EVALUATION OF CHARACTERISTIC PERIOD CORRESPONED SEISMIC RESPONSE OF IRREGULAR TOPOGRAPHIC FEATURES

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ABSTRACT

Since the 2D modeling of topographic features, through numerical analysis, has been done up to now, all by symmetrical geometries, there is a problem that, whether the seismic response of asymmetrical models are so different or not. As the natural features are not symmetric, it is so important for engineers to know whether they can analyze them based on symmetrical models and how much is their risk. Therefore, in this paper we have evaluated the 2D site response based on parametric study of several asymmetric geometry models of hill (asymmetric semi-sine, triangular and trapezoidal shapes) and have compared them with the response of their corresponded symmetrical models. The studies have been done in time domain and soil material is considered linear elastic. Also, the assumed input motion was a Ricker type wavelet which was considered as SV and P plane wave and applied vertically. All calculations are executed in time-domain using the direct boundary element method. Clear perspectives of the amplification patterns of the hill are presented by investigation of the frequency-domain responses. Comparison of the obtained models characteristic periods indicated that they are mainly related to geometric properties of a part of models which includes larger surface of model plane and asymmetry factor has second rule.

KEYWORDS: Characteristic Period, Asymmetric Model, Shape Ratio, Amplification

1. INTRODUCTION

In the recent past there have been numerous cases of recorded motion and observed earthquake damage pointing toward topographic amplification as an important effect. Very high acceleration recorded at Pacoima Dam (1.25g) during the 1971 San- Fernando earthquake [26,5] and Tarzana hill (1.78g) during the 1994 Northridge earthquake [25] have been at least partly attributed to topographic effects. Observations from the 1983 Coalinga earthquake [10], the 1985 Chile earthquake [9], the 1987 Superstition Hills earthquake [10] as well as observations from recent earthquakes in Greece [2,8] are only some examples of catastrophic events, during which severe structural damage has been reported on high elevated regions.

Although nowadays it is well established that the seismic ground response of surface topographies could be different compared to those of the free field motion during earthquakes, but there are only few structural codes which have considered this issue (Eurocode8) [11]. This is due to complex nature of the seismic wave scattering by topographical structures which can only be solved accurately, economically and under realistic conditions, by advanced numerical methods. A recent compilation of works on the numerical modeling of seismic wave propagation has been presented by Bard [3], Beskos [4] and Sanchez-Sesma et al. [24].

Bouchon [7] was the first who attempted to evaluate the effect of semi-sine shaped hills on the surface motion. He used a frequency domain method which had been developed by Aki and Larner [1] and studied incident SH, P and SV waves. However, as Bouchon [7] mentioned, this method resulted in unreliable amplification factors for incident P and SV waves due to complicated calculations especially in high frequencies. Later Geli et al. [14] studied by use of the Aki and Larner method, the seismic behavior of 2D semi-sine shaped hills affected by non homogeneity of the media and existence of adjacent similar hills. But their study too, was restricted to a specific shape ratio of 0.5 and to the special case of the incident SH wave.

Sanchez-Sesma [23] was the first who assessed the seismic behavior of sharp corner-type hills but he has considered only triangular hills, SH incident wave and one specified Poisson's ratio. Then, Moczo et al. [22] evaluated the seismic behavior of trapezoidal hills. Their studies were consisted of SV incident wave and only one shape ratio, crest angel and Poisson ratio.

Kamalian and his colleagues were the first group who implemented wide range parametric study on the seismic behavior of semi-sine [20], semi-elliptical [18], trapezoidal [17] and triangular [21] Hills subjected to vertical in plane P and SV incident waves for different Poisson ratios. These studies have been done in time domain and soil material is considered linear elastic.

However, as it has been mentioned, all studies carried out on symmetric models, and the asymmetric geometry affect on seismic response of features still is an unconsidered problem. Therefore, this paper presents the results of a wide range numerical parametric study on amplification pattern of 2D homogenous asymmetric semi-sine, triangular and trapezoidal shaped hills subjected to vertically propagating incident SV and P waves, using time-domain boundary element (BE) method.

