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Estimation of Forward Directivity Effect on Design Spectra in Near Field of Fault

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ABSTRACT

In past years, researchers observed different effects of near and far field of fault. They showed forward directivity effect causes a short duration and high magnitude pulse like motions normal to the fault surface in regions located near active faults. Past studies indicated that forward directivity increases middle and long period part of response spectrum. After destructive earthquakes such as Landers, California (1992), Northridge (1994), Kobe, Japan (1995), Chichi, Taiwan (1999) seismic design instructions had started to consider forward directivity effects on their provisions. Today, estimation of earthquake forces based on design spectra is very common for seismic design of new structures. Hence, we studied on forward directivity effect on design spectra provided by seismic design codes in different distances close to active faults by analyzing of 162 earthquake records from important events.Assuming same hazard level for near and far field of fault,results showed, the design spectrum should have both effects of forward directivity and neutral directivity but without same hazard level for near and far fault events, because of economic intends, two types of design spectra should be considered to design new structures in near fault regions. Also studying earthquake records concluded some comments to develop site specific design spectra and at the end, some standard design spectra samples have been proposed to seismic design of structures within regions affected by forward directivity effect where there are not any standard design spectra or any earthquake data to develop site specific design spectra conservatively.
KEYWORDS: Near Fault Regions, Rupture Directivity, Seismic Design, Site Design Spectrum, Building Codes.

1. INTRODUCTION

Pervious studiesabout earthquakes with high magnitude have shown that near field of fault earthquakes have particular characteristics which make them different from far fault earthquakes. During the investigation of this field, it turned out that near field records have shorter effective time than far field earthquakes and due to forward directivity effects there are one or several pulses with high magnitude and high periods in ground velocity records. These pulses are observed in horizontal components perpendicular to the fault [1]. After the earthquakes of Parkfield, California (1966) and Pacoima, San Fernando (1971), the word of near fault was offered by Bolt (1975) [2]. Although the effects of near fault were distinguished but its importance in the design of civil engineering structures was not perceived destructive earthquakes such as Landers, California (1992), Northridge (1994), Kobe, Japan (1995), Chichi, Taiwan (1999) happened [3, 4]. In recent years lots of researches are done on structures behavior near the active faults. Each of them examined near fault effects in different subjects. Studying structures behavior in near fields of faults was done by Anderson and Bertero (1987) by analyzing structures behavior under pulse like ground motions after Imperial Valley earthquake (1979). After them many researchers such as John F. hall (1995-1997), Alavi and Krawinkler (2000), Doulas A. Foutch, Scung-Yul Yun (2001), Collier and Elnashai (2001), Liao and el (2001), El Sheikh and el (2003), Bozorgnia (2004), Saiidi and Somerville (2005), Tehranizadeh and Rahim Labafzadeh (2005-2008) and other researchers have studied about it [1, 3, 5]. Bolt found that amplitude of response spectrumfor period range longer than 0.6s is higherin regions located near an earthquake fault with forward directivity effects. He pointed that this fact depends on the magnitude of earthquake; the distance and the direction of the fault rupture [6]. Alavi and Krawinkler (2001) indicated that horizontal components perpendicular to the fault line is more effective in comparison to the parallel component of the fault line. Because of it, the direction of the structures in this area is important. Studying the projection of both horizontal components on a line that it makes 45 degree angle with the fault line has shown one of the components is more effective than the other and the consequent of the two components has a pulse-like feature [1]. Chang and Yu (2002) by studying response spectra of Taiwan earthquakes showed response spectrum values of Chichi earthquake are larger than mean of 32 events in long period range and they suggested to modify Taiwan seismic design code for near source areas [7]. In the studies which were carried out to investigate of the near fault effect on Korea nuclear plant`s design spectrum (2004), it was pointed out that the design spectrum of seismological plan regulations within the middle to high frequency range is in correspondence with near fault spectrum. But in low frequency range, the near fault spectrum has more values [8]. Saiidi and Somerville (2005) studied the near fault effects on columns designed by Caltrans regulation version 1.3 to develop rules for designing bridge. It turned out that the corrected spectrum near the fault with low frequency (T>1s) is more than the regulations spectrum near and far from fault. It was also pointed that at period shorter than 1s the Somerville corrected spectrum is less than regulation’s spectrum in far and near fault distances [5]. Sue, Anderson and Zeng (2006) compared the design spectrum of the electrical and

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electronic equipment of the U.S. (IEEE693[1]) with %84 mean plus standard deviation spectrum resulting from records of Chichi earthquake in different soil types. They showed because of earthquake recorded too close to the fault rapture, strong directivity effect, hanging wall effects and amplification of earthquake. In places near the source of earthquake, (D<50km) and in soft grounds conditions when a high magnitude earthquake happens, the spectra within low frequency range would have large values [6]. Regarding to the larger effects of near fault earthquakes in comparison to far fault earthquakes, and the growing use of equivalent static analysis methods and spectral dynamic analysis in estimating earthquakes forces by engineers based on standard design spectra, in this study, the forward directivity effect on standard design spectra have been considered in different distances of active fault. To estimate of forward directivity effects in different distance of fault, first 162 earthquake records selected from important earthquake in the world. Selected records divided to 5 groups in different distances from fault as 3 groups contained severe effect of forward directivity then mean plus standard divination of each group obtained and compared with some standard design spectra from valid seismic design instructions.

MATERIALS AND METHODS

2.Specifications of Near Fault Ground Motions

Near fault ground motions within the forward directivity region usually have short duration with a high magnitude pulse that it`s period is medium to high which are observed in horizontal components perpendicular to fault line resulting from rapture directivity. Kitada et al. in 2004 used only 16 records out of 62 records that they recorded in stony and hard grounds for analyzing nuclear power plant structures.The above records had long duration, large directivity effects, and pulse-like movement with low frequency in velocity record. Also, according to figure 1, the used records in analysis were between (1/12) < (PGA/PGV) < (1/7). In figure 1 the magnitude and local distance of earthquake are neglected [3].

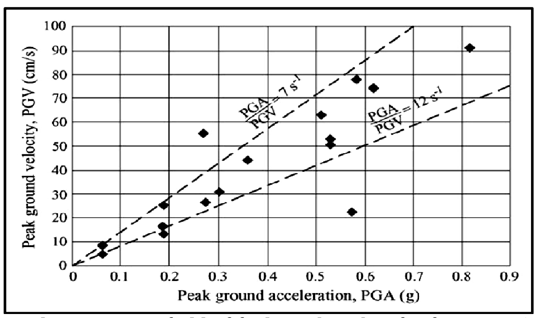


Figure 1.PGA and PGV relation in near field of fault earthquakes for firm sites (Kitada and el 2004) [3]

Alavi and Krawinkler used 22 near fault records and 18 simulated records with following specifications.A) The accelerograms were recorded in soil grounds (the soil type is equivalent to group D in NEHRP classification). B) The accelerograms were chosen from the earthquakes with seismic moment magnitude from 6.2 to 7.4. C) The distance from the source of earthquake (the starting point) to the recording site was from 0 to 10 km. D) to investigating on the directivity effect a number of simulated earthquakes with the seismic moment magnitude of 6,7,7.5 and 3,5,10 km distances were used.E) The simulated earthquakes had directivity effect and their rapture mechanism was assumed to be Strike-slip [1]. Galal and Ghobarah (2005) used design spectrum resulting from 54 records of near fault earthquake. The used records were recorded in 20 km away from fault distance, and in more cases, the horizontal component perpendicular to fault was taken into account. Also earthquake data were recorded within the forward directivity effect region and the used records were selected from strong earthquakes [4].Edalat and Alaghbandian (2003), in their studies, used some earthquakes that they recorded at sites less than 15km away from fault. Also earthquakes `s mechanism was Strike-slipor Dip-slip and shear wave velocity in ground’s conditions was more than 180m/s. They chose the 2 horizontal components of accelerograms with PGA>200cm/s^2 and PGV>20cm/s^2 and their selected records were from strong earthquakes with a high amplitude pulse[10].Regarding FEMA356 provisions selecting of earthquake records that they are used for structural analysis and to making response spectra must be based on geotechnical specifications of site. Therefore all records had frequency contents; response spectrum, effective duration and soil type same as assuming construction site [11]. These criteria are same as ISREB provisions. As according to part (1-6-3-3) of the Instruction for Seismic Rehabilitation of Existing Buildings (ISREB),Time histories must have frequency content, response spectrum, effective time, magnitude, fault distances, and source mechanisms equivalent to strong motions that they have high chance to occur in the construction site.Also it is important to attention to site specifics and site location. Earthquake records that they are recorded near active faults must have near fault effects in their characteristics within 15km of fault [12]. Therefore, according to part (2-4-1-4) Iranian Seismic design code [13, 14], the acceleration time histories representing the ground motioneffects shall reflect the expected earthquake acceleration at the site. Also the records shall be as followings:

a- Time histories shall have magnitudes, fault distances and sourcemechanisms as they can indicates main features of site seismology.b- Time histories shall belong to the siteswith geologic, tectonic,seismology

[1]Institute of Electrical and Electronics Engineers (Standard 693)

andparticularly soil characteristics, similar to construction site.c- The time duration of the strong ground motion accelerograms shall be atleast 10 seconds or three times the fundamentalperiod of vibration of the structure, whichever is greater. This duration may be evaluated by recognized methods such as the cumulative energy distribution method [13, 14].Table 1 shows all earthquake records that are used in this study.

Table 1. Earthquake records that are used in this study

Near Fault Records (PGA≥0.1g, 0<R<15km)

