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Study of Height Effect on Earthquake Modal Response in Embankment Dams

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ABSTRACT

Knowledge of the earthquake behavior of embankment dams comes from four sources: observations made from the dam response during earthquakes, experiments conducted on prototype dams for determination of their dynamic properties, experiments conducted on reduced scale models of dams including shaking table and centrifuge testing and finally analytical studies. From numerical analysis point of view, two dimensional seismic response analyses is usually applied to seismic design of embankment dams. Evaluation of seismic behavior for different height of dam is important. Many embankment dams have been made in different height in the world that we have not general point of view about seismic behavior of them. To achieve this goal, Masjed Soleyman dam for a case study has been selected. Masjed Soleyman zoned rock fill dam with 177 m height was constructed and impounded in South-West of Iran in 2001. Finite Element model of Masjed Soleyman dam has been constructed and the Mohr-coulomb elastic-perfectly plastic constitutive model is taken into account to reflect the soil stress-strain relation. First, layer analyses have been carried out considering 12 layers in end of construction stage. Then, this analysis has been continued considering water table and weight of dam reservoir. 2 earthquake records have been applied horizontally to the bedrock for dynamic analysis. For study of mode of vibration and distribution of acceleration, 10 models have been used with different height. Then seismic response of earth dam due to some known earthquake has been investigated. These data were used to identify the modes of vibration of the dam. Result shows that First and second mode of vibration in Masjed Soleyman dam case to peak horizontal displacement and acceleration decreased in height of dam. Also changing of peak horizontal acceleration and peak horizontal displacement in height of dam depends on dominant mode of vibration, height of dam, properties of materials and frequency specification.

1. Introduction

The past 25 years have resulted in significant progress in methods and tools to evaluate the seismic performance of embankment dams. The simplest of these methods relies on empirical correlations and simplified procedures derived from observed or calculated seismic response data, and requires few input parameters. Simplified procedures for embankment dam analysis only require the peak ground acceleration, PGA and velocity, PGV as input parameters (Newmark, 1965), or the PGA and the magnitude of the

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causative event (Bureau, 1985). Other simplified methods need a response spectrum and the specified magnitude (Makdisi and Seed, 1977). In all other cases, such as the classic (Newmark's) double integration method of dam evaluation and in equivalent-linear, EQL or nonlinear, NL detailed analyses, one or several horizontal acceleration time histories must be specified, depending on whether two- or three-dimensional analysis is considered. It is customary to use the largest component of horizontal motion in the upstream–downstream direction.

Earth and rock fill embankment dams are the structures most commonly used to impound water. For these dams most sites are relatively good and, since everything from clay to large stones is used in their construction, it requires low capital investment and can be completed in short period of time with minimum environmental impact. However, improper use of construction material and carelessness during investigation stage causes embankment failure by piping and seepage, foundation failure, overtopping and others (Seed, 1979).

Dynamic loads induced by earthquakes are often major factors in the design of earth dams. Earthquake induced stresses are major factors in determining the angles of the dam slopes and significantly influence the selection of materials, the zoning of the dam, and the construction method. Awareness about more rigorous seismic stability analysis is also growing during recent years. The seismic performance of embankment dams is evaluated by using numerical techniques. The Finite Element Method and model tests are some of the methods used for analyzing dynamic behavior of embankments (Gazetas, 1987). Seismic stability of dams is an important segment of dams design process. Also this segment is more complicate. In this paper, seismic behavior of dam with different height has been evaluated considering Masjed Soleiman dam for a case study. Masjed-Soleyman embankment dam location in Iran has been shown in Fig. 1.

2. Material and Methods

Presented article provide the numerical assessment for layered analysis of the Masjed Soleiman embankment dam. In this regard the elevation considered as variable and dynamic analyses conducted for each layers which 12 layers have been used for making of the model. Finally by considering the dynamic Mohr-Coulomb criterion in steady seepage, the different stage of analysis presents.

3. Results and Discussions

3.1. Static Analyses

Most analysis procedures require static properties (unit weight, moisture content, and total and effective stress strength parameters). The effective static shear strength is essential to some NL dynamic analyses (Roth et al., 1991). Finite element analyses used to define the initial state of static stresses often rely on hyperbolic soil models (Duncan, 1991). Variations of the initial tangent static modulus E_i with the confining pressure (Janbu, 1963).

$$E_i = KP_a\left(\frac{\sigma}{P_a}\right)^n \tag{1}$$

where K is a constant, σ the minor principal stress, P_a the atmospheric pressure, and n an exponent defining the rate of variation of E_i with σ.

In order to perform static and dynamic analyses, Masjed Soleiman dam has been modeled with critical cross section, based on the proposed sections in the technical plans of the dam, extracted in which the height of the model from the foundation and width of crest have been simulated as 170m and 15m, respectively. Masjed Soleyman dam is highest embankment dam in Iran. This dam is a zoned rock fill dam constructed in South West of Iran, in Khuzestan province. The dam is located in Zagros Mountains (North 320, East 49.40) on Karun River. The body of dam with the volume of 13.5 million cubic meters, the width of crest is 15m, the width of dam in foundation 780m and the volume of excavation 1.8 million cubic meters has been constructed.