2. PARAMETRIC STUDY METODOLOGY

The properties of the 2D homogenous asymmetric semi-sine, triangular and trapezoidal shaped hill models (Figure 1) investigated in this parametric study defined as (Table 2.1).The chosen parameters are based on previous studies on corresponding symmetrical models [17, 20, 21]. In this paper and due to keeping abbreviation, only the results of SV waves and one of the Poisson ratios (0.33) will be presented and discussed.

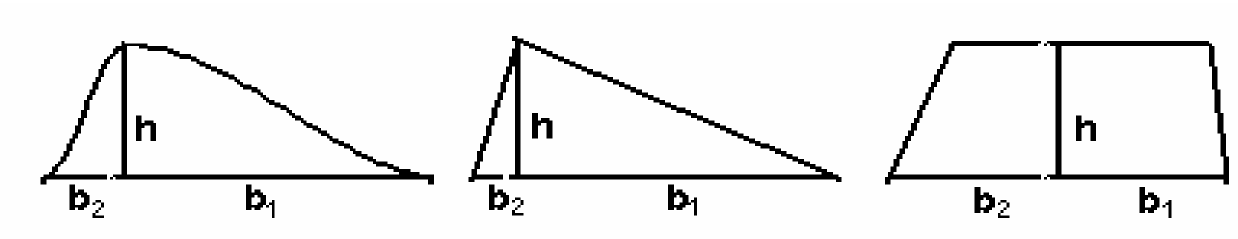

Figure 1. Geometry of the studied 2D homogenous asymmetric semi-sine, triangular and trapezoidal shaped hills

Table 2.1. Formulas and Properties Used for Modeling in the Study

Feature Shape	Boundary Formula (ξ)	Shape Ratio (h/b_i)		Slope Angle (degree)	
		Left Side	Right Side	Left Side	Right Side
Semi-Sine	$\lvert x\rvert \le b_i : \xi_i(x) = 0.5h(1+\cos(\pi\ x/b_i))$ $\lvert x\rvert \ge b_i : \xi_i(x) = 0$ $i=1,2$ (See Figure 1)	0.2	0.1	-	-
		0.4	0.3	-	-
		0.6	0.5	-	-
		0.8	0.7	-	-
		0.5	0.3	-	-
		0.7	0.5	-	-
		0.5	0.1	-	-
		0.7	0.3	-	-
		0.7	0.1	-	-
		0.8	0.2	-	-
		0.8	0.1	-	-
Triangular	$\xi_i(x) = x(h/b_i)$ $i=1,2$ (See Figure 1)	0.2	0.1	-	-
		0.4	0.3	-	-
		0.6	0.5	-	-
		0.8	0.7	-	-
		0.5	0.3	-	-
		0.7	0.5	-	-
		0.5	0.1	-	-
		0.7	0.3	-	-
		0.7	0.1	-	-
		0.8	0.2	-	-
		0.8	0.1	-	-
Trapezoidal	---	0.1	0.1	15	30
		0.1	0.1	15	45
		0.1	0.1	30	45
		0.3	0.3	30	45
		0.5	0.5	30	45

Where $\mathbf{b_i}$ and $\mathbf{h}$ denote the half of width and height of the hill, respectively.

In order to find out the pattern of asymmetric hill response, models were subjected to the vertically propagating Ricker type SV and P wave (Figures 2-a, 2-b), formulated as follows (Eqn 2.1):

$$f(t) = [1-2(\pi.f_p.(t-t_0))^2]e^{-(\pi.f_p(t-t_0))^2} \qquad (2.1)$$

Where $\boldsymbol{f_p}$ and $\mathbf{t_0}$ denote the predominant frequency and an appropriate time shift parameter, respectively. The applied incident Ricker-typed wavelet in all models here has had same parameters such as: f_P= 3(Hz), t_0= 0.45(s).

