Seismic Performance Evaluation of Salman Farsi Dam with Considering the Influence of Sediment

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Abstract

In this study, a three-dimensional finite element software was used to investigate a concrete arch gravity dam through a nonlinear time history analysis method. The system is subjected to a scaled horizontal component of Manjil earthquake accelerogram and decreasing coefficient of 0.1and 0.6. The lake is modeled with Eulerian elements and nonlinear effects of dam body are included. Besides, the effects of existing interactions between dam, sediment and lake are also considered. The analyseswere done at sediment heights of 0, 2, 5, 10, 25, 50 m under reservoir conditions at normal water levels of 60 m and without water. The results showed that low earthquake accelerograms reduced displacement of dam body. The results indicate that low height sediments in the reservoir could initially increase displacement of dam body, however, as the height of sedimentation is increased, displacements will be reduced.

Keywords: Nonlinear dynamic analysis, Concrete arch gravity dam, Finite element software.

1. INTRODUCTION

Given, the importance of dam safety during earthquakes, investigation of seismic behavior of concrete dams and their seismic safety assessment has been attracted many researchers; because destruction of these structures caused by earthquakes can have adverse economic and social consequences. One of the most important issues affecting the seismic behavior of dams is dam-reservoir-sediment interaction. In addition to the hydrostatic pressure, the interaction of dam and reservoir produces hydrodynamic pressure, as well. The hydrodynamic pressure is caused by dam movement and the force is imposed by dam on the reservoir. Similarly, sedimentation increases the inertia imposed on dam due to the displacement of water and soil particles. Considering such effects, it is clear that precise seismic analysis of dams is a complex process.

Amin Mahmoudi, Mohammad Reza Gholami and Morteza Asadollahi (2015) investigated the effects of increasing the height of sediments inside the reservoir on stability of a concrete gravity dam using CADAM software and concluded that as sediments increase, stability decreases. Changing drainages heights, however, it was observed that the best point for drainage ditch is 50 meters from the heel [1].

Sadeghioun et al (2015) examined sediments of Salman Farsi Dam reservoir hydraulically. In this research, the sediment volume deposited in the reservoir of Salman Farsi Dam located in Fars province was calculated using Karoon92-salam software. The amount of sediment at Salman Farsi Dam site was estimated 10.8 MTPA (million tons per annum) and total sediment volume deposited in the reservoir during the 50-year period was estimated at 540 MTPA [2].

Ghaemian et al (2015) surveyed seismic analysis of a concrete gravity dam taking into account the effect of sediment layers using finite element method. In this study, the interactions between components of concrete dam system were evaluated. Researchers mainly emphasized on the effects of sediment layer on dam response, to this end, the developed model was analyzed at different heights of sediment layer from various types using ABAQUS software. The results of analysis suggested that not only the type but also elevation (height) of sediment layer affects concrete dam response. Thus, both effects of type and height of sediment layer must be included when it analyzes concrete dam system [3].

Seyfi et al (2016) studied the influences of sedimentation inertia on seismic performance of a concrete gravity dam with regards to the impact of interactions. To examine seismic behavior, sedimentation of the reservoir floor was modeled regarding to equivalent fluid pressure assumption. Considering the complexity of dam-reservoir-foundation-sediment system, finite element method was used for modeling and analysis as it is suited to apply different boundary conditions. To perform the seismic analysis of the system, a finite element model was developed using ANSYS software. When extracting domains governing equations, the effects of interactions between dam, reservoir, foundation and sediment were included in the model and various boundary conditions were foreseen to be imposed on the system. Further, time domain analysis was employed in terms of dynamic stimuli and then Newmark's method was used to solve dynamical equations, that are an unconditionally and numerically stable technique. To demonstrate the impacts of sedimentation inertia on seismic response of a concrete gravity dam, Pine Flat Dam was selected as a case study and 20 El Centro earthquakes accelerogram was applied as simulating seismic input. The developed model was analyzed and compared in two states of reservoir without sediment and with a volume percentage of sediment. According to the results of analyzes, the inertia of sediment deposited in the reservoir increased seismic response of concrete gravity dam [4].

