Effects of Earthquake Wave Direction on Dynamic Response of Earth Dams - Case Study: Shohada Dam

Yazdan Shams Maleki[1][1]

[1]Assistant professor, Civil Engineering Department, Kermanshah University of Technology (KUT)

Abstract

In this paper, the irregularity effects in the initial directions of the seismic loading on the nonlinear time-history responses of the Shohada dam have been investigated. The maximum cross-section of the dam has been simulated by the 2D finite element method under the normal lake level conditions. The near-fault acceleration record of the Tabas earthquake has been applied as dynamic input motion to the two-dimensional numerical models. Numerical analysis has been conducted in the Newmark explicit time integration scheme framework. The main three patterns of horizontal, vertical, and oblique directional seismic loading are considered to investigate the effects of the initial directions of seismic motion propagation. In each case, the seismic responses are compared to the conventional seismic loading responses in the horizontal direction from the upstream (reservoir) to the downstream of the dam. The hardening soil model with small strain (HS-small) and Mohr-Coulomb model were used to model the dam's body and the foundation materials, respectively. In most 2D simulations, the initial direction of the input seismic movements has been only in one or two dimensions and in the horizontal or vertical orientation. This study has attempted to compare these traditional seismic loading patterns with other possible states in 2D numerical models. The present study results show that the seismic loading mode with the initial direction of inclination of 45 degrees has the worst and most significant effect on the seismic response of the dam compared to the traditional method of horizontal loading.

Keywords

Irregular input motions, Seismic loading, Earth dam, Non-linear analysis, Constitutive model.

[1] Corresponding Author: Email: y.shamsmaleki@kut.ac.ir

1. Introduction

Seismic analysis of earth dams is one of the important and necessary steps in the design and control stages of the performance of these strategic structures. So far, various methods such as linear, equivalent-linear and non-linear methods in total and effective stress frameworks have been used for seismic analysis and design of earth dams [1-4]. The non-linear method, which is based on effective stress assumptions, is in a way the most accurate method of seismic analysis of earth dams [5-7]. Extensive studies have been conducted in recent decades to better evaluate the seismic behavior of earthen and rockfill dams. However, according to available technical literature [5-7], so far the issue of the effect of seismic loading primary directions in 2D plane-strain finite element models of the earth dams has been less studied [5-7]. In most 2D numerical modeling, the initial direction of seismic loading in the bedrock of numerical models is only in one horizontal (from upstream to downstream) or vertical direction. In defining the framework of this study, as a computational necessity in 2D plane-strain models, as a conservative approximation a real 3D directional loadings is reduced to the 2D models as changes in the initial direction of the bedrock seismic motions in different irregular directions.

2. Methodology

2.1. Introduction of Shohada earth dam (Case Study)

In this section, at the beginning, the location and characteristics of the earth-rockfill dam studied by the present paper are introduced and then the static and seismic characteristics and its numerical modeling are reviewed. Shohada earth-rockfill dam is located near Soleimanshah village in Sonqor city, in the northeast of Kermanshah province in western Iran. The clay core of the dam is of vertical type and has a rockfill body (Ab Niroo [8]).

2.2. Details of the parametric numerical models

To study the effect of the initial direction of seismic wave propagation in plane-strain models and to perform 2D FE modeling of the present study, PLAXIS 2D software can be used [9]. Selecting the appropriate constitutive model to simulate the static and dynamic stress-strain of body and foundation materials of the dam is one of the most important first steps in the implementation of the numerical modeling process. In this study, the constitutive model of hardening soil with small strain or HS-small model has been used. In this paper, numerical modeling in the framework of plane-strain logic has been performed by non-linear 2D finite element method. In this study, the HS-small hardening soil model has been used to model the seismic behavior of different earth dam body materials. This model is a generalization of the Mohr-Coulomb elastic-perfect plastic model and the HSM hardening soil model. Compared to the standard hardening soil model, the HS-small model requires two additional stiffness parameters as input, which are G_{0ref} and $\gamma_{0.7}$. These values for strain $\gamma_{0.7}$ with respect to the threshold ratio of 0.722 for G/G_0 can be obtained precisely from the available laboratory curves [10].

2.3. Problem definition

In this study, to calculate the effect of changing the initial direction of seismic wave input and the movements caused by them, in the bed of the earth dam, three different categories of seismic loading with irregular directions have been considered, which are: Loading groups in the directions of (1) horizontal, (2) vertical and (3) oblique. Also, in each group, 2 possible modes of directional loading have been investigated (Figure 1).

