Studying the Effects of Non-Uniform Earthquake Excitations on Dynamic Response of Concrete Arch Dams

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Abstract

In structures with large dimensions such as bridges and dams, owing to the extent of supports, seismic ground motion at interface of different points of the structure and foundation might vary significantly. These real non-uniform motions in usual designs, due to analytical complexities, has been marginalized. While few studies reveal that for exact evaluation of seismic safety of dam, attention to non-uniform excitation is necessary. This paper studies the seismic response of dam-reservoir-foundation systems subjected to non-uniform motions. A high concrete arch dam is selected as the case-study example and its analytical model is subjected to seismic uniform and non-uniform motions. After performing finite element linear dynamic analysis, the results are compared and assessed. According to the results, imposing non-uniform excitation lead to significant differences in displacement responses and stresses.

Keywords: Non-Uniform Excitations, Linear Dynamic Analysis, Double Curvature Dam.

1. INTRODUCTION

Dams are strategic structures of high importance because of their key role in supplying water for people and agriculture and also generating electricity. Dam failure can cause immense property and environmental damages and take thousands of lives. Therefore, identification of all parameters affecting the safety of arch dams are important. Seismic load is one of the most essential loads which is considered in designing and analyzing processes.

Seismic analysis of dams is usually performed based on the assumption that the earthquake input motions are uniform at different supporting points [1, 2]. In large structures such as dams, long span bridges and piping systems, due to long structure-foundation interface, uniform seismic excitation assumption is not logical and can lead to inaccurate results [1, 3]. Recorded motions have revealed non-uniformity existing along dam-foundation interface at arch dams because of the finite speed of propagation of earthquake waves [1, 4]. Effective factors affecting the ground motion characteristics mainly stem from three mechanisms including “wave passage effect” due to differences in arrival time of waves at supporting points depending on their relative distances away from the source; “incoherency effect” due to reflections and refractions of seismic waves through the soil during propagation that causes changes in amplitude and frequency away from their source; and finally, the “site-response effect” due to differences in local soil conditions at the supporting points [5,6]. Nowak and Hall (1990) analyzed the seismic response of Pacoima dam in two parts and showed that the stresses for a full reservoir were higher than the stresses for an empty one and also non-uniformity in the stream component of the excitation reduced the response [2].

In recent years, few dams are equipped with accelerometers arrays. The accelerometers have been employed at different positions of the dam- foundation interface and have recorded several earthquakes ground motions [7]. Chopra and Wang (2010) computed the responses of two arch dams to spatially varying ground motions recorded during earthquake by developed linear analysis procedure considering dam-water-foundation rock interactions effects. They concluded that the influence of spatially varying ground motion for the same dam could differ from one earthquake to another, depending on the epicenter location and the focal depth of the earthquake relative to the dam site [8].

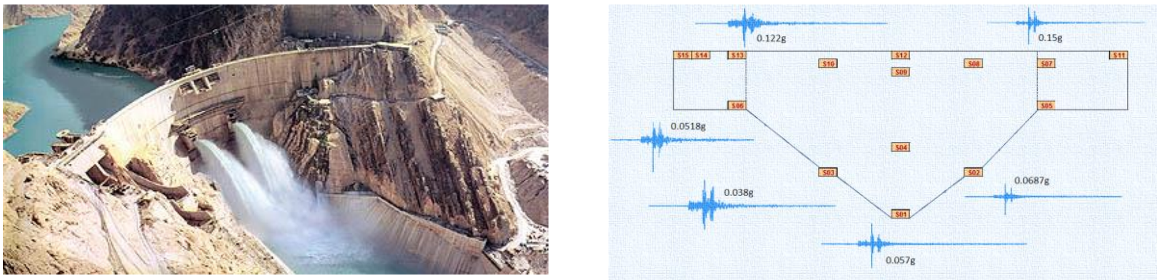
Sohrabi-Gilani and Gaemian (2012) investigated the seismic response of Karun III dam subjected to spatial variation of ground motions along dam-foundation interface. They studied topographic amplification between various points of the interface by obtaining ratios of the response spectral displacement and spectral pseudo acceleration. Time shift and amplification between stations show the non-uniform nature of ground motions. The results revealed that non-uniform ground acceleration can have extensive effects on dam behavior and can increase the responses [9]. Mirzabozorg et al (2013) investigated the seismic response of dam-reservoir- foundation system subjected to spatially varying ground motion. They utilized Monte Carlo simulation approach for generating spatially non-uniform ground motion. The results showed that the non-uniform input response is substantially different from uniform input response and can increase the structural response of the system [10].