Garci et al (2014) examined geometric properties of the reservoir and their effect on seismic performance of arch dams using finite element method. It was determined that smaller reservoirs decreased dam response and deformations of the crest of the dam depend on the reservoir geometry in the upstream face and sediments of the floor [5].

Sharafi and Mohammadi (2016) evaluated occurrence of damage mechanisms in Karun-3 Dam. In this study, the impact of earthquake accelerograms on seismic behavior of the concrete arch dam was investigated. In this regard, Karun-3 concrete arch dam was modeled and simulated in ABAQUS finite element software and accelerograms of Tabas and Northridge earthquakes were imposed on it, where the model was subjected to hydrodynamic pressures caused by fluid. The results indicate that major damages were imposed on Karun-3 dam by Tabas earthquake. The reason is simply that this earthquake is much stronger than the other. Upstream face and crest of the dam were seriously damaged and cracked [6].

Rezaei and Heirany (2017) surveyed the evaluation of seismic behavior of arch concrete dams including the effects of reservoir conditions using finite element method. The results indicate that low height sediments in the reservoir initially increased displacement of dam body; however, as the height of sedimentation is increased, displacements will be decreased [7].

2. ASSUMPTIONS

In this section, structural and hydrodynamic considerations of the problem are formulated. Then, the effect of sediments deposited in the reservoir as elastic solids on the reservoir is demonstrated. At the same time, the water inside the reservoir is assumed to be a non-sticky, incompressible fluid with small displacements. The dam is also considered as a solid plastic damage model. Eulerian-Lagrangian formulation method was employed to solve the water-structure interaction problems. In this method, hydrodynamic pressure of the reservoir is imposed on the dam as an equivalent nodal force. This technique was performed due to the importance of fluid behavior and pressure parameters in dam modeling [8].

3. GOVERNING EQUATIONS

The equation governing dam behavior is called equation of motion. To take into consideration and define the fluid-structure interaction, however, the load applied by fluid's hydrodynamic pressure to the point where structure and fluid meet must be added to the structural equations.

$$\mathrm{M}\ddot{\mathrm{u}} + \mathrm{C}\dot{\mathrm{u}} + \mathrm{K}\mathrm{u} = \mathrm{M}\ddot{\mathrm{u}}_{\mathrm{g}} + \mathrm{F}^{\mathrm{pr}} \quad (1)$$

Where, M represents mass matrix, C is damping matrix and K structural stiffness matrix. In addition, u is relative displacement vector, $\dot{u}$ is the velocity vector, $\ddot{u}$ is the structural motion acceleration vector, $\ddot{u}_g$ ground acceleration vector and F^{pr} is the hydrodynamic pressure vector loaded from the reservoir on the dam at contact point.

4. MODEL ANALYSIS

To perform the seismic analysis of the concrete arch gravity dam, ABAQUS software was used. This software is suited for seismic analysis taking into account the irregular geometry of domains and reservoir-dam interaction effects. The effects of surface water waves are neglected due to the depth and high elevation, instead the effects of dam-reservoir-sediment interaction are considered. Given the conditions governing the behavior of concrete arch gravity dam and geometric shape of the reservoir, dam model developed here was deemed as a simplified three dimensional model and the effect of interaction with foundation were eliminated. The 8-node 6-face brick element (C3D8R) was employed to perform dam body and sediment finite element model. To mesh the reservoir, Eulerian's flowing elements (EC3D8R) was used which are suited for modeling water.

