Journal of Theoretical
and Applied Mechanics
Sofia 1993, Year XXIV No 2

EXPERIMENTAL DYNAMIC ANALYSIS OF CHAIRA CONCRETE GRAVITY DAM

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Introduction and objective of the investigation

The concrete walls of big dams are large spatial structures, whose analyses are performed by mathematical models. These models have to be accurately formulated though they treat reality in an idealized way. To verify the reliability of mathematical models, detailed in-situ tests have to be carried out to determine the desired dynamic characteristics of the structure. The main objective of the conducted experiment is the evaluation of the dynamic properties (natural frequencies, vibration mode shapes, damping capacity and amplification functions between different levels and relative to the structure's base and ground surface) of the Chaira concrete gravity wall. These provide important data for assessment, correction and adjustment of the mathematical models, applied for seismic stability analysis. This investigation is a part of the programme of the World Bank for evaluation of the seismic risk for Chaira concrete gravity dam.

Description of the dam

Chaira dam is a concrete gravity dam situated in the Eastern part of the Rila Mountain and it is a part of the PAWPP "Chaira". Its wall consists of twelve blocks. The crest is linear with total length of 305 m (Fig. 1.a). Thickness varies from 6 m at the crest to almost 63 m at the base. The maximum height of the wall is about 85 m. The cross section consists of rectangular and trapezium-shaped blocks, connected with an intermediate curvilinear section (Fig. 1.b). At several levels are constructed horizontal galleries.

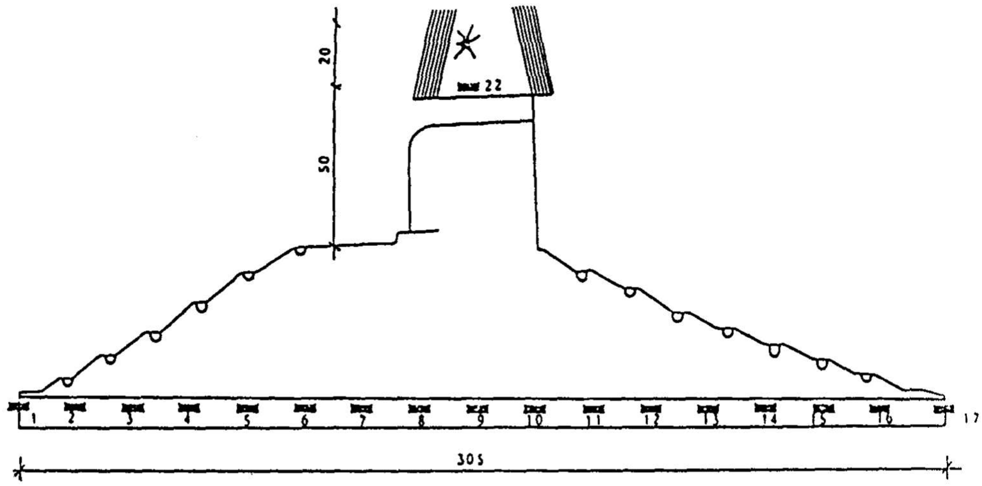

Fig. 1a

Measuring system

The "OYO" system "McSeis 1500" is used in this investigation. This system consists of four units (Seismic Amplifier, Signal Enhancement, Display and Processing Units) and 24 seismometers. All records can be stored in a digital form on a floppy disk, ready for further computer processing. In this investigation there have been used seismometers type "VEGIK", with a sensitivity of 20 Vs/m and an amplitude range from 0.0001 mm to 2 mm for frequencies between 1 Hz and 100 Hz, and type "SM-2", with a sensitivity 39 Vs/m and range from 0.0001 mm to 3 mm for frequencies 0.7 Hz - 200 Hz.

Experimental procedure

Detailed explanation of the experimental procedure may be found in [1]. The processing and analysis of the experimental data is carried out by the original program package PEDA (Package for Processing of Experimental Data and Analysis) that comprises: elimination of the trend; zero padding; windowing for solution of the leakage problem; filtering in the frequency domain; Inverse and Direct Fourier transform; correction with the Spectral coefficients of the respective channels; computation of the Amplitude, Phase and Amplification Spectra and modes extraction.

