THE PROBLEMS OF ENGINEERING SEISMOMETRIC SERVICE ORGANIZATION AND INSTRUMENTAL DATA ANALYSIS

by

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SYNOPSIS

The paper deals with the problems of the organization of the engineering seismometric stations. The development of the investigations carried out in the USSR, the choice and principles of disposal of the equipment at these stations are discussed. The second part of the paper describes the methods used while analysing the data obtained at the stations. Some results of the analysis connected with a statistical study of earthquake records using a digital computer are presented as well. The main aim of the study is to have correct characteristics of a real earthquake process.

Recently a significant success has been achieved in elaboration and improvement of the methods of analysis of the behaviour of buildings and structures during earthquakes. For a long time the use of these methods for the earthquake design and development of research and earthquake engineering was kept in check for lack of instrumental data on ground movements and building constructions under seismic loads. Now earthquake engineering can not be based only on the hypothetical assumptions and on the results of visual observations. To create the methods satisfied earthquake engineering theory and practice it is necessary to have reliable quantitative characteristics of ground and structure movements. The application of the statistical methods to modern investigations demands this information to be extensive and various.

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There are two systems of seismic observations registering oscillations during earthquakes: Uniformed System of Seismic Observations of the USSR (USSO) and Engineering Seismometric Service on Buildings and Structures (ESS).

USSO has a net of seismic stations equipped with modern registering apparatus. The stations are located in different regions of our country. The main task of the net is constant instrumental observations during earthquakes for the purpose of seismic zonation of various seismic active areas and the whole territory of the Soviet Union. Obtained data are used for the compilation of seismic maps and in the earthquake design codes. These data are applied to seismomicrozonation of single regions as well. USSO studies seismic regime of some areas, relation between characteristics of weak and strong earthquakes, finds out the earthquake nature, connection between earthquakes and ruptures of the Earth's crust and other factors. Also USSO examines the problems of earthquake prediction, etc. USSO of the USSR is a part of the World Net of seismic observations, it registers earthquakes occuring over the world with a view to study the Earth's internal structure. Registering instruments of the USSO seismic stations are disposed on the grounds (in adits, wells, on basements, etc.). To a certain extent this system of observations provides the earthquake engineering with the information about earthquake forces.

The task of ESS is registration of vibrations of buildings, structures and adjacent parts of ground under strong earthquakes (the checking of the ESS activity is under way on the part of the Council of Seismology and Earthquake Engineering and Kucherenko TsNIISK). The data obtained at the ESS stations are original information to check and make more precise the design preconditions in earthquake engineering. They allow a real carrying power of structures to be estimated. The data may be used for determination of a seismic load, as the basis of theoretical investigations for creation of design methods, as the criterion of the results of scientific research and practical calculations in earthquake engineering, as the basis for elaboration of the laboratory methods of investigations of earthquake resistance of constructions and materials. Principles of location of the seismic stations and of the seismometric apparatus, discussed and formulated by the representatives of many soviet institutions at their meetings, are the following: during the earthquakes the instruments should register accelerations, velocities, displacements along the central axis of a building by three components, as a minimum at two levels according to the height. In some cases many-channel record is provided at different sensitivities. At a distance of 20-25 m from the building it is desirable to have the record of ground movements. For some buildings the number of instruments is increases for many detail studying of the forms of vibrations in plan and according to the height of the structure.

The net of engineering seismometric systems includes the following types of buildings and structures:

I. Buildings and structures of one and the same type being in different ground conditions;

2. Buildings and structures of various types being in similar ground conditions;

3. Unique buildings and structures.

The specification is presented for each building with instruments including a plan, section, short description of the building's construction and dynamic characteristics, and ground conditions. It should be stressed that the data availability for each seismic oscillation record is of great importance. A possibility of this record use and analysis largely depends on dynamic characteristics of the surface ground part or any structure where this record was obtained. The record of seismic oscillations without dynamic characteristics of constructions and ground conditions of the place of recording practically gives little information for the study and analysis both of seismic processes and the behaviour of buildings and structures during earthquakes.

