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The Effect of Far and Near Fault Earthquake on Non-uniform Excitation of Concrete Gravity Dams

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1. Introduction

In the analysis of structures under the influence of earthquakes, the effect of non-uniform excitation is often not considered. It is assumed that at the same time, without changing the frequency content, seismic waves reach all structural supports. In general, depending on the ratio of the wavelength of the earthquake to the horizontal dimensions of structure, seismic waves may be non-uniform to structural supports.

Factors of non-uniform distribution of earth acceleration that cause non-uniform excitation of concrete gravity dams can be attributed to two factors of time and space. Time factor includes wave passage effect and is caused by traversing the pass length by seismic waves. It appears as a delay in the arrival of waves from one point to another at the ground. This factor just creates phase differences and it doesn't change in the shape and the frequency content in seismic waves. Space factor includes site effect and incoherence effect. These effects can change the amplitude of the waves or frequency content and as a result of the time history of earth's acceleration. Site effect that is affected by the soil and region of topography of the support points is less important for concrete gravity dams based on homogeneous bedrock. Incoherence effect means random alterations of the shape and phase of waves. It depends on how are the reflection and refraction of waves in the direction of movement from the earthquake focus to the points of support in different layers of the earth.

The non-uniform distribution of ground acceleration causes changes in the responses of the structure. This effect can be significant depending on factors such as far fault, near fault, focus, epicenter, focal depth, and frequency content. Therefore, non-uniform analysis is necessary to achieve more accurate results. Near fault refers to earthquakes that the distance of epicenter to the earthquake recording station is less than a certain limit. Some researchers find this distance up to 15 Km and some even up to 50 Km away. Generally, velocitygram and seismogram of near fault have a strong pulse while this feature is not in far fault records. Acceleration of far fault generally has a low frequency content compared to near fault.

2. Materials and Methods

In this study, the effect of time and space factors on non-uniform excitation has been investigated separately and their responses are compared with the results of uniform excitation. All results are investigated for three accelerations of far fault and three accelerations of near fault on different positions of the epicenter in the toe and heel of the dam and also in the upstream of the reservoir.

Non-uniform excitation of time is assumed to be based on homogeneous and isotropic property. This excitation is modeled with delay when the earthquake component arrives at a specific shear wave velocity. In order to produce non-uniform spatial excitation components, the acceleration of the earthquakes is converted from the time domain to frequency domain by the Fourier transforms. Different models are used to determine the coherence function. The difference between these models are in earthquake events, earthquake sites, numerical process of recorded information and different interpolation functions. In this research Harichandran-Vanmark model is used for modeling the coherence function, which is the most common and most accurate model in this field.

In this research, the Lagrangian-Lagrangian method is used for analyzing the dam-reservoir system of concrete gravity dams. 9-nodes elements with 4 integration points for reduced integration have been used for modeling the fluid environment in the Lagrangian method and 8-nodes elements with 9 integration points for solid and plane stress conditions. In order to apply the boundary condition between solid and fluid, 6-nodes interface elements with three integration points and zero thickness were used. The mass matrix used in this study is considered by Hinton method in the form of diagonal matrix. Three boundary conditions is considered for two-dimensional model of dam-reservoir system, which include propagation of waves in upstream of the reservoir, the boundary condition of the interaction between the dam and the reservoir and surface waves in the reservoir. The stiffness matrix of total system is calculated by the assembly of the stiffness matrix of the dam, reservoir and interface elements. The stiffness matrix of the interface elements is considered by applying the boundary conditions between solid and fluid environment, which include sliding freedom in the vertical direction and also the non-separation of the reservoir from the dam (no sliding freedom in the horizontal direction). The damping matrix of total system is also calculated from the internal viscous damping of the dam and reservoir and the damping caused by the propagation of waves at the upper boundary of the reservoir.

3. Results and Discussion

In this study, the responses of the Pine Flat concrete gravity dam at a height of 122 meters and a length of 96.8 meters are investigated with the assumption of isotropy, homogeneity, the linear elastic behavior of materials and uniform and non-uniform excitation. The Taft (S69E horizontal component), Tabas (longitudinal component) and El centro (N-S component) accelerations are related to the far fault and Northridge (longitudinal component), Sanfernando (S74W) and Bam (longitudinal component) accelerations are related to the near fault and three positions of the epicenter in the toe and

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heel of the dam and also in the upstream of the reservoir. Based on the model of dam-reservoir system provided, the computer program is written in the language of Fortran 90. The number of elements of the dam, reservoir and interface elements are based on the sensitivity analysis 12, 20 and 5, respectively.

