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Far-Field Accelerograms for Nonlinear Two-Dimensional Analysis of Steel Moment Frame

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Abstract: Due to destructive effects of earthquake loads, acceptable assessment of these loads and create a coordinated approach adapted to each seismic zone, is important. In this study, the main purpose is preparing an appropriate list of far field accelerograms for nonlinear two-dimensional analyses. The main focus of this study is to evaluate all parameters affecting on proper accelerogram selection. By considering 2000 accelerograms and all effective parameters include distance, magnitude, frequency content, earthquake mechanism, soil and properties of earth layers, a list of 20 accelerograms were presented for nonlinear two-dimensional analyses. These proposed accelerograms represent the actual ground motion as much as possible. Also, the study of final scale factor of accelerograms for steel moment frame have been obtained with point-to-point difference in periodic intervals corresponding to each frame method.
Keyword: Accelerogram; Far-field records; Nonlinear analysis; Steel moment frame.

1. Introduction

The importance of building stability under various loads is one of the most significant issues in civil engineering. Applied loads acting on building are divided into two categories include gravity and lateral that gravity loads have more certainty due to their specific nature. Lateral loads are very important due to the uncertainties. Earthquakes are one of the most important lateral loads and creation of a coordinated approach is necessary due to destructive effects of seismic loads and the importance of acceptable assessment of these loads. Time history analysis is the most natural method which is compatible with the physical behavior of structures during earthquakes. The effect of ground acceleration is applied as a function of the ground level of the building and the use of conventional structural dynamics calculations. Accelerograms, used in time history analysis, must represent the actual ground motion in the place of structures during earthquakes. Thus, the selection of the accelerograms is so important in time history analysis. Unfortunately, this point, that the appropriate records must be selected by considering all conditions of seismic source, characteristics of geology, tectonics, fault distance and magnitude, is negligible. With respect to this matter that Iran is located in an area where there is a risk of large earthquakes, appropriate records considering conditions for the analysis have not been proposed yet. However, seismic codes (Standard 2800 [1,2], ASCE-7 [3-5] and Eurocode-8 [6]) represent that suitable records must be selected by considering all characteristics like geology, tectonics, seismic source mechanism, fault distance and magnitude.

For evaluation of behavior of structure and its components under seismic loads, creation of a time history load is necessary for experiments to show a proper modeling of real conditions. These necessities create time history loads nominated protocol loadings. These protocols are created to simulate loads which can include applied load spectrums by earthquakes in all areas with different magnitude and frequency content.

One of the most significant protocols is ATC-24 [7] in 1992 and a protocol prepared by Clark *et. al.* [8] in 1997 for steel structures and structural elements. To obtain a suitable time history load, providing catalog of proper accelerograms, which have all conditions of area perfectly and workable for structure and its element, is needed with respect to previous earthquakes. Ghassemieh *et al.* [9-13] developed a new cyclic loading protocol for Western Asia; while presenting the loading protocol to evaluate steel moment connection, proposed a set of records for the West Asia region. Which shows the importance of selecting the set records in time history analysis. Hassani *et al.* [14], while proposing the far-filed records for the seismicity conditions of Tehran city, have done a statistical and numerical analysis of the proposed list with the far-filed records of FEMA-P695 [15].

In FEMA-P695 suggests 22 earthquake records for far field. These records are selected among earthquakes which have occurred in 1971 to 1999. Fourteen accelerograms are for California and the rest of them are for the other areas. In FEMA-P695 [15] characteristics like seismic source mechanism, magnitude, soil type and fault distance have been considered for selection of far field accelerograms. Average moment magnitude of selected accelerograms is 7 and the soil types of stations are C and D. About seismic source mechanism, the most mechanisms are considered as strike-slip with respect to earthquakes, which occurs in US, are located in California with strike-slip mechanism.

In this study by considering International Institute Earthquake Engineering and Seismology accelerograms bank, about 2000 accelerograms, which have occurred in Iran, are evaluated. All parameters and effective factors on appropriate accelerograms selection, are assessed. Finally proper accelerograms are suggested for nonlinear two-dimensional analysis and based are scaled for steel moment frame. Standard 2800 [1,2] has been presented criteria for scale of each accelerogram in two-dimensional analysis. Scale factor, obtained from this standard, is higher than the other codes (ASCE-7 [3-5] and Eurocode 8 [6]). Actually, selected accelerograms must be compared with standard design spectrum. Standard design spectrum in Standard 2800 and ASCE-07 are for the highest earthquake with 475 years return period.

