Seismic Evaluation of Narmashir, Iran, Concrete-Face Rockfill Dam by Using Dynamic Finite Element Analysis

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Summary:
The Concrete Faced Rockfill Dam (CFRD) has been increasingly used in recent years. One important factor in the safety and stability of CFRDs is the behavior of the concrete face slabs. The interaction between the dam body and the concrete face slabs is one of the most important factors in the design and the construction of CFRDs. This study aims to reveal the effect of concrete slab-rockfill interface behavior on the earthquake performance of a CFRD considering contact analyze. Three-dimensional finite element model of Narmashir CFRD is used for this purpose. Linear and materially nonlinear time-history analyses considering dam-reservoir interaction are performed using ANSYS software. The linear dynamic response of the dam is carried out for the MCL earthquake records. Empty and full cases of the dam reservoir are considered in the analyses, and the maximum displacement and principal stresses induced in the dam are investigated.

Keywords: Interaction of dam and its concrete face, Three-dimensional dynamic analysis, Material nonlinearity

1. INTRODUCTION

Concrete Faced Rockfill Dams is quickly developed in recent decades due to it's good adaptability to topography, geology and climate and easily available construction materials. Many CFRD designs have been used for dam construction worldwide, because overcome technical difficulties such as dam construction on a soft foundation, complex dam erection, and related problems. CFR dams involve fluid-structure interaction problems. Hydrodynamic pressure resulted from earthquake considerably affect dynamic response of dams. Earthquake analysis of CFR dams subjected to ground motion was carried out by various researchers. Liu et al proposed a method to predict the maximum settlement at the end of construction and the maximum face slab normal displacement during reservoir option, based on the physically and mechanically properties of rockfill, the load factor, and geometric profile of the Concrete Faced Rockfill Dams section.

Bureau et al. presented a study dealing with the seismic performance of CFR dams and seismic forces and bending moment on the concrete face slab. Their results showed most of the dam section under strong excitation is in a state of plastic deformation. Kim et al. used the optimal artificial neural network (ANN) model to predict settlement of crest in the concrete face rock-fill dam and showed Predicting the relative settlement of crest in ANN model is compatibility to obtained data settlement of crest of CFR dams in several countries. Kong et al. using discontinuous deformation analysis (DDA), which is subsets of distinct element method (DEM), analyzed a CDR dam two-dimensionally. Finally, concluded that the failure of the dam start downstream slope and the crest and the upstream slope due to concrete slab has better stability.

This study investigates the effect of interface behavior between concrete slab and rockfill dam on the earthquake response. The separation may produce major cracks in the concrete face slab and thus reduce safety factor due to seepage failure. The separation concrete face slab from cushion layer is inevitable due to the difference settlement or deformation of dam body and concrete slab. For this purpose, evaluate the seismic behavior of the dam a three dimensional FEA procedure was employed which involves a realistic modeling of the embankment material, the face slab, and the interface of face slab and the rock-fill. The dam was modeled by using 4500 elements for its main rock-fill body, and 450 elements for its concrete face slab, and surface to surface contact elements with Coulomb friction were also used between the rock-fill and the concrete face. The developed model was three-dimensional, and in its time history analyses the dam-reservoir interaction was taken into account, and the dam foundation was assumed to be mass-less and semi-infinite. The materials were assumed to behave elastic and linear. For time history analysis the three-component records of Tabas (1978), Manjil (1990) and Bam (2004).earthquakes, were selected, which are in good compatibility with the site conditions, and were normalized to the PGA value obtained by hazard analysis of the dam site. Both empty and full cases of the dam reservoir were considered in the analyses, and the maximum displacement and principal stresses induced in the dam and its concrete face were investigated. The sloshing effects were neglected in these analyses.

2. MODELING PROCESS

For modeling, finite element method is considered. The simplified models of water and the foundation are evaluated element model. The effect of the hydrodynamic pressure on dam is modeled by hydrodynamic mass finite element. The considered dam is modeled with the part of foundation and soil. Simply assumed to be the foundation model is no weight and the effect of its inertia is ignored. In this case, it is necessary meshing of foundation is extended around and below of the dam the dam height. The nodes at the bottom of the foundation in all directions are assumed restrained and lateral supports are modeled roller support.

