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USING RECORDED EARTHQUAKE SIGNALS FOR DYNAMIC ANALYSIS OF MASJED SOLEIMAN EMBANKMENT DAM

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ABSTRACT

There is a worldwide interest in the proper seismic design of embankment dams in high seismic hazard zones. The seismic behavior of embankment dams can be evaluated by in-situ dynamic tests (such as processing recorded earthquake signals on dam body), experimental methods (i.e. experiments using large shaking table, centrifuge tests) and numerical methods Using recorded earthquake signals on dam body is a powerful tool for researchers for dynamic analysis of embankment dams. In this research, recorded accelerograms are used to dynamic analysis of Masjed Soleiman embankment dam, the highest rockfill dam in Iran. Using recorded earthquake signals in the basement of the dam as input excitation, dynamic analysis of the dam body was also performed and the results of the numerical modeling was compared with recorded earthquake signals on the dam body. The calculated responses are compared with recorded accelerograms on mid-height and crest of the dam. In comparison, the modern signal processing method, Time-Frequency Distribution (TFD), is used. This comparison leads to more appropriate modeling of the dam body in earthquake loading condition. The results indicate that TFD results show that %20 to 30% mass foundations have closer results to the recorded earthquake signal.

INTRODUCTION

Prediction of the seismic behavior of an embankment dam during earthquakes is one of the most complicated problems to geotechnical subjects. Several earth dams have experienced failures or significant damage resulting from earthquakes (the San Andrews dam, 1906, the Sheffield dam, 1925, the San Fernando dams, 1971). A careful study of the behavior of dams during earthquake occurrences provides a valuable insight into earthquake – resistant design of dams. The state of the art in the seismic analysis and design of rockfill dams have been described by Gazetas and Dakoulas (Gazetas and Dakoulas, 1992). Identification of systems involves an inverse procedure to identify the parameters from the recorded response of real systems. Seismic behavior study of embankment dams can be performed by different methods: observations made from dam response during earthquakes, experiments on prototype dams to determine dynamic properties such as explosion and ambient tests, experiments on reduced scale models such as shaking tables or centrifuge testing and finally, analytical studies.

The seismic waves observed in earthquake records manifest clearly non-stationary characteristics, as well as wide frequency content. Earthquake records are used to evaluate dynamic response of dams, but in the lack of available earthquake records, explosion tests can be used to determine dam's dynamic response characteristics for validating numerical models.

Relevant available dynamic analysis methods contain some simplifying assumptions both in modeling the soil behavior and modeling the earthquake excitation in embankment dams (Abouseeda H., Dakoulas P., 1996, Dakoulas P., Abouseeda H., 1997, Elgamal A.., 1988, Gazetas, G., 1987 and Prevost, J. et al., 1985). The seismic stability evaluation of the dam includes a dynamic response analysis of the embankment using two dimensional (2-D) and three dimensional (3-D) finite element procedures. There are some examples that the researchers have used in-situ tests on dams to identify dynamic properties of dam systems. Kassa embankment dam in Japan with 90m height and 478m length was excited by different vibrations. This dam was investigated by classical signal processing techniques under forced, ambient and blasting tests and the obtained system identification results were compared with the results of earthquake records (Ohmachi et. al. 1979).

Recently, for the first time in Iran, the recorded earthquake, explosion, ambient and forced vibration tests are used to evaluate dynamic characteristics of an embankment dam. Dynamic characteristics of Masjed Soleiman embankment dam, the highest embankment dam in Iran, are extracted based on classical and modern signal processing methods (Jafari and Davoodi, 2006, Davoodi et al. 2007, Davoodi and Amel Sakhi, 2008, Davoodi et al. 2008).

As the available softwares can not evaluate the exact solution of dam-foundation interaction problem, they use mass-less foundation theory. In this theory, the mass of foundation is neglected in dynamic analysis. But this approach is not necessarily the exact solution. Consequently the mass of foundation should be studied in seismic analysis of embankment dams.

Using earthquake recorded signals on different installed accelerometers stations, MS embankment dam dynamic response is computed in January 6, 2004 earthquake. The accelerograms recorded by the instrument station at the gallery is used to calculate the dynamic response of the dam during the earthquake. In this paper the related results based on dam-foundation interaction problem and dynamic behavior of MS dam during earthquake are presented and discussed in time-frequency domain.

