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Spectral Assessing of Topographic Effects on Seismic Behavior of Trapezoidal Hill

M. Amelsakhi, A. Sohrabi-Bidar, A. Shareghi

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***Abstract*—**One of the most important issues about the structural damages caused by earthquake is the evaluating of the spectral response of the site on which the construction is built. This fact has demonstrated during many earlier earthquakes and many researchers' reports have concerned with it. According to these reports, features of the site materials and geometry of the ground surface are considered the main factors. This study concentrates on the specific form of topographies like hills. Assessing of spectral responses of different points on the hills and beside demonstrates considerable differences between 1D and 2D methods of geotechnical analyses. A general trend of amplifications on the top of the hills and de-amplifications near the toe of the hills has been appeared within the acceleration, velocity and displacement response spectrums of horizontal motion. Evaluating of spectral responses of different sizes of the hills revealed that as much as the hill-size enlarges differences between spectral responses of 1D and 2D analyses transfers to longer range of periods and becomes wider.

***Keywords*—**Topography effect, Amplification ratio, Response spectrum.

I. INTRODUCTION

RECENTLY recorded ground motions and construction damages during the earthquakes have illustrated significant effects of surface irregularities on patterns of surface wave propagation. Researchers' observations during 1983 Coalinga earthquake, 1985 Chile earthquake, 1987 Superstition hill earthquake, 1999 Greece earthquake, and recorded accelerations in Pacoima dam during 1971 San Fernando Earthquake and Tarzana Hill (1.78g) during 1994 Northridge earthquake are some samples of the earthquake events in which topography have had an effective role in damage distributions [1]-[7].

The concept of a response spectrum was first introduced by Housner and Biot [8], and [9]. Spectra have been widely used for the purposes of differentiating between the significant characteristics of accelerograph records and providing a simple method of evaluating the response of all types of structures to ground shaking. After, Housner (1959), Hayashi et al. (1971), Mohraz et al. (1972), Blume et al. (1973), Newmark et al. (1973), Seed et al. (1976) and many others conducted wide studies on response spectrum of different type of sites induced by different earthquake records [10]-[15]. All these investigations were based on results of one-dimensional analysis. The extensive experimental studies conducted by Borcherdt et al. (1991) and Borcherdt (1994) which showed the short period site coefficient could be approximated as the spectral amplification averaged over the period interval 0.1 to 0.5 sec, whereas the moderately long period site coefficient could be approximated as the spectral amplification averaged over the period interval 0.4 to 2.0 sec [16], and [17].

Assimaki et al. (2005) introduced the concept of 2D / 1D response spectral ratio to describe the effects of topography as a function of local soil conditions, and suggested a frequency and location-dependent topographic aggravation factor to be introduced for the modification of design spectra in a seismic code [18]. Kamalian et al. (2008) Estimated the seismic site coefficients for the crest of the semi-elliptical shaped hills with various shape that were period dependent and therefore more representative of the amplification pattern of 2D hills, whereas the constant topography factors proposed by AFPS (1990) and Euro code 8 (1998) do not take this important controlling factor into account [19]-[21].

In this study, seismic behavior of different sizes of the trapezoidal shaped hills analyzed by vertically propagation of the earthquake recorded waves. Then, acceleration, velocity and displacement spectral responses at different points on the hills and besides compared with each other's. Those comparisons performed properly between 1D and 2D methods of analyses.

II. METHODOLOGY AND OUTLINE

FLAC software applied to the numerical modeling of both the one-dimensional site profiles at different points on the ground surface and two-dimensional hills with different sizes as shown in Fig. 1 [22]. Relative verification has been shown in previous studies [23]. In order to the parametric evaluation of the trapezoidal shaped hills, shape ratio of 0.7 has considered for 200, 400 & 600m hill-widths and slope of 45 degrees. The results are presented for specific case of uniform site material with VS = 760 m/s, Poisson's ratio $\upsilon = 0.4$, mass density $\rho = 2400$ kg/m^3, elasticity modulus E = 4 GPa, induced by vertically propagating of different earthquake recorded waves. A detailed illustration of the 2D analytical model and its boundary conditions is provided in Fig. 2.