One can assume that the investigators working in the field of seismology and earthquake engineering will have enough information about various seismological processes occuring during earthquakes. On the basis of this information the results describing with great confidence the behaviour of buildings' constructions during earthquakes will be obtained. And then the problems connected with the unification and the methods of this information treatment will arise. These methods of the treatment of real earthquake records are greatly interrelated with the tasks set by the investigators. For example, the study of statistical properties of real earthquake records using the analysis of functions of distribution and central moments of different orders is being run at the Kucherenko Central Research Institute for Building Structures. The data which have been given by the investigators can be used in different works connected with the study of seismic processes. The methods of earthquake records' treatment are widely used for determination of dynamic characteristics of these constructions. In this case both the possibility of direct determination of record spectral composition and the other methods are applied (for example, the method connected with the usage of autocorrelation functions and spectral densities).

By the way of example some results of the analysis of instrumental data obtained during the earthquake with magnitude 6.5 (energetic class - I5, epicentral intensity - 8) are presented below.

At a distance of I50 km from the epicentre this earthquake was registered on buildings and structures as the earthquake with intensity 5-6 at the stations of Engineering Seismological Service (ESS).

Ground shaking and building vibrations were felt within a minute during the earthquake. Duration of the most strong vibrations was I0-I5 sec (Fig.I).

Processing of received seismometric data was realized with the help of the electronic computer "Minsk-22" using special programs. The results are given in the Table and on Fig.2 and Fig.3. Interpretation of seismometric data includes harmonic and correlated analysis, determination of the amplitude of Fourier spectra and rate-set correlated functions of seismic loads and structures' responses.

The analysis of oscillograms and Fourier spectra, run by T.Zh.Zhunusov and Yu.A.Vypryazhkin, testifies that spectral composition of ground vibrations depends on engineering geological structure. On rigid boulder-pebble rocks displacement maxima are over the periods from 0.5-0.8 to I.5 sec, and acceleration spectra maxima are over the periods from 0.I5 to 0.2 sec (Table). On soft loamy grounds maximal amplitudes of displacements and those of accelerations are over the periods from 0.5 to 0.6 sec (Fig.I).

The buildings with installed ESS stations vibrated with dominant periods close to natural ones during the earthquake. Four-storeyed framed buildings had main-tone periods from 0.38 to 0.4 sec in a longitudinal direction and from 0.45 to 0.5 sec in a transverse direction. A five-storeyed large-panel building with ground framed storey had main-tone periods from 0.37 to 0.4 sec and a four-storeyed large-panel building from 0.I8 to 0.2 sec.

It should be noted that the periods of building's vibrations determined from displacements' and accelerations' records coinside.

Natural vibrational periods of buildings during this earthquake with intensity 5-6 turned out to be by I5-20 % greater than those during early registered weak earthquakes with intensity 4 and lower.

Low-frequency forced vibrations caused by ground movements are observed on displacement records obtained at the level of roofing of the building along with the periods of their natural vibrations. This phenomenon is expressed to a lesser extent for framed buildings than for large-panel ones. (Fig.I). Forced vibrations are completely absent on acceleration records for all buildings.

Maximal amplitudes of horizontal displacements and accelerations are 2-3 time greater at the level of the highest storey of buildings than on the ground and at the level of basements of buildings.

Logarythmic decrements of building vibrations during this earthquake, determined from the curves of rate-set correlated functions and from amplitude-frequency characteristics

(Fig.2) are over the periods from 0.I5 to 0.35 for framed buildings; from 0.2 to 0.5 for a five-storeyed large-panel building with a flexible ground storey and 0.25 - 0.5 for a four-storeyed large-panel building. Approximately the same values of logarythmic decrement of vibrations were obtained for these buildings under natural vibrations caused by immediate down-throw of loads and weak earthquakes.

