SPATIAL VIBRATION STUDY OF AN EARTH DAM

by

G.S.Seleznyov[I] and Kh.Sh.Abduraufov[II]

The results of spatial vibration experimental study of an earth dam are presented in this paper. The peculiarities of the dam dynamics are studied under harmonic impacts on a physical model. Seven modes of natural vibrations which are in a good accordance with the shear wedge solutions are found.

The Nurek hydroelectrical power plant is in the process of construction on the Vakhsh river in the Tajik SSR in the zone of high seismicity. According to the project the earth dam of the power plant will be 300m high and form the reservoir with the volume of 10.5 milliard cubic metres. The unique character of the construction required the detailed study and thorough analyses of the dam seismic resistance what is an important element of a power plant.

A great complex of prospecting, experimental and analytical investigations has been conducted by different institutions of the USSR for grounding the seismic resistancy of the Nurek earth dam. The seismic resistance analysis of the dam was carried out on plane mathematic models - the existing analytical methods are based on consideration of plane, two-dimensional structural design schemes that doesn't give a full picture of a structural behaviour under seismic effects.

The construction studied, the earth dam, has the sizes commensurable in three directions, a seismic effect is also of a three dimensional character. It requires treatment of versatile boundary tasks of the elasticity theory, the solution of which faces certain difficulties.

For the solution of complicated problems in the engineering practice one usually resorts to model tests which are often the only opportunity to study one or another phenomenon. We have chosen the way of model tests for the specification of the dynamical behaviour of an earth dam located in a rigid undeformed canyon with the different directions of an excitation vector.

The peculiarities of dam dynamics are studied on the physical model with the scale of 1/280 (the height of the model is 115cm) using a shaking table with the harmonic impacts. Thus, the following tasks are solved:

1. Experimental determination of the periods and shape modes of natural vibrations, damping coefficients of the volume dam model during the shaking table

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[I,II] Scientific workers of the Institute for Seismic Resistant Construction and Seismology (ISRCS) of the Academy of Sciences of the Tajik SSR, Dushanbe, the USSR.

vibrations both in horizontal (along and across the canyon) and vertical directions.

2. Determination of directions of the dam model vibration vector with the different directions of the exciting load vector.

The most widely used research method of structural dynamical characteristics is testing under harmonic vibrations. These vibrations are excited with smooth modifications of frequencies which envelope the spectrum of natural vibrations of the construction studied. The study was conducted on the shaking table with the dimensions in plan of 6.0 by $3.5m^2$ and the range of obtained frequencies from 5 to 40Hz [1].

The model was constructed in a tray installed at the shaking table. The details of the canyon were modelled by a layer of concrete. The general view of the model is shown in Figure 1. A low-modulus material on the basis of rubber chipplings was used as the body material. It has the following characteristics of physics and mechanics: the volumetrical weight of $0.34t/m^3$; the Poisson ratio of 0.45; the elasticity modulus of $4.5 \cdot 10^5$Pa; shear and longitudinal wave propagation velocity $V_p = 36m/s$ and $V_s = 21m/s$, correspondingly.

Four measuring points were placed along the height of the model. The recording of the displasement vector was conducted at every point. For this purpose the seismic detectors CГ 1-10 and CB 1-10 with the 5Hz galvanometres installed in the magnetic block of the oscillograph H-700 [2] were used.

The shaking table is put into vibration by a vibrator. The rotation of the vibrator and flexible props of the table provides translational movement along one of the axes. When the table vibrates in the fixed direction, the dam body produces spatial vibrations which are determined by the displacement vector. The latter represents the geometrical sum of the components (projections) along the axes ox, oy and oz.

$$U = \sqrt{U_x^2 + U_y^2 + U_z^2} \qquad (1)$$

The response characteristics are given in Figure 2, in addition the model was aternatively excited in one of the directions: along and across the dam and vertically. The analysis of the experimental data allowed to fix three shape modes of vibrations in the lateral direction (along the ox), two shape modes in the longitudinal direction (along the oy), two shape modes in the vertical direction (along the oz). The mentioned values of natural frequencies of the dam model are given in Table 1. The shape modes of natural vibrations are given in Figure 3.

Table 1.

Shape mode number	α_n	Frequency, Hz		
		f_x	f_y	f_z
1	2.40	9(8.2)	12(10)	11(12.7)
2	5.52	16(18.2)	25(21.6)	28(28.6)
3	8.65	24(28.2)	(33.3)	(45)

As a result of the experiment the coefficients of vibration transmission in the directions were determined. The values of the coefficients depend on the shape mode and the direction of vibrations (Table 2).

