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LOW PERIOD AMPLIFICATION PATTERNS OF TOPOGRAPHIC FEATURES SUBJECTED TO VERTICALLY PROPAGATING INCIDENT SV WAVES

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ABSTRACT

This paper concentrates on the preliminary results of an extensive 2D parametric study of the high frequency (low period) input motion site response analysis in time domain and evaluates the effects of such input motion on seismic behavior of different shapes surface topographies (semi-elliptical, semi-sinusoidal and trapezoidal shapes). The soil is assumed to have a linear elastic behavior. Also, the assumed input motion of Ricker-typed wavelet is considered as an Incident SV in-plane wave. The results are presented in the form of dimensionless parameters as Shape Ratio (the ratio of height to half width of the topography) and dimensionless frequency (the ratio of half width of the topography to wave length). Therefore the conclusions of this study can be generalized and used for different geometries and input motions. The results of the parametric study show that in all studied geometries, interference of different distributed plane waves makes a very disturbed field of waves inside the topography and in-plane wave scattering, where separation of different waves is very difficult. Finally, the preliminary relationships between the ratio of 2D/1D peak ground acceleration (PGA) and shape ratio is proposed.

Keywords: Time Domain, Topography Effects, Amplification, Shape Ratio, Frequency, Scattering

INTRODUCTION

Nowadays, site effects studies is one of most important issues in earthquake engineering practice. The conditions of the soil layering and the topography of sites can be affected all parameters of strong ground motion such as time duration, amplitude, wavelength, etc. Engineers traditionally have evaluated such effects through simple models based on one-dimensional (1D) soil profile and seismic wave propagation. The recent occurred earthquakes such as Kobe city earthquake in Japan, where 6000 people lost their lives, showed the complexity of seismic patterns due to site effect. The uncertainty and underestimation of magnitude of earthquakes resulted from 1-D analysis, can be so dangerous, because the 2-D and 3-D site effects may happen more in the alluvial valleys or on the topographies where cities are constructed on.

At present the state of knowledge on surface irregularities (topography) effects is less advanced compared to the subsurface irregularities effects despite the numerous studies conducted on the subject during the last 30 years. A recent compilation of works on the numerical modeling of seismic propagation has been presented by Beskos (1997) and Sanches-Sesma et al (2002). One reason for the scarcity of research on this subject is that topographic site effects are generally smaller than those due

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to subsurface irregularities and that, at the same time, there is the lack of good quality instrumental data.
The review of published studies on the effect of topographies on seismic motion shows that up to now, perfect parametric study which include the whole effects of geometrical and geomechanical properties (such as type and length of incident waves and shape, dimensions and geomechanical properties of hills) of this type of topographies hasn't been implemented. Most of the implemented studies of seismic behavior of 2D hills are concentrated on the evaluation of numerical method's capability rather than the seismic behavior analysis.
Bouchon (1973) 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 (1970) and studied incident SH, P and SV waves. However, as Bouchon (1973) 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. (1988) studied by use of the Aki and Larner method, the seismic behavior of 2D semi-sine shaped hills affected by nonhomogenity 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 and Campilo (1991) were the first group who evaluated the semi-elliptical hills effects on the ground surface seismic motion. While their studies was considered both P&SV body waves, but was limited to only one shape ratio and on Poisson's ratio. Pedersen et al. (1994) also was the next group who studied the seismic behavior of 2D semi elliptical hills subjected to different incident angles and azimuths, but their studies was restricted to only one shape ratio and Poisson's ratio, too. Sanchez-Sesma 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. (1997) was evaluated the seismic behavior of trapezoidal hills. Their studies were consisted of SV incident wave and only one shape ratio, crest angel and Poisson's ratio.
Kamalian et al. (2006) were the first group who implemented and completed wide range parametric study on the seismic behavior of semi-sinusoidal (2006), semi-elliptical (2004) and trapezoidal hills (2004) subjected to vertical in plane P&SV incident waves. These parametric analyses through boundary element method has been included the effects of shape ratio, the ratio between incident wave length and hill dimension (width), the crest angel (only for trapezoidal hills), wave type and Poisson's ratio, separately at low to medium range frequencies of input motion . In this study and in order to extend the results of above-mentioned studies for appointment the preliminary relationships between the ratio of 2D/1D peak ground acceleration (PGA) and shape ratio , extensive parametric studies at high frequencies (low periods) is performed. This paper were presented the selective comprehensive results and simple formula for estimating the 2D/1D PGA versus shape ratio of the different type of hills, which could be easily applied in site effect microzonation studies for topographic areas

