A STUDY ON DYNAMICS OF EARTH DAMS DURING EARTHQUAKES

by

T.S.Atrakhova[I], G.N.Belgorodskaya[I], A.P.Valov[I], V.L.Golubyatnikov[I], M.M.Nikiforova[I], G.S.Seleznev[I], G.I.Tschalkina[I], U.L.Zaslavskiy[I]

SYNOPSIS

Since 1968 in the Tadjik SSR a seismometric observations at an earth dam (30 meters in height) are carrying out during earthquakes. The results of analysis of obtained materials indicate that under a Magnitude 4 or greater earthquakes (MSK scale) the structure behaves nonlinearly. The experimental materials are compared with the results of investigations of a mathematical models of the structure.

The most reliable information on dynamics of earth dams could be obtained by means of analysis of a behaviour of a real structures during earthquakes. For this purpose the permanent observations were organized at one of the Tadjikistan's earth dams (30 meters in height) /1/.

The cross section of the dam consists of the following constructive elements : the upstream thrust prism poured out with pebbles, the upstream slope being spred over with sandstone; the alluvial body of the dam from sandy loam, the slopes being spred over with pebbles; the drainage prism is made from a gravel-pebble ground contained a fine sand.

The arrangement scheme of 11 measuring points is shown in Fig.I. The standard seismometric instruments are used for measurements /2,3/. The instruments of the measuring complex are working in a waiting conditions in two ranges of sensibility : in the range I the earthquake vibrations of intensities from 1 to 4 (MSK scale) are registered, and in the range II - above 4.

The engineer-seismometric survey at the dam is functioning since 1968. Since that time 44appreciable earthquakes of a Magnitude 1 to 5 (10 to 15 class of energy, $K=\lg E_{gж}$) have been recorded. Among these, 4 earthquakes were of 14-15 class of energy ('strong'earthquakes), 8 earthquakes were of 13 class of energy ('moderate') and the rest - of 10-12 class of energy ('weak'). The epicenters of the majority of the recorded earthquakes were located in the Pamirs-Hindu Kush

[I]Research Assistants, Institute of Earthquake Engineering and Seismology, Academy of Sciences, Tadjik SSR, Dushanbe.

zone at a distance 200-220 km from the dam.

In order to discover a qualitative relation on the basis of the data obtained by means of initial treatment, the diagrams of the displacements and dynamical coefficients along the height of the structure have been drawn (Fig.2). For the more detailed analysis, the diagrams of changes of the maximum displacement, velocity and acceleration amplitudes of the structure points and their ratios to the maximum amplitudes of the base (rock) have been drawn depending on the earthquake power defined by the maximum displacements, velocities and accelerations of the rock base (Fig.3).

On the basis of the analysis, the following features were observed :

1/ the maximum amplitudes of vibrations at the top of the dam increase 1,5 - 5 times as compared with the amplitudes at the base.

2/ the ratio of the maximum amplitudes of the displacements, velocities and accelerations at the top of the dam to those at the rock base deareases under stronger earthquakes.

A more complete information on a behaviour of the structure under a dynamical excitation could be obtained by means of its amplitude-frequency characteristic ($\bar{\bar{K}}$), which permits the natural frequencies and damping value of the structure to be determined /4/. The amplitude-frequency characteristics defined by amplitude spectra

$$K = \frac{S_i(\omega)}{S_1(\omega)} ,$$

and those by the energy spectra

$$K = \sqrt{\frac{G_i(\omega)}{G_1(\omega)}} ;$$

are comparable.

Ror the analysis, the diagrams of a natural frequencies (ν) and damping value (n) of a structure vibration versus an earthquake power in the dam site (measuring point I) have been drawn.

