AN EVALUATION OF IRANIAN DESIGN RESPONSE SPECTRA USING DATA OF RECENT EARTHQUAKES IN IRAN

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The Iranian design code has been recently revised after the 2003 of Bam earthquake and currently proposes two standard shapes for the design response spectra. These propositions, however, were not constrained using actual strong motion data. In the present study, the high quality data from five recent earthquakes in Iran from 2002 until 2005 were used to evaluate the proposed design response spectra. A database of 696 strong motion records from 242 stations were employed. Using these records, the sites were classified and the response spectra together with their means were calculated for each site catagory. The mean response spectra used to review the shape of the proposed design response spectra. In particular, the plateau-PGA ratio level and the period interval where this plateau is constant.

Key Words : *Design response spectra, Iranian design code (standared 2800), soil amplification, site classification.*

1. Introduction

The local site conditions are an important factor in the recorded waveform of earthquake ground motions. Different site conditions can induce amplifications of different period ranges in the response spectra (Seed et al., 1976; Mohraz, 1976). A building may be more severely damaged if the natural periods of the structure happen to be close to the amplified periods of the ground. Thus, the sites are classified into several classes so that the conditions within the same site class are similar and design engineers may understand the general soil amplification characteristics by the class that it belongs to. An earthquake response spectrum compatible with local soil condition, anchoring to appropriate peak ground acceleration (PGA), is a common input for design of structures and structural dynamic analysis. Therefore, the local soil conditions and its effect in design response spectra become important in earthquake resistant designs. Given the possibility of the large damage that can be followed, it is of practical importance to assess the accuracy and effectivness of proposed response spectra in earthquake design codes.

The most effective tool to consider the local site effects is the seismic microzonation with zone specific design spectra. However, this can not be carried out for all relevant industrial and residential areas due to economic reasons. Consequently, site-specific investigations are only done in special cases. Therefore, in most building codes, like the current Iran code (Standard 2800), the influence of local site conditions is taken into account by design spectra for different soil classes. These design response spectra for different soil classes of Iran have been recently revised after the Bam earthquake in 2003 and the thired revion of Iranian design code was presented. The current Iranian code proposes two standard shapes for the design response spectra. type 1 spectra are suggested for high seismicity regions. Conversely, type 2 spectra are proposed for low to moderate seismicity areas and exhibit both a larger amplification at short period with respect to type 1 spectra. These propositions, however, were not constrained using actual data. In the present study, the high quality data from five recent earthquakes in Iran, namely Changureh-Avaj (2002), Bam (2003), Firozabad-Kojour (2004), Dahooye-Zarand (2005) and Qeshm (2005) earthquakes, offered many good quality strong motion data at 242 Iranian free-field strong motion stations. In this study, an attmpt is made to evaluate the accuracy and efficiency of proposed response spectra in Iranian design code using a set of 696 high quality strong motion recordes from the recent earthquakes in Iran.

2. Geological setting

Based on geological map and some field investigations, the studied areas mainly covered by sedimentary Tertiary rock (limestone, sand stone, shale and marl) with limited outcrop of the igneous and metamorphic rocks (Class B or Class C in IBC 2003). Late Quaternary deposits, such as sand, silt, silty clay, clay and gravel deposits are considered as engineering soils (class D or class E in IBC 2003). There was no hard rock (Class A in 2003 IBC) or very soft soil (Class F in 2003 IBC) in the sites under study. The vast fan deposits, sand dunes, and rugged mountains are the main morphological features in the areas. The thickness of deposits is different from a few meters in slopes up to more than few hundred meters at alluvial plains.

Geophysical and geotechnical borehole data are limited and mostly available in the urban areas and some highway projects. Komak Panah et al. (2002) gathered the available shear-wave velocities and geotechnical information at the station sites in east and south-east of Iran. They investigated on the relation between shear-wave velocities (Vs) and SPT-N values for the upper-most 30 meters for fine and course material as:

$Vs= 106\ N^{0.41}$ Fine Material (Silt & Clay) (1)

$Vs= 75\ N^{0.50}$ Course Material (Sand& Gravel) (2)

The above relations are used to estimate the shear-wave velocity of the sites at which only geotechnical information were available. Due to scarce amount of geotechnical and geophysical data, the classification of free-field strong motion stations are mainly carried out using horizontal to vertical spectral ratio (HVSR) that will be explained later on.