DESCRIPTION of MASJED SOLEYMAN DAM

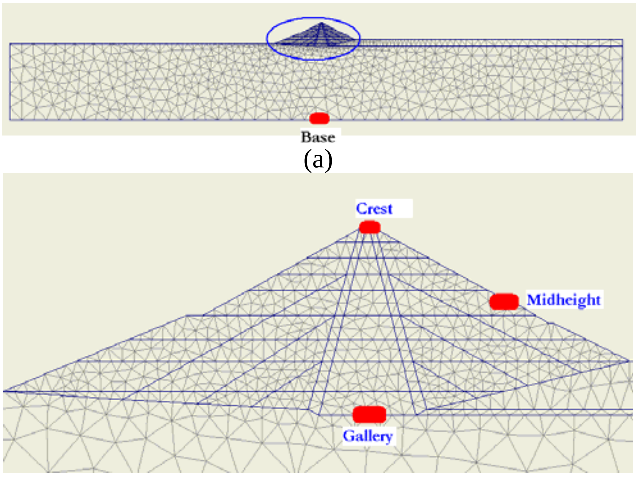
The Masjed Soleiman dam is a rock-fill type with clay core and a maximum height of 177m located on the Karun River in southwest Iran, 25.5 km to Masjed-E-Soleyman town (Fig.1). Length of the crest is 480 meter and the dam body volume is nearly 13.4 million m^3. The objective capacity of the power plant is to generate 2000 MW of hydroelectric energy. The width of the dam at foundation and the width of the crest are 480 and 15 meter respectively.

Fig.1. Masjed Soleyman embankment dam view

ANALYSIS OF RECORDED DATA

In order to analyze the Masjed Soleiman embankment dam to earthquake excitation, different element numbers are examined and the optimum element number is selected in the PLAXIS software. The 2-D dam-foundation system was modeled by with 2381 elements and 4996 nodes; see Figure 2. To study dam-foundation interaction, different foundation masses are considered; rigid foundation and foundation with % 0, % 25, % 50, % 75 and % 100 of the total mass foundation and also decreasing mass. In decreasing mass, the full mass is just beneath the dam body and the mass of the foundation decreases as the depth and the width of the foundation increases. After modeling the dam based on optimum element numbers, the initial stresses in the embankment dam are determined.

To study the dynamic behavior of the dam, the recorded acceleration time histories are used. In this research, GeoSIG sa 99 accelerometers are used and the sample per second (SPS) for each record were 200. The accelerometers locations on Masjed Soleiman dam body are presented in Figure 2 that can be seen, they are located in gallery, in the midheight of the dam and the crest of dam body. One sample of installed accelerometers on dam body is presented in figure 3. The earthquake signals used in the analysis were recorded in three components in January 6, 2004 earthquake. For example one of the recorded events is summarized in table 3.



(a)

(b)

Fig.2. the 2-D mesh of the Masjed Soleiman dam body and the considered foundation and also the location of accelerometers, (a) general view, (b) a more coarse view of dam body

Fig.3. the located accelerometer on the crest

In order to analysis the MS embankment dam to earthquake excitation, the following method is used:

- First of all, based on finite element method theories, different element numbers are examined and the optimum element number is selected. After modeling the MS dam and using optimum element numbers, the initial stresses in the embankment dam are determined.
- An appropriate acceleration time history is selected. This time history is expected to develop in the foundation of the dam. It should be mentioned that for using the recorded earthquake signals in the analysis, the base line are corrected and the band pass filter are applied. In this research, the recorded earthquake signal in the gallery station is selected as the excitation signal.
- Finally the dynamic response of dam body due to the earthquake under consideration is obtained. In this step, dam body is tested to the combination of pre-earthquake stress conditions, and super-imposed dynamic stress applications in order to determine the seismic strength and deformation characteristics.

Different static and dynamic soil properties in different zones are used in static and dynamic analyses, respectively, see Tables 1 and 2. Since the recorded event is a weak motion, the linear elastic model is used in the analysis.

In the next part, dynamic analyses are performed using related parameters. In dynamic analysis, absorbent boundaries are used to prevent wave reflection inside the model during dynamic analysis. In order to use the recorded earthquake signals in the analysis, the base line are corrected and the band pass filter are applied. After selecting a proper acceleration time history, this time history is expected to develop in the foundation of the dam. In this research, the recorded earthquake signal in the gallery station is selected as the excitation signal.