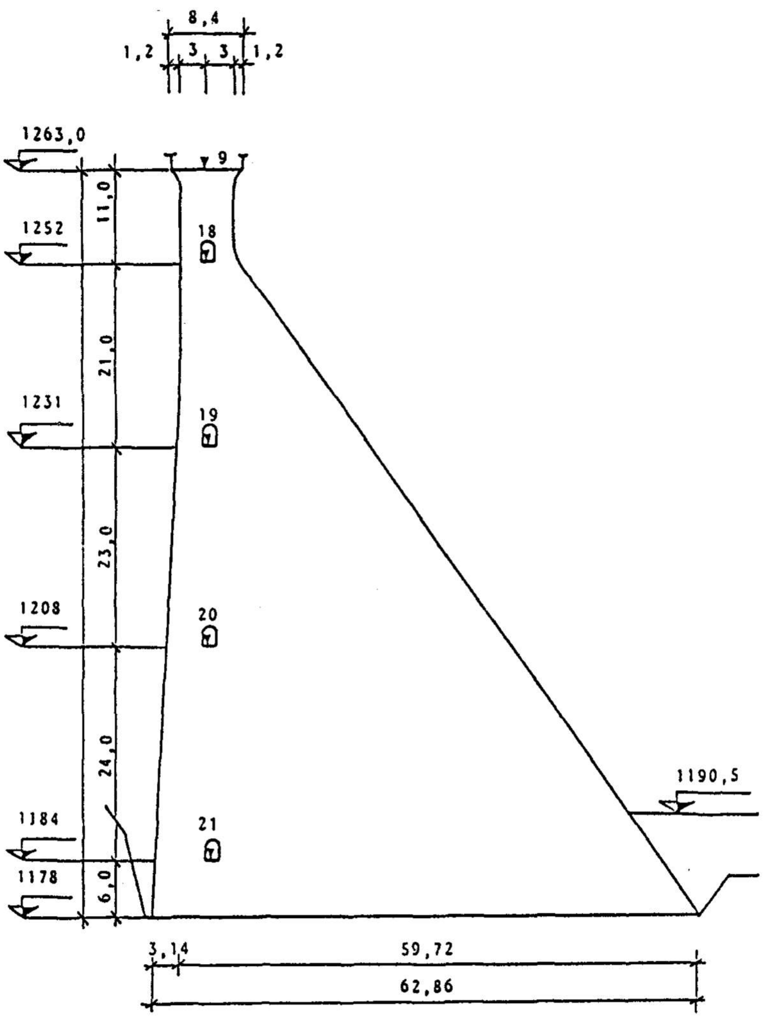

Fig. 1b

Analysis of data

The identification of the natural frequencies is carried out by analysis of the Amplitude, Phase and Amplification Spectra. The "j"-th mode shape coefficient at recording coordinate "i" is

(1) $$a_{ij} = \frac{|X_i(f_j)|}{|X_r(f_j)|} \cdot C_{ir}(f_j),$$

where $|X_i(f_j)|$ and $|X_r(f_j)|$ are the magnitudes of the Amplitude Fourier Spectra of the recorded signals at coordinates "i" and "r" for natural frequency f_j. C_{ir} is the corrective spectral factor that provides for the compatibility of all records. The relative phase of the complex product $X_i(f_j)$ and $X_r(f_j)$ gives the mode shape direction. Damping estimates are obtained by the half bandwidth method for the Amplitude Spectrum peak, corresponding to the modal frequency of interest.