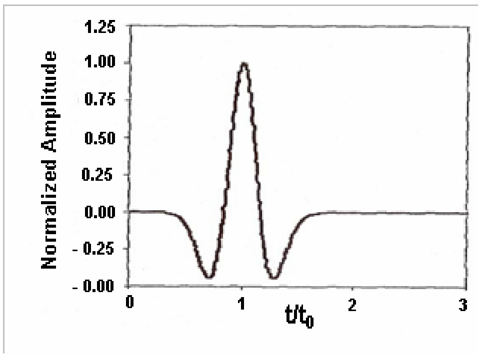

Figure 2-a. Normalized input motion of the Riker wavelet in time domain

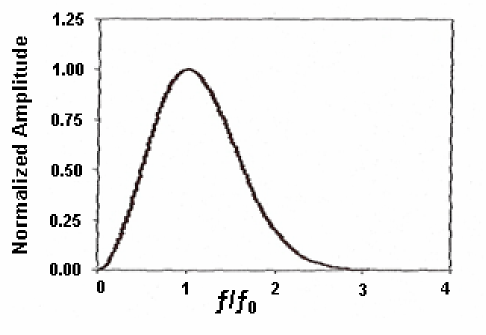

Figure 2-b. Normalized input motion of the Riker wavelet in frequency domain

The BE formulation was implemented in a general purpose two-dimensional nonlinear two-phase BEM/FEM code named as HYBRID [12,13,15]. Several examples were solved in order to show the accuracy and efficiency of this implemented BE algorithm in carrying out site response analysis of topographic structures [16 to 21].

All results have been presented in dimensionless forms, using the dimensionless frequency **Ω** (or its inverse: the dimensionless period) definition. The dimensionless period physically means as the ratio of the incident's wave length to the width of the hill ($\Omega = Bf/V$, where B, f and V are feature width, frequency and velocity of shear incident wave, respectively).

Based on engineering interests, a dimensionless period interval of 0.25 to 8.33 was considered, which corresponds to incident waves with wave lengths of 0.25 to 8.33 times the hill's width. This broad period interval was divided into the following five subintervals: 0.25 to 0.50 (P1), 0.50 to 1.00 (P2), 1.00 to 2.00 (P3), 2.00 to 4.17 (P4) and 4.17 to 8.33 (P5), corresponding to incident waves with very short, short, medium, large and very large wave lengths, respectively. For the reason of simplicity and following the well known concept of average horizontal spectral amplification (AHSA) defined by Borcherdt et al. [6] as spectral ratios representing averages over short, intermediate, mid and long period bands, five distinct amplification factors were computed for every point along the hill, by averaging the corresponding amplification curve over each of the above mentioned five period subintervals P1 to P5. Whereas the results will be used for engineering purposes and microzonation study of areas the mean deamplification of features considered as unit.

3. RESULTS OF PARAMETRIC ANALYSIS

This section presents the results of the implemented parametric study, which demonstrates the sensitivity of 2D shaped hill's amplification patterns on various asymmetry geometry conditions. As already was mentioned, in this paper only the seismic response of features subjected to incident SV will be presented. So the results illustrated in this paper have been limited to SV wave responses. But, In general the final conclusions include both P and SV wave patterns.

3.1. Amplification Pattern at the Crest of Hills

Figure 3 shows the crest amplification patterns of 2D symmetric and asymmetric semi-sine shaped hills with a various combinations of sides shape ratio which subjected to incident SV and P waves. The amplifications about incident SV wave major component (horizontal component) at features crest are indicated in the figure.

As indicated, increasing of shape ratio increases the characteristic period of the hill and its corresponding amplification factor. Characteristic Period (C.P.) is the period of subjected seismic motion which causes that all point of hill feature be in a same phase and have greater than 1 amplification value. Also, the greatest feature crest amplification occurs caused by characteristic period (C.P.). The amplification patterns show that if the motion period of incident wave be higher than characteristic period of feature, the shape ratio changing and geometry irregularity affect on amplification could be negligible, but in fewer motion period condition or equal with, the amplification will be affected considerably, especially in the case of larger shape ratios. In condition that a side of feature has small shape ratio (e.g. shape ratio=0.1) or large angle, the shape ratio (or angle) changes of other side don't have noticeable effect on crest amplification. Because generally, the amplification of feature response are affected by part of feature includes larger area, so the smaller shape ratios (or larger angle) which resulting larger area have main rule in this cases. As example, the amplification of asymmetric feature included 0.8 and 0.1 oppositely shape ratios is not noticeable different with the symmetric feature included 0.1 and 0.1 oppositely shape ratios. But the amplification of a feature included two big shape ratios (e.g. 0.7 and 0.8 oppositely) will be considerable. The amplification pattern and characteristic period changing of features subjected to incident P wave are similar to ones subjected to SV wave. Although the range of characteristic period and crest amplifications due to incident P wave are less than SV wave ones.

