UCT JOURNAL OF RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY 2018(01)

Available online at http://journals.researchub.org

Effect of Valley Slope on Static and Dynamic Response of Earth Dams Supported on Rock Foundation

Mehran Javanmard[1*], Isa Alamiparvin[2] and Farhang Farrokhi[3]

[1]*Assistant Professor, Department of Civil Engineering, University of Zanjan, Zanjan, Iran*
[2]*PhD. Student, Department of Civil Engineering, University of Zanjan, Zanjan, Iran*
[3]*Assistant Professor, Department of Civil Engineering, University of Zanjan, Zanjan, Iran*

ARTICLE INFO

Article history:
Received 15 July. 2017
Accepted 17 Oct. 2017
Published 30 Nov. 2017

Keywords:
Earth Dam,
Arching,
Valley slope,
Amplification factor,
Pore water pressure

ABSTRACT

In earth dams with a simple geometry, especially when the valley width is large, various analyses are performed in two-dimensional plain strain condition. In contrast, when the valley width is small or dam foundation is not uniform, the dam structure would be three dimensional and requires 3D analysis. Furthermore, valley slope of and dam sides may influence the dam behavior. The main objective of this study is to investigate valley slope on the behavior of earth dams at end of construction, first impounding, steady seepage stages, and under dynamic loading. Therefore, three similar earth dam with the different valley slopes (30˚♀45˚○and 60˚○) were analyzed. Results of analysis show that the valley slope has no significant impact on arching phenomenon and maximum pore water pressure and minimum settlement at the end of construction are associated with the dam with valley slope of 30□. Results of the study indicate that the pore water pressure induced by dynamic loading is independent from valley slope and response acceleration of dam crest increases by an increase in the slope of valley.

Introduction

Earth dam is the largest structure constructed from natural materials with non-linear behavior and has the most contact with earth. Giving persistent tensions and the amount and type of later loading, dam foundation should resist loads at all stages; hydraulically, the amount of water passing through the dam foundation and body should be at the permitted limit. On the other hand, regarding the materials used, and the level and distribution of stresses and strains, dam body is responsible for keeping the water in the reservoir and must be stable under various conditions. Water and the influence of water dewatering not only create pore water pressure, but makes soil behavior more complicated and also influence mechanical properties of beneath soil.

In earth dam analysis, selecting 2 or 3-dimensional dam analysis model is of great importance which may have significant effect on the results. According to simplicity of two-dimensional analysis, general tendency is toward this analysis, but in some cases results of 2-dimensional analysis are not enough accurate. Geometry of dam, foundation type, form and width of the dam valley are factors affecting analyze path. In earth dams with simple geometry, especially when the dam valley is high, 2-dimensional analysis in plane strain condition gives reasonable results. While, when the dam valley width is small or dam foundation is unsteady, geometry of dam is totally 3-dimensional and need 3-dimensional analysis.

Heydari studied 2 and 3-dimensional behavior of Alborz earth dam under static and dynamic loading and concluded the maximum tension on dam body in 3-dimensional analysis is less than corresponding value in 2- dimensional analysis. They also studied the effect of valley form on dam behavior in 3-dimension for some hypothetical valley with different crown length to height (L/H). Results of the study indicate that decreasing the ratio of crown length to height, reduces dam body deformations. In another word, narrowing the valley will decrease deformations because of further effect of dam body stiffness on the fulcrum [1].

Palasi et al. studied behavior of Maroon earth dam using accurate tool data and compared 3-dimensional results and concluded pore water pressure obtained from numerical model in lower levels of the dam is more than corresponding recorded values in accurate tools [2].

Wolfgang et al. investigated seismic performance of stone canyon dam on a narrow valley in 2- and 3- dimension. Comparing settlement value of 2- and 3-dimensional analysis indicate that dynamic analysis of low height dams are conservative and non-economic, while results of 3-dimensional analysis are more realistic [3].

Review of literature indicates that the effect of 3-dimensional valley slope is not studied on behavior of earth dams. In this regard, three similar earth dam are constructed on valley with different slopes, and analyzed in construction and dewatering level, and steady leakage under earthquake loading; the effect of valley slope on behavior of this dam, such as arcing phenomena, deformation and pore water pressure were studied.

2. Dam geometry and construction material

This study analyzes three similar earth dam constructed on valleys with different slopes (30º, 45º and 60º). All three dam foundations were considered with equal thickness, similar slope of the crust and core form of the dam. Figure 1a shows a view of the dam structure with various slopes of the valley. Foundations of all dams are selected with similar

**Corresponding author:* Mehran.Javanmard@gmail.com
DOI: https://doi.org/10.24200/jrset.vol6iss01pp1-11

stones and material of dam body (table 1). Figure 1b indicates a dam body section in longitude of river, with foundation thickness and dam height of 75 and 50 meters, respectively.

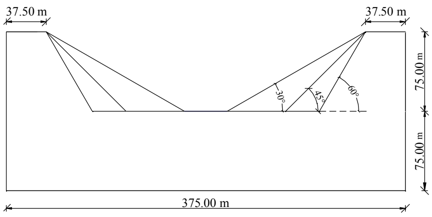

Figure 1.a) schematic geometry of dam site with different support slopes

To study the effect of valley slope on dam behavior, section 1-1 is located in the middle valley axis and section 2-2 and 3-3 are considered in 20 and 75 meters distance from middle valley axis, respectively (figure 2).

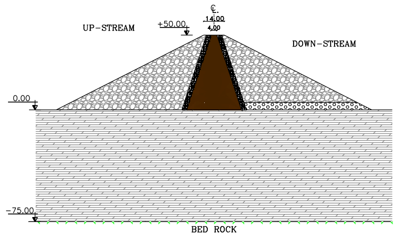

Figure 1.b) dam section in longitudinal line of river

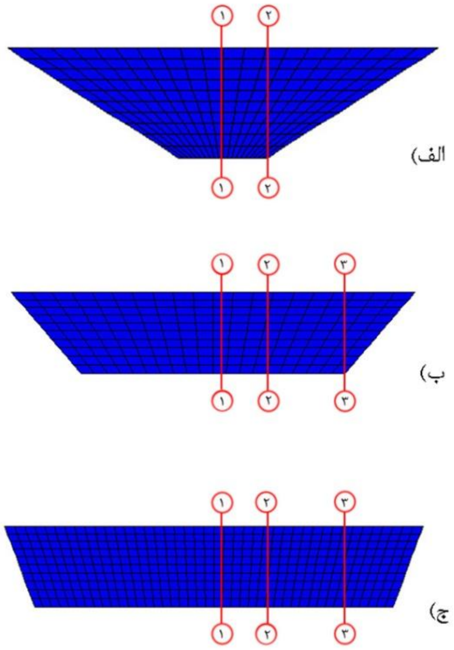

Figure 2. cross sections in valleys with different slopes: a) 30° , b) 45° , c) 60°

