EFFECTS OF FLING STEP AND FORWARD DIRECTIVITY ON SEISMIC RESPONSES OF SOIL SITES

Javad ASADI FALLAH
M.Sc. in Geotechnical Engineering, Khajeh Nasir Toosi University of Technology, Tehran, Iran
asadifallah@yahoo.com

Vahid MALEKI
PhD Candidate in Geophysics, University of Tehran, Tehran, Iran
vahid.maleki@ut.ac.ir

Hasan GHASEMZADEH
Associate Professor, Geotechnical Engineering, Khajeh Nasir Toosi University of Technology, Tehran, Iran
ghasemzadeh@kntu.ac.ir

Keywords: Fling Step, Forward Directivity, Response Spectra, Ground Motion, Equivalent Linear

ABSTRACT

It is observed that ground motions in the near source zone of large earthquakes are significantly affected by tectonic fling (in this paper called fling step effect) and rupture directivity. In this paper effect of different types of ground motion on response spectra of soil site was evaluated. For this purpose, according to geotechnical and geophysical studies across the Iran, two models for two common soil types in Iran (B and C based on ASCE-07 code classification) were extracted. Equivalent-linear earthquake site response analysis was implemented with simplified assumptions of soil condition like horizontal soil layer in infinite extent. Furthermore record processing effects were considered in this study especially in near field records (fling step records) where conventional record processing can't fully recover near field effects like residual displacement in displacement time series. It is observed that applying different types of ground motion can change the shape of design spectra especially in short and long periods, so they can have significant impact on engineered structures. Computed site spectral responses show a peak in short periods and long periods for far fault and near fault records, respectively.

INTRODUCTION

Near field and far field ground motions can cause significant changes in the shape and frequency content of recorded waves in seismic stations. Near field records have two known effects that are rupture directivity and fling step. The characteristics of near field ground motions surprisingly differ from those of far-field ground motions. When the rupture propagates towards the site and the direction is aligned with it, large amplitude pulses with short durations and long periods emerge in recorded ground motions (Somerville et al., 1997). This phenomenon is called the forward directivity effect and usually occurs where the velocity of rupture propagation is close to the shear wave velocity.

Fling step is the other effect of near field ground motions that is recognized from the residual ground displacement as a result of tectonic deformation. It is generally characterized by a large amplitude velocity pulse and a monotonic step in the displacement time history (Ghodrati et al., 2011). The residual displacement is a consequence of wave propagation from a finite dislocation and is not related to any other physical process (Somerville et al., 1997). As it is in the direction of the fault slip, the occurrence of fling step does not coincide with the forward directivity effect (Abrahamson, 2001). It is observed specially in

Kocaeli and Duzce strike-slip earthquake (1999) and in the ChiChi dip-slip earthquake(1999) (Kalkan and Kunnath, 2006).

Because of the lack of such data, these effects have been less studied. Also, because of the complexities that exist in this type of data, the use of this data should be of special considerations. For example data recorded in Yarimca (YPT) during the Kocaeli earthquake(1999) have this kind of complexity. The station is located about 4 km north of the east-west striking fault. The epicenter was about 20 km east of YPT. Based on the fault type (strike-slip) and fault to station geometry, we would expect large rupture directivity effects at YPT. Typically, rupture directivity produces a large pulse of ground velocity on the fault normal component with relatively minor motion on the fault parallel component of ground velocity. However, due to the large fling experienced at this site, the fault parallel ground velocity (east component) is nearly as large as the fault normal ground velocity (south component). The difference is in the shape of their time series, as the fault normal velocity has two-sided pulse with a period of about 5 seconds, while the fault parallel velocity has one-sided pulse with a period of about 8-10 seconds (figure 1). This is a proof that indicates complexity of these types of records (Graves, 2004).

