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EFFECTS OF CANYON SHAPE ON THE SEISMIC RESPONSE OF EARTHFILL DAMS

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ABSTRACT

The dynamic response of fill dams is usually determined by computing the dynamic response of individual sections of dam using two dimensional analysis procedures based on plane strain condition. Evaluation of sensitivity of dam seismic response to the shape and depth of canyon can be well studied using three dimensional numerical models. In this study, the comparison of three dimensional and two dimensional static and dynamic analysis of Alborz dam under maximum design level of earthquake (MDL), as input motion, are discussed. Non-liner dynamic analysis has been carried out by using FLAC2D and FLAC^{3D}. In order to assess the effect of canyon on dam response, three hypothetical models with the same main section as Alborz dam but in various crest lengths are analyzed and their results are compared. The results show that for dam placed in narrow canyon (L/H smaller than 4) two dimensional analysis with assumption of plane strain is not accurate, and three dimensional analysis should be used to simulate in field condition more adequately.

Keywords: Earth dams, Seismic response, 3D analysis, Dynamic analysis

INTRODUCTION

The Behavior of embankment dams, as one of the most important structures, under earthquake loading has attracted the attention of many researchers and dam designers. In the last decade, improvements in the different numerical methods have resulted in widespread use of these methods to study dynamic behavior of earth dams; and using three dimensional models has revealed various aspects of dam response to seismic shaking (Baziar et.al, 2003 and 2004).

The most important factors that influence the dynamic response of an earth dam to seismic loading are: 1- The geometry of the dam, 2- The dynamic properties of the materials comprising the dam, 3- the nature of the input motion. Due to the dam geometry, the effect of canyon shape on seismic response of dams, particularly for the dams located in hazardous seismic zones, has been the focus of many researchers.

Ambraseys (1960) studied the dynamic response of dams in rectangular canyons, using shear wedge method of analysis. It was found that for ratios of crest length to dam height, L/H, greater than four, the difference in the fundamental frequency of vibration between the 2-D and 3-D representations of a dam was less than 10%.

Makdisi (1976) performed dynamic finite element analyses of dams in triangular canyons subjected to harmonic and earthquake motions. For a 100 ft (30 m) high dam with a constant shear wave velocity of 500 fps (155 mps) the analyses show that even for crest length to height ratio, L/H, as high as six

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there are significant differences in the crest amplification functions and fundamental periods computed from 3-D and 2-D models of a dam.

Gazetas (1981) has presented analytical solutions for the natural mode shapes and frequencies of vibration of homogeneous elastic dams subjected to dynamic excitation in the longitudinal direction.

Mejia and Seed (1983) studied dynamic response of Oroville Dam, situated in a triangular canyon with crest length to height ratio of about 7. They compared these results with dynamic response of a hypothetical dam with the same main section but with L/H ratio of 2. They concluded that plane strain analysis of the maximum section of Oroville dam gave values for shear stresses that were within 20% of those computed from a 3-D analysis of the dam. For dam in steeper canyon than that of Orville dam, the results seem to indicate that plane strain analyses cannot correctly simulate the behavior of the embankment.

Jafarzadeh and Javaheri (2002) compared two and three dimensional dynamic responses of Masjed-Soleyman rockfill dam using finite element method. They showed that 3-D models predict larger maximum accelerations along vertical axes than those predicted by 2-D ones.

In this paper, two dimensional and three dimensional dynamic analysis of Alborz dam has been carried out using explicit finite difference method under an earthquake with maximum design level of seismic risk. To assess the effect of canyon on dynamic response of the dam, three hypothetical dams with the same main section and the same material properties but with different ratio of crest length to height of dam (L/H=8, 4, 2) has been analyzed. The obtained results are compared and discussed in this paper.

LOCATION AND SEISMO-TECHTONIC FEATURES OF THE ALBORZ DAM SITE

Alborz dam, which is under construction, is located 269 km north east of Tehran. It is constructed on the route of the Babol River to supply agricultural and drinking water. It is a clay core rockfill dam with 83 m height from the foundation and with crest length of 838 m. Figure 1 shows typical cross section of the dam. Alborz dam has been located in a wide trapezoidal canyon with a crest length to height ratio, L/H, of about 10. The geological formation of the site is mainly Marlstone, which is covered with a layer of alluvium, and weathered rock with varied thickness.