Also the results show that the irregularity of features has a considerable effect on seismic responses for opposite component of incident wave. As can be seen in Figure 4 the amplification of symmetric features motion subjected to opposite component of incident wave is naught, but in the case of asymmetric features it will be considerable.

3.2. Mean Amplification of Hills

Figure 5 shows the mean amplification factor of 2D triangular shaped hills with a various combinations of side shape ratios which subjected to incident SV waves in the classified dimensionless period limits and serious differential shape ratios. The range of mean amplifications related to incident SV wave major component on the asymmetric shaped hills with 0.1 differential shape ratios for sides (feature left shape ratio minus right shape ratio) are shown in the figure. The curves patterns addition to confirming the results of Figure 3 in previous paragraph shows that irrespective of the shape ratio, the dimensionless period of incident wave motion which illustrates wave length plays a key rule in determining the amplification range of the hill. Regarding the P and SV major component, if the incident waves posses a long or very long wave length (medium or short dimensionless period limits), the hill would experience greater amplification, which increases with the shape ratio.

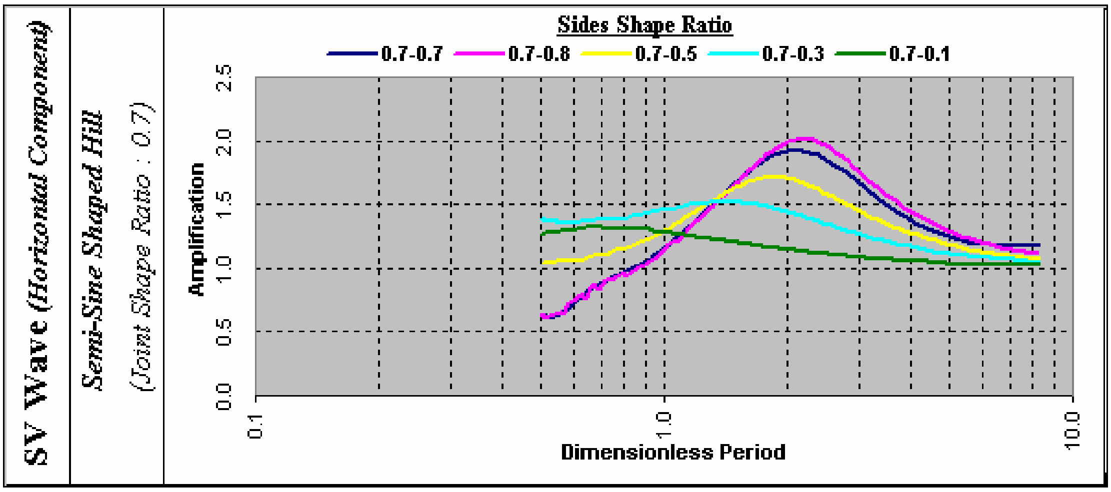

Figure 3. Comparative curves of features crest amplification and C.P. Vs. dimensionless period for major component of incident SV wave, with various combinations of side shape ratios, for asymmetric semi-sine shaped hill.