Research on the responses of dams to earthquake non-uniform support excitations in Iran is limited. So this study aimed to investigate and compare the seismic responses of Karun III dam to uniform and non-uniform support excitations.

2. Karun III Arch Dam

Karun III Dam, located in Khuzestan province, Iran, is a 205m high concrete double curvature arch dam. The dam was built with the aim of supplying electric power, flood control and increasing the potential water supply for drinking and agricultural utilization. Figure 1, a) shows a view of Karun III dam and Table 1 indicates the main characteristics of the dam.

An array of 15 accelerometers has been installed in Karun III dam to investigate the dam's response and characteristics of earthquake ground motions at the dam-foundation interface. As it is illustrated in Figure 1,b) channels S_{01}, S_{02}, S_{03}, S_{05}, S_{06}, S_{11} and S_{015} have been located at the dam-foundation interface and designed to record all three components of any probable acceleration. Channels S_{04}, S_{07}, S_{08}, S_{09}, S_{10}, S_{12}, S_{13} and S_{014} have been installed within the dam's body.



(a) (b)

Figure 1. a) View of Karun III dam, b) Location of accelerometer installed on Karun III dam and upstream-downstream component of November 20, 2007 earthquake

Table 1- main characteristics of the dam

Crest level	850 m
Maximum height above the foundation	205m
Crest length	462 m
Crest width	5.5 m
Dam thickness at the base	29 m
Normal level of operation	845 m asl
Minimum level of operation	800 m asl
Reservoir capacity in normal level of operation	2970 Mm^3
Reservoir capacity in minimum level of operation	1250 Mm^3

3. Corrected Recorded Ground Accelerations at Dam-Foundation Interface

A major event has been recorded by this array during dam operations on November 20 of 2007. The recorded ground motion had a PGA of 0.312g at the crest. All recorded accelerations at dam-foundation were corrected by Seismosignal Software, and the corrected records were matched with three seismic performance levels including DBE, MDE and MCE by Sismomatch Software. The PGA of the recorded and corrected ground motions are presented in Table 2.

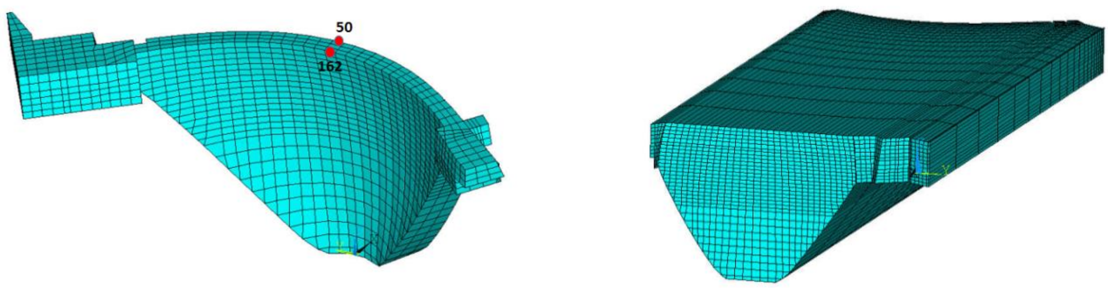
Table 2- The PGA of the recorded and corrected ground motions