No.	Event	Date (M/D/Y)	Station	PGA (g)	No.	Event	Date (M/D/Y)	Station	PGA (g)	No.	Event	Date (M/D/Y)	Station	PGA (g)
1	Chi-Chi, Taiwan	9/20/99	CHY101	0.35	16	Kocaeli, Turkey	8/17/99	Duzce	0.31	31	Landers	6/28/92	Lucerne	0.71
2	Chi-Chi, Taiwan	9/20/99	CHY101	0.44	17	Kocaeli, Turkey	8/17/99	Duzce	0.36	32	Loma Prieta	10/18/89	Gilroy - Gavilan Coll	0.36
3	Chi-Chi, Taiwan	9/20/99	TCU068	0.57	18	Northridge	1/17/94	Sylmar - Converter	0.49	33	Morgan Hill	4/24/84	Coyote Lake Dam	0.71
4	Chi-Chi, Taiwan	9/20/99	TCU068	0.46	19	Kobe, Japan	1/16/95	Takarazuka	0.69	34	Kocaeli, Turkey	8/17/99	Arcelik	0.15
5	Imperial Valley	10/15/79	El Centro Array #6	0.44	20	Kobe, Japan	1/16/95	Takarazuka	0.69	35	Cape Mendocino	4/25/92	Cape Mendocino	1.49
6	Denali, Alaska	11/3/02	Pump Station #10	0.32	21	Bam,Iran	12/26/03	Bam	0.81	36	Cape Mendocino	4/25/92	Cape Mendocino	1.04
7	Kobe, Japan	1/16/95	Takatori	0.61	22	Bam,Iran	12/26/03	Bam	0.59	37	Cape Mendocino	4/25/92	Petrolia	0.66
8	Kobe, Japan	1/16/95	Takatori	0.62	23	Karebas,Iran	5/6/99	DEHBALA	0.34	38	Chi-Chi, Taiwan	9/20/99	TCU045	0.51
9	Loma Prieta	10/18/89	LGPC	0.97	24	Manjil,Iran	6/20/90	Ab-bar	0.50	39	Chi-Chi, Taiwan	9/20/99	TCU095	0.38
10	Northridge	1/17/94	Rinaldi	0.49	25	Silakhor ,Iran	3/31/06	Chalan Choolan	0.45	40	Loma Prieta	10/18/89	LosGatos-Lexington Dam	0.43
11	Northridge	1/17/94	Sylmar - Converter	0.60	26	Silakhor ,Iran	3/31/06	Chalan Choolan	0.41	41	San Fernando	2/9/71	Pacoima Dam	1.23
12	Northridge	1/17/94	Sylmar - Converter	0.84	27	Tabas, Iran	9/16/78	Tabas	0.84	42	Kocaeli, Turkey	8/17/99	Gebze	0.24
13	Imperial Valley	10/15/79	Centro Array #7	0.46	28	Tabas, Iran	9/16/78	Tabas	0.85	43	Kocaeli, Turkey	8/17/99	Gebz ,Turkey	0.14
14	Kocaeli, Turkey	8/17/99	Yarimca	0.27	29	Zanjiran,Iran	6/20/94	meymand	0.30					
15	Erzican, Turkey	3/13/92	95 Erzincan	0.52	30	Gazli, USSR	5/17/76	Karakyr	0.61					

Near Fault Records (PGA≥0.1g, R=10-15Km)

No.	Event	Date (M/D/Y)	Station	PGA (g)	No.	Event	Date (M/D/Y)	Station	PGA (g)	No.	Event	Date (M/D/Y)	Station	PGA (g)
1	Chi-Chi, Taiwan	9/20/99	TCU056	0.13	7	Imperial Valley	10/15/79	Parachute Test Site	0.17	13	Northridge	1/17/94	LA - N Faring Rd	0.24
2	Chi-Chi, Taiwan	9/20/99	TCU123	0.16	8	Loma Prieta	10/18/89	San Andreas-Santa Cr	0.28	14	Northridge	1/17/94	Canyon Country-WLostCany	0.41
3	Corinth, Greece	2/24/81	Corinth	0.24	9	Loma Prieta	10/18/89	Gilroy Array #2	0.32	15	Superstition Hills	11/24/87	Westmorland Fire St.	0.21
4	Imperial Valley	15/10/79	alexico Fire Statio	0.20	10	Loma Prieta	10/18/89	Gilroy Array #3	0.37	16	Superstition Hills	11/24/87	Poe Road (temp)	0.27
5	Imperial Valley	15/10/79	El Centro Array #1	0.36	11	Loma Prieta	10/18/89	Gilroy Array #4	0.21	17	Duzce, Turkey	11/12/99	Bolu	0.73
6	31614	G 54171 Bi	0.174995	0.36	12	Kocaeli, Turkey	8/17/99	Duzce	0.36					

Near Fault Records (PGA≥0.1g, R=15-30Km)

No.	Event	Date (M/D/Y)	Station	PGA (g)	No.	Event	Date (M/D/Y)	Station	PGA (g)	No.	Event	Date (M/D/Y)	Station	PGA (g)
1	Chi-Chi, Taiwan	9/20/99	CHY025	0.16	10	Landers, USA	6/28/92	SCE 23 Coolwater	0.42	19	San Fernando, US	2/9/71	CDMG 24303 LA-Holly.	0.17
2	Chi-Chi, Taiwan	9/20/99	CHY025	0.15	11	Landers, USA	6/28/92	CDMG2149 Desert H.Sp.	0.15	20	St Elias, Alaska	2/28/79	USGS 2734 Icy Bay	0.18
3	Chi-Chi, Taiwan	9/20/99	CHY036	0.21	12	Landers, USA	6/28/92	USGS5071 Morongo Va.	0.14	21	Superstition Hills	11/24/87	USGS 5210 Wildlife Liquef	0.13
4	halfant Valley, US.	7/21/86	CDMG54100Benton	0.21	13	Loma Prieta, USA	10/18/89	DMG57425 Gilroy Ar.#7	0.26	22	Superstition Hills	11/24/87	CDMG 1335 El Centro	0.36
5	Coalinga, USA	5/2/83	CDMG 6314	0.28	14	Morgan Hill, USA	4/24/84	USGS 1656 Hollister Diff	0.09	23	Superstition Hills	11/24/87	CDMG 1335 El Centro	0.26
6	Coalinga, USA	5/2/83	CDMG36138 Parkf.	0.11	15	N. Palm Springs	7/8/86	CDMG12204 San Jacinto	0.24	24	Tabas, Iran	9/16/78	Boshrooyeh	0.09
7	Coalinga, USA	5/2/83	CDMG 36456 Parkf.	0.28	16	Northridge, USA	1/17/94	USC90054 LA-Centi. St	0.32	25	Cape Mendocino	4/25/92	Petrolia	0.66
8	Kobe, Japan	1/16/95	Shin-Osaka	0.21	17	Northridge, USA	1/17/94	USC90091 LA-Saturn St	0.44	26	Victoria, Mexico	6/9/80	UNAMUCSD6621 Chihuah.	0.15
9	Imperial Valley	10/15/79	USGS 931	0.97	18	San Fernando, US	2/9/71	CDMG 24303 LA-Holly.	0.21	27	Victoria, Mexico	6/9/80	UNAMUCSD6621 Chihuah.	0.09

Far Fault Records (PGA≥0.1g, 45<R<145km)

No.	Event	Date (M/D/Y)	Station	PGA (g)	No.	Event	Date (M/D/Y)	Station	PGA (g)	No.	Event	Date (M/D/Y)	Station	PGA (g)
1	Chi-Chi, Taiwan	9/20/99	CHY065	0.12	17	Northridge	1/17/94	Loma Linda; VA Hos.	0.16	33	Bam,Iran	12/26/03	Abaragh	0.17
2	Chi-Chi, Taiwan	9/20/99	CHY065	0.60	18	Kocaeli, Turkey	8/17/99	Ambarli	0.25	34	Bam,Iran	12/26/03	Abaragh	0.11
3	Chi-Chi, Taiwan	9/20/99	TAP095	0.15	19	Kocaeli, Turkey	8/17/99	Ambarli	0.18	35	Garmkhane,Iran	2/4/97	Rezvan	0.11
4	Chi-Chi, Taiwan	9/20/99	TAP095	0.10	20	Kocaeli, Turkey	8/17/99	Bursa Tofas	0.10	36	Garmkhane,Iran	2/4/97	Rezvan	0.10
5	Kobe, Japan	1/16/95	HIK	0.14	21	Kocaeli, Turkey	8/17/99	Bursa Tofas	0.11	37	Karebas,Iran	5/6/99	Khan zeynioun	0.15
6	Kobe, Japan	1/16/95	HIK	0.15	22	Kocaeli, Turkey	8/17/99	Cekmece	0.18	38	Karebas,Iran	5/6/99	Khan zeynioun	0.13
7	Loma Prieta	10/18/89	SF Intern. Airport	0.24	23	Kocaeli, Turkey	8/17/99	Cekmece	0.13	39	Chi-Chi, Taiwan	9/20/99	TAP032	0.11
8	Loma Prieta	10/18/89	SF Intern. Airport	0.33	24	Avaj,Iran	6/22/02	Kaboodar Ahang	0.17	40	Chi-Chi, Taiwan	9/20/99	TAP032	0.12
9	Loma Prieta	10/18/89	Oakland - Title & Trust	0.20	25	Avaj,Iran	6/22/02	Kaboodar Ahang	0.09	41	Chi-Chi, Taiwan	9/20/99	TCU026	0.12
10	Loma Prieta	10/18/89	Oakland - Title & Trust	0.24	26	Manjil, Iran	6/20/90	Qazvin	0.18	42	Chi-Chi, Taiwan	9/20/99	TCU026	0.09
11	Hector Mine	10/16/99	Riverside Co Fai.	0.12	27	Manjil, Iran	6/20/90	Qazvin	0.13	43	Kern County	7/21/52	Santa Barbara Courth.	0.09
12	Loma Prieta	10/18/89	Oakland-Outer Har.	0.27	28	Tabas, Iran	9/16/78	Ferdows	0.09	44	Kern County	7/21/52	Santa Barbara Courth.	0.13
13	Loma Prieta	10/18/89	Oakland-Outer Har.	0.29	29	Tabas, Iran	9/16/78	Ferdows	0.11	45	Northridge	1/17/94	Montebello - Bluff Rd	0.18
14	Loma Prieta	10/18/89	Richmond City Hall	0.12	30	Zarand,Iran	2/22/05	Ravar	0.11	46	Northridge	1/17/94	Montebello - Bluff Rd	0.13
15	Northridge	1/17/94	Featherly Park – Maint	0.10	31	Avaj,Iran	6/22/02	Abgarm	0.15	47	Kocaeli, Turkey	8/17/99	Eregli	0.11
16	Northridge	1/17/94	Featherly Park – Maint	0.10	32	Avaj,Iran	6/22/02	Abgarm	0.12	48	Kocaeli, Turkey	8/17/99	Eregli	0.09

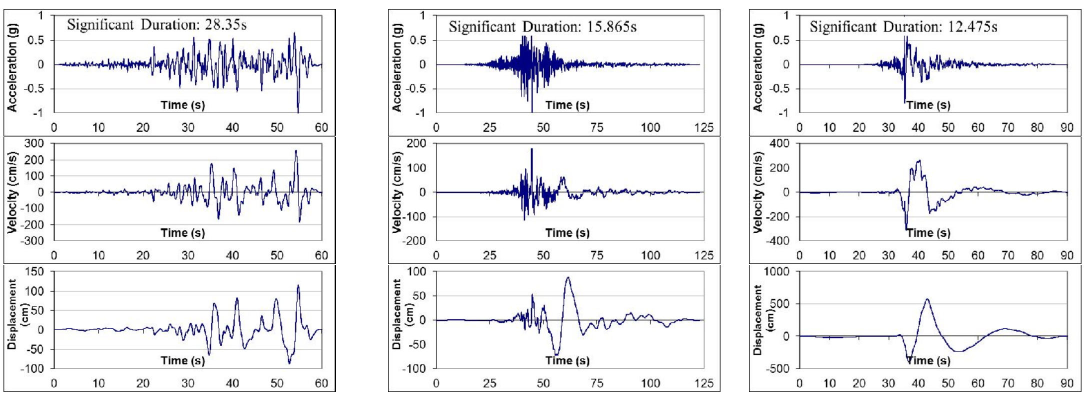
Very Far Fault Records (PGA≤0.05g, R>100km)

