THE FORECAST OF SEISMIC EFFECTS ON CONSTRUCTIONS

By

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INTRODUCTION

The problem of forecasting the time of earthquake occurrence has not been solved up to now. However, to project buildings and constructions in seismic regions the forecast of earthquakes can be determined on a small scale. It is necessary then to forecast what maximum oscillations can influence upon the planned building during its exploitation. The forecast of seismic effects on constructions involves the solution of three problems: 1) the seismic scale, 2) seismic zoning and 3) seismic microzoning.

1. Seismic Scale

The main aim in creating the seismic scale is to make a quantitative determination of intensity of seismic oscillations and their effects on constructions. Oscillations of ground during earthquakes are far from being harmonical. Therefore, it is necessary, first, to find methods of a quantitative estimate of non-stationary seismic oscillations. Second, to determine the very quantities of oscillations in conformity with the methods found.

It was suggested that intensity of seismic oscillations should be described with a spectrum of earthquake effects on constructions (1,2). The effect spectrum $\varkappa$ is given in the form of a product of three functions.

$$\varkappa = \mathcal{X}_0 \, \psi \, \mathcal{E}$$

Here value $\mathcal{X}_0$ characterizes the earthquake intensity, which stands for the displacement of the centre of a standard pendulum with fixed values of the period of own oscillations $T_0 = 0.25$ sec. and of the logarithmic decrement of the oscillation damping $\lambda = 0.50$.

Coefficient ψ determines the dependence of the effect spectrum on the period of oscillations of pendulum T, i.e. $\psi = \psi(T)$ and therefore the value ψ is called a spectral coefficient. If $T = T_0 = 0.25$ sec., $\psi = 1.0$. Coefficient $\mathcal{E} = \mathcal{E}(\lambda)$ determines the dependence of the effect spectrum $\varkappa$ on the logarithmic decrement of the pendulum damping λ. Therefore the value $\mathcal{E}$ is called a damping coefficient. If $\lambda = \lambda_0 = 0.50$, $\mathcal{E} = 1.0$.

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Different spectral forms of seismic oscillations were suggested by investigators in different countries, no review of such papers being given here. A peculiarity of the suggested method of determining the effect spectrum is that it permitted to obtain quantitative values by an elementary statistic treatment.

To choose the values of T_0 and λ which are parameters of the spectrum, a condition was adopted that earthquakes intensity is characterized by its destructive effect. The destructive effect is determined by a damage degree of the most typical buildings. Therefore there were adopted values $T_0 = 0.25$ sec. and $\lambda_0 = 0.50$, i.e. those which correspond to buildings that are widely spread.

Seismic oscillations of a structure can be approximately described as pendulum oscillations with different periods T and logarythmic decrements of damping λ during the motion of the basement $u = u(t)$.

$$\frac{d^2x}{dt^2} + \frac{2\lambda}{T}\frac{dx}{dt} + \frac{4\pi}{T^2}\mathcal{H} = \frac{d^2u}{dt^2}$$

The numerical solution of this equation enables us to obtain maximum values of $\mathcal{H}$ for different values of T and λ, function $u(t)$ being expressed graphically in the form of a seismogram and its second derivative $\ddot{u}(t)$ in the form of an accelerogram.

At T = 0.25 sec. and $\lambda = 0.50$, $\mathcal{H} = x_0$ as $\psi = 1$ and $\mathcal{E} = 1$. Thus, the numerical values of x_0 during strong earthquakes have been found. The scale of these values was compared with a descriptive characteristics of the earthquake consequences. With respect to the division to degrees in our scale the descriptive characteristics itself is parallel to that which exists in other scale (Wood-Neumann, and Mercalli-Cancani-Sieberg). The descriptive indications in our scale are given in more differential manner than in the above-mentioned scales. The differentiation is made according to types of buildings, number of buildings, damage degree, etc.

The interpretation of materials has shown that the growth of the values of x_0 goes two times with increase of intensity J by one unit. The quantitative scale of the values of x_0 determining earthquake intensity is sited on table 1.

The scale of the values of x_0, determining the earthquake intensity was adopted as a state standard (3). The seismometer SBM which has been designed by the author to determine intensity 2 has been mounted at the seismic stations of the USSR.