MCE	MDE	DBE				
Corrected intensity	Corrected intensity	Corrected intensity	First intensity	Duration	Situation	Row
0.62g	0.41g	0.275g	0.151g	11s	S07	1
0.58g	0.37g	0.25g		11s	S2-7	2
0.55g	0.34g	0.21g	0.068g	11s	S02	3
0.53g	0.33g	0.19g		11s	S1-2	4
0.5g	0.32g	0.177g	0.057g	11s	S01	5
0.48g	0.3g	0.15g		11s	S1-3	6
0.44g	0.28g	0.128g	0.038g	11s	S03	7
0.459g	0.29g	0.138g		11s	S3-6	8
0.47g	0.3g	0.157g	0.052g	11s	S06	9
0.536g	0.35g	0.2g		11s	S6-13	10
0.58g	0.37g	0.245g	0.122g	11s	S13	11

4. FINITE ELEMENT MODEL OF KARUN III DAM

Figure 2 shows the provided finite element model of the dam body and the reservoir of Karun III dam. Primary coordinates of the dam body, horizontal and vertical arch attributes were used to model the body and the main appurtenant structures like the spillway, the left and the right thrust blocks. Accordingly, the reservoir length was considered about 3.5 times of the dam height in the upstream direction. It is worth mentioning that the reservoir was modeled with the prismatic fixed section along its length. According to the particular topography of the region, the surrounding foundation rock was extended twice of the dam height in all directions.

3958 8-node solid elements are used for modeling the dam body, appurtenant structures, Foundation medium and there are 2302 8-node fluid elements in the reservoir [11].
Also the material properties for concrete and foundation briefly are presented in table 3.



(a) **(b)**

Figure 2. Finite element model of Karun III a) dam body, b) the reservoir

Table 3 Concrete and foundation parameters used in the finite element model

Concrete mass density	2400 kg/m3
Concrete modulus of elasticity	30 GPa
Concrete Poison's ratio	0.2
Foundation deformation modulus	14 GPa
Foundation Poison's ratio	0.2

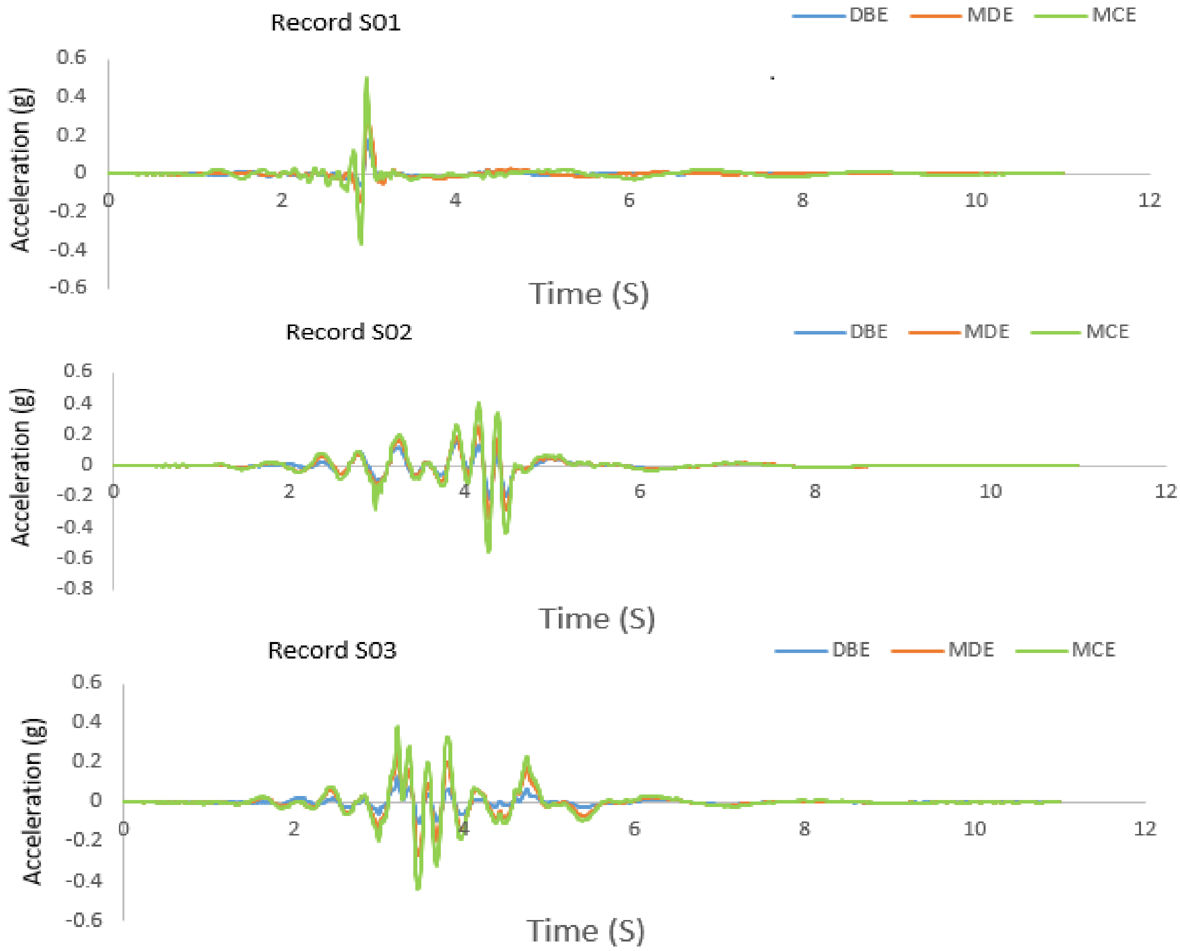
The recorded ground acceleration time histories used at dam-foundation interface in this study, therefore, in the finite element model, the foundation was excluded. The ground motion distribution across the thickness of the dam is considered uniform.

