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SEISMIC INTERACTION EFFECTS IN EARTH AND ROCKFILL DAMS

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ABSTRACT

A numerical procedure based on the finite element method is presented for investigating the behavior of earth and rockfill dams, with emphasis on the interaction between the dam and the surrounding canyon, including effects of spatial variability of the seismic excitation on the response. A two dimensional dam-canyon model has been developed based on the idealization of the dam as a shear beam, and the surrounding canyon as a halfspace. The model is capable of simulating canyons of arbitrary shape, arbitrary seismic wave excitation, and inhomogeneous distribution of soil properties with depth. It is found that the interaction between the dam and the canyon affects greatly the response of the dam.

KEYWORDS

Dams, dam-canyon interaction, seismic response analysis, finite elements, SH waves.

INTRODUCTION

Earth and rockfill dams are large, heterogeneous three dimensional structures built in canyons with irregular shapes. Various analytical and numerical methods have been developed for predicting the seismic performance of earth and rockfill dams. Reviews of related developments have been surveyed in two comprehensive state-of-the-art papers by Gazetas (1987) and Gazetas and Dakoulas (1992).

The vast majority of studies of the seismic response of earth and rockfill dams have ignored all the coupling effects between the dam and its support, mainly because of limitations in modeling capabilities, as well as the effects of the spatial variability of the incoming wave, by assuming a uniform, prescribed excitation of the base and sides of the dam. This assumption amounts to neglecting two potentially important effects: (i) the interaction that takes place between the dam and its foundation, and (ii) the destructive wave interference that occurs in the dam due to phase and amplitude differences.

Yet, increasing evidence from the records obtained at dam sites indicate that ground motion varies considerably over the dam-canyon interface (Ohmachi and Soga, 1984, Fedock, 1986). Chopra and Perumalswami (1971) found that for a halfspace that is stiff relative to the dam, damping values were of the order of 0.3 and 5 percent in the first and second modes; for a softer foundation the corresponding damping values in the first two modes increased to 16 and 78 percent of critical. Haroun and Abdel-Hafiz (1987) found that the response of the dam can be sensitive to the assumed spatial variation of the ground motion along its base. In a more recent study, Dakoulas and Hashmi (1992) have incorporated the effect of a deformable rectangular canyon on the seismic response of a damped, homogeneous dam. Other simple canyon shapes (e.g., semicylindrical shape canyon by Dakoulas, 1993) have also been studied.

Despite of all these efforts, many questions remain to be answered regarding the seismic behavior of dams. This paper investigates the seismic canyon interaction between the dam and the canyon, including effects of spatial variability of the seismic excitation on the response.

MODEL OF THE DAM

A two-dimensional dam-canyon model was developed based on an idealization of the dam as a shear beam and of the surrounding canyon as a halfspace. The problem was formulated variationally, thereby yielding a natural interface traction condition at the interface between the dam and the canyon which is consistent with the shear beam idealization of the dam.

In order to provide a realistic representation of earthquake dam behavior the model is capable of simulating canyons of arbitrary shape, arbitrary seismic wave excitation, and inhomogeneous distribution of soil properties with depth. The region surrounding the dam is truncated by means of an artificial boundary, on which an approximate radiation condition is imposed to limit the occurrence of spurious reflected waves. To represent the energy dissipated in the soil material, a special choice of Rayleigh damping is introduced, which can represent approximately the rate independent character of damping losses commonly associated with soils, within a prescribed frequency range. The problem is solved directly in the time domain. Spatial discretization is performed by the finite element method.

The response of the dam is examined by finding the displacement in the upstream-downstream direction within the dam under a prescribed SH-incident plane wave in the form of a Ricker pulse. Such pulse allows a precise control over the frequency range of interest. The excitation is imposed by means of a set of effective forces which act on a single strip of elements exterior to the dam.

