Science Arena Publications
Specialty Journal of Architecture and Construction
ISSN: 2412-740X
Available online at www.sciarena.com
2019, Vol, 5 (3): 9-20

Evaluation of the Effects of Ground Motion Parameters on the Response Acceleration, Velocity and Displacement Spectra

Elham Rafiei[1]*, Vahid Ahmadi Malayeri[2], Hamidreza Ghaem Maghami[1]

[1] MSc in civil engineering, Khajeh Nasir Toosi University of Technology, Tehran, Iran.
[2] MSc in civil engineering, Malayer University, Hamedan, Iran.

***Corresponding Author**

Abstract: *The dynamic response of structural system depends upon the frequency content of ground motions. The response spectrum also as a function of the natural frequency is not a direct representation of the frequency content of the excitation, but rather of the effect that the signal has on a system with a single degree of freedom (SDOF). The design response spectrum provides the engineers with an envelope over the happened and anticipated earthquakes to analysis structures. Thus, most building and seismic codes produces such spectra which has not considered the effects of all ground motion parameters. In this regard, this study aims to consider the effects of the epicentral distance, soil classification, and the type of faults on the design response spectra; acceleration, velocity, and displacement spectrum. 79 records from the PEER strong-motion database has been selected through three groups; 20, 21, and 38 records and normalized to the peak ground motion parameters. Then the acceleration spectrum has been compared with the one obtained from ASCE and Standard No. 2800. The results showed that in most frequency domain, the spectral acceleration response obtained from this study does not fully conform to the spectrum of the codes.*

Keywords: *Epicentral Distance, Fault, Ground Motion Parameter, Mechanism, Soil*

INTRODUCTION

The importance of the response spectrum in analyzing and designing earthquake-resistant structures for structural engineers is irrefutable. The maximum response spectrum defines the response of damped single degree of freedom systems (SDOF) with different natural periods and frequencies. Using the response spectrum is the dominant and common method in the dynamic analysis of structures which describes the characteristics of the ground motion, and represents a set of responses to various simple structures and serves as the basis for calculating displacements and forces in structures of one and several degrees of freedom in the linear and nonlinear behavior range. To achieve this, the elastic spectrum is modified to consider the linear behavior of the SDOF structure. In this regard numerous studies evaluated the effects of ground motion parameters such as magnitude, soil condition and distances from the earthquake's epicenter on the acceleration spectrum (Maniatakis and Spyrakos, 2012; Ahmadizadeh and Shakiba, 2007). Also, the influences of damping on the response spectra have been investigated by using a special coefficient (Tehranizadeh and Hamedi, 2002; Akkar S, Bommer JJ, 2007; Dwairi et al., 2007). In addition, several studies concluded that most seismic codes are required to be adjusted to reflect the near-fault directivity effect of sever earthquakes (Xu Longjun et al., 2010; Xu Longjun et al., 2006; Champion et al., 2012). The influence of such parameters on acceleration spectrum has been taken to consideration, while the effects of these parameters on velocity and displacement spectrum have been ignored. On the other hand, during earthquakes, many failures have been observed in structures with a low mass, such as buried pipelines, and others, along with the destruction of massive buildings, and their destruction has sometimes brought more serious damage. Therefore, the only use of the methods based on the earthquake acceleration parameters in such structures cannot be suitable. And the existence of a design spectrum for earthquake velocity and displacement along with the acceleration spectrum is necessary because linear and network structures that are largely buried are mostly affected by the velocity and displacement response of those earthquakes.

Based on the aftermath of the previous earthquakes, an increase in the acceleration of the earthquake has always been accompanied with the further damage of those structures located on the ground which is proportional to their mass. In cases of the low velocity, there is no significant damage to subsurface excavations and underground structures such as pipelines and tunnels. The effect of inertia on the buried linear and the network structures is far less than those located on the ground, because in buried structures the behavior of the structure is practically influenced by the behavior of the soil and its mass is negligible in comparison to its peripheral soil. The velocity response spectrum is used for underground structures such as pipelines, tunnels, buried tanks, whose operation is controlled by the seismic behavior of their adjacent land. The seismic design of these structures is based on the displacement response method. Thus, this study aims to investigate the influences of site conditions, distance from epicenter, and the type of faults on the acceleration, velocity, and displacement spectra. In this regard, 79 records have been selected from the PEER strong-motion database (Berkeley). Each of these records has been normalized and use to produce spectra. In addition, the response acceleration spectra obtained from codes; ASCE and Standard No.2800 are compared to the acceleration spectra resulted from this study.

