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EVALUATION OF BASIN EFFECT ON GROUND MOTION

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ABSTRACT

Evaluation of site effect is one of the important problems, considered in the geotechnical earthquake engineering field. In many cases, a site might be located on an alluvial valley and two or three dimensional analysis should be performed to obtain reliable surface accelerations. In this research a number of rectangular and parallelipedic valleys with different ratios of width to thickness and length to thickness are modeled in two and three dimensions and the acceleration responses of the soil on the surface are evaluated. Results indicate that the amplification of the motions in two dimensional analyses with different width to thickness ratios of the valley differs from those calculated by one dimensional analysis. The ratio of the width to thickness in which the results of two and one dimensional analysis are similar, are also determined. Also, three dimensional analyses are performed and the results are compared with the two dimensional ones. Moreover, in some models of two dimensional analyses Sinusoidal form of the input motion with variable number of cycles are applied and results are compared with the cases in which Ricker Wave are used.

Keywords: Basin Effect, Ground Motion, Alluvial Valley, 2D and 3D Analyses, Ricker Wave

INTRODUCTION

Evaluation of site effect is one of the most important problems considered in geotechnical earthquake engineering field. Macmurdo (1824) noted that buildings situated on rock were not by any means so much affected as those whose foundations did not reach to the bottom of the soil in the 1819 earthquake in cutch, India. In the report on the 1857 neapolitan earthquake, mallet (1862) noted the effect of local geology conditions on damage. Wood (1908) and Reid (1910) showed that the intensity of ground shaking in the 1906 San Francisco earthquake was related to soil and geologic conditions.

Since these early observations, the effects of site conditions on ground motions have been illustrated in earthquake around the world. Site effect plays an important role in earthquake resistant design and must be accounted in each case. Although the local soil effect was considerably evidenced, provisions specifically accounting for site effects did not appear in building codes until the 1970s. Local site conditions can influence the important earthquake characteristics such as amplitude, frequency content and duration of the motions. The extent of the influence of the soil depends on the geometry and material properties of the soil layers, site topography, and the characteristics of the input motion. The effect of local soil and site geometry is illustrated in Figure 1.

In many cases, the site effect response of an alluvium filled valley is obtained assuming vertical propagation of shear waves and one dimensional equivalent linear method (Schnabel et al, 1972) or nonlinear model (Finn et al., 1988; Lee and Finn, 1978). However, one dimensional analysis is used only for nearly flat regions. In other words, in many cases, a site might be located on a narrow alluvial

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valley and two dimensional or three dimensional analysis should be performed to obtain reliable results.