The determination of the spectral coefficients ψ (T) from earthquake records has been made within the range of periods from T = 0.1 sec. to T = 2 sec. The dependence of ψ on T is different for different period ranges. This dependence can be approximately expressed in the form:

$$\psi = \frac{T^2}{T_0^2}; \qquad \text{at } 0.1 \text{ sec.} \leqslant T \leqslant 0.5 \text{ sec.}$$

$$\psi = \frac{2T}{T_0} \; ; \qquad \text{at } 0.5 \text{ sec.} \leq T \leq 1.5 \text{ sec.}$$

It is important to note that for different earthquakes the values of ψ much vary and the above numerical data are mean data for ψ.

To determine the damping coefficient $\varepsilon(\lambda)$ average computations, analogous to those for ψ, have been performed. In addition experiments have been undertaken to test a specially designed device SD-1. This device has eight independent pendulums with equal periods of oscillations $T = 0.25$ sec. However, their decrements of damping ranged from 0.15 to 2.0. As a result of this, the simplest dependence has been derived (fig.1).

$$\varepsilon = \frac{1}{\sqrt{2\lambda}} \; ; \qquad \text{at } 0.25 \leq \lambda \leq 1.5$$

Fig. 2 gives values of the effect spectra for different periods of the own oscillations of system T. For the same systems the values of the velocities of oscillations V_T in cm/sec. (4) cited in fig. 3 have been computed with one degree of freedom.

The oscillation accelerations α_T of these systems (4) in dependence on the period of own oscillations T are shown in fig. 4.

To make computations of buildings, it is necessary to have, besides the above cited numerical values of the effect spectra, data on the expected values α of the proper oscillations of the ground. Especially important is the knowledge of the acceleration of the ground oscillations for buildings with large horizontal dimensions or for buildings with a deep-set foundation. For this purpose, the records of accelerations have been collected and generalized and the intensity in degrees for each of these earthquakes determined under a seismic scale (5).

An accelerogram represents an irregular oscillation with a variable amplitude and period. Therefore we shall conditionally call the oscillation period τ on the accelerogram a doubled interval of time between two adjoining zero values of the acceleration, and the acceleration amplitude α - the deviation value corresponding to that period.

The measured values of the periods and accelerations for the horizontal components are given in fig. 5. The graph shows a general regular growth of acceleration values with intensity increase from 5 to 8 degrees for different values of periods τ. This permitted to distinguish those parts of the graph which focus points relating to some degree. Within the range of periods from 0.1 sec. to 0.5 sec. the accelerations do not, on the average, change with the change of period. Within the range of periods from 0.5 sec. to 1.5 sec. the boundaries of the sections of different degrees are hyperbolas.

The obtained laws of the acceleration growth two fold with the increase of intensity J by one unit and the hyperbolic dependence of the acceleration on the period of the ground oscillation τ make it possible to record the following formula in which $\alpha_k = 0.0008 = 8 \text{ mm/sec}^2$.

$$\alpha_o = \alpha_k \, 2^J \quad ; \quad \text{at 0.1 sec.} \; \leqslant \; \tau \; \leqslant \; 0.5 \text{ sec.}$$

$$\alpha_o = \alpha_k \, 2^J \, \frac{0.5 \text{ sec.}}{\tau} \quad ; \quad \text{at 0.5 sec.} \leqslant \tau \leqslant 1.5 \text{ sec.}$$

The statistical treatment of the data shows that the mean quadratic deviation $Q\,(lg\,\alpha) = 0.149$ and the probability of conformity of the acceleration value with a certain degree $P(\alpha) = 0.684$.

2. Seismic Zoning

The map of seismic zoning of the USSR was compiled on the scale 1-5.000.000 (6). It divides the territory into zones according to different shock forces on the Earth's surface estimated in degrees on a seismic scale compiled in the Institute of the Earth's Physics of the USSR Academy of Sciences (1). The intensity of the estimated earthquakes is referred to the mean ground conditions.