No.	Event	Date (M/D/Y)	Station	PGA (g)	No.	Event	Date (M/D/Y)	Station	PGA (g)	No.	Event	Date (M/D/Y)	Station	PGA (g)
1	Chi-Chi, Taiwan	9/20/99	HEN	0.03	10	Hector Mine	10/16/99	Bombay Beach Fire St.	0.05	19	Landers	6/28/92	est Covina-S Orange A	0.05
2	Chi-Chi, Taiwan	9/20/99	HEN	0.02	11	Hector Mine	10/16/99	Bombay Beach Fire St.	0.04	20	Northridge	1/17/94	San Bernardino	0.03
3	Chi-Chi, Taiwan	9/22/99	KAU058	0.02	12	Kobe, Japan	1/16/95	FUK	0.03	21	Northridge	1/17/94	San Bernardino	0.04
4	Chi-Chi, Taiwan	9/22/99	KAU058	0.02	13	Kocaeli, Turkey	8/17/99	Balikesir	0.02	22	Manjil, Iran	6/20/90	Tehran-Building & Housing	0.03
5	Denali, Alaska	11/3/02	Anch.-Dowl Eng Wareh.	0.01	14	Kocaeli, Turkey	8/17/99	Canakkale	0.03	23	Manjil, Iran	6/20/90	Tehran- Building & Housing	0.03
6	Denali, Alaska	11/3/02	Anch.-Dowl Eng Wareh.	0.01	15	Kocaeli, Turkey	8/17/99	Canakkale	0.02	24	Manjil, Iran	6/20/90	Tehran-Sarif Universit	0.01
7	Duzce, Turkey	11/12/99	Ambarli	0.04	16	Landers	6/28/92	Villa Park-Serrano Ave	0.03	25	Manjil, Iran	6/20/90	Tehran-Sarif Universit	0.01
8	Duzce, Turkey	11/12/99	Ambarli	0.03	17	Landers	6/28/92	Villa Park-Serrano Ave	0.04	26	Tabas, Iran	9/16/78	Kashmar	0.03
9	Duzce, Turkey	11/12/99	Aslan R	0.01	18	Landers	6/28/92	West Covina-S Orange Ave	0.05	27	Tabas, Iran	9/16/78	Kashmar	0.04

According to standard No.2800 and ISREB, it is observed that there aren't any criteria for choosing near fault records and only the maximum 15km away from fault is pointed out in the ISREB. Also the rules of UBC97 regulation for choosing record in part (1631) are similar to standard No.2800 [13, 14, 15]. According to above rules and studies carried out by other researchers, in this study 5 groups of records are chosen based on their distances from fault related to important earthquakes in the world. The first group is earthquake records within distancesbetween 0-15km from fault and mean distance of 4.75km. The second group is near fault accelerograms recorded within 10-15km away from fault with mean distance 13.3km.Third group is earthquake records located in distances 15-30km from active fault with mean distance of 21.27km. Fourth group is far fault records which their recording has been within 45 to 145 km away from fault and has a PGA>0.1g. The fifth group isstrong motion records with distance more than 100km from fault (Very far from fault (VFF), R>100km), and have PGA<0.005g. Also earthquake records in groups one, two and three contain severe effect of directivity. And far fault records are within neutral directivity regions. All accelerograms are from earthquakes with seismic moment more than 6.5 and based on the site category[1] are divided in to two groups. The first group is Class D or stiff soils based on FEMA356 soil classification (soil type 3 based on standard No.2800) and second group is Class B and C orVery dense Soils or Rocky grounds based on FEMA356 (soil type 1&2 in standard No.2800). Also, in choosing near fault records the followings were considered.

1. The distance from recording site to the generator fault is to be less than 30km.
2. The existence of directivity effect in record (the presence of one or two pulses with long periods in velocity time history of earthquake).
3. Choosing records from earthquakes with M_w>6.5
4. The acceleration peak of more than 0.1g.
5. Choosing more effective component within high period range (more than 1s) in response spectrum.

Because ofsevere effect of forward directivity in horizontal earthquake component perpendicular to fault line [16] and developing ofseismic design codes based on one-dimensional seismic waves propagation method such as UBC 1994, UBC 1997, and IBC 2000 [17]. In this study, only thehorizontal earthquake component perpendicular to fault line considered to make response spectra in near field of faults. Also, to choosing far fault records, it was attempted that earthquake records as much as possible to be chosen from same events of near fault records. In other word, it has tried to use near and far fault records from an event in this study.Most of accelerograms data in table 1 have been selected from Peer strong motion database[2]and BHRC[3] accelerogram data bank. All of acceleration records have been analyzed by Seismosignal program and baseline correction has been done for some records. To removing vibration noise from some records, the Butterworth band-pass filtering method has been used in 0.1 to 25Hz frequency range (0.04~10s in period range). Also for comparison intends, all design spectra obtained by seismic codes scaled to 1g.



HEN (Very Far Fault, PGA<0.05g) TAB095 (Far Fault, PGA>0.1g) TCU068 (Near Fault, PGA>0.1g)

Figure 2. Comparison of Chichi earthquake records (Taiwan 1999) in three different distances away from fault

Based on Figure 2, the comparison of Chichi earthquake records(Taiwan1999) in 3 different distances showed that with increasing ofdistance between record station and earthquake fault,the duration of strong motionrecord become more too. For example the effective time of acceleration record in TCU068 station in a 0.32km away from the fault is 12.4s and the effective time of recordat TAB095 station in 109km away from fault is 15.8s and the effective time of earthquake recordat Hen station in 162.68km away from fault is 28.35s.

3. Near and Far Faults response spectra

To study about near and far fault spectrum, maximum response of acceleration calculated for a single degree freedom oscillator with 5% damping and natural period within 0.1-5s range by solving of Equation 1. Then same as figure 3, maximum responseacceleration in each period vs. period of oscillators aredrawn. Also, the relation between acceleration, velocity and displacement are shown by Eq.2 [19].

Eq.1 $$\ddot{u}+2\zeta\omega_n\dot{u}+\omega_n^2u=-\ddot{u}_g(t)$$

Where $\ddot{u}_g(t)$ is the earth acceleration time history function and $u, \dot{u}$ and $\ddot{u}$ are displacement, velocity and acceleration of oscillator respectively, ω_n is natural circular frequency of oscillator and ζ is damping ratio.

Eq.2 $$\frac{T_n}{2\pi}A=V=\frac{2\pi}{T_n}D$$

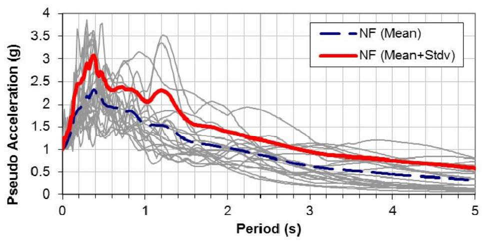
[1]Site types are classified based on shear wave velocity in 30m under surface of ground also some of seismic design codes are classified soil types based of dominate periods of ground [11, 13, 14, 15]. To determination of soil type based of dominate period of ground the equation f_0=V/4h shows relation between natural frequency (f_0) of soil and shear wave velocity (V), h is the soil thickness [18].

[2]Peer strong motion database related to Berkeley university of California is an updated source of earthquakes data. (http://peer.berkeley.edu/smcat/)

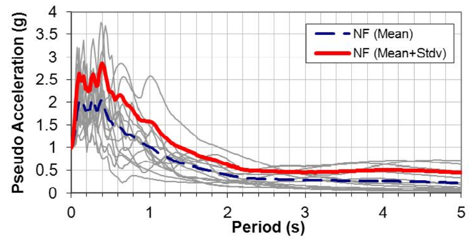
[3]Iran Strong Motion Network (ISMN) related to BHRC (http://www.bhrc.ac.ir/portal/Default.aspx?tabid=635)

In Eq.2, the parameters A, V and D are pseudo acceleration, Velocity and displacement Spectrum respectively. T_n is natural period of oscillator. According to part (1-6) of FEMA356 and Part (1-6-1) of ISREB,two methods are presented to estimate of strong motions parameters on the surface of earth for different hazard levels. First one is "standard design spectrum" and second is "site specific design spectrum".

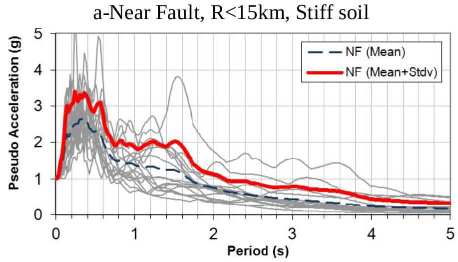
To investigate on near and far field of fault spectra, first peck ground acceleration of all records were scaled to 1g, second the response spectrum of each record in table 1 were calculated by the Seismosignal program with 5% damping based on Eq.1, then mean spectrum and mean plus one standard deviation spectrum for far and near faults spectra were obtained from response spectra of earthquake records in table 1.Strong motion processing results out came from records listed in table 1 have been shown in figures 3-a to 3-h.



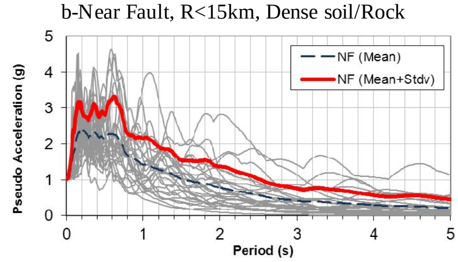
a-Near Fault, R<15km, Stiff soil



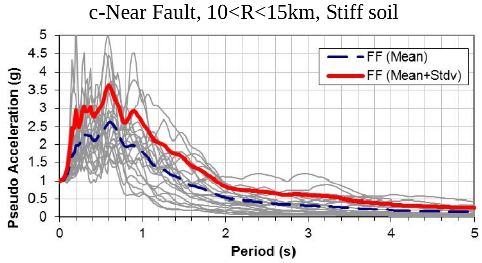
b-Near Fault, R<15km, Dense soil/Rock



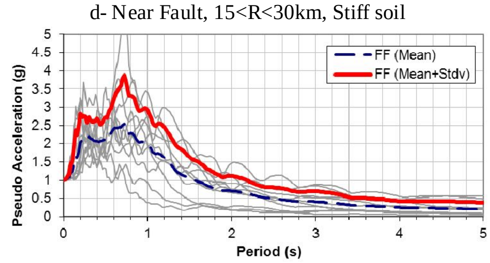
c-Near Fault, 10<R<15km, Stiff soil



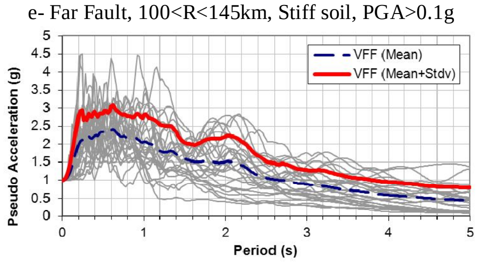
d- Near Fault, 15<R<30km, Stiff soil



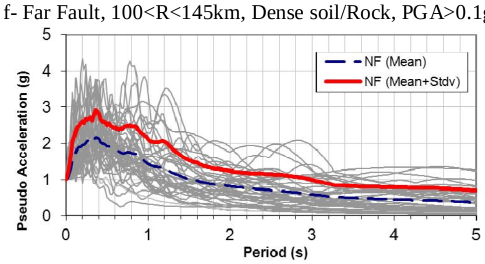
e- Far Fault, 100<R<145km, Stiff soil, PGA>0.1g



f- Far Fault, 100<R<145km, Dense soil/Rock, PGA>0.1g



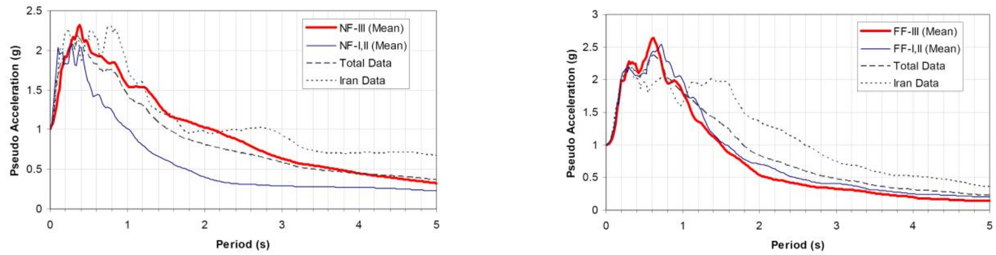
g-Very Far Fault, R<100km, Stiff soil, PGA<0.05g



h- Near Fault, 0<R<15km, all typeof soil

Figure 3. Mean and Mean pulse Standard Deviation response spectra resulted from records listed in table 1