Table 1. characteristics of materials used in numerical analysis

Characteristics of material / Dam body	Special weight (kg/m^3)	Bulk modulus $\times 10^7$ (kPa)	Shear modulus $\times 10^6$ (kPa)	Cohesion (kPa)	Internal friction angle (°)	Porosity ratio	Permeability (m/s)
Core	1780	6	6.2	50	20	0.35	10^{-8}
Crusts	2220	10.26	44.656	0	40	0.3	2×10^{-3}
Filter	1960	8	26.67	0	38	0.3	10^{-1}
Sandstone foundation	2500	9	59.34	2000	27.8	0.25	10^{-3}
Drainage	2300	6.16	28.46	0	42	0.5	2×10^{-2}
Alluvial materials	2400	8.3	38.46	7000	60	0.25	10^{-3}

3.Modeling and analysis

First, dam body and foundation were modeled using 8-node cubic elements. After modeling valley and dam body, dam body elements were removed to determine situ stresses, and dam foundation was analyzed with the valley [4]. Then, dam body was modeled as 5 meter layers (in 10 layers). To analyze dam construction stage, each layer was formed after two continuous analyses. To model embankment and slamming each layer, mechanical non-coupled analysis (un-drained behavior of the core) was performed. After that, to model strength and dissipation of pore water pressure, couple analysis (with simultaneous mechanical and fluid calculations) was performed according to the construction time of each layer [5].

In next step, assuming free height of 5 meters and reaching water surface up to 45 meters balance, reservoir dewatering was analyzed. Then, behavior of dam was studied in sustainable leakage current on body and foundation.

After analyzing sustainable leakage, dam behavior was evaluated under dynamic loading. In this regard, improved records of Tabas earthquake was performed at the bottom of foundation balance. In this study, accelerogram of input wave of Tabas earthquake was filtered using Seismosignal software for maximum acceleration of 0.4 g (PGA=0.4g), and applied in foundation bottom balance. Dynamic analysis time (earthquake time) is 33 seconds.

In dynamic analysis of dams, horizontal acceleration was applied in two different modes, as shown in figure 3:

a) along the direction perpendicular to the river (toward X)
b) along the river (toward Y)

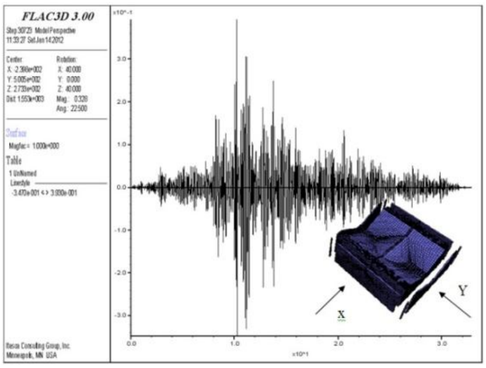

Figure 3. accelerogram of Tabas earthquake and its directions

4.Stress transfer and arcing phenomena

The amount of horizontal and vertical stress on core of earth dam and their changes on dam life play significant role on its sustainability. When vertical stresses and the following horizontal stresses are low, the probability of hydraulic fail increases.

Due to the difference on stiffness of material adjacent to the dam body, weighing force of soil mass core transfers to the crust. This phenomena, known as arcing, decreases vertical stress result from soil weight in lower balances and lead to the decrease of soil compaction rate and consolidation. Shear strength created in shared boundary of two environments also prevents settlement of core material. On the other word, settlement easily occurs inside the core by getting away from both sides of the core.

It is to say that due to arcing, measured amount of stress in different levels of dam core is lower than predicted amounts based on γh. Increasing core width decreases this phenomena, while in upper parts of the core with less tensile stress width, it leads to crack on the core.

Arcing can happen in cross and longitudinal section of the dam. Height difference in vertical sections of dam body and difference in settlement properties of body material can also lead to this phenomenon. To evaluate the phenomena, arcing ratio is defined as: $\frac{\sigma_v}{\gamma h}$, where σ_v is vertical stress applied to the desired point and γh high overhead of the point. Lower amount of this ratio leads to more probability of arcing.

5.Results

End of construction

Arcing

Figures 4 and 5 represent arcing ratio changes in sections 1-1 and 2-2 in different balances for all three types of dams at the end of construction. These figures indicate the lowest arcing coefficient of all three types of dam in 5 meter distance from middle dam axis within the core, where 34 meter balance of dam body is 0.67. Furthermore, these figures indicate slope angle of dam valley has no significant role on arcing ratio of these sections. In lower balances, arcing ratio is higher.