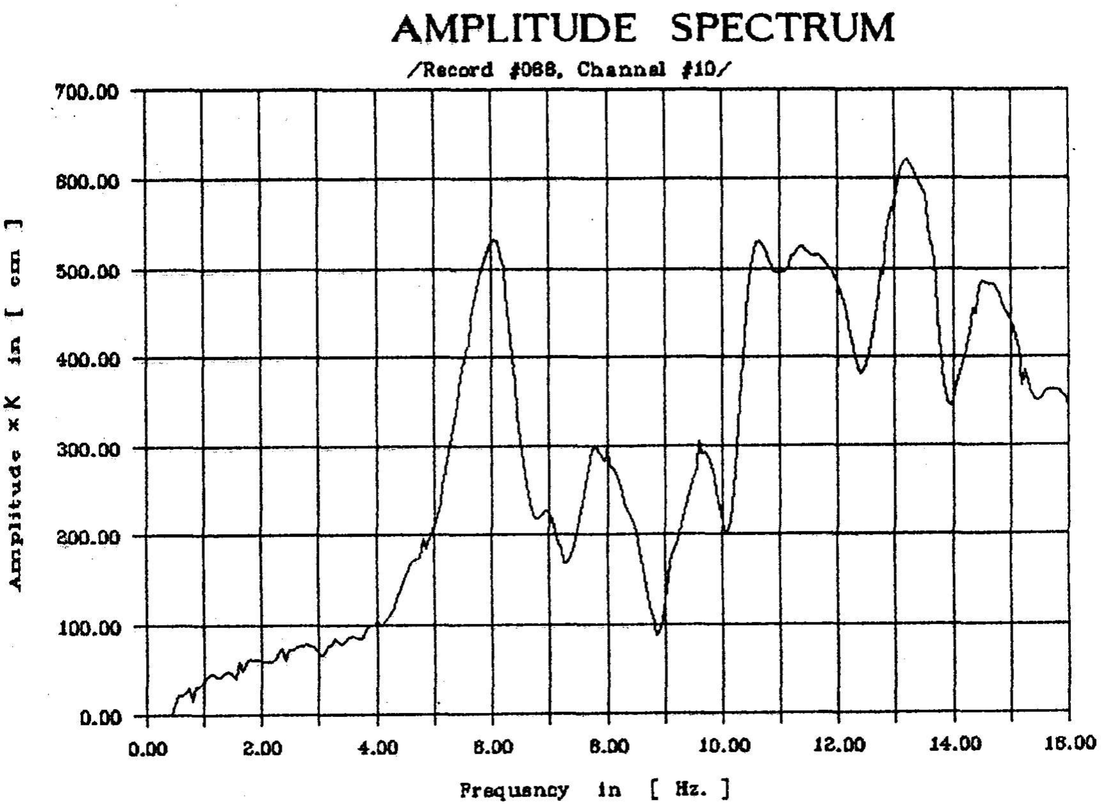

Fig. 2

Application of experimental results

The experimental results can be used for correction and adjustment of the mathematical models, depending on the type of structure whose response has been analyzed. There are two possible approaches – correction of the mass or of the stiffness characteristics of the relevant model. The equation for free undamped vibrations of a many degree of freedom system is

$$(2) \qquad [m]\{\ddot{x}\} + [k]\{x\} = 0,$$

$[m]$ and $[k]$ are mass and stiffness matrices of order $n \times n$, where n is the number of degrees of freedom of the model, while $\{\ddot{x}\}$ and $\{x\}$ are the vectors of acceleration and displacement. Equation (2) may be written in normal coordinates as follows