The rock types in the dam site comprise a variety of sedimentary rocks of alternation soft and resistant weathering characteristics. Rock types include Bakhtyari, Aghajari, Mishan and Gachsaran formations, combined with intense seasonal rainfalls. The area is subjected to ongoing compression forces, which have warped the sediments into a series of folds and given rise to high angle reverse fault movement throughout the basement rocks. Over the past century that modern seismic instruments have been installed, a large number of high level earthquakes were recorded in the region. Major earthquakes in Khuzestan are shallow and have focal depths in the range of 8 to 15 km; somewhere below the level of sedimentary rocks in the crust. Also in Fig. 2 the section view of the dam is shown (Davoodi, 2003).

3.2. Layer Analyses

The static analysis of Masjed Soleiman has been carried out considering the elstoplastic constitutive model with Mohr-Coulomb criterion in the final stage of construction and the steady seepage stage. At the end of the construction, the embankment dam is still undergoing internal consolidation under its own weight.

Stage construction has been done after realizing in-situ stress in the dam foundation. Then displacement of foundation has been considered zero. Number of layer is an important parameter in this step of analyses.

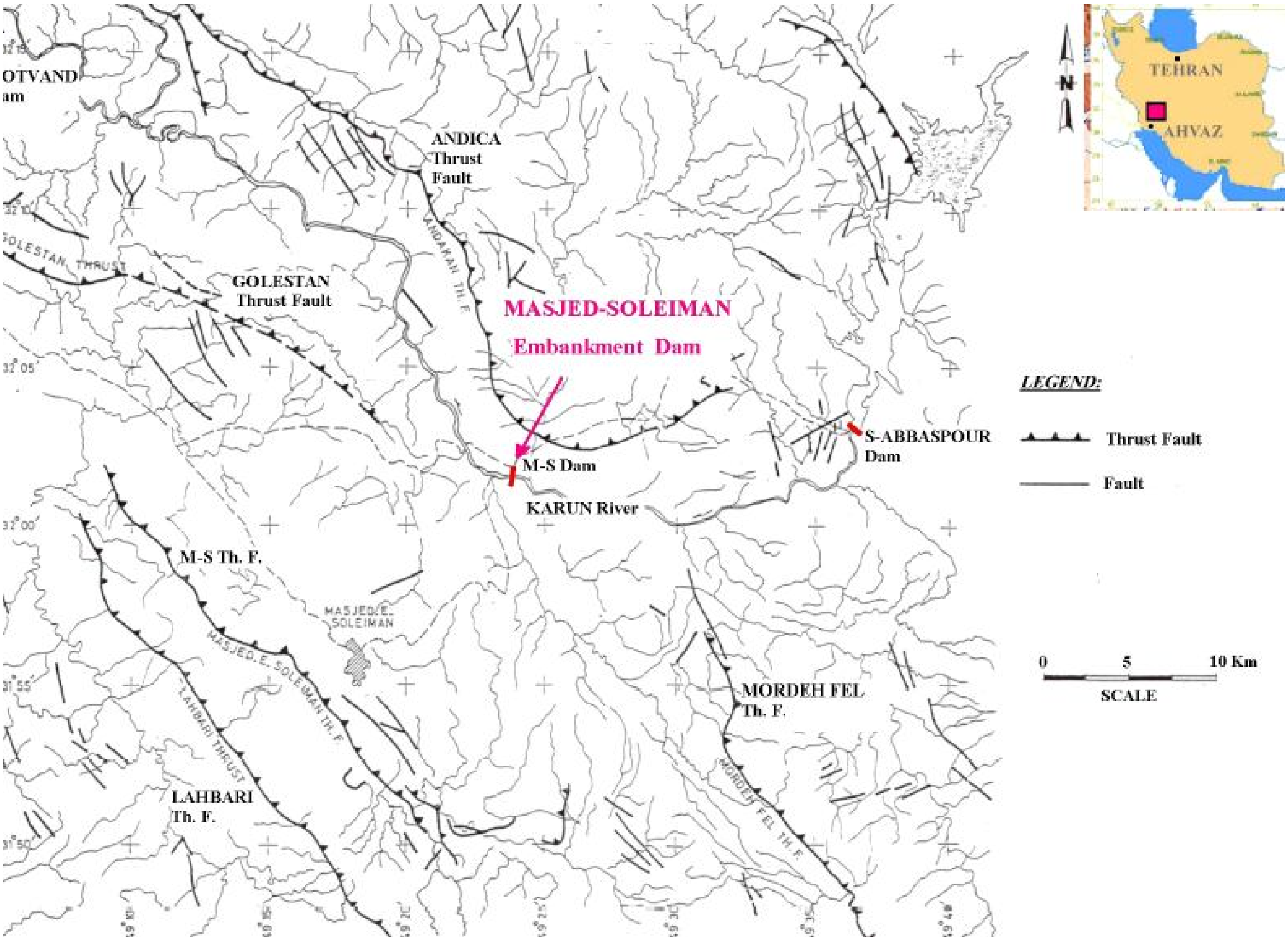


Figure 1. Location of the studied Dam (Jafari et al., 2003)