Applied methods of the processing of real earthquake records are connected as well with the methods of determination of design seismic loads on buildings and structures. Assuming one or another method of the determination of seismic loads in any concrete case the authors have used the necessary treatment methods of earthquake records. These methods determine the accuracy of the foundation method of seismic force. While analysing real earthquake records various statistical characteristics of a seismic process in the input of a chosen system are often found (correlated functions, spectral densities, density of probability, and others). Then analytic process approximation is picked out in the input. The approximation may be of different precision depending on the complexity of this chosen system and on a calculation method. Having an analytic expression in the input and modulated with a help of an electronic computer the structure, it is possible to determine the process in the output. Analysis of this process permits the value of calculated seismic load to be found. Similar investigations are carried out while solving linear and non-linear tasks.

The other way is the solving of similar tasks by the method of direct integration, while determining vibrational process in the system's input using analog and digital electronic computers. In this case the determination of the process in the output of the calculated system and its further analysis demand a lot of time. Show the results of the second method's application while solving this problem. The most simple single-mass vibrational system with damping was chosen. Accelerograms of the earthquake with intensity 8 were tabulated with the 0.02 sec. step. With the help of the accelerograms the actions on the linear oscillators modulated at the electronic computer were given and then system responses were presented in tables and graphs.

Fig.4 shows accelerations of vibrations of a four-storeyed large-panel framed building recorded with seismometric instruments and calculated theoretically using a real accelerogram. Maximal values of system response are chosen and then the curves of spectra of system response are plotted for every accelerogram (Fig.5), Then the obtained spectra is treated statistically. As it has been already noted this method of treatment demands more computing time than the first one. Evidently, it is the reason of often application of the first treatment method to research works on a great number of earthquake engineering problems, although the second treatment method allows more reliable results to be obtained as it excludes errors arisen while approximating the input process. Calculations and plotting of the curves of response spectra of a single-mass system with damping were made. To run a statistical analysis of response spectra, maximal displacements for single-mass systems with different periods of natural oscillations (T = 0.I - 6.0 sec) and with decrements of vibrations (0.2; 0.4; 0.6; 0.8; I.0) were calculated. For every accelerogram the curves of a response spectrum have been plotted. Fig. 5 shows the two spectra presented with a dotted line (decrement of vibrations is 0.2).

A set of response spectra is calculated for each value of decrement of vibrations as realization of a random function for which mathematical expectation and root-mean-square deviation have been found. Fig. 5 presents a plot of mathematical expectation of maximal displacement for logarythmic decrement 0.2. Distributional density of the maximal displacement relative to mathematical expectation was assumed according to Gauss normal law. The plotted curves are those of equal probability and with their help design values of seismic loads can be accepted. The maximal displacement is adopted depending upon taken probability of appearance of design probability that is determined by the capitality of a structure and according to its dynamic characteristics.

As well Fig. 5 gives the graphs of maximal displacements with the following probabilities of their appearance p = 0.84I; p = 0.977; p = 0.998. These displacements correspond to deviations from mathematical expectation by one, two, three standards. The law of distribution of maximal displacement is adopted as a normal one in this case. One can plot many curves of equal probabilities with different p, it is convenient while taking design values of maximal displacements. All the calculations have been made according to the program for the electronic computer M-220.

The described method is one of possible ways to refine the design of buildings and structures on seismic forces. But final recommendations concerning the methods of determination of calculated seismic loads may be made when the instrumentational information has been accumulated and this information hes been analysed by various methods on the basis of seismic loads.