Table 1. Geotechnical parameters for materials in static analysis (Davoodi, 2003)

Material		ρ (kg/m^3)	υ	C ($\times 10^5$ N/m^2)	φ (0)	ψ (0)	E ($\times 10^8$ Nm^2) Depth (m)				
							12	31	43	93	148
Core	Saturated	2200	0.34	0.4	19	0	-	0.3	-	0.7	1.2
Shell	Dry(3A,3C)	2200	0.4	0	45	22	0.85	-	0.86	1.13	1.43
	Dry(3B)	2200	0.38	0	37	18	-	-	0.67	0.95	1.24
	Saturated	2350	0.4	0	45	22	-	0.64	-	1.09	1.33
Filter	Wet	2200	0.36	0	40	0	-	0.7	-	1.06	1.55
	Saturated	2350	0.36	0	40	0	-	0.49	-	0.94	1.44

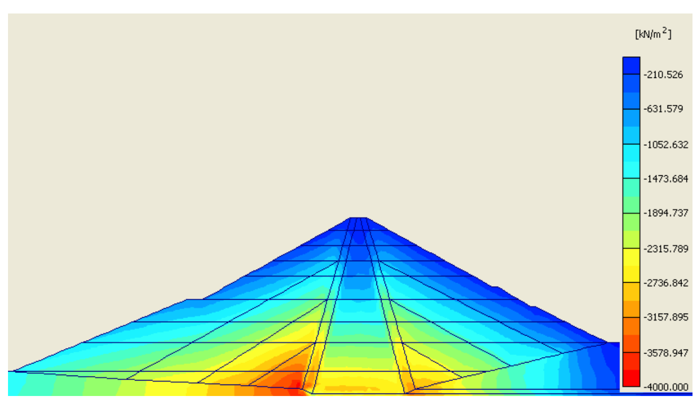
Table 2. Geotechnical parameters for materials in dynamic analysis (Davoodi, 2003)

Material		ρ (kg/m³)	υ	Depth (m)					
				12	31	43	93	148	
Core	Saturated	2200	0.45		2.153		3.3	3.46	E_0*10^9(N/m^2)
					0.74		1.14	1.196	G_0*10^9(N/m^2)
					580		719	736	V_s(m/s)
Shell	Dry	2200	0.4	0.85		3.7	4.61	4.76	E_0*10^9(N/m^2)
				0.3		1.324	1.64	1.69	G_0*10^9(N/m^2)
				372		775	865	876	V_s(m/s)
	Saturated	2350	0.4		2.268		2.57	2.58	E_0*10^9(N/m^2)
					0.81		0.912	0.92	G_0*10^9(N/m^2)
					587		624	622	V_s(m/s)
Filter	Wet	2200	0.4		1.744		3.076	3.296	E_0*10^9(N/m^2)
					0.632		1.098	1.177	G_0*10^9(N/m^2)
					532		706	730	V_s(m/s)
	Saturated	2350	0.4		1.344		1.712	1.824	E_0*10^9(N/m^2)
					0.48		0.612	0.64	G_0*10^9(N/m^2)
					451		509	514	V_s(m/s)
Foundation & Abutment	Right	2500	0.3	9.36					E_0*10^9(N/m^2)
				3.6					G_0*10^9(N/m^2)
				1320					V_s(m/s)
	Left			7.8					E_0*10^9(N/m^2)
				3					G_0*10^9(N/m^2)
				1200					V_s(m/s)
	Foundation			10.92					E_0*10^9(N/m^2)
				4.2					G_0*10^9(N/m^2)
				1300					V_s(m/s)

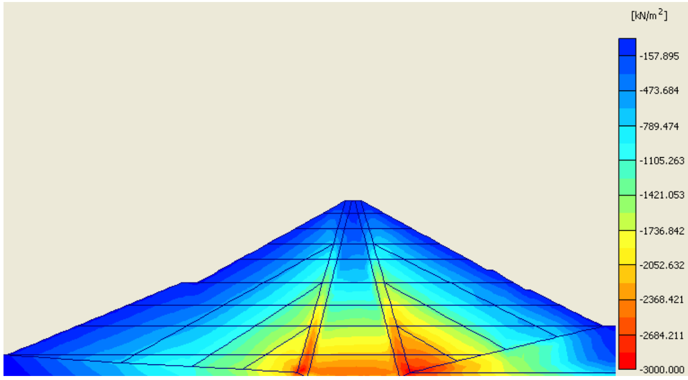
Table 3. General characteristics of recorded earthquakes on Masjed Soleiman dam dated 2004.1.6