To determine the scale in Standard 2800, all accelerograms must be scaled to the peak ground acceleration and response spectrum of each accelerogram is determined with 5% damping ratio and the average response spectrums of accelerograms must be compared in 0.2 to 1.5 times of structure period with 1.4 times of standard design spectrum. Scale factor must be determined how no one of accelerograms average response spectrum is less than 1.4 times of standard design spectrum. How to change the scale factor according to the contribution of each accelerogram in average response spectrum of accelerograms, which a method is presented for assessment of scale factor in this study, is so important. Scale factor determination in a ASCE-7 [3], written in 2005, is not scaled to the peak ground acceleration in two-dimensional analysis and the average response spectrums of accelerograms must be compared in with 1.3 times of standard design spectrum. In 2010 version of this code (ASCE-7) [4] average response spectrums of accelerograms is compared in with standard design spectrum. Two points, mentioned before, cause that scale factor of Standard 2800 is high compared to the other codes. Actually, final scale factor is obtained from multiplication of two factors. In this study scale factor of each accelerogram has been obtained for bending steel frame. Scale factor of each accelerogram is calculated based on its proportion in average response spectrums of accelerograms.

2. Selection method of appropriate accelerograms for far field earthquakes

In this study, 20 accelerograms is proposed for Iran with respect to effective parameters in accelerograms selection for nonlinear analysis in far field. These accelerograms are obtained from earthquakes which occurred in 1978 to 2007 in Iran. All 20 accelerograms are presented in table 1. About 2000 accelerograms from different stations are evaluated in this study. All accelerograms are modified in this paper. In first stage of evaluation of accelerograms, the distance between record station and location of earthquake is obtained and then near field accelerograms were eliminated.

In next stage, geology and earth layer properties are studied in record station. The final purpose is finding shear wave velocity in stations and soil types in that region. For this aim, Building and Housing research center reports have been used [16]. For instance, with seismic average shear wave velocity method in depth of 30 *m*, 1111 m/sec is obtained in Avaj; which is one of the record station with 42.219 degree of longitude and 35.375 degree of latitude and 1904 *m*, high from sea level. Also, shear wave velocity and soil type of Alborz fault area has been assessed [17, 18]. For all record stations shear wave velocity and categorizing of soil types were done. Topographic maps of shear wave velocity in 30 *m* deep is observed for all regions of Iran with respect to topographic map of this area. More than 85% of area have shear wave velocity in 30 *m* deep more than 360 m/sec. Thus, the main part of this area has soil type II based on building seismic design codes. This matter caused that the main part of selected accelerograms are chosen from record stations with shear wave velocity between 375 m/sec and 750 m/sec.

Next, earthquake mechanisms, which occurred in samples, were evaluated. For all seismic source mechanisms have been investigated. In this stage with assessment of earthquake curves, earthquake mechanisms were obtained. For instance, Zanjiran earthquake, which occurred with magnitude of 5.8 in 1994, has strike-slip mechanism. Also, with evaluation of data like JICA report [19] which studied micro zonation of these areas, faults of Tehran [20], active faults in Iran and fault mechanisms which is cause of earthquake in Iran [21], it is concluded that the main part of active fault of this area have reverse and strike-slip mechanisms. In this respect, the contribution of reverse and strike-slip mechanisms in accelerogram selection has been proportioned in earthquake record stations. Also, to show the behavior of structure in two-dimensional analysis, accelerograms with perpendicular to the fault is evaluated. With assessment of all effective parameters on appropriate accelerogram selection, 20 accelerograms are proposed for nonlinear analysis in Iran. Actually, the list of proper accelerograms of the area, which shows the real ground motion in Iran, was represented.

After presenting the approach of appropriate accelerograms selection, twenty parameters considered in selected approach is represented. Table 2 shows the distance between each station and earthquake center in kilometer, shear wave velocity in 30 *m* deep in m/sec and soil type based on Standard 2800.