The dam site is located in Alborz seismic zone where active periods have been observed. One of the most important earthquakes that occurred in this area, was the June 1990 Manjil earthquake, with Mb=7.3 and Ms=7.7.

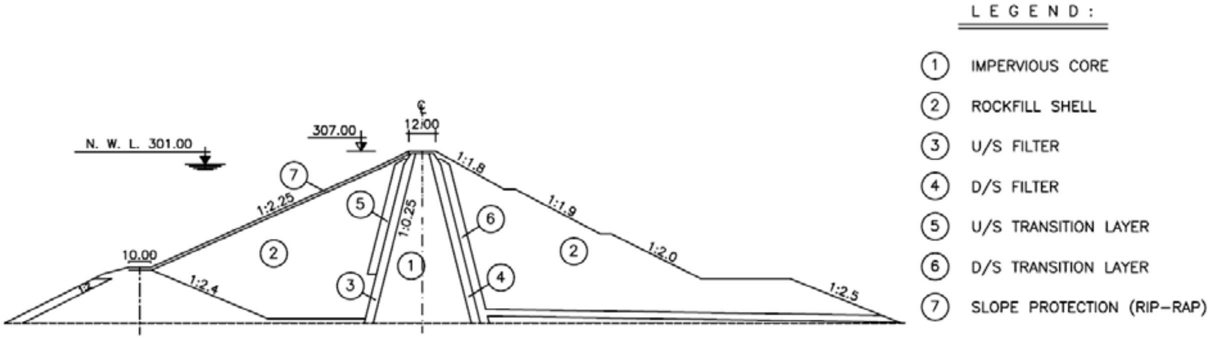


Figure 1. Typical section of Alborz dam

NUMERICAL MODELING

The numerical modelling for the static and dynamic analyses has been performed using the FLAC^{3D} and FLAC2D programs, which are based on finite difference method. Two-dimensional dynamic analysis has been performed on the maximum cross section of the dam, and Figure 2 shows the geometry and grids of the numerical model. As shown, it consisted of about 1300 elements.

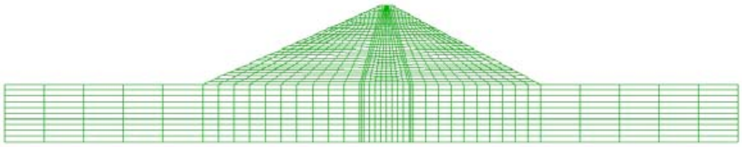


Figure 2. Two dimensional model of the dam and its grids

Figure 3 shows the geometry of the 3D model and its grid for Alborz dam. The dam with its foundation (down to 60m) was modelled by generating different types of elements including bricks, wedges, pyramids and tetrahedrons. Longitudinal section of Alborz dam and other hypothetical dams are shown in Figure 4.

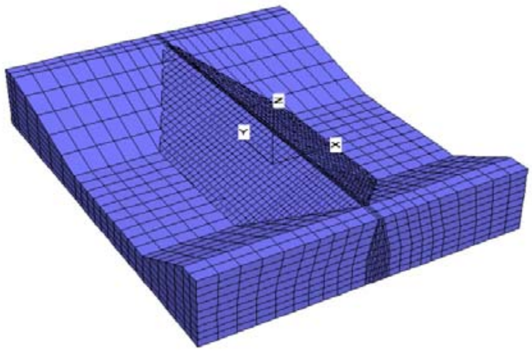


Figure 3. Three dimensional model of Alborz dam

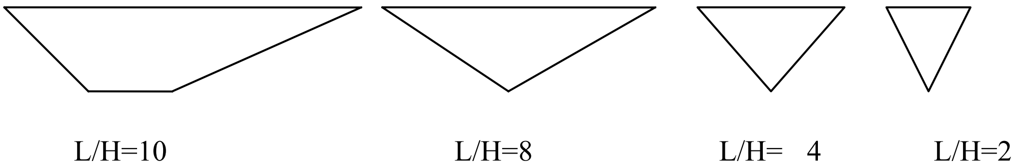


Figure 4. Longitudinal section of Alborz dam (L/H=10) and three hypothetical dams (L/H=8, 6, 4)

The construction of dam embankment was modelled with 15 layers of compacted fill. Static and dynamic analyses were performed for the end of construction stage using the Mohr-Coulomb model for material behaviour. To simulate free-field condition in dynamic analyses, viscous dashpots have been placed at the lateral boundaries and acceleration time history has been applied at the base of models as input excitation. The geotechnical parameters for the dam body are presented in Table 1.

