The Effect of Geometry Dimensions on the Earthquake Response of the Finite Element Method

Morteza Jiryaei Sharahi

Abstract—In this paper, the effect of width and height of the model on the earthquake response in the finite element method is discussed. For this purpose an earth dam as a soil structure under earthquake has been considered. Various dam-foundation models are analyzed by Plaxis, a finite element package for solving geotechnical problems. The results indicate considerable differences in the seismic responses.

Keywords—Geometry dimensions, finite element, earthquake

I. INTRODUCTION

THE Finite Element Method is a good choice for solving wave propagation through bounded and unbounded elatodynamic problems. In the finite element method for unbounded problems such as seismic wave propagation through the soil, a closed boundary must be considered for the foundation so the geometry of the model which has a significant effect on the response changes.

In this study dynamic analysis of Narmaab earth dam (Iran) considering dam-foundation interaction, under Manjil earthquake (after scaling to a $_{max}$ =0.28g), as input motion, carried out by Plaxis, a finite element package for solving geotechnical problems. In order to study the effect of the dam height and foundation width in the finite element model, on the calculated earthquake responses, nine dam-foundation coupled models have been solved with Plaxis

The behavior of embankment dams, as one of the most important structures, under earthquake loading has attracted the attention of many researchers and dam designers. In the last decade, improvements in the different numerical methods have resulted in widespread use of these methods to study dynamic behavior of earth dams; and using dam-foundation coupled model has revealed various aspects of dam response to seismic shaking [1,2].

In simplified dynamic analyses of structures, it is normally assumed that the structure is fixed at the ground level and

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subjected to a base motion. The base motion represents the ground motion anticipated at the pro-posed site and is influenced by the nature and extent of the soil deposit at the site. In addition, the presence of the structure could also influence this base motion. This mutual influence of the structure and the foundation on their responses is commonly referred to as soil-structure interaction. When the response at the base of the structure is essentially identical to that with no structure present, there is no interaction between the soil and the structure. On the other hand, when the response at the base is significantly different for the two cases, strong interaction exists between the soil and the structure. For cases where the interaction is strong, the soil and structure systems should be analyzed together using a coupled system. For cases where the interaction is insignificant, the soil and structure systems can be uncoupled and each analyzed separately [3]. Earth dams on flexible foundations represent such a soil-structure system [3]. Very little work has been done regarding the seismic response of dams on flexible foundations. Most of the research has been directed toward the analysis of dams on rigid foundations [3], [4], [5], [6], [7], [8], [9], [10]. Ambraseys [11] extended previous work for dams on rigid foundations to dams on flexible foundations, but did not discuss the aspects of interaction. Chopra and Perumalswami [12] presented an analysis for dams on a semi-infinite medium subject to periodic excitations. Their studies covered both damping and the ratio of the elastic modulus of foundation soils to elastic modulus of the dam as they affect interaction. Wilson [13] utilized the finite element method to study the seismic response of an earth dam on a flexible foundation. The cases he presented indicated a high degree of interaction. Finn and Khanas [14] also evaluated the response of an earth dam on a flexible foundation using the finite element method of analysis. Their results indicated strong dependence of the response on the ratio of the fundamental periods of the dam and the foundation layer.

Finn and Reimerg [15] considered the interaction problem between the dam and the underlying foundation layer. They

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analyzed both the coupled and the uncoupled dam-foundation systems and showed significant differences in the response depending on the period of the systems compared to the fundamental period of the base input motion. Seed et al. [3] showed that the interaction effects cannot be uniquely related to either the ratio of the period of the dam to the period of the foundation layer, or to the material properties of the dam and foundation layer. However, for the limited number of cases investigated, the interaction effects were found to be uniquely related to the ratio of the depth of the foundation layer to the width of the dam section.

Chopra et al. [16] by considering dam as an assemblage of two-dimensional finite elements, and the foundation as an elastic half space, determined the dynamic properties of earth dams including foundation interaction effects. Their results indicate that foundation interaction may have significant influence on the frequencies and mode shapes of vibration of earth dams and the influence of foundation interaction depends significantly on the geometry of the earth dam cross-section, being relatively more important for dams with flatter side slopes. Among the geotechnical software, Quad4m and Plaxis can be used to seismic analysis of the dam-foundation model considering foundation-structure interaction. Quad4m is a dynamic, time-domain, equivalent linear two dimensional computer program to evaluate the seismic response of soil structures. Plaxis with dynamic module can be used to model advanced constitutive behaviors for the simulation of the non linear, time dependent and anisotropic behavior of soils and/or rock.