Table 1. Proposed accelerograms

NO.	Earthquake Magnitude	Year	Name	Record Station Name	Component
1	6.4	2002	Changoreh	Avaj	Fault Parallel
2	6.4	2002	Changoreh	Avaj	Fault Normal
3	7.1	1979	khulibaniabad	Ghayen	Fault Parallel
4	7.3	7990	Roudbar	Ab bar	Fault Parallel
5	7.3	1990	Roudbar	Ab bar	Fault Normal
6	7.3	1990	Roudbar	Ghazvin	Fault Parallel
7	6.3	2005	Zarand	Zarand	Fault Parallel
8	6.3	2005	Zarand	Zarand	Fault Normal
9	6.3	2005	Zarand	Sadde ghadroni	Fault Parallel
10	5.8	1994	Zanjiran	Meymand	Fault Parallel
11	5.8	1994	Zanjiran	Meymand	Fault Normal
12	5.8	1994	Zanjiran	Firoz abad	Fault Normal
13	6.1	2006	Silakhor	Toshak ab sard	Fault Normal
14	7.4	1978	Tabas	Deyhok	Fault Parallel
15	7.4	1978	Tabas	Deyhok	Fault Normal
16	7.4	1978	Tabas	Tabas	Fault Parallel
17	7.4	1978	Tabas	Tabas	Fault Normal
18	6.6	1988	Fandogha	Sirch	Fault Parallel
19	6.6	1988	Fandogha	Sirch	Fault Normal
20	6.2	2004	Kajour	Pol	Fault Parallel

Table 2. Distance between stations and earthquake center, shear wave velocity and soil type

Earthquake name	Station	Component	Distance (km)	Shear wave velocity (m/sec)	Soil type
Changoreh	Avaj	Fault Parallel	6	1111	I
Changoreh	Avaj	Fault Normal	6	1111	I
khulibaniabad	Ghayen	Fault Parallel	52	360-490	II
Roudbar	Ab bar	Fault Parallel	32.3	360-490	II
Roudbar	Ab bar	Fault Normal	32.3	360-490	II
Roudbar	Ghazvin	Fault Parallel	98.2	360-490	II
Zarand	Zarand	Fault Parallel	16.2	271	III
Zarand	Zarand	Fault Normal	16.2	271	III
Zarand	Sadde ghadroni	Fault Parallel	22.7	300-490	II&III
Zanjiran	Meymand	Fault Parallel	22.5	360-490	II
Zanjiran	Meymand	Fault Normal	22.5	360-490	II
Zanjiran	Firoz abad	Fault Normal	27.8	360-760	II
Silakhor	Toshak ab sard	Fault Normal	35.9	360-760	II
Tabas	Deyhok	Fault Parallel	18.7	300-490	II&III
Tabas	Deyhok	Fault Normal	18.7	300-490	II&III
Tabas	Tabas	Fault Parallel	57	360-490	II&III
Tabas	Tabas	Fault Normal	57	360-490	II&III
Fandogha	Sirch	Fault Parallel	12.4	689	II
Fandogha	Sirch	Fault Normal	12.4	689	II
Kajour	Pol	Fault Parallel	11.5	180-360	II

Earthquake mechanism is suitable as one of the determinant factors in accelerogram selection. Table 3 shows earthquake mechanism, Peak Ground Acceleration (PGA) in g and Peak Ground Velocity (PGV) in m/sec for accelerograms.

In the last stage, selected accelerograms response spectrum have been evaluated and compared with standard design spectrum for two soil types. Figure 1 shows the selected accelerogram response spectrums and standard design spectrum for soil type II. As seen, by selection of proposed accelerograms, proper distribution of response spectra will be obtained in comparison of standard design spectrum.

Table 3. Earthquake mechanism, PGA (g) and PGV (cm/sec) for accelerograms.

