SIMULATION OF NEAR FIELD STRONG GROUND MOTIONS AT TOMBAK SITE IN IRAN USING HYBRID METHOD

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ABSTRACT :

The main objective of this paper is to simulate the near fault strong motion records. Due to uncertainty and unavailability of strong recorded ground motion in near field and also existence of some important structures such as the massive LNG storage plants near to fault, simulation of ground motion has been carried out using the hybrid method proposed by Mavroeidis and Papageorgiou (2003) and stochastic model of Boore (2003) for simulating reliable time histories for Tombak region in south-eastern part of Iran. The ground motion spectrum is generated by Atkinson and Boore model (1995). Firstly, macro-source parameters characterizing the whole source area, i.e., global source parameters such as fault length, fault width, rupture area, average slip on the fault plane and etc., are estimated; secondly, slip distributions characterizing heterogeneity or roughness on the fault plane, i.e., local source parameters are reproduced by hybrid slip model; finally, the finite fault source model, which is developed based on the global and local source parameters, is combined with the stochastic method and also the impulsive character of near fault ground motion has been incorporated. Then, the response of site under simulated ground motion has been studied by conducting one dimensional ground response analysis. Based on the present study bed rock acceleration and ground surface acceleration of the site have been established. Comparisons show good agreements and confirm that selected source parameters were satisfactory reliable. The results can be used in hazard analysis of specific sites in the region under study particularly for performance analysis of structures.

KEYWORDS: stochastic model, impulsive character, long period pulse, ground motion generation, earthquake, site response

1. INTRODUCTION

The stochastic method of synthesizing ground motion based on seismology interests engineers greatly in simulating higher-frequency ground motions and is widely used to predict ground motions for regions, in which ground motion recordings from damage earthquake are not available (Boore, 2003). Ever since, many researchers have applied the method to simulate ground motion from point sources (e.g., Boore and Atkinson, 1987; Toro and McGuire, 1987; Chin and Aki, 1991; Atkinson and Boore, 1995; Zafarani and Noorzad, 2005, 2006, 2007 and 2008). On the other hand, realistic time-histories acceleration should be used in structural analysis to reduce uncertainties in estimating the standard engineering parameters (Hutchings 1994), particularly for non-linear seismic behavior of structures. At the high frequency (f >1Hz), ground motions become increasingly stochastic in nature. On the one hand, the gradually increasing number of recorded near source time histories has recently enabled strong motion seismologists to analyze more precisely the character of the near-fault ground motions and therefore contribute to the physical understanding of those features that control them (e.g., Campillo et al., 1989; Somerville and Graves, 1993; Abrahamson and Somerville, 1996; Somerville et al., 1997; O'Connell, 1998). Mavroeidis and Papageorgiou (2002) presented a comprehensive review and study of the factors that influence the near-source ground motions. In another article (Mavroeidis et al., 2003), they presented a comprehensive study of the elastic and inelastic response of single-degree-of-freedom (SDOF) systems subjected to synthetic near-fault ground motions generated by the analytical model. The model adequately describes the impulsive character of near-fault ground motions both qualitatively and quantitatively.

In this paper, due to unavailability of strong recorded ground motion, firstly, the stochastic method proposed by Boore (2003) is applied to simulate the acceleration time histories. The Ground motion spectrum is generated by Atkinson & Boore model (1995) and after that, a simple, yet effective, analytical model proposed by Mavroeidis and Papageorgiou (2003) is used to adequately describe the impulsive character of near-fault ground motions both qualitatively and quantitatively. The calculated response spectra are compared with those of the mentioned in IBC 2000, Iranian Code of Practice for Seismic Resistance Design Building (Standard No. 2800) to validate the availability and practicability of the proposed method for near filed Tombak site in south-eastern part of Iran. Then the response of site under simulated ground motion has been studied by conducting one dimensional ground response analysis. Based on the above study bed rock acceleration and ground surface acceleration of the site have been established.