Earthquakes are one of the manifestations of the tectonical activity of the Earth's crust. The primary role in the tectonical processes is played by vertical oscillatory motions. The vertical oscillatory motions of the Earth's crust and the tectonical activity in general are caused by deep processes occurring in the Earth's Interior at a depth of a few hundred kilometers called processes of the primary tectogenesis. The essence of these processes, the conditions of their occurrence and change in striking are far from being explained. However, the assumption is that the processes of the primary tectogenesis are caused by the transformation of large quantities of energy. At the Earth's surface these processes manifest themselves mainly in the form of mechanical motions: elevations and subsidences of the Earth's surface, folding, earthquakes. One can assume that the processes of the primary tectogenesis are followed by displacements of considerable masses of substances in the Earth's mantle. An essential part in the processes is played by a change of the volume, i.e. of density of substance that caused elevation of subsidence of the Earth's surface.

For the seismic zoning it is important that the processes of the primary tectogenesis causing vertical forces should appear on the Earth's surface on such a territory, the linear dimensions of which are commensurable with depth at which these processes take place. However, heterogeneities of plastic properties of substances of the Earth's crust in depth and striking lead to the fact that a relatively wide territory subjected to vertical displacements is different in intensity of these displacements thereby complicating the elucidation of seats of probable occurrence of earthquakes.

The methods of compiling the map of seismic zoning of the USSR of 1957 were outlined as follows. The contouring of zones with equal seismic danger was carried out on the basis of seismic and geological data, using the data on the distribution of earthquake foci in space and time, on latest tectonic motions and their relations with seismicity and many other characteristics. The intensity of the expected earthquakes within the boundaries of the contour zones was estimated from data of engineering seismology on the strongest earthquakes which occurred in the past in these

zones and their evaluation in degrees on a seismic scale.

The following data have been used to compile the map of seismic zoning: 1)the materials of the Seismicity Atlas of the USSR, as well as data obtained from the seismic stations of the USSR on the past earthquakes, 2) the data of seismogeological investigations in seismic regions of the USSR; 3) reports and materials on the inspection of destructive consequencies of strong earthquakes and results of investigations in engineering seismology.

The Seismicity Atlas permitted to more completely and accurately use the instrumental data on earthquakes which is important for all regions of the USSR and, especially, for scarcely-populated regions, the non-instrumental seismic statistics of which is poor. The knowledge of intensity, i.e. of relative energy of earthquakes, as well as of earthquake foci makes it possible to approximately estimate degrees of earthquakes in epicentres. The revealing of a peciliarity of the distribution of different-force foci enables us to use for seismic zoning not only data on destructive earthquakes but also observation data of weak earthquakes. The necessary for this data on earthquakes of last years have been taken from bulletins of the seismic stations of the USSR. The reports on the inspection of the consequencies of strong earthquakes in the past were also used.

A great volume of investigations has been undertaken in the field of seismotectonics both, to study the regional peculiarities of separate regions, and to discover general laws in the relation of seismicity and tectonics. The results of these investigations were used to insert amendments and additions to maps of seismic zoning of the territory of the USSR given in fig. 6.

On the territory of the USSR one can distinguish a few categories of regions with high seismic activity:
a) regions adjoining the boundaries of continental and oceanic zones; for example, a belt in the area of Kamchatka and Kuril Islands;
b) regions of the Alpine geosynclines on the territory of the USSR including the Carpathians, Crimea, Caucasis, Pamirs;
c) platform regions in which beginning from the Tertiary era occur intensive motions, for instance, the regions of Tien Shan and of the Baikal Lake.

On a general map of seismic zoning degrees of earthquakes correspond to mean ground conditions. The majority of populated areas and settlements are located precisely on medium grounds due to which the "zeropoint" of the map of general seismic zoning with respect to grounds stands for the most wide-spread grounds. As a rule, these are sandy soils and loams and analogous depositions.

Contributions to the work on the compilation of the map of seismic zoning of the USSR territory of 1957 on the scale 1-5.000.000 were made, directly or by their materials or papers, by the workers of many research institutes.