In order to comparison, in figure 4-a mean response spectral of near fault is shown in stiffsoils and rockysites. It is observed that near fault pseudo-acceleration spectrum in stiff soils(type 3 in standard No.2800) from period 0.2s have more values in comparison to pseudo-acceleration spectrum in rockysites (type 1&2 in 2800 standard). As in period 2s, the stiff soil spectrum values are 2 times more than rocky site spectrum values. It can be due to the non-linear motions of soils in near fault regions. The comparison of pseudo-acceleration mean response spectral in far field of fault for both of stiff soils and rocky sites indicated that the values of both spectra are very close, and the maximum difference in pseudo-acceleration mean response spectrum in period 2s is about %40 (figure 4-b).



a) Near field of fault b) Far field of fault

Figure 4. Mean response spectrum comparison between stiff soils and rocky sites

On the figure 5, the values of near and far fault response spectra in stiff soils are compared. It was indicated that the mean and mean plus standard deviation values of the near fault response spectrum are more than mean and mean plus standard deviation of far fault spectrum in stiff soils, after period 1.1s. As the Values of near fault pseudo-acceleration response spectrum after period 2 seconds is around 2 times more than Far fault spectrum. All spectra obtained by earthquake data recordedin soil type 3 in standard No.2800 classification and all of records have PGA>0.1g.Also results indicate the near fault spectrum has more effects in soft and stiff soils than dense soils and rocky sites conditions.

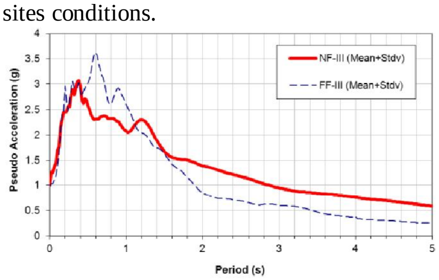


Figure 5. Mean response spectrum comparison in near and far field of fault for Stiff soil (soil Class D in UBC97)

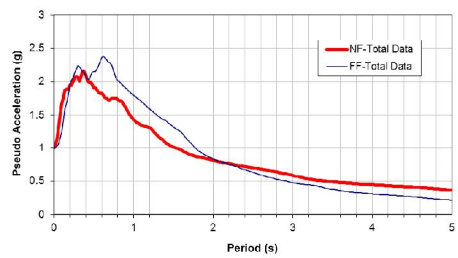


Figure 6. Comparison between mean response spectrum in near and far field of fault without soil type considering

Studding of response spectra prepared from earthquake records without soil classificationin figure 6 shows procuring of design spectrum without considering of soil category makes significant wrongs. So based on figure 5 the near fault spectrum has values more than far fault from period 1.1s but in the figure 6 the near fault spectrum is more than far fault spectrum from period 2.5s. Also the near fault spectrum value at period 2s is 2 times more than far fault spectrum in figure 5 while in the figure 6 the value of near fault spectrum in period 2s is equal to the far fault spectrum. Therefore specific site response spectrum obtaining without soil classification considering is not valid in near and far field of faults.

RESULTS AND DISCUSSIONS

4.Studying Design Spectra provided by Iranian Seismic Code and UBC97

In this section some Standard design spectra provided by valid seismic design instructions introduced and compared together. Before UBC97, in UBC94 there were not any special criteria to evaluation of near fault effects on structures for evaluation and designing intends. After UBC94, the 1997 version of uniform building code (UBC97) offered some parameters to design of structures in near field of fault. Since 1997 to some years after it, before commonly use of International Building Code (IBC)[1] in the US, some structures had been designed based on UBC97. Because UBC97 is first seismic design code that it considers forward directivity effect in design spectra clearly and UBC97 presents design spectra in different distances away from fault specifically. Hence, Design spectra of UBC97 have been selected to study for forward directivity effects. Reviewing of strong motions evented in Iran have been shown, each 5 years a disaster is being occurred in Iran by earthquakes [16]. For example, some of huge Persian earthquakes[2] that they have happened in 50 years ago are Bou'in-Zahra earthquake in Sep 1962 with 12225 victims, Tabas earthquake in Sep 1978 with 15000 victims, Manjil earthquake in Jun 1990 with 40000 victims and Bam earthquake Dec 2003 with 30000 victims[2].Regarding to that some populous cities of Iran are located near active faults and numerous buildings are designed based on 2^{th} and 3^{th} Iranian seismic code within near active faults [16], In this study the 2^{th} and 3^{th} edition of Iranian seismic design code are selected to study for effect of forward directivity.

The UBC97 regulation has divided the earthquake zones to 5 regions for the United States and for each region has determined the maximum peak acceleration. This regulation has considered the parameters of near fault effects just for region 4(based on region classification of UBC97) with the acceleration peak of 0.4g. The regulation has suggested N_a and N_v parameters for near fault effects. These two parameters cause to increase basic shear forces in zone 4. The

[1]International Building Code (IBC) presented by The International Code Council (ICC), Washington, USA.
[2] List of earthquakes in Iran, Wikipedia, the online encyclopedia (http://en.wikipedia.org/wiki/List_of_earthquakes_in_Iran)

study of UBC97 regulation shows that this regulation makes N_a and N_v parameters dependent on the seismicity of the construction site and surface projection[1]distance to the site [15].

Seismic sources (seismicity of regions)have been divided to 3 categories based on maximum moment magnitude and slip rate of causative fault by UBC97. Table 2 has shown 3 categories of seismic sources. UBC97 presents some design spectrum for each seismic sources based on distance of construction sites from active fault. This code has provided 4 design spectra in 2, 5, 10, 15 km and more in regions with high rate of seismicity (A), 3 design spectra for regions with middle seismicity (B) and 1 design spectra for regions with low rate of seismicity(C).The near fault design spectrum in low rate of seismicity is equal to the design spectrum in middle and high rate of seismicity regions with distance more than 15 km away from active fault. Also UBC97 presets another design spectra for regions with PGA<0.3g and this regulation does not purpose any near fault parameters for regions with PGA<0.3g. [15] So in this study, the design spectrum of regions with PGA=0.3g has been assumed to be far fault design spectrum.

Table 2. Seismic source type [15]

SEISMIC SOURCE DEFINITION		SEISMIC SOURCE DESCRIPTION	SEISMIC SOURCE TYPE
Slip Rate (SR) (mm/year)	Maximum Moment Magnitude, M		
SR ≥ 5	M ≥ 7.0	Faults that are capable of producing large magnitude events andthat have a high rate of seismic activity	**A**
SR < 5	*M ≥ 7.0*	All faults other than Types A and C	**B**
SR > 2	*M < 7.0*		
SR < 2	*M ≥ 6.5*		
SR ≤ 2	*M < 6.5*	Faults that are not capable of producing large magnitude earthquakesand that have a relatively low rate of seismic activity	**C**

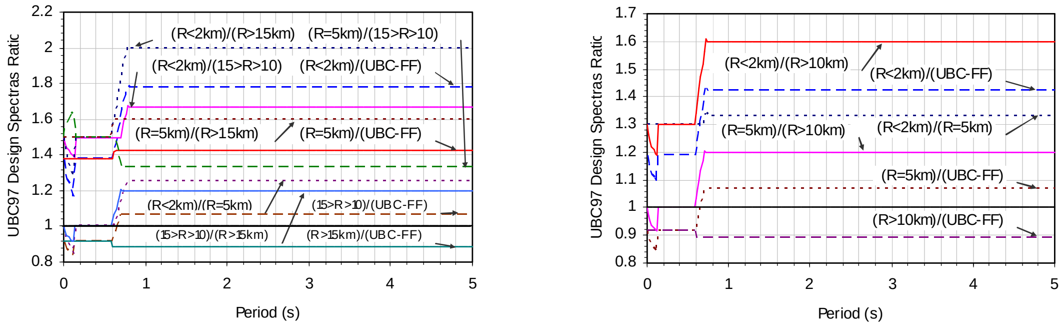
Before UBC97, in UBC94 there were no rules for near fault earthquake effects on buildings. In UBC97, the effects of near fault for sites within the distance less than the 15 km is considered as an additional base shear force. Generally, in UBC97, near fault effect is average effect of the 2 horizontal components. However, this regulation doesn’t directly predict the effect of horizontal component normal to the slip of the fault in high magnitude earthquakes (Somerville, 1998) [20].

After Bou'in-Zahra earthquake in 1 Sep 1962, Studying buildings safety under effect of earthquake was started and the temporary edition of Buildings protection against earthquake instruction was published in 1964 by Planning and Management Organization of Iran. After that, Ministry of Civil and Housing of Iran presented a seismic design code with title of “the Code of Buildings Safety Against Earthquake” in 1967.The first official improved version of Iranian Design Seismic code (Standard No.2800) published in 1988 by Building and Housing Research Center of Iran (BHRC). In 1999,the second edition of Iranian seismic design code presented by BHRC [13, 14]. After Bam earthquake with at least 30000 deaths, BHRC has presented 3^{th} edition of Iranian seismic design code since 2005. Both of 2^{th} and 3^{th} edition of Iranian Seismic code are the same as UBC94 but the 3^{th}edition is more conservative than 2^{th} edition. Also the 3^{th}edition has provided 4 design spectra for regions with low and middle seismicity (PGA≤0.25g) and 4 design spectra for regions with high seismicity rate (PGA≥0.3g) but 2^{th}edition has provide 4 design spectra for all rates of seismicity. The 2^{th} and 3^{th} edition of Iranian Seismic code presents two methods to estimation of earthquake forces, first method is equivalent static procedure, the second method is dynamic analysis contains spectrum analysis method and time history method that all methods are same as UBC94 provisions. Iranian Seismic code introduced 4 seismic regions in Iran.Also, it divided the ground conditions to 4 types based on shear wave velocity of ground in depth of 30m bellow surface of ground. Iranian Seismic Code presented 8 design spectra for all situations of construction sites [13, 14].To make more understanding about Standard design spectra, the design spectra provided by standard No.2800 and UBC97 compared. According to part (1-3-1) of standard No.2800 3^{rd} edition, Building construction is not allowed to be on top or in the vicinity of active faults that may cause surface rupture during an earthquake. However, if buildings are constructed in the vicinity of active faults, special technical consideration shall be observed in addition to the regulations of Standard No.2800. But there is not any special technical comment to make buildings in the standard No.2800 E.3 for construction sites near the active faults. In followings the UBC97 and Iranian seismic code design spectra have been compared and near fault effect on seismic design spectrum of Iranian code has been evaluated based on UBC97.

