DYNAMIC BEHAVIOR OF ROCKFILL AND EARTH DAMS STUDIED ON ELASTIC MODELS

by

G. Oberti [I], A. Castoldi [II], M. Casirati [III]

SYNOPSIS

Small rockfill and earth dam models, made of materials with a very low Young's modulus, have been tested on an electrodynamic shaking table. Various types of models were tested, reproducing dams with and without a core, having different span-to-height ratios and located in valleys of various shapes. The dynamic behavior in the elastic range has been determined by means of a number of accelerometers applied at the surface and inside the models. The dynamic response, resonance frequencies and mode shapes have been obtained, and the pattern of the distribution of the inertia forces in the three-dimensional structure of the dam has been determined.

FOREWORD

The damages caused by earthquakes to rockfill and earth dams are numerous and serious, and also recently there occurred various cases of disaster (1). The knowledge of the dynamic behavior of these structures is, therefore, of great importance, especially when considering that very high dams with steep slopes are at present under construction. The problem, however, is a very difficult one as these dams are three-dimensional, anisotropic and non-homogeneous structures that are subjected to complex and not yet clarified phenomena (pore pressure), and has not yet been solved. The design in many cases is, therefore, based on empirical systems or highly simplified theoretical analyses which are limited to a more or less complete treatment of the elastic aspect of the two-dimensional problem (2), (3), (4). On the other hand, a model study can supply the exact elastic response to the three-dimensional problem and thus permits to appraise the maximum value and the distribution of the forces of inertia acting on the structure owing to an assigned earthquake. The test technique described below has been set up in order to evaluate these forces of inertia on various types of dams.

TESTED MODELS AND EXPERIMENTAL EQUIPMENT

The following five models have been tested (fig. 1):

[I] Guido Oberti, Technical adviser, Experimental Institute for Models and Structures (ISMES), Bergamo, Italy.

[II] Aldo Castoldi, Manager Dynamic Department, ISMES.

[III] Mario Casirati, Dynamic Department, ISMES.

- with free lateral walls and no core (model 1);
- with rigid lateral walls and no core, rectangular (model 2) and triangular (model 4) valley cross-section;
- with rigid lateral walls and a core, rectangular (model 3) and triangular (model 5) valley cross-section.

Young's modulus of the material used for the body of the dam (cold cured silicone rubber) is about 10 Kg cm^{-2}, while that of the core (fish glue and glycerine) is about 1 Kg cm^{-2}. The behavior of these materials, within the limits of the strains induced during the tests, was of the linear elastic type. In the adopted scheme there is no possibility of mutual sliding and separation of the core-rockfill contact surfaces. For all the five models, the foundation has, for simplicity's sake, been assumed to be rigid. It is, however, possible to study models on elastic foundations of various types, due also to the fact that, by adequately modifying the composition of the used materials, it is possible to obtain a sufficiently large range of values of Young's modulus.

The models were fastened to a shaking table consisting of an aluminium slab floating on a film of oil. The slab is actuated by two electrodynamic exciters which impress to it a sinusoidal, random or earthquake, horizontal motion (5). The motion of the table is controlled electronically both in amplitude and frequency. In particular, a reverse feedback system prevents the variations ofthe mechanical impedance of the slab-model system from changing the pre-established excitation value. In the case under examination, the models were excited with a sinusoidal motion of constant amplitude and a frequency that changed very slowly with time. The response was measured by piezoelectric accelerometers embedded in the body of the model both horizontally and vertically. The connection cable could move freely inside the dam without interfering with it. The response (frequency, amplitude, phase) was registered automatically for each point. The various models tested were obtained through a successive modification of only two initial models; this was done in order to have homogeneous results which could more easily be compared with one another. The total number of the tests was ten (five with horizontal accelerometers and five with vertical ones).

TEST RESULTS

The results show that the elastic behavior of the tested structures is quite complicated, indicating the presence of vibratory phenomena caused not only by shearing action but also by flexural, rocking and vertical effects. In fact, a great number of resonances is obtained in a rather restricted interval of frequencies associated with accelerations having both a horizontal and a vertical component (fig. 2). The horizontal component is in some cases smaller than the vertical one, especially for the higher frequencies and the lower gage points (fig. 3). Moreover, it is not constant for points located at the same elevation, but diminishes in passing from the internal points to those situated along the slope (fig. 4). This is of importance as the stability of the slope is one of the basic criteria for judging the behavior of the dam.

Comparing the test results obtained from model no. 1, which can be assumed as "two-dimensional", with those of a one-dimensional calculation and a two-dimensional calculation by the finite element method (4), it can be seen that, while the former proves to be absolutely inadequate (fig. 5), the latter furnishes closely coinciding results, especially as regards the resonance frequencies. However, the schematization of the two-dimensional problem proves also to be too simplified for reliably describing the real behavior of the three-dimensional system. In fact, one can clearly see the influence exerted by the lateral restraint conditions, even when the span-to-height ratio is not too small, as is the case of model no. 2. In fact, the resonance frequencies are higher and the amplitudes of the induced acceleration are lower (fig. 2b). Similarly, the influence of the shape of the cross-section of the valley is very considerable (fig. 2c). It can analytically be taken into account only by drastically simplifying the shape of the cross-section itself.