$$(3) \qquad y_i + \frac{K_i}{M_i} \cdot y_i = 0, \qquad i = 1, 2, \ldots, n.$$

$$(4) \qquad \frac{K_i}{M_i} = \Theta_i^2.$$

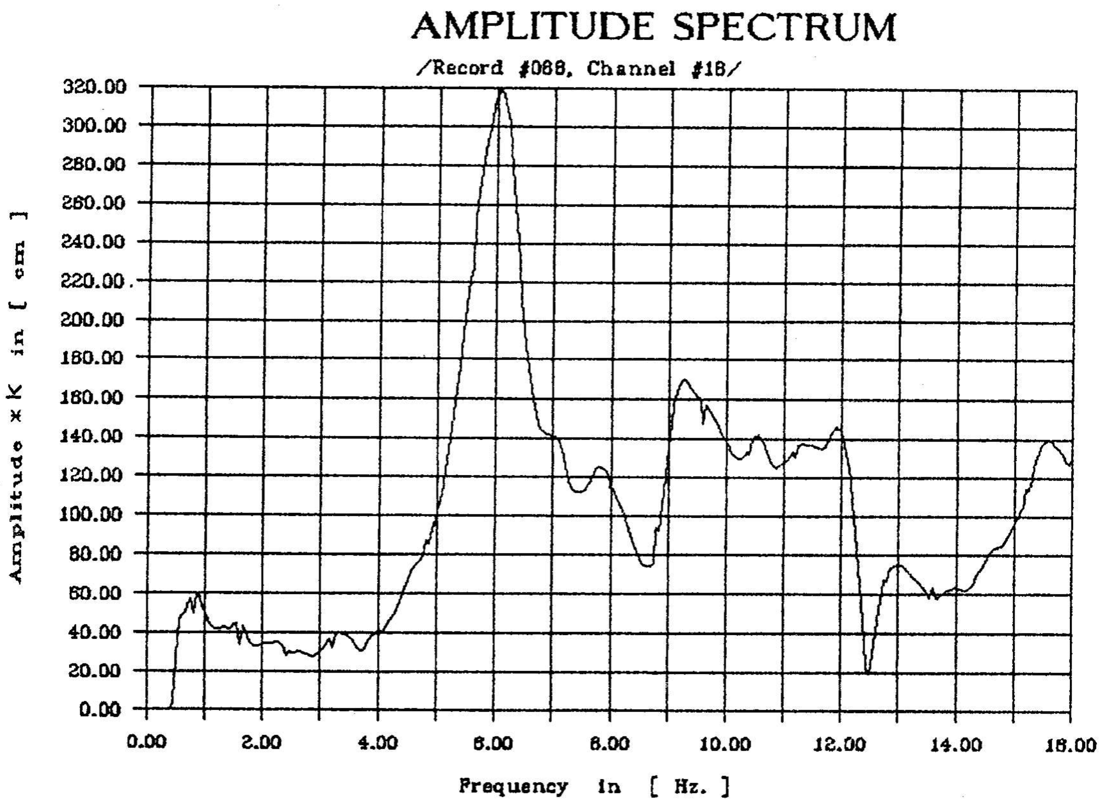

Fig. 3

Θ_i is the "i"-th natural frequency (rad/s). K_i or M_i can be evaluated by equation (4). They are the non-zero elements of the diagonal matrices $[K^*]$ and $[M^*]$, obtained by matrix multiplication, i.e.

$$[K^*] = [A]^T \cdot [k] \cdot [A] \tag{5}$$

$$[M^*] = [A]^T \cdot [m] \cdot [A], \tag{6}$$

where [A] is a matrix of the normal modes of order nxn.
Equations (4), (5) and (6) give the possibility for a correction of the stiffness or mass characteristics of the models given, the experimentally determined frequencies and modes of free vibration of the structure have already been identified.