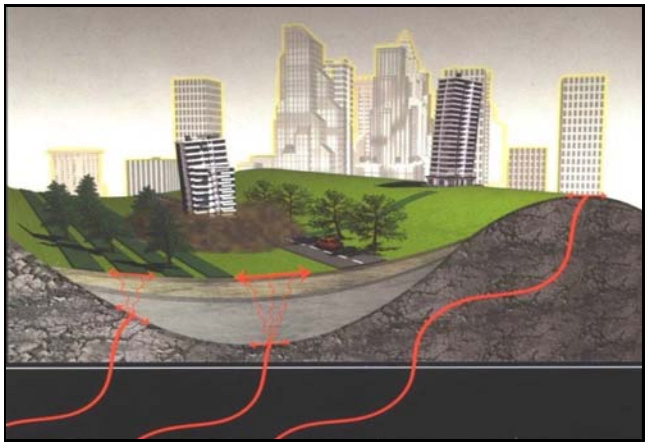

Figure 1. Effect of the local soil on earthquakes

It is well recognized that the ground motions are strongly affected by sublayers irregularities. Researchers have shown that in many cases with sublayer irregularities, one dimensional analysis can not simulate reflection of the waves from the boundaries of the valley. The alluvium basement rock interface generates surface waves and may trap body waves in the alluvium (Finn and Nichols, 1988; Silva, 1989). These waves amplify the motion and increase the duration over that predicted by one dimensional analysis. A number of cases which show the engineering implications of valley and slope effects have been presented by Bard and Gariel (1986). Assimaki and Gazetas performed a parametric study on the eastern bank of the Kifisos river canyon to evaluate the significance of topographic and soil effects on the seismic response of slopes (Assimaki and Gazetas, 2004). Athanasopoulos et al. (1999) studied the non-uniform distribution of damage in terms of surface topography effects by conducting seismic response analyses of a simplified two dimensional profile of the Egion town. Makra et al. (2005) studied the two dimensional model which has been constructed and validated for Euroseistest valley in northern Greece and compared the results with the obtained ones from one dimensional models. Also, comparisons were performed between the simplified and real model of the Euroseistest valley to obtain the influence of the knowledge of the local geology on site amplification simulations (Semblat et al. (2005). Moreover, Tafazzoli and Baziar (2005) investigated the site effect problem in the city of Bam in Iran and showed the importance of the knowledge of the soil characteristics and the bedrock. The two dimensional analysis of the Bam city was also studied and comparisons were performed between the results obtained from one and two dimensional modeling (Baziar et al., 2006).

In this research a number of rectangular and parallelipedic valleys with different ratios of width to thickness and length to thickness are modeled in two and three dimensions with artificial form of input motions called Ricker waves with different amplitudes and periods, applied to the bedrock, and the responses on the ground surface are evaluated. Also, comparison between the maximum surface acceleration obtained from Ricker waves and sinusoidal waves is performed.

SOIL MODELING AND INPUT MOTION

In this research a number of models of the valleys with rectangular shape and different alluvium shear wave velocities, strength parameters, and thickness of alluviums are considered and comparison between the amplifications of one dimensional and two dimensional analyses are performed. The typical shape of these valleys can be seen in Figure 2. Thickness of the alluviums in these models is 30m, 50m and 70m. Details of the models are summarized in Table 1.

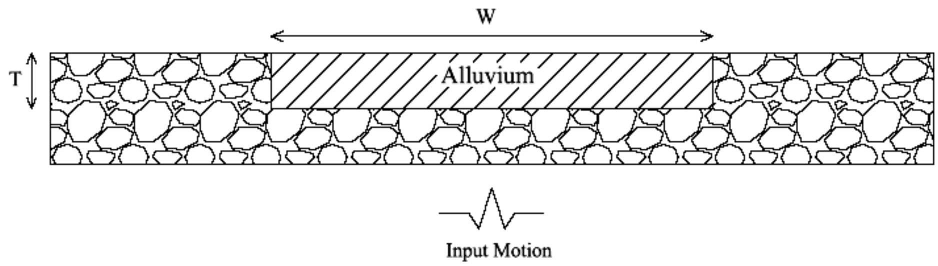

Figure 2. Rectangular valley filled with alluviums

For one dimensional analysis, SHAKE software was employed. In one dimensional analysis, the nonlinear behavior of soils can be considered by equivalent linear method. The equivalent linear method has been used for many years to calculate the wave propagation and response of the acceleration in soil and rock layers. This method doesn't capture directly any nonlinear effects because it assumes linearity during the solution process. In this method strain dependent modulus and damping curves are only taken into account in an average sense, in order to approximate some effects of nonlinearity. The equivalent linear shear modulus is generally taken as a secant shear modulus and the equivalent linear damping ratio as the damping ratio that produces the same energy loss in a single cycle as the actual hysteresis loop. Since the linear approach requires that G and ξ be constant for each soil layer, determining the G and ξ values, consistent with the level of strain induced in each layer, are required. To solve this problem, an objective definition of strain level is needed. The modulus reduction and damping ratio curves, obtained from laboratory tests, and simple harmonic loading are used to characterize the strain level by the peak shear strain amplitude. In this research the model presented by Vucetic and Dobry (1991) were applied.