Earthquake Parameters

faults

Faults may be vertical, horizontal, or inclined at any angle. Although the angle of inclination of a specific fault plane tends to be relatively uniform, it may differ considerably along its length from place to place. As it is shown in Figure 1 In a strike-slip fault, the fault surface (plane) is usually near vertical and the footwall moves laterally either left or right with very little vertical motion which is defined by the direction of movement of the ground as would be seen by an observer on the opposite side of the fault (Allaby, 2013). Normal dip-slip faults are produced by vertical compression as the Earth's crust lengthens. The hanging wall slides down relative to the footwall. Normal faults are common; they bound many of the mountain ranges of the world and many of the rift valleys found along spreading margins of tectonic plates. Normal oblique is responsible for certain mountain ranges and other interesting geological features in the earth's crust. A fault, which is a rupture in the earth's crust, is described as a normal fault when one side of the fault moves downward with respect to the other side. The opposite of this, in which one side moves up, is called a reverse fault (USGS).

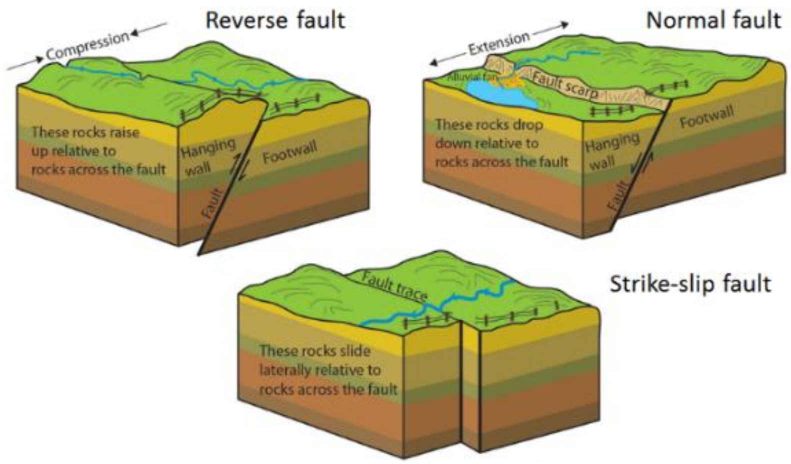

Figure 1. Normal, Reverse and Strike-slip Faults

peak ground acceleration

The most commonly used scale range in ground motion is the Peak Ground Acceleration (PGA). The PGA for a component of motion is the largest value (absolute value) of the acceleration resulting from that acceleration mapping component. Horizontal acceleration is used to describe the motion of the earth due to their relationship with the forces of inertia. The most dynamic forces generated in very rigid structures are closely related to the PGA. Maximum acceleration has a wide application in scaling design spectrum and it is also related to the severity of the earthquake. In earthquake engineering, vertical acceleration is less attractive than horizontal acceleration (Korzec, 2016). In engineering applications, it is generally assumed that the maximum acceleration is equal to two-thirds of the maximum horizontal acceleration of the PGA. But research shows that the horizontal-to-vertical acceleration ratio is completely variable and its value in areas close to earthquake resources is more than this in large distances (Kalkan and Polat, 2004).

peak ground velocity

Horizontal Peak Ground Velocity (PGV) is another important parameter in describing the range of ground motion. Because the sensitivity towards speed for the high frequencies ground motion is low, the PGV at intermediate frequencies is more appropriate than the PGA to accurately describe the range of ground motion. For structures or installations that are sensitive to medium-frequency loading (such as high or flexible structures, bridges, etc.), PGV is a more precise parameter for evaluating failure to PGA. In buried structures, structural behavior is mostly affected by peripheral soil behavior and also their mass is extremely small and negligible compared to its peripheral soil. Therefore, the use of accelerated methods to design of such structures cannot be sufficient and the existence of a velocity spectrum along with the acceleration spectrum is necessary. Because the seismic design of such structures is based on the displacement methods (Pineda-Porras and Ordaz-Schroeder, 2003).

peak ground displacement

The Peak Ground Displacement (PGD) is associated with the components of moving an earthquake at lower frequencies which is less common than PGA and PGV. However, the failure occurred in very soft structures is directly related to this parameter.

definition and design of response spectra

A set of maximum response values for a degree of freedom system is defined in the form of a function of three parameters; the natural frequency of the system ω_n, the amount of damping ξ, and a time history for the ground acceleration, &z& (t). The maximum response of any SDOF system, within a given frequency domain or period, can be obtained by plotting the responses of a SDOF system with the various natural frequency which is a response spectrum. It should be noted that the maximum acceleration for each SDOF device can be directly read from the spectral response spectrum. The response spectrum of displacement, pseudo-velocity, and pseudo-acceleration are related to each other and can be converted by using equation 1.

$$Sv = \frac{S_A}{\omega} = \frac{S_A T}{2\pi} = \omega S_D = 2\pi S_D T^{-1} \qquad (1)$$

characteristics of the response spectrum and its implications

In general, the response spectrum has the following characteristics:

Relative displacement, velocity and acceleration of the SODF system of the stiff system is zero and the absolute acceleration of the system is equal to the acceleration of the earth. Relative values of displacement, velocity and acceleration of a flexible SDOF system is equal to these values for the earth, and the absolute acceleration of the system is zero. The GPA, GPV and GPD are controlled by high, intermediate and low frequencies, respectively. All three response spectra can be plotted in a logarithmic scale. The response to the response spectrum is as follows:

