Dynamic Behaviour of Earth Dams for Variation of Earth Material Stiffness

Y. Parish, and F. Najaei Abadi

***Abstract*—**This paper presents a numerical analysis of the seismic behaviour of earth dams. Analysis is conducted for the solid phase. It may correspond to the response of the dam before water filling. Analysis is conducted for a simple case which concerns the elastic response of the dam. Numerical analyses are conducted using the FLAC3D program. The behaviour of the Shell and core of the dam and the foundation behaviour is assumed to be elastic. Result shows the influence of the variation of the shear modulus of the core and shell on the seismic amplification of the dam. It can be observed that the variation of the shearing modulus of the core leads to a moderate increase in the dynamic amplification and the increase in the shell shearing modulus leads to a significant increase in the dynamic amplification.

Keywords—Numerical, earth dam, seismic, dynamic, core, FLAC3D.

I. Introduction

SEED et al [1,2] reported that the seismic performance of embankment dam has been good in general, except when liquefaction or unusual circumstances have been involved. They noted that a well-built compacted embankment dam can withstand moderate earthquake shaking, with peak accelerations of 0.2g and more, with no detrimental effects. The efficiency of modern compacted embankment dams was further demonstrated in 1994 when the Los Angeles Reservoir, was severely shaken by the Northridge Earthquake [3]. The seismic performance of embankment dams has been closely related to the nature and state of compaction of the fill material [4, 5]. Well-compacted modern dams can withstand substantial earthquake shaking with no detrimental effects.

The most common method used in engineering practice to assess the seismic stability of earth fill dams consists on a pseudo static approach where the earthquake effect on a potential soil mass is represented by means of equivalent static horizontal force equal to the soil mass multiplied by a seismic coefficient. This approach is based on several simplified assumptions neglecting the soil deformability, misestimating therefore of the earthquake effects on dams. Since the 1971 San Fernando earthquake in California [6], major progress has been achieved in the understanding of earthquake action on dams. Progress in the area of geotechnical computation offers interesting facilities for the analysis of the dam response in considering complex issues such as the soil plasticity, the evolution of the pore pressure during the dam construction procedure and real earthquake records.

This paper presents numerical study of the seismic behaviour of earthfill dams. Analysis is conducted for the solid phase using the finite difference program FLAC3D [7]. It corresponds to the response of the dam before water filling.

The behaviour of the Shell and core of the dam is described by "equivalent-linear" method. The "equivalent-linear" method is common in earthquake engineering for modeling wave transmission in layered sites and dynamic soil-structure interaction. Since this method is widely used, and the fully nonlinear method embodied in FLAC3D is not, it is worth pointing out some of the differences between the two methods. In the equivalent-linear method (Seed and Idriss 1969), a linear analysis is performed, with some initial values assumed for damping ratio and shear modulus in the various regions of the model.

The use of this model is justified by the difficulty to obtain constitutive parameters for more advanced constitutive relations including both isotropic and kinematic hardening. A parametric study is conducted for the investigation of the mechanical role of shell and core and their interaction under a dynamic loading.

II. Problem Under Consideration

The selected example is a simplified representation of typical earth dam geometry. The dam section assumed in the present survey is a symmetric zone section with clay core and foundation as shown in Fig. 1. The behaviour of the Shell and core of the dam is described by "equivalent-linear" method, while the foundation behaviour is assumed to be elastic and very stiff (E=1000 MPa). Geotechnical properties used in the analyses are presented in Table I for foundation soil and earth dam materials. The materials properties though are chosen more close to reality. Numerical analyses are conducted using the finite difference FLAC3D program based on a continuum finite difference discretization using the Langrangian approach. Dynamic loading is applied at the base of the foundation layer as a velocity excitation (Fig. 1). The earth dam is subjected to earthquake loading representative of the 1999 Kocaeli earthquake in Turkey with a magnitude Mw=7.4 [8]. The estimated peak velocity is approximately 40 cm/sec

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(peak acceleration 0.247g), and the duration is approximately 30 sec. The record for base acceleration, velocity, and displacement waves are shown in Fig. 2a-b-c. Fourier analysis of the earthquake velocity record results in a power spectrum depicted in Fig. 2d. The velocity spectrum reveals a dominant frequency of about 0.9 Hz.