As a quantitative measure of an earthquake power, the value of energy released in a time unit of an excitation have been taken ; this value is named a dispersion

$$D = \frac{E_T}{T} = \int_{\omega_1}^{\omega_2} G(\omega)\, d\omega$$

where

$$E = \int_{\omega_1}^{\omega_2} \left[S(\omega)\right]^2 d\omega$$

When an earthquake power (dispersion D) increased, the decrease of natural frequencies of the structure is observed for I, II and III modes (Fig.4). In turn, a level of an amplitude-frequency characteristic falls down : it is about 10 for a weak earthquakes, and about 4 for a strong earthquakes (Fig.5); it corresponds to a change of damping from 0.05 (according to the experimental data /5/) to 0.15 (Fig.6).

A change of a natural frequencies of the structure, a decrease of a level of an amplitude-frequency characteristics and an increase of a damping value when an earthquake power increased indicate the nonlinear behaviour of the structure under a Magnitude 4 or greater earthquakes and it should be taken into account for a dynamical calculations.

A study on behaviour of the structure have been carried out along with a study on determining a relations between a spectral-time parameters of an earthquake vibrations of the base and a source energy value of earthquakes. The quantitative formulation of these relations is of great interest for the engineering seismology, because the knowledge of those would allow us with the aid of a spectra of a weak shocks to have an idea on a strong excitation that could occur in the same seismic region.

The main results were obtained by treatment of uniform material recorded in a several points of the structure during many years with the aid of the frequency-selective seismic stations (FSSS) /6/. The amplitude-frequency characteristic of a small period variation of the FSS station is shown in Fig.7. About 600 records of earthquakes of the Pamirs-Hindu Kush seismoactive zone with the source depths from 50 to 280 km (with classes 8 to 15) have been treated.

As a result of these records treatment, the relation between a spectral amplitudes (A) on each channel of registration and a class of energy K (Fig.8) was obtained. Quantitatively the relation is defined /7/ as follows

$$\beta(\nu) = \frac{d\lg A}{d\lg E} = \frac{d\lg A}{dK}$$

The diagram of the function $\beta(\nu)$ is shown in Fig.9; it enables for transition from a weak excitation spectra to a strong ones:

$$\ell g S_K(\nu) = \ell g S_{K_0} + \beta(\nu)\left[K - K_0\right].$$

As a first approximation, there have been established that the $\beta(\nu)$ function doesn't depend on a type of wave, a station site, an epicentral distant , i.e., it has a great community /7/.

As a system of parameters described approximately the time change of the spectral density, the matrix of the peak amplitudes aiong the time intervals (Δt=2.0 sec) of each channel have been taken. Averaging the variety of the matrix elements, one could obtain the average matrix which gives the generalized characteristic of the fenomenon under study. Fig.10 shows the spectral-time area obtained by the average matrix of 10 records of Pamirs-Hindu Kush earthquakes of 13 class, and Fig.11 shows the generalized accelerogramm.

A study of the mechanical characteristics of the dam material have been carried out in the laboratory conditions by means of the ultrasound applience, the one-dimensional dynamical shearing apparatus and the stabilometer. For 3 types of material (sandy loam, gravel and breakstone with the volume weight 1.48 , 1.64 and 1.53 g/cm^3 relatively) the following parameters have been determined : the dynamical shear modulus G ; the general shear modulus G_1, which indicates an elasto-plastic work of a material; and the maximum shear load τ , under which the plastic shear of a sample occured. The investigations were carried out under the normal stresses from 1 to 6 kg/cm^2,in the frequency range from 1 to 3 hz.

The above data are used for plotting the diagrams of the ground deformation versus the shear loads. An example of such diagram for the sandy loam is shown in Fig.12. The dependence curve of deformation versus loading is conditionally substituted for the broken line consisted of three sections.

The shear modulus obtained by means of measuring of the shear wave distribution velocity in the ground sample and these obtained by the stabilometer tests appeared to be comparable and the Poisson ratio appeared to be equal 0.32.

As a mathematical models of the object under study, two design schemes have been considered : a cantilever scheme with a concentrated masses, the elements of which undergo the shear deformation only, and a plane scheme, solved by means of the finite element method (Fig.13). The problem have only been solved in an elastic stage, and the generalized accelerogram (shown in Fig.11) have been taken as the input.