3. Seismic Microzoning

The destructive consequencies of strong earthquakes differ, in dependence

on the type of soils representing the foundation of the building, within the boundaries of one town. Therefore, the division of the town territory into regions of different seismicity is called seismic microzoning. The general seismic zoning of the territory of the USSR yields the figure of an expected degree of earthquake for the town as a whole. Different geological and hydrogeological conditions of the town regions may be the reason for assigning to each of them greater of lesser intensity by one degree.

It was established that the change of intensity degree may take place due to: a) difference of elastic properties of grounds, b) presence of ground waters, and c) difference in the depths of soil layers. The methods of seismic microzoning were worked out on the basis of the materials obtained from: 1) the study of the consequencies of strong earthquakes, 2) the measurement of oscillations at different grounds during weak earthquakes, 3) the study of ground oscillations caused by artificial sources.

It was established (7) that the increase of earthquake intensity n_i during the transition from some ground conditions to some others can be determined from the following empirical formula:

$$n_i = 1.67 \left[lg\,(v_0 \rho_0) - lg\,(v_n \rho_n) \right] + b \cdot e^{-0.04 h^2}$$

where: n_i is increment of the earthquake intensity expressed in degrees of a seismic scale for soils with v_n and ρ_n with respect to soils having v_0 and ρ_0 ;
v_n , v_0 – propagation velocities of P elastic waves in soils of natural moisture;
ρ_n , ρ_0 – soil densities;
h – depth of the ground waters level in m.;
b – coefficient depending on the type of ground;
for gravel b = 0.5; for clay and sandy soils b = 1.0.

Basing on experimental data in conformity with the above formula computations have been made of the earthquake intensity n_i for different soils. The nomenclature of points has been adopted in a form adopted in construction practice, say, in determining permissible stress on soil.

The values of increments of earthquake intensity n_i cited in the table have been determined with respect to granite. It is adopted that for granite n_i = 0, so for all other soils n_i have positive values. While carrying out the seismic microzoning the characteristics of medium ground conditions (n_i) are being determined. They correspond to a figure of seismic intensity established by the general seismic zoning of the USSR. The difference between the increments (n_i) n_i serves as a basis for compiling the map of seismic microzoning, tenth parts of the intensity degrees being rounded up to integers of degrees.

The values cited in fig. 3 can be made more accurate from data of temporary and portable seismic stations. In dependence on the type of soils there was introduced correction factor of intensity K_i used to take into account seismic effects on structures. This intensity factor K_i the values of which are given in tab.3 is multiplied by the horizontal seismic force of inertia. If intensity is determined from the map of seismic zoning, the effect spectrum $\mathcal{H}$ and acceleration α_0 must be multipled by factor

K_t depending on the soils.

CONCLUSION

The described quantitative solution of the problem of forecasting seismic effects on constructions including the seismic scale, seismic zoning and seismic microzoning is now only approximate and requires additional accuracy and progress. To improve the forecast of the seismic effects, it is necessary, firstly, to extend the investigations in the field of engineering seismology, and, secondly, to coordinate the efforts of research institutions of different countries.

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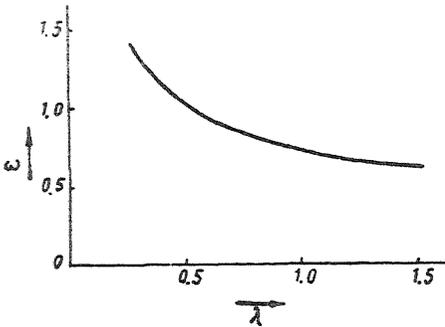
Fig. 1   The graph of the damping
coefficient $\varepsilon = \varepsilon (\lambda)$
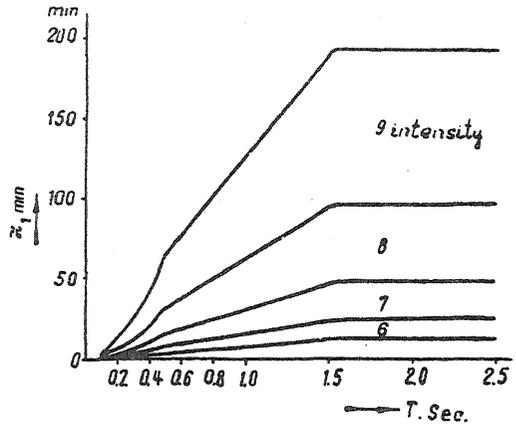
Fig. 2   The value of the effect
spectra $\varkappa$ for earthquakes
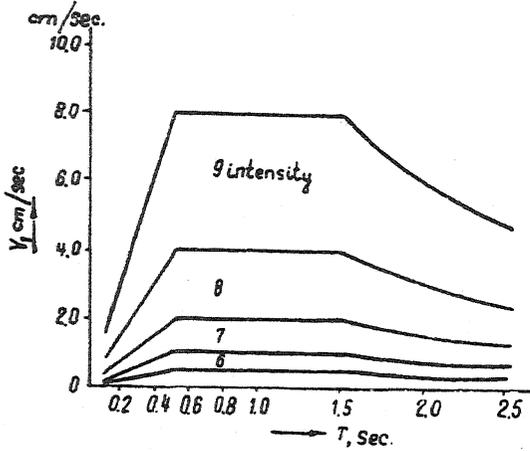of 6 to 9 degrees at $\varepsilon = 1$.

