FORCED VIBRATION FULL-SCALE TESTS ON EARTH-FILL AND ROCK-FILL DAMS

by

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SYNOPSIS

The influence of several factors which effect the evaluation of the dynamic characteristics of earth and rock-fill dams is discussed. The principles and procedure of full-scale forced-vibration studies of such structures are presented.

Experimental results of dynamic tests carried out on two earth-fill and two rock-fill dams are also included.

INTRODUCTION

The earthquake resistant design of dams is of extreme importance due to the devastating consequences of the failure of dams under seismic forces. Unfortunately, the dynamic characteristics as influenced by the foundation, the vertical acceleration, the reservoir, the pore pressure changes and the amplitude of the structural displacements on the dynamic response are complex and difficult to be analysed accurately.

It is generally agreed that dams should be designed and constructed to withstand moderate to large earthquakes without damage. Hence, the analysis considers the linear elastic response of the structure. Complete knowledge of the dam-foundation system and the correct mathematical representation of the same is a primary requirement for prediction of the dynamic properties. The earthquake response of earth dams, without the reservoir, have been analysed satisfactorily by representing the dam as a two-dimensional truncated shear wedge with rectangular boundaries (1,4) or trapezoidal boundaries (8) also by means of finite element procedure (2). However, the analytical procedures available at present are inadequate for accurate prediction of the dynamic characteristics of a dam when coupling effect of dam, foundation and reservoir is presented. There are indications that the coupling effect of reservoir and earth-fill dams is small but there is a considerable effect of the dam-foundation interaction.

Though the accuracyin evaluating the response has undoubtedly been improved through the use of computers and the possibilities of a more accurate formulation of the structal mathematical model, experimental data are urgently needed. Experimental studies will provide the necessary information to

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determine the accuracy of the assumptions which are used to formulate the mathematical model. The information that has been accumulated is obtained by structural model tests (6), vibration measurements on dams and abutments during earthquakes (5) and vibration measurements on dams subjected to exciting forces produced by proximity blasting (10) or by vibration generators (18,9). Considering the complexity of several factors influencing the response of dams, it is obvious that the prototype studies will yield the information necessary to formulate an accurate mathematical model of the dam, the foundation and the reservoir. At present, only forced vibration studies using vibration generators will provide this information.

FORCED VIBRATION STUDIES

The exciters used in forced vibration studies at the Institute of Earthquake Engineering and Engineering Seismology,Skopje,Yugoslavia are,like several vibration generators built in the last several years, of the two-mass,counter-rotating, excentric-weight type (3). The weights rotate in horizontal planes about the same vertical shaft. By means of this equipment, sinusoidally varying forces can be applied to the structure along a predetermined axis. As baskets containing the weights rotate in opposite directions, maximum forces are attained twice each cycle when the baskets pass one another. When the baskets are 90° to the force axis, the centrifugal forces are opposed, and thus no resultant force is produced. In general, two of such generators are used in these studies. Each shaker is designed to generate a maximum force equal to 5 kips (5000 pounds). However, during tests, this load limit can only be attained for a limited number of shaker speeds. At other speeds,for instance, with frequency range of 2.5 to 8 cycles per second, the applied forces vary between 3 and 5 kips, depending on the weights placed into the baskets.

To obtain information on the dynamic properties of a dam, the response of the dam is measured under steady-state force vibrations. Natural frequencies and damping coefficients are determined by measuring the response of the dam over a range of forced vibration frequencies extending from 1 to 9 cycles per second. The response is commonly recorded by observing the signal derived from several accelerometers (maximum 0.25 g). By using two generators on the crest, symmetrically placed with respect to the center of the dam, mode shapes for the crest,for several up-stream and down-stream berms as well as several for vertical sections can be determined for each of the natural frequencies. To determine these mode shapes the response of the dam at a number of predetermined locations is recorded while being subjected to force vibrations excitation frequencies corresponding to the natural frequencies. By using two generators with in-phase forcing conditions the mode shapes associated with the odd-numbered natural frequencies can be excited. Through an 180° out-of -phase forcing condition the even-numbered mode shapes can be developed most accurately. For example, to find the horizontal and vertical mode shapes for the first mode, measurements related to the deflections of the dam are normally recorded as a function of time while the crest of the dam is being subjected to known sinusoidally varying exciting forces applied at the resonant frequency found for the first mode.