Figure 1 and 2 show the crest displacement and the heel normal stress of the Pine Flat dam in the empty and full reservoir, respectively. In figure 3 the heel hydrodynamic pressure is compared under uniform and time-non-uniform excitation of Taft earthquake while the epicenter is on the toe of dam. Figures show that the differences between uniform and non-uniform responses in the empty reservoir mode is more than full reservoir mode and in general, the responses under uniform excitation is more than non-uniform excitation. For other 5 earthquakes and space-non-uniform excitation, these figures have been prepared and explained.

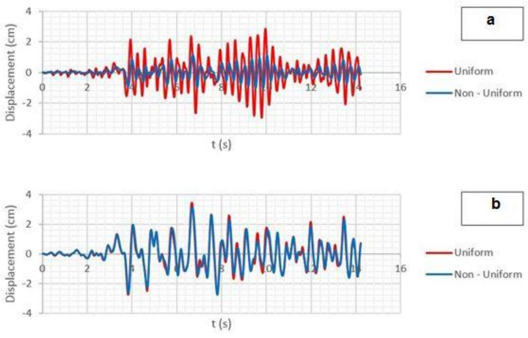

Figure 1. Crest displacement under uniform and time-non-uniform excitation of Taft earthquake (a) empty reservoir, (b) full reservoir

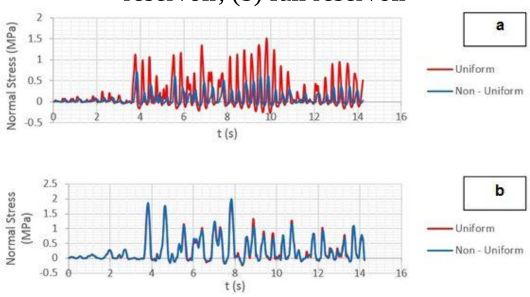

Figure 2. Heel normal stress under uniform and time-non-uniform excitation of Taft earthquake (a) empty reservoir, (b) full reservoir

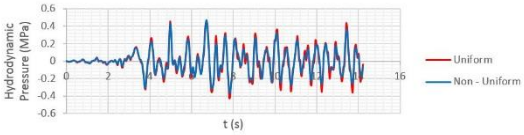

Figure 3. Heel hydrodynamic pressure under uniform and time-non-uniform excitation of Taft earthquake (a) empty reservoir, (b) full reservoir

Table 1 shows the maximum response values under uniform and time-non-uniform excitation of the Taft earthquake as one of the three far fault earthquakes on three positions of epicenter. For other 5 earthquakes and space-non-uniform excitation, these tables have been prepared and explained.

4. Conclusion

1. The structure response strongly depends on the frequency content and shear wave velocity of the earthquakes.
2. Non-uniform excitation of time and space in the empty reservoir mode significantly reduces the response to uniform excitation.
3. Unlike empty reservoir mode, the differences between responses in full reservoir mode under non-uniform excitation of time and space are less than uniform excitation. However, responses under non-uniform excitation are mostly more than uniform excitation.
4. The position of the earthquake epicenter changes maximum responses values and the response histories also significantly are changed under non-uniform excitation of time and space.
5. The effect of non-uniform excitation on the response of hydrodynamic pressure is lower than displacement of dam crest and heel stress of dam.
6. The effect of non-uniform of time and space on maximum displacement value of dam crest and maximum heel stress of dam for the empty reservoir under far fault earthquake is much greater than near fault earthquake.
7. The effect of non-uniform doesn't have a particular trend for the full reservoir mode. But, maximum hydrodynamic values under near fault earthquake is more than for far fault earthquake.

Table 1. The maximum response values under uniform and Time - non - uniform excitation of Taft earthquake.

Response	Epicenter	Empty reservoir					Full reservoir				
		Uniform		Non-Unifrm		Difference (%)	Uniform		Non-Unifrm		Difference (%)
		Content	Time	Content	Time		Content	Time	Content	Time	
Crest displacement (cm)	Toe	-2.962	9.80	1.139	6.72	138.454	3.433	6.68	3.133	6.70	8.739
	Heel			1.285	10.14	143.383			2.896	6.70	15.642
	Upstream of reservoir			1.285	11.04	143.383			2.891	6.70	15.788
Heel normal stress (MPa)	Toe	1.517	9.80	0.718	3.84	52.670	1.880	7.80	1.993	7.82	-6.011
	Heel			0.641	7.00	57.745			1.978	7.82	-5.213
	Upstream of reservoir			0.641	7.90	57.745			1.775	7.84	5.585
Hydrodynamic pressure A (MPa)	Toe	-	-	-	-	-	0.454	6.70	0.470	6.72	-3.524
	Heel			-	-	-			0.478	6.72	-5.286
	Upstream of reservoir			-	-	-			0.450	6.72	0.880