Because the dam body consists of the heterogeneous materials, the adduced values of elastic characteristics have been determined for each element of the design scheme. The damping was taken to be equal 0.06 of critical. The analysis of the design results have been carried out by the procedure established for treating results of instrumental observations : the amplitude-frequency characteristics for separate points ofthe structure have been plotted with respect to the input excitation and the response of the mathematical models of the dam. The comparison of the obtained results is shown in Table.

LITERATURE.

1. Сейсмостойкость плотин. Выпуск 2. Сборник статей, Душанбе, 1972.

2. Сейсмические приборы. Выпуск 5. Изд."Наука",Москва,1969.

3. Сейсмические приборы. Выпуск 6. Изд."Наука",Москва,1972.

4. Дж.Бендат, А.Пирсол. Измерение и анализ случайных процессов. Изд."Мир", Москва,1971.

5. Г.С.Селезнев, Р.С.Шусер. К вопросу оценки динамических параметров плотин из местных материалов. Труды ТПИ, Выпуск 2. Ирфон, Душанбе,1967.

6. К.К.Запольский. Частота сейсмических волн.Методы детального изучения сейсмичности. Изд."Наука",Москва, 1960.

7. В.И.Халтурин, Т.Г.Раутиан, А.Нурмагамбетов, Е.С.Благовещенская, И.Ф.Беликова. Зависимость спектра сейсмических колебаний от энергии землетрясения. **Earthquake engineering, Sofia,1971.**