5. RESULTS AND DISCUSSION

In this section, responses of Karun III to uniform and non-uniform excitations of ground motions at three performance levels, including BDE, MDE and MCE, were studied, and compared with each other.

According to the displacement time histories in stream direction in the central crest for uniform and non-uniform excitation at three hazard levels (Fig.4), the results indicates that at three hazard levels, displacement values in uniform excitation was greater than non-uniform excitation. Increased hazard level can cause higher displacement. Also, the displacement pattern in the three levels was almost the same, and according to Fig.3, the peak of energy in both states of uniform (S13) and non-uniform was at intervals of 2-4 seconds. The maximum displacement also occurred at intervals of 2-4 seconds.

The minimum and maximum displacement of the central crest in two states of uniform and non-uniform for up-stream and down-stream faces (Table 4) revealed the displacement trend to down-stream face of dam. According to Table 5. In DBE level, the first principal stress (S1) and the third principal stress (S3) at non-uniform excitation is higher compared to the uniform excitation. Based on the results it can be concluded that by increasing in earthquake intensity, the values are increased.



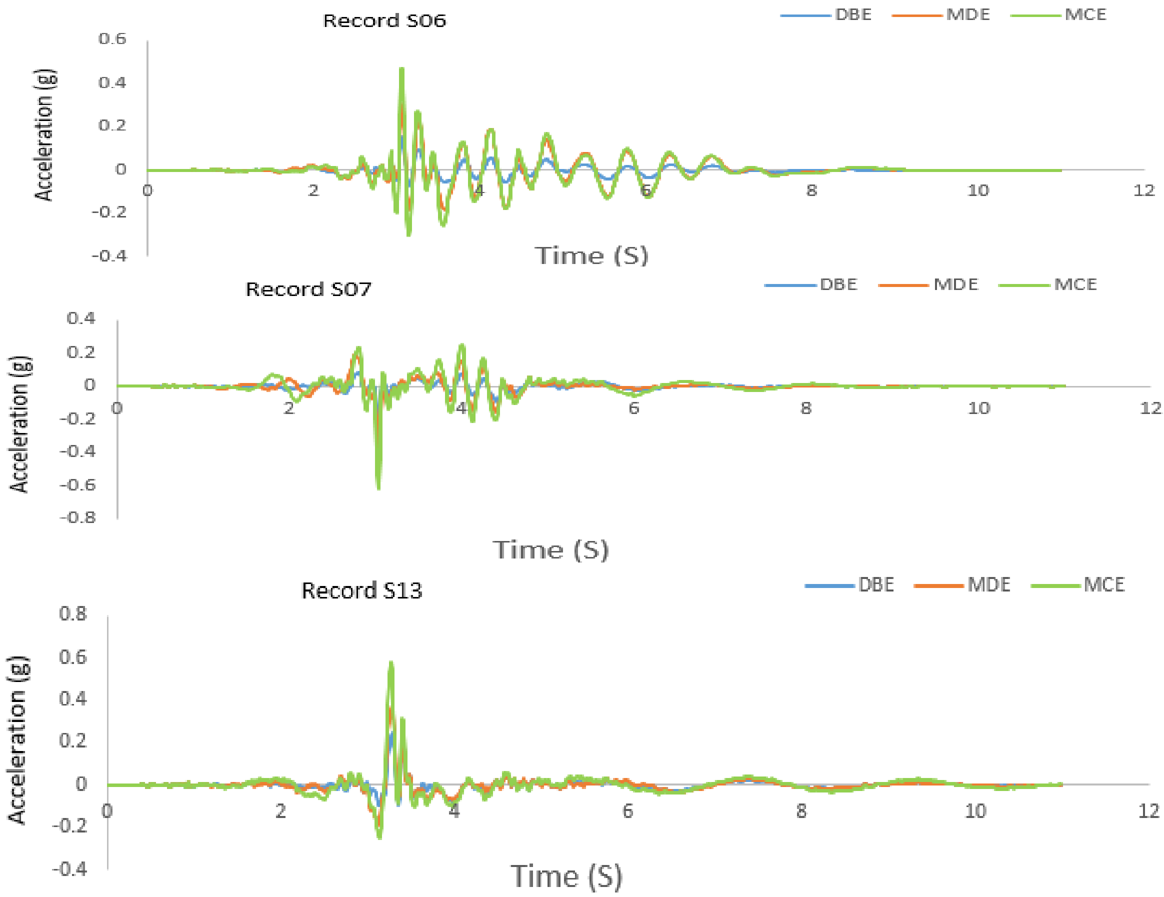
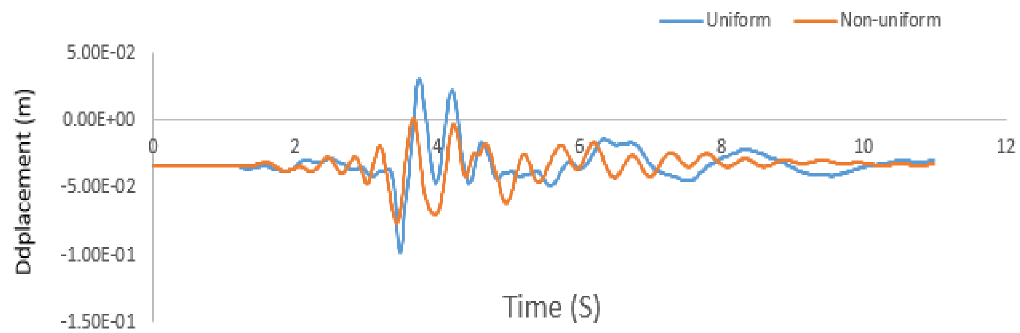
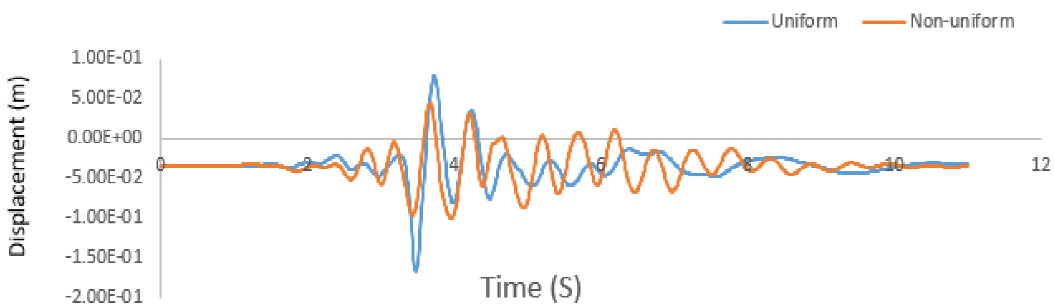