Table 1. Geotechnical parameters of Alborz dam used in static analysis

Type of Material	γ (KN/cm^3)	C (KPa)	Φ	Shear Modulus (MPa)	Bulk modulus (MPa)
Shell	21	-	42	24	41.32
Clay	19.5	50	11	5.6	8.26
Filter	19	-	35	15.9	20.66

One of the important parameters for the dynamic analysis is the selection of shear modulus. To determine the shear modulus of various granular soils and rockfill at very low levels of strain, (G_{max} or G_0), a number of empirical formula based on laboratory tests (resonant column and cyclic triaxial tests) have been proposed by several researchers. For coarse-grained soil and for a sufficiently small shear strain of γ=10-5, the shear modulus, G_0, is given by Kokusho.

For filter material, G_0 was calculated using Equation:

$$G_0 = 8400 \frac{(2.17 - e)^2}{1 + e} (\sigma_0)^{0.60} \tag{1}$$

For the shell material of the dam, G_0 was calculated by the Equation:

$$G_0 = 13000 \frac{(2.17 - e)^2}{1 + e} (\sigma_0)^{0.55} \tag{2}$$

where σ_0 is the mean effective stress, G and σ_0 are both in kPa and "e" is the void ratio of the material. The dynamic shear modulus of clay material was equal to the value, obtained in a similar clay core dam.

For accurate representation of wave transmitted in the model, the element sizes should be selected small enough to satisfy the following criteria expressed by Kuhlemeyer & Lysmer:

$$\Delta l \leq \frac{\lambda}{10} \tag{3}$$

where λ is the wave length associated with the highest frequency component that contains appreciable energy and Δl is the length of element. Considering to these criteria, the element size have been selected as fine as possible. The maximum element size in the direction of dam height used in the analysis is 5.53m. Therefore, frequencies up to 6.5 Hz could be transmitted through the core material.

STATIC ANALYSIS

Figure 5 shows the displacement distribution on the longitudinal section and maximum cross-section of the dam body. It is observed that the maximum settlement occurred at the middle height of the dam in the core and was of 1.48 m. The horizontal displacements were symmetrical, as was expected and the maximum value was 17.4 cm at the downstream and upstream shells.

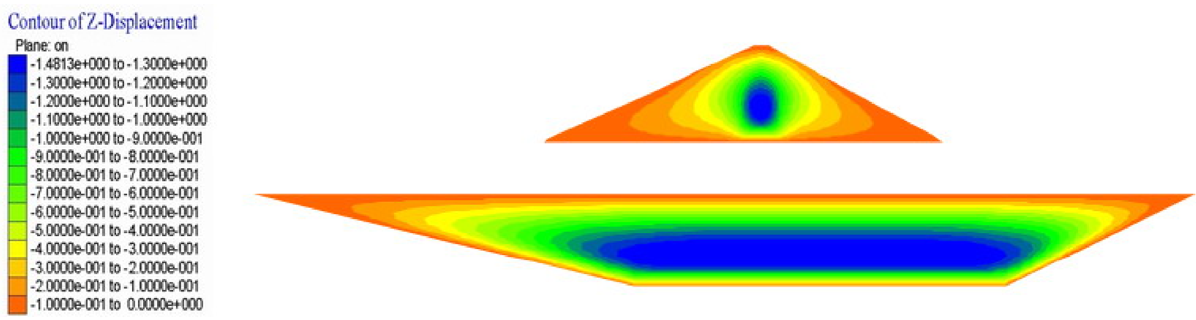
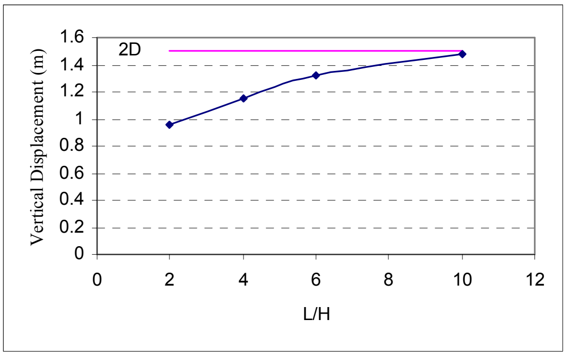