1- Earthquakes, features, and thus unique response spectra, are unlikely to be expected for future earthquakes in the same phenomenon and spectrum.
2- Periods and different modes of buildings cannot be accurately estimated, and the slight differences in the response spectrum due to severe deterioration make it a big difference.
3- The unavoidable changes in mass and the hardness of buildings make the natural period change and their damping ratio comparable to that used in the design.

the methods of calculating the design spectrum

Since the maximum ground acceleration, velocity, and displacement associated with different earthquake records, generally, calculated response cannot be based on independent principles of averaging. Therefore, various methods are used to normalize the response spectra before the averaging. From the structural engineering view point, a design spectrum or a paved spectrum is described in terms of the structural seismic forces or displacements associated with structures with various period and damping. The design spectrum can be both elastic and inelastic. Based on the earthquake scenario and structural response characteristics, appropriate inelastic acceleration and displacement spectra are selected and used to predict the response (Borzi and Elnashai, 2000).

The inelastic design spectra can be obtained directly by scaling the elastic spectra by the force reduction factors. Generally, these spectra are the average of acceleration response spectra, which are matched using two or three control periods. Main curves are obtained with a damping of 5%. But there are simplified expressions for obtaining spectra for different values of attenuation. In this case, the correction of spectral heights using the coefficient η can be as follows:

$$\eta = \sqrt{\frac{10}{5+\xi}} \geq 0.55 \qquad (2)$$

In which ξ is the viscous damping (%). Two or three control periods have been used to match the acceleration response spectra. The maximum effective acceleration (design basis acceleration) is sometimes used to scale normalized spectra. The spectra can be presented in various formats; for example, spectral heights (acceleration, velocity, and displacement) in terms of period, three-dimensional charts, and spectral acceleration in terms of spatial variations. The last extension is called the compound spectrum, which is used to evaluation of CSM (Capacity Spectrum Method).

Also, spectral values can be plotted in terms of frequency. It should be noted that in some cases, determining the shape of the design spectra for a particular site is complex and should be cautious in selecting the representative seismic mapping. For example, the components of the period of strong ground motion in certain areas of frequency influence the response of the structures. Recent strong data suggest that the components of the great period are affected by factors such as the type of faults, the distribution of rupture, the directivity and the type of site. In addition, when using the design spectra, the difference between them and the response spectrum should be considered. The graphic response spectrum is the maximum response of an oscillator of a degree of freedom system with different frequencies and attenuation ratios to a certain ground motion. While the smooth design spectrum is a reference point for obtaining the design earthquake force and displacement of the structure with a given frequency or period of vibration and damping. Since the peak of acceleration, velocity, and displacement of the earthquake mapping are different, the calculated response cannot be averaged completely. Before applying averaging, various methods are used to normalize the design spectra. Of these, two commonly used methods are; normalization in terms of spectral intensity, in which the areas below the spectral curves between the two frequencies or the given period are equal, and normalization in terms of the peak of earth's shaking, in which the spectral heights are divided by the peak of acceleration, velocity, or displacement of the earth. Other methods have been proposed based on the effective acceleration peak and rms acceleration.

Earthquake Records

An ideal method for choosing strong motions to use in the analysis is to obtain records which are produced in the same conditions as the seismic design scenario. If all of the characteristics of the earthquake are consistent with the previous earthquakes, the likelihood of matching the records of the record will be one. Because the earthquake is defined in terms of only a few parameters, the problem seems to be to ensure that the selected records accurately match all the characteristics of the earthquake in the source, across the path, and to the surface of the ground in the site.

distance

The properties of Near-fault earthquakes compared to far-fault earthquakes are significantly different. Due to the phenomenon that the pulses of the component perpendicular on fault are longer with wider range than those of the parallel component. The earthquake ground motion is obtained from the PEER strong-motion database (Berkeley). A number of records are included to enrich the sample in the range of moment magnitude MW>5.0, with epicentral distance less than 10 km and between 10 and 20 km. These earthquakes occurred by strike slip faults and the type of soil is Deep broad soil which is listed in table 1.

Table 1- Records in strike slip faults and deep broad soil type

NO.	MAGNITUDE	DISTNCE	EARTHQUAKE	STATION
1	4_6	0_10	Anza (Horse Cany) 1980/02/25 10:47	5045 Anza - Terwilliger Valley
2	4_6	0_10	Coyote Lake 1979/08/06 17:05	47379 Gilroy Array #1
3	4_6	0_10	Coyote Lake 1979/08/06 17:05	57217 Coyote Lake Dam (SW Abut)
4	4_6	0_10	Helena, Montana 1935/10/31 18:38	2022 Carroll College
5	4_6	0_10	Hollister 1974/11/28 23:01	47379 Gilroy Array #1
6	4_6	0_10	Kocaeli, Turkey 1999/08/17	Izmit
7	4_6	0_10	Landers 1992/06/28 11:58	24 Lucerne
8	4_6	0_10	Livermore 1980/01/27 02:33	57T02 Livermore - Morgan Terr Park
9	4_6	0_10	Morgan Hill 1984/04/24 21:15	57217 Coyote Lake Dam (SW Abut)
10	4_6	0_10	Parkfield 1966/06/28 04:26	1438 Temblor pre-1969
11	4_6	10_20	Anza (Horse Cany) 1980/02/25 10:47	5044 Anza - Pinyon Flat