2. SIMULATION METHOD

2.1. Stochastic Finite-fault Simulation Method

A simple and powerful method for simulating ground motions is to combine parametric or functional descriptions of the ground motion's amplitude spectrum with a random phase spectrum modified such that the motion is distributed over a duration related to the earthquake magnitude and to the distance from the source using SMSIM FORTRAN code. This method of simulating ground motions often goes by the name ''Stochastic method.'' It is particularly useful for simulating the higher-frequency ground motions of most interest to engineers (generally, f > 1 Hz), and it is widely used to predict ground motions for regions of the world in which recordings of motion from potentially damaging earthquakes are not available. The ground spectrum Y (Mo, R, f) is conveniently broken into several simple functions – the Earthquake source (E); the Path (P); the Site (G) and the instrument or type of motion (I).

$$Y(M_0, R, f) = E(M_0, f)P(R, f)G(f)I(f) \tag{2.1}$$

Where, M_0 is the seismic moment, R is the shortest distance from the fault to the site and f is the frequency. Atkinson & Boore model (1995) has been used to obtain the ground motion spectrum. The source spectrum E is obtained by the following equation specifying both the shape and the amplitude as a function of the earthquake size.

$$E(M_0, f) = CM_0S(M_0, f) \tag{2.2}$$

$$S(M_0, f) = S_a(M_0, f) \times S_b(M_0, f) \tag{2.3}$$

The expression of each function, related parameters and the steps of synthesizing ground motion can be found elsewhere (Boore, 2003).

2.2. Analytical Model Proposed by Mavroeidis and Papageorgiou (2003)

In the case of near field strong ground motions, most of the elastic energy arrives coherently in a single, intense, relatively long period pulse at the beginning of the record, representing the cumulative effect of almost all the seismic radiation from the fault. The phenomenon is even more pronounced when the direction of slip on the fault plane points toward the site as well. Mavroeidis and Papageorgiou (2003) proposed a simple, yet effective, analytical model for the representation of near-field strong ground motions. The pulse duration (or period), the pulse amplitude, as well as the number and phase of half cycles are the key parameters that define the waveform characteristics of near fault velocity pulses. In this study the analytical wavelet signal proposed by Mavroeidis and Papageorgiou (2003) has been chosen and expressed by

$$f(t) = A\,\frac{1}{2}\left[1 + \cos\left(\frac{2\pi f_P}{\gamma}t\right)\right]\cos(2\pi f_P t + \nu) \tag{2.4}$$

Parameter A controls the amplitude of the signal, f_P is the frequency of the amplitude-modulated harmonic (or the prevailing frequency of the signal), ν is the phase of the amplitude-modulated harmonic (i.e., $\nu = 0$ and $\nu = \pm\pi/2$ define symmetric and antisymmetric signals, respectively), γ is a parameter that defines the oscillatory character (i.e., zero crossings) of the signal (i.e., for small γ the signal approaches a deltalike pulse; as γ increases the number of zero crossings increases), and t_0 specifies the epoch of the envelope's peak. The analytical expressions for the ground acceleration time histories compatible with the ground velocity are

$$a(t) = \begin{cases} -\dfrac{A\pi f_P}{\gamma}\left[\begin{array}{l}\sin\left(\dfrac{2\pi f_P}{\gamma}(t-t_0)\right)\cos[2\pi f_P(t-t_0)+\nu] \\ +\gamma\sin[2\pi f_P(t-t_0)+\nu]\left[1+\cos\left(\dfrac{2\pi f_P}{\gamma}(t-t_0)\right)\right]\end{array}\right], & t_0 - \dfrac{\gamma}{2f_P} \le t \le t_0 + \dfrac{\gamma}{2f_P} \text{ with } \gamma > 1, \\ 0, \quad \text{otherwise} \end{cases} \tag{2.5}$$