Earthquake name	Station	Component	PGA(g)	PGV(cm/sec)	Earthquake mechanism
Changoreh	Avaj	Fault Parallel	0.494	23.6	reverse
Changoreh	Avaj	Fault Normal	0.465	19.3	reverse
khulibaniabad	Ghayen	Fault Parallel	0.215	11	strike slip-thrust
Roudbar	Ab bar	Fault Parallel	0.597	54.4	thrust
Roudbar	Ab bar	Fault Normal	0.54	57.9	thrust
Roudbar	Ghazvin	Fault Parallel	0.206	29	thrust
Zarand	Zarand	Fault Parallel	0.326	26.3	reverse
Zarand	Zarand	Fault Normal	0.241	22.1	reverse
Zarand	Sadde ghadroni	Fault Parallel	0.223	15.5	reverse
Zanjiran	Meymand	Fault Parallel	0.448	18.4	strike slip
Zanjiran	Meymand	Fault Normal	0.502	18.9	strike slip
Zanjiran	Firoz abad	Fault Normal	0.289	9.2	strike slip
Silakhor	Toshak ab sard	Fault Normal	0.382	8.6	strike slip
Tabas	Deyhok	Fault Parallel	0.325	20.3	reverse
Tabas	Deyhok	Fault Normal	0.4	27	reverse
Tabas	Tabas	Fault Parallel	0.863	118.4	reverse
Tabas	Tabas	Fault Normal	0.849	92.3	reverse
Fandogha	Sirch	Fault Parallel	0.684	36.6	strike slip-thrust
Fandogha	Sirch	Fault Normal	0.481	91.85	strike slip-thrust
Kajour	Pol	Fault Parallel	0.296	10.8	reverse

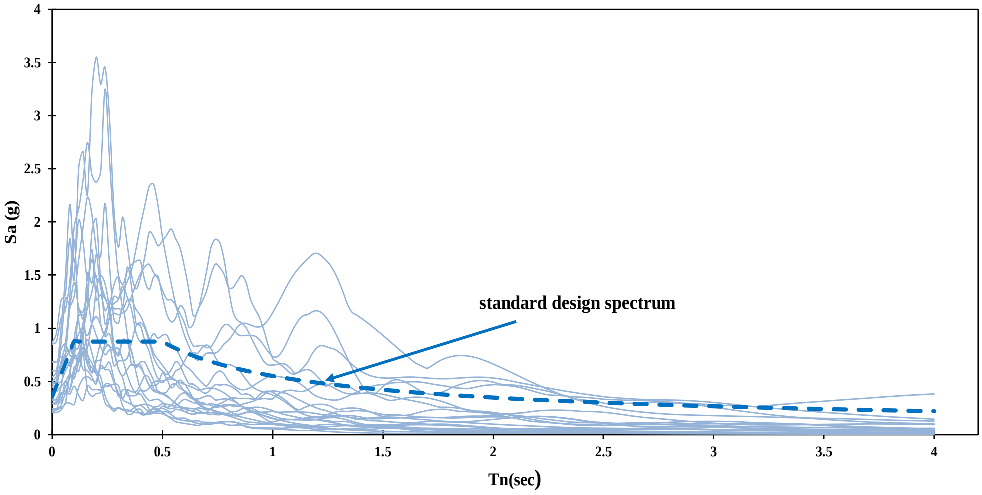

Figure 1. Comparison of standard design spectrum for soil type II with response spectrums of records list

3. Determination of scale factor for normal steel moment frames in nonlinear two-dimensional analysis

In previous section, twenty appropriate accelerograms have been selected and proposed for Iran by considering all factors and effective parameters in accelerograms selection. In this section, scale factor determination will be considered for normal steel moment frames. Considered frames in this section were similar to the study sample of Ghasemieh *et al.* [9-12]. this samples are 7-storey and 12-storey. Height of each story is 3.2 *m* and total height of each frame of 7-storey and 12-storey are 22.4 *m* and 38.4 *m* respectively.

Since these frames were located in Iran, Standard 2800 must be used. As known the scale factor is high in this standard, considered frames are 7-storey and 12-storey. Height of each story is 3.2 *m* and total height of each frame of 7-storey and 12-storey are 22.4 *m* and 38.4 *m* respectively. Natural period of frames is calculated as follows:

$$T = 0.08h^{\frac{3}{4}}$$

where T, is Natural period of frame and h is total height from ground elevation and factor 0.08 is for steel moment frames. Thus, models of 7-storey and 12-storey have period 0.824 sec and 1.23 sec respectively. In determination of scale factor, all accelerograms must be scaled to peak values. For instance, Khoulibaniabad earthquake recorded in Ghayen station has PGA equal to 0.215g in fault direction. Scale factor to g in this accelerogram is equal to 4.65. Figure 2 shows Khulibaniabad accelerogram and Figure 3 presents this accelerogram after scale.