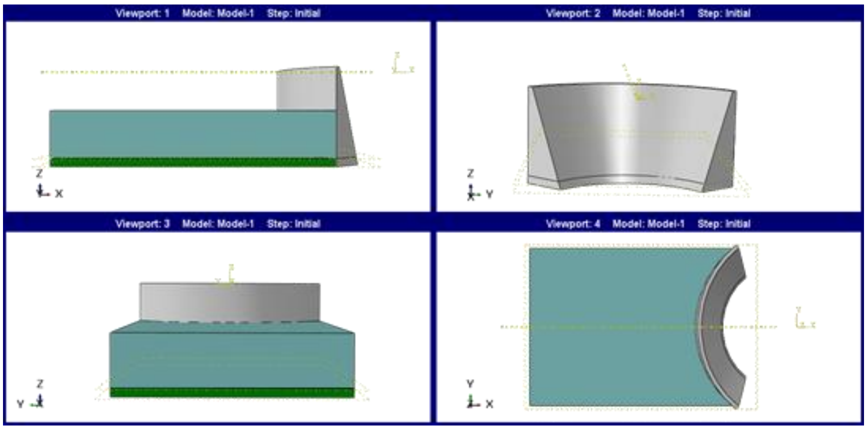

Figure 1. The model designed in the software

In order to demonstrate the capability and applicability of the model provided while investigating the seismic behavior of a concrete arch gravity dam located in seismically active regions, Salman Farsi storage dam (Ghir) was chosen to be studied which is located 180 km south of Shiraz and about 20 km northeast of Ghir town in Mond watershed areasouthwest of Shiraz built on Qare Aqaj River in a place called Tang Karzin with a watershed area of 11800 km^2. Geographically, dam limits chosen in this study is between 28° 30' and 28° 45' eastern longitude and 53° 20' north longitude. The bed level f the dam is 833 m above the free water level and is defined parabolically in the plan. The height of the dam from the base is 125 m and crest central brink has a 7-meter thickness. Dam's height at the lowest level is 58 m upstream and that makes' the dam look like a vertical cylinder. The radius of the dam is 175 m with an angle of 105° and the length of dam's crest is 320 m.

It should be noted that the materials used to construct the dam is concrete with a density of 2400 kg/m^3, an elastic modulus of 27 GPa, a Possion coefficient of 0.29 and deflection angle of 36°. Assuming solidity of sediment in the reservoir, density of sedimentation is 1300 kg/m^3, Possion coefficient is 0.2 and elastic modulus is equal to 20 GPa. Moreover, the water stored in the reservoir has a density of 1000 kg/m^3, dynamic viscosity of 0.001 Ns/m^3, and the fluid sound velocity is 1500 m/s. In order to perform the analysis process, scaled horizontal accelerogram of Manjil earthquake was applied.

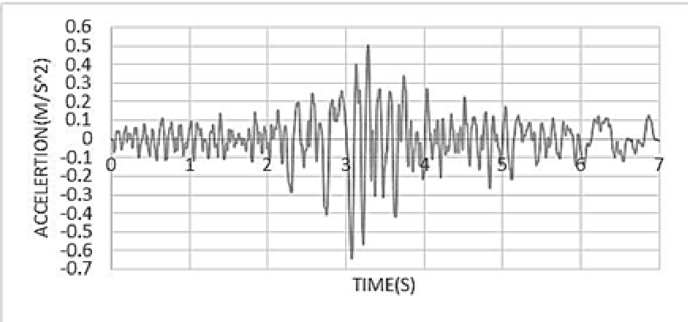

Figure 2. Manjil earthquake scaled horizontal accelerogram (PGA0.5)

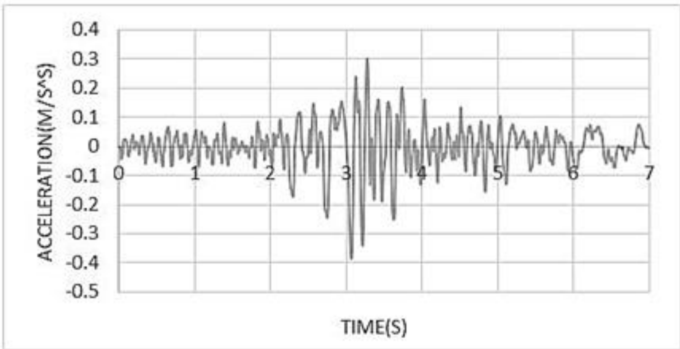

Figure 3. Manjil earthquake scaled horizontal accelerogram and decreasing coefficient of 0.6 (PGA0.3)