3. Iranian strong motion network (ISMN) and acceleration data

ISMN has started its activities since 1973 under the responsibility of planning organization. In 1981, the strong motion network was transferred to the building and housing research center, which is now the official organization in charge of ISMN. The network was installed first with the Kinemetrics SMA-1 analog instruments, and then have been gradually expanded by the SSA-2 digital instruments since the Manjil earthquake of 1990 (Mw=7.3) in the north of Iran. There are presently 29 SMA-1 analog and 1036 SSA-2 digital free-field strong motion stations operating in Iran. Most of the instruments are concentrated near the fault zones, cities or villages in seismically active areas, and dam sites. In most of the stations, no geophysical and geotechnical information are available regarding local soil conditions. Since the installation of the first station, the network has recorded about 6120 accelerograms. Among them, the maximum peak acceleration of 1g was recorded by Tabas and Bam stations during Tabas (1978) and Bam (2003) earthquakes.

In order to obtain good quality accelerograms with large signal-to-noise ratio for the HVSR analysis and response spectrum estimation, we carefully selected records from five large shallow earthquakes, which recently occurred in north, north-west, south-east and south of Iran, triggering 242 ISMN stations during their occurrences. The epicentral location of these earthquakes and distribution of triggered stations are shown in Figure 1. To reduce the uncertainty, the records that could reveal significant source or basin effects, such as Bam station record in Bam earthquake, are not used in the analysis. Description of these earthquakes and number of stations triggered by each earthquake are listed in Table 1. It is interesting to note that all the earthquakes are in the same range of magnitude and depth. A total of 696 strong motion records from 242 stations are used for the present study. The data are corrected for the base line drift and filtered mostly from 0.2 to 20 Hz using Butterworth (FIR type) filter.

4. Site effect estimation

The empirical methods for determining dynamic characterization of surface layer are often based on spectral ratio analysis in the frequency domain. There are various type of spectral ratios for estimation of site amplification characteristics using earthquake data, such as reference site method (Borcherdt, 1994), HVSR (Nakamura, 1989), and uphole to downhole spectral ratio in downhole arrays (Elgamal et al. 1995, Ghayamghamian and Kawakami, 1996). The first compares soil motions with motions from a reference site (usually rock), while the second dose not use a reference site. The second approach has the advantage of being able to incorporate essentially all available earthquake recordings. However, the application of the first one needs to employ the reference site motion in the appropriate distance from the soil sites that restrict its application.

The HVSR, which originally proposed for microtremor measurements, extrapolated to the earthquake ground motion records by Lermo and Chavez-Garcia in 1992.

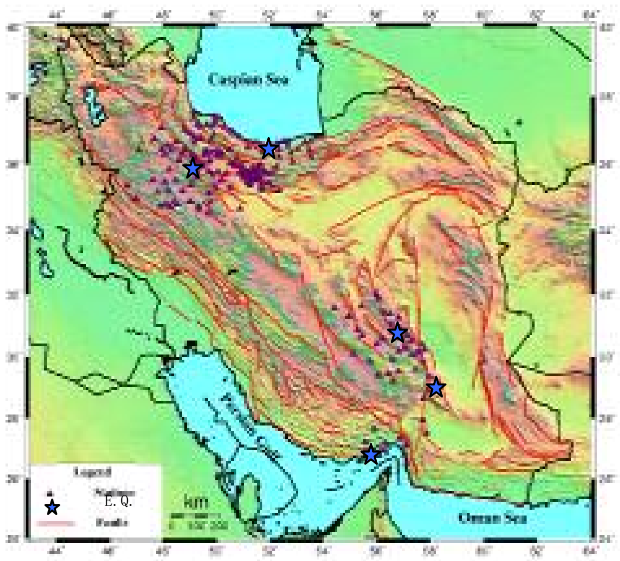

Figure-1 The epicenter location of five recent earthquakes in Iran and distribution of ISMN triggered stations. The lines show active faults in Iran. Elevation are also indicated by different colours.

Table-1 Earthquake specifications used in this study.