Amelsakhi, Masoud is with the Dept. of Civil Eng., Faculty of Eng., University of Urmia, 11 km road from Urmia to Serow, West Azer-baijan Province, Iran (Tel.: +98 441 2972944; fax: +98 441 2773591. e-mail: M.Amelsakhi@urmia.ac.ir).

Sohrabi-Bidar Abdollah is with the Department of Geology, University of Tehran, Iran.

Shareghi, Arash (Corresponding author) is with the Dept. of Civil Eng., Faculty of Eng., University of Urmia, 11 km road from Urmia to Serow, West Azer-baijan Province, Iran. (Tel.: +98 451 7717065; Cell: +98 914 3586901. e-mail: St_A.Shareghi@urmia.ac.ir).

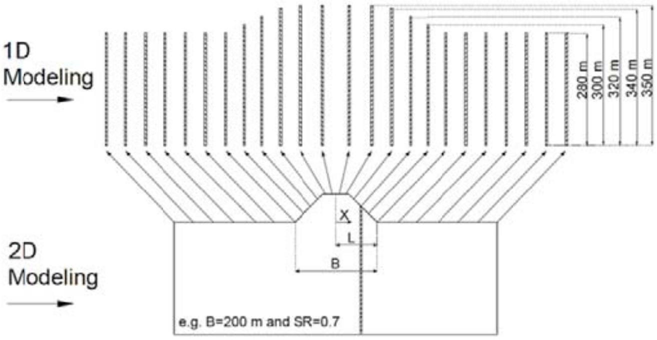


Fig. 1 Schematic illustration of a two-dimensional model and corresponding one-dimensional models at different points on the trapezoidal shaped topography by 0.7 shape ratio and 200 m hill-width

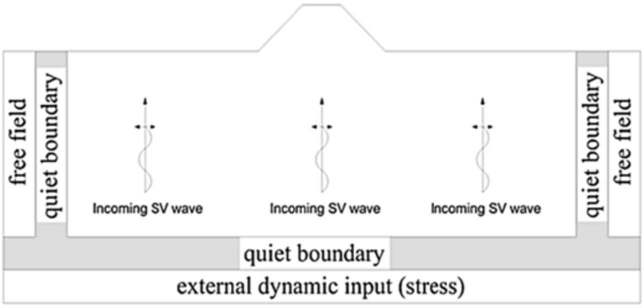


Fig. 2 Detailed boundary conditions of the finite difference model in order to the assessing of the effects of the trapezoidal shaped topography on ground seismic behavior

In order to reduce the effects of artificial wave reflections from the boundaries at the area of interest, model sizes set enough large according to Bouckovalas, and Papadimitriou suggestion [24]. Also the wide of the models set to 8 × (B / 2), the distance that the topographic effect was negligible, i.e. the results of 2D analyses and 1D analysis (free field) were almost the same. 12 far-fault ground motion records are used to evaluate the seismic behavior of topography. Those records selected according to IBC code [25]. Magnitude, 6 to 7.5; distance, more than 20km; PGA range, 0.8 to 1.86 m/s^2; and rocky outcrop taken as the selection criteria into account for all records. Table I presents far-fault records in detail.

In order to perform the mesh sensitivity for models, Kuhlemeyer and Lysmer (1973) criteria satisfied [26]. Accordingly, all the mesh dimensions should be smaller than $\lambda/10$, in which λ is related to incident seismic waves. So, some frequencies should be filtered. To do that, Chebyshev low pass filtering applied with appropriate ripple and order by using of seismosignal software [27].

III. RESULTS AND DISCUSSION

In order to assess the topography effects on seismic behavior of the trapezoidal shaped hill in term of the response spectrum of linear SDOF (single degree of freedom) oscillators, points A (X / L = 0), B (X / L = 0.3), C (X / L = 1) and D (X / L = 2) intended at specific distances from the hill center and their acceleration, velocity and displacement response spectrums of horizontal component resulted from 1D and 2D analyses compared with each other's. The distances are normalized by dividing to the half-width (L) of the hill.