Hydraulic structures are affected by fluid-structure interaction that it is effected the energy waste at reservoir bounds. The fluid-structure interaction cause additional deformation in structure Which in turn the changes the hydrodynamic pressure on the main structure will follow. Due to the natural shape of the earth, reservoir behind the dam has an irregular geometry and Lake water in upstream dams usually extends to large distances. In such cases it is not possible to model the entire range of lake water; Good practical solution is to use the semi-infinite fluid elements that on one hand, these elements are connected to concrete face in the dam upstream and the other side goes to infinity. In this model, fluid flow in three-dimensional space is assumed and Water is considered linear compressibility, cohesionless and without rotational waves.

In general, the foundation and structural interactions may increase the period of structure and damping. However, the flexible foundation-structure interaction can be reduced damping. For stiff foundation can be used massless Foundation model considered only the kinematic effect and inertia and damping effects are ignored. In this case it is appropriate that the foundation is extended twice the height of dam at upstrearm, downstream and depth of the dam. The record of earthquakes recorded in the surface region can be used to stimulate the floor. Necessary specifications to define a linear analysis of concrete face on upstream dams in ANSYS include; Young's modulus, Poisson coefficient and Specific gravity that directly related to the stresses and strains created in the concrete. If failures don't occur in concrete face dam and weakness of the support don't cause inefficiency of dam, to create small cracks and join them will cause minor and major damage, water penetration to the rockfill body dam and eventually the dam will become unstable. Since there are not complex cracks in the dam on the initial loads and the risk of instability isn't then a linear analysis can be used.

3. THE DYNAMIC FINITE ELEMENT ANALYSIS PROCEDURE

3.1. Geometry and material modeling of the dam

In this study, typical CFR dam is on the Narmashir river in south IRAN. This dam is 111 m and 590 m long and the crest is 10 m wide. The slope is 1V:1.4H at upstream and 1V:1.5H at downstream and a

0.40 m thickness concrete face slab. The reservoir is at its maximum level, 105 m above the base. A picture of the Narmashir dam is shown in Figure 1, its finite element model in Figure 2, and the dynamic behavior of a rockfill element is described in table 1.

Figure 1: A general view of the Narmashir CFRD

Table 1. Design parameters of CFR dam materials.

Material	**E (MPa)**	**Poisson coefficient**	**Density (t/m^3)**
Rockfill	**120**	**0.26**	**2.1**
Concrete	**21000**	**0.2**	**2.45**

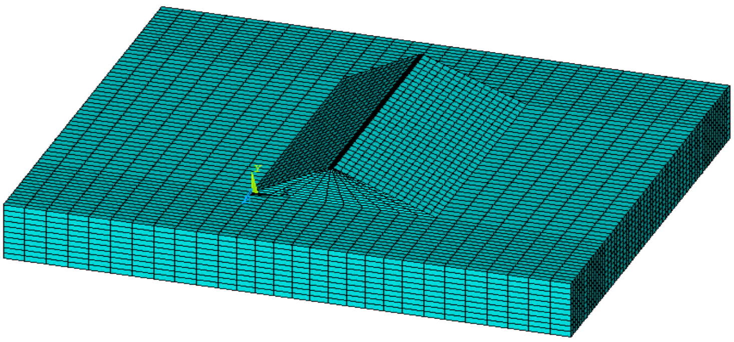


Figure 2. A three-dimensional finite element mesh of the dam

The typical dam is modeled 3D that is used 4500 elements solid 186 in rockfill body, 150 elements solid 65 in concrete face and 16800 elements solid 185 in foundation. To study the effect of type of slab-rockfill interface behavior on the distribution of maximum tension of the slab, contact analyze is used in the study. To model the reservoir is used fluid 30.

3.2. Static and modal analysis

The first, static analysis was performed on the dam under the weight load. Settlement and stresses in the dam was calculated. The results showed the maximum settlement occurred in the middle of the dam body for the empty and full modes and are respectively 47 cm and 55 cm. Tensile and compressive stresses in the body is low and tensile stress in concrete slab is close to it’s maximum allowable.

Then the modal analysis was done to obtain the modes and periods of structural. Fig. 3 shows the comparison between the full dam and empty dam for the modal analysis. As the figure indicates water reservoir acts as a compressible and has a considerable effect on the mode shapes of structure and interaction of water on the periods.