12	4_6	10_20	Chalfant Valley 1986/07/20 14:29	54424 Bishop - Paradise Lodge
13	4_6	10_20	Chalfant Valley 1986/07/21 14:51	54424 Bishop - Paradise Lodge
14	4_6	10_20	Coalinga 1983/09/09 09:16	1703 Sulphur Baths (temp)
15	4_6	10_20	Kocaeli, Turkey 1999/08/17	Gebze
16	4_6	10_20	Mammoth Lakes 1980/05/25 19:44	54214 Long Valley dam (Upr L Abut)
17	4_6	10_20	Mammoth Lakes 1980/05/25 19:44	54214 Long Valley Dam (Downst)
18	4_6	10_20	Mammoth Lakes 1980/05/25 19:44	54214 Long Valley Dam (L Abut)
19	4_6	10_20	Mammoth Lakes 1980/05/25 20:35	54214 Long Valley dam (Upr L Abut)
20	4_6	10_20	Mammoth Lakes 1980/05/25 20:35	54214 Long Valley Dam (Downst)
21	4_6	10_20	Mammoth Lakes 1980/05/25 20:35	54214 Long Valley Dam (L Abut)

site effects

Before the 1971 San Fernando earthquake, the number of accelerometers available from previous earthquakes was limited and most of them were recorded in alluvial fields. So, in the design spectra that are based on mapping of alluvial lands, soil type factor has not been considered. In order to investigate the effect of soil type on the response spectra a series of ground motions were selected which obtained from the PEER strong-motion database (Berkeley). The records are included to enrich the sample in the range of moment magnitude M_W>5.0, with epicentral distance less than 10 km and peak ground acceleration $a_g > 50$ cm/s^2. The selected records listed with ascending moment magnitude are shown in Table 3. Filtering details for the worldwide records occurred by strike slip faults are available at the PEER site. The classification of the soil is based on ASCE code; Rock (A), Shallow soil (B), Deep narrow soil (C), Deep brod soil (D), Soft deep soil (E). And their characteristics are described in table 2.

Table 2- The description of soil types

Soil Type	shear-wave velocity (m/s)	Description
A	Vs > 1500	Includes unweathered intrusive igneous rock. Occurs infrequently in the bay area. We consider it with type B (both A and B are represented by the color blue on the map). Soil types A and B do not contribute greatly to shaking amplification.
B	1500 > Vs > 750	Includes volcanic, most Mesozoic bedrock, and some Franciscan bedrock. (Mesozoic rocks are between 245 and 64 million years old. The Franciscan Complex is a Mesozoic unit that is common in the Bay Area.)
C	750 > Vs > 350	Includes some Quaternary (less than 1.8 million years old) sands, sandstones and mudstones, some Upper Tertiary (1.8 to 24 million years old) sandstones, mudstones and limestone, some Lower Tertiary (24 to 64 million years old) mudstones and sandstones, and Franciscan melange and serpentinite.
D	350 > Vs > 200	Includes some Quaternary muds, sands, gravels, silts and mud. Significant amplification of shaking by these soils is generally expected.
E	200 > Vs	Includes water-saturated mud and artificial fill. The strongest amplification of shaking due is expected for this soil type.

Table 3- Near fault records in strike slip faults

NO	GEOMATRIX	EARTHQUAKE	STATION	M
1	A rock	Cape Mendocino 1992/04/25 18:06	89005 Cape Mendocino	7.1
2	A rock	Coalinga 1983/05/09 02:49	46T06 Oil fields - Skunk Hollow	5

3	A rock	Coalinga 1983/05/09 02:49	1607 Anticline Ridge Pad	5
4	A rock	Gazli, USSR 1976/05/17	9201 Karakyr	6.8
5	A rock	Northridge 1994/01/17 12:31	24207 Pacoima Dam (downstr)	6.7
6	B shallow (stiff) soil	Coalinga 1983/05/09 02:49	46T05 Anticline Ridge - Palmer Ave	5
7	B shallow (stiff) soil	Coalinga 1983/05/09 02:49	1604 Oil City	5
8	B shallow (stiff) soil	Northridge 1994/01/17 12:31	24088 Pacoima Kagel Canyon	6.7
9	B shallow (stiff) soil	San Fernando 1971/02/09 14:00	128 Lake Hughes #12	6.6
10	B shallow (stiff) soil	Whittier Narrows 1987/10/01 14:42	90071 West Covina - S Orange	6
11	C deep narrow soil	Cape Mendocino 1992/04/25 18:06	89324 Rio Dell Overpass - FF	7.1
12	C deep narrow soil	Northridge 1994/01/17 12:31	90013 Beverly Hills - 14145 Mulhol	6.7
13	C deep narrow soil	Northridge 1994/01/17 12:31	90060 La Crescenta - New York	6.7
14	C deep narrow soil	Tabas, Iran 1978/09/16	9101 Tabas	7.4
15	C deep narrow soil	Whittier Narrows 1987/10/01 14:42	90068 Covina - S Grand Ave	6
16	D Deep broad soil	Cape Mendocino 1992/04/25 18:06	89486 Fortuna - Fortuna Blvd	7.1
17	D Deep broad soil	Cape Mendocino 1992/04/25 18:06	89156 Petrolia	7.1
18	D Deep broad soil	Northridge 1994/01/17 12:31	24087 Arleta - Nordhoff Fire Sta	6.7
19	D Deep broad soil	Point Mugu 1973/02/21 14:45	272 Port Hueneme	5.8
20	D Deep broad soil	Whittier Narrows 1987/10/01 14:42	80053 Pasadena - CIT Athenaeum	6