Name	Date	Lat. (N)	Lon. (E)	Depth (km)	Mag. (M_W)
Changure-Avaj	2002/6/22	35.67	48.93	10	6.5
Bam	2003/12/26	29.01	58.26	8	6.5
Firozabad-Kojour	2004/5/28	36.37	51.68	14	6.2
Dahoye-Zarand	2005/2/22	30.76	56.74	12	6.4
Qeshm	2005/11/27	26.78	55.90	10	6.0

Their study revealed very good matching between earthquake motion-based HVSR estimates and those supplied by the reference site method. The comparison between HVSR for the shear-wave of earthquake motion and ideally uphole to downhole spectral ratio using dwonhole array data also verified a good correlation (Tsubio et al., 2001; Rodriguez & Midorikawa, 2003; Ghayamghamian, 2005). Furthermore, the HVSR is commonly more stable among different earthquakes because it is more independent of the earthquake source and wave propagation path (Aki, 1988; Atkinson 1993; Yamazaki & Ansary, 1997). Thus, although the physical concept of the HVSR for shear waves of earthquake motion is not yet clear, the HVSR seems to reasonably estimate the site dominant period and provide a powerful tool for site effect estimation and classification based on the surface accelerograms when finding a suitable reference site turns difficult.

The HVSR was applied for estimation of soil amplification characteristics at all the strong motion station sites. For this purpose, the Fourier amplitude spectra for horizontal and vertical components were generally calculated for 10s time window after S-wave arrival and were smoothed using a rectangular moving average window of bandwidth 0.4 Hz. Next, the HVSR was calculated as an average of N/V and E/V spectral ratios for two horizontal components at each station. Furthermore, different time window lengths and spectral methods (e.x. cross-spectrum) were analyzed in the calculation of spectral ratio to assure the accuracy and stability of the results (Bendat and Piersol, 1993). The calculated HVSR are averaged for different events at a station and determined as a representative of site amplification function for that station. Finally, the dominant period of identified site amplification functions was determined and utilized in site classification of the strong motion stations. In addition, the reference site method is also applied using the same fashion of spectral ratio analysis for the sites where the suitable reference site can be found (Ghayamghamian, 2004b, Ghayamghamian and Rahimzadeh, 2005; Jafari et. al. 2006). The microtremor measurements were also available at some sites that were analyzed using HVSR technique and used for checking purpose (Jafari et al. 2006; Ghayamghamian et al., 1995).

Komak Panah et al. (2002) performed theoretical 1D equivalent linear analysis using SHAKE91 program at 51 ISMN station sites in east and south-east of Iran, where they conducted the geophysical and geotechnical investigations at the sites. They compared the identified site dominant period using HVSR with the theoretical ones obtained by SHAKE91 and found a very good agreement. In addition, a good correlation between shear wave velocities in most-upper 30 meters with dominant period form HVSR for Iranian strong motion station sites was shown (Komak Panah et al., 2002). These results also validate the application of identified site dominant period from the HVSR and its accuracy in site classification of Iranian strong motion station sites.

5. Site Classification

Extensive site effect studies have been undertaken over the past decades and many site classification scheme, such as Japanese code (1980), UBC (1997), NEHRP (1997), and IBC (2003) have been proposed. By increasing strong motion recordings, the site classification are mostly incorporated the dominant period of the site, which can be reliably estimated from empirical methods such as HVSR (Rodriguez and Midorikawa, 2003; Yamazaki et al., 2000). Thus, the recent classification schemes utilized not only the geological, geotechnical, and shear wave velocities of the upper-most 30 meters (V_S^{30}) information, but also incorporate the dominant period of the site as a key parameter (Rodriguez-Marek et al., 2001; Lee et al., 2001; Japan Road Association, 1980).

In this study, we use the identified dominant period of the sites from HVSR to categorize the site conditions. The site classes I, II, III, and IV, comparable to B, C, D and E in the 2003 IBC provision are used in the present classification system. There was no hard rock (Class A in 2003 IBC) or very soft soil (Class F in 2003 IBC) in the sites under study. Hence, class A and class F in 2003 IBC provision are not used at present. In the first step, the site stations are classified using Japanese code (1980) that is based on the dominant period of the site. According to Japanese code, the dominant period (TG) for rock and hard soil sites is less than 0.2 seconds (Type I), for hard soil TG=0.2-0.4s (Type II), for medium soil TG =0.4-0.6s (Type III), and for soft soil TG≧0.6s (Type IV). We determine the site classes according to identified dominant period, which fall within the above-mentioned period bands. In the second step, we classified the sites using Iranian code (2004) provision by employing geologic, geomorphologic, and if available geophysical and geotechnical information. When the detail geophysical or geotechnical information were not available at the sites, the type and thickness of soil deposits were evaluated from geologic and geomorphologic maps and/or by visual inspection of existing hand made boreholes in the area during field investigations. An evaluation of the site class for each strong motion station is made by comparison between the results of different classifications. If there is no consistency between the results from different classification methods, the questionable sites is marked and checked further before any final site classification can be made. However, a few stations are excluded since they are not so consistent for the different classification types and/or the reliable information need to be used for classification by different methods can not be found. For instance, the classification of the stations located at the edge of a terrace, the edge of a basin or near to the border of a plain or hills may not be accurate due to complicated subsurface geology and may need more detail information (Ghayamghamian, 2007, Ghayamghamian 2004a).