In general, it is possible to identify three ranges of structural periods which the response is dependent on the values of ground motion acceleration, velocity or displacement [28]. Short period structures (typically less than 0.5 second) are sensitive to peak ground acceleration, while structures of moderately long period (i.e. 0.5 to 2.0 seconds) are sensitive to peak ground velocity. The response of structures of exceptionally long period (i.e. longer than 2-3 seconds) is likely to be more dependent on displacement. The dependence of intermediate period structures on velocity is directly recognized by some codes of practice, such as in the Japanese code, where peak ground velocity is used for the design of tall buildings [29].

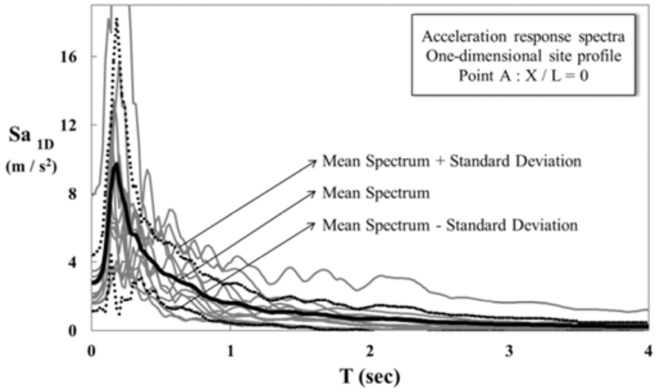
Here, the trapezoidal shaped hills with a shape ratio of 0.7 and various hill-widths induced by far-fault earthquake records and their results justified consequently.

The acceleration response spectrums for the all records at any of specified points resulted from 1D and 2D modeling prepared. Then, the mean spectrum calculated as a representative curve. For instance, Fig. 3 has shown the curves related to 1D and 2D analyses at point A, on the crest center of 200m-width hill induced for 12 far-fault records. In order to make the results comparable, the mean acceleration spectrums at the points A, B, C and D for the various hill-widths induced by far-fault earthquake records represented together in Fig. 4. This is the same way to represent the results for velocity and displacement in Figs. 5 and 6.

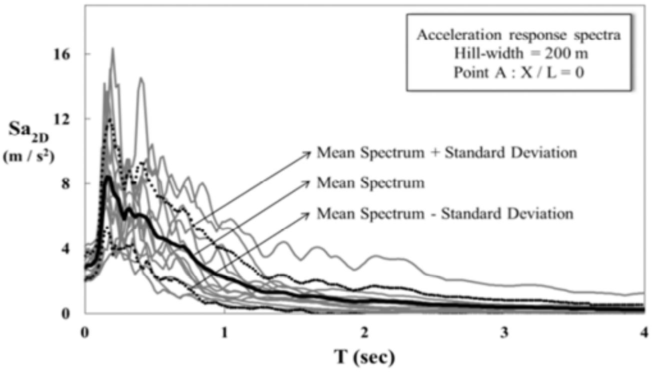
The mean acceleration response spectrum resulted from 2D analyses at the Points A and B have almost shown for all ranges of periods that topography caused slightly higher acceleration responses in comparison with those resulted from 1D analyses. While, at points C and D located at the toe of the hills, 2D acceleration response spectrums were lower than 1D analyses result. These facts were the same amplification (and de-amplification) of the ground motion acceleration at the points on the crest (and at the points of hill-toe) have been illustrated over the evaluating of time domain studies such as [30]-[32], [19], and [23]. It should be noticed that all the differences were within specific period intervals and didn't apply similarly all ranges of periods. Also, 2D analyses resulted significant acceleration response pulse around the periods of 0.2 sec that caused by topography and increased by enlarging the hill at the point A on crest center of the hill (Fig. 4). But, these points are not discussed more here. As, all response spectra represented here are reliable for limited periods more than approximately 0.15 second, because in order to satisfy Kuhlemeyer and lysmer element size qualifications, the frequencies more than 7.6 Hz (periods less than 0.15) filtered for the all records.