type of faults

In order to evaluate the effects of the type of faults on the spectral acceleration, velocity and displacement, a number of records are included to enrich the sample in the range of moment magnitude M>5.0, with epicentral distance less than 10 km and the Deep broad soil-type. The selected records which are listed in Table 4 is obtained from the PEER strong-motion database (Berkeley). Five different type of faults have been investigated which are; strike slip, normal, reverse normal, reverse oblique, and normal oblique. Each individual record is scaled in terms of amplitude in time domain to match 5% damped elastic design spectrum of ASCE Code.

Table 2- Near fault records in Deep broad soil type

NO	MECHANISM	EARTHQUAKE	STATION
1	strike slip	Chalfant Valley 1986/07/21 14:42	54171 Bishop - LADWP South St
2	strike slip	Coyote Lake 1979/08/06 17:05	47380 Gilroy Array #2
3	strike slip	Duzce, Turkey 1999/11/12	Duzce
4	strike slip	Hollister 1974/11/28 23:01	1377 San Juan Bautista, 24 Polk St
5	strike slip	Hollister 1974/11/28 23:01	1028 Hollister City Hall
6	strike slip	Imperial Valley 1940/05/19 04:37	117 El Centro Array #9
7	strike slip	Kocaeli, Turkey 1999/08/17	Yarimca
8	strike slip	Mammoth Lakes 1980/05/25 20:35	54099 Convict Creek
9	strike slip	Morgan Hill 1984/04/24 21:15	1652 Anderson Dam (Downstream)
10	strike slip	Parkfield 1966/06/28 04:26	1013 Cholame #2
11	normal	Oroville 1975/08/02 20:22	1546 Up & Down Cafe (OR1)
12	normal	Oroville 1975/08/02 20:22	1545 Oroville Airport

13	normal	Oroville 1975/08/08 07:00	1546 Up & Down Cafe (OR1)
14	normal	Oroville 1975/08/08 07:00	1550 Duffy Residence (OR5)
15	normal	Oroville 1975/08/08 07:00	1549 Pacific Heights Rd (OR4)
16	normal	Oroville 1975/08/08 07:00	1545 Oroville Airport
17	reverse normal	Cape Mendocino 1992/04/25 18:06	89486 Fortuna - Fortuna Blvd
18	reverse normal	Coalinga 1983/05/09 02:49	46T04 CHP (temp)
19	reverse normal	Coalinga 1983/06/11 03:09	46T04 CHP (temp)
20	reverse normal	Coalinga 1983/07/25 22:31	46T04 CHP (temp)
21	reverse normal	Northridge 1994/01/17 12:31	24087 Arleta - Nordhoff Fire Sta
22	reverse normal	Point Mugu 1973/02/21 14:45	272 Port Hueneme
23	reverse normal	Whittier Narrows 1987/10/01 14:42	80053 Pasadena - CIT Athenaeum
24	reverse normal	Whittier Narrows 1987/10/01 14:42	24461 Alhambra, Fremont Sch
25	reverse normal	Whittier Narrows 1987/10/01 14:42	24402 Altadena - Eaton Canyon
26	reverse normal	Whittier Narrows 1987/10/01 14:42	14368 Downey - Co Maint Bldg
27	reverse oblique	Coalinga 1983/05/02 23:42	1162 Pleasant Valley P.P. - bldg
28	reverse oblique	Coalinga 1983/05/02 23:42	1162 Pleasant Valley P.P. - yard
29	reverse oblique	Mammoth Lakes 1980/05/25 16:34	54099 Convict Creek
30	reverse oblique	Mammoth Lakes 1980/05/27 14:51	54099 Convict Creek
31	reverse oblique	N. Palm Springs 1986/07/08 09:20	12149 Desert Hot Springs
32	reverse oblique	N. Palm Springs 1986/07/08 09:20	12025 Palm Springs Airport
33	reverse oblique	Santa Barbara 1978/08/13	283 Santa Barbara Courthouse
34	reverse oblique	Whittier Narrows 1987/10/04 10:59	24402 Altadena - Eaton Canyon
35	reverse oblique	Whittier Narrows 1987/10/04 10:59	24400 LA - Obregon Park
36	reverse oblique	Whittier Narrows 1987/10/04 10:59	24461 Alhambra - Fremont Sch
37	normal oblique	Oroville 1975/08/02 20:59	1546 Up & Down Cafe (OR1)
38	normal oblique	Oroville 1975/08/02 20:60	ville Airport

