Mathematical correlation evaluation between earthquake intensity-energy parameters and dynamic responses of earth dam - case study: Jamishan dam

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ABSTRACT

Until now, the seismic behavior of earth dams has been studied in the form of time and frequency analyses. In addition to these two frameworks, the issues of energy and seismic wave intensity are very influential concepts that can be used to evaluate the seismic behavior of earth dams based on them. In this research, the effects of changes in specific energy density and intensity measures of incoming earthquake waves, such as Arias, Characteristic and Housner intensities, on the values of the seismic responses of Jamishan earth-rockfill dam have been studied. Therefore, the 2D finite element modeling of the dam has been implemented in the framework of plane-strain logic and time-history nonlinear dynamic analysis method (NLDAM). In order to reduce and eliminate the unpleasant effects of the return of seismic waves in the lateral end boundaries of the dynamic models, the concept of the infinite element with the definition of the pole point has been used. The number of 9 different records of near-fault earthquakes with scaled and un-scaled acceleration amplitudes with different energy contents and seismic intensities have been applied to the dam model. Amplification values of the seismic responses of the dam's crest compared to the incoming seismic motions in the bed rock have been investigated during the application of different seismic motions. Based on the findings of this study, there is an exponential relationship between the seismic responses of the dam's crest and the energy and intensity parameters of the input seismic motions.

KEYWORDS

Earth dam, Energy density, Earthquake intensity parameters, Seismic analysis, Finite element analysis.

1. Introduction

The level of seismic energy and intensity of different earthquakes has fundamental differences with each other. These different energy and intensity levels lead to the occurrence of various seismic responses in most engineering structures. Among the most important structures that may be affected by the destructive effects of changes in the energy and intensity of seismic waves are earth-rockfill dams. Damage of earth dams due to earthquakes can have irreparable financial and life consequences, especially in the downstream of the dams. In the field of investigating and modeling this important issue, the main approach of previous articles has been based on performing dynamic analysis in the time-domain. Currently, valuable studies have been carried out in various aspects of seismic analysis of earth dams. For example, studying the effects of dynamic loading on the failure of high earth-rockfill dams [1-2], seismic evaluation of small dams using laboratory methods such as geotechnical centrifuge modeling [3-4], the effects of added new materials and components such as polymer

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anti-seepage walls [5], geo-composite internal drains [6] to different parts of the body of the earth dam on its seismic behavior, the effect of large earthquakes and reverse fault failure on rupture and non-linear seismic response of earth dams [7-9], side seismic effects such as dynamic liquefaction of materials at the foundation and body of the earth dam [10-11], investigation of spatial changes in soil properties [12], geometric changes of the dam [13], and the study of surface waves at the dam site [14] and their effect on the dynamic response of the earthen dam. All of the important titles of valid studies related to the topic of this article have been in the last few years. In addition, in a research similar to the subject of this article, the evaluation of the impact of the optimal ground motion intensity measure in predicting the seismic vulnerability of earth dams has been presented by Regina et al. [15].

In their study, the seismic vulnerability of two dams has been calculated using analytical fragility functions, for different damage mechanisms and ground motion intensity measures (IMs) based on probabilistic earthquake hazard analysis. Anyway, according to the comprehensive studies carried out in this article, the main criteria for examining most of the dynamic simulations of earth-rockfill dams are the two main criteria of the time and frequency characteristics of the earthquake records. And the effects of energy measures of incoming seismic movements and their intensity have been less researched. Therefore, in this study, the characteristics of seismic loads from the point of view of input energy content-intensity and their effects on the seismic response of the earth dam have been researched.

2. Methodology

In this article, two-dimensional finite element analyzes in the Quake/w software [16] are the basis for conducting numerical simulations of the research subject. The two-dimensional plane strain model of the Jamishan earth-rockfill dam [17], according to the geometric ratio between the height of the crest and the length of the dam (between the two side abutments of the U-shaped valley, Figure 1), is considered in the stages of numerical calculations of the present study. The boundary conditions of the numerical model of the dam in the stages of gravity loading and seismic loading are defined completely differently from each other [16] (Figure 2).