TABLE I
FAR-FAULT EARTHQUAKE RECORDS AND STATION DETAILS ADAPTED FROM PEER STRONG MOTION DATABASE [33]

Earthquake event - Date	Station / Component (deg)	Site classification (USGS)	Magnitude (M)	Distance (km)	PGA (m / s^2)	PGV (cm / s)	PGD (cm)
Landers - 1992/06/28	Amboy / 90	A > 750 m / s	7.3	69.2	1.40	18.59	6.81
Loma Prieta - 1989/10/18	San Francisco, Sierra Pt. / 205	A > 750 m / s	6.9	68.2	0.80	9.41	1.96
Northridge - 1994/01/17	Lake Hughes #9 / 0	A > 750 m / s	6.7	26.8	1.70	5.99	1.95
Northridge - 1994/01/17	LA - Wonderland Ave. / 185	A > 750 m / s	6.7	22.7	1.70	13.71	2.03
Northridge - 1994/01/17	Mt Wilson - CIT SeisSta. / 0	A > 750 m / s	6.7	36.1	1.86	7.80	0.55
Northridge - 1994/01/17	Leona Valley #3 / 90	A > 750 m / s	6.7	37.8	0.83	6.89	1.88
Northridge - 1994/01/17	San Gabriel - Grand Ave. / 180	A > 750 m / s	6.7	41.7	1.43	7.33	1.33
N. Palm Springs - 1986/07/08	Anza - Red Mountain / 360	A > 750 m / s	6.0	45.6	1.05	3.37	0.43
N. Palm Springs - 1986/07/08	Silent Valley - Poppet F. / 0	A > 750 m / s	6.0	25.8	0.96	2.83	0.47
San Fernando - 1971/02/09	Lake Hughes #9 / 21	A > 750 m / s	6.6	23.5	0.88	5.49	0.62
Whittier Narrows - 1987/10/01	Mt Wilson - CIT SeisSta. / 10	A > 750 m / s	6.1 (ML)	58.3	1.10	6.19	1.41
Victoria, Mexico - 1980/06/09	SAHOP Casa Flores / 90	A > 750 m / s	6.0	21.2	1.46	4.73	0.23



(a)



(b)

Fig. 3 Acceleration response spectra curves resulted from 1D analyses (a) and 2D analyses (b) on center of the crest of a trapezoidal shaped hill with a shape ratio of 0.7 and a hill-width of 200 m for far-fault earthquake records

Fig. 5 shows the mean velocity responses spectrum curves for 1D and 2D analyses induced by far-fault earthquake records at points A to D for a shape ratio of 0.7 and the various widths of the hill. Due to the aggregative effect of the hill for points on the crest, the mean velocity response spectra of results of 2D analyses at points A and B were higher than those were related to 1D analyses as well as the mean acceleration response spectrums. while, because of the depreciatory effect of the hill for the points on the toe of the hill, the mean velocity response spectrums of results of 2D analyses at points C and D were lower than those were related to 1D analyses. These amplifications (at points A & B) and de-amplifications (at points C & D) happened for displacement response spectrums as shown in Fig. 6.

The Fourier amplitude spectrum shows how the amplitude of an earthquake records distributed with respect to period. Comparing the Fourier amplitude spectrums of acceleration, velocity and displacement illustrated that Fourier amplitude of an earthquake record in term of acceleration, velocity and displacement distributed over short, moderately long and long period intervals, respectively. Thus, they excited corresponding period intervals in term of response spectrums, but this matter observed for both 1D and 2D modeling and it's already hard to distinguish the topography effect (see Figs. 4-6).

In order to concentrate on difference of the 1D and 2D analyses response spectrums at the specified points (A to D) for various hill-size, their spectral amplification ratios prepared in Fig. 7. By this way it could be found more clearly that by enlarging the size of the hill, from 200 m to 600 m, differences between results of two methods of modeling transferred to the longer period intervals and also became wider. In other words, by enlarging the hill, amplification at the points on the crest of the hill and de-amplification at the points of the hill occur within longer period intervals. By increasing the hill-width, natural period of the hill increased and the differences caused by the hills occurred within the longer periods of earthquake records. So, it is possible to express spectral amplification ratios for the topographies irrelevant to their sizes.