Figure 3. Comparison of records of main stations at three performance levels



(a)



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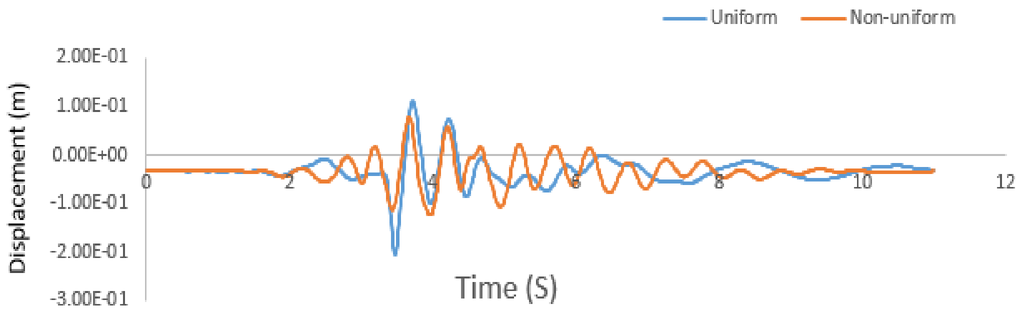

(c)

Figure 4. Graph of comparison of displacement time histories in stream direction at central crest point for Uniform and Non-uniform records at three performance level a) DBE, b) MDE and c) MCE

Table 4. Maximum and minimum displacements of dam crest in stream direction for up-stream and down-stream faces

		DBE		MDE		MCE	
		Crest mid-point		Crest mid-point		Crest mid-point	
		US(cm)	DS(cm)	US(cm)	DS(cm)	US(cm)	DS(cm)
Uniform	min	-9.79	-9.84	-16.7	-16.75	-20.47	-20.53
	max	3.05	3.02	7.8	7.8	11.22	11.18
Non-uniform	min	-7.64	-7.68	-9.98	-10.02	-12.37	-12.42
	max	0.0918	0.0597	4.52	4.5	7.86	7.84

Table 5. Maximum and minimum principal stresses of dam at three performance levels

		S1 (MPa)	S3(MPa)
BDE	Uniform	2.5	-11.7
	Non-uniform	11.7	-19.6
MDE	Uniform	4.55	-11.8
	Non-uniform	17.4	-24.5
MCE	Uniform	4.18	-19.1
	Non-uniform	18.7	-27.3

6. CONCLUSIONS

This investigation studied the earthquake non-uniform excitation effects on dynamic response of arch dam. The Karun III concrete double curvature was selected as the case study for this purpose. The recorded ground motions were used at stations of dam-foundation interface on November 20, 2007. The recorded ground motion was corrected by Seismosignal Software, and the corrected records were matched with three seismic performance levels including DBE, MDE and MCE by Sismo Match Software. The earthquake horizontal component (stream direction) was applied as input in the ANSYS Finite Element Software. The corrected records at stations of dam-foundation interface was used as the non-uniform input and also one of the most intense records (S13) was applied as uniform input.

The obtained results indicate that displacement values in the uniform excitation at three performance levels were greater than the non-uniform excitation. With hazard level increasing, the displacement values enhanced. The non-uniform displacement ratio in compare with uniform increased at the levels DBE (22%), MDE (40.2%) and MCE (60.5%), respectively. However, the displacement pattern in three hazard levels was almost the same. Minimum and maximum displacement of central crest of cantilever at two modes of uniform and non-uniform excitation for up-stream and down-stream faces showed the displacement trend to down-stream face of dam.

Based on the obtained results, maximum principal stress (S1) and minimum principal stress (S3) at non-uniform excitation is greater than uniform excitation and increase in hazard level can cause higher stress. It was generally observed that the non-uniform excitation had significant effect on structural responses of dam-reservoir-foundation system. Therefore, for more precise identification of dynamic behavior and reliable calculation of dam responses, the non-uniform excitation should be incorporated in seismic safety evaluation and seismic design of large dams.

7. REFERENCES

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