Table 1. Different models for dynamic analyses with ricker motions

Soil Parameters	Case No.	φ (°)	C (kPa)	a_{max} (g)
V_s= 800 m/s Unit Weight=23 (kN/m^3)	1	35	0	0.1
	2	35	0	0.3
Vs= 500 m/s Unit Weight =19 (kN/m^3)	3	30	0	0.1
	4	25	0	0.1
	5	30	0	0.3
	6	25	0	0.3
Vs= 270 m/s Unit Weight =18 (kN/m^3)	7	23	0	0.1
	8	20	0	0.1
	9	23	0	0.3
	10	20	0	0.3
Vs= 120 m/s Unit Weight =17 (kN/m^3)	11	20	8	0.1
	12	17	10	0.1
	13	20	8	0.3
	14	17	10	0.3

Finite Difference method was used for three dimensional response analyses of models. Also Rayleigh damping was used with minimum damping of 5%. The maximum acceleration on the surface of the models was considered as representatives of ground motion characteristics. The distribution of these quantities on the ground surface was studied considering the effects of geometric irregularities. Furthermore, two dimensional acceleration responses were compared with one dimensional response for horizontally stratified layers. The bedrock with shear wave velocity of 1500 m/s, cohesion of 45MPa, and friction angle of 40 degrees was considered.

For the input motion of the dynamic analysis, beta type of Ricker wavelets with different frequencies as defined in Equation 1, were applied to the bedrock and the acceleration responses in different points of the soil were evaluated for different models.

$$U(t)=\left[1-2b(t-t_0)^2\right]\exp\left[-b(t-t_0)^2\right] \quad (1)$$

Where b= $(\pi f_0)^2$, with f_0 as the characteristic frequency, and t_0 is time of max amplitude of the wave.

The size of mesh, used in finite difference solutions, was selected to be less than one-tenth of the wavelength associated with the frequency component of the input wave. The input motion was applied to the bedrock while the vertical boundaries of the sides have been placed far enough from the topographical irregularity, where free field motion could be assumed. The lateral boundaries of the main grid were coupled to the free field grid by viscous dashpots to simulate a quite boundary.

COMPARISON OF ONE AND TWO DIMENSIONAL ANALYSES

The results of the analyses indicate that the amplification of the motions in two dimensional analysis of the valleys filled with alluviums with different width to thickness ratios differs from the amplification of the motions in one dimensional analysis. The response of valley for different ratio of the width to thickness in two dimensional analysis was determined for different values of soil parameters. The effects of surface topography and alluvium-filled valleys on site response have been previously evaluated by Silva (1989). He showed that with the ratio of width to thickness less than four, in locations away from the edges, one dimensional analysis results are usually underpredicted within a factor of two to four. Here it seems that for width to thickness ratio greater than around eight the response of two dimensional analysis is quite similar to one dimensional analysis with small difference. Results of analyses for four models covered with different types of the alluviums with the thickness of 50m are shown in Figures 3 and 4. In all of the models, the frequency range of 1 to 10Hz for input motion was applied and the maximum response when the resonant occurred was considered. In Figure 3, the maximum amplitude of the Ricker wave is 0.1g and the results are shown in form of normalized acceleration (In this paper normalized acceleration is the ratio of maximum acceleration on the middle of the surface in two dimensional analysis by the one dimensional analysis). In Figure 4 the maximum amplitude of the input motion is 0.3g. It can be concluded that in all types of the soils and different input motions, the trend of the curves are similar but the surface response acceleration is changing. These results can be considered for locations far away enough from the edge of the valley.