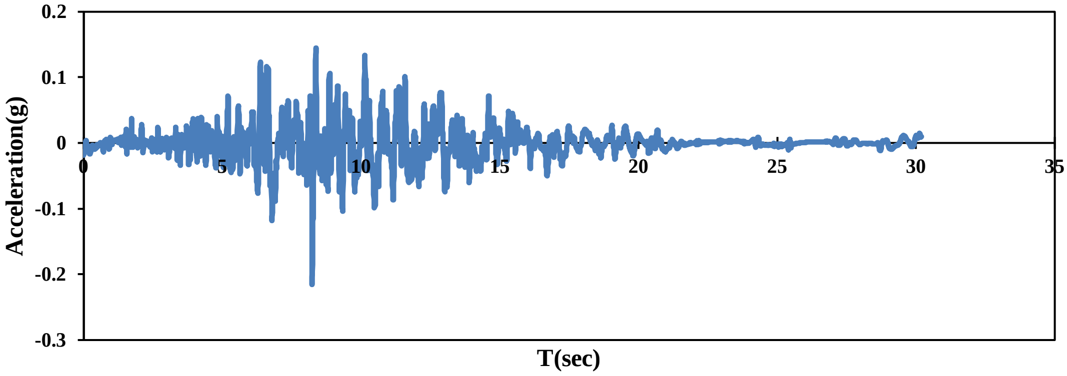

Figure 2. Khulibaniabd accelerogram in Ghayen station in fault direction

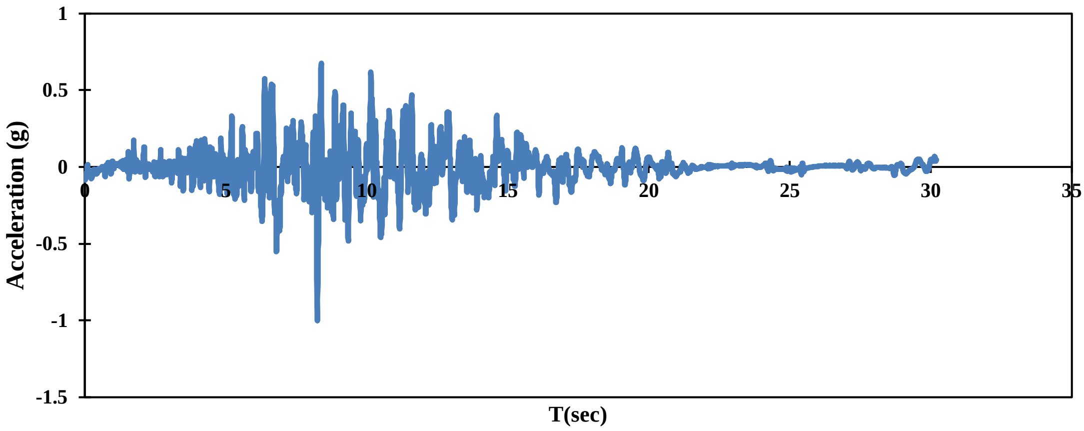

Figure 3. Khulibaniabad accelerogram in Ghayen station in fault direction with scaling

In the next stage, response spectrum with 5% damping is obtained and their average will be compared with 1.4 time of design spectrum in 1.2 to 1.5 times of natural period for each structure. Determination of scale factor is very important and proposed procedure is that point-to-point difference is evaluated for each accelerogram, response spectrum of each accelerogram in various periods with respect to periodic intervals for each frame is compared with 1.4 times of standard design spectrum. Factors is calculated for accelerograms so that the point-to-point differences in average response spectrum and standard design spectrum is less than 10 percent. This procedure must be done in 1.2 to 1.5 times of natural period for 7-storey frame that is equal to 0.82 sec to 1.23 sec. Each accelerogram is compared in periodic intervals with point-to-point differences of standard design spectrum and scale factor will be determined so that this difference is less than 10 percent. This procedure is done for each accelerogram and all scale factors is applied to each accelerogram separately in this stage and proportion of scale factor of each accelerogram is considered. Finally mean value of 20 accelerogram response spectra is compared with 1.4 times of design spectrum in 1.2 to 1.5 times of period to not have the average less than response spectra. In this stage, final control will be done and scale factor obtained from point-to-point differences for each accelerogram will be changed in necessary. How to apply final change is corresponding to point factors for each accelerogram in previous stage. Final scale factor is obtained from multiplication of two factors of equalization and scale factor in point-to-point differences stage. For 7-storey and 12-storey frames scale factor of point-to-point differences have been done in periodic intervals. Table 4 shows factors of equalization to g, point to point differences and final scale factor for 7-storey steel moment frame. Average final scale factor is 2.95 for 7-storey frame. Table 5 shows factors of equalization to g, point to point differences and final scale factor for 12-storey steel moment frame. Average final scale factor is 3.1 for 12-storey frame.