Finally, it should be pointed out that the adopted method permits to show and evaluate quantitatively the considerable difference in behavior caused by the presence of the core as regards both the natural frequencies (which are lowered, fig.2c) and the distribution of the accelerations (fig. 6).

ACKNOWLEDGMENT

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MODELS TESTED: DIMENSIONS IN mm

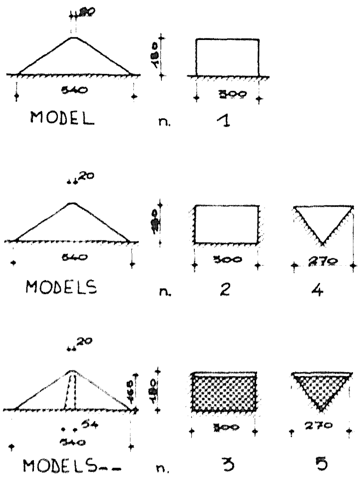

FIG. 1

RESONANCE ACCELERATION PATTERNS

- STATIONARY INPUT MOTION $\ddot{y} = \ddot{y}_0 \sin 2\pi f t$ -

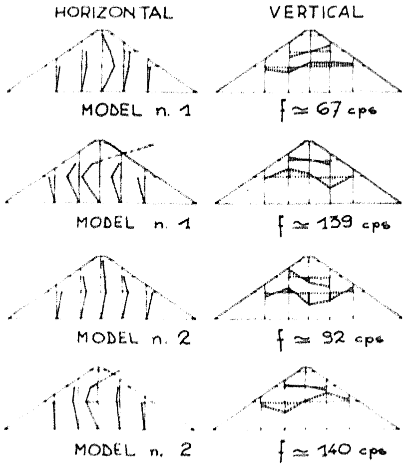

FIG. 3

COMPARISON BETWEEN THEORETICAL AND EXPERIMENTAL RESULTS

MODEL n.	MODE	FREQUENCY RESONANCE VALUES SHEAR METHOD	EXPERIMENTAL
1	1	35,78 cps	35,4 cps
	2	82,05	54,0
	3	128,64	66,5
	4	177,95	80,5
2	1	46,08	45,3
	2	87,06	89,6
	3	131,89	93,0
	4	190,81	118,0
3	1	43,73	43,0
	2	82,82	65,0
	3	125,16	75,4
	4	171,11	82,0

FIG. 5

ACCELERATION RESPONSE CURVES FOR STATIONARY INPUT MOTION $\ddot{y} = \ddot{y}_0 \sin 2\pi f t$

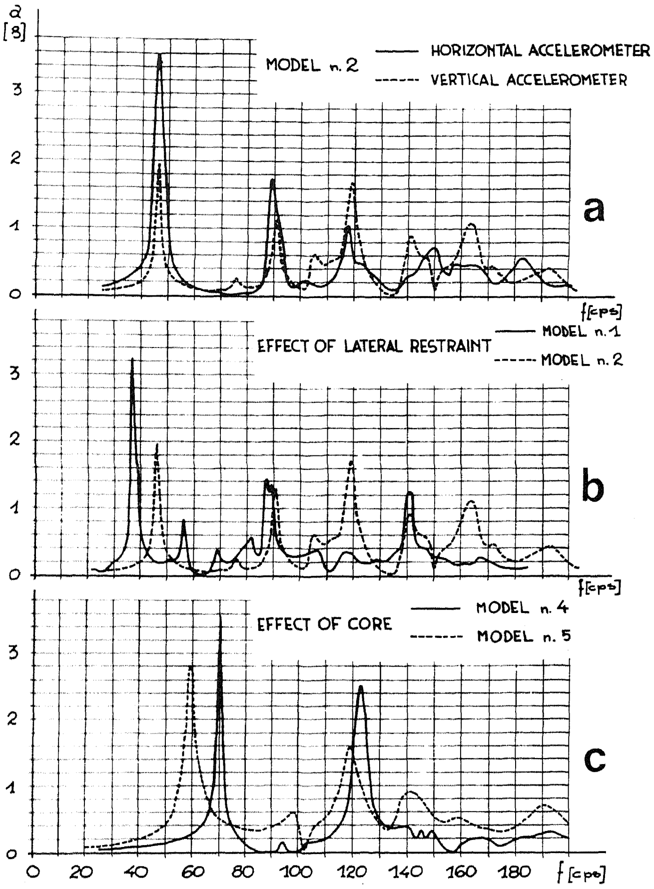

FIG. 2

HORIZONTAL RESONANCE ACCELERATION PATTERNS

- STATIONARY INPUT MOTION $\ddot{y} = \ddot{y}_0 \sin 2\pi f t$ -

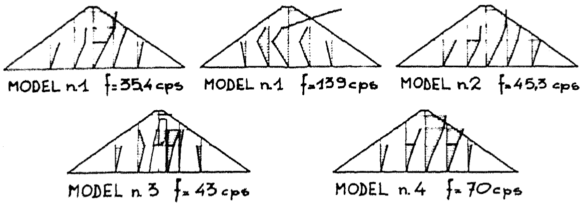

FIG. 4

EFFECT OF CORE ON ACCELERATION PATTERN

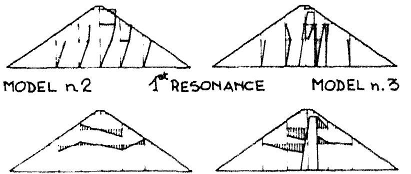

FIG. 6