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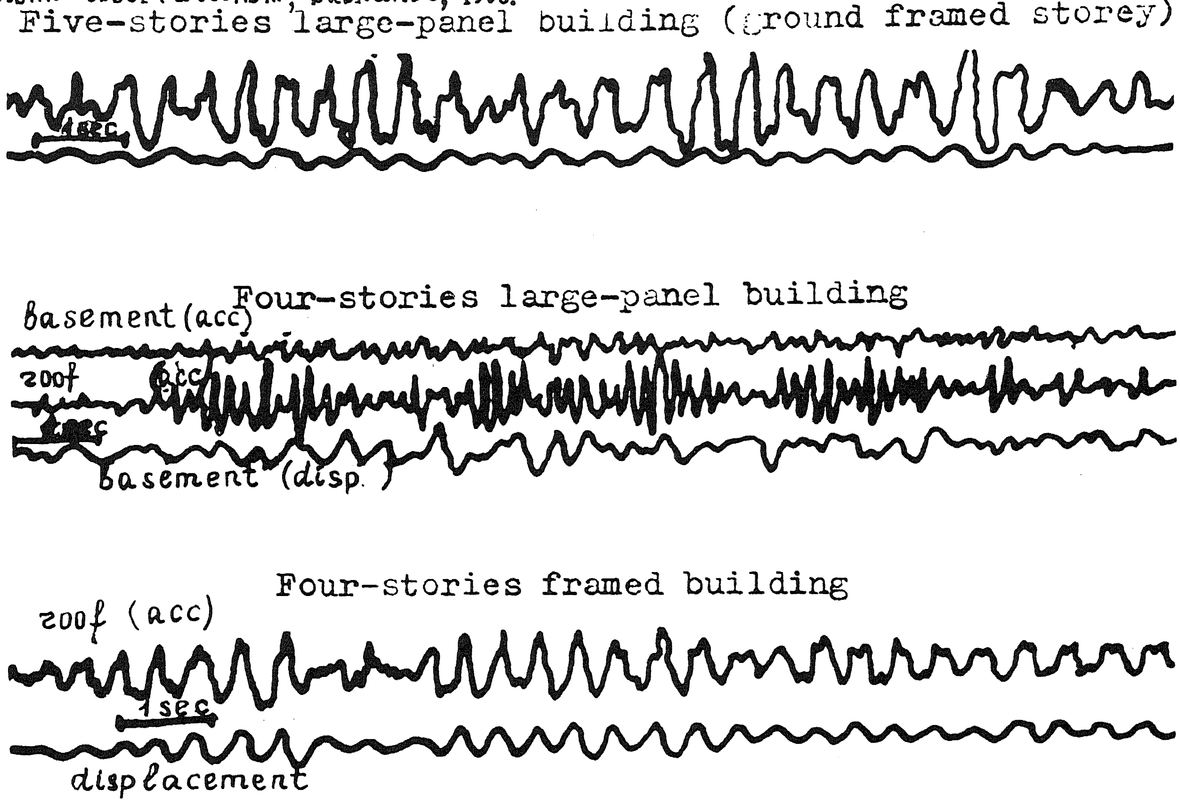

Fig.I. Earthquake registered at the stations of Engineering-seismometric Service.