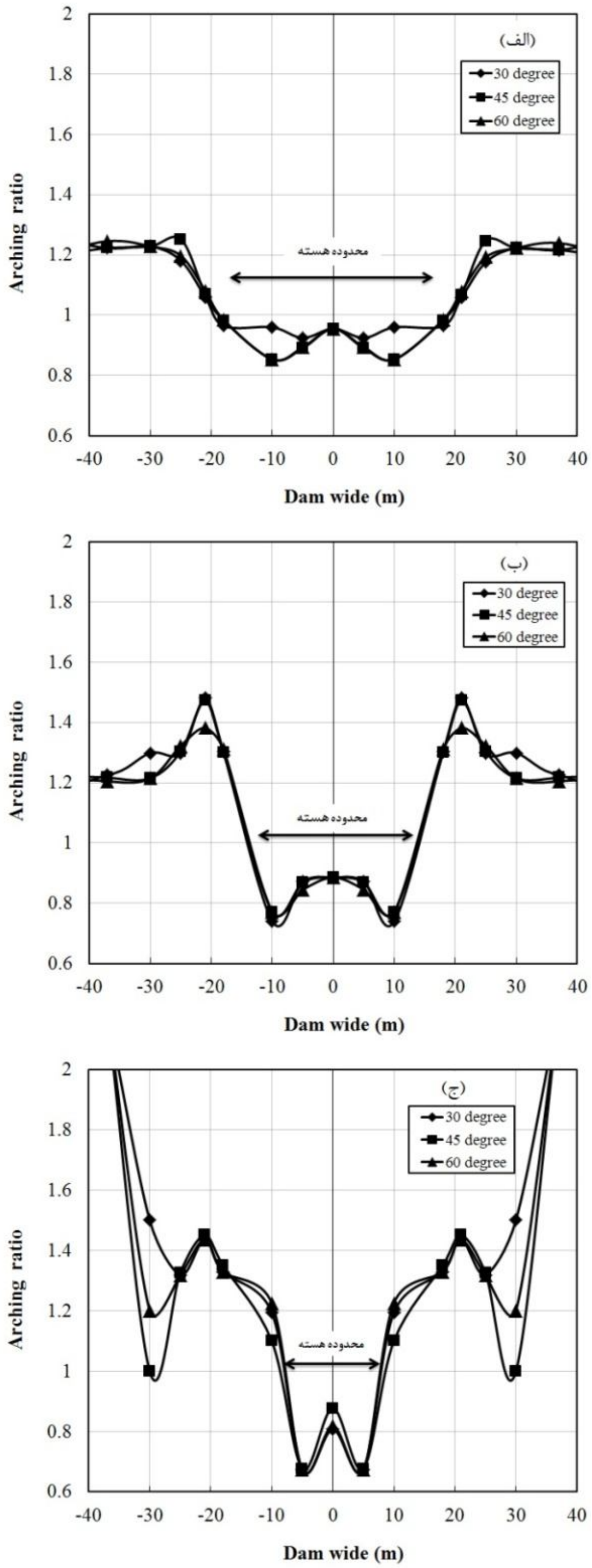

Figure 4. arcing ratio changes in section 1-1 at the end of construction for balance a) zero, b) 17 and c) 34 meters

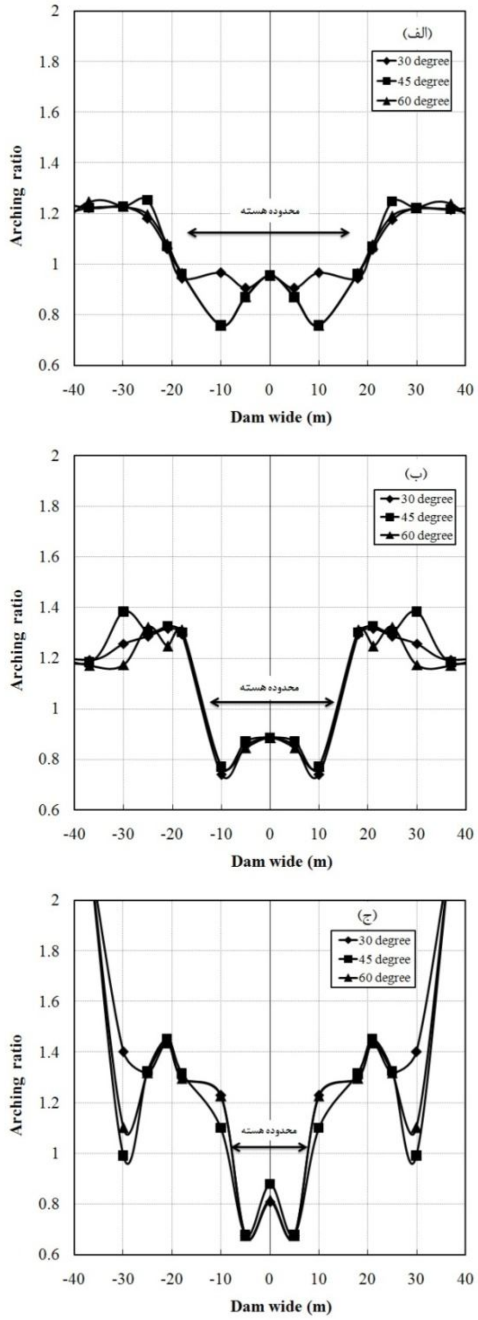

Figure 5. arcing ratio changes in section 2-2 at the end of construction for balance a) zero, b) 17 and c) 34 meters

Pore water pressure

During performance of earth dams and simultaneous with increase of dam height, additional pore water pressure is created due to the weight of upper layers inside the core material. Its amount depends on various factors such as moisture content, compaction and soil properties, speed of construction operations, etc. Figure 6 presents balance lines of extra pore water pressure at the end of construction of each dam in section 1-1. Moreover, changes of pore water pressure on dam height in medial axis of sections 1-1, 2-2 and 3-3 are presented in figure 7. These figures indicate increase of valley slope decreases pore water pressure created in all three sections, especially in middle part of dam height.

In all three sections, regardless of valley slope, maximum pore water pressure occurs in lower 1/3 of dam body. The reason for decrease of pore water pressure with increasing valley slope is that the ratio of L/H of all three dams is equal to increasing slope, and bottom of valley becomes wider. Therefore, lateral limit created by the support decreases and leads to reduction of pore water pressure.

Figure 8 indicates changes of pore water pressure due to the primary dewatering in section 1-1 of all three modes. Regarding this figure, pore water pressure has significant increase due to the primary dewatering and maximum amount of it is in 5 meter balance above the riverbed level. However, at the end of construction the maximum pore water pressure was at higher balance. This figure indicates valley slope has no significant effect on pore water pressure of dam dewatering.

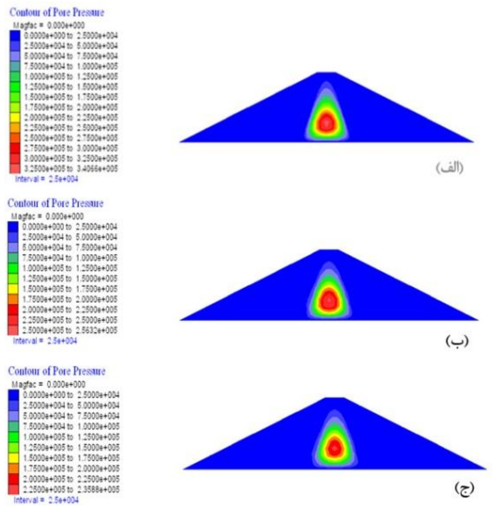

Figure 6. balance lines of pore water pressure of core at the end of construction for section 1-1 for valleys with slopes a) 30º , b) 45º , c) 60º

Settlement

Changes of dam core settlement at the end of construction in sections 1-1 to 3-3 in medial axis based on dam height is drawn in figure 9. It can be observed that regardless of valley slope, in all sections settlement amount has the maximum amount in balance limit of 25-40 meters (distance 1/3 middle of dam height) of riverbed. The values increase in all three sections by increase of valley slope. Less displacement in valley with 30 degree slope is lateral limit created by narrow valley against movement of dam body. It is worth to note that this effect is not considerable and increasing valley slope from 30 to 60 degree increase settlement about 7.5 percent.