PARAMETRIC STUDY METHODOLOGY

The parametric study included three distinct cases of trapezoidal, semi-sine and semi-elliptical shaped 2D hills. Formula used for definition of geometry and the range of parameters which used in parametric analysis are presented in table (1). Figures (1-a) to (1-c) schematically show the geometry of studied topography. Also, Figures (2-a) and (2-b) present the input motion for the Ricker –typed wavelet.

The BE formulation was implemented in a general purpose two-dimensional nonlinear two-phase BEM/FEM code named as HYBRID (Kamalian & Gatmiri, 2001). All results have been presented in dimensionless forms, using the dimensionless frequency Ω (or its inverse: the dimensionless period) definition. The dimensionless period means physically as the ratio of the incident's wave length to the width of the hill.

The hills were subjected to vertically propagating incident SV waves of the Ricker- typed wavelet:

$$f(t) = \left[1 - 2 \cdot (\pi \cdot f_p \cdot (t - t_0))^2\right] e^{-(\pi \cdot f_p \cdot (t - t_0))^2} \quad (1)$$

in which, f_p and t_0 denote the predominant frequency and an appropriate time shift parameter, respectively. The incident Ricker-typed wavelet had in all cases a predominant dimensionless frequency of 1.5 and a dimensionless time shift parameter of 0.9.

Several examples were solved in order to show the accuracy and efficiency of the above mentioned method in carrying out site response analysis of topographic structures (Kamalian et al. 2003).

Table 1. Formula and the range of parameters which used in parametric analysis

Parameters / Shape of Topography	Geometric Properties			Geomechanical Properties
	SR=h/b	Inclination Slope (degree)	Equation	Possion`s ratio
Semi-Elliptical	0.1-0.2-0.3-0.4-0.5-0.6-0.7-1.0	-	$\xi(x) = -\sqrt{h^2\left(\left(1 - x^2/b^2\right)\right)}$	0.33
Semi-Sinusoidal	0.1-0.2-0.3-0.4-0.5-0.6-0.7	-	$\zeta(x) = \frac{h}{2}(1 + Cos\frac{\pi x}{b})$	0.33
Trapezoidal	0.1-0.2-0.3-0.4-0.5-0.6-0.7	45	-	0.33