Assuming that the duration of the pulse is independent of the source–station distance for stations located within ~10 km from the causative fault, the pulse period and the moment magnitude are related through the following empirical relationship obtained by least-squares fit analysis:

$$\log T_P = -2.2 + 0.4\,M_w \tag{2.6}$$

The proposed methodology consists of the following steps. A program has been written in MATLAB to provide the following steps:
(1) Select the moment magnitude M_w of the potential earthquake and calculate the prevailing frequency, f_P, using equations (2.6). For selected values of the parameters A, γ and ν (or for a suite of values of these three parameters), generate the coherent component of acceleration time history (or a suite of time histories) using equation (2.5). (2) For the selected fault–station geometry, generate synthetic acceleration time histories for the moment magnitude, M_w, specified previously, using the specific barrier model. (3) Calculate the Fourier transform of the synthetic acceleration time histories generated in steps 1 and 2. (4) Subtract the Fourier amplitude spectrum of the synthetic time history generated in step 1 from the Fourier amplitude spectrum of the synthetic time history produced in step 2. (5) Construct a synthetic acceleration time history so that (1) its Fourier amplitude spectrum is the difference of the Fourier amplitude spectra calculated in step 4 and (2) its phase coincides with the phase of the Fourier transform of the synthetic time history generated in step 2. (6) Superimpose the time histories generated in steps 1 and 5. The near-source pulse is shifted in time so that the peak of its envelope coincides with the time that the rupture front passes in front of the station.

3. THE SEISMOTECTONIC AND SEISMICITY OF TOMBAK REGION

The Zagros regions one of the most seismically active regions in Iran. The Tombak LNG terminal are located along the Persian Gulf northern coast, south of the Zagros Mountains, which mark the deforming zone separating Arabia (Arabian plate) and Central Iran (Eurasian plate). The massive LNG storage tanks exist in terminal. These tanks have high importance from engineering and economical point of view so seismic loads should be considered in design and so in the relevant codes of LNG storage containers emphasize that a seismic hazard investigation should be conducted for regional seismicity and earthquake events of known near fault.

4. RESULTS AND DISCUSSION

All parameters used for simulation are summarized in Table 4.1. The near field strong motion time histories that have been obtained from the stochastic method are presented for two levels of earthquakes (475y and 5000y) in Figures 1 and 2. The long period pulse has been calculated and presented in Figures 3 and 4 for both return periods.

Table 4.1 model parameters

	Input parameters	Value	
Stochastic model parameters	Seismic Moment, M_0	6.5×10^{22} Nm	
	Average asperity stress drop, $\Delta\sigma$	60 bars	
	Shear wave Velocity of the bedrock (site), v_s	3.5 km/s	
	Density of the bedrock, ρ_s	2.8 gr/cm^3	
	Shortest distance between source and site, R	5 km	
	Duration of Strong Ground Motion, T_{gm}	15s	
	Q (frequency dependent quality factor)	$100 \times f^{0.8}$	
	f_{max} (cutoff frequency)	10 Hz	
	C_Q (Rupture velocity)	$0.8 \times$ shear-wave velocity	
	Return period	***475 year***	***5000 year***
General parameters	Magnitude	6.5	7.0
	Epicenteral distance	5	5
	Depth	11	14
	Hypocenteral distance	12	15
M & P model parameters	Amplitude of pulse, A	50	90
	Phase of pulse, ν	134°	100°
	Oscillatory character of the signal, γ	1.5	2
	Time shift, t_0,	5 s	6.4 s

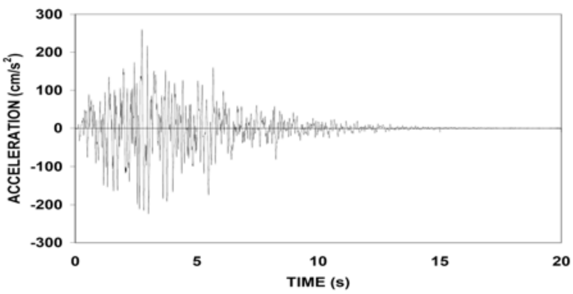

Figure 1 Synthetic acceleration time history
(Return period = 475 year)