Results and Discussion

One of the most important applications of the response spectrum is in the seismic design of structures. Since the basic design response spectrum proposed by the codes is general, it does not include the characteristics and frequency content of the various types of earthquakes. This spectrum is an average response of different type of earthquakes. However, it is not clear what types of earthquakes are related to what kind of fault and what the characteristics of the site are. Also, the occurrence of near field or far field earthquakes with different frequency content require separated considerations. In this study, 79 earthquake records have been used to investigate the effect of three parameters (i.e. distance, type of fault and soil type) on the response spectra of acceleration, velocity and displacement.

distance

Figure 2(a) shows that the acceleration response spectrum from near field earthquakes in all frequency domains is less than the spectra introduced by the codes. This is more evident for structures with period less than 0.7s which is affected by near field earthquakes. Also, the responses of near field and far field earthquakes for conventional buildings whit periods between 0.2s and 1s are totally different. However, the effects of epicentral distance of the earthquakes for long-period structures can be neglected because the responses values are close together. It has been showed by the Figure 2(b) that despite the fact that the response spectral velocity for short and long periodic domains is the same for both near field and far field earthquakes, the responses for the far field earthquakes in intermediate periods are more than that of the near field earthquakes. Thus, for structures with fundamental periods between 0.7s and 2s it would be more logical to use the far field or near field displacement spectrum instead of one general spectrum. Nevertheless, the response spectral displacement of near field earthquakes in all frequency domains is far more than the values obtained from far field earthquakes.

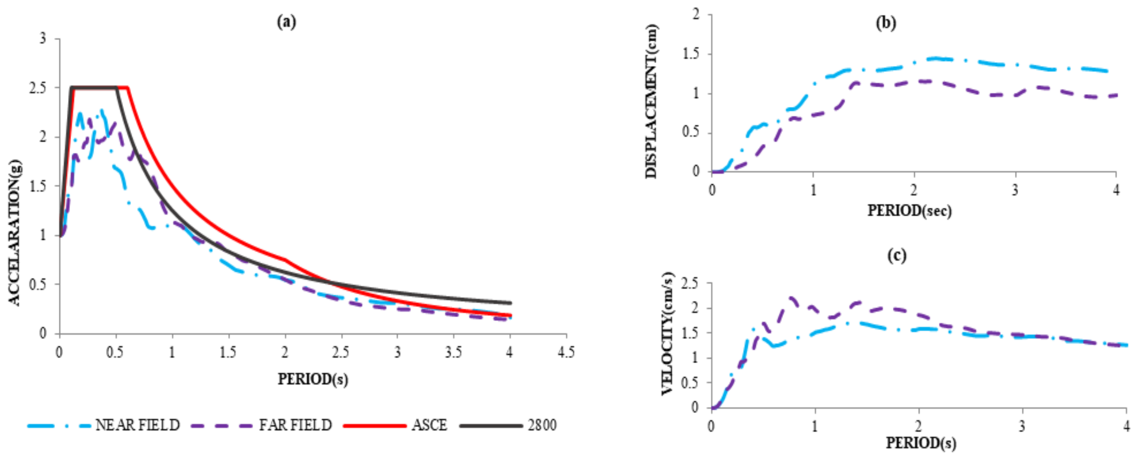

Figure 2- (a) acceleration, (b) velocity, and (c) displacement spectrum for Near field fault and far field records

geometry

In order to evaluate the effects of soil type on the response spectrum, the average response spectra in different sites, which the distance from the earthquake epicenter are less than 10 km and the type faults are strike slip, was calculated. Figure 3(a) shows that the amplitude and shape of the response spectrum is totally different in various site conditions. For instance, for periods less than 1 second, the acceleration response spectrum values for soil Type B are low, but for periods over 1 second, these values increase suddenly. In addition, earthquakes in the soil Type E causes greater acceleration, especially for lower periods. For structures with the fundamental period between 0.3 and 0.8s, the response spectra of seismic codes (ASCE and Standard No.2800) are unrealistic in both shape and amplitude. However, in areas where the soil is of rock type, the spectral acceleration values for inclusion in the seismic codes are far greater than the spectral acceleration obtained directly from the ground shaking in those types of soil. In order to seismic design of structures located in such lands, using spectra from the seismic codes leads frequently to overdesign and increased cost of the construction.