Dam settlement balance lines in dewatering level of section 1-1 are presented in figure 10. Maximum amount of core settlement of section 1-1 during primary dewatering has no significant change compared to the maximum settlement of core at the end of construction. Nevertheless, the upstream settlement type during dewatering is different from the end of construction. Settlement place of maximum core in primary dewatering of all three dams was transferred to the dam upstream about 6 meters.

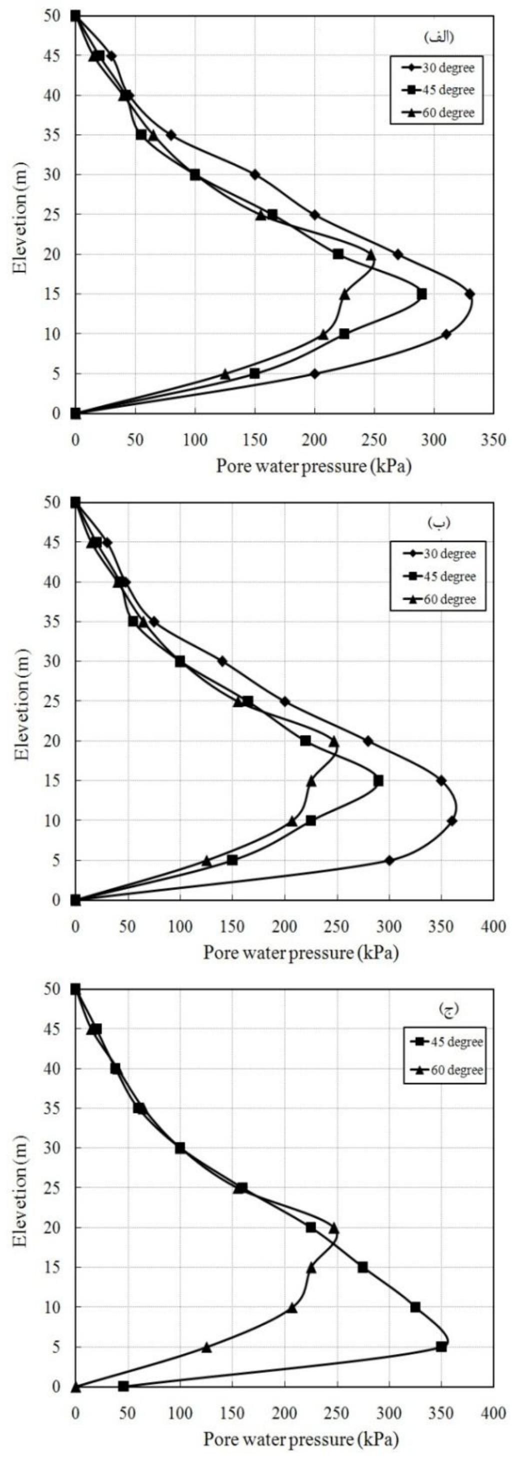

Figure 7. pore water pressure changes at medial axis of core at the end of construction for sections a) 1-1, b) 2-2, and c) 3-3

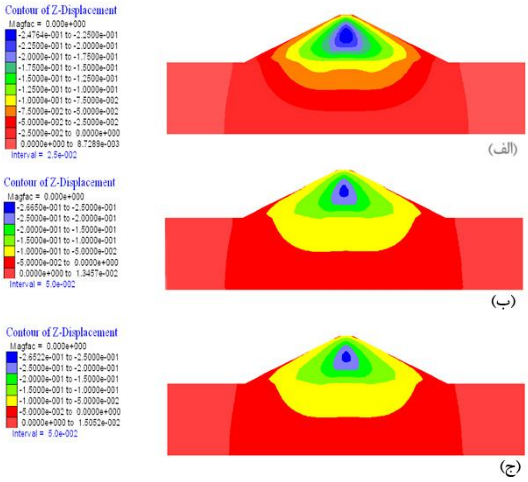

Figure 8. pore water pressure changes due to end of construction in section 1-1 for valley with 30º , 45º , 60º slopes

Dynamic analysis

Arcing

Regarding the importance of vertical stress and arcing phenomena, this part studies arcing phenomena under applying dynamic loads. For instance, figure 11 indicate changes of arcing coefficient for all three dams in section 1-1. It was observed that applying dynamic load increases arcing coefficient significantly and the minimum amount of this coefficient in both sections are in 34 meter balance.

Pore water pressure

Figure 12 represent additional pure pore water pressure caused by dynamic loading in sections 1-1, 2-2 and 3-3 of all three dams. According to this figure, maximum pore water pressure is created in section 1-1, and decreases a little when getting closer to the support. Maximum pore water pressure of static analysis is 365 Kpa in section 2-2 in dam with valley slope of 30 degree and in height of 12 meters of dam foundation. However, maximum pore water pressure in dynamic analysis occurs for dam with valley slope of 45 degree in section 1-1 and height of 5 meters from dam foundation. Difference between pure pore water pressure due to dynamic loading are imperceptible for all three sections and valley slope has no significant effect on pore water pressure.

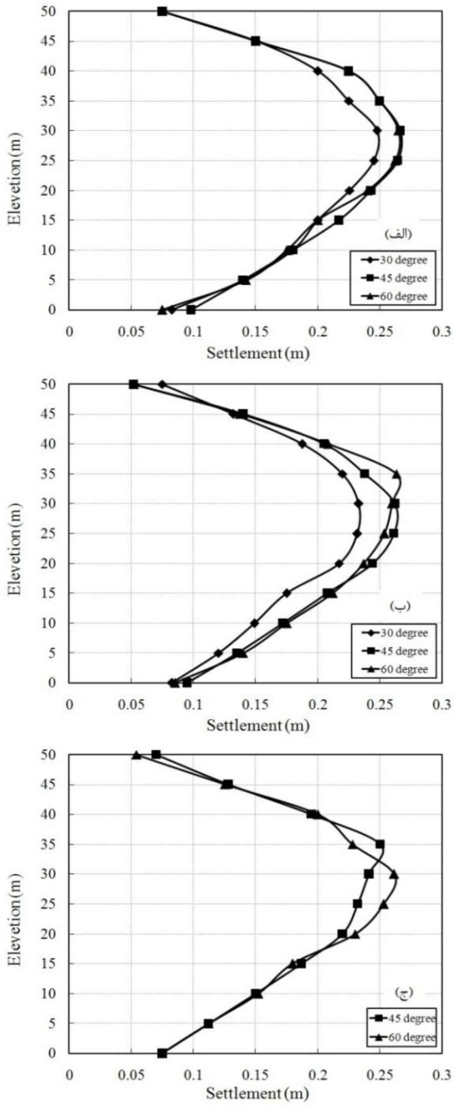

Figure 9. core settlement value changes in dam height at the medial axis of sections a) 1-1, b) 2-2, c) 3-3