Figure 5. Static vertical settlement contour at longitudinal and cross section of Alborz dam (m)

In order to study the effect of canyon shape on the dam deformation, several three dimensional analyses of dams with different length of canyon and the same maximum cross section were carried out. In these analyses, the triangular canyons were considered such that the shape factor, L/H (ratio of length to height of canyon) varied in the range of 2-10.

The obtained results are summarized in Table1. Figure 6 shows the variation of dam displacements (vertical and horizontal displacements) with canyon shape factor (L/H). As it can be seen in the Table 2 and also in the Figure 6, by decreasing canyon shape factor, the smaller deformations occurred in the dam body. This is due to the fact that in a narrow canyon, the stiffness of abutments significantly affects the dam body deformations. Also it can be observed that for a dam placed in a wide canyon (with L/H>4), induced displacements (vertical and horizontal displacements) are getting very close to the results obtained from two dimensional analysis. While, for L/H=2 or L/H=4 there is a high difference between two and three dimensional analysis.



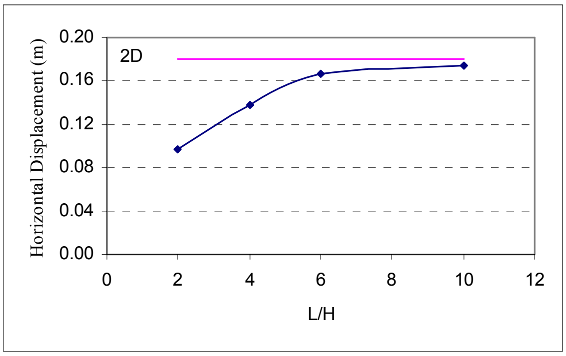


Figure 6. Maximum static vertical and horizontal displacement (m) versus L/H

Table 2. Summary of two and three dimensional static analysis of dams with various L/H

Type of Analysis	Shape ratio L/H	Crest Length	Max. Horizontal Displacement (cm)	Max. Vertical Displacement (m)	Max. Shear Stress (N/m^2)
Two dimensional	-	-	18	1.5	3.0e5
Three dimensional	10	840	17.4	1.48	2.68e5
	8	680	16.0	1.29	2.65e5
	4	340	13.8	1.15	2.54e5
	2	170	9.7	0.96	2.26e5

DYNAMIC ANALYSIS

Fully non-linear two and three dimensional dynamic analyses were carried out for Alborz dam and also for the dams placed in canyons with different lengths. Elasto-plastic model (Mohr-Coulomb) for the dam body materials and elastic model for their rock foundation was considered.

Dynamic response analyses were carried out for Manjil earthquake excitation after scaling to amax=0.35g. The acceleration time history of the Manjil Earthquake as input motion is shown in Figure 7. A comparison between the response acceleration at the dam crest (Figure 8) with the input motion shows that the maximum horizontal acceleration at the dam crest has reached to 7.42 m/s2, giving a magnification factor of 2.2. It is concluded that seismic waves are strongly amplified in the dam body and its foundation.

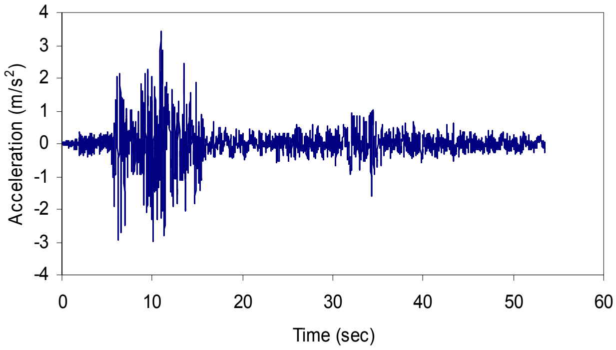


Figure 7. Acceleration time history of Input motion (MDL)