II. Narmab Earth Dam

Narmab earth dam, which is under construction, is located 120 km north east of Gorgan-Iran. It is constructed on the route of the Narmab River to supply agricultural and drinking water. It's height is 60 m from the foundation and with crest length of 807 m. Fig. 1 shows typical cross section of the dam-foundation coupled model. The dam site is located in Alborz seismic zone where active periods have been observed. One of the most important earthquakes that occurred in this area, was the 1990 Manjil earthquake, with Mb=7.3 and Ms=7.7.
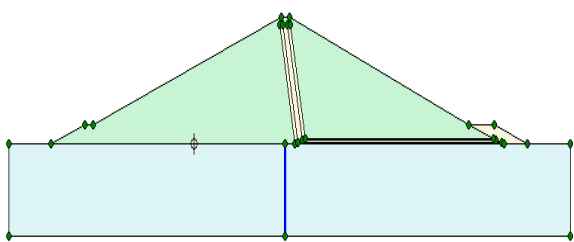

Fig. 1 Typical section of the dam-foundation coupled model

III. Dynamic Analysis

The numerical modeling for the dynamic analyses has been performed using the Plaxis program, which are based on finite element method. Fig. 2 shows the geometry of the dam-foundation coupled model of the Narmab earth dam.
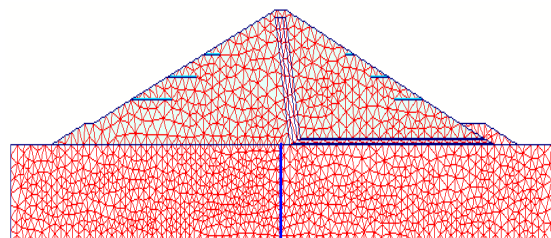

Fig. 2 Coupled model of Dam-foundation

Dynamic analyses were performed for the end of construction stage using the elasto-plastic Mohr-Coulomb model for material nonlinear behavior. Material properties of dam body and foundation have been presented in table 1. In order to absorb the increments of stresses on the boundaries caused by dynamic loading, absorbent boundaries has been used. For accurate representation of wave transmitted in the model, the element sizes should be selected small enough to satisfy the following criteria expressed by Kuhlemeyer & Lysmer [17]:

$$\lambda \leq \frac{\Delta l}{10} \tag{1}$$

Where λ is the wave length associated with the highest frequency component that contains appreciable energy and Δl is the length of element. Considering to these criteria, the element size have been selected as fine as possible. Earthquake response analyses were carried out for Manjil earthquake. The acceleration time histories of the Manjil Earthquake as shown in Fig. 3, were normalized to a maximum acceleration of 0.28g which has been considered in accordance with Maximum Design Level (MDL).

IV. Results

In order to evaluate the effects of dam height (H) and width of the foundation (W) on the finite element solution, following dam heights and lateral extents (B) of the foundation has been considered as given in table 2.

The horizontal acceleration and displacement time histories, the Fourier transform (FFT) of the horizontal acceleration computed at the dam crest due to normalized Manjil earthquake are presented in Fig. 5 to 7. maximum accelerations at the dam crest are given in table 3. As mentioned in the table 2 three lateral extents, 50, 100 and 200 meters, considered for each desired dam heights to calculate the earthquake responses of the dam-foundation coupled models.

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TABLE I
MATERIAL PROPERTIES

Type of material	γ (KN/m3)	C (KPa)	φ	E (MPa)	υ
Dam body	21	27	22	214.6	0.3
foundation	21	1	42	267	0.3
Drain material	20.7	1	42	348	0.25