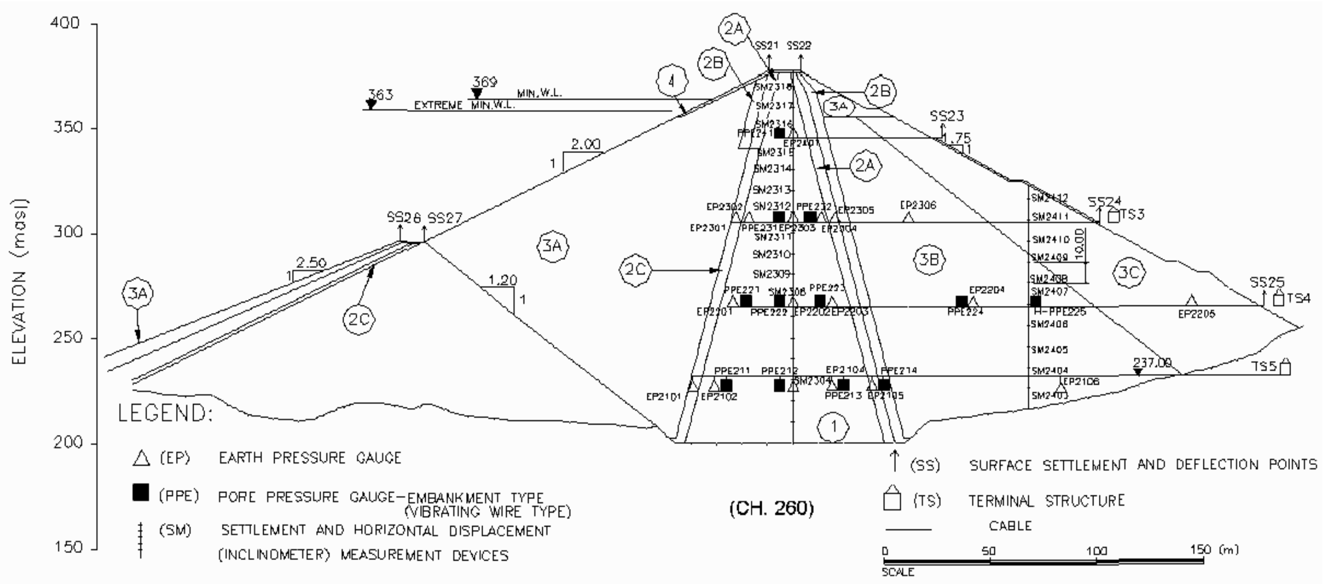


Figure 2. Section view of the Masjed Soleyman dam

Table 1. Geo-materials properties in the construction stage of analysis (Davoodi, 2003).

Zone	C (kPa)	ϕ	ν	P (kg/m^3)	ψ	E * (10^5 kPa)				
						12 m	31 m	43 m	93 m	148 m
Core	50	10	0.34	2050	0	-	0.30	-	0.70	1.60
Upstream Shell	0	45	0.4	2350	22	0.86	0.64	-	1.09	1.33
Down Stream Shell	0	37	0.38	2200	18	-	-	0.70	1.02	1.30
Saturated Filter	0	40	0.36	2350	0	-	0.49	-	0.94	1.44
Wet Filter	0	40	0.36	2200	0	-	0.70	-	1.06	1.55
Foundation	700	30	0.30	2500	-	-	-	3.87	-	-

Eisentein (1979) have showed that 10 layers is an adequate number of layers for making a good model. In this research, 12 layers have been used for making of the model. Table 1 is show the property of the used materials in the staged construction analysis and Fig. 3 is illustrates the obtained results in the final stage.

3.3. Steady Seepage Analyses

Steady seepage develops after a reservoir pool has been maintained at a particular elevation (e.g., maximum storage pool) for a sufficient length of time to establish a steady line of saturation through the embankment. Steady seepage stage comes up after the constant flow of water is maintained. In this condition, effective stresses and pore pressures remain constant in their limiting values. This condition occurred after some years. In the general manner, there are two types of stress analyses that are used in the evaluation of existing and proposed embankments. These are the total stress analysis and the effective stress analysis. The total stress analysis is used in the design of embankments for loading conditions during construction, rapid drawdown, and earthquake. The effective stress analysis should be used only in cases where the soils behave drained and piezometer data are available (Yanagisawa, 1991).

In this research the effective stress analysis for steady seepage condition has been used. Properties of the used materials in the steady state seepage are same for end of construction stage that noted in Table 1 except internal friction angle that is equal 19 and cohesion is equal 40. Fig. 4 illustrates the obtained results of steady seepage analyses.

3.4. Dynamic Analyses

Various natural strong motion records are normally considered to select acceleration time histories as seismic input. Selection criteria consist of magnitude and duration of the causative earthquake, mode of fault rupture, distance, subsurface conditions at the recording station, and possible presence of near field effects. A digitization interval of 0.02 sec is sufficient for embankment dam analysis (Gazetas and Dakoulas, 1992). Their seismic performance has been closely related to the nature and state of compaction of the fill material. Well-compacted modern dams can withstand substantial earthquake shaking with no detrimental effects. In particular, earth dams built of compacted clayey materials on competent foundations and rock fill dams have demonstrated excellent stability under extreme earthquake loading (Gazetas, 1987).