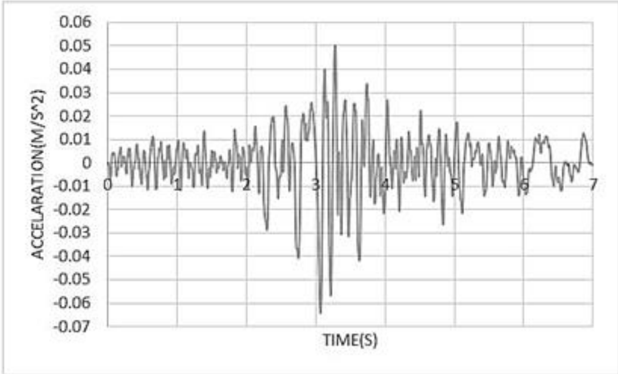

Figure 4. Manjil earthquake scaled horizontal accelerogram and decreasing coefficient of 0.1 (PGA0.05)

Riley's damping method was used to apply the damping coefficients. Further, the Sommerfeld method was used to measure reservoir's far-reaching boundary conditions where time step of $\Delta t = 0.02$ is considered. The non-massive foundation and dam-sediment interaction were employed in the analyzes. According to the research, it is clarified that dam's seismic response is affected by the amount and volume of sediment deposited in the reservoir.

To investigate the exact dynamic behavior of a concrete arch gravity dam, a through model was developed in this study. Dynamic analysis was carried out through a time-domain model. To this end, various boundary conditions such as nodal displacements and nodal forces can be regarded in the finite element model proposed. The interaction between domains of dam, reservoir and sediment is well predicted in the model. Regarding the selection of finite element method and its capabilities, complicated geometries can be studied by the model provided. The interaction between dam and foundation was eliminated in this study.

5. CONCLUSIONS

After modeling and dynamic analysis completed, the results of responses to displacements and stresses imposed on the dam body were extracted. Considering that the main objective of this study was to investigate the effect of sediment on seismic performance of Salman Farsi concrete arch gravity dam, the model was analyzed at 6 different sediment heights of 0,2,5,10,25 and 50 m at two reservoir heights of 60 applying Manjil earthquake scaled horizontal accelerogram and decreasing coefficient of 0.1and 0.6 and the results were represented as time history (results of horizontal displacement of the dam crest center from the ground).

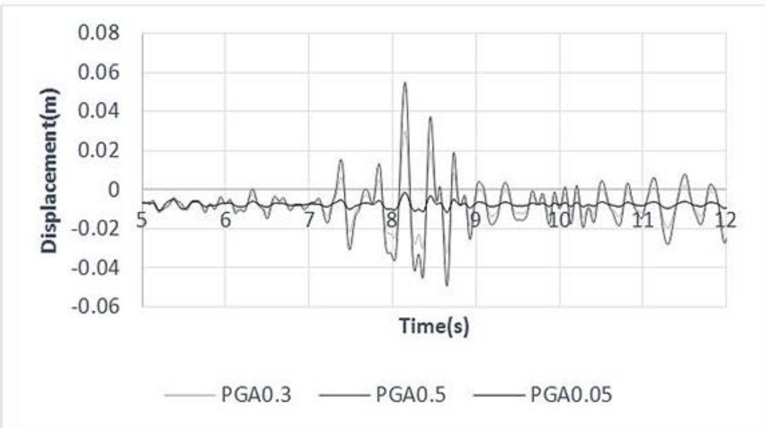

Figure 5. Displacement of the node in the dam crest center from the ground in the empty reservoir state