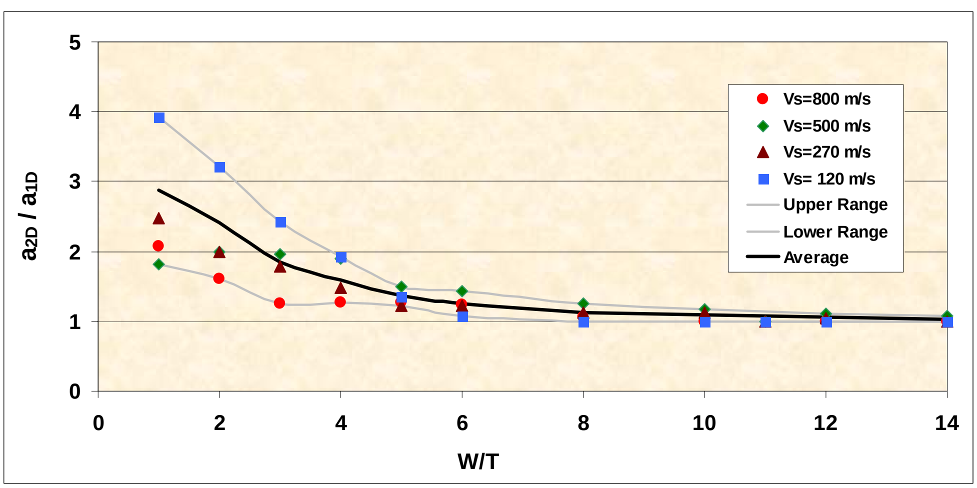

Figure 3. Normalized acceleration for different ratios of width to thickness with amplitude of 0.1g for input motion

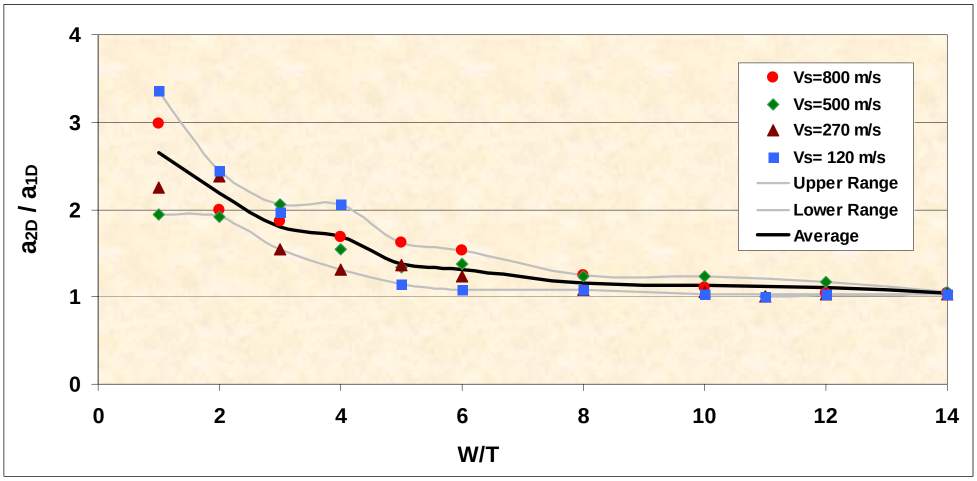

Figure 4. Normalized acceleration for different ratios of width to thickness with amplitude of 0.3g for input motion

COMPARISON OF THE RESULTS OF THE ANALYSES WITH RICKER AND SINUSOIDAL MOTION

For some of the models, the Sinusoidal form of input motion was applied instead of the Ricker Wave. For sinusoidal waves, the number of the cycles applied to the model was varied as 1, 4 and 10. Figure 5 shows the response of valley alluvium with soil parameters of case 4 in Table 1. As seen, the shape of the curves for normalized acceleration for all of the cases is similar to each other although the amplitude of the response acceleration becomes greater when the number of the cycles increases.