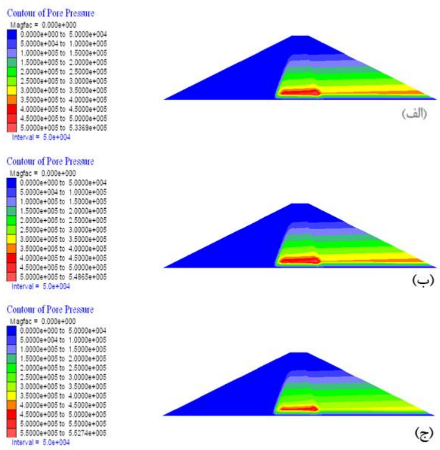

Figure 10. balance lines of core settlement in primary dewatering in section 1-1 for valley with slopes: a) 30º , b) 45º , c) 60º

Settlement

Pure settlement changes due to dynamic loading along dam height in medial axis of all three sections are presented in figure 13. Maximum settlement place in dynamic mode has moved to the dam crest in all three dams compared to the end of construction (from about 27 meters at the end of construction to 34 meters in dynamic mode). Maximum amount of pure dynamic settlement in dams with valley slope of 30, 45 and 60 degree in all three sections are relatively equal; that is, the effect of valley slope on dynamic settlement is almost negligible.

Amplification factor

Local site effects play significant role on resistant design of structures against earthquake. In most of the sites density and shear wave rate of layers near to ground level are less than corresponding values in the deep earth. Due to the elastic wave energy conservation principle, by reaching wave to the surface, density decreases and particle rate increase, therefore, amplification occurs. In this regard, amplification factor is defined as maximum acceleration of response to maximum applied base acceleration. In performed analyzes, maximum negative and positive accelerations of different valleys are determined in X and Y directions and amplification factors were calculated by them.

Diagram of amplification factor change based on valley slope angle in both directions is drawn in figure 14. It is observed that increasing valley slope (or widening valley) increases amplification factor. So that, its value in dams with valley slope of 60 degree has been 2.0-2.3 times more than dams with valley slope of 30 degree.

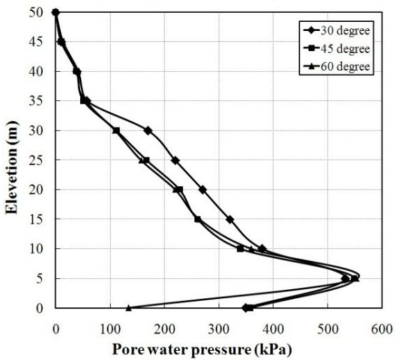

Figure 11. pore water pressure changes due to first dewatering in section 1-1 for valley with slopes: a) 30º , b) 45º , c) 60º

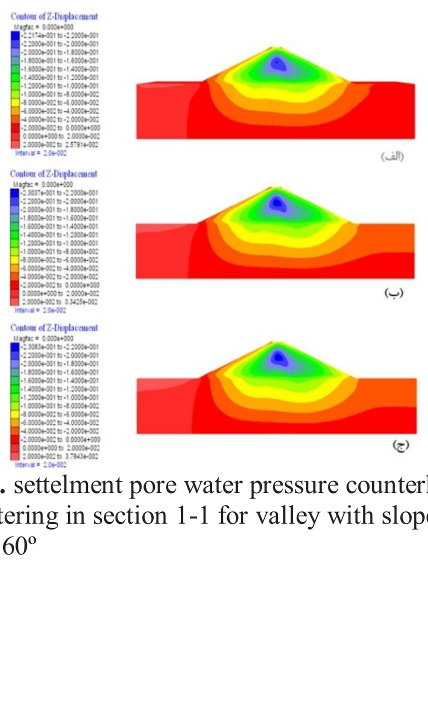

Figure 12. settelment pore water pressure counterline due to first dewatering in section 1-1 for valley with slopes: a) 30º , b) 45º , c) 60º

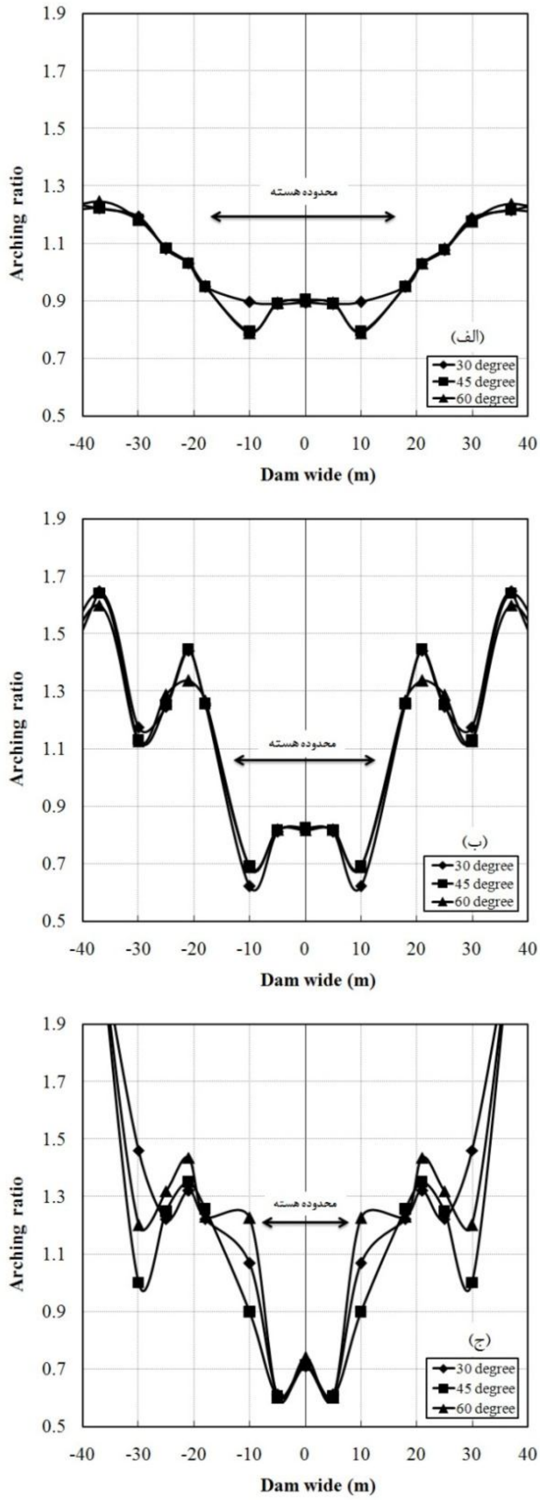

Figure 13. arcing ratio changes of section 1-1 due to first dewatering in section 1-1 for valley with slopes: a) 30º , b) 45º , c) 60º