4.1. Comparison of Design spectra provided by UBC97 in deferent distances of fault

To determination of N_a and N_v Effects on UBC97 design spectra in deferent distances of the fault all of design spectra are compared in figures 7-a and 7-b. For example, figure 7-a shows that the base shear of structures located in a distance less than 2km from fault is about 2 times as such as structures which are located in 15 km or more from fault. Similarly, the base shear of structures located in a 5 km away from fault is %60 more than the structures which are located in a distance more than 15 km from fault.

[1]Surface projection is projection of fault rupture plate with depth less than 10km on surface of ground [15].



a-High activity of seismicity (A) b-Low and Mean activity of seismicity (B, C)

Figure 7. Ratio of UBC97 spectra at different distance of active faultfor stiff soil condition

Based on figure 7, it has been indicated that in regions with high seismic activity, the values of near fault spectrum are 2 times more than far fault spectrum in period range of 0.6~0.7s and more. Also, in regions with low and medium seismic activity the ratio of near fault spectrum to far fault spectrum for period range of 0.6~0.7s and more is 1.6.

4.2. Comparison of Standard No.2800 Design spectra with UBC97 design spectra

At the last section the ratio of UBC97 deign spectra are discussed.In this section, the design spectra of Iranian seismic design code evaluated in deferent distances away from active faults with considering forward directivity effect based on UBC97 design spectra.

4.2.1. Evaluation of Iranian seismic design code 3th edition based on UBC97 design spectra

In the next sections, the 3th edition of Iranian seismic deign code is studied based on UBC97 spectra for each seismicity zones.

4.2.1.1. Evaluation of Standard No.2800v3 within regions with high seismicity rate

According to figure 8, comparison of UBC97 and Standard No2800 V.3 in regions with high hazard levelwithin sites less than 2 km away from active faults shows the values of Standard No.2800 design spectrum in stiff soils (Class D based on UBC97) at the periods shorter than 0.8s between %33 to %37.5 and in 5 km distance away from fault up to period 0.6s is %33 lower than the values of the spectra presented by UBC97 in near fault fields, also the Standard No.2800 spectrum in range of periods more than 1.7s in 5 km distance away from the fault is more than UBC97 spectrum. For example, Standard No.2800 design spectrum estimates the base shear of a 25 stories steel frame structure with height of 80m (25-story building,height floor is 3.2m,main period is 2.14s) about %8.6 more than what is estimated by UBC97 spectrum.

Standard No.2800 design spectrum within 10 to 15 km away from fault up to period 0.7s is near to UBC97 values, but after 0.7s the Standard No.2800 design spectrum values in stiff soils are more. For example the Standard No.2800design spectrum estimates the base shearofamoment frame structurewith 80m height about %42 more than UBC97 design spectrum. Figure 8 shows that in distance range more than 15 km away from fault, UBC97 spectrum and Standard No.2800 spectrum up to 0.6s period are equal and after that the values of 2008 standard 3rd edition are more. The comparison of far fault UBC97 spectrum and Standard No.2800 design spectrum has been shown that Standard No.2800 design spectrum up to 0.6s is about %9 less than UBC97 design spectrum located in far fault regions but after period 0.7s the UBC97 design spectrum is less. For instance,Standard No.2800 design spectrum estimates base shear of a structure with steel moment frame and height of 80m (2.14s periods) about %47 more than UBC97 far fault design spectrum. The above result shows that the values of Standard No.2800 are non-conservative about %33 to %37.5 than UBC97 within 5km from fault. Also the comparison of Standard No.2800 with UBC97 in far field of fault shows that Standard No.2800 design spectrum within long period range (T>0.6s) is uneconomical and within short period range (T<0.6s) is about %9 non-conservative.

4.2.1.2. Evaluation of Standard No.2800v3 within regions with low and middle seismicity rate

In figure 9 the values of Standard No.2800 design spectrum is compared with UBC97 design spectrum for areas with low and average seismic activities in stiffgrounds (soil type 3 in standard No.2800).It was observed that in distance less than 2km away from fault in regions with middle seismicity rate (UBC-NF-B R<2km), the UBC97 spectrum values up to 0.7s period are about %30 more than Standard No.2800 values. From period 1.6s and more the values of Standard No.2800 design spectrum are more than UBC97 spectrum values asat period 5s UBC97 spectrum is %30 less than Standard No.2800. In distances of 5km,10km and more away from fault,the Standard No.2800 design spectrum within period range up to 0.7shas the same values as UBC97 and in period range more than 0.7s the Standard No.2800 design spectrum has more values.The results of figure 9 shows that, in regions with distance less than 2 km away from fault, the Standard No.2800 design spectrum within period range up to 1.6s is about %30 non-conservativeforregions with low and middlerate of seismicity but in 5, 10km and moreaway from fault approximately covers UBC97 design spectrum and it is conservative in period range more the 0.7s.

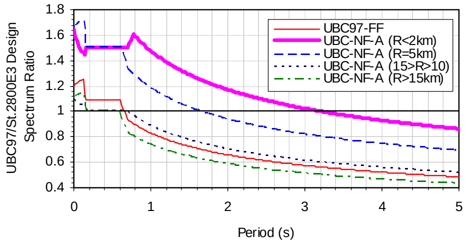


Figure 8. Ratio of UBC97 design spectra to Standard No.2800E3 design spectrum within regions with high seismicity rate (Type A in table 2)

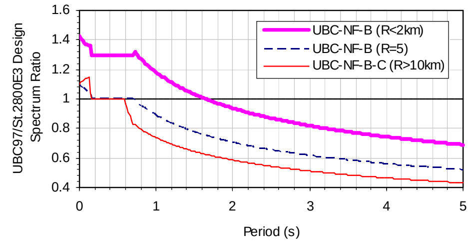


Figure 9. Ratio of UBC97 design spectra to Standard No.2800E3 design spectrum within regions with low and middle seismicity rate (Type B & C in table 2)

4.2.2. Evaluation of Iranian seismic design code 2thedition based on UBC97 design spectra

In follow section, the 2th edition of Iranian seismic deign code is studied based on UBC97 spectra for each seismicity zones.

4.2.2.1. Evaluation of Standard No.2800v2 within regions with high seismicity rate

Based on figure 10, design spectrum of Standard No.2800v2 in distances less than 2km away from fault in areas with high rate of seismicitywithin period range up to 0.8s is about %39 to %44 less than UBC97 design spectrum.Within 5 km away from fault, The Standard No.2800v2 spectrum up to period 0.6s is about %39 less than UBC97 design spectrum and from period range 2.2s and more the values of Standard No.2800 spectrum are more than UBC97 values as within period 5s the Standard No.2800 spectrum is about%31.5 more than the UBC97 spectrum values. In the distance between 10 to 15 km and more than 15 km away from the fault, the Standard No.2800 design spectrum up to period 0.7s is about %9 less than UBC97 spectrum and from period 0.7s and more the Standard No.2800v2 is more, as in 5s the Standard No.2800v2 spectrum is about 2 times as much as UBC97 spectrum in the distance more than 15 km.

According to above results, if UBC97 is considered as a criterion for evaluating Standard No.2800E2, it will be observed that the Standard No.2800E2 up to 5km away from fault within short period range (T<0.8s) is about %39 to %44 non-conservative in comparison to UBC97.For far fault regions, the Standard No.2800E2 spectrum in shortperiodrange (T<0.6s) is non-conservative about 16.75%. Also,Standard No.2800E2 spectrumin period range 0.6s and moreestimates the base shear of structures uneconomical.

4.2.2.2. Evaluation of Standard No.2800v2 within regions with low and middle seismicity rate

It has been shown by figure 11 that in regions with middle rate of seismicity and distance less than 2km away from fault, the Standard No.2800E2 design spectrum up to period 0.7s is about %30 less than UBC97 spectrum values. From period 2.2s and more Standard No.2800E2 design spectrum values are more. Considering of Standard No.2800E2 in regions located in middle seismicity rate within 5, 10 and more kilometers away from fault shows the Standard No.2800E2 spectrum up to period 0.7s is less than the UBC97 spectrum about %10. In period range more than 0.9s the Standard No.2800E2 design spectrum is more than UBC97 spectrum as in period 4.4s the Standard No.2800 is about %67 more than UBC97 spectrum. Figure 11 shows that Standard No.28003th edition design spectrum is about %10 more than the Standard No.2800 2th edition design spectrum values. Also the values of Standard No.2800E2 design spectrum are 10% to 42% less than UBC97 spectrum in regions with distance less than 5km from active fault.

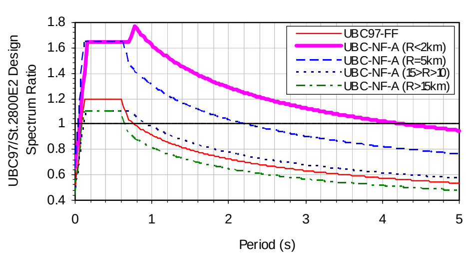


Figure 10. Ratio of UBC97 design spectra to Standard No.2800E2 design spectrum within regions with high seismicity rate (Type A in table 2)

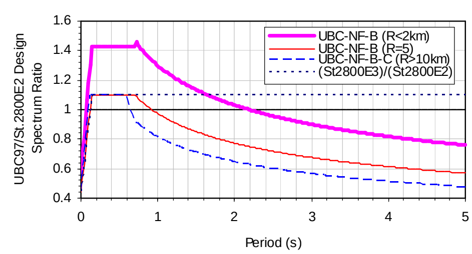


Figure 11. Ratio of UBC97 design spectra to Standard No.2800E2 design spectrum within regions with with low and middle seismicity rate (Type B & C in table 2)

4.3. Discussion on comparison between Design spectra provided by Standard No.2800 and UBC97

Evaluation of Standard No.2800 based on UBC97 design spectra in near and far field of faultaccording to Figures 8 to 11 and Table 3has been shown that design spectrum ofStandard No.2800 3thedition in regions with high seismicity within 2km distance away from active fault is 50% non-conservatively. This design spectrum in 5km away from fault related to high seismicity regions and 2km away from fault related to middle seismicity regions is 50% non-conservative within period range of 0~1.6s and also it is about 5% to 25% uneconomical for period range of 1.6s and more. Design spectrum of Standard No.2800 for high seismicity regions located in 10km, 15km away from fault and for low and middle seismicity regions located in 5km and 10km away from fault is about 20% to 40% uneconomical for long period range (T>0.8~1s). Hence, based on UBC97, design spectrum of Standard No.2800 is severely non-conservative to design new structures located in 2km away and less from fault for high seismicity regions. Also, it predicts base shear of structures with period less than 1.6s about 50% non-conservative and predicts base shear of structures with period more than 1.6s about 20% to 40% uneconomical within 5km away from fault related to high seismicity regions and 2km away from fault related to middle seismicity regions. Standard No.2800 estimates base shear of long period structures (T>0.8s) about 20% to 40% uneconomical for high seismicity regions located in 10km, 15km away from fault and for low and middle seismicity regions located in 5km and 10km away from fault. Considering of both the Standard No.2800 2thedition and 3th edition shows that results for 2th edition spectrum is the same as 3th edition with maximum 10% difference also, it is concluded that the 2thedition is 10% less than 3th edition in all range of period range.