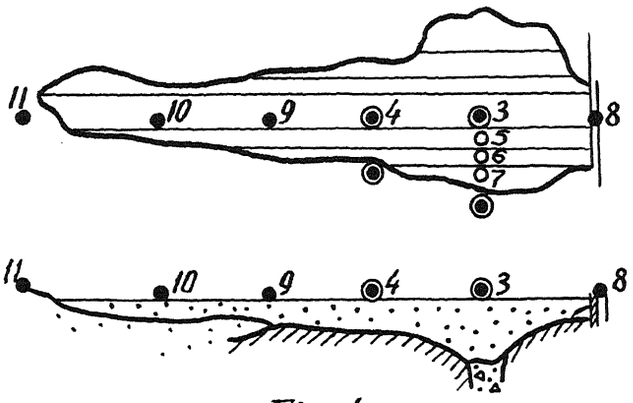

Fig.1

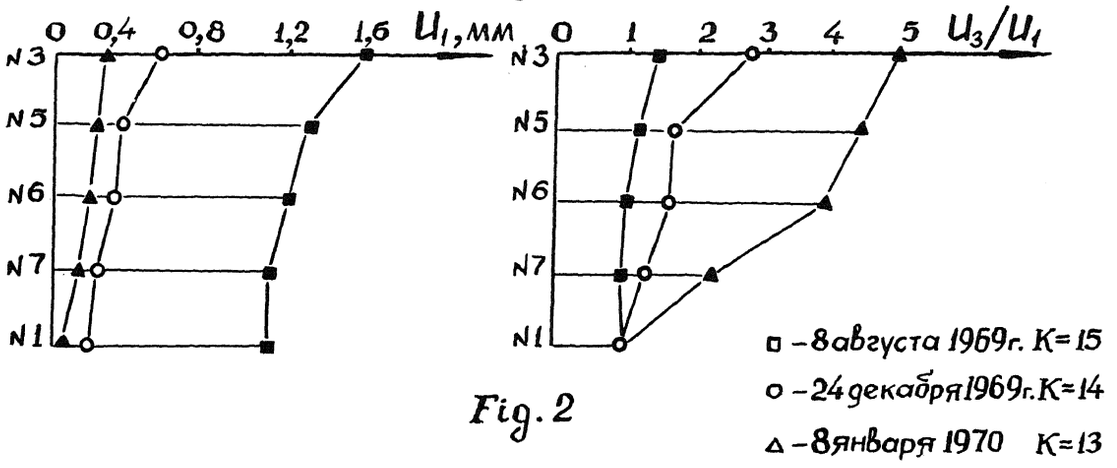

Fig. 2

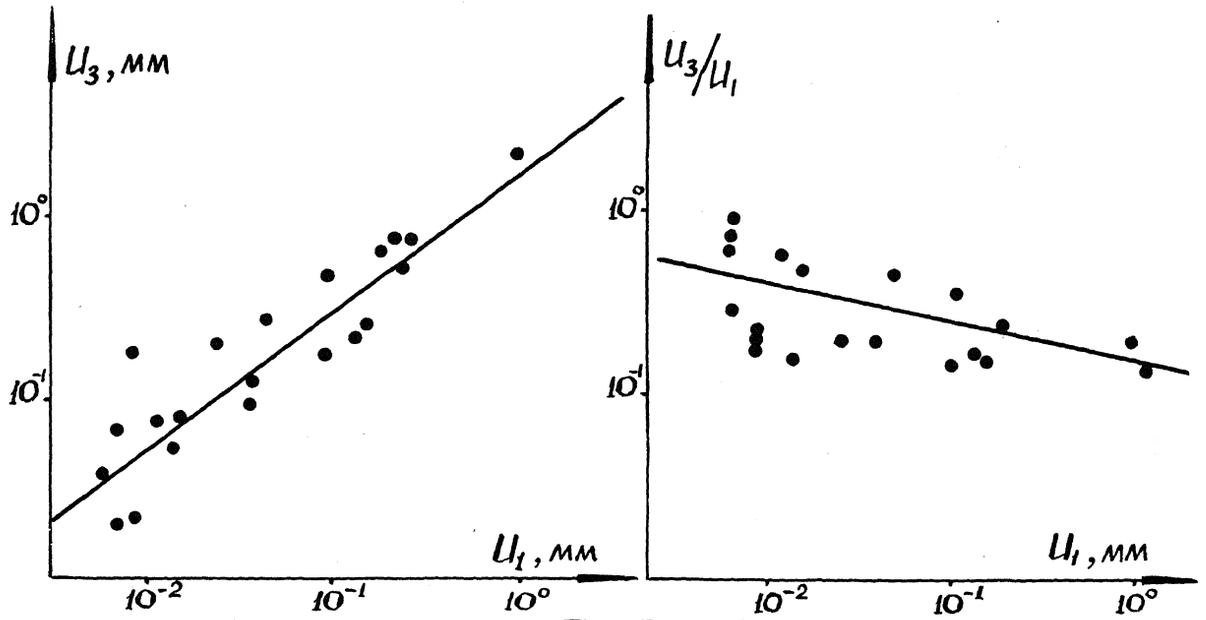

Fig.3

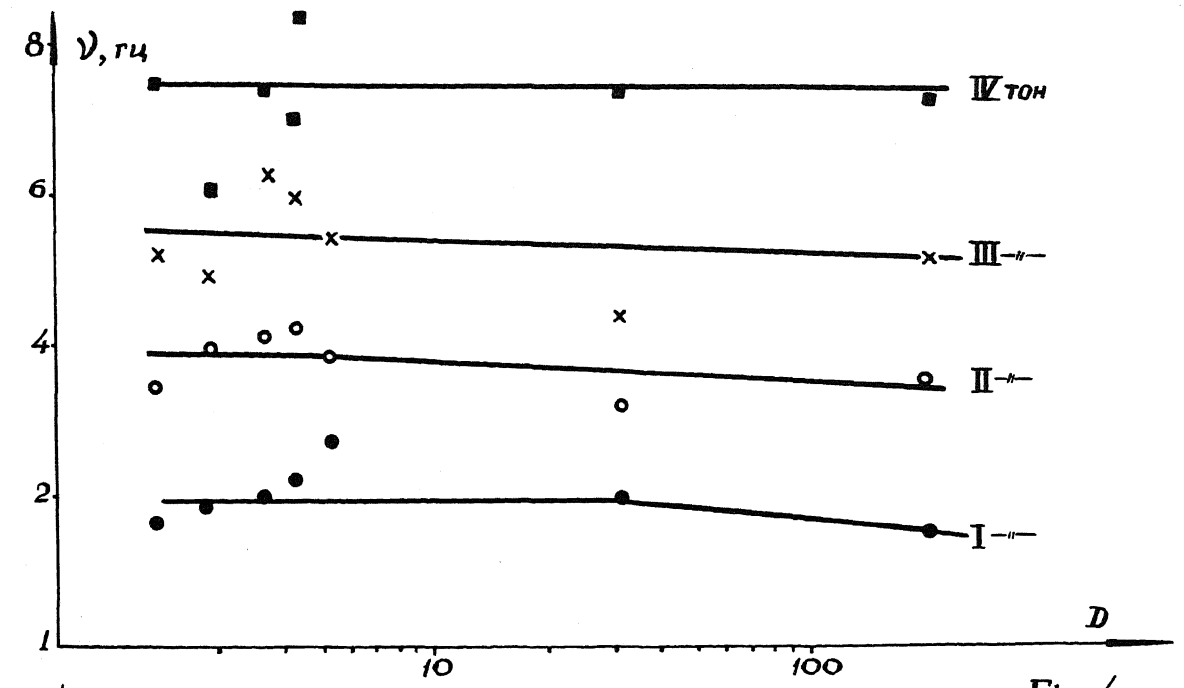

Fig.4