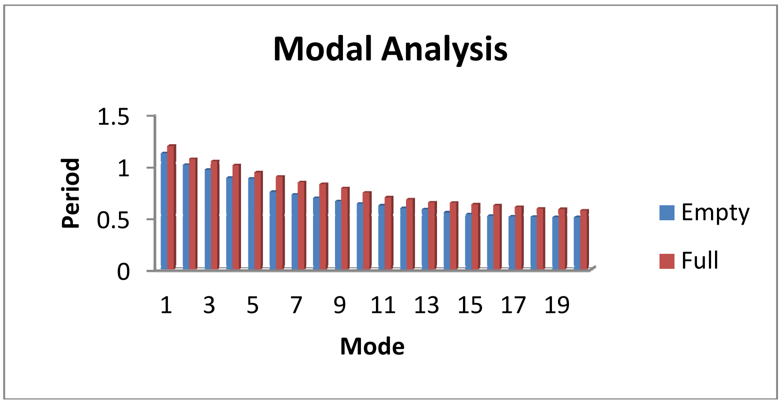


Figure 3. Comparisons between the periods of various modes in the full and empty mode

3.3. The ground motion

The used records have different frequency and PGA. In this study, Three records are used that induced to the dam in x, y, z direction on the dam. Information on the records and the earthquake events are summarized in Table 2.

Table 2. Characteristics of records

Earth quake	**Bam**	**Manjil**	**Tabas**
Time	2004	1990	1978
PGA	0.778	0.456g	0.35g

The frequency content of the chosen records is reflected in their acceleration response spectra, shown in Figure 4.

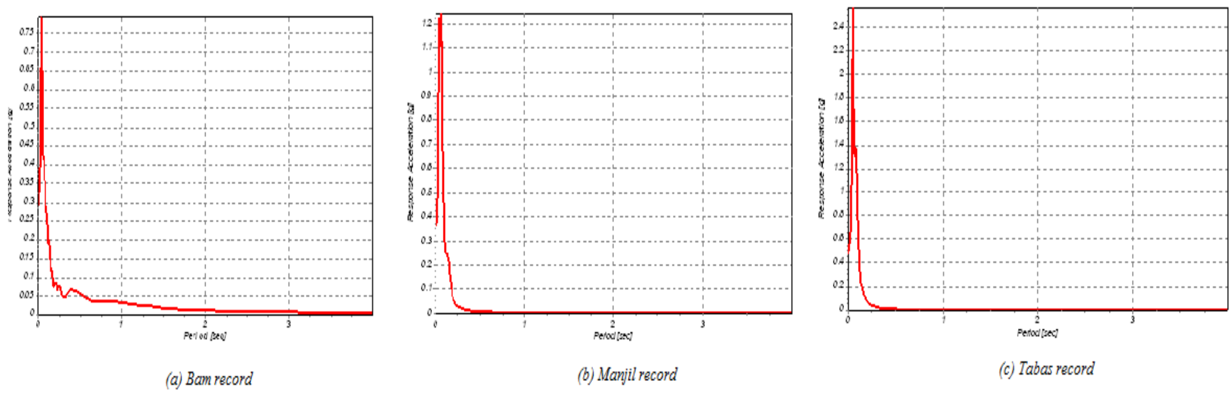


Figure 4. Response acceleration for MCE records: (a)Bam record, (b)Manjil record ,(c)Tabas record

3.4. Results of the Dynamic Analyses

Considering the interaction dam and fluid and foundation, dynamic analysis was performed on three-dimensional model of the concrete face rockfill dam that subjected to the weight load, earthquake load, and hydrostatic pressure in the two modes: after the construction (empty) and after the dewatering (full) by ANSYS. The obtained results were evaluated at three critical points A (at the crest), B (in concrete face at upstream) and C (at downstream) that are showed at figure 5.

Figure 5 to 8 depicts displacement and stresses at specified points in full and empty mode for Bam record. The results show that the maximum displacement in the dam crest and maximum stress at bottom of the concrete slab occurs. Consider the graphs can be deduced with increasing height, displacement increase and stress decrease. Body dam sustain less stress than concrete slab. Maximum tension (S1) occurs at bottom of the concrete slab is 50 MPa in empty mode and 90 MPa in full mode. These stress values are more than tensile strength of concrete and there is the possibility of cracking in the part of the concrete.