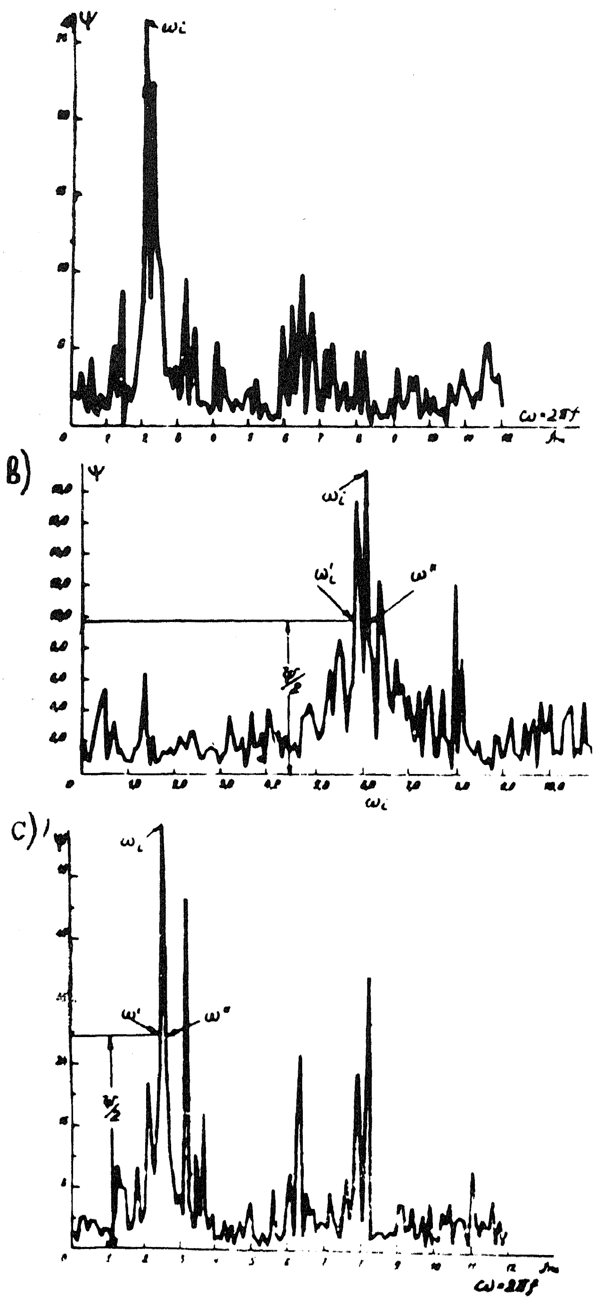

Fig.2. Amplitude-frequency characteristics of framed (a), large-panel (b) and five-stories large-panel with ground framed storey (c) buildings, obtained using earthquake records.

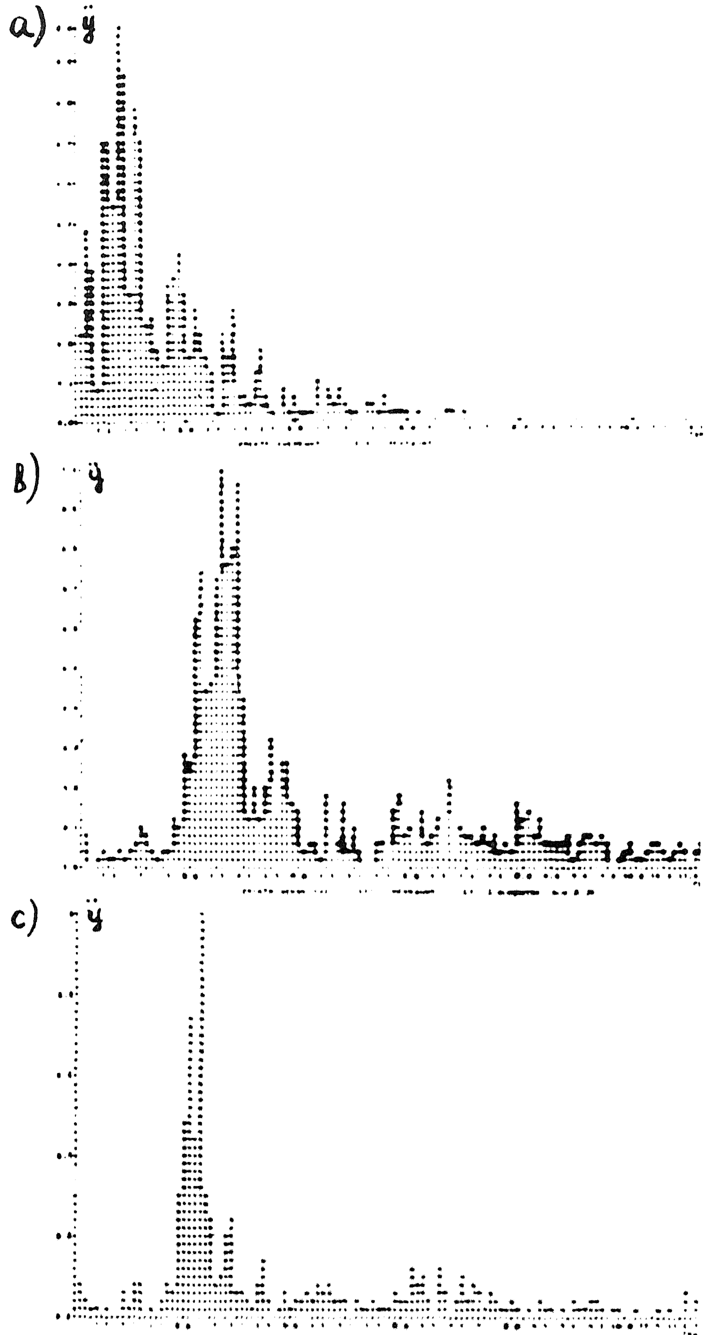

Fig.3. Fourier spectra calculated using the records of vibrations of basement of large-panel building (a), upper floor of five-stories large-panel with ground framed storey building (b) and four-stories building (c).