The natural frequencies of the foundation-dam system were determined by a Fourier analysis of the free response of the dam (Fig. 3). It shows a fundamental frequency f_1 = 0.7 Hz which is close to dominant frequency of seismic loading (f=0.9 Hz); the second frequency is close to f_2 = 1.45 Hz.

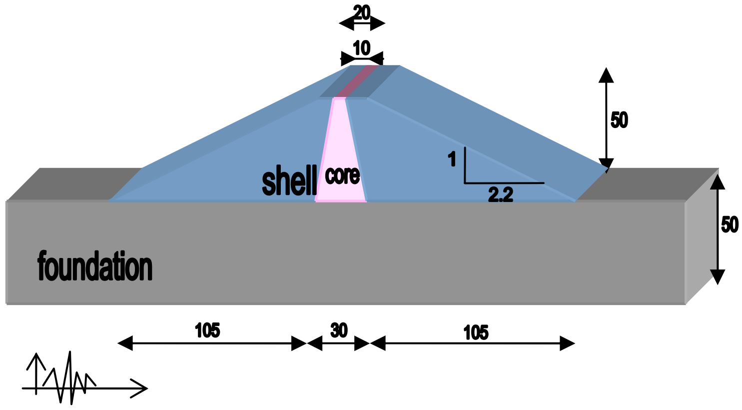
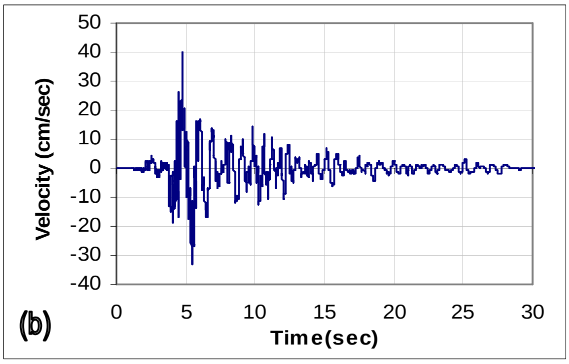
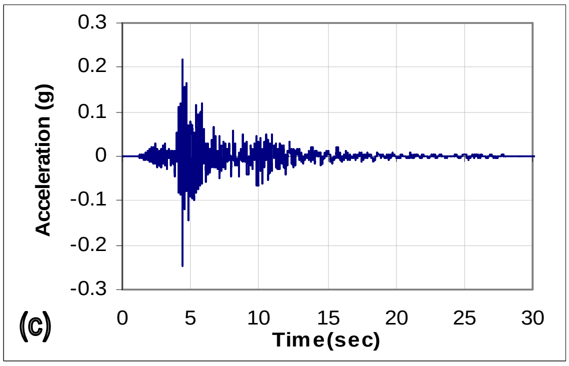


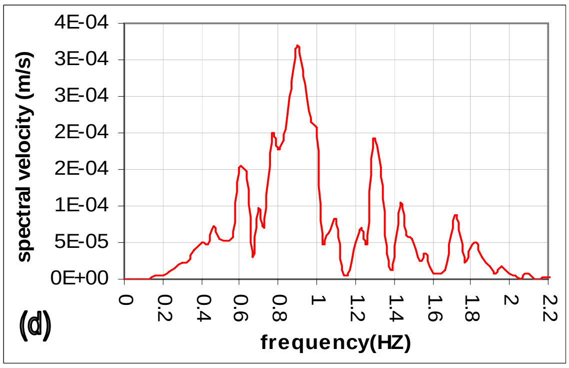
Fig. 1 Geometry of dam and the shape of zones (units in meter)

TABLE I
PROPERTIES FOR FOUNDATION AND EARTH DAM SOILS

Parameter	Units	Core	Shell	Foundation
Dry density (ρ)	(kg/m3)	1800	2000	2200
Young's modulus (E)	(MPa)	40	60	1000
Poisson's ratio (ν)		0.3	0.3	0.25
Elastic shear modulus (G)	(MPa)	15	23	400
Bulk modulus (K)	(MPa)	33	50	666