Considering Figure 3(b) and comparing the normalized velocity spectra in different soils, it can be seen that soft soils E and D experience a greater spectrum velocity, while the spectral velocity in the hard soil Type A is minimal. Therefore, it can be said that for construction of structures with intermediate periods on soft soils, more considerations would be required. Additionally, the shape of displacement spectrum of soil Type E is totally different compared to other soil types. As it can be seen from Figure 3(c) the spectral displacement of soil Type A in low periods is greater than that of other soils. For the soil Type D, the spectral displacement in periods less than 2 seconds is less than that of soil Type A, B and C while for periods more than 2 seconds it is more than others, except soil Type E.

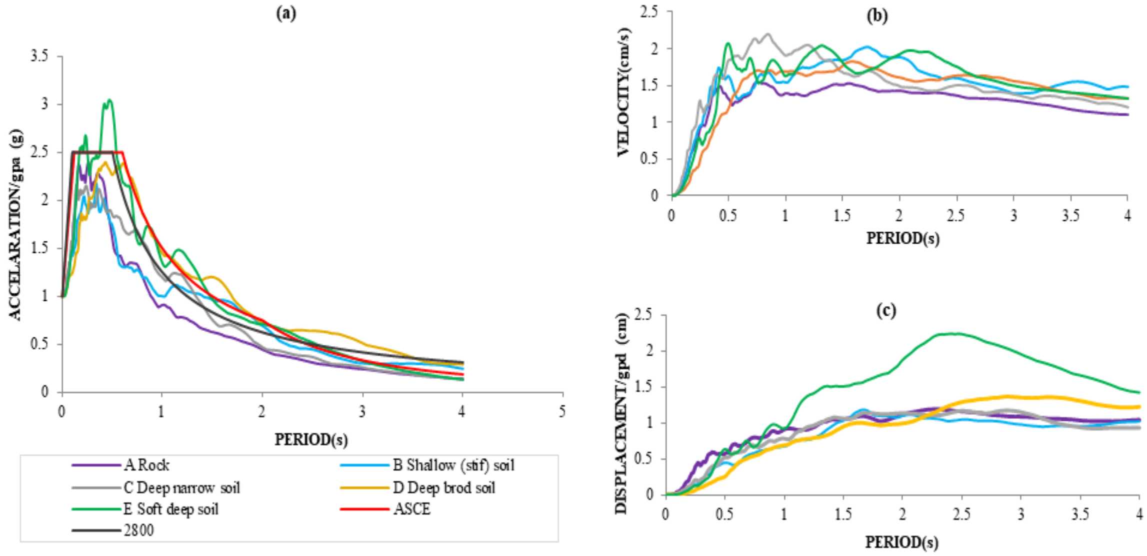

Figure 3- (a) acceleration, (b) velocity, and (c) displacement spectrum for records in five different soil types, the fault is strike slip, the epicentral distance is less than 10 km

mechanism

In order to investigate the effect of the fault type on the response spectral values, the average acceleration, velocity and displacement of the soil Type D and distance less than 10 km from the earthquake epicenter are shown in Figure 4. As can be seen in the Figure, the values of the spectral acceleration for a normal and normal oblique fault in the region of constant acceleration and constant velocity are far less than the proposed values of the regulation. So, at period equal to 1 second, the spectral acceleration under the influence of this type of faults is 0.5, while the regulation recommends 2.5. This issue is also less visible in the reverse normal fault. Moreover, the results show that in the constant accelerated region, the spectral acceleration for normal and normal oblique faults is much lower than for other faults. This is while the spectral velocity in these faults is higher than in all frequency regions. Therefore, in areas where there is a risk of earthquakes occurring in these faults, for structures with a short fundamental period, the use of spectrum from the codes is not optimal. In addition to all, from the study of the displacement spectra it was observed that the value of spectral displacement in these two faults is far less than in other faults.

The acceleration spectrum for earthquakes occurring in strike slip faults is closer to the suggested spectrum of codes. Spectral acceleration in long periods region, especially for strike slip faults, is higher than the value of regulations, and for the analysis and design of long-term structures, the use of the spectrum of the codes is not recommended.