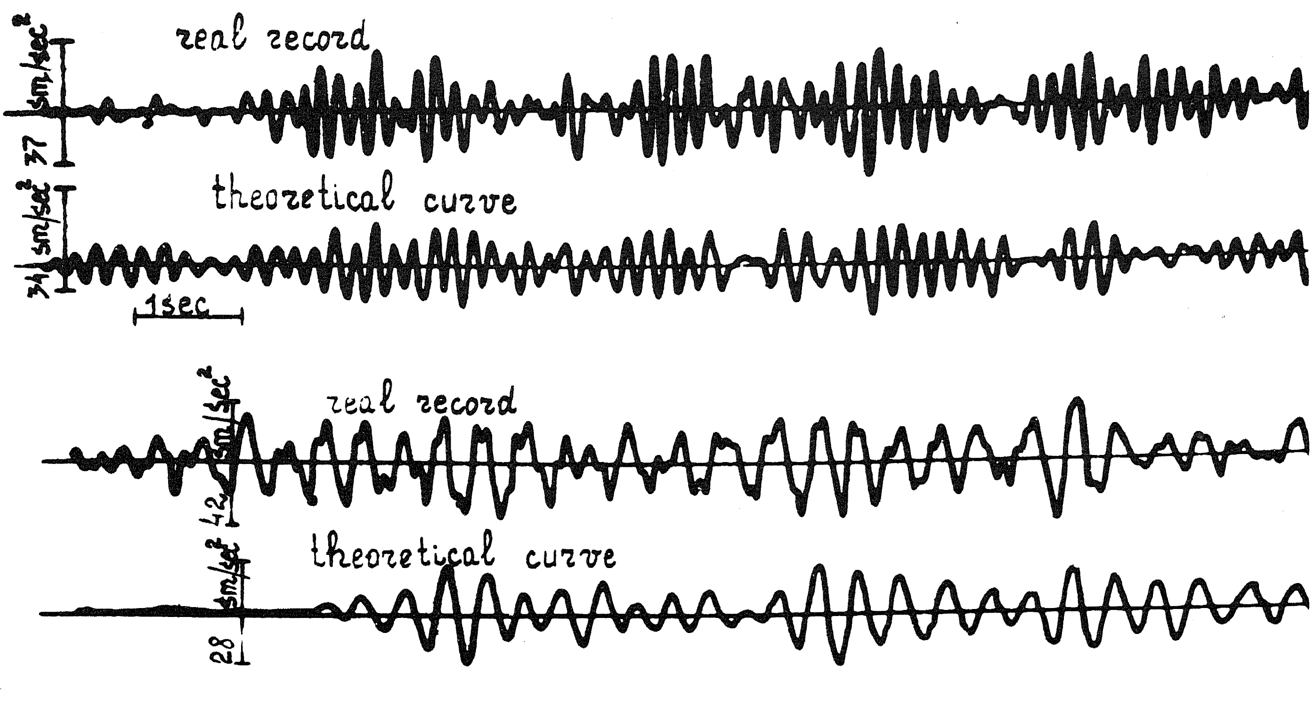

Fig.4. Accelerations of vibrations of four-stories framed (a) and large-panel (b) buildings recorded with seismometric apparatus and calculated theoretically using a real accelerogram.