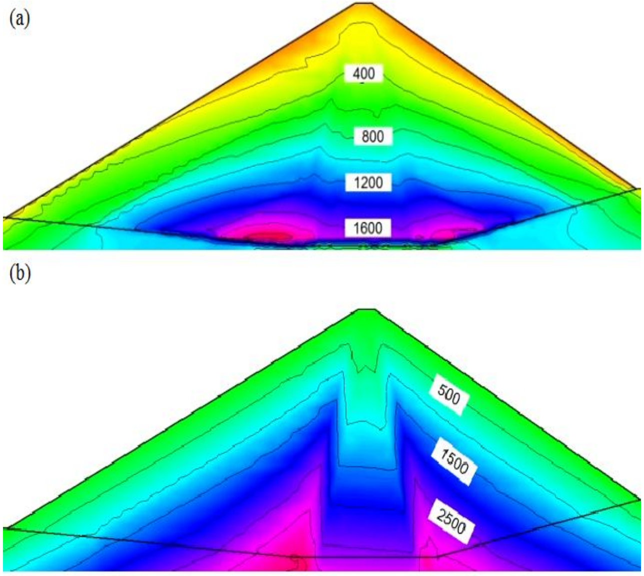


Figure 3. Contours variation for parameters in construction's final stage in kPa: (a) vertical effective stress, (b) horizontal effective stress

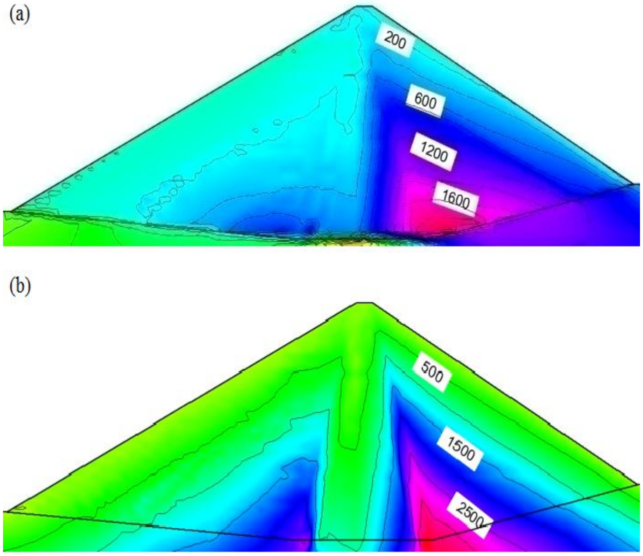


Figure 4. Contours variation for steady state seepage stage in kPa: (a) vertical effective stress, (b) horizontal effective stress

The two earthquake records of Loma prita-1989 and Northridge-1994 in the far field condition have been applied horizontally to the bedrock as the input motion for dynamic analysis. Before analyzing the earthquake records, in all the records, the base line has been corrected and the band pass filter has been used. Also Earthquake records that are used for analyzing should be compatible with site conditions. It has been common practice to scale and modify natural earthquake records to match a specified peak acceleration and spectral content. The earthquake records are scaled 0.34g based on seismic levels. Properties of the employed accelerometers are presented in Table 2 and Figs. 5 and 6.

Strain-dependent equivalent dynamic shear modulus and damping ratios as first introduced by Seed and Idriss (1970), are essential to EQL analyses. The dynamic shear modulus decreases with the average induced shear strain, while damping increases. Dynamic properties for the body of dam, core materials, shell and filters have been extracted from the reports presented by the consultant of the project as can be observed in Table 3 and Fig. 7. The dynamic response behavior of embankment dams was recognized as a key factor in correctly understanding and evaluating the seismic performance of dams. Effect of material nonlinearity in dynamic analysis is considered using the equivalent linear method. In equivalent linear method, behavior of material is linear; but damping ratio increases and shear modulus decreases due to increasing of shear strain. Also the two earthquake records have been used to specify distribution of acceleration along the height of dam. Considering a base point located on the foundation and referring the central axis of dam at each elevation, changes in acceleration and displacement along the height of dam have been investigated. In this study 10 finite element models have been considered, details of models can be observed in Table 4. Then, Dynamic analyses have been performed on these models. The maximum recorded accelerations in the middle axis of embankment dam in temporal domain are demonstrated in Fig. 8. Also result of acceleration monitoring in crest presented in Fig. 9. Then slope of Amplification for acceleration in central axis of dam has been shown in Fig. 10.