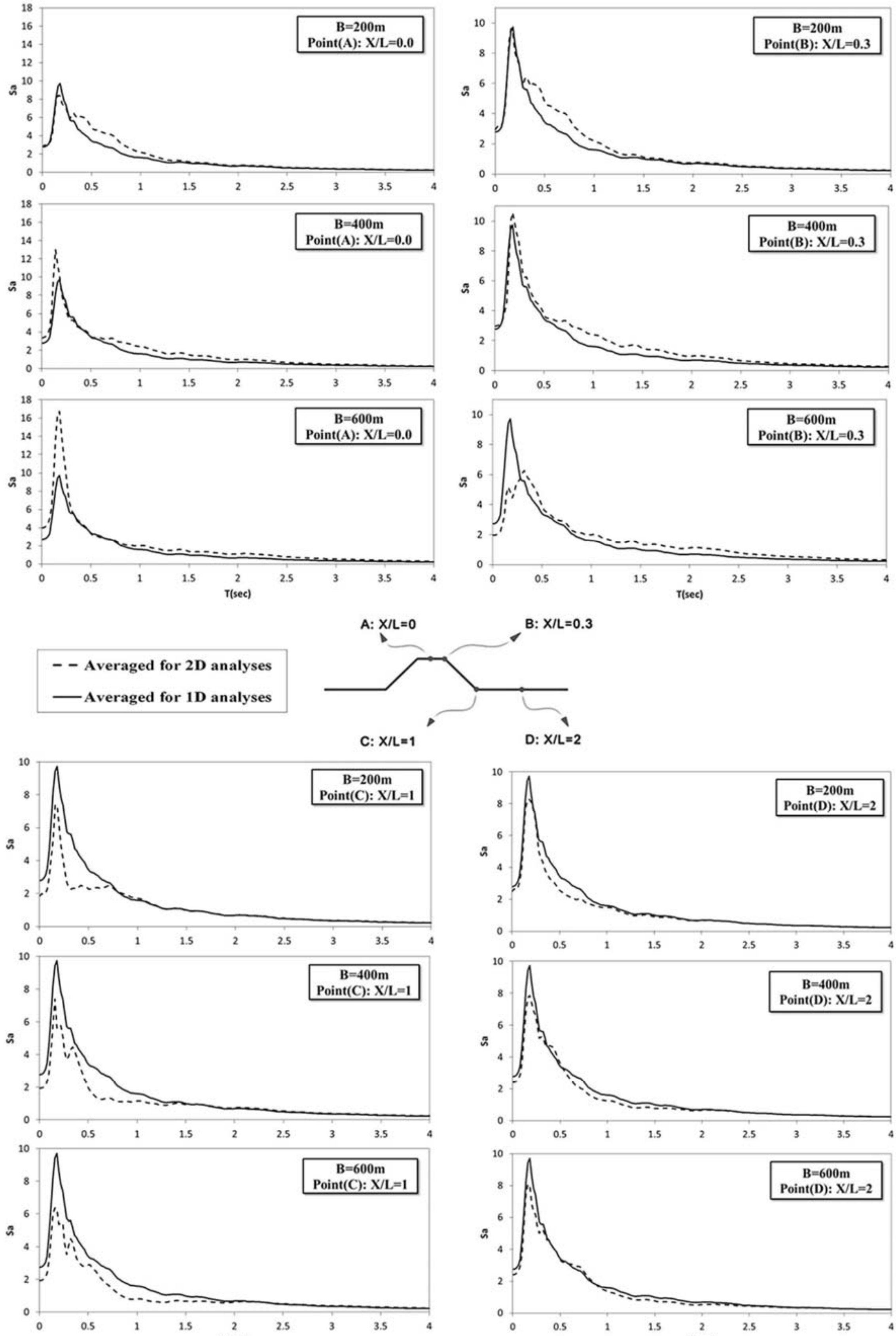


Fig. 4 Acceleration response spectrums at points A, B, C and D resulted of 1D and 2D analyses; for a shape ratio of 0.7 and various width of the trapezoidal shaped hill; averaged for 12 far-fault earthquake records