Fig. 3

The values of the oscillation
velocities V_T in cm/sec at
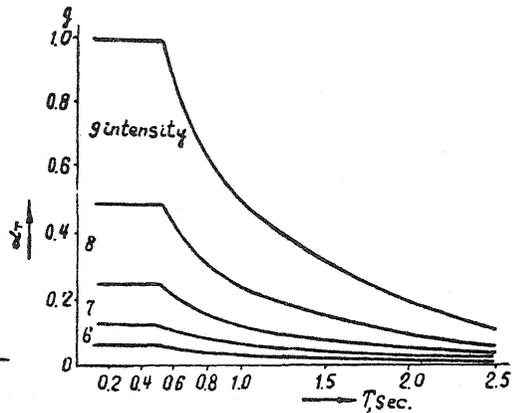$\lambda = 0.5$ for a system with one
degree of freedom.

Fig. 4

The values of the oscillation
accelerations α_T in parts from
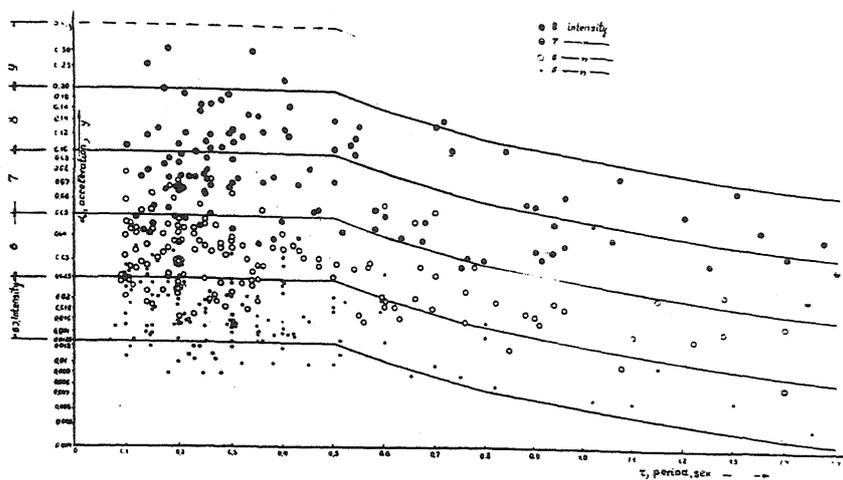g for a system with one degree
of freedom.