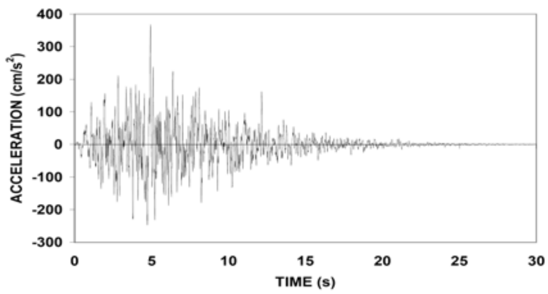

Figure 2 Synthetic acceleration time history
(Return period = 5000 year)

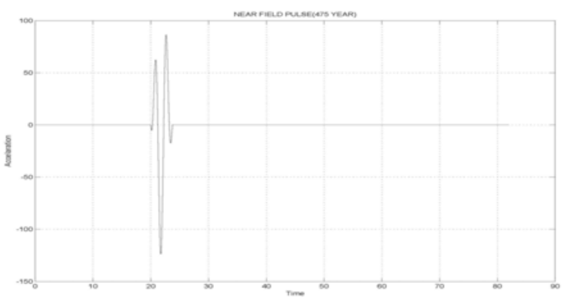
Figure 3 Long period pulse
(Return period = 475 year)

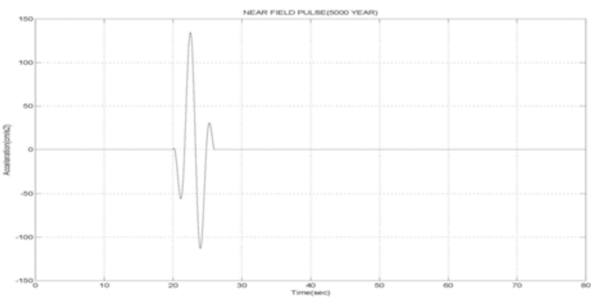
Figure 4 Long period pulse
(Return period = 5000 year)

In this stage, the pulse acceleration superimpose to the synthetic acceleration time history. The near-source pulse is shifted in time so that the peak of its envelope coincides with the time that the rupture front of the station. The final acceleration time histories for both levels of earthquakes are shown in figures 5 and 6. The response spectra obtained from simulated strong ground motion analysis for 5% damping are shown in figures 7 and 8 for return periods 475 and 5000 year, respectively. As it is clear in Figure 7, the response spectrum has a sudden increasing for period range of 1 to 4 seconds that shows the effect of long period pulse and also in Figure 8 this increasing has happened in period rage of 2 to 6 seconds. Therefore, structures which their periods settle in these ranges, are influenced from near field with long period pulse ground motion. In Figure 9, the smoothed response spectra which have obtained for return period of 475 year have been compared with IBC 2000, Iranian Code of Practice for Seismic Resistance Design Building (Standard No. 2800). This Figure shows, in the period range of 0 to 1 second, the response spectrums are close to each other but when the period exceeds than 1 second, the effect of long period pulse become apparent in response spectra.

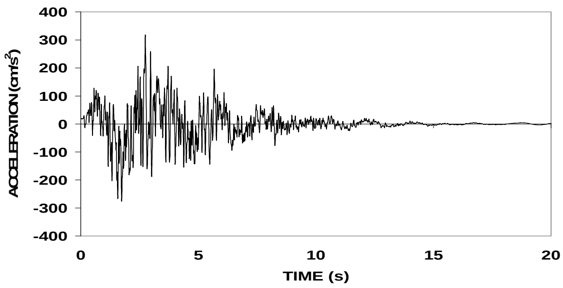

Figure 5 Final acceleration time history
(Return period = 475 year)