Table 2. Properties of the applied earthquake records in dynamic analyses

Record	Year	Magnitude	Epi-central Distance (km)	PGA (g)	PGV (cm/s)	PGD (cm)
Loma Prieta	1989	6.93	92.21	0.0726	7.98	3.01
Northridge	1994	6.69	90	0.0645	4.44	0.73

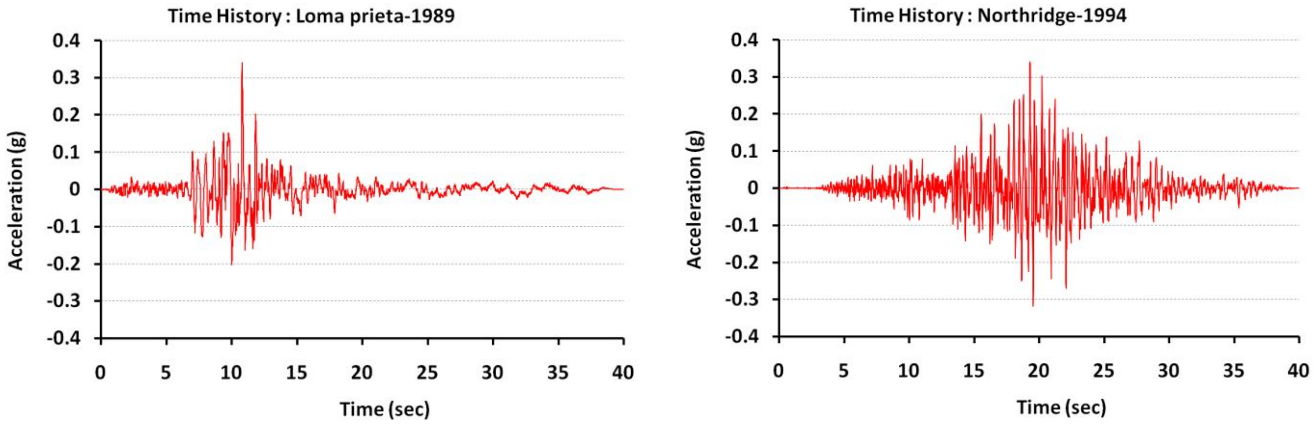


Figure 5. Time history of the far-domain earthquakes used in this research

Table 3. Material properties used in the dynamic analyses

Zone	C (kPa)	ϕ	ν	P (kg/m^3)	ψ	E * (10^5 kPa)				
						12 m	31 m	43 m	93 m	148 m
Core	40	19	0.45	2200	0	-	2.23	-	3.85	4.21
Upstream Shell	0	45	0.40	2350	22	-	2.35	-	2.99	3.15
Down Stream Shell	0	37	0.40	2200	18	0.88	-	3.85	5.40	5.80
Saturated Filter	0	40	0.40	2350	0	-	1.34	-	1.71	1.82
Wet Filter	0	40	0.40	2200	0	-	1.74	-	3.07	3.30
Foundation	700	30	0.30	2500	-	-	-	10.92	-	-

Table 4. Details of numerical models with deferent height

Earthquake records	Height of Dam (m)				
	130	150	170	190	210
Loma prieta-1989	O.K.	O.K.	O.K.	O.K.	O.K.
Northridge-1994	O.K.	O.K.	O.K.	O.K.	O.K.