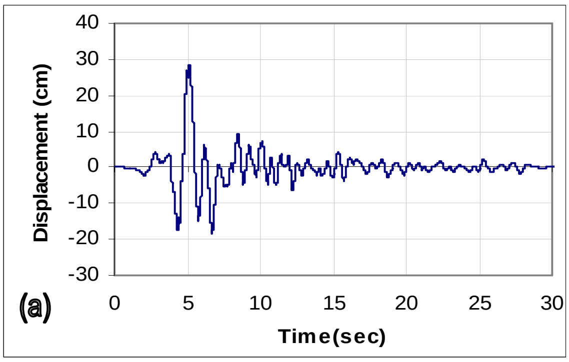


Fig. 2 Kocaeli earthquake record (1999) : a) Displacement, b) Velocity, c) Acceleration, d) Fourier Spectra of Velocity Component

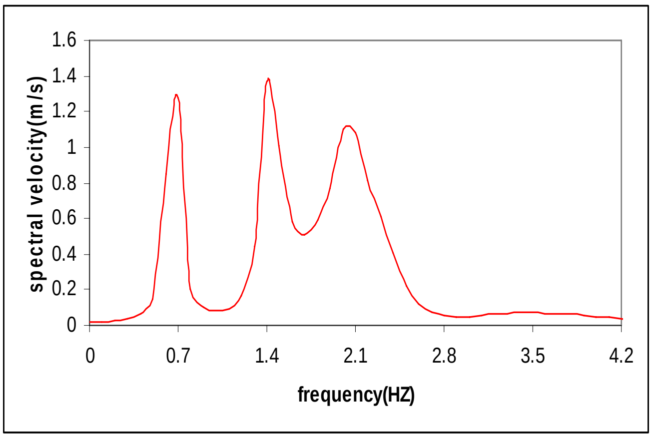


Fig. 3 Response spectra of design free surface motion of the dam

III. Analysis of the Seismic Induced Response in the Dam

The response of the dam at the maximum excitation is presented in Fig. 4. It shows an increase in the lateral velocity with the distance from the dam foundation. The variation of the lateral velocity in the horizontal direction seems to be low.

Fig. 5 shows the velocity amplification in the axis of the dam. It can be observed that the amplification increases with the distance from the foundation; it attains 3.45 at the top of the dam. Fig. 6 shows the variation of the lateral amplification in the horizontal direction at the middle height of the dam and the crest. In the first section, we observe a variation in the dynamic amplification between 2 and 2.5. At the crest, we observe a uniform distribution of the amplification (close to 3.45).

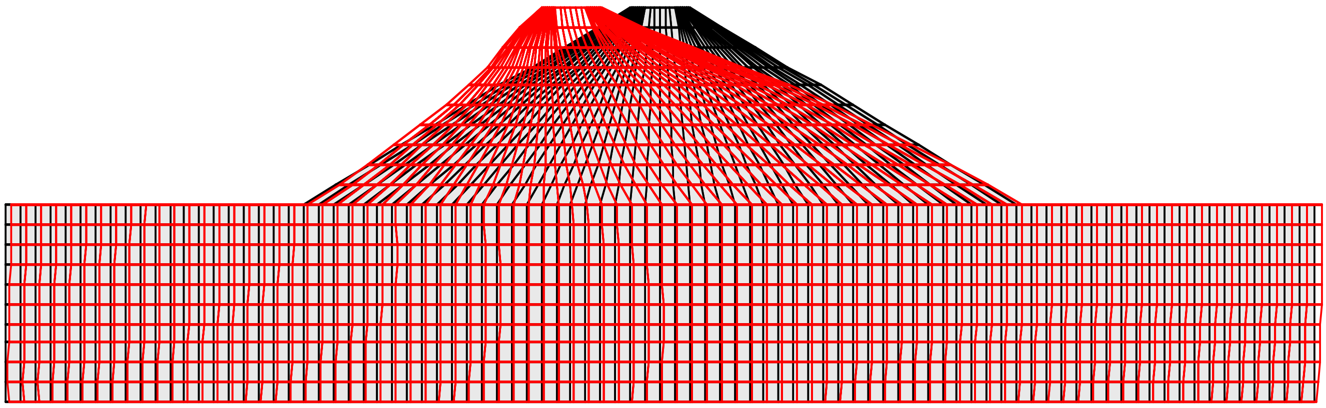


Fig. 4 Dam deformation at the maximum of excitation (Kocaeli earthquake record),(U_{max} = 0.30 m at the dam crest)

