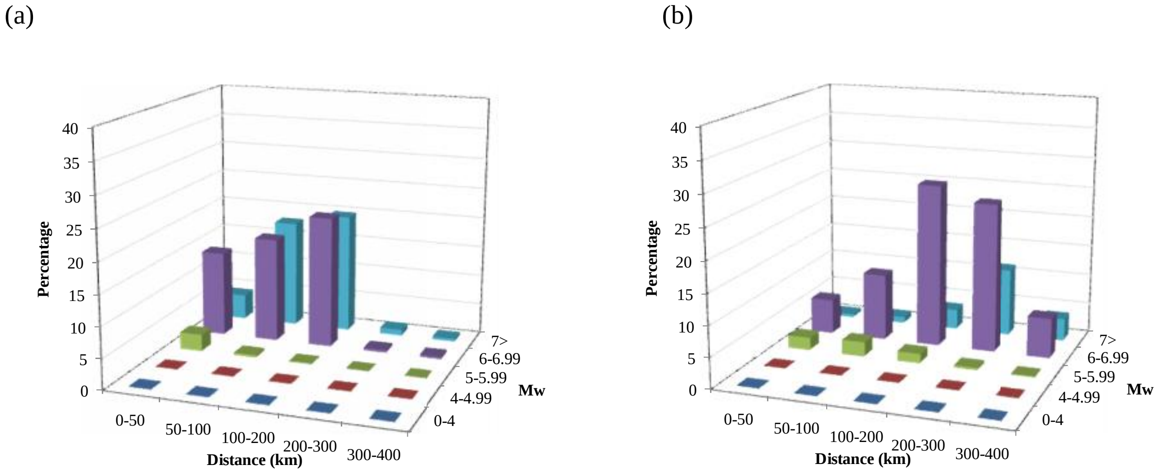

Figure 5. Hazard deaggregation for Tehran (a) and Arak (b) sites.

CONCLUSION

Partially completed structures must have enough structural integrity in various stages of construction to ensure stability and resistance against the seismic loads. Stability of the structures and the probability of progressive collapse should be considered in seismic design. Using reduced seismic load will be reasonable for seismic design during construction. To achieve this goal, we should estimate the site-specific spectrum by probabilistic seismic hazard analysis at short return periods due to shorter exposure periods. In spectra with short return periods, the low values of recorded accelerations will be important which can be produced by large distant and small near earthquakes. So, two sites with different seismicity zones are selected. To provide the catalogs, three different radii around two sites are considered; 100, 200 and 400 km. So, the effect of the radii on spectrum with different return periods can be observed.It is shown that the chosen radius around the site and the level of seismicity are the major parameters in describing the specification of spectra withshort return periods, especially in long periods.

REFERENCES

Bommer JJ (2002) Deterministic Vs. Probabilistic Seismic Hazard Assessment: An Exaggerated and Obstructive Dichotomy, *Journal of Earthquake Engineering*, 6(S1): 43-73

Bommer JJ, Scherbaum F, Bungum H, Cotton F, Sabetta F and Abrahamson NA (2005) On the Use of Logic Trees for Ground-Motion Prediction Equations in Seismic-Hazard Analysis, *Bulletin of the Seismological Society of America*, 95(2): 377-389

Boore DM, Stewart JP, Seyhan E and Atkinson GM (2014) NGA-West 2 Equations for Predicting PGA, PGV, and 5%-Damped PSA for Shallow Crustal Earthquakes, *Earthquake Spectra*

Chen SZ and Atkinson GM (2002) Global Comparisons of Earthquake Source Spectra, *Bulletin of the Seismological Society of America*, 92(3): 885-895

Cornell CA (1968) Engineering Seismic Risk Analysis, *Bulletin of the Seismological Society of America*, 58(5): 1583-1606

Erdik MK, Şeşetyan K, Demircioğlu MB, Tüzün C,Giardini D, Gülen L, Akkar DS and Zare M (2012) Assessment of Seismic Hazard in the Middle East and Caucasus: Emme (Earthquake Model of Middle East) Project, *In Proceedings of 15th World Conference on Earthquake Engineering*

Frankel A (1995) Mapping Seismic Hazard in the Central and Eastern United States, *Seismological Research Letters*, 66(4): 8-21

Gardner JK and Knopoff L (1974) Is the Sequence of Earthquakes in Southern California, with Aftershocks Removed, Poissonian, *Bulletin of the Seismological Society of America*, 64(5): 1363-1367

HessamiKh, Jamali F and Tabassi H (2003) Major Active Faults of Iran, IIEES, Tehran

Irsyam M, Dangkua DT, Hendriyawan H, Boediono RB, Kusumastuti D and Kertapati EK (2008) Proposed Site-Specific Response Spectra for Surabaya-Madura Bridge, *Civil Engineering Dimension* ,10 (2) 70-81

Kijko A, Retief SJP and Graham G1 (2002) Seismic Hazard and Risk Assessment for Tulbagh, South Africa: Part I–Assessment of Seismic Hazard, *Natural Hazards*, 26 (2): 175-201

Kolathayar S, and Sitharam TG (2012) Comprehensive Probabilistic Seismic Hazard Analysis of the Andaman–Nicobar Regions, *Bulletin of the Seismological Society of America* 102(5): 2063-2076

MacGuire RK (1976) Fortran Computer Program for Seismic Risk Analysis: *US Geological Survey*

Mohammadi J and ZamaniHeydari A (2008) Seismic and Wind Load Considerations for Temporary Structures, *Practice Periodical on Structural Design and Construction*,13(3): 128-134

Pailoplee S, Sugiyama Y and Charusiri P (2010) Probabilistic Seismic Hazard Analysis in Thailand and Adjacent Areas by Using Regional Seismic Source Zones, *Terrestrial, Atmospheric and Oceanic Sciences,* 21(5): 757-766

Ratay RT (2004) Temporary Structures in Construction: USA Practices: Temporary Structures, *Structural engineering international*, 14(4): 292-295

Scordilis EM (2006) Empirical Global Relations Converting M S and M B to Moment Magnitude, *Journal of seismology*, 10 (2): 225-236

Wiemer S and Wyss M (1994) Seismic Quiescence before the Landers (M= 7.5) and Big Bear (M= 6.5) 1992 Earthquakes, *Bulletin of the seismological society of America,* 84(3): 900-916

Wiemer S and Wyss M (1997) Mapping the Frequency-Magnitude Distribution in Asperities: An Improved Technique to Calculate Recurrence Times?,*Journal of Geophysical Research: Solid Earth (1978–2012),* 102(B7): 15115-15128