Fig. 5   The ratio of accelerations and oscillation
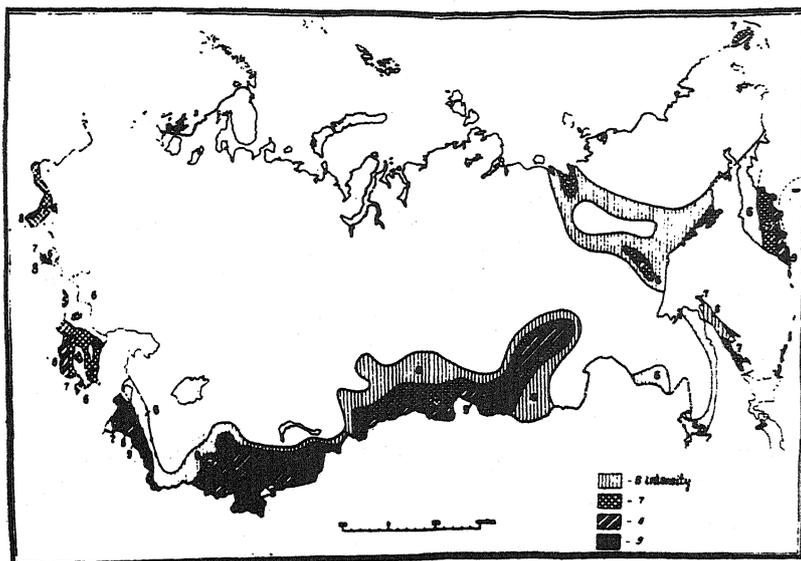periods of ground during earthquakes of
different degrees.

Fig. 6   The map of seismic zoning of the USSR of 1957.

Table 1

The value of x_0 in mm of the displacements
of a spherical elastic pendulum at $T_0 = 0.25$ sec.
and $\lambda = 0.50$ for different intensities.

J, degree	x_0, mm	J, degree	x_0, mm
4	< 5	8	4.1-8.0
5	0.5- 1.0	9	8.1-16.0
6	1.1- 2.0	10	16.1-32.0
7	2.1- 4.0	11	> 32.0

Table 2

The accelerations of the ground oscillations α_0
at periods from 0.1 sec. to 0.5 sec.

J in degrees	Accelerations in parts of gravity g
6	$0.025\,g < \alpha_0 \leq 0.05\,g$
7	$0.05 < \alpha_0 \leq 0.1$
8	$0.1 < \alpha_0 \leq 0.2$
9	$0.2 < \alpha_0 \leq 0.4$

Table 3

The values of increments of earthquake intensity n_i
and intensity factors K_i

Name of soil	v, km/sec	n_i, degrees	K_i
I. Rocky Soils			
Granites	5.6	0	0.3-0.4
Limestones, shales, close gneisses	3.5-4.5	0.2-0.4	0.4-0.5
Close sandstones	2.2-3.0	0.5-0.8	0.5-0.7
Limestones, shales, disturbed sandstones	1.5-2.3	0.7-1.1	0.6-0.8
II. Semi-Rocky Soils			
Gypsum	2.4-3.0	0.6-0.8	0.6-0.7
Marls	2.0-2.6	0.7-1.0	0.6-0.8
Cemented sands	1.4-1.9	1.0-1.2	0.8-0.9
III. Large-Fragment Soils			
Crushed-stone soils and coarse gravels	1.3-2.1	0.9-1.3	0.7-0.9
Gravels(from crystalline rocks)	1.2-1.9	1.0-1.4	0.8-1.0
Gravels(from sedimentary rocks)	1.1-1.7	1.1-1.5	0.8-1.1
IV. Sands			
Gravel and coarse-grained soils	1.1-1.6	1.2-1.4	0.8-1.0
Medium-grained sand	1.0-1.4	1.3-1.6	0.9-1.2
Fine-grained and pulverized sands	0.7-1.2	1.4-1.8	1.0-1.3
V. Clay Soils			
Clays	0.9-1.5	1.2-1.6	0.9-1.2
Loams	0.8-1.4	1.3-1.7	0.9-1.2
Sandy Loams	0.4-1.2	1.4-1.8	1.0-1.3
Sandy Loams and weak Loams	0.5-0.8	1.7-2.1	1.2-1.6
VI. Made and Subsoil Grounds			
Made Soils	0.3-0.5	2.3-2.6	1.9-2.3
Subsoils	0.2-0.3	2.6-3.0	2.3-3.0

Name of soil	$\mathcal{V}$, km/sec	n_i, degrees	K_i
VII. Watered Soils			
Gravels and Coarse Gravels	-	1.6-2.0	1.2-1.5
Sands	-	2.0-2.4	1.5-2.0
Clays (Loams and Sandy Loams)	-	2.4-2.8	2.0-2.6
Made Soils and Subsoils	-	3.3-3.9	3.7-5.6