Table 2.

Natural frequency, Hz	Transmission coefficient, % Direction		
	x	y	z
9	100	5	12
16	100	8	23
24	100	23	30
12	77	100	14
25	15	100	13
11	0	0	100
28	0	0	100

The data from Table 2 show that the coefficients of vibration transmission are rather insufficient. This indicates that these vibrations separate well. Thus, plane dynamical design schemes can be successfully used in evaluation of the dynamical characteristics of earth dams.

Let us consider some volume, representing the earth dam body. All its three dimensions (the length, width and height) are of one order. The section along the dam is given in Figure 1 (the plane yoz). Vibrations given in this Figure allow to make the following conclusions: vibrations along the axis oy are confined by two edges; oscillations in the direction oz are made difficult due to the earth gravity which presses all the body elements to the base; longitudinal movement along the ox is relatively free.

The solution of the problem given is presented in reference (3) assuming that vibrations are carried out primaraly due to shear strain and they are separated in the directions ox, oy and oz. Hence, movements in each direction are descibed as follows:

$$\mu\left[\frac{\partial^2 U}{\partial z^2} + \frac{1}{z}\frac{\partial U}{\partial z} + \frac{\partial^2 U}{\partial y^2}\right] = \rho\frac{\partial^2 U}{\partial t^2} \quad , \qquad (2)$$

where μ is a shear modulus, ρ is material density. As a result the equation of natural frequencies definition is

$$f_{m,n} = \frac{U}{2\pi H}\sqrt{L_n^2 + L'\left[\frac{m\pi H}{L}\right]^2} \quad , \qquad (3)$$

where H is a dam height; L is a dam length; m,n is an ordinal number of vibrations along the dam in height; V is an elastic wave propogation velocity in the dam body material. At lateral and longitudinal vibrations in equation (3) V_s is used and at vertical vibrations V_p is used. L_n is the Bessel equation root $J_0(L_n) = 0$; $L' = 0$ for a rather extended dam; $L' = 1$ at lateral vibrations; $L' = V_s/V_p$ at longitudinal vibrations; $L' = V_s/V_p$ at vertical vibrations. Design frequencies of model natural vibrations are given, Table 1 (in brackets).

CONCLUSIONS

Analysing the results of the experimental data obtained the following conclusions can be made:

1. From consideration of the response characteristics seven shape modes of the dam model natural frequencies are determined, they have the following values (Hz): $f_1 = 9$; $f_2 = 11$; $f_3 = 12$; $f_4 = 16$; $f_5 = 24$; $f_6 = 25$; $f_7 = 28$.

2. The design frequencies of natural vibrations (the shear wedge) gave the following values (Hz): $f_1 = 8.2$; $f_2 = 10.1$; $f_3 = 12.7$; $f_4 = 18.2$; $f_5 = 21.6$; $f_6 = 28.2$; $f_7 = 28.6$.

3. The comparison of the design and experimental frequencies shows that the model vibrates as a shear wedge.

4. The comparison of the logarithmic decrements of the first shape mode vibrations in three directions received due to the shaking table vibrations and a stroke have satisfactory coinsidence lying in the range of the experimental error.

5. The vibration vectors of the model base have the dominant orientation in the direction of the shaking table vibrations at all the frequencies.

At the model crest the vibration vector has the following directions:

under the lateral impact (along the canyon): 9, 16, 24Hz-lateral; 12, 25Hz - longitudinal; 11, 28 - vertical;

under the longitudinal impact (across the canyon): 9, 16, 24, 28Hz lateral; 12, 25Hz - longitudinal; 11Hz - vertical,;

under the vertical impact: 9Hz - lateral; 16Hz - longitudinal; 11, 12, 24, 25, 28Hz - vertical.

Otherwise, if model base vibrates along the application direction of the exciting load, at the model crest the vibrations in the direction of natural vibrations mainly dominate.

6. The periods of the field natural vibrations of the Nurek dam at $E = 3100 MPa$; $\rho = 2.2 t/m^3$; $\mu = 0.35$ were obtained as following: $T_1 = 1.11s$; $T_2 = 0.89$; $T_3 = 0.82s$; $T_4 = 0.61s$; $T_5 = 0.41s$; $T_6 = 0.739s$; $T_7 = 0.35s$.

Turning to the field study of the full scale dam was carried out on the basis of the correlations in reference 4 .