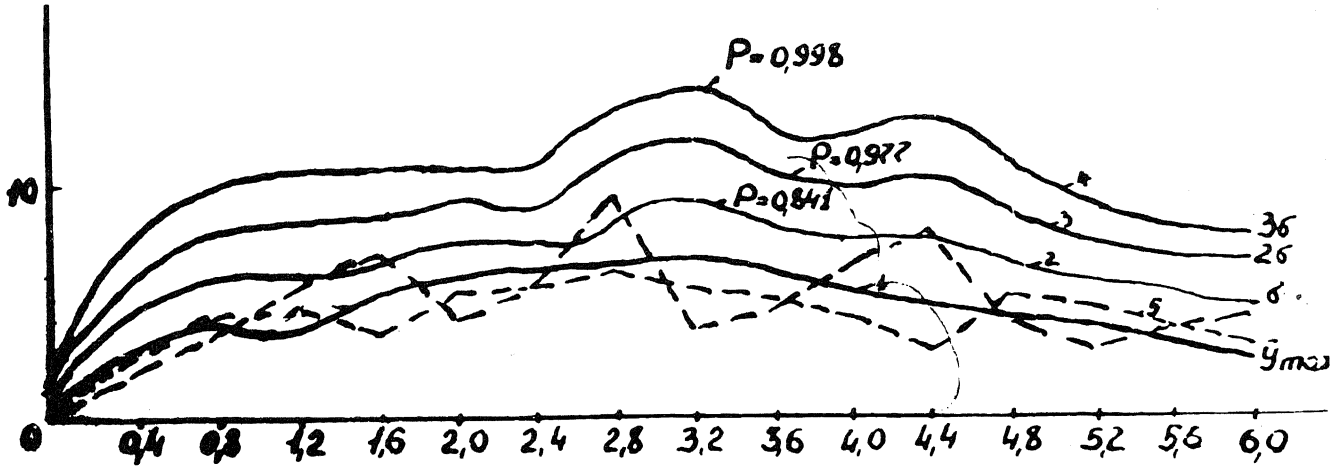

Fig.5. Response spectra of linear oscillators calculated using accelerograms for the earthquakes with intensity 8 (dotted lines) and theoretical curves of maximal displacements of different probability (solid lines).

TABLE I

PARAMETERS OF GROUND AND BUILDING VIBRATIONS FOR THE EARTHQUAKE WITH INTENSITY 5-6

Registering station	Type of instrument	Place of installation and orientation	Total duration of the recording process sec.	Duration (t) and dominant period (T) of the intensive vibrational areas		Maximal amplitude and corresponding period of vibrations			
				t sec	T sec	displacement ampli-tude	displacement period	acceleration ampli-tude	acceleration period
Station I	VBP-M002	Basement-X	II0	II		0.8	0.8		
Four-	S5S-GB3	4-storey-X	II0	25	0.5				
stories	VBP-GB3	4-storey-X	II0	I4	0.45-0.5	2.0	0.5		
framed	S5S-GB3	4-storey-Y	II0	25	0.36-0.4				
building	SPMI6-GB3	Upper-floorX	II0	20	0.5			30	0.5
	SPMI6-GB3	Upper-floorY	II0	8	0.35-0.4			40	0.4
	SPMI6-GB3	Basement-X	II0	I0	0.I -0.2			I0	0.2
Station 2	VBP-GB3	Basement-Y	II0	I2		0.75	0.95		
Four-stories	VBP-GB3	Upper-floorY	II0	I2	0.20-0.22	0.9	0.2		
large-panel building	VEGIK-GB3	Upper-floorX	II0	30	0.20-0.22 (I.5-2.0)				
Station 3	VBP-M002	Basement-x	I50	I8	0.5 - 0.6	0.87	0.6		
Four-	VBP-M002	Upper-floor-X	I50	I9	0.45-0.50	3.0	0.48		
stories	VBP-M002	Upper-floor-X	I50	I9	0.4	3.5	0.5		
framed	S5S-M002	Upper-floor-X	I50	25	0.5 -0.55				
building	SPMI6-M002	Upper-floor-X	I50	20	0.5			27.5	0.5
	SPMI6-M002	Upper-floor-X	I50	20	0.5			30	0.5
Station 4	S5S-M002	Basement-X	I50	20	0.8 -I.6	0.88	0.8		
Four-	SPMI6-M002	Basement-X	I50	I4	-0.2			I5	0.36
stories	S5S-M002	Upper-floor-X	I50	20	0.2(0.8-I.6)	0.75	0.I8		
large-panel	VBP-M002	Upper-floor-X	I50	9	0.2	0.83	0.2		
building	SPMI6-M002	Upper-floor-X	I50	I4	0.I8-0.2			37	0.I8

The instruments have been developed at the Institute of Physics of the Earth, AS of the USSR