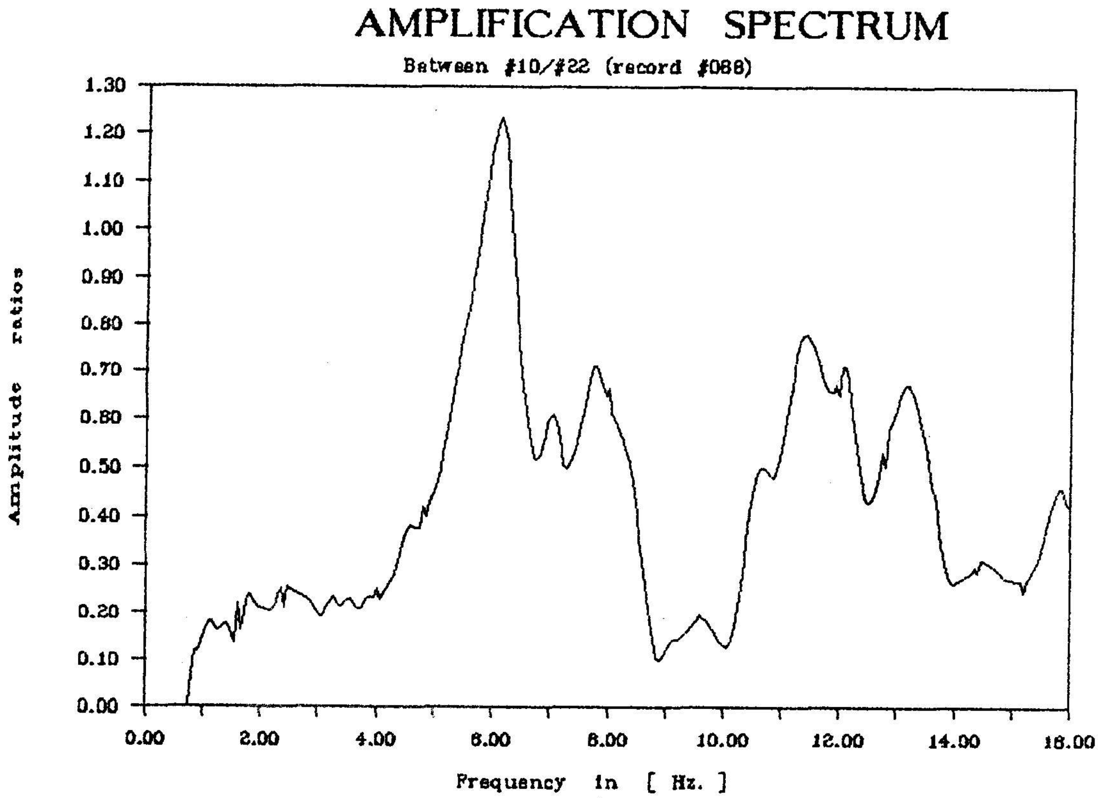

Fig. 4

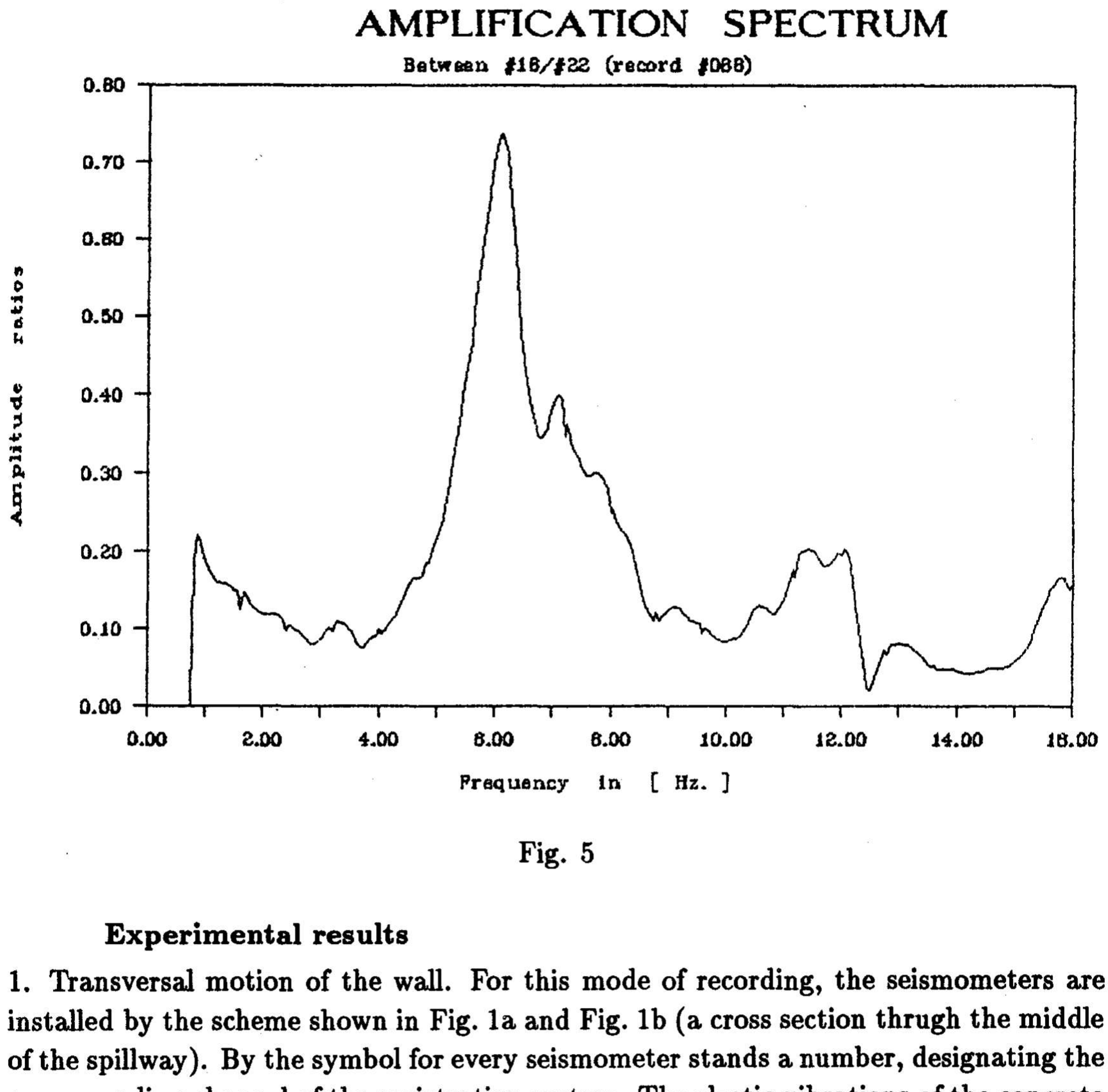

Fig. 5

Experimental results

1. Transversal motion of the wall. For this mode of recording, the seismometers are installed by the scheme shown in Fig. 1a and Fig. 1b (a cross section thrugh the middle of the spillway). By the symbol for every seismometer stands a number, designating the corresponding channel of the registration system. The elastic vibrations of the concrete wall are excited by blasts in a borehole at varied depth 24-27 m and a distance of 70 m from the foot of the wall. As an illustration, in Fig. 2 and Fig. 3 are given the Fourier Amplitude Spectra of the signals, recorded by channels # 10 and # 18. The Amplification Spectra between the signals recorded in channels # 10 and # 18, and the referenced channel # 22 are plotted in Fig. 4 and Fig. 5. By analyzing the complete set of multi channel records (Amplitude, Phase and Amplification Spectra)

the following natural frequencies of the concrete structure have been identified: 6.10 Hz, 7.25 Hz, 8.40 Hz, 8.70 Hz, 10.50 Hz, 11.40 Hz, 12.10 Hz, 13.15Hz, 14.10 Hz and 15.75 Hz. Fig. 6 is a graph of the free vibration mode shapes of the crest (horizontal transversal component). The ability of the structure to dissipate energy is analyzed by the modal damping ratios. The damping ratios for frequencies 6.10 Hz and 8.70 Hz have been evaluated to be 0.074 and 0.036. By these values, applying the algorithm listed in [2], the constants α and β are calculated and then the corresponding damping ratios for all natural frequencies of interest.