File name	Position	Direction	PGA (mg)
Taj1610-003-x	crest	U-D	38.32
Taj1610-003-y		L	21.6
Taj1610-003-z		V	31.68
Dog-way16-10-82-03x	midheight	U-D	17.76
Dog-way16-10-82-03y		L	20.16
Dog-way16-10-82-03z		V	11.2
Gtb16-10-82-x	gallery	U-D	10.88
Gtb16-10-82-y		L	8.48
Gtb16-10-82-z		V	5.56

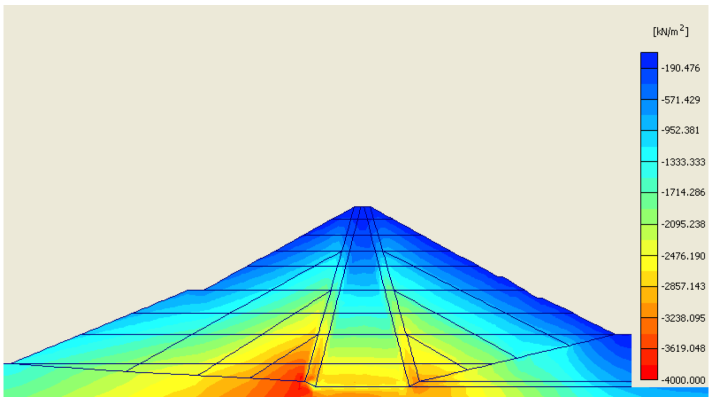
Obtained calculated results are compared with recorded acceleration time histories in the midheight and crest station of dam body. Here, static and dynamic vertical stress distribution of dam body with %50 mass foundation is presented. These results are corresponding to impounding case, see Fig. 4.



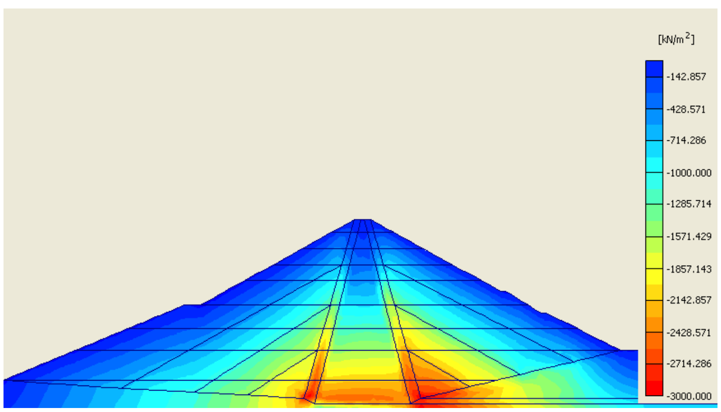
(a)



(b)



(c)

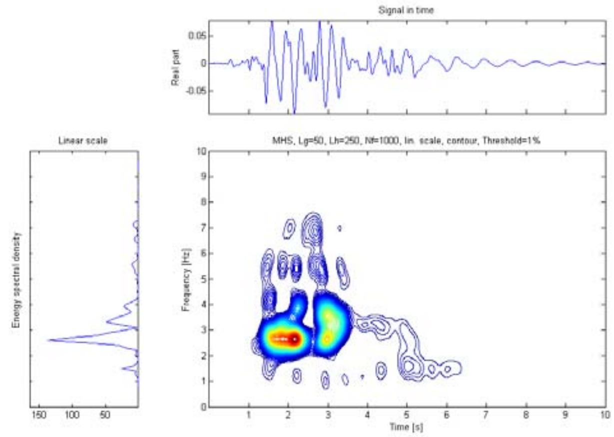


(d)