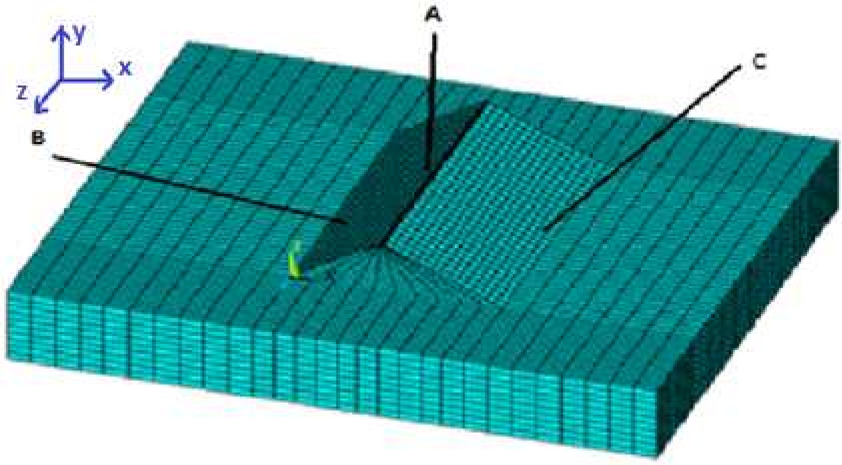
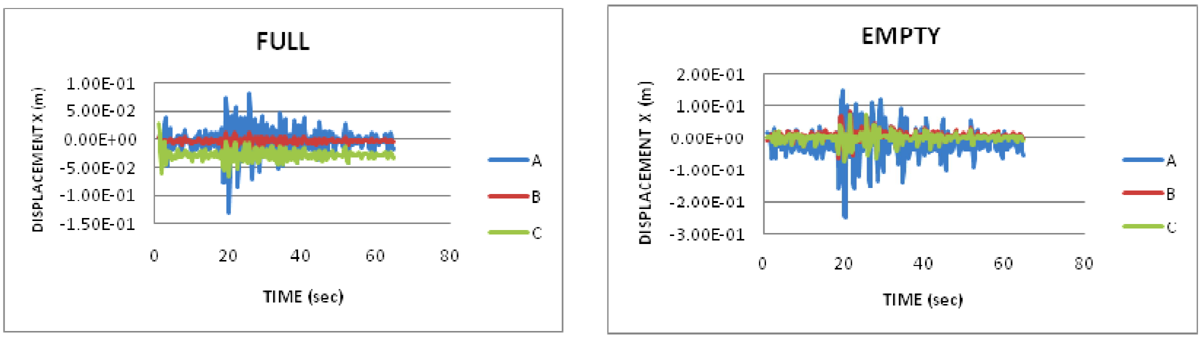


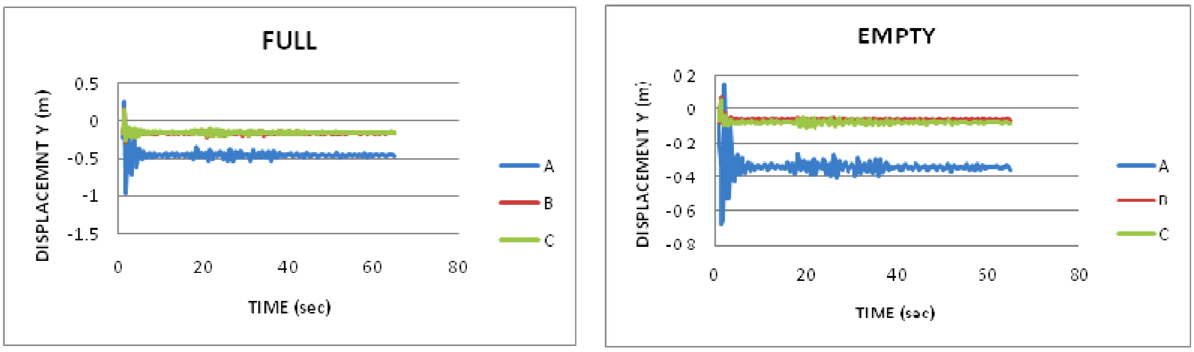
Figure 5. The evaluated points on the CFR dam