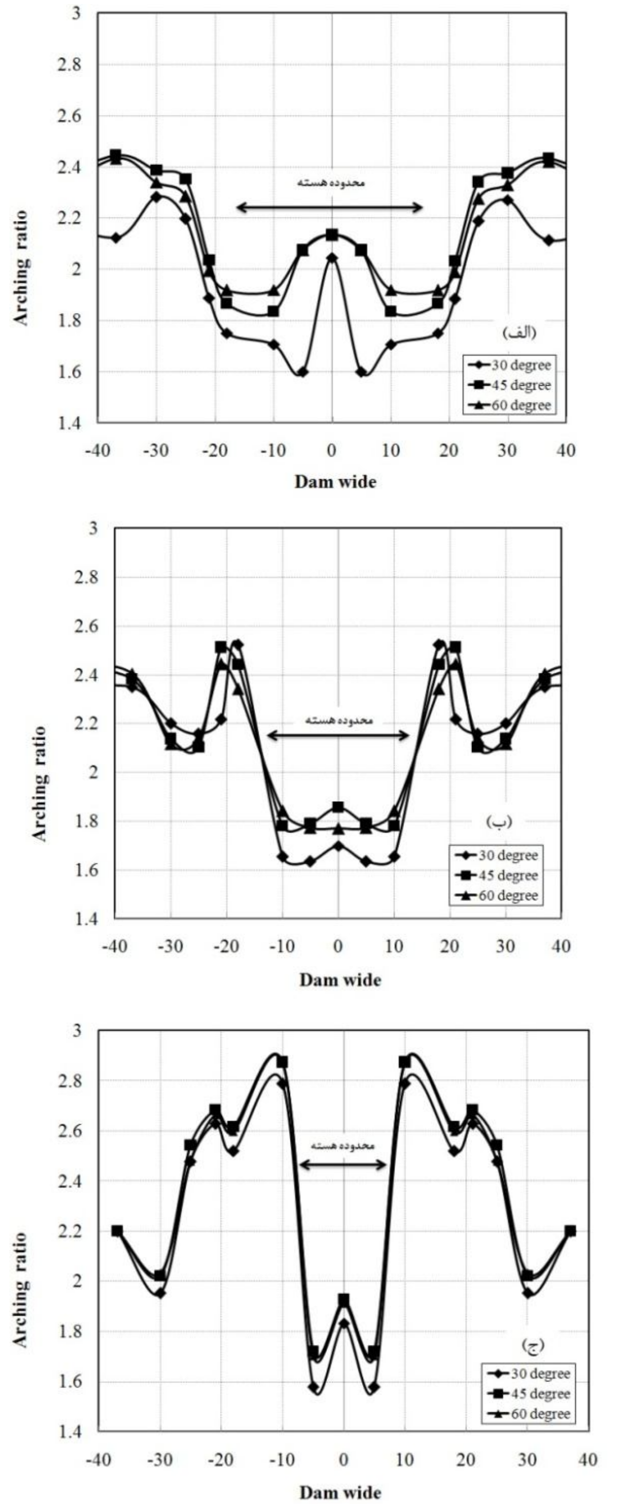

Figure 14. arcing ratio changes of section 1-1 at the end of construction for valley with slopes: a) 30º , b) 45º , c) 60º

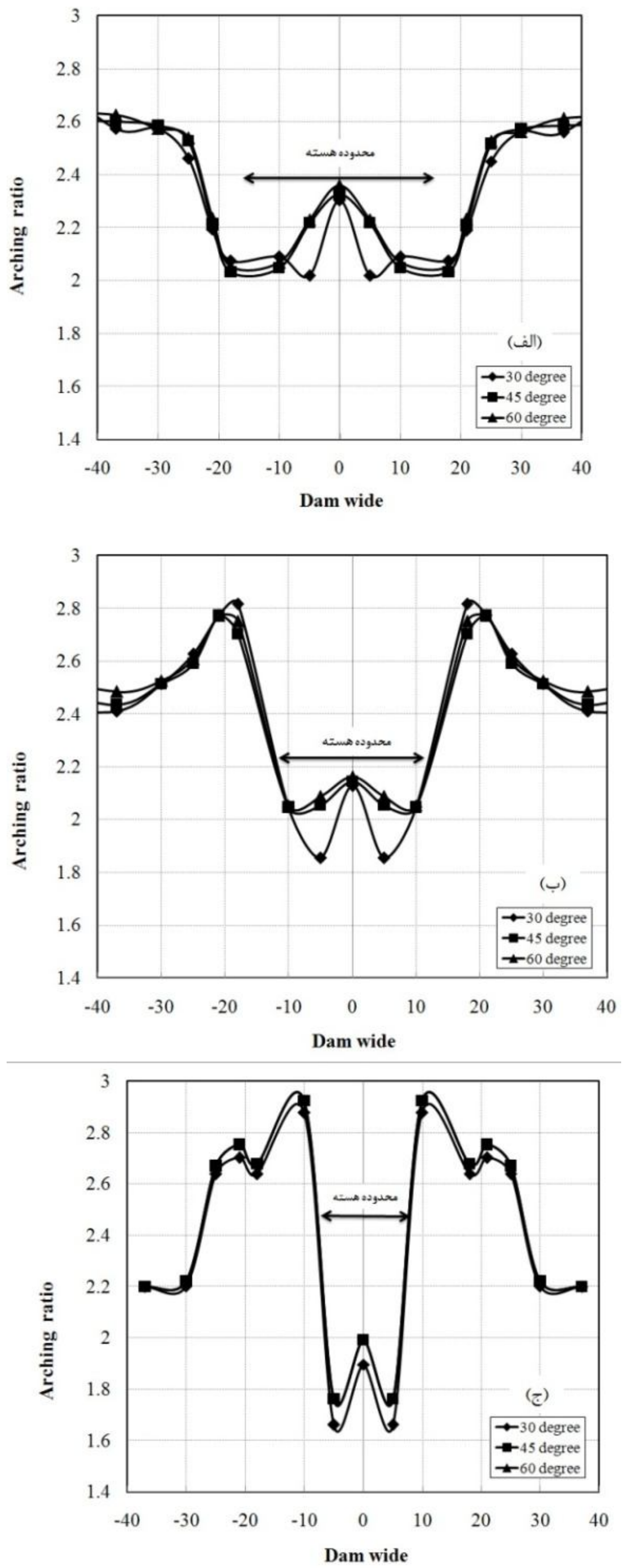

Figure 15. arcing ratio changes of section 2-2 at the end of construction for valley with slopes: a) 30º , b) 45º , c) 60º