Table 3. Summary results of Standard No.2800 Edition 2 and 3 base on UBC97

Iranian Seismic Design Code Version 3 (Standard No.2800 3th Edition)	**Source type**	**Criterion Code**
The Standard No.2800E3 design spectrum is about 33% to 37.5% non-conservative than UBC97 design spectrum in regions located less than 5km away from active fault	High rate of seismicity (Type A in table 2)	UBC97
The Standard No.2800E3 design spectrum is 30% non-conservative than UBC97 spectrum within period range 0~1.6s for regions located less than 2km away from active faults	Low and middle rate of seismicity (Type B and C in table 2)	
Iranian Seismic Design Code Version 2 (Standard No.2800 2th Edition)	Source type	Criterion Code
The Standard Noo.2800E2 design spectrum is about 39% to 44% non-conservative than UBC97 design spectrum in regions located less than 5km away from active fault within short period range (T<0.8s)	High rate of seismicity (Type A in table 2)	UBC97
The Standard No.2800E2 design spectrum is about 10% to 42% non-conservative than UBC97 design spectrum in regions located less than 5km away from active fault	Low and middle rate of seismicity (Type B and C in table 2)	

5. Estimating forward directivity effect on UBC97 and Standard No.2800 based on strong motions response spectra

In this portion based on assumption of section 2 and strong motion response spectra in figures 2-a to 2-h resulted from processing of earthquake records in table 1, the design spectra of standard No.2800 and UBC97 have been discussed under effect of forward directivity.

5.1. Studying UBC97 design spectra

To considering UBC97 design spectra in near fault regions, ratio of near fault spectra that they contains the directivity effect to UBC97 spectra have been studied. The results for regions with high rate of seismicity are presented in figures 12 to 14 and for areas with low and middle rate of seismicity have been offered in figures 15 to 16. Also, near fault design spectra provided by UBC97 has been compared with Far fault spectrum obtained in figure 2-e because of hazard probability of far fault earthquakes with same hazard level on structures constructed in near fault regions based on near fault spectrum.

5.1.1. UBC97 design spectra related to regions with high seismicity rate

In figures 12 to 14 the UBC97 design spectrum has been discussed for regions with distance of 2, 5, 10, 15km away and more from active faults in regions with high seismicity rate.

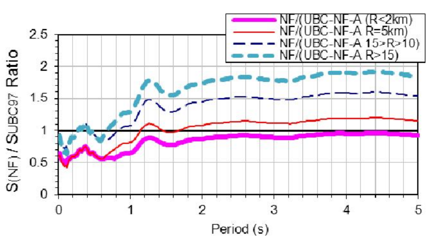


Figure 12. Ratio of Near Fault spectrum (NF) to UBC97 design spectrum within high seismicity regions

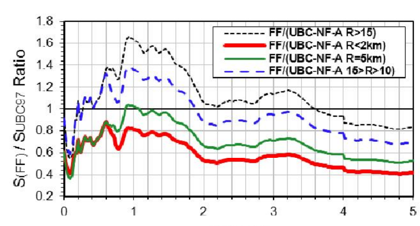


Figure 13. Ratio of Far Fault spectrum (FF) to UBC97 design spectrum within high seismicity regions

5.1.1.1. UBC97 design spectrumfor regions with 2km away from active faults

Based on figure 12, The UBC97 design spectrum up to period 1.2s about 16% to 67% is more than Near Fault (NF) spectrum and after period 1.2s have a good fitness than NF spectrum. In other word, UBC97 design spectrum has covered NF spectrum conservatively for near fault regions located up to 2km away from active faults within high seismicity rate. To evaluate far fault earthquake effects on UBC97 design spectrum within regions up to 2km away from fault, ratio of Far Fault (FF) spectrum to UBC97 spectrum is considered. Based on Figure 13, UBC97 spectrum is 13.6% to 127% more than FF spectrum within total range of periods. Results of Figures 12 and 13 shows UBC97 design spectrum is completely conservative to design structures in 2km away from active faults with assumption about constant hazard for near and far fault earthquakes.

5.1.1.2. UBC97 design spectrum for regions with 5km away from active faults

Considering of UBC97 design spectrum in regions located within 5km away from active fault in Figures 12 and 13 show that UBC97 design spectrum up to period 1.1s is about 25% to 127% more than NF spectrum and after period 1.1s about 7.4% to 16.7% is less than NF spectrum. Also this design spectrum has covered FF spectrum conservatively as it has values 54% to 92% more than FF spectrum. Results has showed than UBC97 design spectrum for 5km away from fault is applicable in near fault regions with 10% to 15% errors for long period ranges (T>1.1s).

5.1.1.3. UBC97 design spectrum for regions with 10km away from active faults

Mean records distance for NF spectrum in figure 12 is 4.75km therefor in figure 14 NF spectrum resulted for records in 10~15 km away from active fault has been compared with UBC97 design spectrum. Related to Figure 14, the UBC97 deign spectrum within period range of 1.1s to 2s is about 10% to 60% less than NF spectrum and within other period range it has values 10% to 28% less than NF spectrum. with assuming same hazard level for near and far filed of fault, considering to far fault effects on UBC97 design spectrum for 10km away from active fault in figure 13 shows UBC97 spectrum has values 38% less than FF spectrum up to period 2s. Results show that with assuming same hazard level for near and far fault strong motions the UBC97 design spectrum for 10 km away from fault is non-conservative.

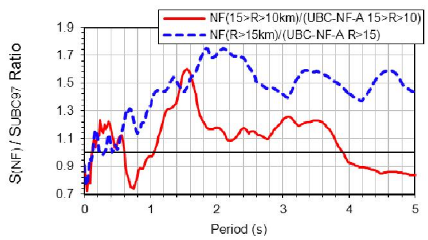


Figure 14. Ratio of Near Fault spectrum (NF) to UBC97 design spectrum for 10km, 15km and more away from active faults within high seismicity regions

5.1.1.3. UBC97 design spectrum for regions with 15km and more away from active faults

Review of UBC97 design spectrum for 15km away and more from fault show the UBC97 spectrum after period 0.6s about 10% to 70% less than NF spectrum, Figure 14. Comparison of UBC97 design spectrum with FF spectrum in Figure 13 shows that FF spectrum has values about 50% more than UBC97 spectrum within period range of 0.5s to 2s. Results showed The UBC97 design spectrum for regions located in 15km away and more from fault in not conservative.

5.1.2. UBC97 design spectra related to regions with low and middle seismicity rate

In figures 15 to 16 the UBC97 design spectrum has been discussed for regions with distance of 2, 5, 10km away and more from active faults in regions with low and middleseismicity rate.

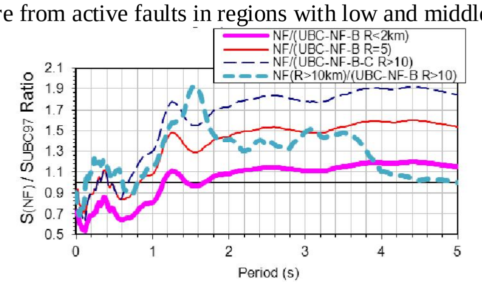


Figure 15. Ratio of Near Fault spectrum (NF) to UBC97 design spectrum within low and middle seismicity regions

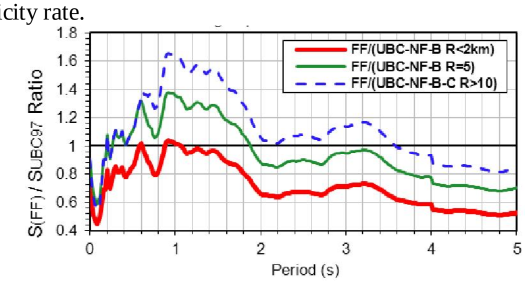


Figure 16. Ratio of Far Fault spectrum (FF) to UBC97 design spectrum within low and middle seismicity regions

5.1.2.1. UBC97 design spectrum for regions with 2km away from active faults

Studying UBC97 design spectrum for 2 km away from fault within regions with medium seismicity showed the UBC design spectrum is 30% more than NF spectrum up to period 1.1s and it has less value about 7.4% to 16.7% than NF spectrum in period range 1.1s and more, Figure 15. Also, based on Figure 16 the UBC97 spectrum covers FF spectrum conservatively. Regarding to assumption of this study that all of near fault records contain severely directivity effect and most of records selected form earthquakes with high magnitude it has been understood that the UBC97 design spectrum for 2 km away from active faults is applicable to design and evaluation purpose with errors less than 16% near active faults within regions with middle seismicity.

5.1.2.2. UBC97 design spectrum for regions with 5km away from active faults

Based on results provided by Figures 15 and 16, UBC97 design spectrum for 5 km away from fault has values about 50% less than NF spectrum within period range more than 1.2s. Also, FF spectrum is 25% more than UBC97 spectrum within 0.2 to 1.9s period range. Results indicate UBC97 design spectrum for regions within 5km away from fault with assuming constant hazard level for near and far fault regions is about 50% non-conservative.

5.1.2.3. UBC97 design spectrum for regions with 10km away from active faults

Consideration of UBC97 design spectrum for 10km away and more from fault within low and middle seismicity regions in Figure 15 shows NF spectrum is 50% to 90% more than UBC97 design spectrum within period range more than 1.1s. Based on Figure 16, UBC97 design spectrum has values about 65% less than FF spectrum in period range 0.2s ~ s2. It is perceived that UBC97 design spectrum for 10km away and more from fault is non-conservative with constant hazard level assumption.

5.1.3. Studying UBC97 far fault spectrum

Based on Figure 17, UBC97 far fault spectrum is about 60% less than NF spectrum within period range 0.8s and more is stiff soils. Also, UBC97 far fault design spectrum is about 40% less than FF spectrum within period range 1.2s and more. Based on above results UBC97 far fault design spectrum maybe non-conservative for far fault regions about 40% within period range 0.6s to 2s and structure designing based on UBC97 far fault spectrum in regions near active faults with forward directivity effect is non-conservative about 60% for long period structures (T>0.8s).