ChiChi earthquake (1999) is another example to confirm this matter. Station TCU049 is on the footwall about 6 km from the fault trace, and station TCU052 is on the hanging wall about 2 km from the fault trace, just across the fault from TCU049. As it can be seen in figure 2 at long periods the motions at these two sites are dramatically different. Virtually all of the residual displacement occurs on the hanging wall (TCU052), with very little long period motion occurring on the footwall (TCU049). From the standpoint of fault rupture dynamics, this observation is consistent with the expected behavior. The reason for this is that most of the tectonic motion occurs on the hanging wall due to the orientation of the stress field and the direction of slip on the fault (Oglesby et al., 2000). In terms of ground motion characterization, the difference between these two sites has potentially important consequences, particularly in the development of empirical ground motion models (Graves, 2004).

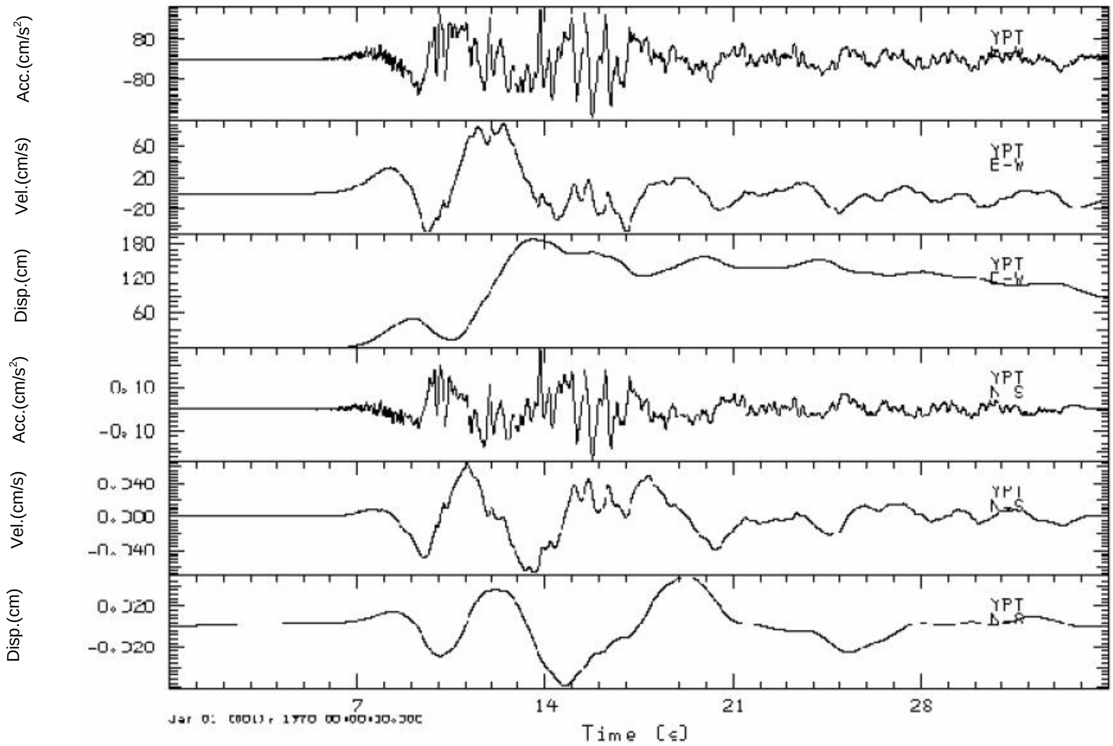


Figure 1. Time series recorded in YPT station during Kocaeli strike-slip earthquake (1999)

These two examples clearly show complexity of near field records. Therefore it is necessary to be considered the effect of this kind of ground motions in vulnerability of structures. Record processing specially in fling step records is too important and without true processing we will have unreal results. In the following, the necessity of correction of this type of records is examined.