Table 4. Factors of equalization to g, point to point differences and final scale factor for 7-storey

Earthquake name	Station	Component	Scale to g	Point to Point Difference	Final Scale
Changoreh	Avaj	Fault Parallel	2.025	1.3	2.6
Changoreh	Avaj	Fault Normal	2.15	1.3	2.8
khulibaniabad	Ghayen	Fault Parallel	4.64	0.75	3.5
Roudbar	Ab bar	Fault Parallel	1.67	1.3	2.1
Roudbar	Ab bar	Fault Normal	1.85	1.1	2
Roudbar	Ghazvin	Fault Parallel	4.85	0.9	4.3
Zarand	Zarand	Fault Parallel	3.07	1.1	3.4
Zarand	Zarand	Fault Normal	4.15	1	4.1
Zarand	Sadde ghadroni	Fault Parallel	4.49	0.75	3.4
Zanjiran	Meymand	Fault Parallel	2.23	1.3	2.9
Zanjiran	Meymand	Fault Normal	2	1.3	2.6
Zanjiran	Firoz abad	Fault Normal	3.46	1	3.4
Silakhor	Toshak ab sard	Fault Normal	2.62	1.3	3.4
Tabas	Deyhok	Fault Parallel	3.07	1.2	3.7
Tabas	Deyhok	Fault Normal	2.5	1.2	3
Tabas	Tabas	Fault Parallel	1.15	1.2	1.4
Tabas	Tabas	Fault Normal	1.17	1.1	1.3
Fandogha	Sirch	Fault Parallel	1.46	1	1.4
Fandogha	Sirch	Fault Normal	2.08	1	2.1
Kajour	Pol	Fault Parallel	3.37	1	3.4

Table 5. Factors of equalization to g, point to point differences and final scale factor for 12-storey

Earthquake name	Station	Component	Scale to g	Point to Point Difference	Final Scale
Changoreh	Avaj	Fault Parallel	2.025	1.4	2.8
Changoreh	Avaj	Fault Normal	2.15	1.4	3
khulibaniabad	Ghayen	Fault Parallel	4.64	0.8	3.7
Roudbar	Ab bar	Fault Parallel	1.67	1.4	2.3
Roudbar	Ab bar	Fault Normal	1.85	1.25	2.3
Roudbar	Ghazvin	Fault Parallel	4.85	0.9	4.3
Zarand	Zarand	Fault Parallel	3.07	1.25	3.8
Zarand	Zarand	Fault Normal	4.15	1	4.1
Zarand	Sadde ghadroni	Fault Parallel	4.49	0.8	3.6
Zanjiran	Meymand	Fault Parallel	2.23	1.4	3.1
Zanjiran	Meymand	Fault Normal	2	1.4	2.8
Zanjiran	Firoz abad	Fault Normal	3.46	1.15	3.9
Silakhor	Toshak ab sard	Fault Normal	2.62	1.4	3.7
Tabas	Deyhok	Fault Parallel	3.07	1.25	3.8
Tabas	Deyhok	Fault Normal	2.5	1.25	3.1
Tabas	Tabas	Fault Parallel	1.15	1.35	1.5
Tabas	Tabas	Fault Normal	1.17	1.3	1.5
Fandogha	Sirch	Fault Parallel	1.46	1.25	1.8
Fandogha	Sirch	Fault Normal	2.08	1.25	2.6
Kajour	Pol	Fault Parallel	3.37	1.15	3.8

After applying the final scale factor of each accelerogram, average response spectra of accelerograms must be compared with 1.4 times of standard design spectrum in 0.2 to 1.5 times of period. Figure 4 shows the comparison for 7-storey frame.