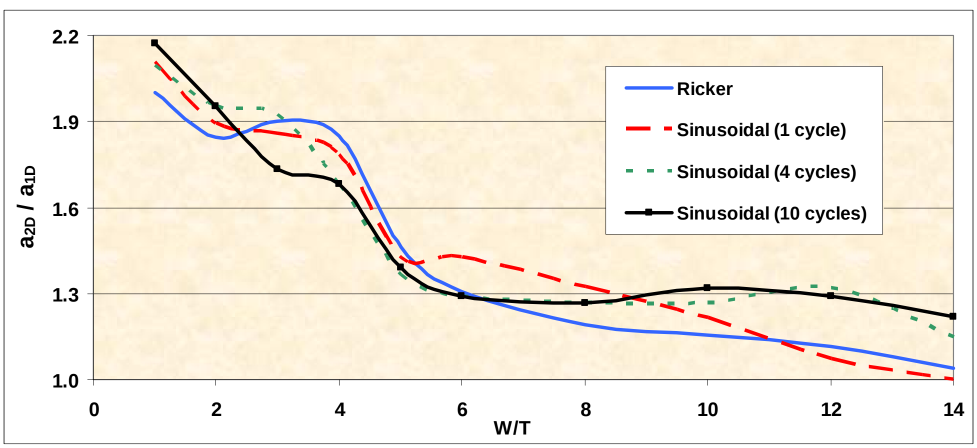

Figure 5. Normalized acceleration for different ratios of width to thickness with variable type of input motions

COMPARISON OF TWO AND THREE DIMENSIONAL ANALYSES

In this section three dimensional analyses of the valleys filed with alluviums are discussed. Finite Difference method was used for two dimensional response analyses of models. Also Rayleigh damping was used for nonlinear solution. The maximum acceleration on the surface of the models was considered as representatives of ground motion characteristics. Moreover, three dimensional acceleration responses were compared with two dimensional responses. In this part, characteristics of the bedrock of the profile were the same as two dimensional models. For input motion, Ricker motions with frequency of 4Hz and maximum amplitude of 0.1g were applied to the bedrock.

The thickness of the parallelipedic valleys is 50 meters. Typical shape of these valleys can be seen in Figure 6. For dynamic analyses, the ratio of four for width to thickness and different ratios of 2, 4, 8 and 10 for length to thickness were considered. Characteristics of different types of the alluviums can be seen in Table 2. The response acceleration was recorded in different points of the ground surface. Distance of these points from the left edge of the valleys was 20, 50, 100, 150 and 180 meters. Amplification of the motions in the mentioned points for different cases can be seen in Tables 3 to 5.

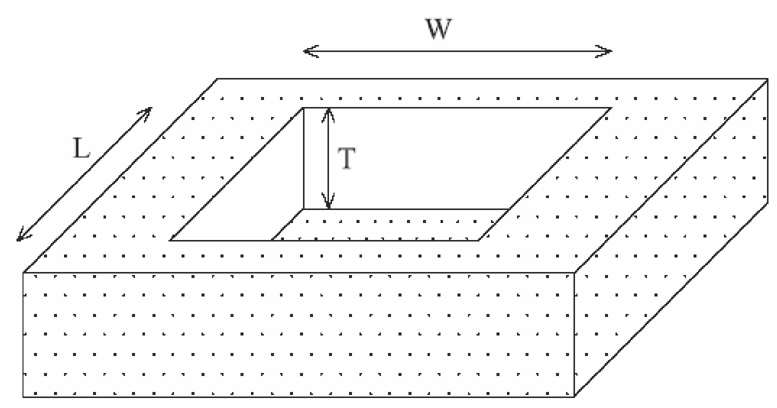

Figure 6. Parallelipedic valley filled with alluviums

Table 2. Different type of the alluviums for three dimensional analyses

Case No.	V_s (m/s)	Density (kN/m^3)	G (MPa)	Bulk (MPa)	φ (º)	C (kPa)	a_{max} (g)	Thickness (m)
1	500	19	475	1425	30	0	0.1	50
2	270	18	131	394	23	0	0.1	50
3	120	17	24	73	20	8	0.1	50