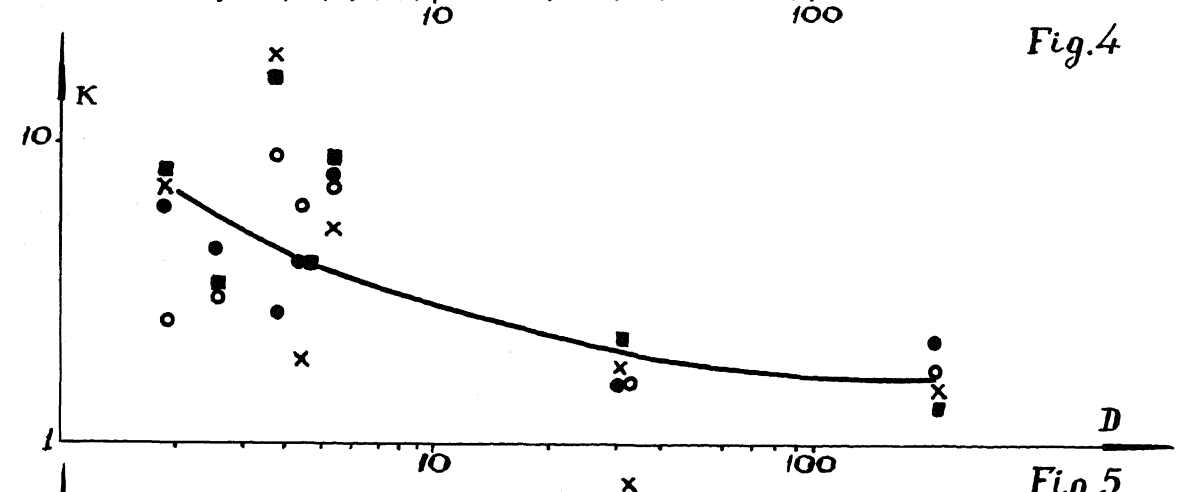

Fig.5

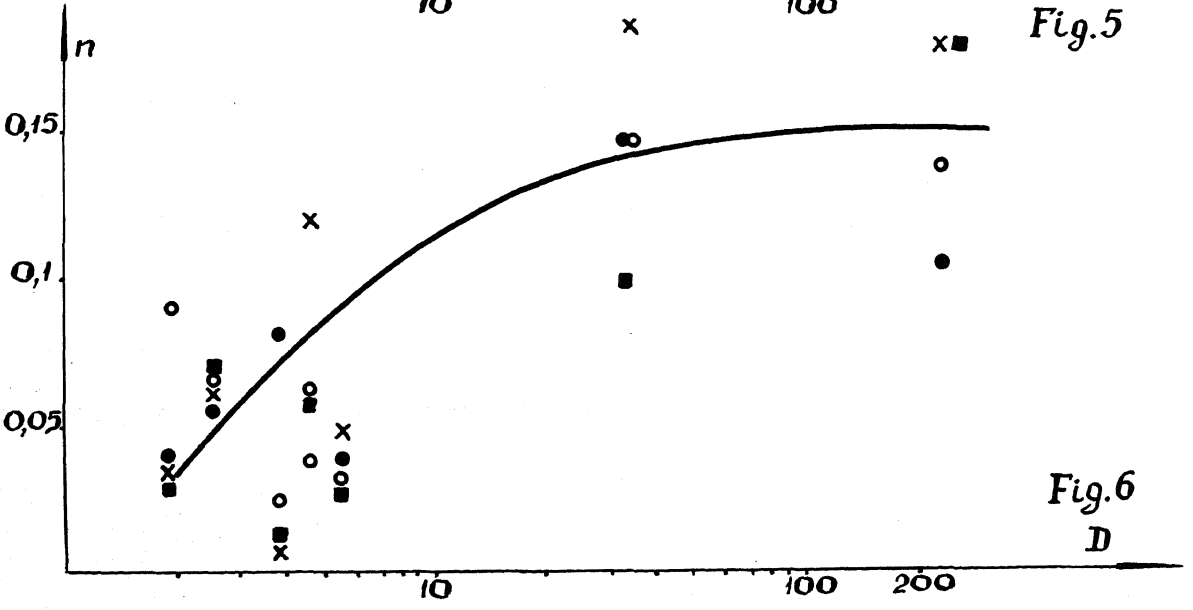

Fig.6

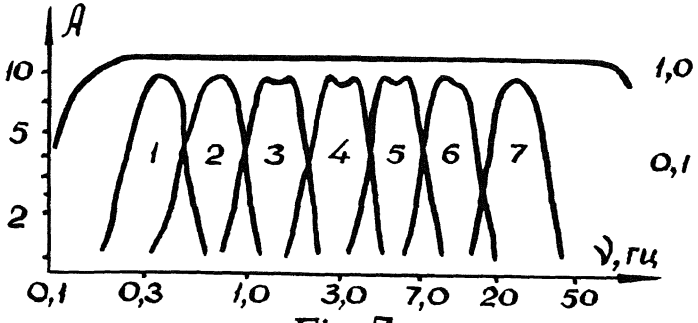

Fig. 7

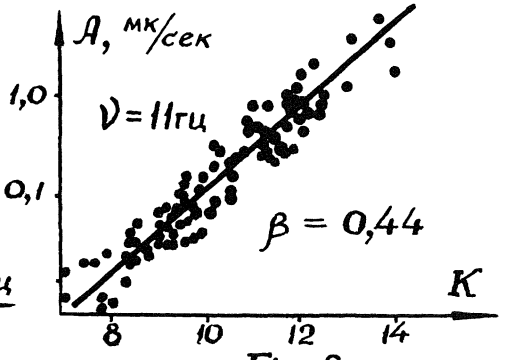

Fig. 8

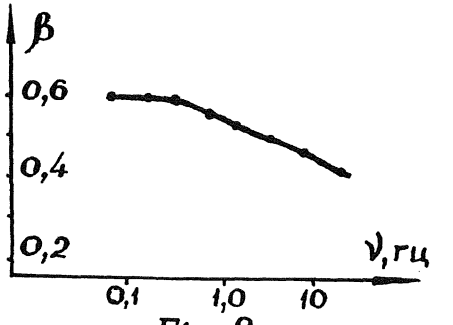