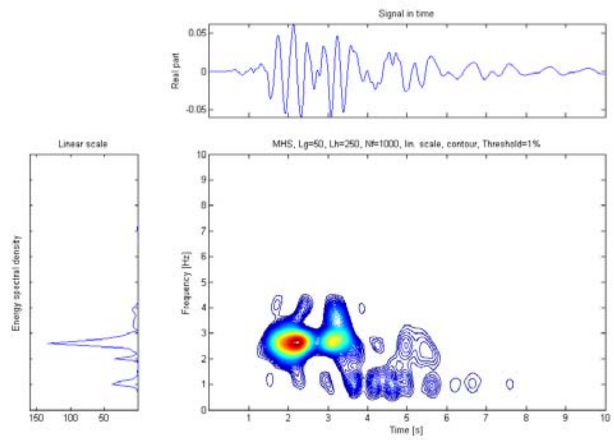
Fig.4. Vertical stress distribution of dam body with %50 mass foundation; (a) total static stress, (b) effective static stress, (c) total static + dynamic stress, (d) effective static + dynamic stress

Because of weak motion, there are a little difference between two static and static + dynamic results, as it was predicted. To compare the results, all the earthquake records are analyzed

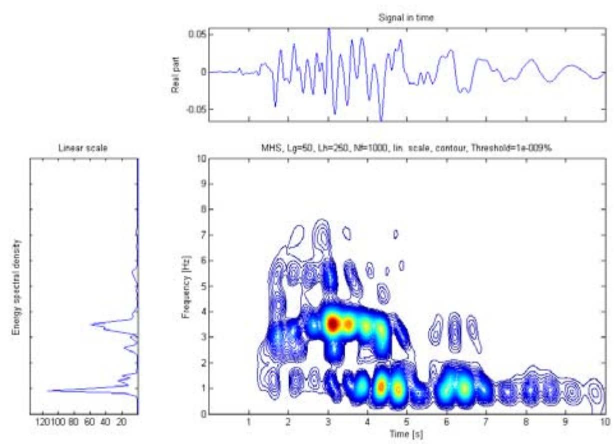
In order to compare the results, time-frequency distribution (TFD) method is used and the processed signals by TFD method are presented in Fig 5.