Table 3. Amplification of the input motion in different points of the ground surface for different ratios of length to thickness (Case 1)

Case 1		Distance (m)				
		20	50	100	150	180
L/T	2	3.1	4.2	5.2	3.6	2.7
	4	3.3	5.6	5.1	4.3	2.9
	8	2.3	3.3	3.9	3.3	3.3
	10	2.2	3.1	3.9	3.2	2.4

Table 4. Amplification of the input motion in different points of the ground surface for different ratios of length to thickness (Case 2)

Case 2		Distance (m)				
		20	50	100	150	180
L/T	2	5.6	5.2	4.6	5.4	5.1
	4	2.7	5.3	3.5	5.2	3.7
	8	3.2	3.2	3.2	3.4	2.9
	10	3.3	3.4	3.2	3.6	3.1

Table 5. Amplification of the input motion in different points of the ground surface for different ratios of length to thickness (Case 3)

Case 3		Distance (m)				
		20	50	100	150	180
L/T	2	2.9	3.7	3.4	3.8	3.3
	4	2.8	2.7	2.5	2.7	2.6
	8	2.7	2.5	2.1	2.4	2.4
	10	2.7	2.5	2.1	2.4	2.5

In Table 6, comparison between the results of the two dimensional analyses and three dimensional analyses can be seen. Also, these results can be seen in Figures 7 to 9. Furthermore, in these Figures the value of two dimensional analyses with the same parameters for alluvium can be seen.

Table 6. Amplification of the input motion in the middle of ground surface for two and three dimensional analyses

L/T	Amplification		
	Case 1	Case 2	Case 3
2	5.2	4.6	3.4
4	5.1	3.5	2.5
8	3.9	3.2	2.1
10	3.9	3.2	2.1
2D	4.9	3.4	2.7

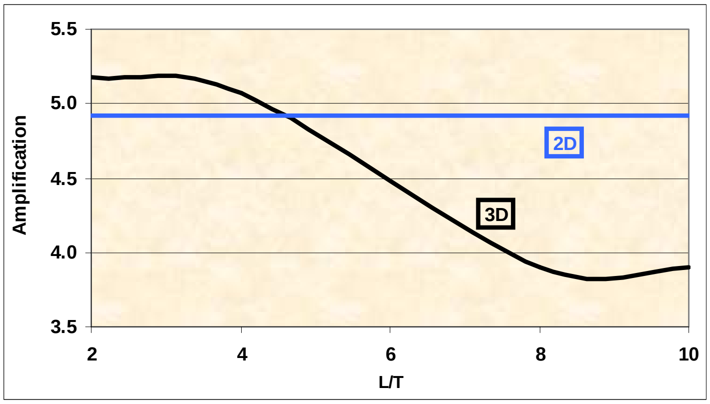

Figure 7. Amplification of the input motion in the middle of the ground surface for different ratios of length to thickness (Case 1)

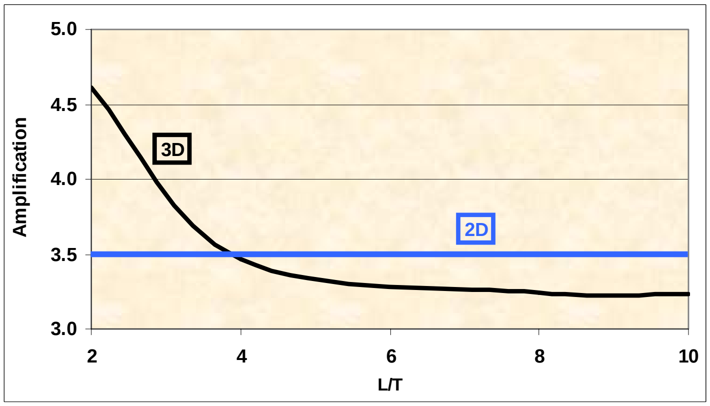

Figure 8. Amplification of the input motion in the middle of the ground surface for different ratios of length to thickness (Case 2)