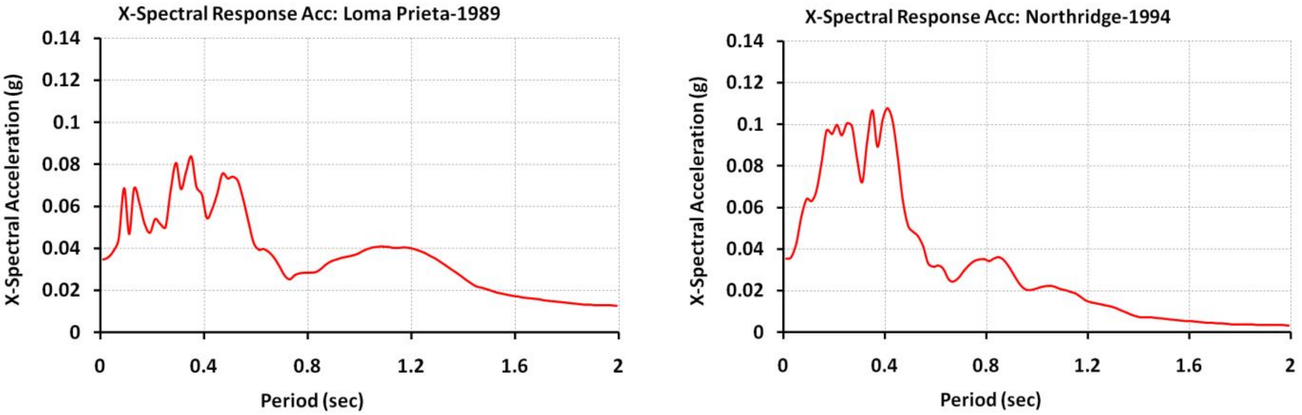


Figure 6. Response spectrum of the far-domain earthquakes used in this research

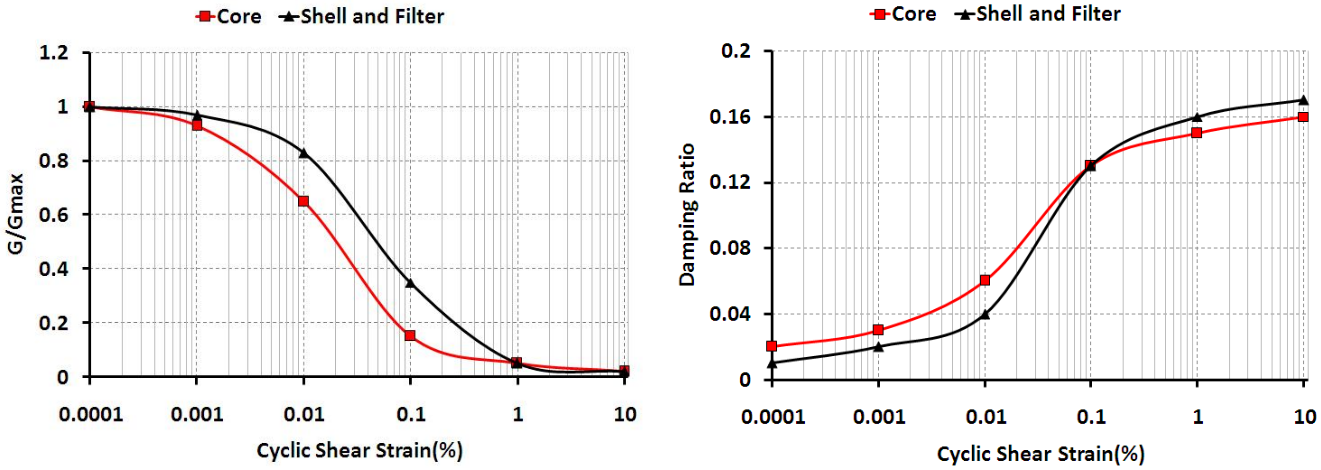


Figure 7. Dynamic properties of materials used in modeling

Acceleration for all model in crest of dam have been investigated. Results showed that the peak horizontal acceleration induced in short embankment dams. So acceleration in crest of dam has decreased while height of dam increased. This occurrence has been happened for both of earthquake records that considered. Also slope of acceleration changes for Northridge-1994 earthquake record was more than Loma prieta-1989 earthquake record.

Slope of amplification in acceleration for central axis of dam have been behaved with different case. Slope of amplification in Loma prieta-1989 earthquake record decreased while height of dam increased but in Northridge earthquake record has been behaved vice versa.

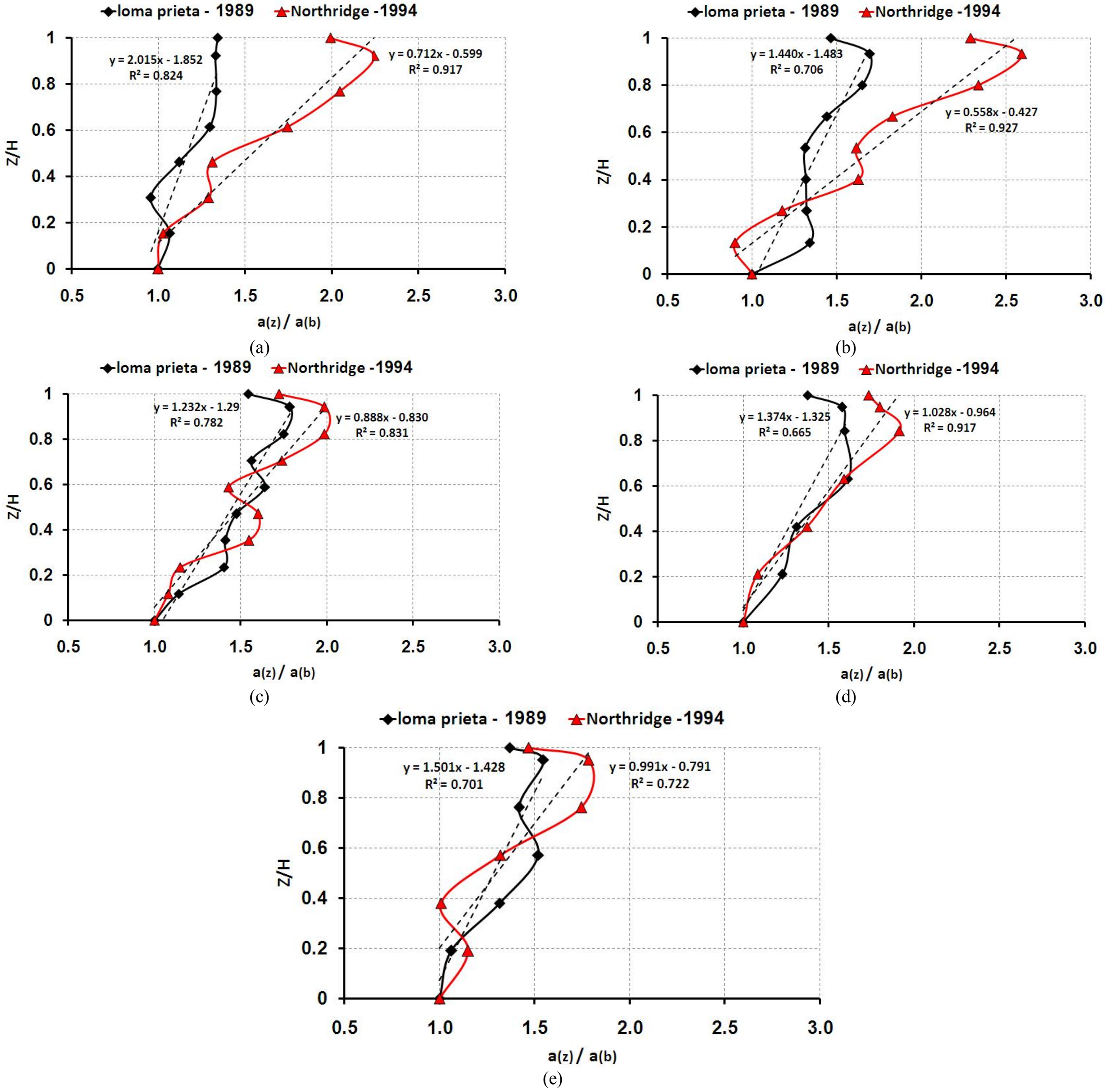
Displacements in height of dam have been investigated in central axis of body for all finite element models. Modes of dam vibrations have been resulted of peak displacement in time domain. Modes of dam vibration presented in Fig. 11. Also peak displacement in crest of dam has been shown in Fig. 12.