According to results, the settlement in full dam is more than empty dam and displacement at x and z direction in the empty dam is more than full dam. Maximum settlement in the empty and full mode is respectively 67 cm and 96 cm. Also be seen the water in the reservoir, tensions are increased in the upstream dam. While In the empty mode, the main stresses are only due to the weight of the dam and earthquake. In the empty dam, stress at rockfill body dam is compressive and at the start of dewatering at the start of dewatering and filling the reservoir, tension stress is increased in the concrete slab and in the low of concrete slab reach to its maximum value. Comparison of shear stress in filled and empty of dam show shear stresses at the upstream dam is increased more due to water load. It is entirely understandable because the rockfill body dam at end of construction tends to spread from the central part of the dam to upstream and downstream levels. While in full dam condition, water pressure all of the body dam to the downstream that ultimately led to the shear stress is positive.

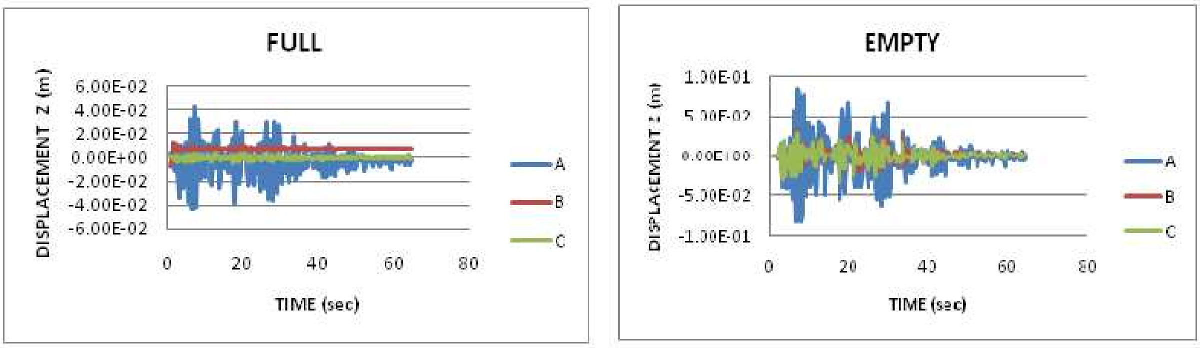
These are very large stresses which would undoubtedly produce severe tensile failure in the concrete slab. It is found that the slab experiences very strong tension stress but less shear forces. The face slab response when Coulomb's friction law governs the behavior of the interface between face-slab and dam, and slippage is allowed to occur whenever the seismic contact shear stresses exceed the frictional capacity of that interface. Therefore, when designing against very strong seismic motions, it is recommended that a thicker and better-rainforced slab be used along with a flatter upstream slab. The distribution of peak stresses along the slab-rockfill interface is also depicted in Figures 6 and 7. It is seen that the stresses are concentrated for the three sets of excitation only in near the foundation the dam, where water pressure is large and the shaking is strong.



(a)

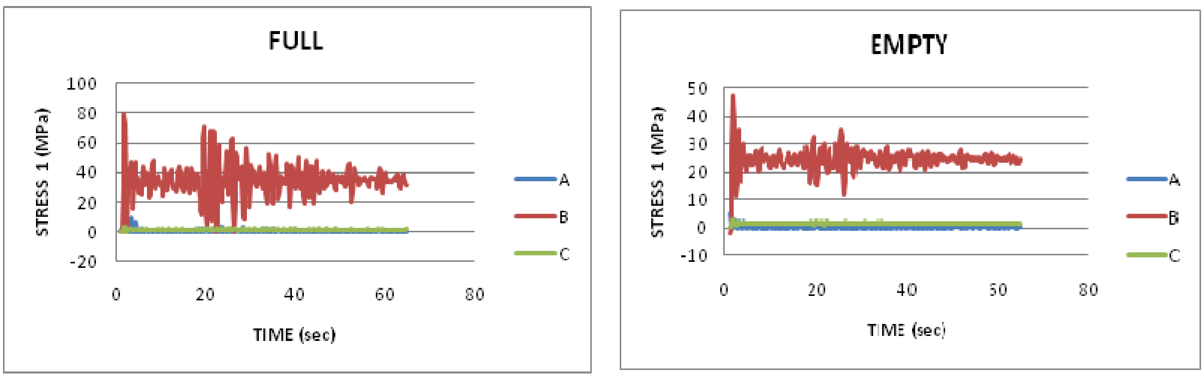


(b)