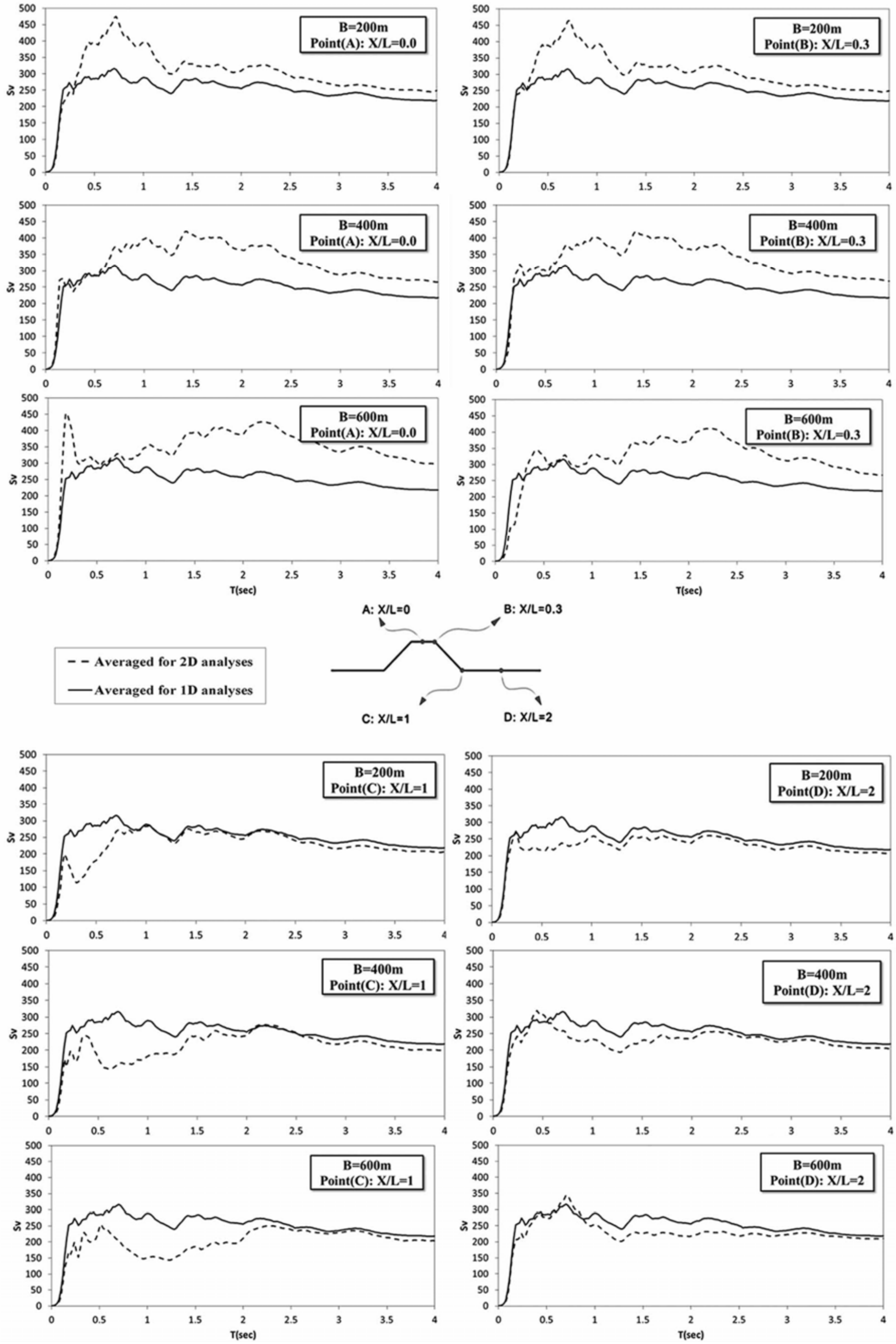


Fig. 5 Velocity response spectrums at points A, B, C and D resulted of 1D and 2D analyses; for a shape ratio of 0.7 and various width of the trapezoidal shaped hill; averaged for 12 far-fault earthquake records