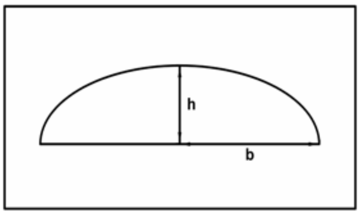

Figure 1-a. semi-elliptical topography

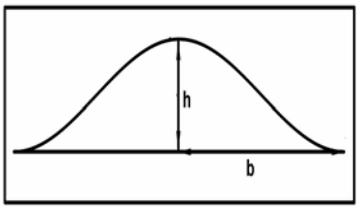

Figure 1-b. semi-sinusoidal topography

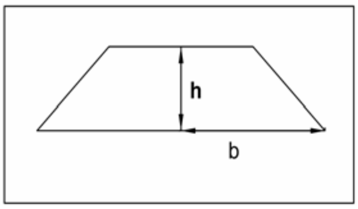

Figure 1-c. trapezoidal topography

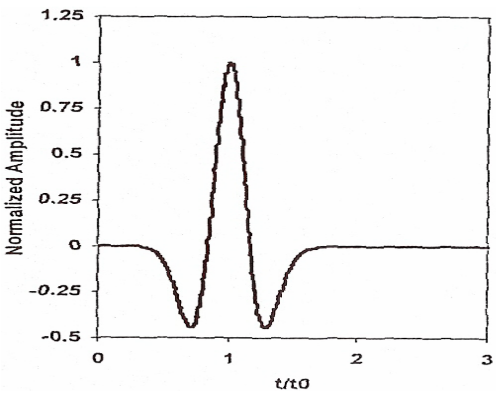

Figure 2-a. Normalized input motion of the Ricker- typed wavelet in time domain

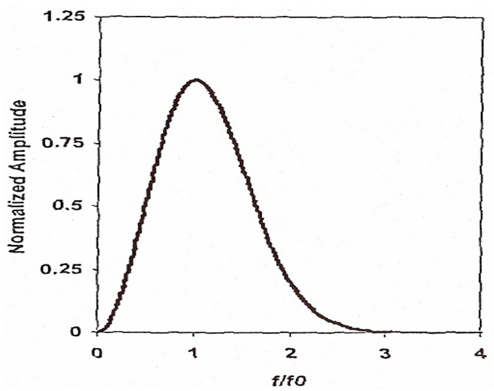

Figure 2-b. Normalized input motion of the Ricker wavelet in Frequency domain

RESULTS OF PARAMETRIC ANALYSIS

Results of parametric analysis on different-typed topographies are presented in two groups. The first group includes the 3-D curves that are sketched beside each other for different point on the topography and its vicinities. These curves contain the time history of vertical and horizontal amplitude component for the whole and a part of chosen region. Some of them are presented in Figures (4) to (6). These outputs contain all ranges of frequency or period and demonstrate the total concept of topography's physical behaviour, and therefore, this is only possible to have a qualitative discussion on these results. In order to achieve applicable and also quantitative results, the number of variables involved the problem should be reduced. This group of results is the second group which have a smoothed and balanced form of the first group .Since, the frequency ranges divided to different separated dimensionless frequency(or periodic) ranges. Therefore dimensionless periodic ranges consist of (0.125-0.25), (0.25-0.5), (0.5-1.0), ((1.0-2.0), (2.0-4.0) and (0.125-4.0) were achieved and figures (7) to (9) show these results. The obtained results of the first group, distinguish the scattering waves and refracted waves by the topography shape.
The waves that are scattered due to topography effects are the reflected waves, inter surface waves and the ones which have changed their modes. In the general form and based on two groups of results it can be understood that:

- With increasing the shape ratio of topography (SR), the amplitude of scattering waves is increased and the effect of topography on seismic response will be magnified. For low values of shape ratio (SR), seismic response of topography will be approached to free field response.
- The Scattering waves coming to the surface of the topography with the P wave velocity have the maximum amplitude near the topography and their amplitude will be reduced proportion to the increase of distance from that topography.
- The scattering waves with SV wave velocity received on the ground surface are mixed with Rayleigh surface waves due to the edges and have a low velocity which is proportional to the distance from the topography.
- In high frequency (low periods), topography have a complicated behaviour and there will be a lot of amplification and deamplification patterns on different points of topography.
- With increasing the shape ratio of topography, the range of amplification and deamplification will be reduced.
- In second group of results, the higher shape ratio causes to increase the amplification factor in horizontal component and all periodic ranges. This trend is more complicated in the range of lower periods. In the vertical component, the higher shape ratio causes to increase the amplification factor and lower periodic range causes to increase the mean amplification factor.