The main purpose of this study is to evaluate the effect of different types of ground motions on response spectra of soil sites. For this purpose after selecting and classifying different types of ground motions, two models were prepared for soil classes B and C (Based on ASCE-07 Code) over bedrock based on geotechnical and geophysical studies across Iran. Ground motion classification includes far fault, near fault (forward directivity) and near fault (fling step) records. According to soil models and different type of ground motion (here is as input motion to base of soil column) the spectral responses were calculated on ground surface as important parameters in design of structures. In the following, a detail of applied method is presented.

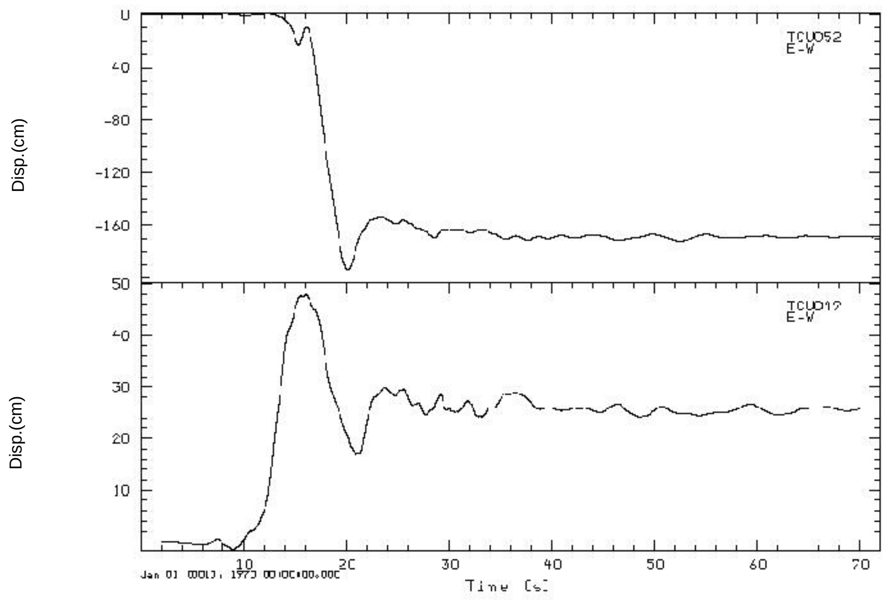


Figure 2. Comparison of time series recorded in TCU049 and TCU052 stations during ChiChi dip-slip earthquake (1999)

RECORD SELECTION AND PROCESSING

As noted above, the main purpose of this study is to evaluate the effect of different types of ground motion including far fault, near fault (forward directivity) and near fault (fling step) on response spectra calculated for two soil classes B and C. the reason that we exclude soil class D is because that, this type of soils may have nonlinear behaviour and so there was little geotechnical and geophysical data for this site class.

Regarding to selecting of ground motion data local site condition, tectonic condition, duration and magnitudes of ground motions were considered especially in far fault records. All of records except fling step records corrected based on common record processing methods. These methods presented in many publications and so far were not described in this study. What is new and important in record processing is related to fling step records. It seems these data shouldn't be process by conventional methods. These data are strongly depending to tectonic condition where the station is located. According to this matter and also lake of this kind of records, there is not a unique standard for processing them especially for baseline correction.

There is different idea about removing or not removing fling step effect from data. Some believe that these data is inconsistent with other data and it might contaminate response spectra and peak motions when included with data that do not show obvious residual displacements in regression analyses to derive equations for predicting strong ground motions (Boore, 2001).