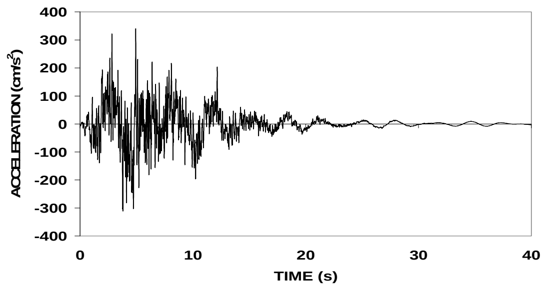

Figure 6 Final acceleration time history
(Return period = 5000 year)

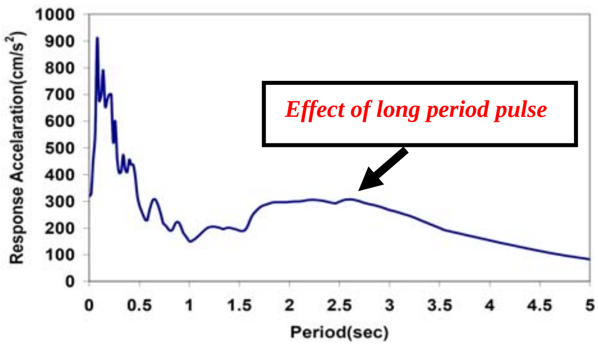

Figure 7 Response spectrum for final acceleration time history
(Return period = 475 year)

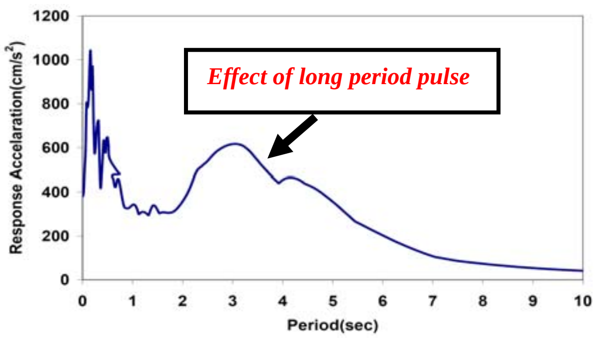

Figure 8 Response spectrum for final acceleration time history
(Return period = 5000 year)

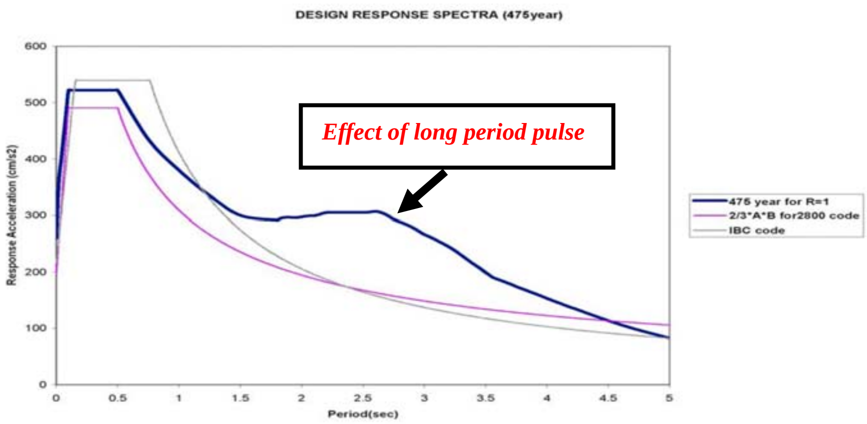

Figure 9 Comparison between response spectrums

5. SITE RESPONSE ANALYSIS

Soil investigation and borings are carried out for the detail design of storage tank foundations and spill basin structures of the Project in Tombak area. Seismic tests of downhole are done for full depth (80m) and shear and compression waves velocity (Vs & Vp) are determined. The results are presented in Table (5.1). Based on Iranian building code the shear wave velocity more than 760 m/s is assigned rock therefore the seismic bed rock is located at 10m. The Iranian Code of Practice for Seismic Resistant Design of Buildings (standard No. 2800) has been used to classify the type of the soil in the project. The soil is type II and class C in according to 2800 standard. One-dimensional ground response analysis of the site was carried out by equivalent linear approach using SHAKE 91 program (Idriss et al., 1992).