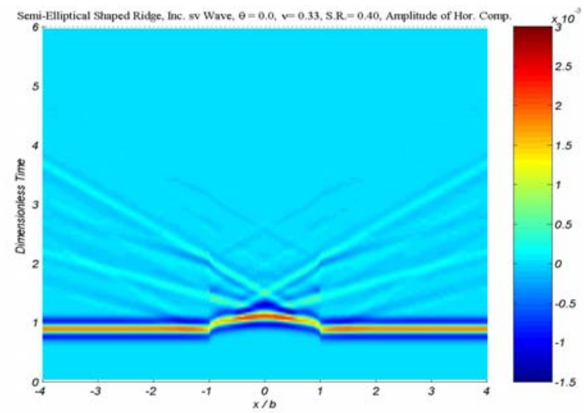

Figure 4-a. Time history for horizontal component of semi-elliptical topography with the SR= 0.4

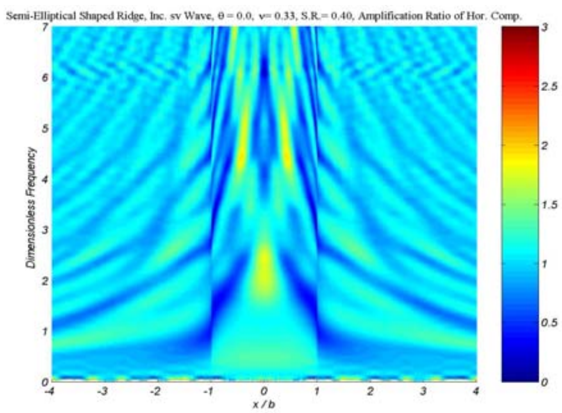

Figure 4-b. Amplification factor for horizontal component of semi-elliptical topography with the SR= 0.4

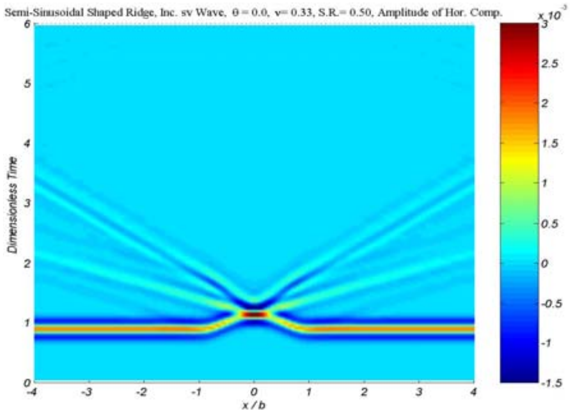

Figure 5-a. Time history for horizontal component of semi-sinusoidal topography with the SR= 0.4

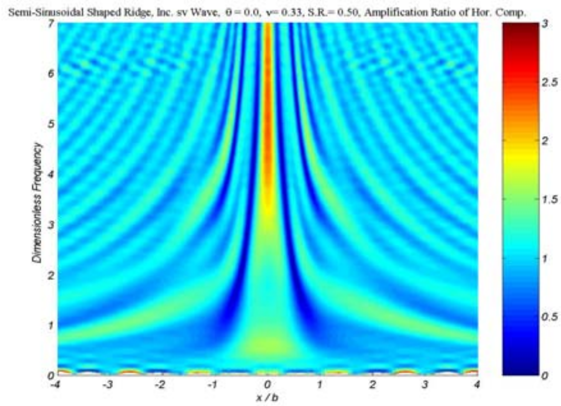

Figure 5-b. Amplification factor for horizontal component of semi-sinusoidal topography with the SR= 0.4

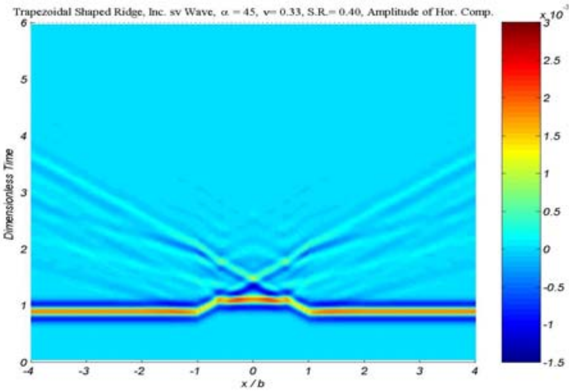

Figure 6-a. Time history for horizontal component of trapezoidal topography with the shape ratio=0.4