After making site classification, the response spectrum was computed for all the recordes in each class. Figure 2 shows the calculated response spectra and their mean together with their standard deviation acoording to the site classes for all the reocords of the earthquakes. The obtained mean response spectral curves were also compared with the mean acceleration spectra proposed by Seed et al. (1976) and those proposed by Lee et al. (2001) for %5 damping in Figure 3. The results show that the general spectral shapes for the site classes are fairly consistent with those four site conditions of Seed et al. (1976), and especially by those of Lee et al. (2001). The similar results are found by the HVSR method that implies our classification results are acceptable.

6. Comparison between design response spectra and response spectra of strong motion recordings

The comparison between design response spectra of Iranian code with the response spectra of mean and standard deviation from strong motion data for different site classes is shown in Figure 4. The current the design response Iranian code proposes two standard shapes for spectra. Type 1 spectra are suggested for high seismicity regions. Conversely, type 2 spectrum is proposed for low to moderate seismicity areas and exhibit a larger amplification for both long and short periods with respect to type 1 spectrum only for site class IV. Thus, the types I and 2 design spectra for site class I, II and III are same and they only differe in suggesting two different design response spectra for site class IV.

From Figure 4, it seems that the proposed design response spectra for site class I and II are a bit underestimated in compare with the ones resulting from strong motion data in short period range. However, the proposed design curves for site class III is reasonably agreed with the one predicted by strong motions. Meanwhile, the big difference between design spectra of the Iranian code and obtained one from the strong motion data can be observed for site class IV. Both design

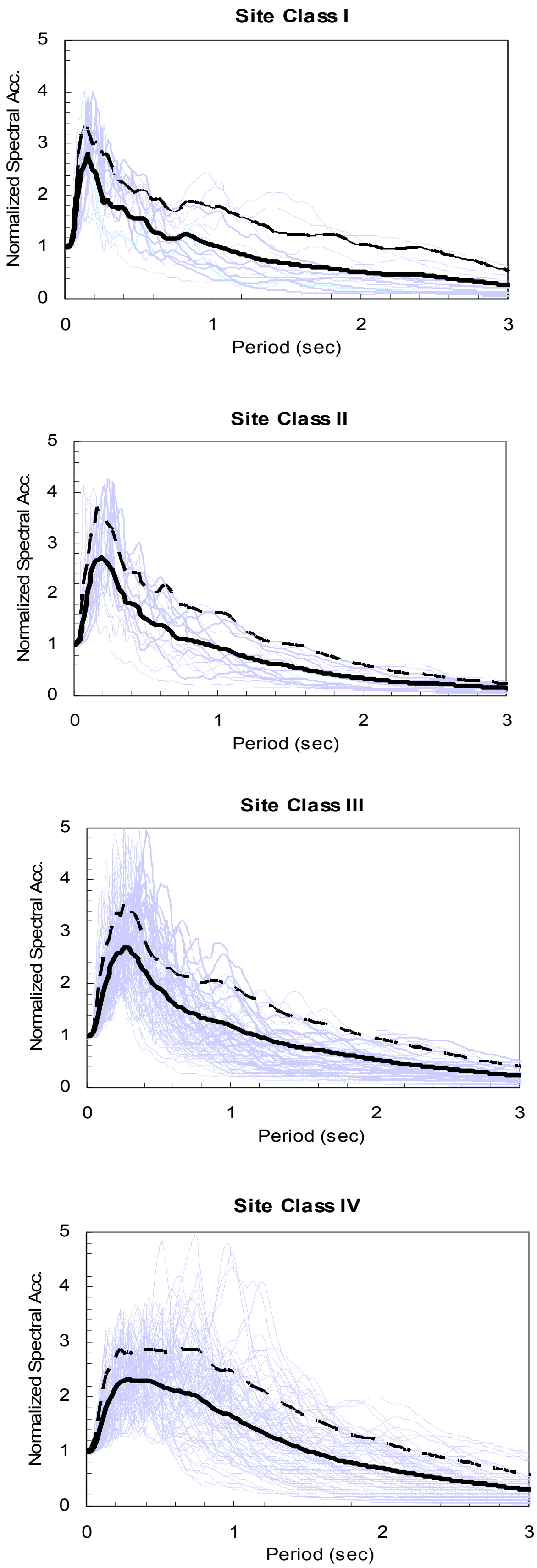

Figure-2 The acceleration response spectra of strong motion data together with the mean (bold continuous line) and 84 percentile (dashed bold line) of response spectra for different site classes of ISMN stations.