TABLE II
DESIRED DAM HEIGHTS, LATERAL EXTENTS AND FOUNDATION WIDTH

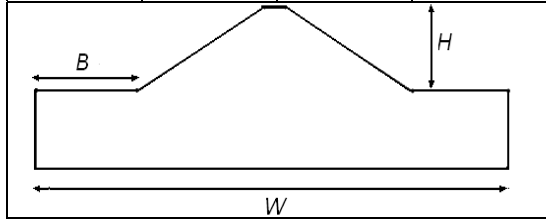| Model number	H (m)	B (m)	W (m)
1	30	50	303
2	30	100	403
3	30	200	603
4	60	50	498
5	60	100	598
6	60	200	798
7	90	50	669
8	90	100	769
9	90	200	969
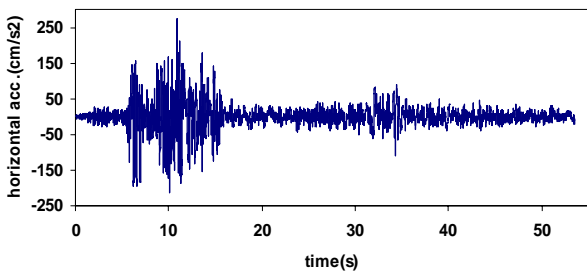
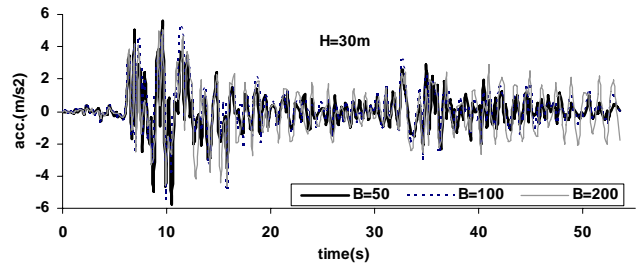Fig. 3 Normalized horizontal component time history of Manjil earthquake

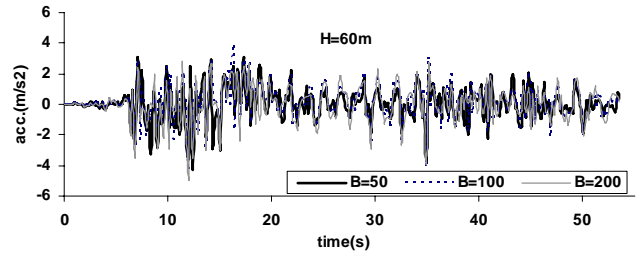Fig. 4 Horizontal acceleration time history at the dam crest (H=30

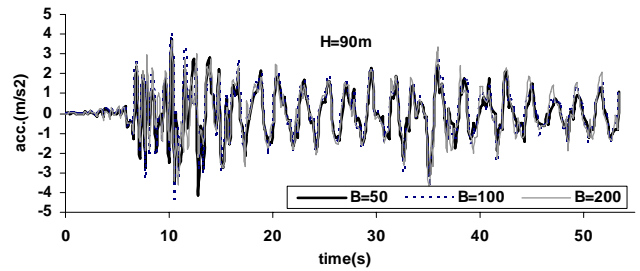Fig. 5 Horizontal acceleration time history at the dam crest (H=60)

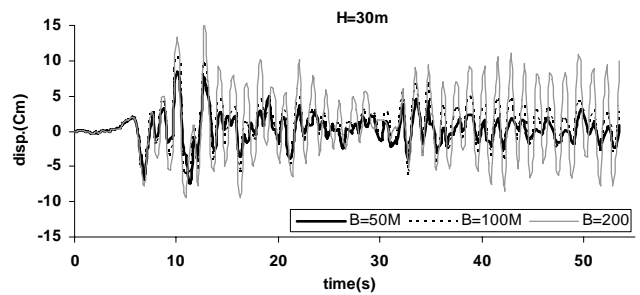Fig. 6 Horizontal acceleration time history at the dam crest (H=90)

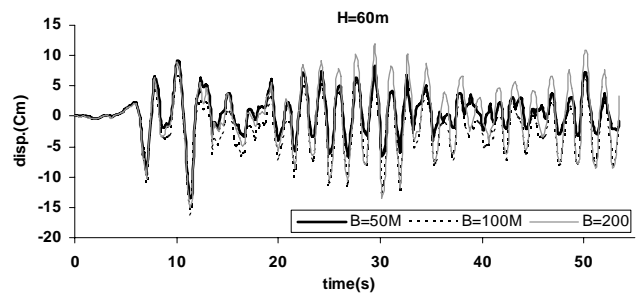Fig. 7 Horizontal displacement at the dam crest (H=30)

Fig. 8 Horizontal displacement at the dam crest (H=60)

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As can be seen from figures 5 to 7:

1- Elastic horizontal displacement at the dam crest increases with increasing B/H ratio, especially when lateral extent (B) is greater than twice the dam height (H). Permanent displacement is not sensitive to the selection of the model width and remains unchanged.

2- Frequency content of the acceleration response at the dam crest varies considerably when lateral extent (B) is greater than twice the dam height (H). But amplitudes of acceleration response do not significantly change with increasing foundation width.