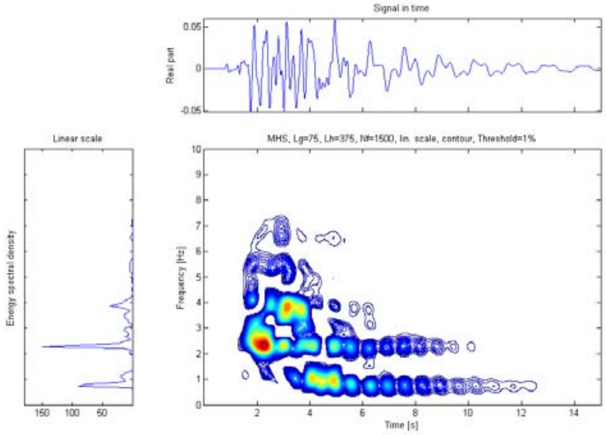
(a) Rigid foundation



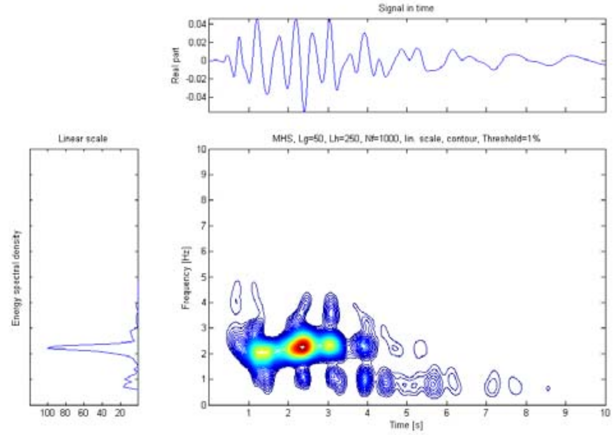
(b) Mass-less foundation



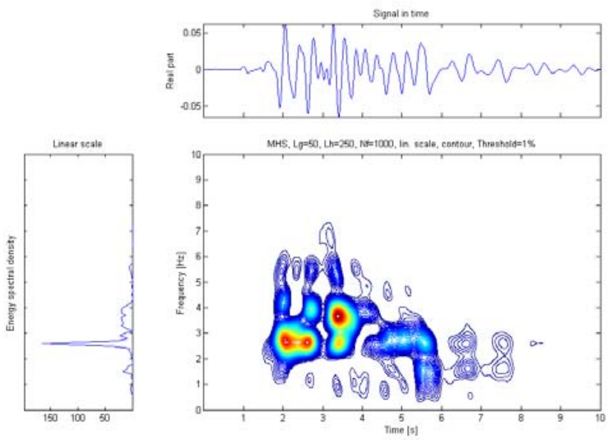
(c) %25 Mass foundation



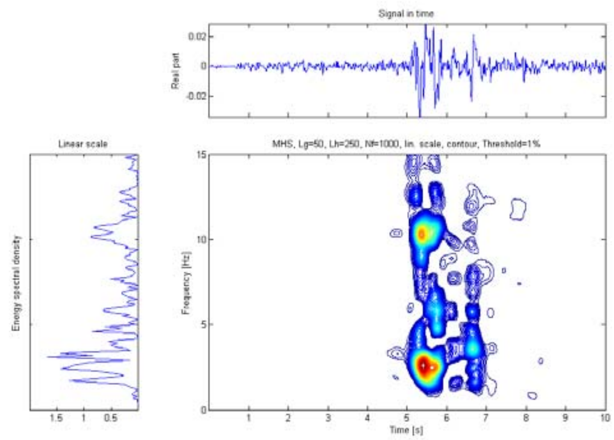
(d) %50 Mass foundation



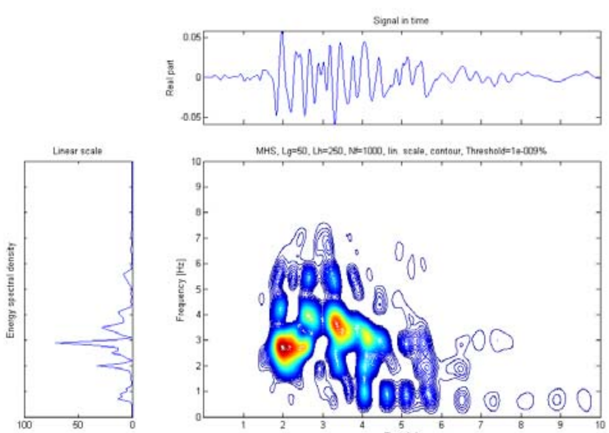
(g) Decreasing mass



(e) %75 Mass foundation



h) Recorded earthquake signal



(f) %100 Mass foundation

Fig.5. Calculated acceleration time history at crest for rigid, %0, %25, %75, %100, decreasing mass foundation and also recorded signal in upstream-down stream direction (top); its corresponding PSD (left); and related TFD contour plot (right).

The results show that the dynamic response of dam body is clearly weak in the comparison with the static analysis. This behavior is based on weak recorded earthquake signal on dam body. Consequently, it can be said that in this case, because of weak earthquake event, the safety factor of dam body against failure doesn't change any more in the static and dynamic analysis. TFD results show that %25 and % 50 mass foundations have closer results to the recorded earthquake signal. Based on obtained results, it can be said that in dynamic analysis of embankment dams, when the free field motion is not available, mass less condition assumption, the usual assumption in the available softwares, is not acceptable. Also results show that in the numerical analysis, assuming foundation with maximum %50 mass, can lead to more acceptable results in comparison with recorded responses on dam body.

CONCLUSION

In this paper, using recorded earthquake signal in the gallery station, dynamic analysis of Masjed Soleiman embankment dam, the highest embankment dam in Iran, is performed and a comparison between the calculated and the measured dynamic response of this dam during January 6, 2004 earthquake is presented.

Considering different masses for modeling the foundation (rigid foundation, mass less assumption, 25%, 50%, 75%, 100% and decreasing mass) indicate that using total mass to model foundation didn't reach to a proper solution in dam-foundation interaction problem. To compare the calculated and recorded results, the modern signal processing method; TFD method, is used that analyses the signals in both time and frequency domains. The obtained results of 25% and 50% mass foundation models and the recorded earthquake signal on dam body are more similar to each other in frequency content in TFD analysis. It is shown that in dynamic analysis of embankment dams, mass less condition assumption can not be acceptable. The processed results indicate that in the numerical analysis, assuming foundation with maximum %50 mass, can lead to more acceptable results.

The obtained results indicate that in-situ measurements can provide properties that are in good agreement with numerical calculated responses of the embankment dams. Also, in-situ measurements are powerful tools to study the dam's dynamic responses.

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