EXPERIMENTAL RESULTS

The correct evaluation of the influence of several factors mentioned above is particularly important for earth and rock-fill dams. Hence, recent force-vibration studies in Yugoslavia have been carried out on two earth-fill and two rock-fill dams, subsequently numbered as follow:

Dam No.1 (Fig 1) is an earth-fill dam with a central clay core 56 m high, 215 m long on the crest and 286 m thick at the base, having average slopes of 1:2.50 and 1:2.86 downstream and upstream respectively . It is constructed in a canyon of assymetric section, formed in diabase. Tectonically, this rock mass is much weathered and has an extensively cracked surface. The river bed is covered by deposits, but as of relatively small thickness, they were included in the body of the dam.

Dam No.2 (Fig.2) is a gravel-fill dam with an inclined clay core 112 m high and 330 m long on the crest, having both slopes of 1:2. The protection of the slopes has been ensured by using rock-fill the thickness of which on the upstream side is 2.5 m and on the downstream side only 1.5 m. The dam is constructed on river sediments of 12 m thickness.

Dam No.3 (Fig.3) is a rock-fill dam with a rather thin central clay core. Amphibolite-chlorite schists are used for the rock-fill. It is a structure 113.50 m high and 338 m long on the crest, having average slopes of 1:1.6 in both upstream and downstream sides. The dam is constructed in a canyon of assymetric section with a very complicated geology. The river bed is covered by deposits with an average thickness of 7 m and they are included in the dam body.

Dam No.4 (Fig.4) is a rock-fill type of dam with a thick clay core and wide transition zones. The dam is constructed on alluvial deposits, impermeability of which is obtained by means of thick grout curtain executed from three grouting galleries below the clay core. It is a structure 90 m high, 196 m long on the crest and about 320 m thick at the base, having average slopes of 1:1.6 in both sides. The dam site underwent considerable tectonic movements so that systems of fissures and cracks are highly pronounced as well as the rock mass permeability.

The recorded natural frequencies and corresponding damping coefficients for all four dams in numerical order are presented in Table 1. In all cases there were observed several symmetric horizontal mode shapes and only the first assymetric. Some horizontal mode shapes of the dam No.4 are presented in Fig.5. However, the vertical mode shapes are very similar to the fundamental modes of a shear cantilever beam with varyable cross section.

The dam No.3 studies were carried out in two stages with a variation of the reservoir water level of about 10 meters. In that case there was an evidence of dam-reservoir interaction causing to drop down the first natural frequency for about 2% (8). In order to evaluate this kind of interaction tests should be repeated in the near future with different reservoir water levels.

CONCLUSIONS

Results from the force vibration studies on prototype structures have been recorgnized as the most accurate data which can be obtained for correct studies between experimental and analytical results. Consequently, more accurate formulations of the mathematical computer model of a structure can be achieved. The complexity of the factors influencing the dynamic characteristics of dams make the force vibration studies on dams particularly important. These studies are basically essential to evaluate the design procedures for dams located in seismic regions.

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Tabl. No 1

NAME OF DAM	RESONANCE FREQUECY / PERCENTAGE OF CRITICAL DAMPING				
1	2	3	4	5	6
DAM No 1	2.80	3.50	4.50	5.80	6.15
	2.70 - 6.90	3.90 - 4.15	4.08 - 7.65	5.35	5.85
DAM No 2	2.25	2.68	4.03	4.58	5.70
	4.45 - 8.60	3.18	2.98 - 4.43	—	—
DAM No 3	2.06	2.83	3.45	4.58	5.07
	3.60 - 4.50	—	3.50	—	3.60
DAM No 4	2.55	3.27	4.30	5.40	6.38
	4.12 - 4.90	2.90	4.40 — 4.75	—	—

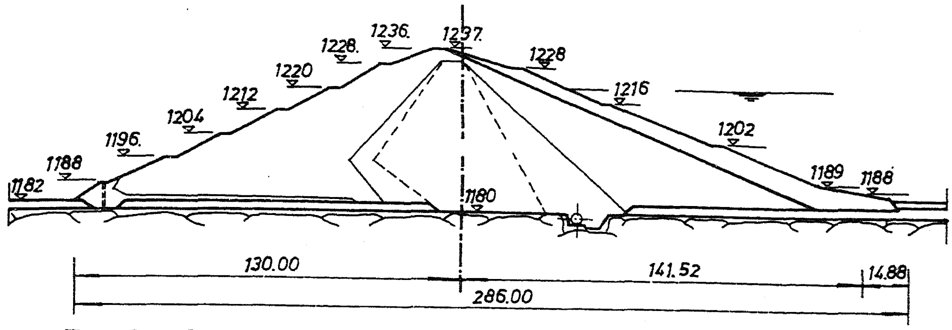

Fig. 1. Cross-section of Dam No 1 through river bed.