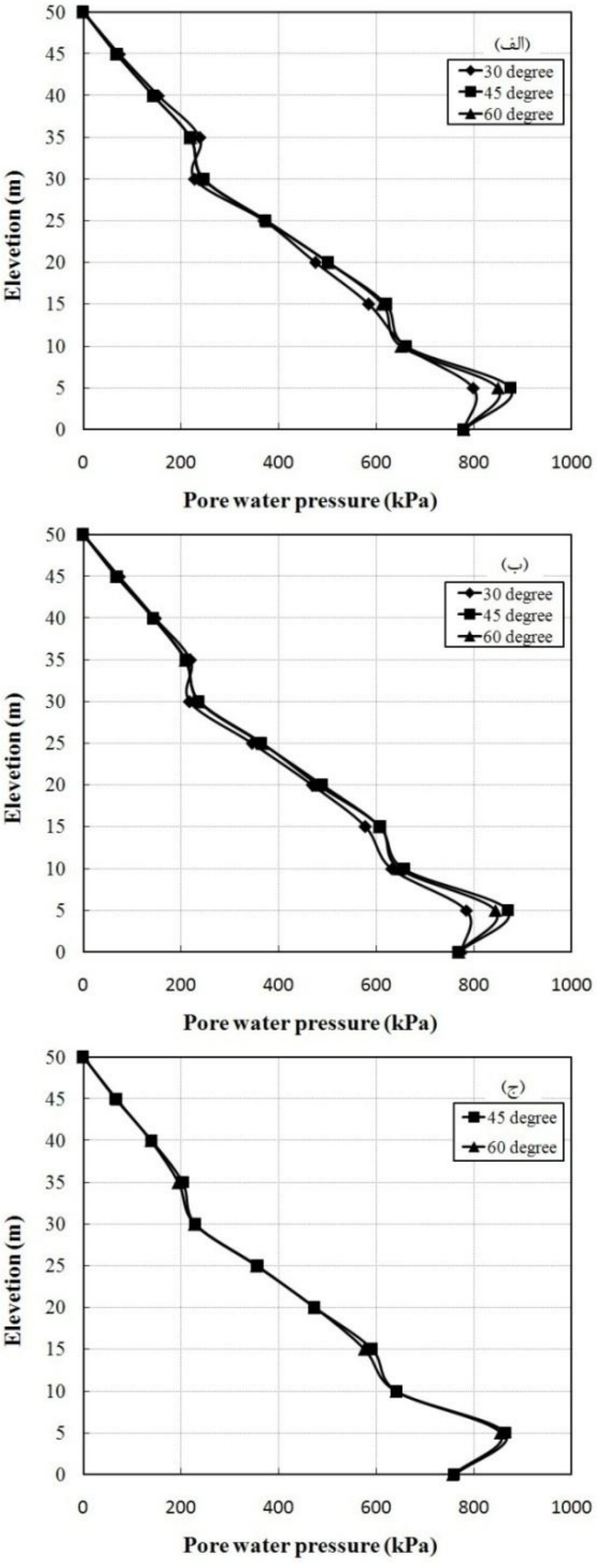

Figure 16. Comparison of cavitation water pressure in the center axis of the core in dynamic analysis in the longitudinal section of the valley in sections a) 1-1, b) 2-2, c) 3-3

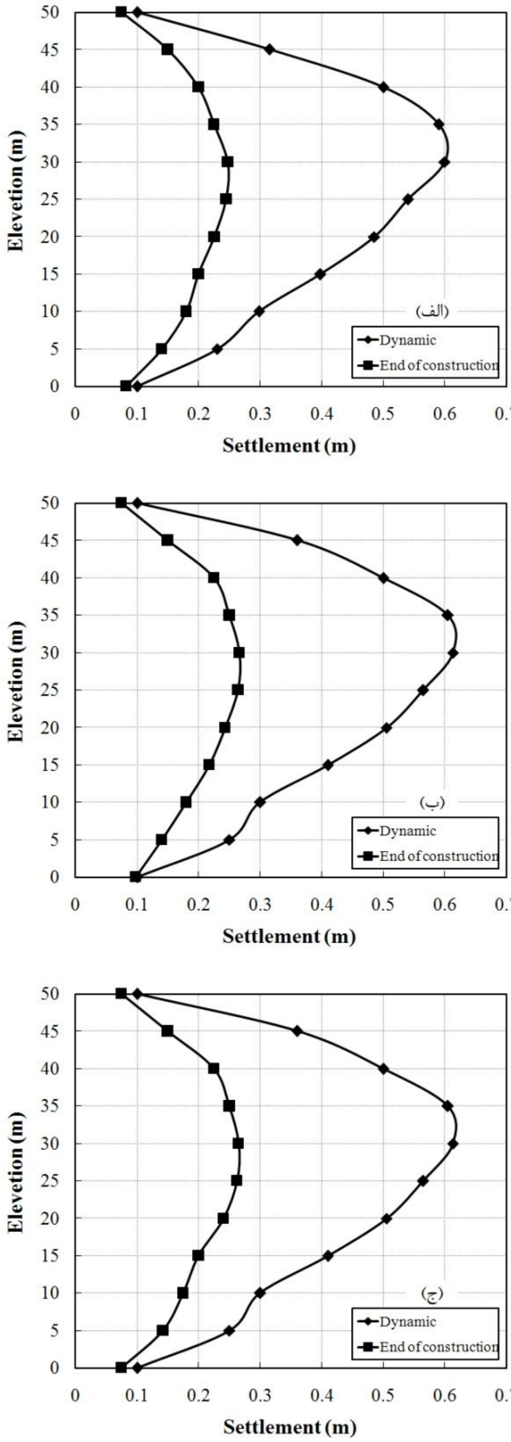

Figure 17. Clay core counterline in dynamic analysis in longitudinal section 1-1 for valley with slopes: a) 30º , b) 45º , c) 60º