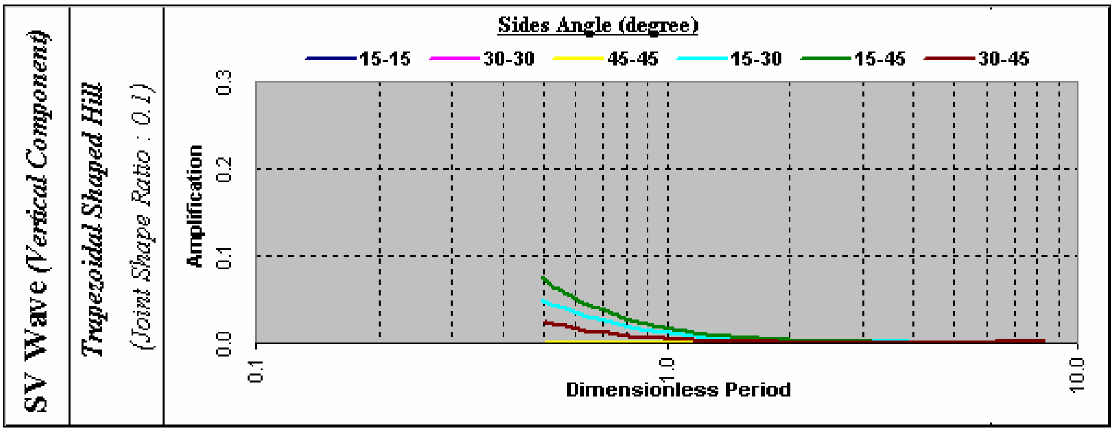

Figure 4. Comparative curves of features crest amplification Vs. dimensionless period for opposite component of SV wave, for various combinations of side angles, for symmetric and asymmetric trapezoidal shaped hill.

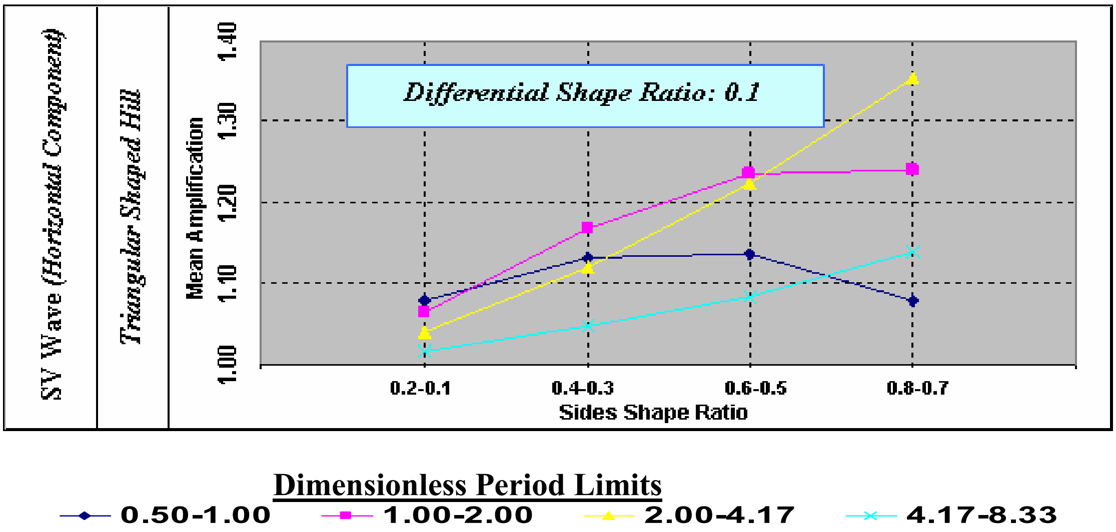

Figure 5. Comparative curves of mean amplification factor for major component of incident SV wave, based on differential shape ratio ($S.R_{left} - S.R_{right}$), for various combinations of symmetric and asymmetric triangular shaped side shape ratios, in considerable dimensionless period limits.

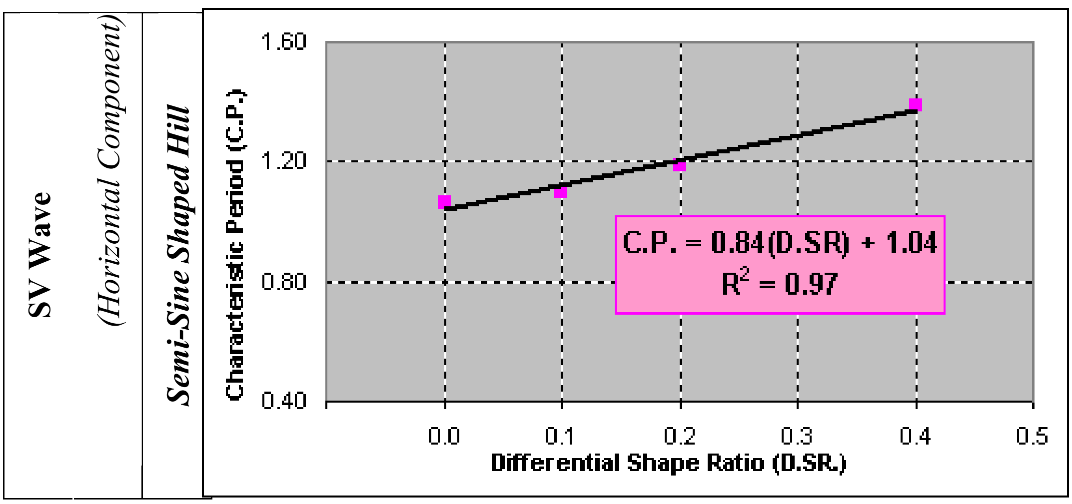

Figure 6. Linear formula for a semi-sine shaped hill with "basic ratio=0.3", subjected to horizontal component of incident SV wave.

