A Dynamic Analysis of the Interaction of Concrete Face and Rockfill Part in Concrete Faced Rockfill Dams

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Extended Abstract

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Introduction

Concrete faced rockfill dams have been considered in recent years more than other types of dams due to their low dependency on the bed and the shape of the valley, as well as the simpler construction technology. In this regard, rockfill dams are a suitable substitute for embankment dams because of higher stability of the body and the availability of rock aggregates. On the other hand, because the permeability of rock aggregates is much higher than other materials, different methods are used to seal these types of dams. One of these methods is the use of non-impermeable concrete facing in the upstream of these dams. This particular type of gravel dams is called Concrete-Faced Rockfill Dams (CRFD). In this study, a contact element with a definition of elastic-plastic failure in the modeling process is proposed to simulate the surface separation and re-contact of the concrete face with the rockfill surface of the dam.

Method

In this paper, behavior of a concrete faced rockfill dam under earthquake loads is investigated. For this purpose, near-field earthquake records with focal depth lower than 15 km (for example Tabas earthquake 1978, M=7.4, and San Fernando earthquake 1970, M=6.6) are used. Moreover, to study the dam behavior under dynamic loads, interaction between concrete face and rockfill part of the dam is investigated and

finally, some parameters including displacement, absorbed energy and base shear are evaluated. So, finite element method and Abaqus software is used for the study. Verification of the models is carried out using the results of previous researches by conducting modal analysis and determining natural vibration period. Then, the interaction between the concrete face and rockfill part as well as the effect of water level changes in stability of dam under dynamic load is investigated. Concrete behavior is simulated using concrete damaged plasticity. Therefore, concrete density, compressive strength and tensile strength and elasticity modulus are 2350 kg/m^3, 25 MPa, 3 MPa and 29 GPa, respectively. Poisson's ratio is assumed to be 0.2. Furthermore, 4-node shell elements are used to simulate concrete face and Drucker-Prager constitutive model is used to define rockfill material behavior.

The density and Poisson's ratio for 2B, 3C and 3B layers are 2150 kg/m^3 and 0.35, respectively. The shear modulus values for these layers are respectively 8.93, 2.89, and 3.85 GPa. In order to perform the simulation, the part of the dam structure beside the bed rock and the surrounding rock is considered as fixed bearing, and only the rockfill part and concrete face of the dam is simulated. Based on this assumption that the bed is rigid, there is no need to consider the dam foundation. This method is frequently used in literature review.

All the surfaces of the dam and bed rock are considered as fixed bearing to simulate the real condition where the dam is attached to bed rock and the surrounding rock. The interaction between dam layers is defined as tie. For defining the interaction between rockfill body and concrete face, tangential and normal contacts are defined using penalty method with friction coefficient equal to 0.5. In the next step, the model is meshed using 4-node shell elements for concrete face, 8-node brick and 4-node pyramid solid elements for rockfill body. Rayleigh damping is used to simulate the structure damping. The effective length of the dam reservoir has been determined by conducting several analyzes, so that the minimum required length for reservoir is reached in order to decrease the number of elements of the model.

Results and discussion

1. Interaction between concrete face and rockfill body

The results show that the increase of friction coefficient between concrete face and rockfill part from 0.5 to 0.7 has not affect the displacement of dam crown along the earthquake direction. However, when the concrete face is fixed to the rockfill part, significant changes are induced in dam crown displacement time history. In all cases, the deflection due to the dam weight is increased when the concrete face is attached to the rockfill body. The reason can be attributed to the tied interaction between these layers which results in similar deflection of concrete face with rockfill body and higher deflection of concrete dam crown. However, after the application of earthquake load, the displacement of the dam crown decreased in both analyses when tie interaction is defined between concrete face and rockfill body. In this study, due to the very high volume of analysis and its timeliness, it was not possible to examine the dam behavior in the free vibration regime, and therefore, it is not possible to assume the last displacement values at the end of analyses as the permanent displacement of dam. Figure 1 shows the relative displacement of the dam for the two selected earthquakes with a friction coefficient equal to 0.5 between the concrete face and the gravel body. According to Figure 1, the maximum displacement induced by the earthquake is related to Tabas and then, San Francisco earthquake. Furthermore, the high energy content of the Tabas record has been more effective in inducing greater displacement than the other record.

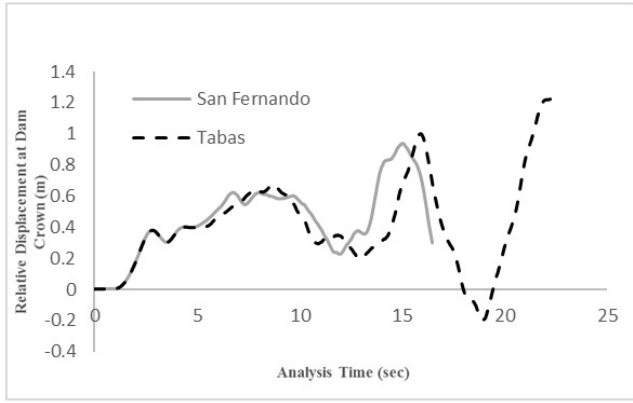

Figure 1. Lateral displacement of dam crown relative to the dam base for the selected earthquakes; Tabas and San Fernando.