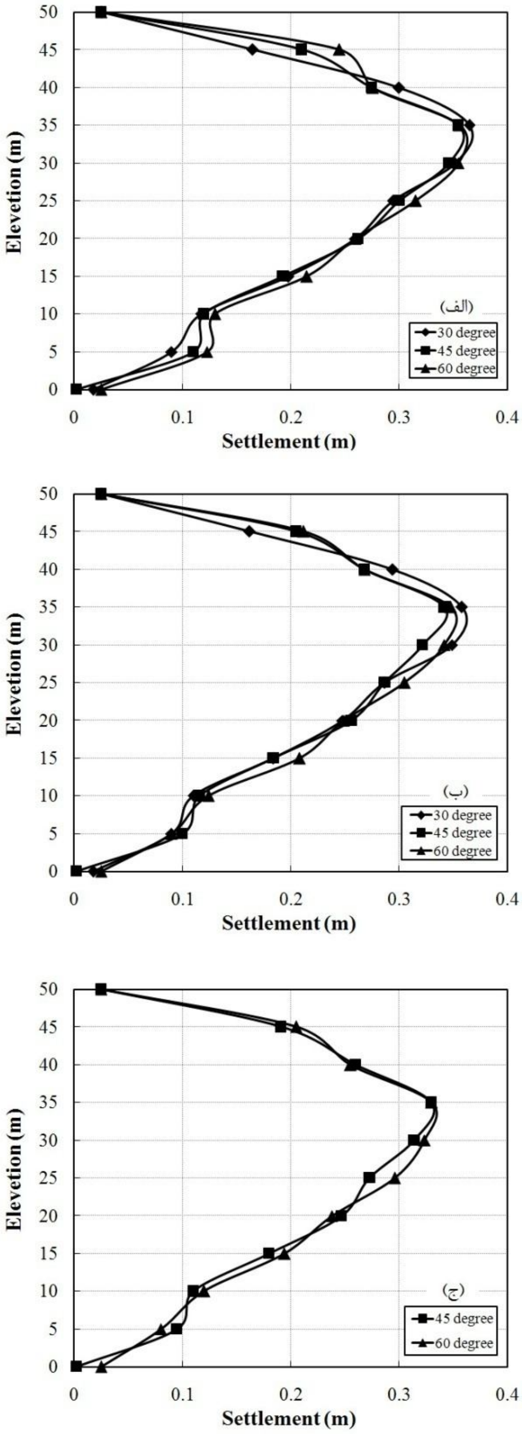

Figure 18. Comparison of the settlement of core of the dam in the dynamic analysis in the longitudinal section of the valley for sections a) 1-1, b) 2-2, c) 3-3

Conclusion

This study investigates the effect of valley slope on 3D behavior of earth dams and the following results have been obtained:

- Valley slope has no significant effect on arcing and the minimum arcing ratio at the end of construction condition is in 34 meter height balance of all three dams.
- Maximum additional pore water pressure at the end of construction occurs in dams with valley slope of 30 degree.
- At the end of construction, the least settlement is for dams with valley slope of 30 degree. Maximum settlement place in primary dewatering level and sustainable leakage with similar settlement at the end of construction is transferred about 6 meters to upstream.
- The amount of settlement and pore water pressure due to dynamic loading is not depending to valley slope.
- Increasing valley slope increases acceleration of dam respond. In another word, increasing acceleration of dam crest depends on geometry of valley.

Table 1. The values of the amplification factor of positive and negative accelerations in both directions X and Y

		Maximum positive acceleration of the dam) g(	Amplification factor	Maximum Negligence acceleration of the dam) g(	Amplification factor
X direction	Valley with slope 30˚	0/509	1/29	0/414	1/05
	Valley with slope 45˚	0/868	2/29	0/936	2/38
	Valley with slope 60˚	1/031	2/62	0/931	2/36
dir ec tio	Valley with slope 30˚	0/469	1/19	0/383	0/974

	Valley with slope 45°	0/771	1/96	0/671	1/70
	Valley with slope 60°	0/946	2/40	0/881	2/24

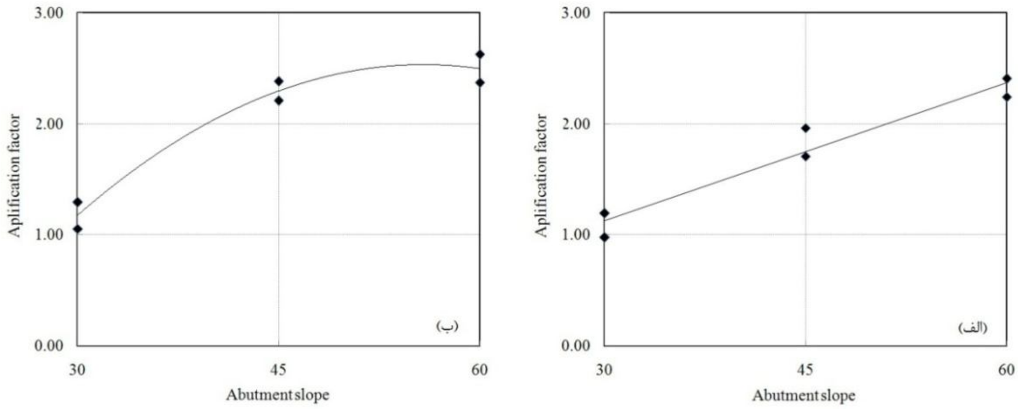

Figure 19. amplification factor changes with valley slopes for acceleration applying modes in direction a)Y and b) X

References:

1. Heydari, Tahereh, “comparing dynamic behavior of earth dams in 2- and 3-dimensional state”, M.A. thesis, Iran University of Science and Technology, 2003
2. Palasi Masoud, Salehi Behnam, and Mirghasemi Ali Asghar, “studying behavior of Maroon Dam in second dewatering phase with the help of information from accurate tools”, Hournal of civil engineering infrastructures, vol. 5, 2003
3. Wolfgang H., Roth, E.M., Dawson, P.S., Carig A. and Davis, C.C. "Evaluation the Seismic Performance of Stone Canyon Dam with 2D and 3D Analyses", 13th World Confrences on Earthquake Engineering, Vancouver, B.C., Canada, August 1-6, Paper No.3249
4. Itasca Consulting Group, Inc, 2004, Flac3DFast Lagrangian Analysis of Continua in 3 Dimension-User’s Guide, Minneapolis, Minnesota
5. Nazari Afshar, Javad, Ravanshenas, Pedram, Tavassoli, Omid, “numerical 3D analysis of earth-rockfill dam construction stages (case study: Maroon Dam), 6th national congress of civil engineering, Semnan University, 2011