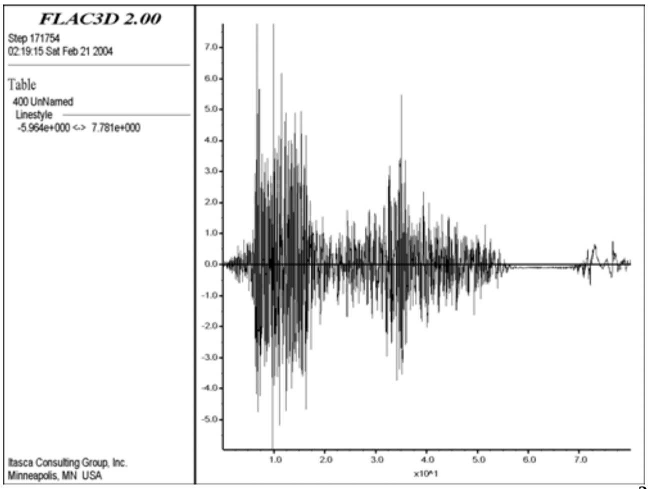


Figure 8. Time history of response acceleration (m/s^2)

THE RESULT OF DYNAMIC ANALYSES FOR THE VARIATION OF L/H

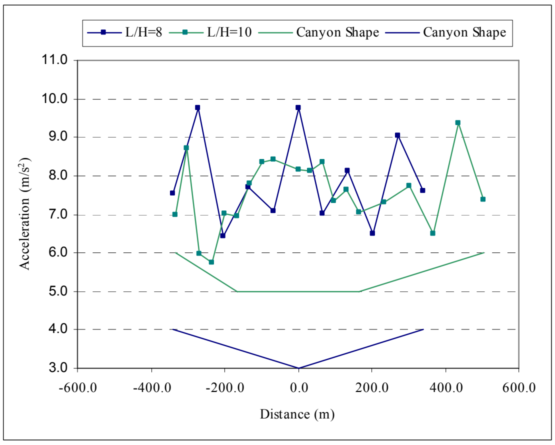
Dynamic analyses have been performed under Manjil earthquake for the dams placed in narrow canyons with the shape factor of 2 and 4 (L/H=2 and L/H=4) and also for wide canyons with L/H=8 and L/H=10. The response accelerations were obtained for each case, which are summarized in Table 3 and discussed as follows.

Table 3. Summary of two and three dimensional dynamic analysis of dams with various L/H

Type of Analysis	Shape ratio L/H	Crest Length	Max. acceleration at the foundation (m/s^2)	Max. acceleration at the crest (m/s^2)	Max. acceleration at cross section (m/s^2)
Two dimensional	-	-	6.13	6.4	10.9 (26m*)
Three dimensional	10	840	5.38	8.15	10.1 (28m*)
	8	680	3.8	9.77	10.5 (55m*)
	4	340	3.6	13.21	13.21(at crest)
	2	170	3.8	13.89	13.89 (at crest)

*height of dam

Figure 9 shows the variation of maximum acceleration along the crest of the dams. It is observed that for a narrow canyon the maximum acceleration is induced at the middle cross section of the dam with a sudden increase, but in a wide valley the maximum acceleration occurs near abutments.



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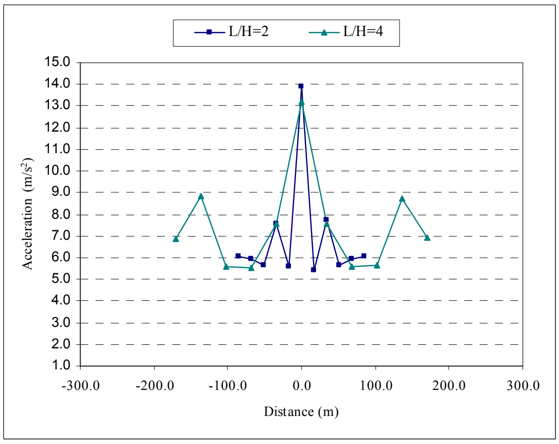