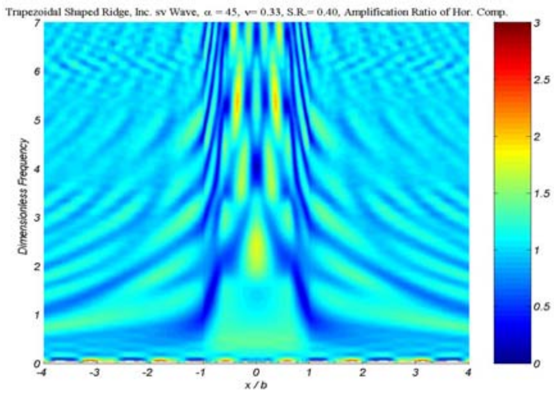

Figure 6-b. amplification factor for horizontal component of trapezoidal topography with the SR= 0.4

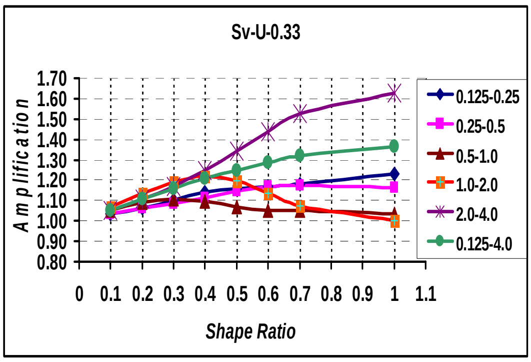

Figure 7-a. Mean amplification factor for horizontal component of semi-elliptical topography for different shape ratio and periodic ranges

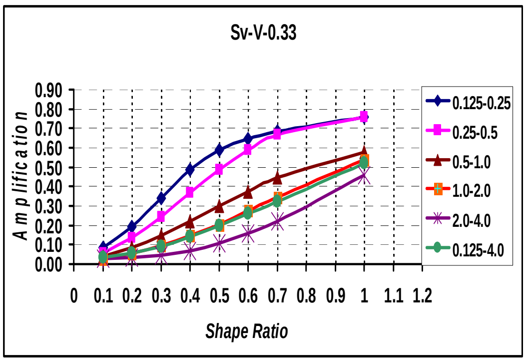

Figure 7-a. Mean amplification factor for vertical component of semi-elliptical topography for different shape ratio and periodic ranges

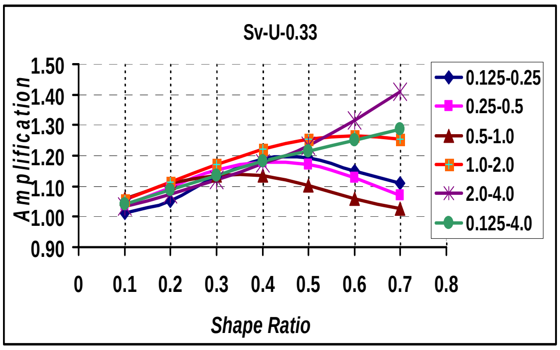

Figure 8-a. Mean amplification factor for horizontal component of semi- sinusoidal topography for different shape ratio and periodic ranges