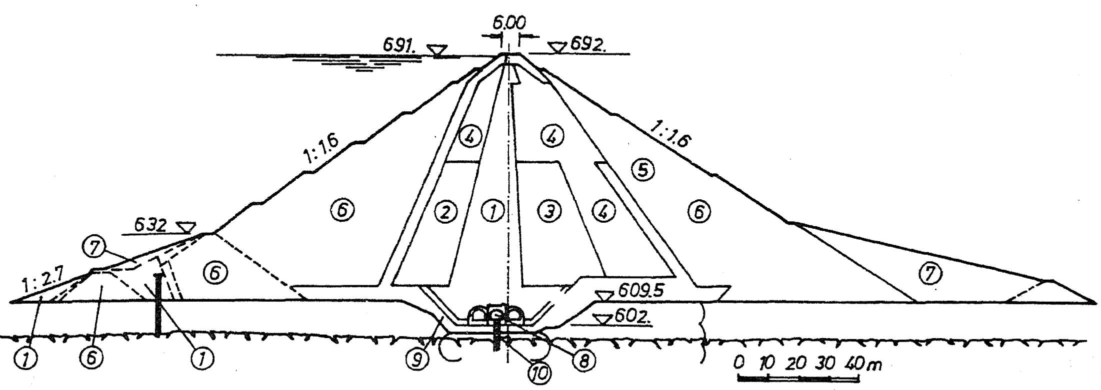

Fig. 2. Cross-section of Dam No 2 through river bed.

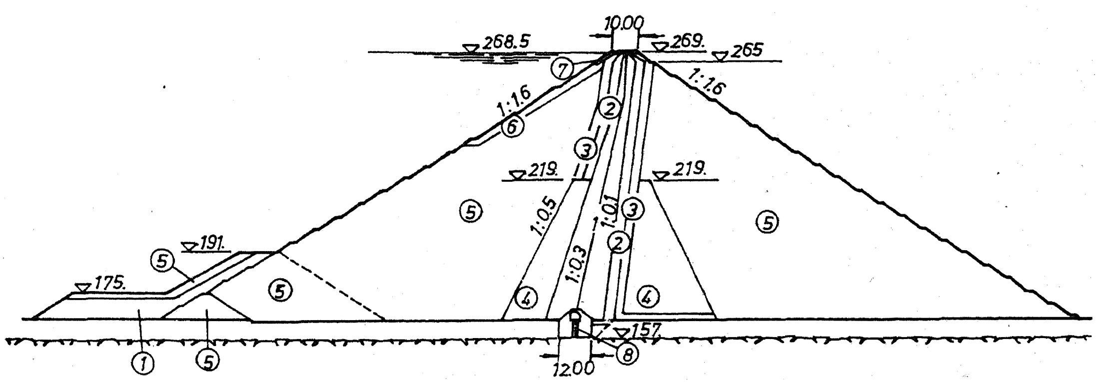

Fig. 3. Cross-section of Dam No 3 through river bed.