Table 5.1 Soil properties

Depth	Density	Vp	Vs	E	G	K	υ
m	gr/cm3	m/sec	m/sec	Mpa	Mpa	Mpa	
0-1.3	2.1	570	330	571	229	377	0.25
1.3-4	2.1	850	500	1297	525	817	0.24
4-5.5	2.1	1040	600	1891	756	1263	0.25
5.5-10	2.1	1500	700	2801	1029	3353	0.36
10-20	2.25	1520	760	3466	1300	3466	0.33
20-30	2.3	1600	800	3925	1472	3925	0.33
30-42	2.15	1600	835	3936	1499	3505	0.31
42-52	1.96	1650	870	3879	1484	3358	0.31
52-62	2.2	1600	820	3911	1479	3660	0.32
62-78	2.17	1650	900	4529	1758	3564	0.29

The average shear wave velocity of soil within 30 m was found to be around 650 m/s. The results of ground response analysis are presented in Figures 10 to 13 which indicate that the increase of PGA at the surface is not so much and about 1.06 and 1.11 times higher than at the bed rock for 475 year and 5000 year, respectively. The response spectra obtained from ground response analysis for 5% damping are shown in Figures 14 and 15.

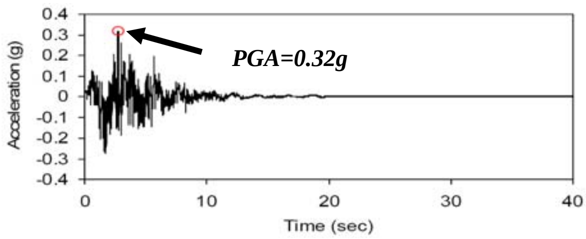

Figure 10 Simulated acceleration time history on bedrock
(Return period = 475 year)

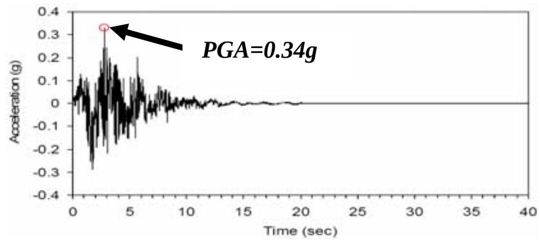

Figure 11 Obtained surface acceleration time history
((Return period = 475 year)

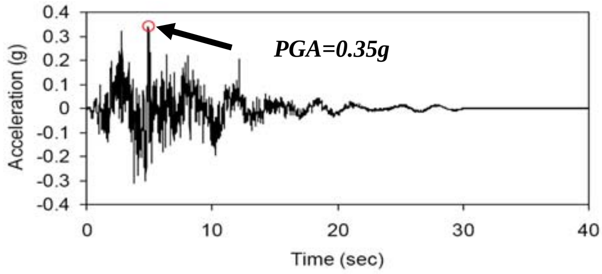

Figure 12 Simulated acceleration time history on bedrock
(Return period = 5000 year)

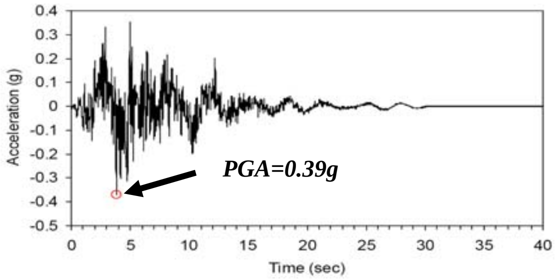

Figure 13 Obtained surface acceleration time history
(Return period = 5000 year)