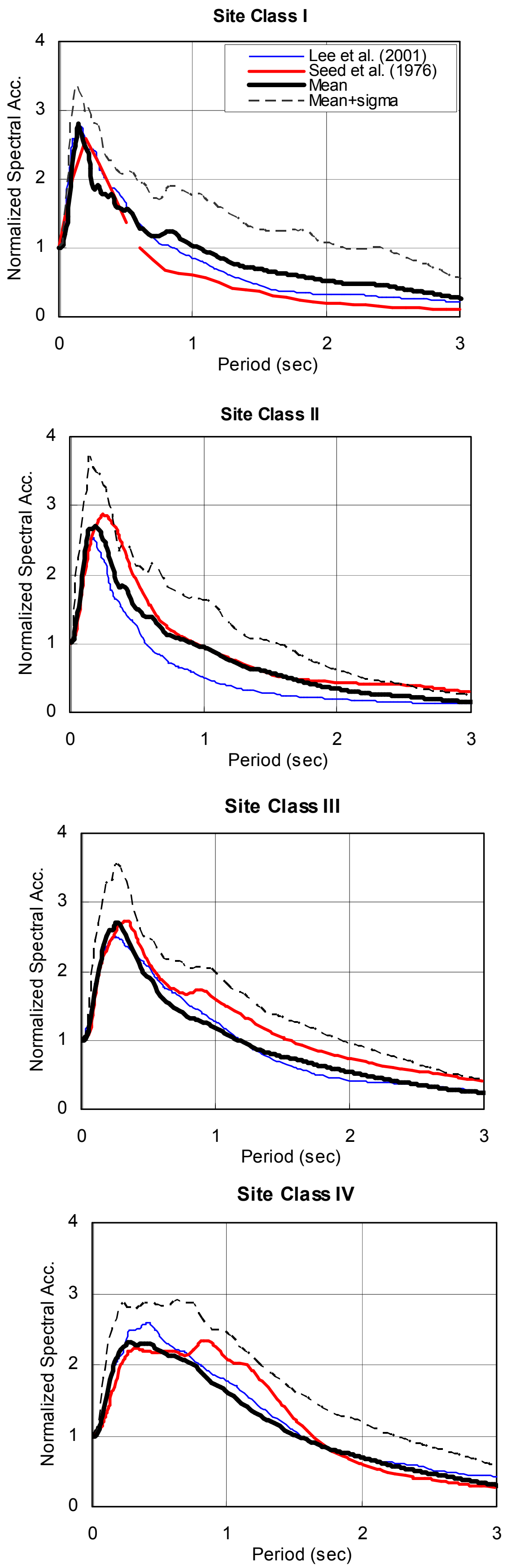

Figure-3 The comparison of the mean response spectra of Iranian strong motion data with those proposed by Lee et al. (2001) in Taiwan and Seed et al. (1976) in US for different site classes.