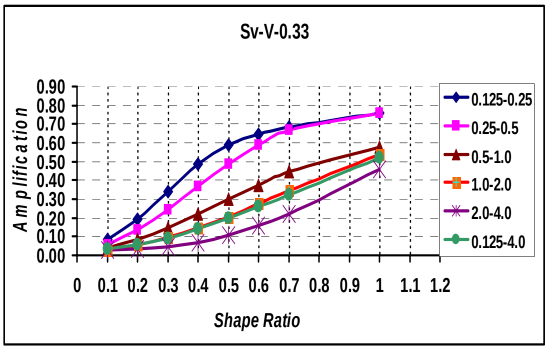

Figure 8-b. Mean amplification factor for vertical component of semi- sinusoidal topography for different shape ratio and periodic ranges

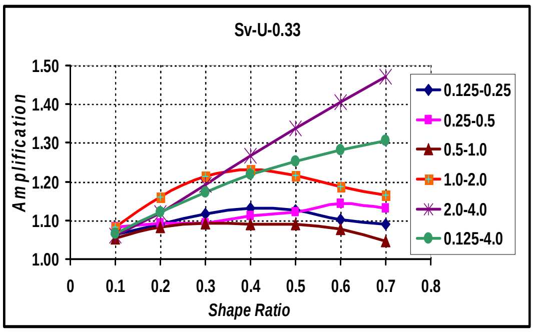

Figure 9-a. Mean amplification factor for horizontal component of trapezoidal topography for different shape ratio and periodic ranges

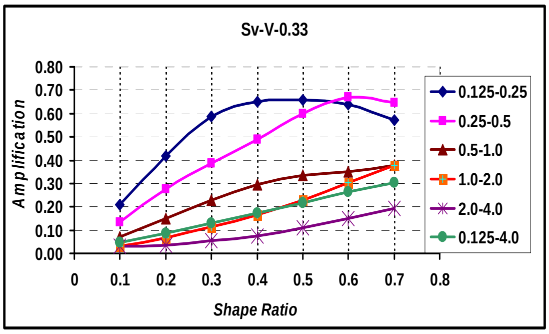

Figure 9-b. Mean amplification factor for vertical component of trapezoidal topography for different shape ratio and periodic ranges

RESPONSE SPECTRUMS BASED ON PARAMETRIC ANALYSES

The output response spectra of 2D analysis for different topographic shapes (Trapezoidal, Semi-Sinusoidal and Semi-Elliptical) at the top point of topography (x/b=0) is obtained for different shape ratios and also, the 1D response spectra for a Ricker-typed wavelet of a free field are calculated using 2D and 1D analysis respectively. The results are presented in Figures (10) to (13).

It is important to note that in all calculations for response spectra, the 5% damping was used. The results are presented as the ratio of 2D/1D PGA for different shape ratios and topographies. Then the best line correlated among them as follows:

The Semi-Elliptical topography:

$$\frac{PGA_{2-D}}{PGA_{1-D}} = -21.126(SR)^4 + 37.816(SR)^3 - 17.124(SR)^2 + 1.7238(SR) + 1.9132 \qquad (R^2 = 0.9831)$$

The Semi-Sinusoidal topography:

$$\frac{PGA_{2-D}}{PGA_{1-D}} = 65.807(SR)^4 - 134.87(SR)^3 + 77.931(SR)^2 - 10.19(SR) + 2.3236 \qquad (R^2 = 0.9992)$$

The Trapezoidal topography:

$$\frac{PGA_{2-D}}{PGA_{1-D}} = -151.55(SR)^4 + 256.22(SR)^3 - 137.13(SR)^2 + 26.358(SR) + 0.4612 \qquad (R^2 = 0.993)$$

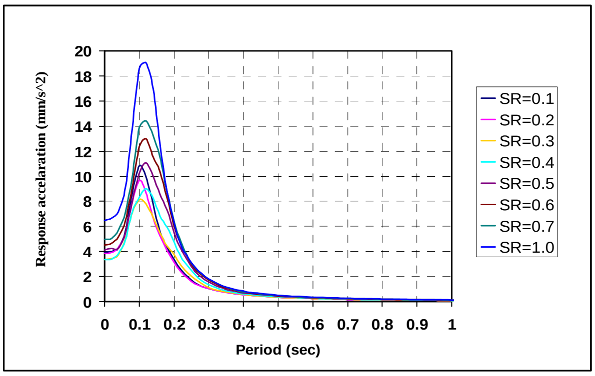

Figure 10. 2D Response spectra of semi-elliptical topography for different shape ratios