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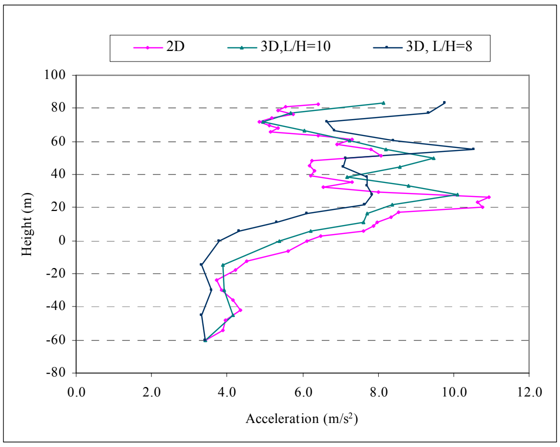
Figure 9. Variation of max acceleration at the dam crest along the longitudinal section for dams located 1) in wide canyons with L/H=10, 8 2) in narrow canyon with L/H=4, 2

Variation of acceleration along height of dam can be observed in Figure 10. The maximum acceleration in the dam with L/H=10 occurred at level of 21.6 m form bottom (1/3 of height of dam), the same as two dimensional results. Contrary to the wide canyon, the maximum acceleration in a narrow canyon is induced at the dam crest.



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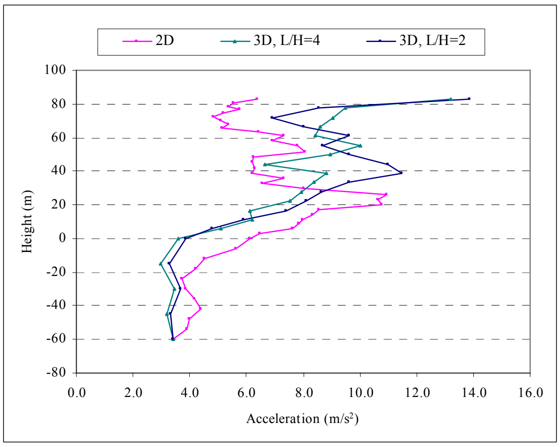

(2)

Figure 10. 2-D and 3-D max acceleration along dam height at cross section of dams located 1) in wide canyons with L/H=10, 8 2) in narrow canyon with L/H=4, 2

As it was mentioned above, results of dynamic analysis showed that response accelerations are strongly magnified in all cases. Figure 11 gives the variation of amplification factor various shape factor. As it is observed by decreasing the shape factor (L/H), amplification factor at the dam crest increases significantly.

Three dimensional analysis of a dam placed in a narrow canyon with L/H=2 shows that a high response acceleration at dam crest is observed which is about two times of the two dimensional analysis. Finally, in comparison with the narrow canyon, the results of three dimensional analysis for a wide canyon are closer to the two dimensional results.

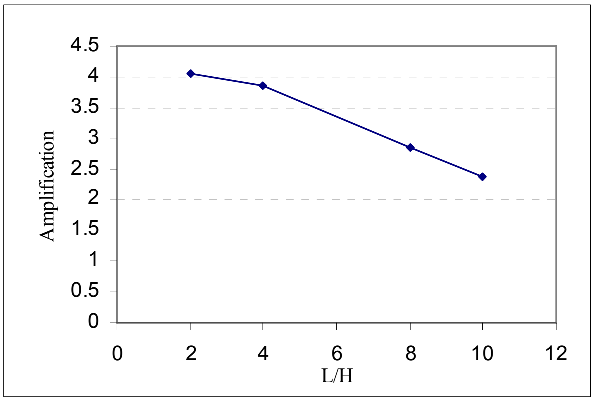

Figure 11. Variation of amplification at dam crest versus L/H

CONCLUSIONS

In this study two and three dimensional dynamic analysis of Alborz dam has been carried out using the finite difference method under an earthquake with maximum design level of seismic risk. To assess the effect of canyon on seismic response of the dam, hypothetical dams with different ratio of crest length to height of dam (L/H=8, 4, 2) have been analyzed. The response accelerations at dam crest obtained from two-dimensional analyses has smaller value than the three-dimensional and its location is completely different. For a dam placed in a narrow canyon with a shape factor (L/H) smaller than 4, a two dimensional numerical model can not simulate the condition realistically and in these cases, three dimensional analysis should be used. In a narrow canyon, a high response acceleration at dam crest can be observed which is about two times of the two dimensional results.

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