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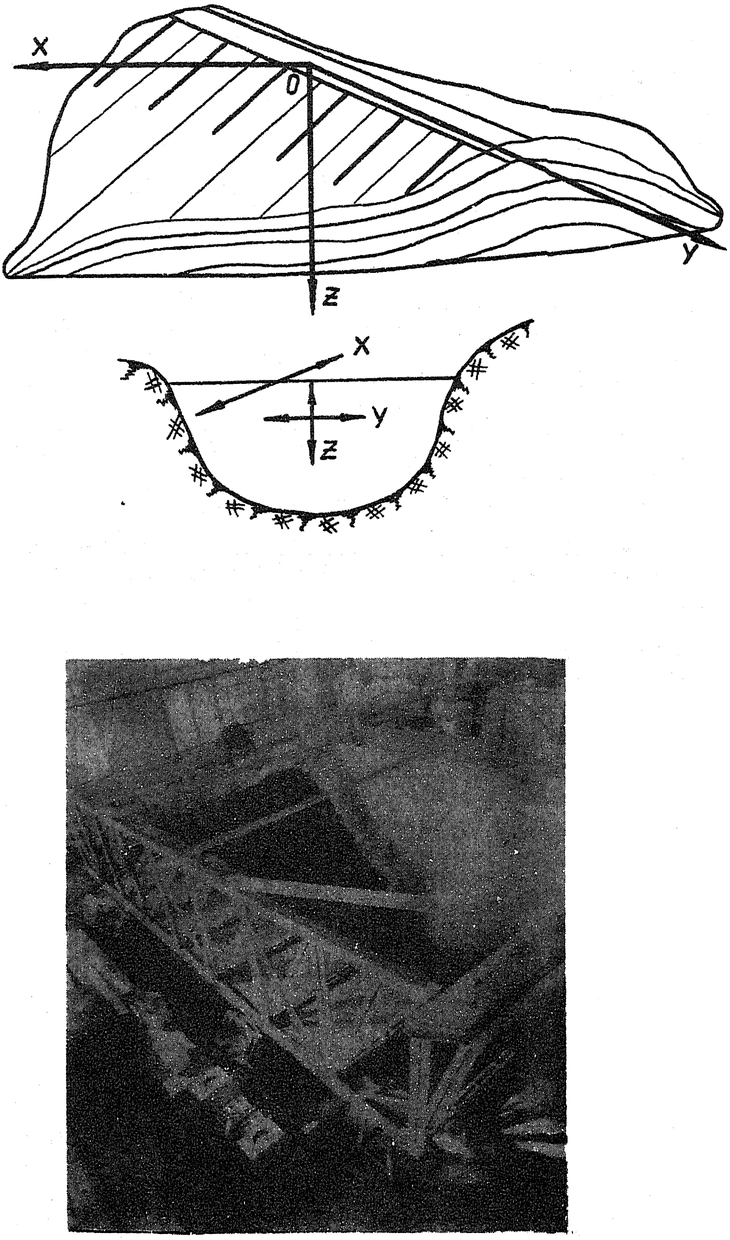

Figure1. Design scheme and general view of model.