Fig. 9

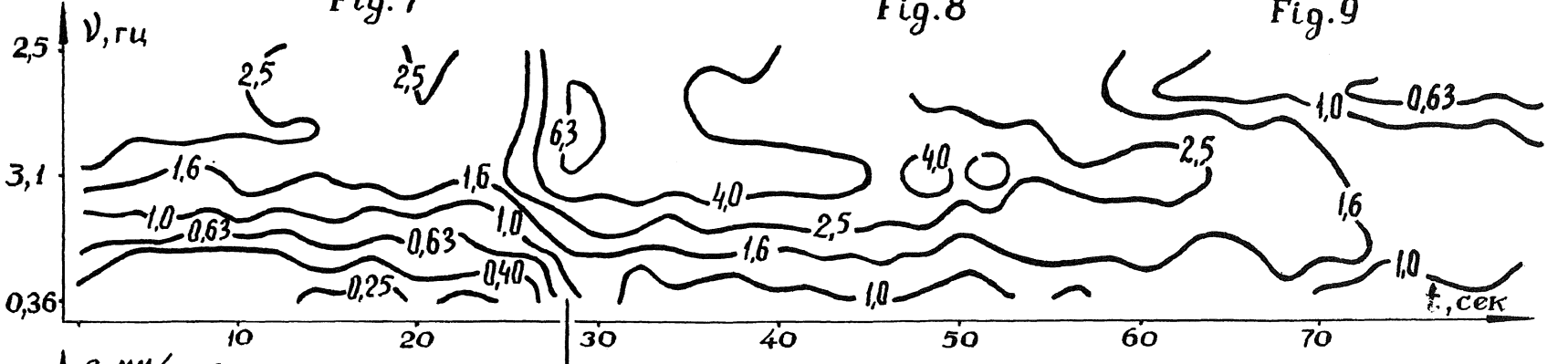

Fig. 10

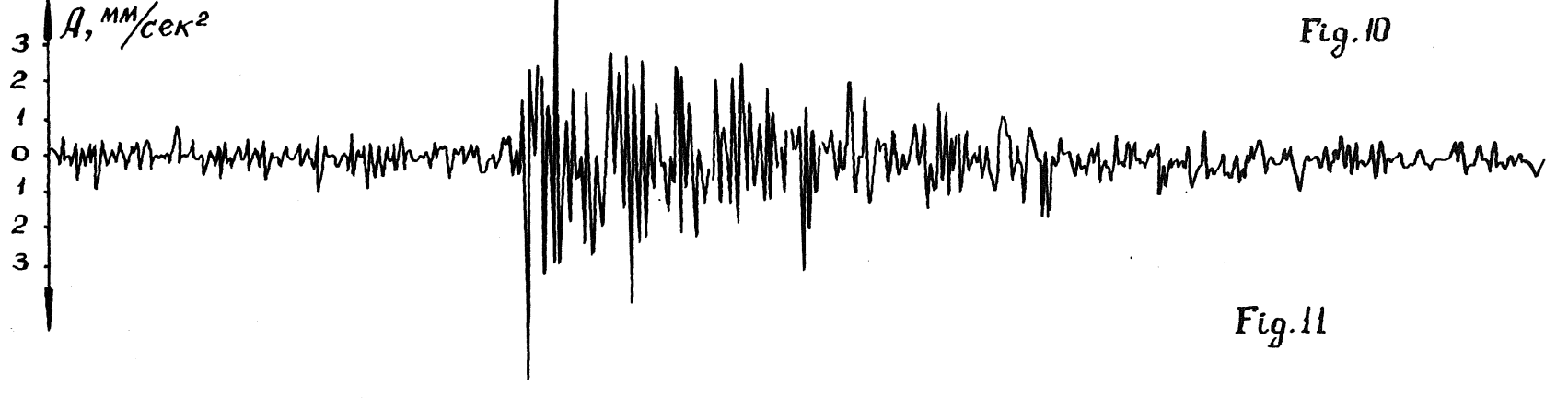

Fig. 11

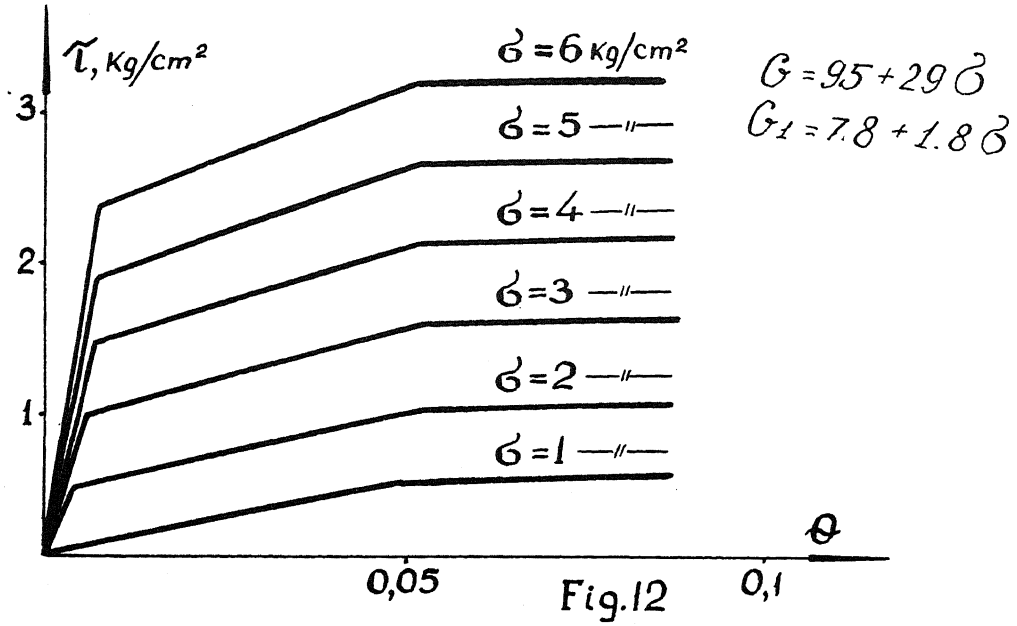

Fig.12

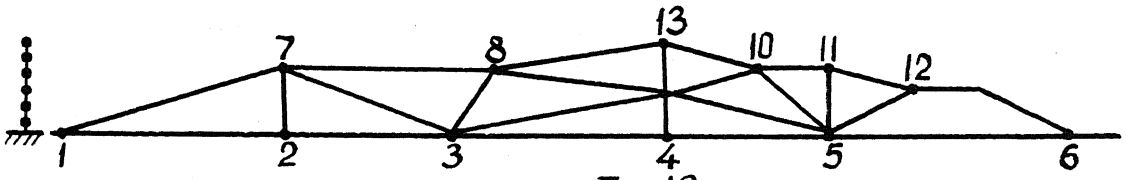

Fig.13

Natural frequencies of the dam

table

experimental				design			
under smoothing		without smoothing		cantilever scheme		finite elemente	
hz	ν_i/ν_1	hz	ν_i/ν_1	hz	ν_i/ν_1	hz	ν_i/ν_1
20	10	2,0	1,0	1,7	1,0	1,6	1,0
—	—	—	—	—	—	1,8	1,1
—	—	2,4	1,2	—	—	1,9	1,2
—	—	2,9	1,4	—	—	2,35	1,5
3,2	1,6	3,2	1,6	2,7	1,6	2,6	1,6
—	—	3,6	1,8	—	—	2,9	1,8
—	—	3,9	1,9	—	—	3,0	1,9
—	—	4,4	2,2	—	—	3,2	2,1
—	—	4,8	2,4	—	—	3,4	2,2
5,0	2,5	5,1	2,5	4,2	2,5	3,6	2,3