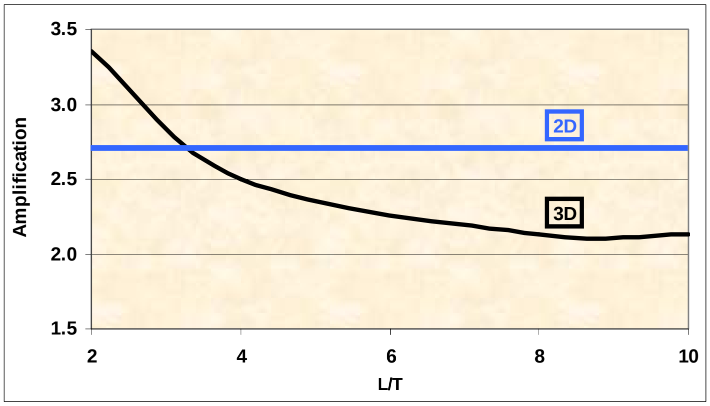

Figure 9. Amplification of the input motion in the middle of the ground surface for different ratios of length to thickness (Case 3)

As it can be seen, for the ratio of length to thickness four, that it is the same as the ratio of width to thickness, the values of amplification for the middle of valley, and the maximum surface acceleration in the middle of the valley obtained from three dimensional analysis are almost the same as the ones obtained from two dimensional analysis. However, for the ratios of length to thickness less than four, the values of amplification decrease and for the bigger ratios these values increase.
It can be concluded that in the choice of two dimensional analyses, the smaller value of length and width must be chosen and dynamic analysis should be performed in the selected direction. However, the results can be less or more than the three dimensional ones related to the length of the third dimension of the valley.

CONCLUSIONS

In this research a number of rectangular and parallelipedic valleys with different ratios of width to thickness for two dimensional analyses and length to thickness for three dimensional analyses were modeled. Also, the artificial form of input motions called Ricker waves with different amplitudes and periods were applied to the bedrock and the acceleration response on the surface of the soil was evaluated. The thickness of the alluvium in two dimensional models was 30m, 50m and 70m.

The results of the one and two dimensional analyses of the motions at the locations far away form the edge of the valley indicated that the maximum response acceleration of the motions in two dimensional analysis with different width to thickness ratios of the valley differs from the ones obtained from one dimensional analysis. It seems that for width to thickness ratio of around eight, results of the one and two dimensional analysis were similar. In all of the models, the frequencies with the range of 1 to 10Hz for input motion were applied and the maximum response for which the resonant occurred were chosen. In some cases, the amplification of the motions near the edge of the valley was higher than the amplification in the middle of that while in the others; the same values at the middle were higher.

Further investigations were performed by applying the Sinusoidal form of the input motions instead of the Ricker Waves to obtain the effect of the input motion. For sinusoidal motions, the number of the cycles applied to the model was varied as 1, 4 and 10. For these values, the shape of the curves of normalized acceleration was similar to each other. However the amplitude of the response acceleration became greater when the number of cycles increased.

Three dimensional models were considered with thickness of 50 meters, ratio of four for width to thickness, amplitude of 0.1g and frequency of 4Hz for input motion. The ratio of the length to thickness of the alluvial valley was considered as 2, 4, 8 and 10. The maximum surface acceleration far enough from the edges of the valley obtained from the three dimensional analysis for ratio of four for length to thickness is the same as the obtained ones from the two dimensional analysis for the ratio of width to thickness equal to four. Also maximum surface accelerations indicated that for the ratios of length to thickness bigger than four, in three dimensional analyses, the values of amplification were less than the results in two dimensional analyses. To summarize, if two dimensional analysis is chosen for a valley, the smaller value of length and width must be chosen and dynamic analysis should be performed in the selected direction. However, the results can be less or more than the three dimensional ones related to the length of the third dimension of the valley.

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