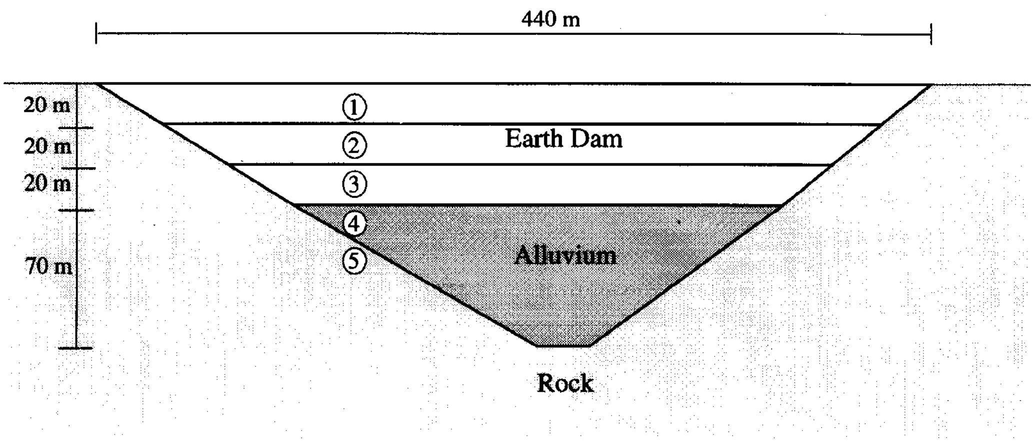
SYSTEM RESPONSE

The particular case of La Villita Dam (Elgamal, 1992) was considered. This is a zoned earth and rockfill dam supported on top of an alluvium layer, which is located in a seismically active area in Mexico. The dam has a non-uniform cross section and variable elastic modulus along its depth as shown in Fig. 1.

Two cases were examined. In the first case we assumed essentially a rigid canyon and in the second case a flexible one. For the case of the flexible canyon we considered an impedance ratio of approximately four between the alluvium layer underlaying the dam and the surrounding canyon. The shear wave velocity, v_s, of the canyon rock was assumed as 1000 m/sec. For the case of the "rigid" canyon we considered an impedance ratio of approximately forty, corresponding to a shear wave velocity of the canyon of 10000 m/sec. The seismic response of the dam to a Ricker pulse excitation propagating vertically is shown in Fig. 2 for the mid-crest of the dam. The top and bottom diagram depict the synthetic displacement for the flexible and "rigid" canyon, respectively, normalized with respect to the free-field displacement. A comparison of the curves shows a distinct reduction in the duration of the response, and most important the peak response for the flexible canyon case is reduced to one half of that for the "rigid" canyon. Thus, it can be seen that the interaction between the dam and the surrounding canyon influences greatly the response of the dam. This reduction is to a large extent a consequence of the amount of energy radiated back to the canyon.

We also examined the seismic behavior of La Villita Dam subjected to an SH plane wave, incident

LA VILLITA DAM



Material	Shear Modulus (MPa)	Mass Density (kg/m^3)	Velocity (m/sec)
1	160	2100	275
2	205	2100	310
3	235	2100	335
4	190	2100	300
5	2300	2300	1000

Fig. 1: Computational model and properties of La Villita Dam.

at various angles. The response at the mid-crest of the dam is shown in Fig. 3 for an incident SH wave propagating vertically and for an incident SH wave propagating at an angle of 45^0 in the form of a transfer function; that is the Fourier transform of the response at midcrest, normalized with respect to the Fourier transform of the free field response. The response of the dam itself is not too sensitive to the angle of incidence of the incoming wave for the first two resonant frequencies, but varies significantly at higher frequencies. Notice that while for vertical incidence the response is highest at the third resonant frequency, destructive interference results in a three-fold reduction in the response, for the inclined wave.

CONCLUSIONS

The seismic canyon interaction effects in earth and rockfill dams built in canyons with irregular shapes were examined by developing a two dimensional dam-canyon model. The influence of some key system parameters on the response of the dam, such as impedance ratio between the dam and the canyon and angle of incidence of the seismic wave was investigated for the particular case of La Villita Dam. The results of this study indicate that the interaction between the dam and the canyon affects considerably the response of the dam.