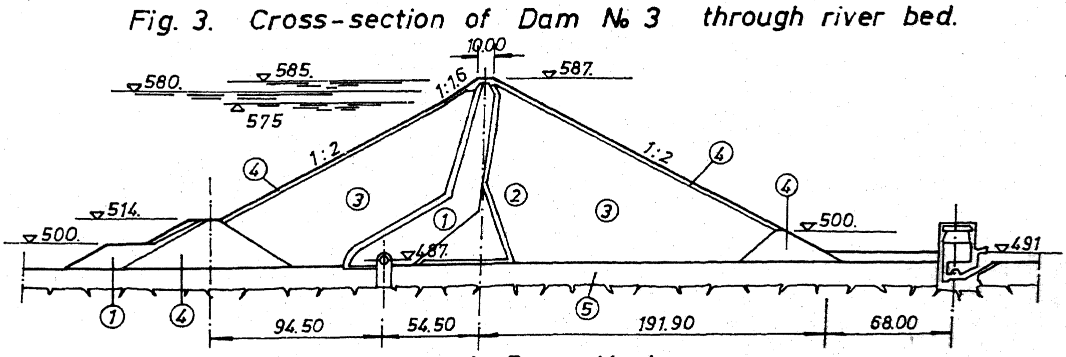

Fig. 4. Cross-section of Dam No 4

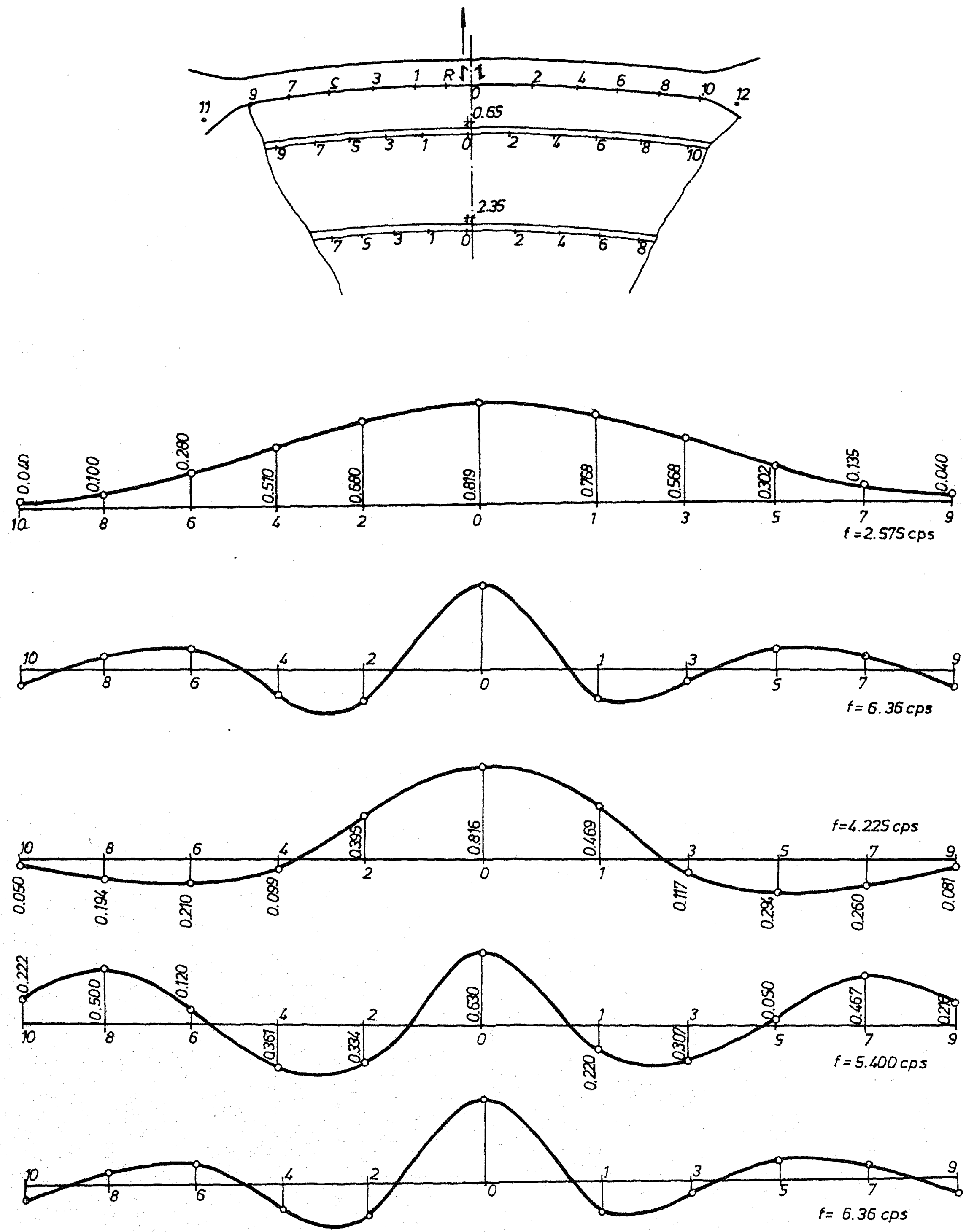

Fig. 5 Horizontal mode shapes of the Dam No 4