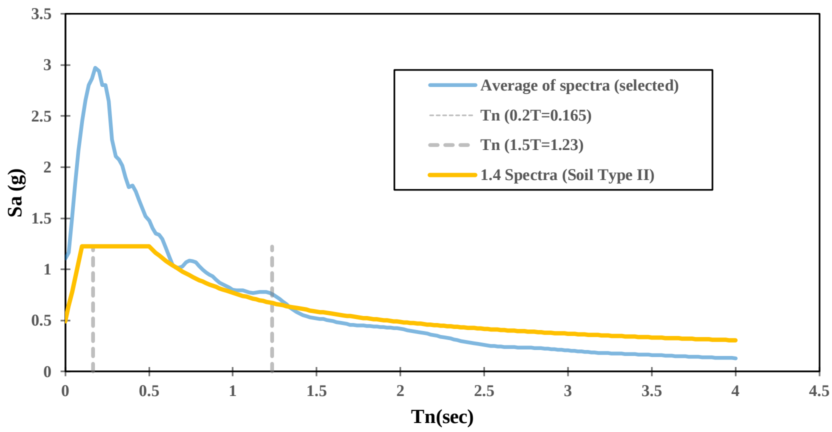

Figure 4. The comparison of standard design spectrum and average response spectra of accelerograms in soil type II for 7-storey frame

Average response spectra of accelerograms is higher than 1.4 times of standard design spectrum in periodic interval. Figure 5 shows the comparison for 12-storey frame.

Average response spectra of accelerograms is higher than 1.4 times of standard design spectrum in periodic interval. Therefore, proposed accelerograms are provided after applying scale factors for normal steel moment frames in time history two-dimensional analysis.

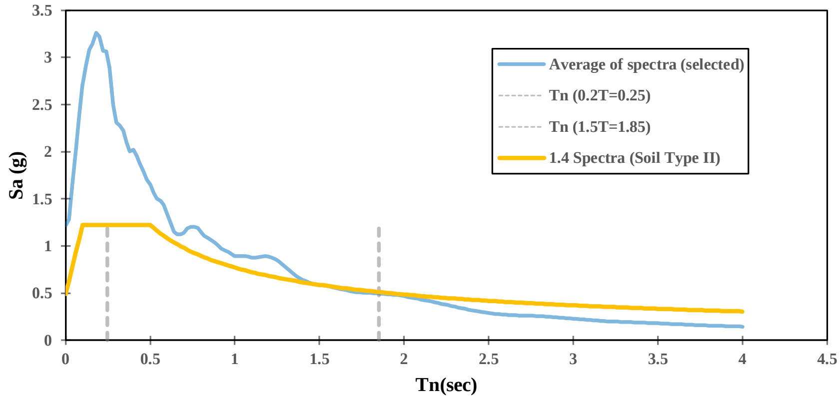

Figure 5. The comparison of standard design spectrum and average response spectra of accelerograms in soil type II for 12-storey frame

4. Conclusion

With respect to the importance of accelerogram selection for nonlinear analysis and creation of suitable list of accelerograms, in this study 2000 modified accelerograms were evaluated and the approach and appropriate accelerograms were selected and finally 20 accelerograms, which show the real ground motion were represented. These accelerograms belong to earthquakes which occurred in 1979 to 2006 in Iran and their magnitudes are between 5.8 and 7.4. Average magnitude for proposed accelerograms is equal to 6.5 and PGA is between 0.206g and 0.863g which has mean value of 0.424g. Average of PGV is 23 cm/sec in proposed accelerograms. In the last step scale factor of normal steel moment frame were obtained based on point-to-point difference method. Mean value of scale factor is 2.95 for 7-storey frame and 3.1 for 12-storey. Differences between Standard 2800 (Iranian Code of Practice for Seismic Resistant Design of Building) and the other codes like ASCE-07 and Eurocode-8 were stated and showed that this scale factor is high in Standard 2800 and finally standard design spectrum was suggested to use in comparison with average response spectra of selected accelerograms for the largest earthquake with 2500 year return period. In the procedure of scale determination, factor of equalization to g, for accelerograms and factor 1.4 multiplied to standard spectrum were eliminated. And the average of accelerograms is compared with standard design spectrum for largest earthquake with 2500 year return period to obtain suitable scale factor for two-dimensional analysis. In this procedure, scale factor is high and scale factor higher than 5 is not suitable. Appropriate accelerogram selection and scale factor is effective on nonlinear analysis result.

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