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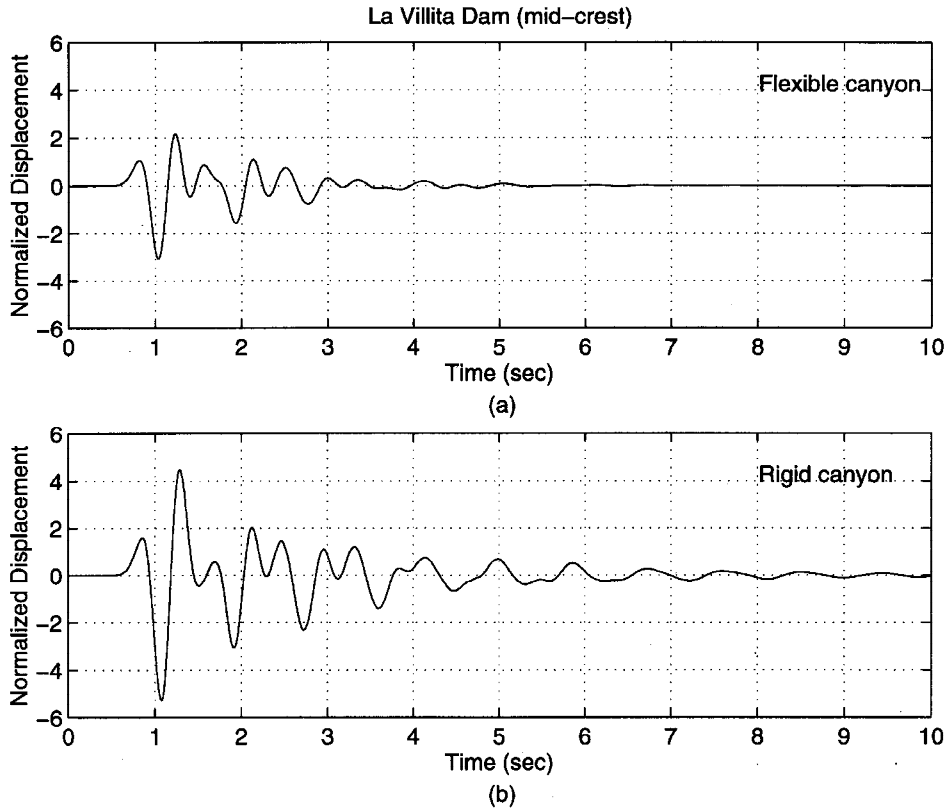

Fig. 2: Normalized mid-crest displacement of La Villita Dam supported on (a) flexible canyon, $v_s = 1000\ m/sec$; (b) rigid canyon, $v_s = 10000\ m/sec$.

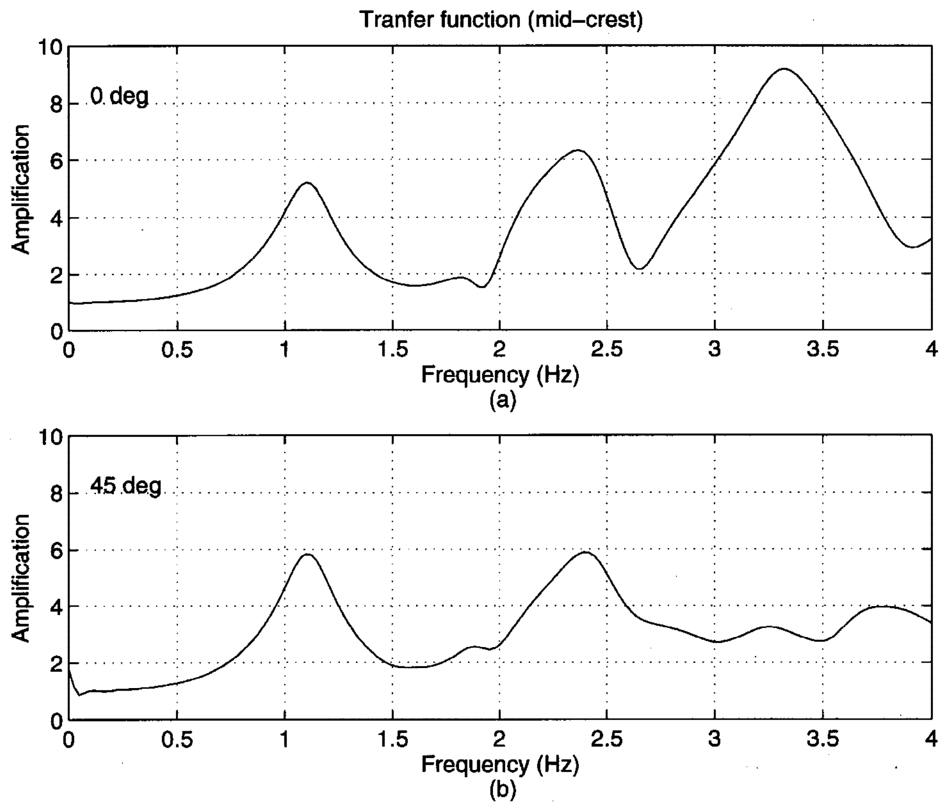

Fig. 3: Transfer function at mid-crest of La Villita Dam supported on a flexible canyon for an incident SH wave angle of (a) 0^0; (b) 45^0.