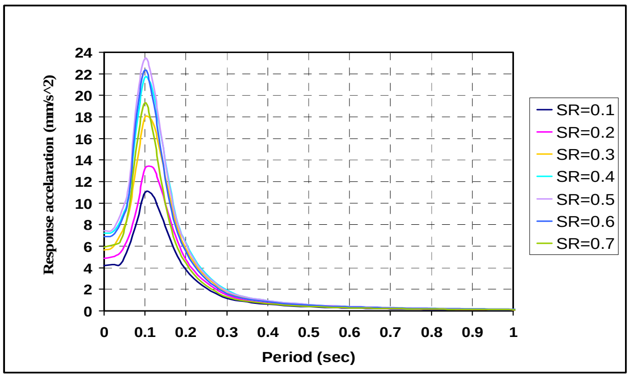

Figure 11. 2D Response spectra of semi-sinusoidal topography for different shape ratio

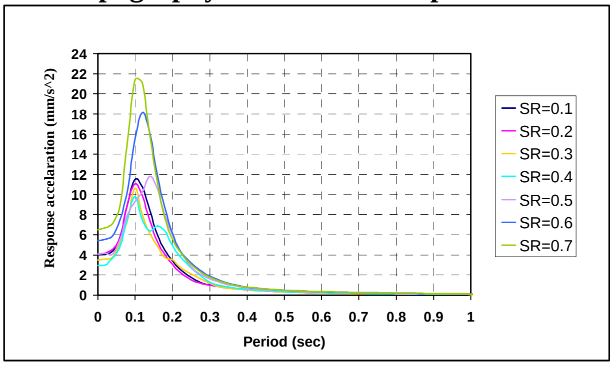

Figure 12. 2D Response spectra of trapezoidal Topography for different shape ratios

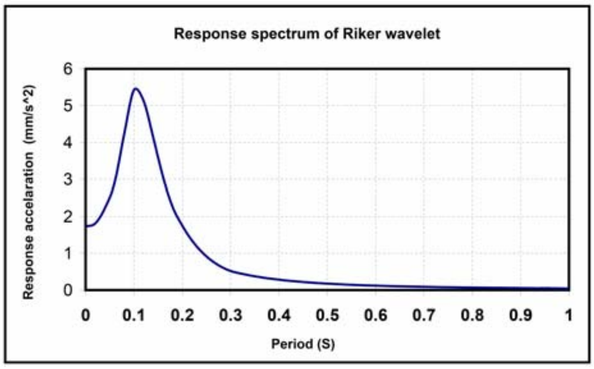

Figure 13. Response spectra of Ricker-typed wavelet in the free field

CONCLUSION

In this paper, extensive parametric analysis for a wide range of surface-typed topographies were performed in order to complete the studies on the effect of topography on the seismic ground response under incident SV in-plane wave at high frequencies (low periods). For this purpose, the program using boundary element method is applied. After making sure about the output results of the program, the verification of model for three topographies are conducted. The parametric analysis also has concentrated on the variation of geometric properties and it was possible to use the results for other combinations of geometry in term of shape ratio and dimensionless frequency. The results are divided into two groups. The first group of results is used for qualitative study of physical behavior of topographies on the vicinities and investigating different phenomena of wave propagations. The second group of output results is applied for comparative evaluation of effective parameters on seismic response. Finally, the responses of 2D analyses at the top of topography for different-typed topographies versus related shape ratios were calculated and then, these results are compared and correlated with the results of response spectra of a Ricker-typed wavelet in the free field.

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