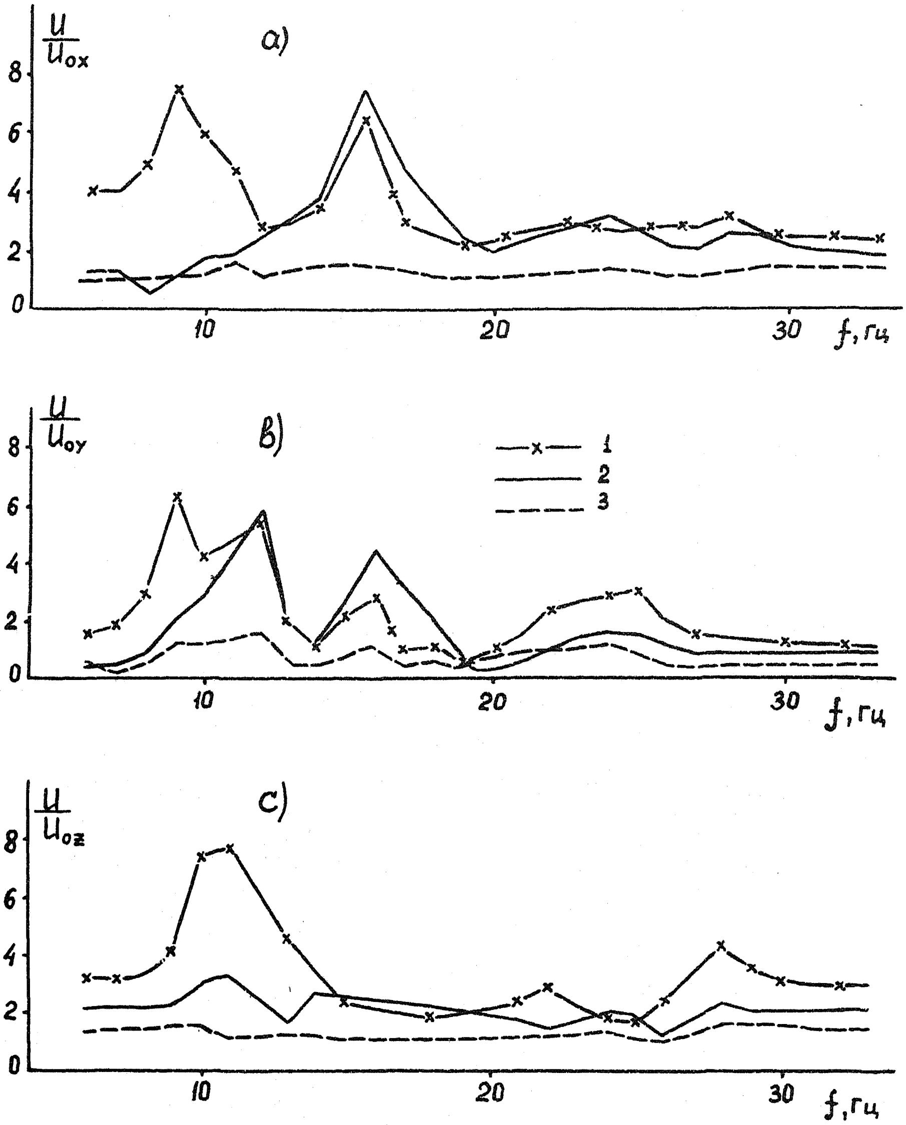

Figure 2. Model frequency characteristics.

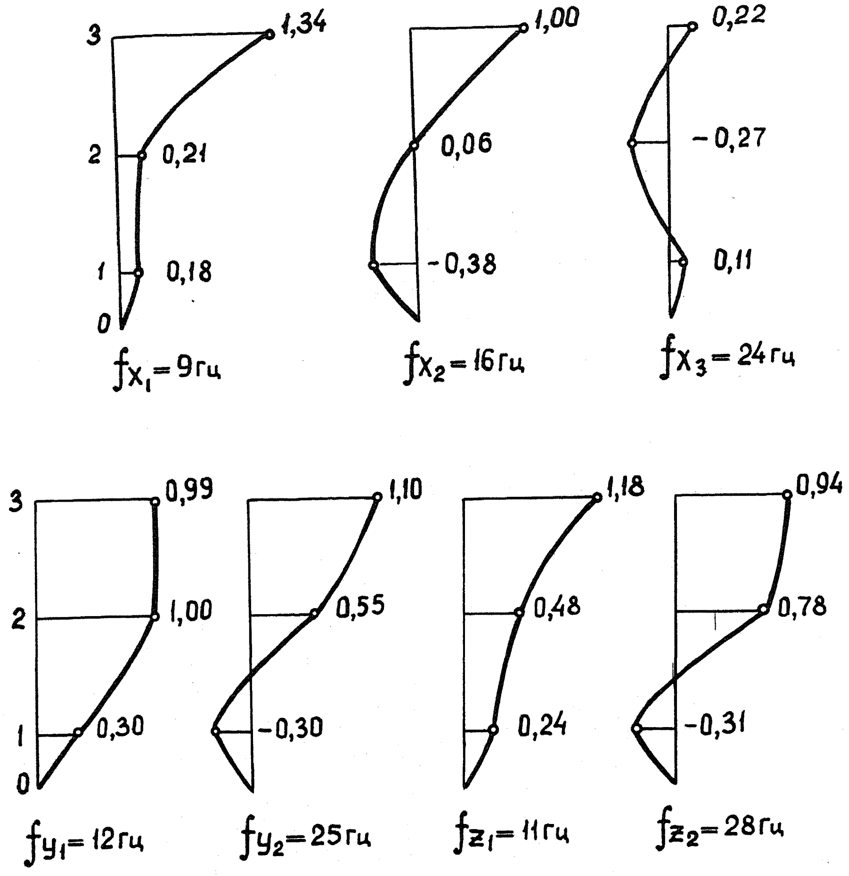

Figure 3. Shape modes of model natural vibrations.