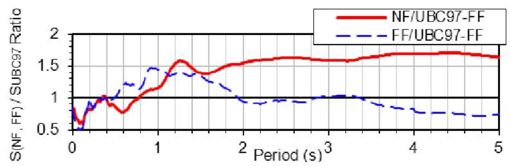


Figure 17. Ratio of Far Fault spectrum (FF) to UBC97 far Fault design spectrum

5.1.4. Discussionof UBC97 Design spectra in near and far field of fault

Summary of results from sections (5.1.1) and (5.1.2) in Table 4-a indicates that with assumingconstant hazard level, the design spectra presented by UBC97 in regions with high seismicity rate within 5km away from fault with a little error are suitable and they are applicable without any special considerations in regions affected by forward directivity effects. But the UBC97 design spectra for 10km, 15km and more from fault are 50% to 70% non-conservativefor regions with sever effect of forward directivity in stiff soils. So, in near fault regions with high seismicity rate, stiff soil (type D in UBC97) and with severe effect of forward directivity, it is proposed to use site specific design spectrum or UBC97 design spectrum related to 5 km away from fault to seismic design of structures within 5 to 15km (maybe more than 15km) away from active faults. Based on results presented in Table 4-b, UBC97 design spectrum related to 2km away from fault is applicable to seismic design of structures near active faults within regions with middle seismicity rate and severe forward directivity effect. For regions in range of 5km, 10km away and more from active faults, UBC97 design spectrum related to 5km and 10km away from fault are not suitable and they are about 50% non-conservative. So, to design new structures near active faults with severe forward directivity within regions with low and middle seismicity rate, it is better to use site specific design spectrum or UBC97 design spectrum for 2km away from fault related to middle seismicity regions conservatively, Table 4-d.

Table 4. Summary results of studying UBC97 spectra in near and far field of fault within stiff soil conditions

a- Near fault regions with high seismicity rate

Description of UBC97 design consideration	Design spectrum distance from active fault
The design spectrum covers near and far fault spectrum conservatively	R<2km
The spectrum covers far fault spectrum completely and it is needed to long period part (T>1.1s) of spectrum be 15% more in near fault regions	R=5km
It is needed the spectrum be 50% more after period range of 0.5s in near and far fault regions	15>R>10
It is needed the spectrum be 50% to 70% more after period range of 0.5s in near and far fault regions	R>15km

b- Near fault regions with middle seismicity rate

Description of UBC97 design consideration	Design spectrum distance from active fault
The spectrum covers far fault spectrum completely and it is needed to long period part (T>1.2s) of spectrum be 7% to 165 more in near fault regions	R<2km
It is needed the spectrum be 25% more is short period part (0~1.2s) for far field of fault and because forward directivity effect the long period part (1.2s~5s) of spectrum should be more 50% in near fault regions.	R=5km
The spectrum values should 50% increase for regions 10km away and more from fault within near and far field of fault.	R>10

d- Near fault regions with middle seismicity rate

Description of UBC97 design consideration	Design spectrum distance from active fault
The spectrum values should 50% increase for regions 10km away and more from fault within near and far field of fault.	Low rate of seismicity
The spectrum should be more about 40% in period range of 0.6s to 1.6s	Far field of fault

Two points should be noted; first, based on table 2 the earthquake magnitude in regions with high seismicity rate is probably more than regions with low and middle seismicity rate. Also, increasing of earthquake magnitude causes to increase the response spectrum values within long period range (T>1s) of response spectrum [9]. In this study, because, it is needed to consider forward directivity effect, most of earthquake records are from events with high magnitude (more than 6.5). So, the ratio of near fault spectrum to design spectra in long period range are probably slightly less than the values predicted for low and middle seismicity rate regions. Second point isabout regions located in near field of fault that there is possibility to affected them by Far fault events with the same hazard level.The structures located in these regions should be controlled by far fault spectrum too or both effects of near and far field of fault should be considered in design spectrum of the structures. Because of the second point, in this study, near fault design spectra of UBC97 have been evaluated by far fault spectrum and some incremental coefficients presented in Table 3 to considering far fault effects on near fault design spectra. Also, from above, it is perceived that in near fault regions when the near fault site specific design spectrum is selected to use, it is important to consider far fault strong motion effect with same hazard level for structure designing in near active fault if there is probability to affect construction site be under far fault strong motion effect with same hazard level.

5.2. Studying design spectra of Iranian seismic code

Standard No.2800 2th edition provides 4 design spectra for all seismicity regions but the 3th edition provides 4 design spectra for regions with low and middle seismicity and 4 design spectra for high seismicity regions. In this section, design spectrum related to high seismicity regions of 2th and 3th edition of Standard No.2800 for stiff soils have been compared with Near Fault (NF) spectrum and Far Fault (FF) spectrum, Figure 18.

5.2.1. Standard No.2800 3th Edition

Based on Figure 16,the design spectrum of No.2800 3th Edition has well fitnesson near fault spectrum. the near fault spectrum areresulted by records within distance less than 15km away from active fault so, it is perceived that Standard No.2800 design spectrum is consistent with near fault spectrum in 15km away from active faults. Comparison of FF spectrum with Standard No.2800 design spectrum showsthe values of Standard No.2800 design spectrum are about 30% less than far fault spectrum in short period range (0.2s<T<1.1s). Based on figure 18, the design spectrum of Standard No.2800 E3 should be about 30% more in period range 0.5 to 1.5s.Because of NF and FF spectrum exceeded from that.

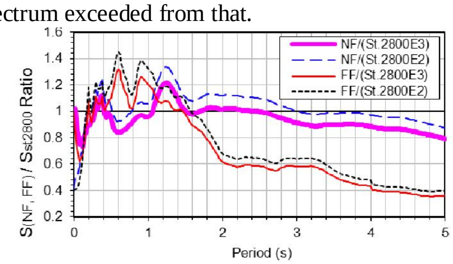


Figure 18. Ratio of near and far fault response spectrum to design spectra provided by 2th and 3th edition of Iranian seismic design code

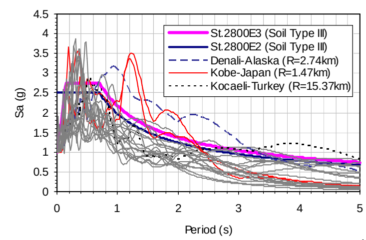


Figure 19. Comparison of Standard No.2800 2th and 3th edition design spectrum with some near fault recordswithin stiff soil conditions

5.2.2. Standard No.2800 2th Edition

Consideration of Figure 18 shows that Design spectrum of Standard No.2800 E2 is about 10% to 35% less than NF spectrum within period range 0.8s to 3s. also it`s values between period 0.2s to 1.6s are 20% to 45% less than FF spectrum. Results show that high important structures in near fault regions with fundamental period less than 1.6s that are designed by Standard No.2800 E2 should be evaluated again by near fault specific site spectrum.

5.2.3. Discussion on Design spectra of Iranian seismic code in near and far field of fault

Based on Figure 19 the 2th edition of Standard No.2800 provides a design spectrum 10% less than 3th Edition. Also, without considering far fault effect (neutral effect), review of it shows 2th edition design spectrum for near fault regions within 15km away from fault about 10% to 35% is non-conservative for period range less than 1.6s, Figure 18. With assumingthat Far fault effecthas same hazard level in near fault regions, it is non-conservative about 35% in short period range (T<1s) and it provides values about 25% to 150% uneconomical for period range more than 1.6s. Based on above results it is perceived that Standard No.2800 E2 is about 10% to 35% is non-conservative for near fault regions within 15km away from active faults. So, it is recommended to prevent of near fault earthquake damages on important structures located on stiff and soft soils conditionin near fault regions within 15km and less away from active faults that they areconstructed based on Standard No.2800 E2 should be revaluated.

Base on figure 18, design spectrum of Standard No.2800 E3has well adoption with mean plus standard deviation of near fault records in regions up to 15km away from active faults. Also based on results of section (4.3) it is concluded that design spectrum ofStandard No.2800 3thedition has a non-conservative prediction up to 5km away from fault and it is uneconomic for regions located in more than 10 km away from faults. Also in regions with long distances from causative fault without near fault effect, Based on Figure 18, the design spectrum of Standard No.2800 E3 is uneconomic for long period range structures (T>1.3s). In figure 19, the design spectrum of Standard No.2800 E3 is compared with some earthquake response spectra within different distances away from fault. Results show that design spectrum of Standard No.2800 E3 is about 30% non-conservative in short period range (T<0.6s) and in long period range some response spectra in 5km away from fault have more values than values of Standard No.2800 design spectrum. Based on above results, without same hazard level for near and far fault events, the Standard No.2800 design spectrum predicts the near fault spectra in long period (T>1s) conservatively but for far fault regions, it predicts the values of response spectrum uneconomical for long period range structuresand it has non-conservative values for short period range. So, Standard No.2800 E3 design spectrum predict base shear of tall buildings 10%~40% uneconomical within far field of faults and it predicts base shear of short structures 30% non-conservative for both of near and far field of faults.Based on summery results of Studying about 2th and 3th edition of Standard No.2800 in Table 5, it indicates the structures are designed by Standard No.2800 located in 15km away and less than active fault for stiff and soft soil conditions should be revaluated based on near fault specific design spectrum and if there is probability to occur far source earthquake with same hazard level in near fault regions the short period structures should be reviewed well as.

As the other result, when a uniform design spectrum developed to design new structures for near and far source events with different hazard level, the design spectrum contains both effects of forward directivity and far fault effects. So it causes to evaluate seismic design parameters being uneconomical for long period structures (T>1s) located in far fault regions without forward directivity effect and also it causes to evaluate seismic design parameters being uneconomical for short period structures (T<1s) within near source regions without any far fault effects. Therefore, to economical design of new structures based on uniform design spectrum, it is important to develop three types of design spectrumby uniform seismic design instructions. One type should be based on far source events without forward directivity effects and the second type is for near fault events with forward directivity effect that the regulation in near fault regions for different distances from causative fault a distinct design spectrum should be provided. The third design spectrum obtain from envelop of type one and type two design spectra therefore the third type has both forward directivity and far fault effect. The type one is suitable to design of new structures located within long distances from causative fault without directivity effect. The second design spectrum is suitable for regions near causative fault with severe forward directivity effects that there is not far fault effects or hazard level of far source strong motion is negligible than near source hazard level and third type spectrum is useable to design of structures in regions that are affected by forward directivity effect near the causative fault and the regions affected by far source events with far fault effect too. Of course the structures located in the second situation, should be controlled with first type design spectrum with maximum hazard level related to far source events.