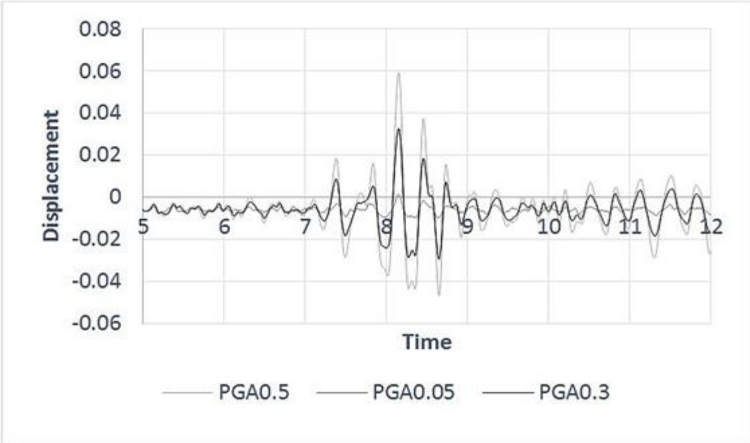

Figure 6. Displacement of the node in the dam crest center from the ground with a water depth of 60 m

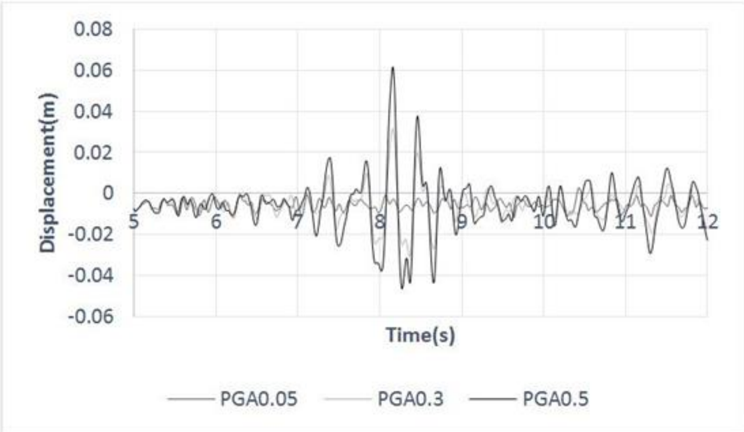

Figure 7. Displacement of the node in the dam crest center from the ground with 60-meter water depth and 2-m sediment height

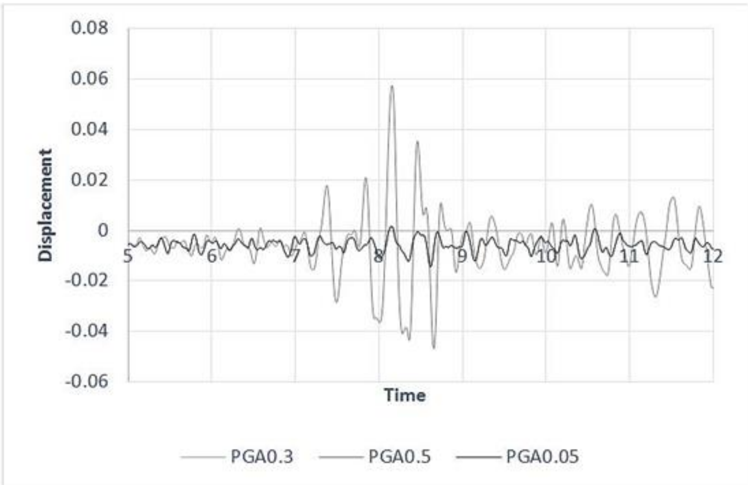

Figure 8. Displacement of the node in the dam crest center from the ground with a water height of 60 m and a sediment height of 5 m