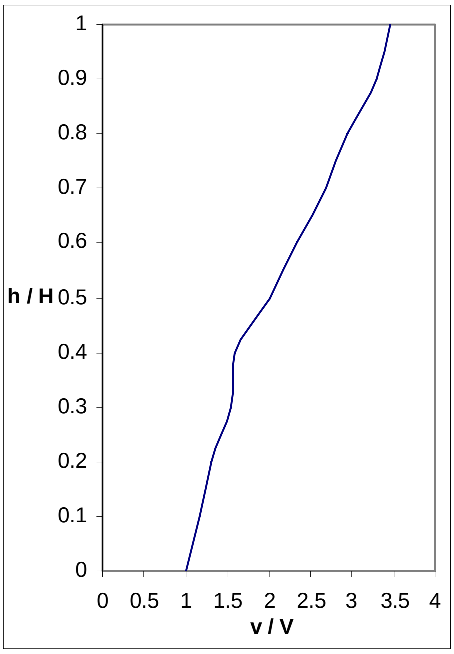
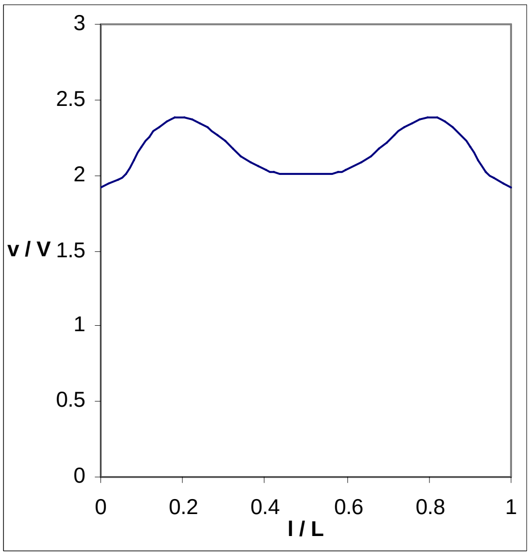
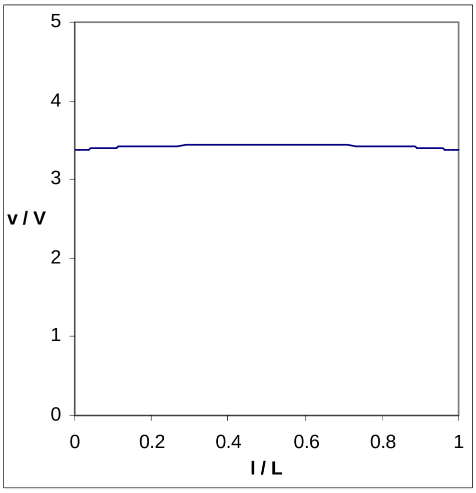


Fig. 5 Velocity amplification in the dam axis (Kocaeli earthquake record)



(Middle height)



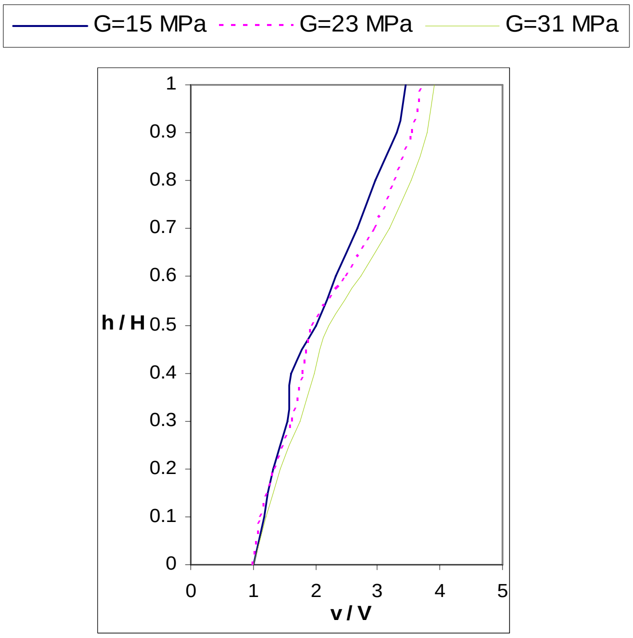
(Dam crest)