Table 5. Summary results of studying design spectrum of Iranian seismic design code in near and far field of fault within stiff soil conditions

a-Result of Standard No.2800 Edition 3

Description of Iranian seismic code version 3	Seismic Region
The spectrum has fairly fitness with near fault spectrum within 15km away from fault and it is not suitable for regions less than 15km away from fault and it is severe non-conservative in distances less than 5km from fault.	Near field of active fault
The design spectrum values should be 30% more for periods 0.2s to 1.5s for stiff soils condition	Far field of active fault
With assuming same hazard level for near and far field of fault, the design spectrum should be more about 30% for periods 0.2s to 1.5s and to design of new structures in near fault regions less than 15km away from fault should be used of specific site design spectrum.	Consideration results Standard No.2800 design spectrum

b-Result of Standard No.2800 Edition 2

Description of Iranian seismic code version 2	Seismic Region
The deign spectrum values are 10% to 35% less than near fault spectrum in 15km away from fault for period range 0.8s to 3s and it is severe non-conservative in distances less than 10km from fault.	Near field of active fault
The deign spectrum values are 20% to 45% less than far fault spectrum for period range 0.8s to 3s.	Far field of active fault
Important structures located in less than 15km and less away from fault in stiff and soft soil site condition should be revaluated for near and far fault by specific site design spectrum.	Consideration results Standard No.2800 design spectrum

6. Effectofearthquake records with very low acceleration amplitude on design spectrum of near and far fault regions

Based on investigation of Edalat and Alaghebandian (2003) number of oscillation cycles effects on response spectrum amplitude as with increasing of oscillation cycles the response spectrum value be more within period of oscillation [10]. Regarding to that, the effective time of earthquake records grows with increasing distance of active faults and the acceleration amplitude of record be less when the distance from fault increasing, in very far fault regions (VFF) the earthquake records has a low amplitude and long duration than records with forward directivity effect near active faults. According to above, because of low amplitude (PGA<0.05g) and long duration of very far fault records, when the records scaled to higher hazard level in middle and high seismicity regions (for example PGA>0.3g) , it is expected that the response spectrum of low amplitude records has a salient amplitude within period of records frequency content. To investigate on response spectrum of earthquake records from very far fault sources with very low PGA, a mean plus standard deviation response spectrum is obtained by earthquake records with PGA less than 0.05g that listed in Table 1.

Figure 20 shows that the values of very far fault response spectrum[1] resulting from records with PGA<0.05g has values more than near fault spectrum from period 0.4s and more. Also comparison of far fault spectrum (resulting from records with PGA>0.1g) with the spectrum related to records with PGA<0.05g showed the very far fault spectrum (PGA<0.05g) has values more than far fault spectrum (PGA>0.1g) from period 0.9s and more. For example,

[1] Very Far Fault response spectrum obtained by earthquake records that they recorded more than 100 kilometers away from faults and their PGA are less than 0.05g. The far fault response spectrum has shown by VFF abbreviation

based on figure 5, the very far fault spectrum at period 2 seconds has values 1.5 times more than the near fault spectrum and it has values 3 times more than the far fault spectrum.

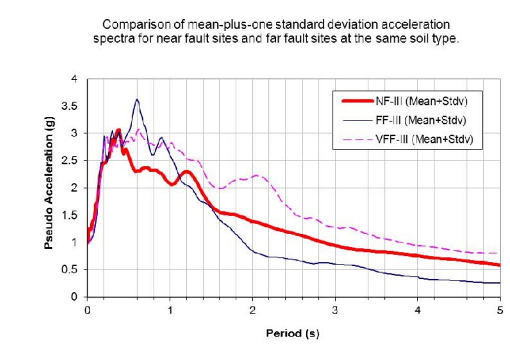


Figure 20. Response spectrum comparison in near and far field of fault for Stiff soil (soil Class D in UBC97)

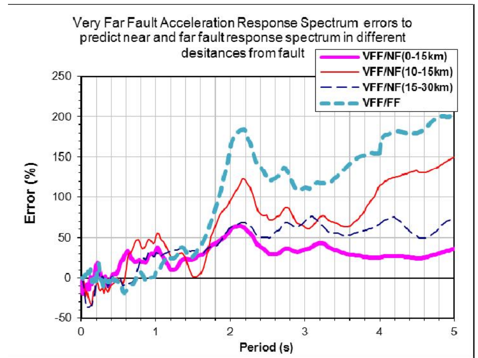


Figure 21. Response spectrum comparison in near and far field of fault for Stiff soil (soil Class D in UBC97)

Based on Figure 20, Earthquake accelerograms recorded in long distances from causative fault with low PGA (PGA<0.05) have big errors to predict both of near and far field spectra. Regarding to figure 21 response spectra resulted from low amplitude accelerograms (PGA<0.05) have 20% to 50% error within period range 0 to 1.6s and 50% to 200% error within period range 1.6s to 5s than near and far fault response spectrum in different distances from active faults. According to above, it is resulted that very low amplitude earthquake data that are occurred in far source regions can make major error in site specific design spectrum. Therefore, to develop site specific design spectra should be neglect to use very low amplitude earthquake data that are occurred in far source regions.

To study for applicability of very far source records with PGA<0.05g to predict near fault design spectrum, the ration of very far fault spectrum (from records with PGA<0.05g) to design spectrum of UBC97 and Standard No.2800 in Figures 21 and 22 have been obtained for different distances away from fault.

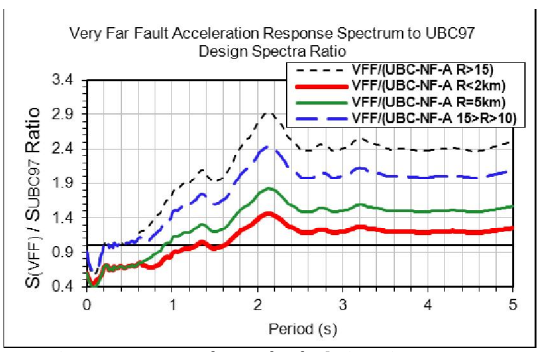


Figure 22. Ratio of very far fault (VFF) response spectrum to design response spectrum of UBC97

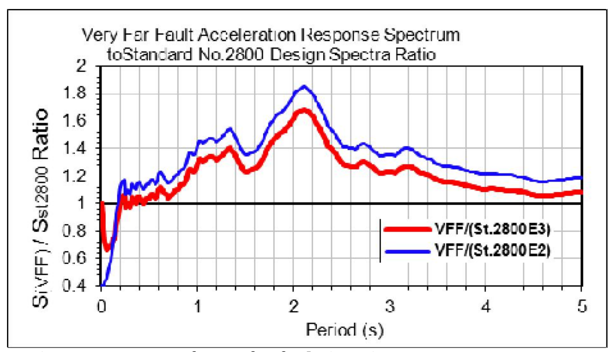


Figure 23. Ratio of very far fault (VFF) response spectrum to design response spectrum of Standard No.2800 E2 & E3

Regarding to Figures 22 and 23, the response spectrum of very far source earthquakes with PGA<0.05g have values 1.3 to 2.9 times more than UBC97 design spectra and Standard No.2800 in long period range (T>0.9s). So As a result of this investigation, when near fault response spectrum is needed and there is not any earthquake data near the active fault, it is possible conservatively to use very far fault earthquake records with PGA<0.05g and long duration to obtain site response spectrum within near active faults in stiff soils to design new structures with fundamental period more than 0.9s.Alsobased on ratio of VFF spectrum to UBC97 design spectrum related to 2km away from faults, to correction of short period range part of design spectrum obtained by low amplitude data, values of the spectrum should beincreased 1.6 times in period range of 0 to 1s.

6. Conclusions

Regarding to previous studies, near fault records that contain forward directivity effect causes to increase long period range(T>0.8~1.1s) of response spectrum. So in this study with investigation on forward directivity effects on design spectra of UBC97 and Iranian seismic design code in stiff soils the below results has been obtained.

- Observation of this study shows Forward directivity have severe effect on design response spectrum in near fault regions as it causes to increase long period part (T>1s) of response spectrum about 2 times more than response spectrum without forward directivity effect.

- Results have been shown far fault records cause to increase short period values of response spectrum (T<1s) and near fault records with forward directivity effect cause to increase long period part of response spectrum (T>1s). Hence,in near fault regions when the near fault site specific design spectrum is selected to use, it is important to consider far fault strong motion effect with same hazard level for structure designing in near active fault if there is probability to affect construction site be under far fault strong motion effect with same hazard level.
- Studying UBC97 design spectra showed with assuming constant hazard level for near and far fault earthquakes, the design spectra presented by UBC97 in regions with high seismicity rate within 2km away from fault is conservative and the other response spectrum within 5km away from fault with a little error are suitable and they are applicable without any special considerations in regions affected by forward directivity effects. But the UBC97 design spectra for 10km, 15km and more from fault are 50% to 70% non-conservative for regions with sever effect of forward directivity in stiff soils. So, in near fault regions with high seismicity rate, stiff soil (type D in UBC97) and with severe effect of forward directivity, it is proposed to use site specific design spectrum or the UBC97 design spectrum related to 5 km away from fault to seismic design of structures within 5 to 15km (maybe more than 15km) away from active faults.
- Investigation onUBC97 design spectra related to regions with low and middle seismicity rate showed that with assuming same hazard level for both of near and far fault earthquakes, the UBC97design spectrum related to 2km away from fault is applicable to seismic design of structures near active faults within regions with severe forward directivity effect. For regions in range of 5km, 10km away and more from active faults the UBC97 design spectrum are not suitable and they are about 50% non-conservative. So, to design of new structures near active faults with severe forward directivity within regions with low and middle seismicity rate, it is better to use site specific design spectrum or the UBC97 design spectrum for 2km away from fault related to middle seismicity regions conservatively.
- Without same hazard level for near and far fault events, the Standard No.2800 design spectrum predicts the near fault spectra conservatively up to 15 km away from causative fault but for far fault regions, it predicts the values of response spectrum uneconomical for long period range and it has non-conservative values for short period range structures.
- When a uniform design spectrum develops to design new structures for near and far source events with different hazard level, the design spectrum contains both effects of forward directivity and far fault effects. So it causes to evaluate seismic design parameters being uneconomical for long period structures (T>1s) located in far fault regions without forward directivity effect and also it causes to evaluate seismic design parameters being uneconomical for short period structures (T<1s) within near source regions without any far fault effect. Therefore, for economical design of new structures based on uniform design spectrum, it is important to develop three types of design spectrum by uniform seismic design instructions. One type should be based on far source events without forward directivity effects and the second type is for near fault events with forward directivity effect that the spectrum should be presented in near fault regions for different distances from causative fault. The third design spectrum should be obtained from envelop of type one and type two design spectra therefore the third type has both forward directivity and neutral directivity effect. Type one is suitable to design new structures located within long distances from causative fault without directivity effect. The second design spectrum is suitable for regions near causative fault with severe forward directivity effects that there is not far fault effects or hazard level of far source strong motion is negligible than near source hazard level and third type spectrum is useable to design of structures in regions that are affected by forward directivity effect near the causative fault and the regions affected by far source events with far fault effect well as. Of course the structures located in the second situation, should be controlled with first type design spectrum with maximum hazard level related to far source events.
- Very low amplitude earthquake data that are occurred in far source regions can make major error in site specific design spectrum. Therefore, to develop site specific design spectra should be neglect to usevery low amplitude earthquake data that are occurred in far source regions.
- In near fault regions with high probability of severe forward directivity effect when there is not valid earthquake data from near source. To design important structures very close to active faults is possible conservatively to use low amplitude earthquake records (PGA<0.05g) and long duration that they are recorded in the construction site from other far sources. To obtain site specific design response spectrum with high directivity effect from low amplitude earthquake records, the records data should have very low amplitude (for example PGA<0.05g) and long effective duration (T>10s) and the values of spectrum should increase about 1.6 times within 0 to 1.6s period range.
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