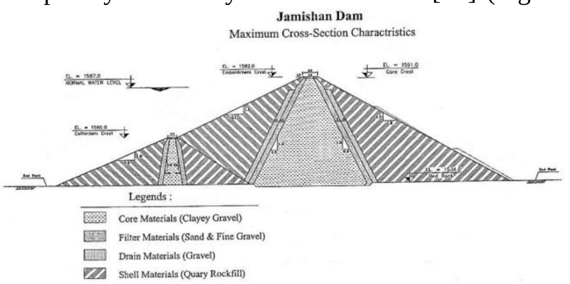

Figure 1. Geometrical dimensions and typical maximum cross-section of Jamishan reservoir earth-rockfill dam [17].

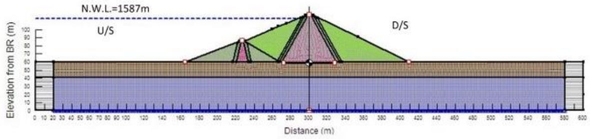

Figure 2. Location of time history points in crest and bedrock and infinite elements in lateral boundaries.

3. Results and Discussion

In this section, the graphs obtained from the changes of intensity parameters and amount of seismic energy of input motions against the seismic responses of the dam's crest are presented. According to Figure 3, the process of changes between the seismic response of dam's crest with changes in energy parameters or seismic intensity values, is a non-linear, ascending and exponential relationship. According to Figure 3 (3b and 3c), the highest coefficient of determination, R^2, is related to the graphs between the crest horizontal acceleration response and characteristic intensity, besides, Arias and Housner intensities and specific energy density for the proposed exponential function, have lower fitting accuracy. The reason for the low accuracy of the Housner intensity fit for the acceleration is that the Housner intensity is of the displacement type and in units of meters and is intrinsically incompatible with the acceleration quantity. Also, since the quantity of the characteristic intensity is unitless and independent of the dimension, it has shown a good correlation with the lateral acceleration of the crest.

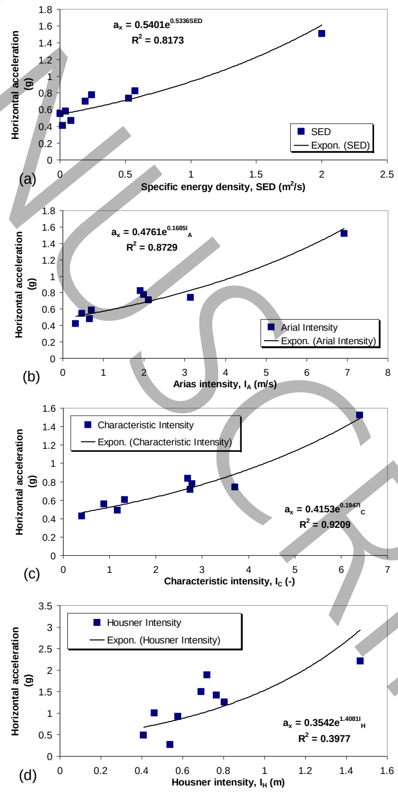

Figure 3. Graphs of changes in horizontal acceleration response of the dam's crest versus parameters related to energy criteria and seismic intensity measures.

4. Conclusions

Based on seismological concepts [18-19], the energy content released by different earthquakes in different parts of the world depends on various factors such as the focal depth of the earthquake, the faulting mechanism, the type of soil layers, the values of frequency characteristics, bedrock location and many other factors may be very different from each other. Accordingly, in this study, various components of near-fault earthquake records have been applied as input motions to the bedrock of the model of Jamishan dam. Each of these records have different seismic energy levels and intensities. In this study, the mathematical relationship between (1) the energy and intensity parameters of incoming earthquakes and (2) the responses of the time history of acceleration, lateral and vertical displacements, spectral acceleration response and dynamic shear strains of the crest and bedrock sections of the dam, has been calculated by performing 2D FE non-linear analysis. Based on the findings of the numerical studies of this article, the following results can be expressed:

1. The graph of specific energy density changes and input loading intensity measures against seismic responses of the dam's crest, in most cases, are exponential functions with high fitting accuracy (i.e. with a suitable coefficient of determination, R^2).

2. The final result of this study confirms that between the energy-intensity parameters of the input motions and the seismic responses of the dam, the highest correlation between the responses of the crest and characteristic intensity, I_C, is established. Also, for the lateral displacement of the dam's crest and its shear strains, the Housner intensity, I_H, provides a good fitting accuracy.

5. References

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