Fig. 6 Variation of the amplification in the horizontal direction: a) At the middle height b) At the dam crest

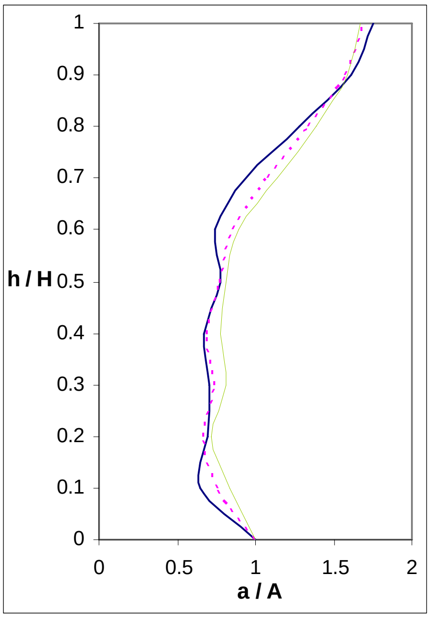
IV. Mechanical Role of Core and Shell

Analyses were also conducted for the Kocaeli earthquake record for:

- Three values of the Young's modulus of the core: E = 40, 60 and 80 MPa; G = (15, 23 and 31 MPa).
- Three values of the Young's modulus of the shell: E = 30, 40 and 60 MPa; G = (11, 15 and 23 MPa).
- Three values of the Young's modulus of the foundation: E = 500, 750 and 1000 MPa; G = (200, 300 and 400 MPa).



(Velocity)

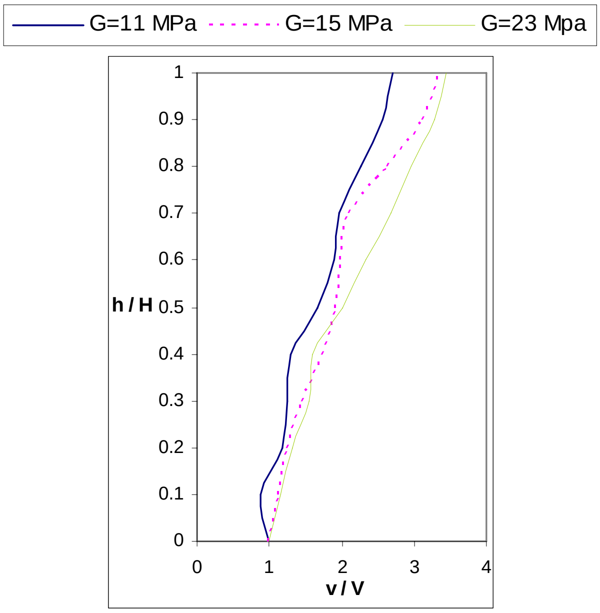


(Acceleration)

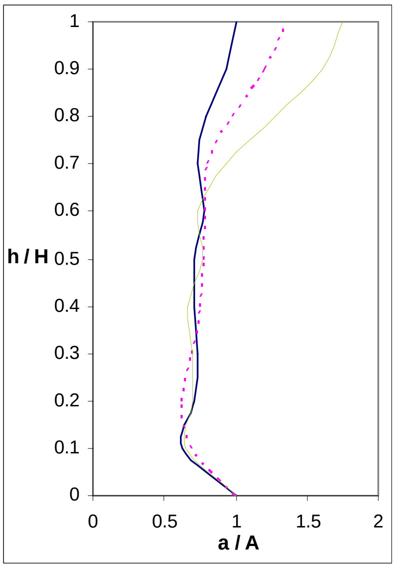
Fig. 7 Influence of the core stiffness on the seismic response of the dam, (Kocaeli earthquake record)

Fig. 7 shows the influence of the variation of the shear modulus of the core on the seismic amplification of the dam. It can be observed that this variation leads to a moderate increase in the dynamic amplification. This increase results from the increase of the fundamental frequency of the dams towards the dominate frequency of the loading. The influence of the variation of the shearing modulus of the shell on the seismic amplification in the dam is illustrated in Fig. 8. It can be observed that the increase in the shell shearing modulus leads to a significant increase in the dynamic amplification. This result is also expected, because the increase in the shell shearing modulus leads to an increase in its fundamental frequency towards the frequency of the major peak of the input motion.