As it was mentioned above, fling step effect is recognized by long period sinusoidal pulse on accelerograms and half-sine pulse on velocity time series. So with detect of properties of these pulses it seems to be easy to remove them. The pulse parameters could be given through the following equations in figure 3:

$$a(t) = A\sin\frac{2\pi(t-T_1)}{T} \tag{1}$$

$$v(t) = \frac{AT}{2\pi}[1-\cos\frac{2\pi(t-T_1)}{T}] \tag{2}$$

$$d(t) = \frac{AT}{2\pi}[(t-T_1) - \frac{T}{2\pi}\sin\frac{2\pi(t-T_1)}{T}] \tag{3}$$

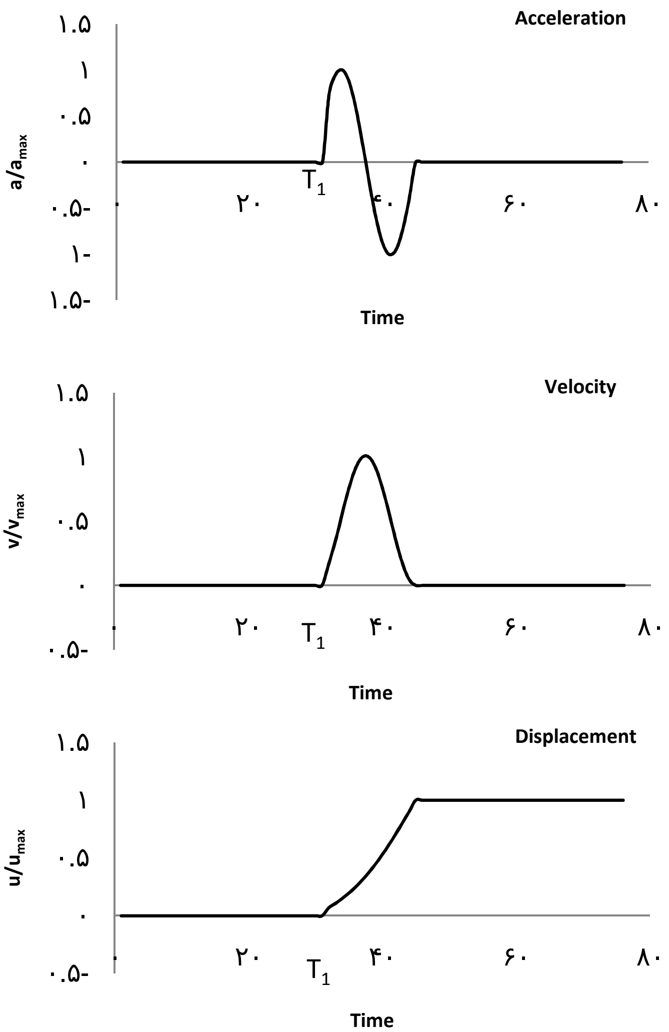


Figure 3. Idealized sinusoidal pulse for fling step record

Where T_1 and T_2 are start and stop time of pulse respectively and A is pulse amplitude. According to these parameters, displacement shift (D) is as follow:

$$d(T_2) = \frac{AT}{2\pi}[(T_2 - T_1)] = \frac{AT^2}{2\pi} = D \quad \Leftrightarrow \quad A = \frac{2\pi D}{T^2} \tag{4}$$

This method of processing is applied in PEER program and residual displacement is removed for fling step records that published in this project. It seems this is not true to remove this effect from records.

What is important in elimination of fling step is that choosing start time (T_1) and amplitude (A) of pulse is straightforward, but there are many criteria in choosing stop time of pulse (T_2) in real time histories. Wrong choice of T_2 could cause unreal results. This method of processing is applied in PEER program and residual displacement is removed for fling step records that published in this project. It seems this is not true to remove this effect from records.

In other hand some believe that residual displacement should be recovered from time series. The full recovery of residual displacement from strong motion records, while theoretically possible, is many times difficult in practice. Very subtle effects such as tilting or other noise contaminants can create severe long period drift in the recorded time history. A number of papers have addressed this topic over the years (Boore, 2001; Graizer, 1979; Iwan et al., 1985) .

The most typical approach for correcting the long period response of these motions is to apply a baseline adjustment. The adjustment may take the form of a polynomial or multiple linear segments (Graizer, 1979). In the end, without any independent constraints, these processing steps are non-unique and the resulting ground motion will be dependent on the choice of the processing parameters. Graizer (2004) suggests that the long period drift is primarily related to rotational components (tilt) that are not accounted for properly in the tri-linear recording system. The use of six-component recording instruments (3 linear and 3 rotational) can alleviate this problem. Thus far, this type of system has yet to be fully tested in the near source region of a large earthquake.