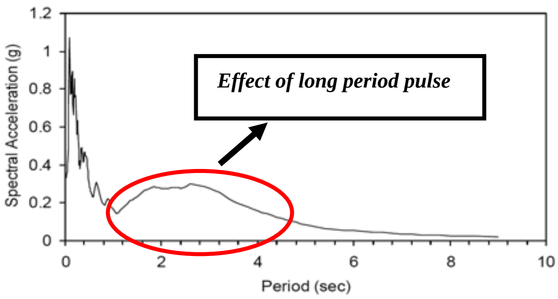

Figure 14 Spectral acceleration obtained by response analysis
(Return period = 475 year)

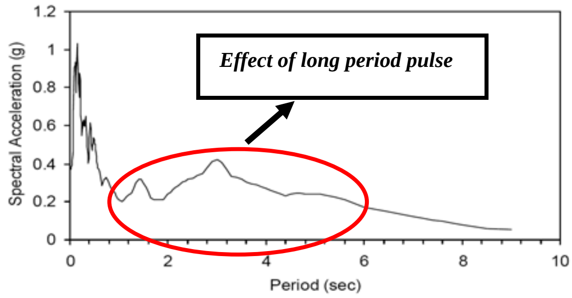

Figure 15 Spectral acceleration obtained by response analysis
(Return period = 5000 year)

6. CONCLUSION

The present study has been focused on the simulation of acceleration time histories for Tombak area in south-eastern part of Iran. The simulation of ground motion has been carried out using the stochastic method proposed by Boore (2003). After that, the analytical model proposed by Mavroeidis and Papageorgiou (2003) is applied to consider the impulsive character of near-fault ground motion. Then the response of site under simulated ground motion has been studied by conducting one dimensional ground response analysis. The results can be used for estimating the probable ground motion acceleration time-histories to be used in hazard analysis of specific sites in the region under study particularly for performance analysis of exiting structures. The ability of this hybrid method in simulation strong motions is also shown in this study. The simulation parameters obtained in this study can be used to asses the strong-motion level at a much larger number of sites, where no record is available, to investigate how different characteristics of motion affected damage distribution in the Tombak region. Based on the above study the following conclusions are arrived:

- The maximum PGA at bedrock at the Tombak site is established as 0.32 g and 0.35 g for return period of 475 and 5000 year respectively.
- Ground response analysis indicates, the small increase of PGA at the surface is about 1.06 and 1.11 times higher than at the bedrock for return period of 475 and 5000 year respectively.
- The response spectra obtained from the analysis indicates that the effect of long period pulse appears in the period range of 1 s to 6 s which is the typical range of period for LNG storage tank structures constructed in the Tomabk region.

References

Abrahamson, N. A. and Somerville P. G. (1996). Effects of the hanging wall and foot wall on ground motions recorded during the Northridge earthquake. *Bulletin Seismological Society of America*, 86, 93–99.

Atkinson, GM. and Boore, DM. (1995). Ground motion relations for Eastern North America. *Bulletin Seismological Society of America*, 85, 17-30.

Boore, D. M. (2003). Simulation of ground motion using stochastic method. *Journal of pure and applied Geophysics*, 160, 635-676.

Boore, D.M. and Atkinson, G.M. (1987). Stochastic Prediction of Ground Motion and Spectral Response Parameters at Hard-rock Sites in Eastern North America, Bull. *Bulletin Seismological Society of America*. 77, 440–467.

Boore, D. M. (2000). SMSIM – Fortran Programs for Simulating Ground Motions from Earthquakes: Version 2.0—A Revision of OFR 96-80-A, *U.S. Geol. Surv. Open-File Rept*. OF 00-509, 55 pp. (available at http://geopubs.wr.usgs.gov/open-file/of00-509/).

Boore, D. M. (2002). SMSIM: Stochastic Method SIMulation of Ground Motion from Earthquakes. In IASPEI Centennial International Handbook of Earthquake and Engineering Seismology (W. Lee, K. Kanamori, P. Jennings, and C. Kisslinger, eds), Academic press, Chapter 85.13, (in press).