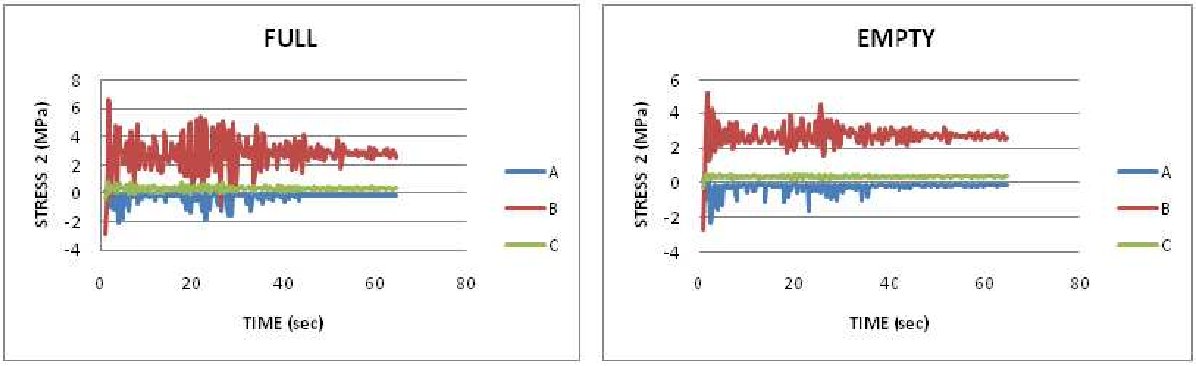


(c)

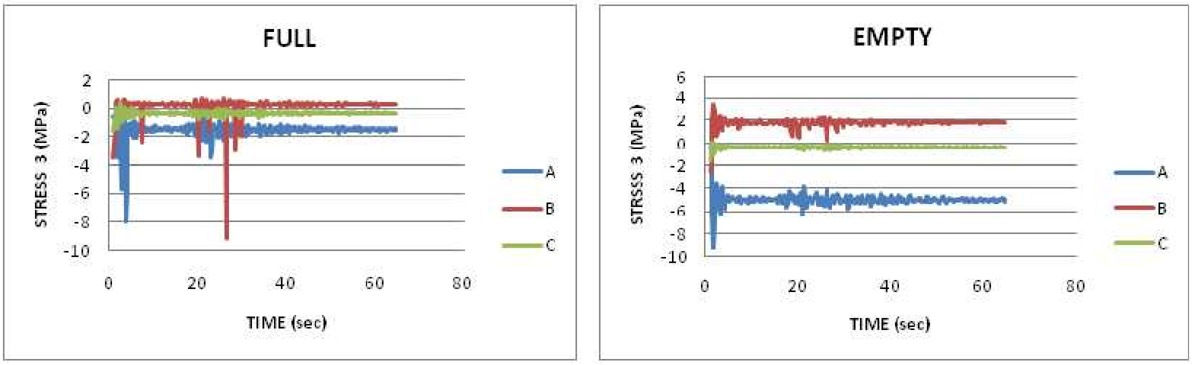
Figure 6. Displacement in (a) x direction, (b) y direction, (c) z direction at the points A, B, C in full dam and empty dam for Bam record .



(a)



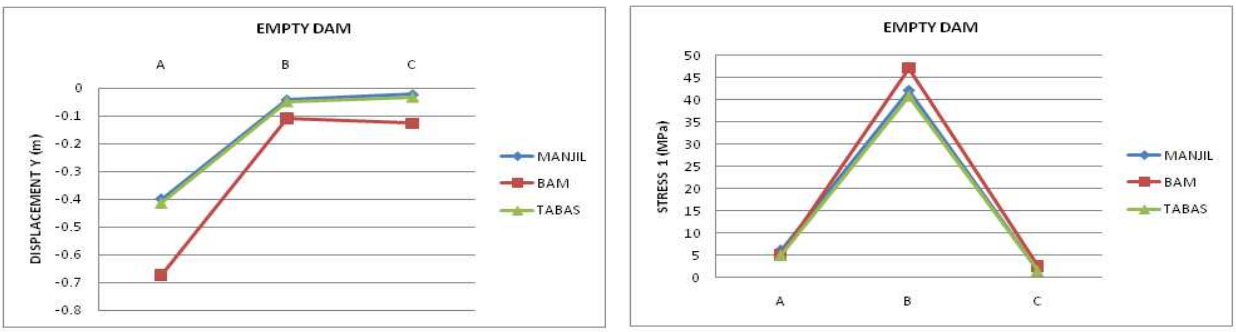
(b)