4. Conclusion

This research has been done considering Masjed Soleiman dam as a case study and also 10 finite element models has been constructed considering 2 different earthquake records for bed rock as input for dynamic analyses. Then with changing height of dam, mode of vibration and distribution of acceleration have been studied. Result of this research shows that:

- Peak acceleration for central axis of dam in Northridge-1994 earthquake record was more than loma prieta-1989 earthquake record, especially for dam with 130 and 150 meter height.

- Mode of vibration has changed when height of dam increased. Also in this time, peak horizontal displacement increased and peak horizontal acceleration decreased.
- Changing of peak horizontal acceleration and peak horizontal displacement in height of dam, depends on dominant mode of vibration, height of dam, properties of materials and frequency specification.
- Increasing rate of acceleration in height of dam has decreased when height of dam increased and material of dam reach to plastic criteria.
- Also, acceleration has decreased when height of dam and plasticity of dam increased. So in short dams with high natural frequency, amplification of acceleration has been occurred.
- Then peak horizontal acceleration and displacement in height of dam decreased when dominant mode of vibration changed of second mode to the third mode of vibration.
- First and second mode of vibration in Masjed Soleyman dam case to peak horizontal displacement and acceleration decreased in height of dam. So, changing mode of vibration depends on vibration frequency and height dam.



(a) (b) (c) (d) (e)

Figure 8. Distribution of acceleration for all models with different height: (a): 130 m, (b): 150 m, (c): 170 m, (d): 190 m, (e): 210 m