The results also indicate that when the friction coefficient between concrete face and rockfill body is 0.5, the lowest damage occurs in the dam compared to that happens when friction coefficient is 0.7 or when the surfaces are tied. When the tied surfaces are used, the most damages takes place in concrete face, since all rockfill body displacement transmits to concrete face which results in much more concrete damages compared to the other interaction cases.

2. Effect of water level in reservoir on dam behavior

In this section, the effect of water level on seismic behavior of dam is investigated. For this purpose, the dam reservoir is analyzed in three cases including empty, half full and full (90% of dam height). Each study cases are examined under San Fernando and Tabas earthquakes. Figure 2 shows the relative displacement of dam crown in the three water level case for San Fernando and Tabas earthquakes.

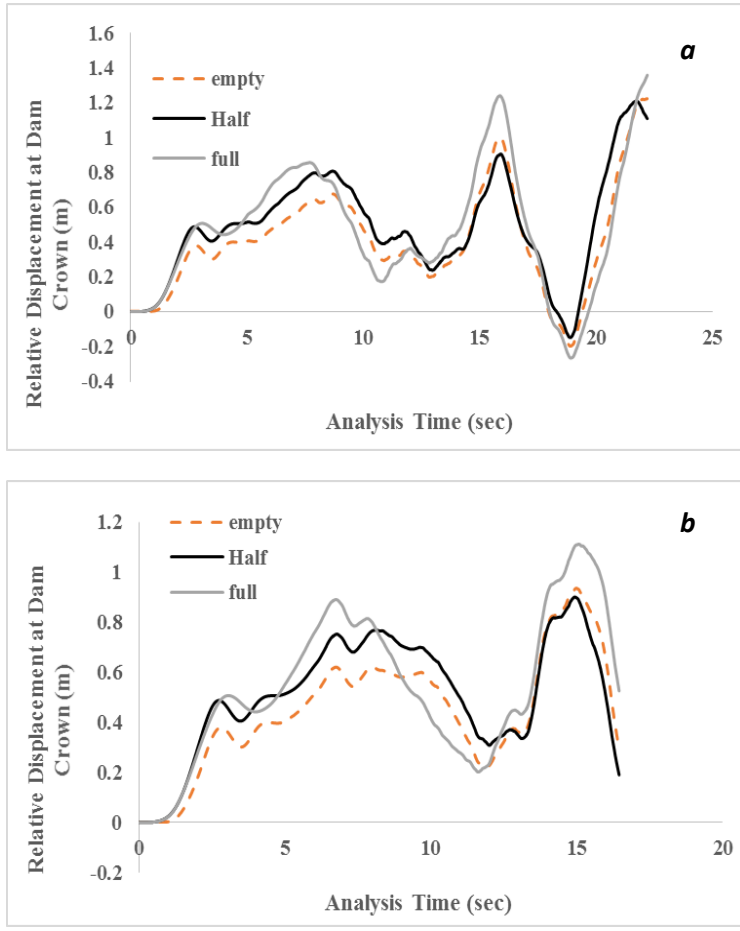

Figure 2. Relative displacement of dam crown in three water level cases of empty, half and full for (a) Tabas and (b) San Fernando earthquakes

According to Figure 2, for both earthquakes, the dam crown displacement along the earthquake direction is significantly increased by increasing the water level, so that the maximum displacement in full case is 50% higher than empty case.

Conclusion

In this study, using the finite element method and simulation by Abaqus, the seismic behavior of concrete face rockfill dams has been investigated. For this purpose, the verification is firstly carried out using previous research results in literature. In the next step, nonlinear dynamical analysis

is carried out, taking into account large displacements for the models under the earthquake record acceleration. The results illustrate that increasing the friction coefficient between the concrete face and the rockfill body from 0.5 to 0.7 has no significant effect on the displacement of the dam crown under earthquake load. Moreover, by using tie interaction between the concrete layer and the rockfill body, there is a substantial difference in the history of the relative displacement of the dam, and the displacement of the dam due to its weight has been increased. Furthermore, the results of this study exhibit that, with increasing the water level in dam reservoir, the deformation of the crown of the dam along the earthquake application direction has had a relatively significant increase, such that in the full state, the maximum displacement is increased by about 50% compared to that of the empty case. This is while the most damage of concrete is observed in the case when half height of dam in filled by water. Due to the more destructive power of near-field earthquakes and their impact nature, only near-fault earthquakes have been used in this research. Therefore, the results of this study are valid only for the behavior of dam under near-field earthquakes.

Keywords: Concrete faced rockfill dams, Dynamic Analysis, Finite element, Interaction, Water level

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