3- Considering large width in the finite element model, may cause amplification of low frequencies amplitudes and reduction the amplitudes corresponding high frequencies.

4- Based on this study, can be proposed that lateral extent must be selected less than twice the dam height in the finite element model, otherwise calculated displacement response and frequency content of the acceleration response, are unreliable.
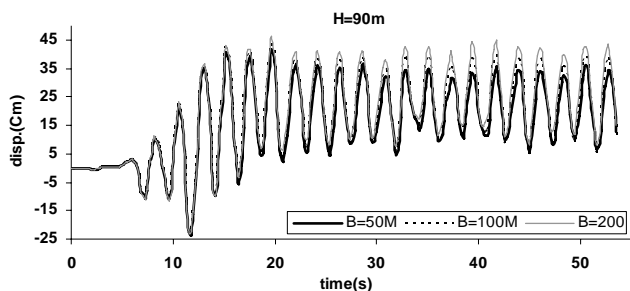

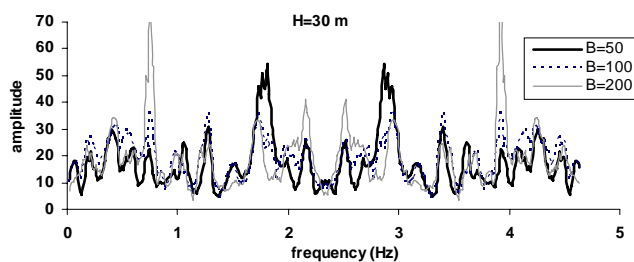Fig. 9 Horizontal displacement at the dam crest (H=90)

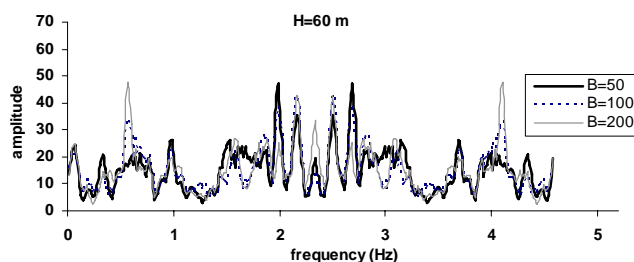Fig. 10 Fast Fourier transform of the horizontal acceleration at the dam crest (H=30)

Fig. 11 Fast Fourier transform of the horizontal acceleration at the dam crest (H=60)

TABLE III
CALCULATED MAXIMUM ACCELERATION AND AMPLIFICATION FACTOR OF ACC.

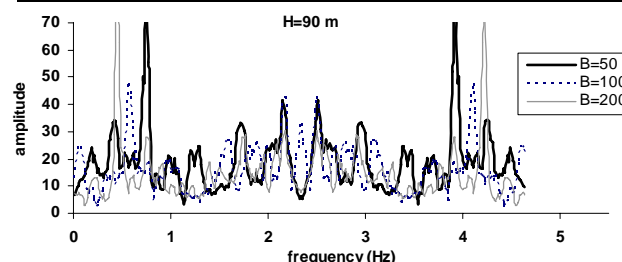| Model number	H (m)	B (m)	Max. Acc. (m/s^2)	Amplification Factor of Acc.
1	30	50	5.7	2
2	30	100	5.3	1.9
3	30	200	5.0	1.8
4	60	50	4.3	1.6
5	60	100	4.9	1.5
6	60	200	4.1	1.8
7	90	50	4.1	1.5
8	90	100	4.3	1.6
9	90	200	4.0	1.5

Fig. 12 Fast Fourier transform of the horizontal acceleration at the dam crest (H=90)

V. CONCLUSION

In this study, dynamic analysis of Narmab earth dam (Iran) considering dam-foundation coupled model with various foundation widths and dam heights under horizontal component of Manjil earthquake has been performed using the Plaxis program. Results indicate that: i) the elastic horizontal displacement at the dam crest increases with increasing lateral extent, especially when lateral extent is greater than twice the dam height. ii) Permanent displacement is not sensitive to the selection of the model width and remains unchanged. iii) Frequency content of the acceleration response at the dam crest varies considerably when lateral extent is greater than twice the dam height but amplitudes of acceleration response does not significantly change with increasing foundation width. Based on this study, can be proposed that the geometry dimensions in the finite element model, must be selected carefully otherwise calculated response and its frequency content, are unreliable.

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