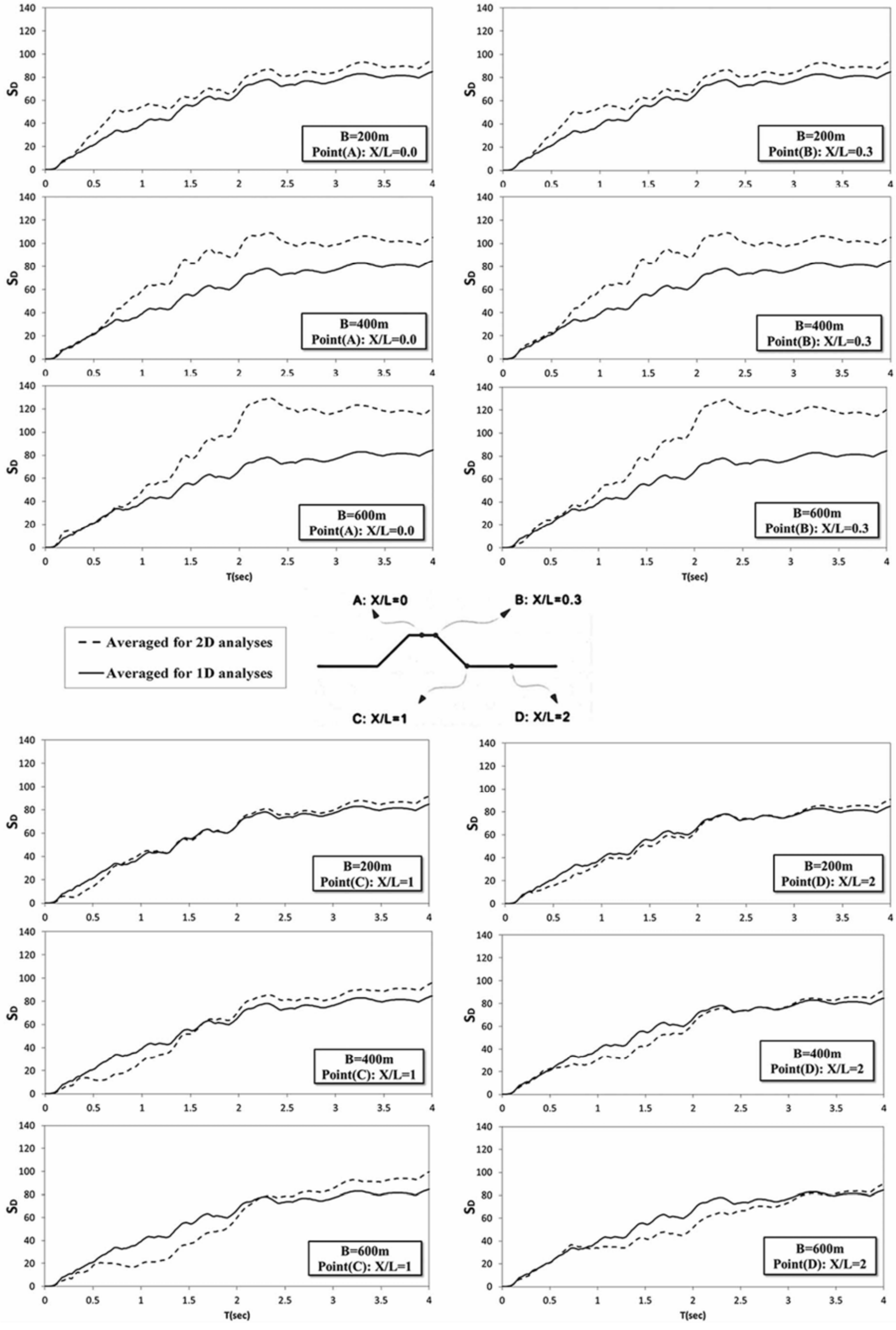


Fig. 6 Displacement response spectrums at points A, B, C and D resulted 1D and 2D analyses; for 0.7 shape ratio and various hill-widths; averaged for 12 far-fault earthquake records