Another approach is to employ geodetic measurements of residual (coseismic) displacement as constraints on the processing of the recorded motions. For example, Clinton and Heaton (2004) has compared continuous 1 Hz GPS records and 7 day averaged GPS records with integrated strong motion records from the 2003 Tokachi Oki, Japan, earthquake. This approach shows promise and may be more practical to implement than the use of six-component instruments. In this paper Iwan's method applied to the time series (Iwan et al., 1985). Choosing T_2 parameter is too important in this method. For T_2, there are three choices: (1) which is the time where the line fit to the tail of the velocity record becomes zero (Boore, 2001); (2) T_2 is set at the time after which the acceleration never exceeds 50 cm/s (Boore, 2001); (3) $T_2 = 2\ T_I - T_1$where T_I is the T_2 value using Iwan’s criterion (choice 2 above). In this paper choice 2 (Boor criterion) was selected for choosing T_2.

What is remarkable in processing record is that baseline correction doesn't have noticeable effect on response spectra in short periods (T<10s). It has been observed that it doesn't have effect on response spectra even in periods lower than 20s (Boore, 2001). For example comparison between response spectra obtained from corrected and uncorrected records of TCU052 is presented in figure 4.

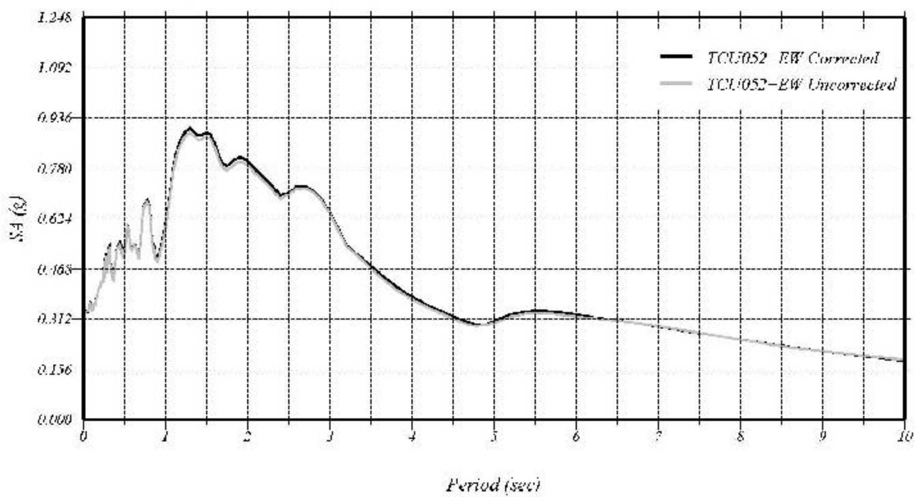


Figure 4. Response spectra for corrected and uncorrected TCU052 record (Black line is related to corrected record and gray line is related to uncorrected record)

Selected records after required correction were divided in three categories in order to be used in soil dynamic analysis; far fault records, near fault (rupture directivity) records and near fault (fling step) records. Selected records are presented in table 1. Given that in soil dynamic analysis it is necessary to input motion should be recorded on seismic bedrock, thus many of records which were recorded on soil type C and D (Based on ASCE-07 code) were excluded from list and just data recorded on soil type A and B were selected. Due to lake of data on these soil types some records on soil type C even were selected. It should be mentioned that all of records were scaled to the maximum acceleration through their time series and 0.35g was selected for design base acceleration (Acceleration on seismic bedrock).