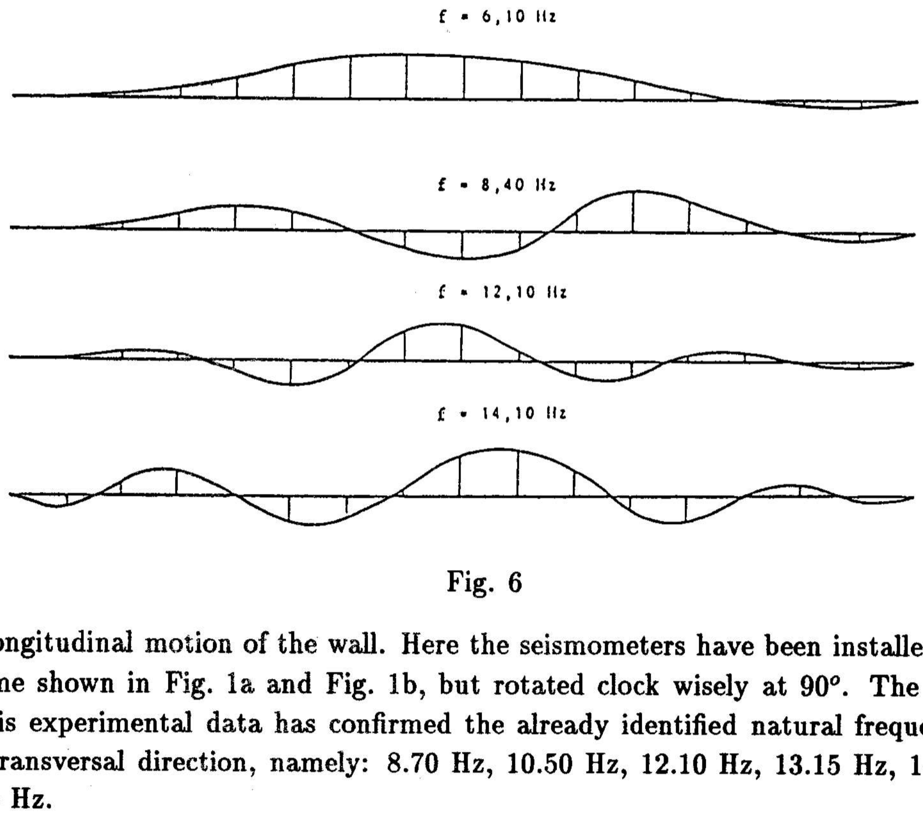

Fig. 6

2. Longitudinal motion of the wall. Here the seismometers have been installed by the scheme shown in Fig. 1a and Fig. 1b, but rotated clock wisely at 90°. The analysis of this experimental data has confirmed the already identified natural frequencies in the transversal direction, namely: 8.70 Hz, 10.50 Hz, 12.10 Hz, 13.15 Hz, 14.10 Hz, 15.75 Hz.

3. Vertical motion of the wall. The layout of the seismometers is by the same scheme as above but they are installed now to record the vertical component of the motion. The experimental data in vertical direction, after being analyzed, confirmed the already identified frequencies in horizontal direction, viz:

12.10Hz, 14.10Hz, 15.75Hz.

Comparison between experimental and analytical results

Numerical static and dynamic analysis of the concrete wall has also been carried out by specialists from Electrowatt (EWI)-Switzerland and Energoproject [3], applying 2-D FEM and the famous computer code ADINA. Results from these numerical experiments and from the field tests for an empty reservoir are given in Table 1.

Table 1.

NATURAL FREQUENCIES [Hz]					
FIELD TESTS	ELECTROWATT			ENERGOPROJECT	
	rigid clamp	no mass at base	with mass at base	modal analysis	pseudodynamic analysis
6.10	5.96	4.41	4.21	4.753	5.86
7.25			5.41	7.824	
8.40			6.39	8.363	
8.70		8.60	7.35	8.755	
10.50		9.83		9.504	
11.40				11.506	
12.10				14.204	
13.15	13.07			14.377	
14.10				15.534	
15.75	16.61	16.21		16.607	

The differences between the experimental and analytical results are within reasonable limits and may be related to the shortcomings of the assumptions that are inevitable when dealing with mathematical modelling of real structures.

REFERENCES

[1] SIMEONOV, S., K. HADJIYSKI ET AL. Seismic analysis of Chaira concrete gravity dam. Vol 2: In-situ full-scale dynamic tests. Energoproject, Sofia, 1992.

[2] BATHE, K-J., E. L. WILSON. Numerical methods in finite element analysis. Prentice-Hall, Inc., 1976.

[3] Chaira and Belmeken dams. Dynamic analysis. Joint Final Report of Electrowatt and Energoproject, Sofia 1992.

Presented at the 7th Congress on Theoretical and Applied Mechanics, Sofia, August 30 – September 1, 1993
section: Applied Mechanics