General conclusion illustrates that the seismic response of asymmetric hills are controlled by the part of feature which have smaller shape ratio (or larger angle for trapezoidal shaped) causes larger area of the feature that we named it "basic shape ratio" here. Therefore, as a result of this parametric analysis some linear formula presented here which make a relation between "basic shape ratio" and irregularity of triangular and semi-sine shaped hill, to estimate the characteristic period (C.P.) of seismic response for symmetric and asymmetric ones. The formula are shown for a semi-sine shaped hill with "basic ratio=0.3" which subjected to a horizontal component of incident SV wave in Figure 6and others listed in (Table 3.1).

Table 3.1 Linear formulas for estimating the characteristic period of symmetric and asymmetric triangular and semi-sine shaped hills

Basic Shape Ratio	*Semi-Sine Shaped Hill*	*Triangular Shaped Hill*
	SV Wave (Horizontal Component)	**SV Wave** (Horizontal Component)
0.1	C.P. =0.32(D.SR.)+0.5	C.P. =0.28(D.SR.)+0.55
0.3	C.P. =0.84(D.SR.)+1.04	C.P. =0.26(D.SR.)+0.59
0.5	C.P. =0.93(D.SR.)+1.67	C.P. =5.03(D.SR.)+0.81
0.7	C.P. =0.94(D.SR.)+2.08	C.P. =10.71(D.SR.)+0.98

4.CONCLUSION

This study includes a comparative analysis for determination of amplification patterns and characteristic period of 2D homogenous asymmetric semi-sine, triangular and trapezoidal shaped hills and symmetrical ones subjected to vertically propagating SV and P waves, by numerically investigation of the hill's response using the time domain boundary element method. It has been shown that:

• The amplification potential of the symmetric and asymmetric shaped hill is strongly influenced by the length of the incident wave, by the shape ratio and in a less order of importance by the wave type.

• In the case of incident waves with lengths of longer than the width of the hill, where the predominant periods are usually equal to or greater than its characteristic period, the amplification curve finds it's maximum at the crest. And in the case of incident waves with smaller lengths the amplification could be negligible.

• The major effect of feature geometry corresponds with the shape ratio or angle of feature part which has smaller shape ratio (or larger angle) causes larger area, named here "basic shape ratio or angle".

REFERENCES

1- Aki K and Larner K. "Surface motion of a layered medium having an irregular interface due to incident plane SH waves" Journal of Geophysical Research , 75, 933-954, 1970.
2- Athanasopoulos GA, Pelekis PC and Leonidou EA. "Effects of Surface Topography on Seismic Ground Response in the Egion (Greece) 15-6-1995 Earthquake" Soil Dynamics and Earthquake Engineering, 18, 135-149, 1999.
3- Bard PY."Effects of surface geology on ground motion: recent result and remaining issues."Proc.10th European Conf. on Earth, Eng.Vienna, 305-323, 1994.
4- Beskos DE. Boundary element methods in dynamic analysis: Pt. II (1986-1996), Appl Mech Rev, 50,149-197, 1997.
5- Boore DM. "The effect of simple topography on seismic waves: implications for the accelerations recorded at Pacoima Dam, San Fernando Valley, California" Bull Seismol Soc Am, 63, 16031609,1973.
6- Borcherdt, RD. "Estimates of site-dependent response spectra for design (Methodology and Justification)" Earthquake Spectra, 10, 617-653, 1994.
7- Bouchon M. "Effect of Topography on Surface Motion" Bull Seismol Soc Am, 63, 615-632, 1973.