Table 1. Selected ground motion records; (a) far-fault records, (b) near-fault records (forward rupture directivity, (c) near-fault records (fling step) (Kalkan and Kunnath, 2006)

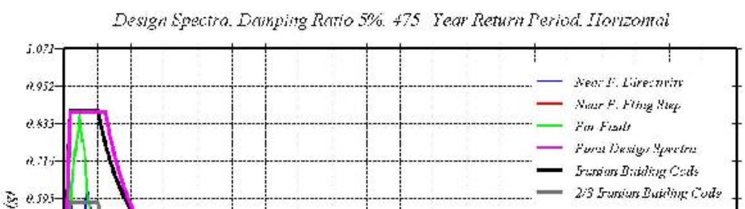
NO.	Earthquake Name	Date	Station Name	Magnitude	Soil Type
			(a) Far-Fault Records		
1	Cape Mendocino	1992/04/25	Cape Mendocino	Ms (7.1)	I
2	Chi-Chi, Taiwan	1999/09/20	TCU046	Ms (7.6)	I
3	Northridge	1994/01/17	Pacoima Dam	Ms (6.7)	I
4	Northridge	1994/01/17	Wonderland Ave	Ms (6.7)	I
5	Tabas	1971/02/09	Dayhook	Ms (7.4)	I I
			(b) Near-Fault Records (Forward-Rupture Directivity)		
1	Loma Prieta	1989/10/18	LGPC	Ms (7.0)	I I
2	Loma Prieta	1989/10/18	Lexington Dam	Ms (7.0)	I I
3	Morgan Hill	1984/04/24	Coyote Lake Dam	Ms (6.1)	I I
4	Erzincan	2002/06/22	Erzincan	Ms (6.5)	I I
5	Morgan Hill	1984/04/24	Coyote Lake Dam	Ms (6.1)	I I
6	Cape Mendocino	1992/04/25	Petrplia	Mb(7.1)	I I
			(c) Near-Fault Records (Fling-Step)		
1	Kocaeli	1999/08/17	Sakarya (SKR)	Ms (7.4)	I I
2	Kocaeli	1999/08/17	Izmit	Ms (7.4)	I I
3	Chi-Chi	1999/09/21	TCU089	Ms (7.6)	I I
4	Chi-Chi	1999/09/21	TCU084	Ms (7.6)	I I
5	Chi-Chi	1999/09/21	TCU128	Ms (7.6)	I I

SELECTED SOIL MODELS

Based on geophysical and geotechnical projects across the Iran that have been done by Zamiran Company, two soil models for soil classes B and C were prepared. Soil response analysis was done by EERA software package, so some assumptions like layered horizontal soil and not using soils with non-linear behaviour were considered in preparing models (Bardeth et al., 2000). Soil classes D was not modelled because of two main reasons; 1- Enough data was not available for this class and 2- Because of non-linear behavior of this soil type, it is not accurate to analyze them in this software. Furthermore, the reason for elimination of soil class A is that there were not data recorded on soil this soil class and for three types of ground motion which were mentioned above.

CONCLUSIONS

After selecting and processing of records, equivalent-linear earthquake soil response analysis was done for two prepared models and ground motions were calculated on ground surface. According to calculated ground motions on surface, mean response spectra were determined for each type of input motions. Figure 5 shows mean response spectra for each type of corrected records. As illustrated in this figure, spectral values increased in long periods for near fault time series where high rise buildings are sensitive to spectral values of these range of periods (T>1). Also spectral values increased significantly in short periods for far fault time series as these kinds of effects are not considered in common seismic design codes like Iranian Building Code (Standard 2800), thus sometimes seismic design based on these codes could result low factor of safety. So it is recommended that in seismic design of structure these significant effects should be considered and site specific studies have to be made for important projects.