Campillo, M., Gariel, J.C., Aki, K., and Sanchez-Sesma, F. J. (1989). Destructive strong ground motion in Mexico City: source, path and site effects during the Great 1985 Michoacan earthquake. *Bulletin Seismological Society of America*. 79, 1718–1735.

Chin, B. H. and AKI, K. (1991). Simultaneous Study of the Source, Path, and Site Effects on Strong Ground Motion during the 1989 Loma Prieta Earthquake: A Preliminary Result on Pervasive Nonlinear Site Effects. *Bulletin Seismological Society of America*. 81, 1859–1884.

Hutchings, L. (1994). Kinematic Earthquake Models and Synthesized Ground Motion Using Empirical Green's Functions. *Bulletin Seismological Society of America*. 84, 1028-1050.

Idriss, I. M. and Joseph, I.S. (1992). User manual for SHAKE 91.

Mavroeidis, G. P., and Papageorgiou, A. S. (2002). Near-source strong ground motion: characteristics and design issues. *in Proc. of the Seventh U.S. National Conf. on Earthquake Engineering (7NCEE)*, Boston, Massachusetts, 21–25 July 2002.

Mavroeidis, G. P., Dong, G. and Papageorgiou, A. S. (2003). Near-fault ground motions, and the response of elastic and inelastic singledegree- of-freedom (SDOF) systems. *Earthquake Eng. Struct. Dyn*. 30, 1023-1039.

Mavroeidis, G. P., and Papageorgiou, A. S. (2003). A Mathematical Representation of Near-Fault Ground Motions. *Bulletin Seismological Society of America*. 93, 1099-1131.

O'Connell, D. R. H. (1998). Synthesizing site-specific near-field ground motions from reverse faults: new perspectives on peak velocity hazards using broadband site responses. *Proc. of the Sixth U.S. National Conf. on Earthquake Engineering (6NCEE)*, Seattle, Washington, 31 May–4 June 1998.

Somerville, P., and Graves, R. (1993). Conditions that give rise to unusually large long period ground motions. *Struct. Design Tall Buildings*, 2, 211–232.

Somerville, P. G., Smith, N. F., Graves, R. W., and Abrahamson, N. A. (1997). Modification of empirical strong ground motion attenuation relations to include the amplitude and duration effects of rupture directivity. *Seism. Res. Lett*. 68, 199–222.

TORO, G. R., and MCGUIRE, R. K. (1987). An Investigation into Earthquake Ground Motion Characteristics in Eastern North America, *Bulletin Seismological Society of America*. 77, 468–489.

Zafarani, H., Noorzad As. and Ansari, A. (2005). Generation of Near-fault Response Spectrum for a Large Dam in Iran, *Hydropower and Dams*, 12, Issue 4, 51-55.

Zafarani, H., Noorzad As. and Bargi, K. (2006). Generation of Near-Field Ground Motions in Tehran from Future Large Earthquakes in the Alborz Seismic Zone, *Proc. of the First European Conference on Earthquake Engineering and Seismology*, Geneva, Switzerland, 3-8 September, Paper No. 448.

Zafarani, H., Noorzad As. and Bargi, K. (2007). Stochastic Finite-Fault Strong Ground-Motion Simulation of the 22 February 2005 (Mw 6.4) Zarand (Central Iran) Earthquake, *Proc. of the 4th International Conference on Earthquake Geotechnical Engineering*, Thessalonica, Greece, 25-28 June, Paper No. 1147.

Zafarani, H., Mousavi, M., Noorzad As. and Ansari, A. (2008). Calibration of the Specific Barrier Model to Iranian Plateau Earthquakes and Development of Physically Based Attenuation Relationships for Iran, *Soil Dynamics and Earthquake Engineering*, 28, 550-576.