8- Bouckovalas GD and Kouretzis G. " Review of Soil and Topography Effects in the September 7, 1999 Athens (Greece) Earthquake," Proceedings of the Fourth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics And Symposium in Honor of Professor WD Liam Finn, San Diego, California, 2001.
9- Celebi M. "Topographical and geological amplifications determined from strong-motion and aftershock records of the 3 March 1985 Chile earthquake," Bull Seismol Soc Am, 77, 1147-1167,1987.
10- Celebi M. "Topographic and geological amplification: Case studies and engineering implications, "Structural Safety, 10, 199-217, 1991.
11- Eurocode8 (EC8),Design provisions for earthquake resistance of structures, 1998.
12- Gatmiri B., Kamalian M. "Time Domain Two-Dimensional HYbrid FEM / BEM Dynamic Analysis Of Non-Linear Saturated Porous Media," Proc. 2nd Canadian Specialty Conference On Computing In Geotechnique, 2002a.
13- Gatmiri B and Kamalian M. "Combination of boundary element and finite element methods for evaluation of dynamic response of saturated porous media" Proc. 5th European Conference on Numerical Methods in Geotechnical Engineering, 2002b.
14- Geli L, Bard PV, Julien B. "The effect of topography on earthquake ground motion: a review and new results," Bull Seismol Soc Am, 78, 42-63, 1988.
15- Kamalian, M. "Time domain two-dimensional hybrid FEM/BEM dynamic analysis of non-linear saturated porous media" Ph.D. Dissertation, Tehran University, 2001 (In Persian).
16- Kamalian M, Gatmiri B, Sohrabi-Bidar A. "On Time-Domain Two-Dimensional Site Response Analysis of Topographic Structures by BEM" JSEE, 5, 35-45, 2003.
17- Kamalian, M., Jafari MK, Sohrabi-Bidar A and Razmkhah A. "Amplification Pattern of 2D Trapezoidal Shaped Hills Subjected To Vertically Propagating Incident Waves", published in Tarbiat Modares Engineering Journal, 2004. (In Persian)
18- Kamalian, M., M.K. Jafari, A. Razmkhah and A. Sohrabi-Bidar, "Amplification Pattern of 2D Semi-Elliptical Shaped Hills Subjected To Vertically Propagating Incident Waves,"published in AmirKabir Engineering Journal, 2004. (In Persian)
19- Kamalian, M., Jafari, MK., Sohrabi-bidar, A., Razmkhah, A., Gatmiri, B., "Time-domain twodimensional site response analysis of non-homogeneous topographic structures by a hybrid BE/FE method," Soil Dyn Earthquake Eng., 26:753-765, 2006.
20- Kamalian, M., Jafari M.K, Sohrabi-Bidar A and Razmkhah A. "Amplification Pattern of 2D Semi-Sine Shaped Hills Subjected To Vertically Propagating Incident Waves" Accepted to published in Earthquake Spectra Journal, 2007.
21- Khosravi H, Razmkhah A, Kamalian M."Parametric Analysis of The seismic Response of Triangular Shaped Topographic Features in Time Domain." M.Sc. Thesis,Islamic Azad University , Arak branch,Iran, 2006.(In Persian).
22- Moczo P, Bystricky E, Kristek J, Carcione J.M. and Bouchon M, "Hybrid modeling of P-SV seismic motion at in homogenous viscoelastic topographic structures," Bull. Seism. Soc. Am., Vol. 87, pp. 1305-1323, 1997..
23- Sanchez–Sesma FJ and M. Campillo. "Diffraction of P, SV and Rayleigh Waves by topographical features: a boundary integral formulation," Bull. Seism. Soc. Am., 81, 1991.
24- Sanchez-Sesma FJ, Palencia VJ and Luzon F. "Estimation of local site effects during earthquakes: an overview," ISET Journal of Earthquake Technology, 39, 167-193, 2002.
25- Spudich P, Hellweg M and Lee WHK."Directional topographic site response at Tarzana observed in aftershocks of the 1994 Northridge, California, Earthquake: Implications for main shock motions" Bull Seismol SocAm, 86, S139-S208, 1996.
26- Trifunac MD. and Hudson DE. "Analysis of the Pacoima Dam accelerograms – San Fernando earthquake of 1971," Bull Seismol Soc Am, 61, 1393-1411, 1971