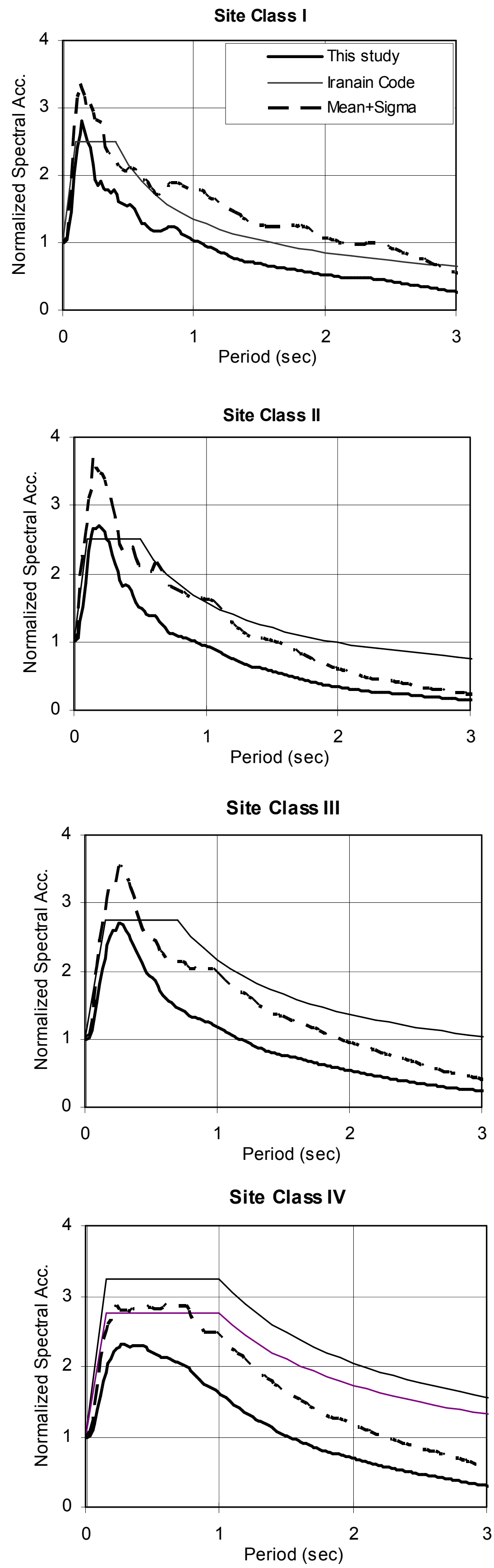

Figure-4 The comparison of the mean response spectra of Iranian strong motion data used in this study with the proposed response spectra in Iranian design code.

response spectra for types 1 and 2 envelop the 84 percentile of strong motion response spectra. Therefore, the design spectra for site class IV in the Iranian design code often lead to very conservative values even in long period in comparison with the actual spectra resulting from strong motion records.

7. Discusions and conclusions

The Changureh-Avaj (2002), Bam (2003), Firozabad-kojour (2004), Dahooye-Zarand (2005) and Qeshm (2005) earthquakes triggered 242 Iranian free-field strong motion stations and offered many good quality strong motion data at the sites. These data provide the unique opportunity to study a practicle site classification shceme and to examine the validity of design response spectra for different site classes proposed in recently revised Iranian design code. Since all the stations were recorded the strong motions at the surface, the horizontal to vertical spectral ratio was basically used to identify the dominant period of the site. To this end, the data were carefully examined and 696 well-recorded data with large signal-to-noise ratio over a wide frequency range were selected for the analysis. Based on dominant period of the sites from HVSR and existing geologic data, the station sites were classified according to the classification schemes given by 1980 Japanese code and Iranian design code. Furthermore, the response spectral shap at station sites were also examined using Seed et al. (1976) classification curves for checking purpose and providing more confirmation to the accuracy of the results. The choice of site class for each strong motion station was made by comparison among different classifications. If there is no consistency between the results from different classification methods and/or the reliable geologic or geomorphologic information can not be found, the site marked as problematic site and excluded from the results. Finally, we assigned a site class for 213 ISMN stations. The station sites were classified into four site classes namely I (rock), II (hard soil), III (stiff soil), and IV (soft soil) comparable to B, C, D, and E in the 2003 IBC provision.

The response spectra for all the strong motion records of the earthquakes together with their mean and standard deviation were calculated for each site class. The mean and standard divition response spectra were compared with those proposed by Iranian design code. It is found that the design spectra in the current Iranian code underestimate the values in comparison with the actual spectra resulting from strong motion recordings for site class I and II in short period range. However, the proposed design curves for site class III is reasonably agreed with the predicted one from strong motion data. Meanwhile, the big difference between design spectra of the code and obtained one from the strong motion data can be observed for site class IV. Both design response spectra for types 1 and 2 envelop the 84 percentile of strong motion response spectrum. Therefore, the design spectra for site class IV in the Iranian design code often lead to very conservative values even in long period in comparison with the actual spectra resulting from strong motion records.

Normalized empirical predictions show a widening of the plateau as the soil conditions degrade. This widening is fairly well covered up to the long periods for site classes II and III of Iranian code. However, the proposed design spectra for site class IV for both types 1 and 2, and especially for type 2, lead to very conservative values in compare with actual spectrum from the earthquake data.

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