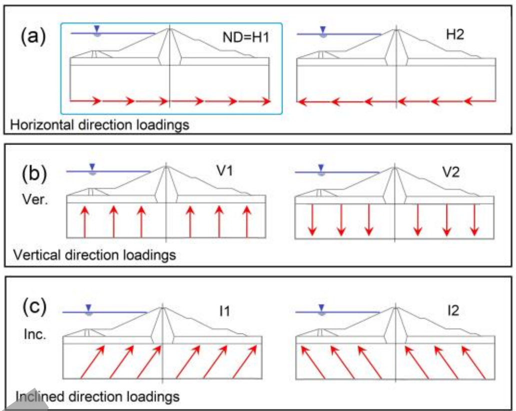

Figure 1: Assumed 2D plane-strain models (6 models) to investigate the irregularity effects in the direction of seismic motions propagation: (a) horizontal, (b) vertical, (c) oblique.

3. Results and Discussion

Figure 2 demonstrates the time-history response of the crest settlement under seismic loadings in the horizontal, vertical and oblique directions. In Figure (2-a) the highest settlement occurred in H2 loading. This is because according to Snell's law, the direction of movement of horizontal loading waves, while leaving the ground, is close to the vertical direction or at least inclined. On the other hand, loads have at least one component towards the reservoir (to cause disturbance in it). The interesting point in Figure (2-b) is that the loadings of this group did not create the permanent displacement in the crest and their responses are cyclical and non-monotonous in nature. In Figure (2-b) it is important to note that both the loads V1 and V2, have completely opposite vertical directions. The responses are almost the same size. Only in terms of

phase of responses, each is in the opposite phase and asynchrony is seen in these two responses. In Figure (2-c) in the oblique load group, I2 and I1 loads have the highest permanent settlement response, respectively.
In some diagrams of Figure 2, obvious asynchrony is observed in some cyclic settlement responses of loads that are in opposite directions (V1 and V2) [7]. Permanent responses also showed weaker asynchrony (as in H1 and H2).

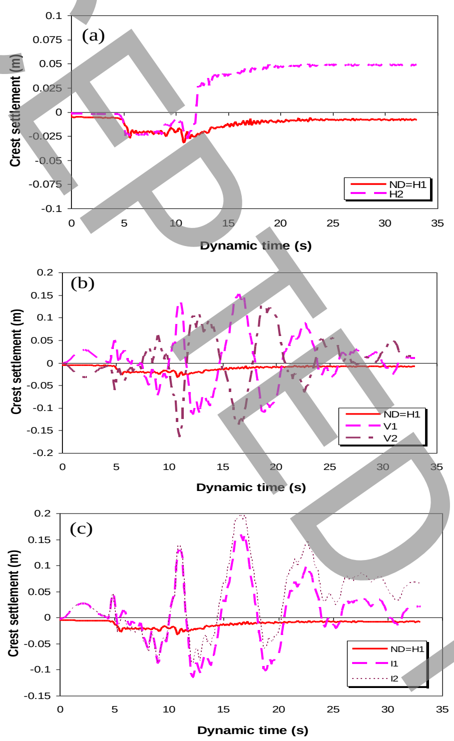

Figure 2: Time- history response of the crest settlement under irregular seismic loadings in the direction of: (a) horizontal, (b) vertical, (e) inclined.

4. Conclusions

In this research, irregular effects in the initial directions of seismic loading ejection on the dynamic response of Shohada earth-rockfill dam have been studied. There are six different possible parametric models, including the typical ND seismic loading model and five other models, in the framework of the non-linear 2D finite element method and in the plane-strain modeling logic. Directional seismic loads have been applied in three groups of horizontal, vertical and oblique loadings to the lowest point of the bedrock of the 2D model of the dam by changing the initial directions in each coordinate axis. And the resulting responses were compared. The HS-small constitutive model is used for materials of different zones of the dam body. The important findings of the present study can be summarized as follows:

1. With a conservative approximation in 2D plane-strain numerical models of the earth dams, it is possible to apply seismic loads in different directions, and this issue is not only limited to 3D numerical models.

4. According to the findings of this study, seismic loading with an initial direction of inclination with a propagation angle of 45°, has created the largest displacement responses in the crest of the dam, which is likely to occur in a real near-fault earthquake. The main purpose of this study is to calculate the effect of real 3D seismic loadings in the form of 2D numerical models.

5. References

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