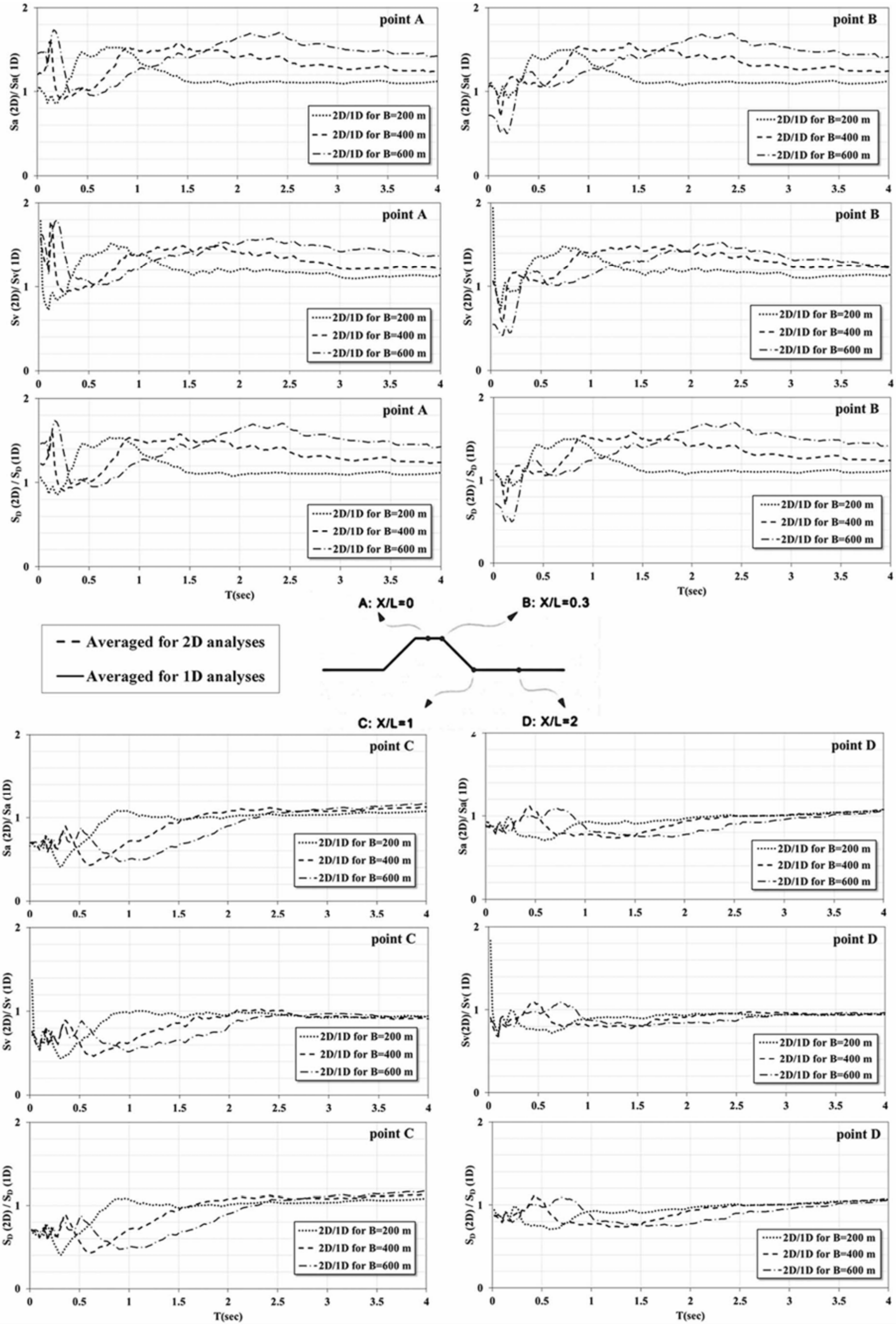


Fig. 7 Acceleration, velocity and displacement response spectra ratios resulted of 2D over 1D analyses at points A, B, C and D; for 0.7 shape ratio and various hill-widths; averaged for 12 far-fault earthquake records

IV. CONCLUSION

In this study, seismic behavior of different sizes of the trapezoidal shaped hills (B = 200, 400 & 600m) evaluated under far-fault earthquake records and their results compared in the terms of acceleration and velocity response spectrums. Evaluating the response spectrums in term of acceleration, velocity and displacement at the specified points revealed that as much as the size of the hill enlarged, it excited longer range of periods so that the amplification on the top of the hill and the de-amplification on the toe of the hill occurred within the longer period intervals and over the wider band. Also, surface irregularities influence similarly on the all ground motion parameters such as acceleration, velocity and displacement in term of response spectrum.

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