The influence of the variation of the shear modulus of the foundation on the dynamic amplification is depicted in Fig. 9. It can be observed that an important variation of this parameter (100%) slightly affects the seismic response of the dam.

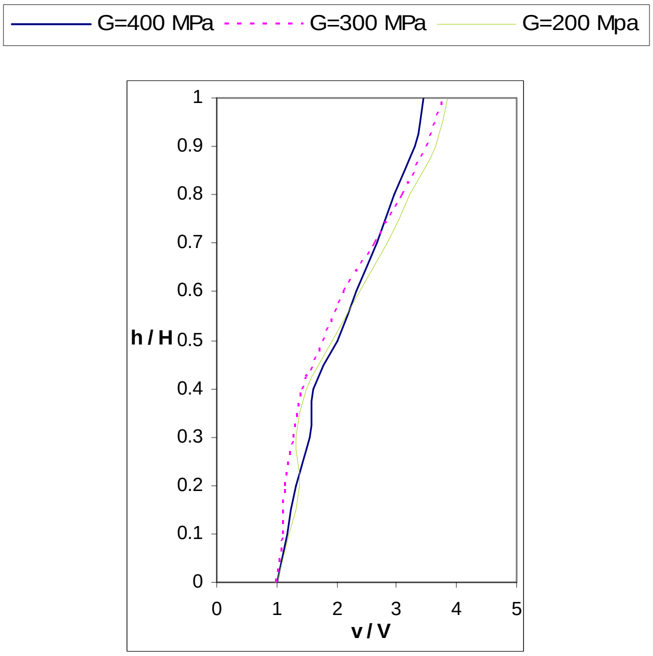


(Velocity)

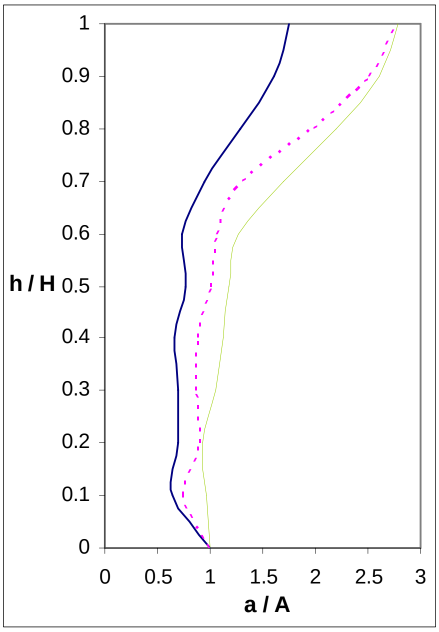


(Acceleration)

Fig. 8 Influence of the shell stiffness on the seismic response of the dam, (Kocaeli earthquake record)



(Velocity)



(Acceleration)

Fig. 9 influence of the foundation stiffness on the seismic response of the dam, (Kocaeli earthquake record)

V. Conclusion

This paper included a numerical analysis of the seismic behaviour of earth dams. It corresponds to the response of the dam before water filling. Numerical simulations were performed for real earthquake records using "equivalent-linear" method.

Elastic analyses show an increase in the lateral velocity with the distance from the dam foundation. The variation of the lateral velocity in the horizontal direction seems to be low. Also, it can be observed that the amplification increases with the distance from the foundation.

It can be observed that variation of the shear modulus of the core on the seismic amplification of the dam leads to a moderate increase in the dynamic amplification. This increase results from the increase of the fundamental frequency of the dams towards the dominate frequency of the loading. Also, the increase in the shell shearing modulus leads to a significant increase in the dynamic amplification. This result is also expected, because the increase in the shell shearing modulus leads to an increase in its fundamental frequency towards the frequency of the major peak of the input motion.

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