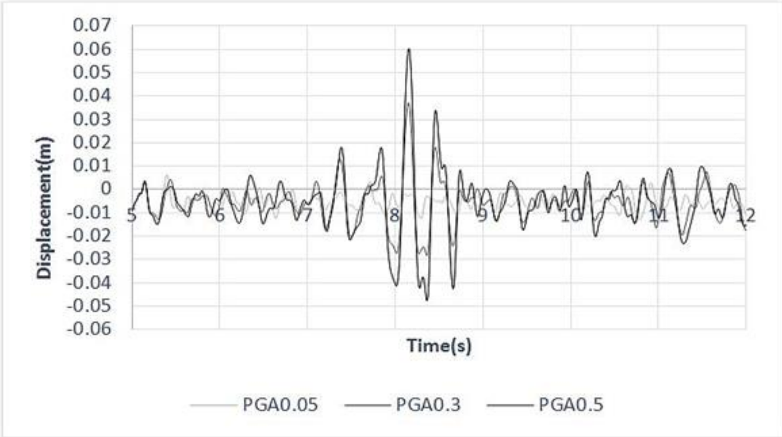

Figure 9. Displacement of the node in the dam crest center from the ground with the water height of 60 m and a 10-m sediment height

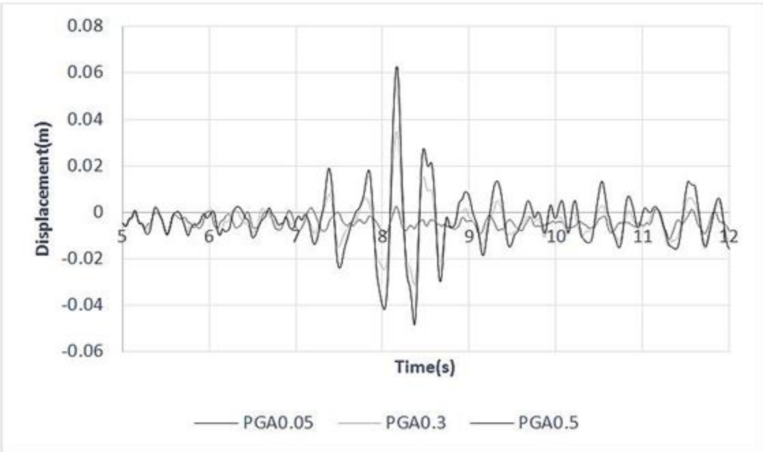

Figure 10. Displacement of the node in the dam crest center from the ground with the water height of 60 m and a 25-m sediment height

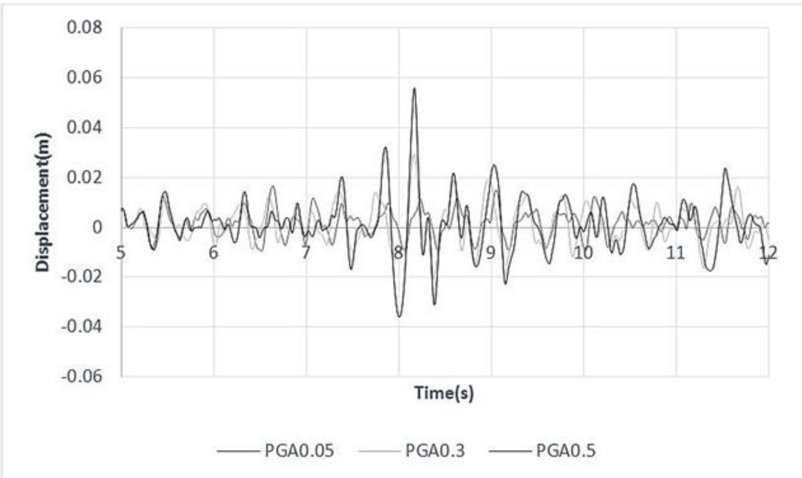

Figure 11. Displacement of the node in the dam crest center from the ground with the water height of 60 m and a 50-m sediment height

In order to reach precise results in this study, 12 models representing sediment height changes with water level of 60 was employed the last of which is performed with a 50-m sediment height. In real situation, such volume of sediment in the reservoir damages the operational ability of the dam and it is only used here to obtain more accurate results. As observed in Figures 5 to 11, low earthquake accelerograms, displacements will be lowered in the center of the crest. The results indicate that the acceleration of the earthquake mapping increases, the damage to the dam will also be greatly increased. The results indicate that low height sediments in the reservoir initially will increase displacement of dam body, however, as the height of sedimentation increases, displacements will reduce.

6. REFERENCES

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