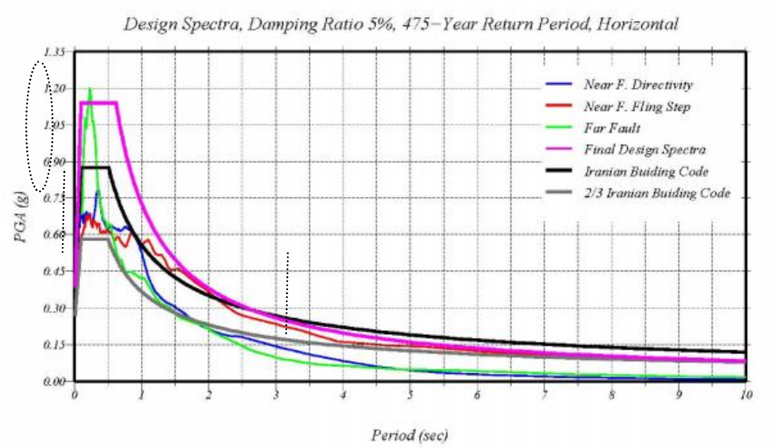


Figure 5. Site response spectra on ground surface caused by different input motions; Soil Class B(top) and Soil class C(bottom), (PGA on seismic bedrock 0.35g, 475 years Return Period, Damping Ratio 5%)

ACKNOWLEDGEMENTS

I would like to express our special thanks of gratitude to Mr. Edvard Babakhanians directing manager of Zamiran Company for his support and providing geotechnical and geophysical data. As well as we would like to thank Dr. Erol Kalkan for his advises and giving us some valuable ground motion data.

REFERENCES

Abrahamson N (2001) Incorporating effects of near fault tectonic deformation into design ground motions, a presentation sponsored by the Earthquake Engineering Research Institute Visiting Professional Program, hosted by State University of New York at http://mceer.buffalo.edu

American Society of Civil Engineering (ASCE07) (2010) Minimum Design Loads for Buildings and Other Structures, ISBN 978-0-7844-1115-5

Bardet JP, Ichii K and Lin CH (2000) A computer program for Equivalent-Linear Earthquake Site Response analyses of layered soil deposits, University of Southern California, pp.19-20

Boore DM (2001) Effect of baseline corrections on displacement and response spectra for several recordings of the 1999 Chi-Chi, Taiwan, earthquake, *Bulletin of the Seismological Society of America*, 91, 1199–1211

Clinton JF and Heaton TH (2004) Lab and field performance of the VSE-355G2/3 strong motion velocity instrument, *Seism. Soc. Am. Ann. Meet. Abstracts*, Palm Springs, CA

Ghodrati Amiri GR, Razeghi HR and Tajik Davoudi AR (2011) The effect of fling Step and forward directivity on the seismic response of MSSS bridges, *Transportation Research Journal*, 1:9-21

Graizer VM (1979) Determination of the true ground displacement by using strong motion records, *Izvestiya Phys. Solid Earth*, 15, 875-885

Graize VM (2004) Record processing considerations for the effects of tilting and transients, Proc. COSMOS Strong Motion Workshop, Richmond, CA

Graves RW (2004) Processing issues for near source strong motion recordings, Strong Motion Instrumentation of Buildings, Richmond, CA: Consortium of Organizations for Strong Motion Observation Systems (COSMOS)

Iwan WD, Moser MA and Peng CY (1985) Some observations on strong-motion earthquake measurements using a digital accelerograph, *Bull. Seismol. Soc. Am.*, 75, 1225–1246

Kalkan E and Kunnath SE (2006) Effect of fling step and forward directivity on seismic response of buildings, *Journal of Earthquake Spectra*, 22, 360-390

Oglesby DD, Archuleta RJ and Nielsen SB (2000) The three dimensional dynamics of dipping faults, *Bull. Seism. Soc. Am*., 90, 616-628

Smith NF, Graves RW and Abrahamson NA (1997) Modification of empirical ground motion attenuation to include the amplitude and duration effects of rupture directivity, *Seismological Research*, 68: 199-222

Standard No. 2800 (2005) Iranian Code of Practice for Seismic Resistant Design of Buildings, Third Revision, Building and Housing Research Center, Iran