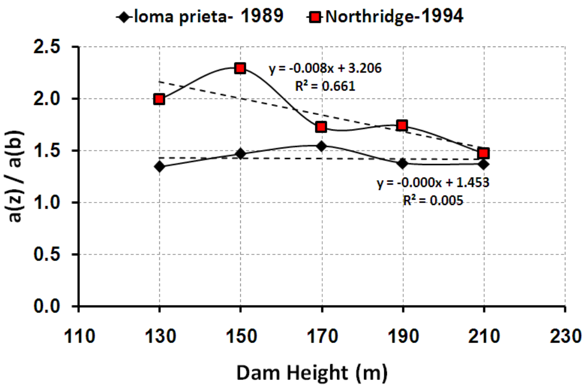


Figure 9. Acceleration in crest of dam for different height

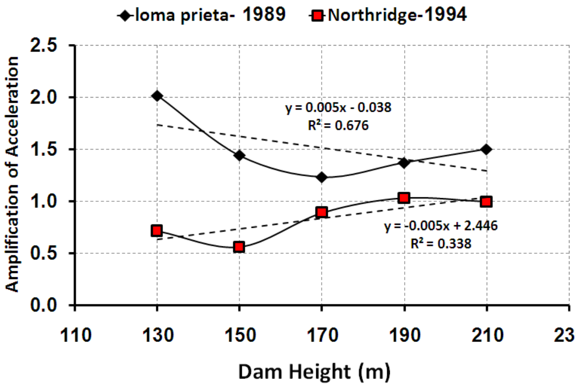
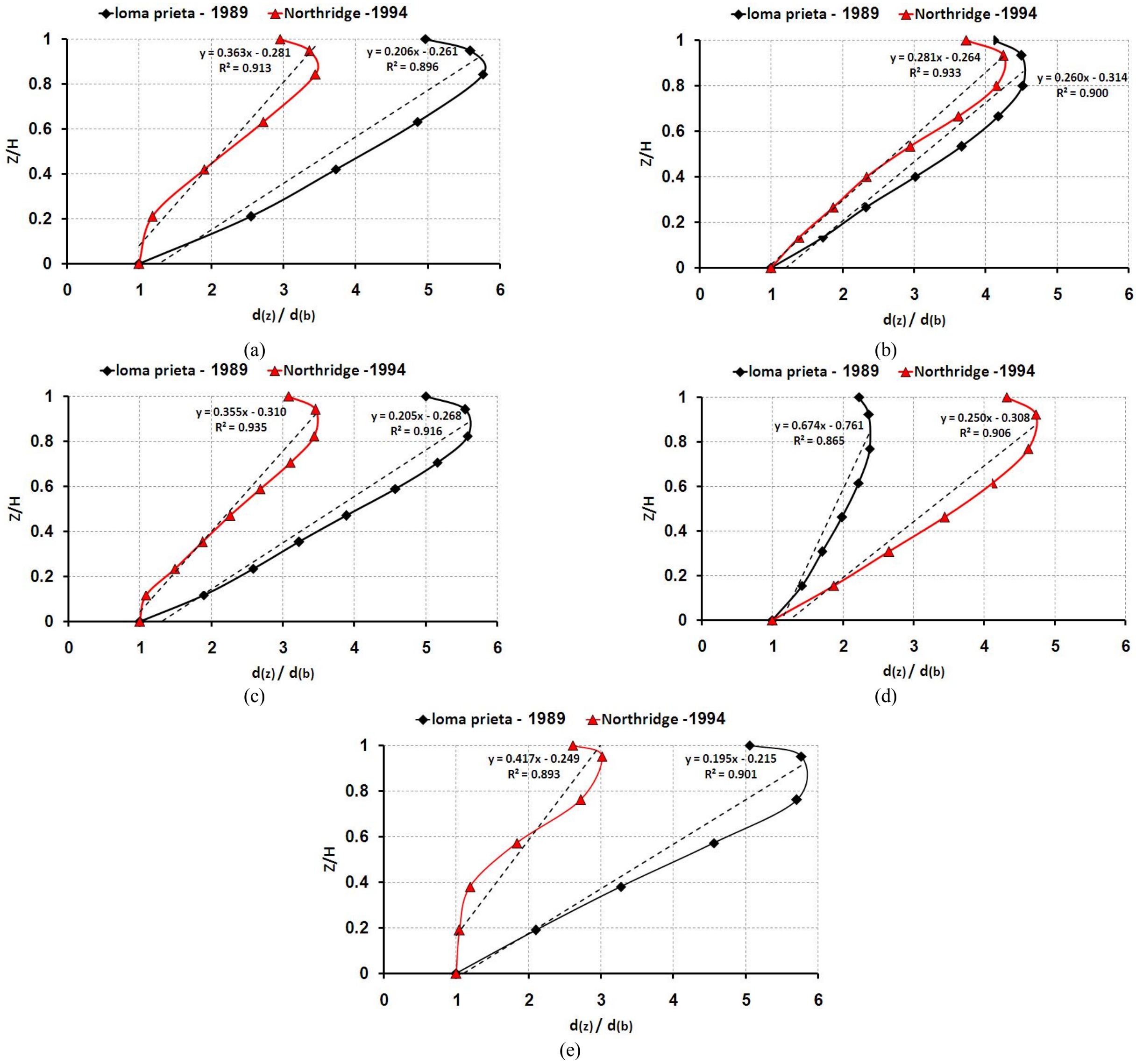


Figure 10. Slope of Amplification in acceleration for central axis of dam for different height



(a)

(b)

(c)

(d)

(e)

Figure 11. Mode of vibration for all models with different height: (a): 130 m, (b): 150 m, (c): 170 m, (d): 190 m, (e): 210 m

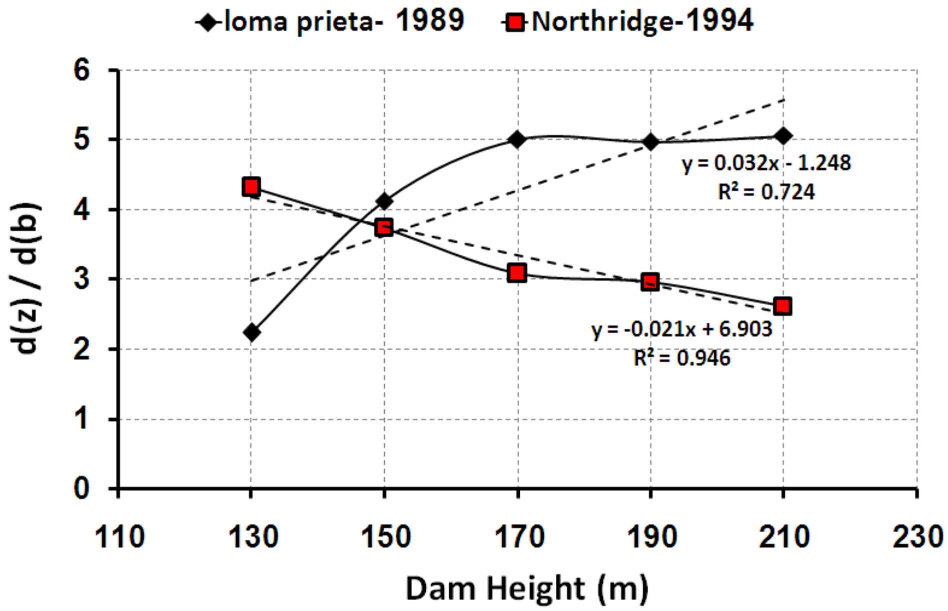


Figure 12. Peak displacement in crest of dam for different height

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