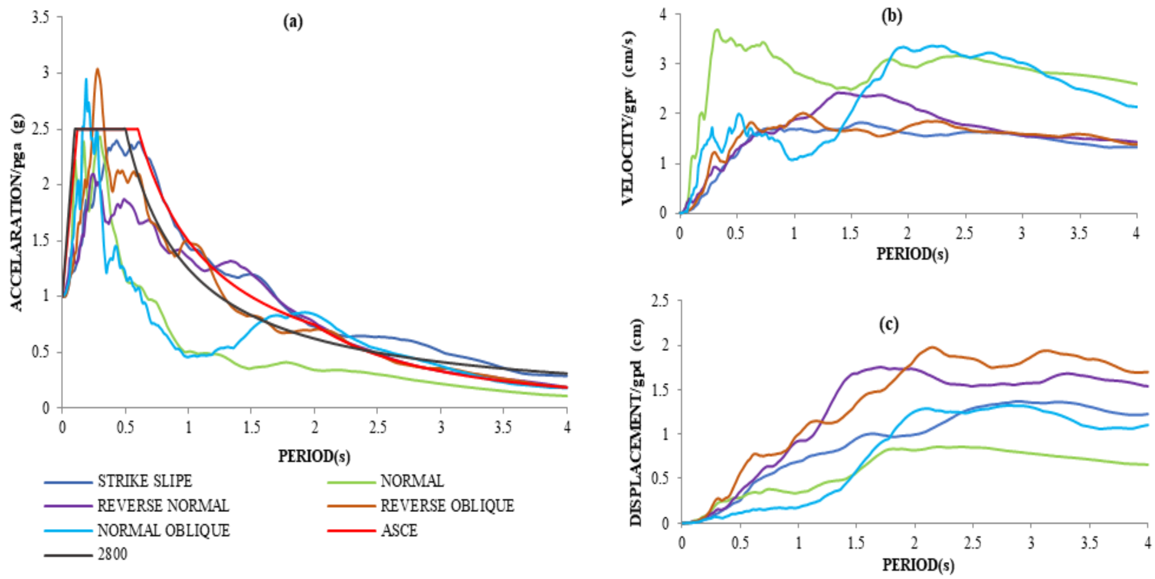

Figure 3- (a) acceleration, (b) velocity, and (c) displacement spectrum for records in five different fault types, soil type D, epicentral distance is less than 10 km

Conclusion

Based on this study the following general conclusions can be deduced

1- The response spectrum on both normal and normal oblique faults are far more than others in low periods;
2- Spectral displacement of soil Type E is critical for intermediate and high periods and it must be considered for underground structures which are more sensitive to displacements;
3- Both reverse normal and reverse oblique produce the relatively same shape of spectrum in most frequency domain;
4- The acceleration spectrum of strike slip fault is more correlated to the suggested spectrum of codes (ASCE and Standard No.2800); and
5- While the spectral velocity of far field earthquakes in all frequency domain is less than that of near field earthquakes, the spectral displacement of far field ground motions is more than that of near field in intermediate frequencies.

References

1. Ahmadizadeh, M., and H. SHAKIBA. (2007). Evaluating the effects of ground motion parameters on response spectra of Iranian earthquakes. 25-48.
2. Akkar S, Bommer JJ. (2007). Prediction of elastic displacement response spectra in Europe and the Middle East. Earthquake Engineering & Structural Dynamics. 36(10):1275-301.
3. Allaby, Michael, ed. A dictionary of geology and earth sciences. (2013). Oxford University Press.
4. BHRC (Building and Housing Research Center). (1986). Iranian Code of Practice for Seismic Resistant Design of Buildings. Standard No. 2800, 1st edn. BHRC: Tehran.
5. Borzi, B., and A. S. Elnashai.(2000). Assessment of inelastic response of buildings using force- and displacement-based approaches. The structural design of tall buildings 9, no. 4: 251-277.

6. Champion, Casey, and Abbie Liel. (2012). The effect of near-fault directivity on building seismic collapse risk. Earthquake Engineering & Structural Dynamics 41, no. 10: 1391-1409.
7. Dwairi HM, Kowalsky MJ, Nau JM. (2007). Equivalent damping in support of direct displacement-based design. Journal of Earthquake Engineering. 30;11(4):512-530.
8. Kalkan, Erol, and Polat Gulkan. (2004). Empirical attenuation equations for vertical ground motion in Turkey." Earthquake Spectra 20, no.3: 853-882.
9. Korzec, Aleksandra. (2016). The Effect of the Vertical Acceleration on Stability Assessment of Seismically Loaded Earth Dams. Archives of Hydro-Engineering and Environmental Mechanics 63, no. 2-3:101-120.
10. Maniatakis CA, Spyrakos CC. (2012). A new methodology to determine elastic displacement spectra in the near-fault region. Soil Dynamics and Earthquake Engineering. 1:35:41-58.
11. Peer ground motion data base, pacific earthquake engineering research center, https://ngawest2.berkeley.edu/
12. Pineda-Porras, Omar, and Mario Ordaz-Schroeder. (2003). Seismic vulnerability function for high-diameter buried pipelines: Mexico City's primary water system case. In Pipeline Engineering and Construction International Conference 2003 American Society of Civil Engineers, no. Volume 2.
13. Tehranizadeh, Mohsen, and Farzaneh Hamedi. (2002). Influence of earthquake source parameters and damping on elastic response spectra for Iranian earthquakes." Engineering Structures 24, no. 7: 933-943.
14. USGS. URL: http://geomaps.wr.usgs.gov/parks/deform/gfaults.html
15. Xu Longjun, Rodriguez-Marek A and Xie Lili. (2006). Design Spectra Including Effect of Rupture-Directivity in Near-fault Region. Earthquake Engineering and Engineering Vibration, 5(2): 159–170.
16. Xu, Longjun, Shengchao Yang, and Lili Xie. (2010). Response spectra for nuclear structures on rock sites considering the near-fault directivity effect. Earthquake Engineering and Engineering Vibration 9, no. 3: 357-365.