(c)

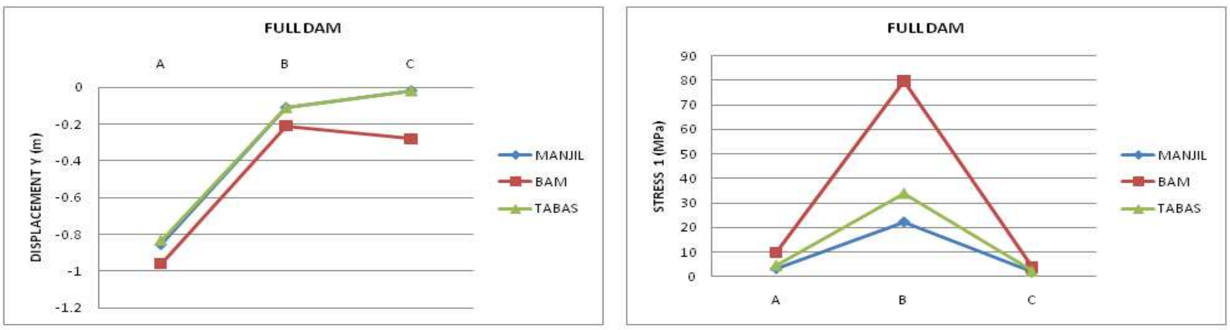
Figure 7. Stresses at the points A, B, C in full dam and empty dam for Bam record (a) tension stress, (b) shear stress, (c) compress stress

Seismic performance o f the CFR dams under three different earthquake records were examined. The used records are MCE records and have different frequency and PGA. Comparison of Records results induced to the CFR dam is shown in Figures 8 and 9.



(a) *(b)*

Figure 8. Comparison the used records for empty dam: displacement Y (a), stress 1(b) at specific point A, B, C



(a) *(b)*

Figure 9. Comparison the used records for full dam: displacement Y (a), stress 1(b) at specific point A, B, C

4. CONCLUSIONS

A dynamic analysis procedure for CFR (concrete- faced rockfill dams is proposed in this paper and described in the context of a finite element study of a typical 111 m CFR dam. The dam is subjected to strong seismic shaking and analysis has been presented using a realistic modeling for the embankment material, the slab, and the slab-rockfill interface. The rockfill is modeled as an equivalent-linear material. The main conclusions:

1. In dynamic analysis conducted on the CFR dam, the maximum settlement in full dam is more than empty mode and displacement in the direction of the river is opposite that is due to the lack of water force. There are tensions in the CFR dam due to hydrostatic pressure in the full dam is more than empty dam.
2. Three different earthquake records are induced the CFR dam, the results obtained from them were compared. The displacement and stress of Bam Record, due to having more PGA, is more than the results obtained from the Manjil and Tabas records.
3. The water level changes have been effective on maximum compressive and tensile stresses on the concrete slab.
4. Mass and large stiffness of concrete slab under severe earthquake can cause slab separation of the dam body.
5. Modulus elasticity of rockfill in the CFR dams has an important role in behavior of this type dam. The rockfill body with a low modulus of elasticity is meeting more damage and more settlement to the slab.
6. The presented method for finite element analysis of CFR dams can be an effective method for the analysis of dams. This method has been modeled and analyzed the end of dam construction, inundation, earthquake and contact interaction concrete slab and dam body. Considering that most of CFR dams are built in areas with low seismic risk and there are low experiences of this type dam's behavior under high seismic shaking, finite element method can be a powerful tool to investigate the seismic performance of CFR dams in the different seismic conditions.

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