A STUDY OF THE REACTION OF STRUCTURES UNDER SEISMIC EFFECTS AND THE MUTUAL EFFECT OF STRUCTURES WITH THE GROUND OF THE BASE

by

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SYNOPSIS

Statistical methods have been applied to determine the reactions of structures due to a definite series of earthquakes of similar intensity. As a result several regular features have been revealed.

A rational classification of the accelerograms of earthquakes along their frequency spectra have led to the discovery of the reaction spectra of structures; accordingly, a model of the intensity scale has been suggested which forms a family of envelope curves restricting zones of varying intensity.

A complex picture has emerged displaying the mutual effect of the structures, their action as barriers to the propagation of seismic waves; it has been noted that the mutual effect grows with the increase of the earthquake intensity and the approximation to the state of resonance;

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the role of the mechanism of the earthquake focus and the spectral composition of the vibrations have been likewise demonstrated.

INTRODUCTION

The present paper sets forth in brief issues concerning the estimation of seismic actions on structures, the plotting of a seismic scale and the study of the mutual effect between the structures and their bases (soils). This is accountable in terms of a common method based on the application of the reaction spectrum. A new seismic scale, that would exclude as much as possible intuitive data, bearing on its descriptive part, seems to be a particularly complicated matter. The problem is quite involved and allows for various solutions of which the most optimal should be selected.

The summary is written by B.K.Karapetian and the introduction - by A.G.Nazarov. The part "A study of the statistical regularities of the vibrations of structures during seismic actions" is written by R.O.Amassian and S.S.Darbinian. The part "Seismic scale of intensity based on recorded devices" is written by S.S.Darbinian, while B.K.Karapetian, N.K.Karapetian and S.S.Simonian are the authors of the part "Mutual effect in the transfer of seismic vibrations from ground to structure".

A STUDY OF THE STATISTICAL REGULARITIES OF THE VIBRATIONS OF STRUCTURES DURING SEISMIC ACTIONS

A general approach to the solution of the stochastic theory of seismic stability is based on the transformation of the probabilistic characteristics of vibrations of the earth into probabilistic characteristics of the action of earthquakes in terms of differential equations describing the dynamic state of the structure during an earthquake. In case of a non-linear formulation of the problem serious difficulties arise relating to the mechanism of random functions.

Another approach to the solution of this problem is suggested here [1,3] which is as follows: each destructive earthquake taken singly is looked upon as a determined process. According to the kinematic data of this earthquake (say, by accelerograms) the stress or deformation of the structure or some other parameters are estimated, such as the bending moments and the transverse forces. For the structure under consideration the same operation is repeated relying on the records of other destructive earthquakes. As soon as a substantial number of seismic facts regarding this structure have been obtained one can determine in quite an elementary way the mean value for force, stress and deformation features in addition to the mean-root-square deflections and other probabilistic characteristics that are better specified as the facts grow in number. Viewed from this angle the present paper offers an analysis of the variations of the statistical characteristics of vibrations of the structure regarded as a system of one degree of freedom taking into account the elastic-plastic deformations. The differential equations of the system for various zones of loading and unloading can be expressed as follows [2] :

$$x'' + \frac{2\pi}{T}\alpha x' + \frac{2\pi}{T}\left[(1-\beta_k\lambda)x + \lambda\beta_k x - (1-\beta_k)\bar{x}_k - \beta_k \bar{x}_{k-1}\right] = x_0'' , \quad (1)$$

where x_0'' -is the law of the vibration of the ground, T -is the period of natural vibrations of the system in the elastic stage, α -is the damping coefficient, λ -is the consolidation of the coefficient, β_k -is the constant parameter assuming the values 0 or 1 for various zones of loading and unloading.

The accelerograms of sixteen earthquakes of Intensity VII have been used as initial material. Calculations made on computers have involved ten values of periods of natural vibrations of the system when the damping coefficient $\alpha = 0.1$.

A statistical treatment of the calculation results of maximum values of accelerations and displacements have yielded functions and densities of the distributions of probabilisties for each period of natural vibrations of the structure. Applying the distribution of Gramme-Charles a satisfactory agreement has been obtained between the empirical and theoretical data. Fig.1 shows the average spectra of accelerations in elastic and elastic-plastic solutions of the problem with 95 % confidence limits.

Dependences have also been derived of disperse characteristics of accelerations and displacements on the period of free vibrations of structures in elastic and elastic-plastic solutions of problems.

SEISMIC SCALE OF INTENSITY BASED ON RECORDED DEVICES

The problem of devising a seismic scale based on recorded devices seems real at the present stage of development of theory and practice of engineering seismology. We shall dwell here on one problem of devising the seismic scale using accelerograms of earthquakes and will suggest a means of its realisation by A.G.Nazarov's method [6] .

Let us suppose that we have a number of accelerograms or seismograms of past earthquakes. For those accelerograms we solve with the help of the computer the equation

(1) when the operation of the linear oscillator is still in its elastic stage at a given value of the damping coefficient α and at various values of the period of natural vibrations T. Finally we obtain n spectra of the given seismic acceleration which we tabulate according to their intensity, in this way classifying also the accelerograms used. We include in the given group those spectra which are more or less close too one another as to their degree of accuracy. Thus we get separate groups consisting of a definite number of acceleration spectra. We plot lower and upper envelopes for those groups and in this way we obtain zones to which we can ascribe corresponding intensities. In a proper classification the upper limit of the lower zone must coincide with the lower limit of the consecutive zones. It should be noted that a dispersion will occur between the spectra of the given group through a variation of soil conditions, epicentral distance and so on.

To devise a scale by the method set forth above the number of the accelerograms used is of great significance. This problem is given a positive solution since an adequate number of strong earthquake accelerograms is available now that can be utilized in solving problems. However, even if such accelerograms are not available, the problem can be solved by the method of interpolation of weak earthquakes. In this way when we have definite zones at our disposal we tabulate the accelerogram or seismogram soon after the earthquake and solving (1) we compile the spectrum for the given record; upon which we specify the particular zone where the derived spectrum falls and on this basis we determine the intensity of the given earthquake.

The method we have advanced has been put into practice using twenty-one accelerograms of earthquakes that occurred in the USA, the accelerograms of which are enlisted in S.V.Medvedev's writing [5] . Calculations have been made for the damping coefficient $\alpha=0.16$. Of the twenty-one spectra derived twelve, to which a zone of Intensity VII was assigned, belonged to one group. We assigned Intensity VII to this zone so as the scale obtained were close to the existing one. Next, through lack of accelerograms of stronger earthquakes the zones of earthquakes with Intensities VIII and IX were established with a transition coefficient which was taken to equal two. Those zones are illustrated in Fig.2. This scale can naturally be specified later on as twelve accelerograms cannot be considered adequately for compiling the eventual scale.

The investigations indicate that in addition to the spectral characteristics of earthquakes the classification of accelerograms by their frequency characteristics is of major importance. When they are used it is necessary to bring into one group accelerograms with more or less close predominant vibration periods. The scale derived in our case can be applied to earthquakes with a predominant period less than 0.5 sec. Those problems are considered in detail in [4]. It should be also noted that to give the scale of intensity a final elaboration it is essential to subject the results obtained to statistical treatment.

MUTUAL EFFECT IN THE TRANSFER OF SEISMIC VIBRATIONS FROM GROUND TO STRUCTURE

Reliable data on the seismic load is essential for an estimation of the seismic stability of the building and the structure as well as in prognosing the seismic effect. Meanwhile it is important to estimate properly the variations of the intensity of seismic vibrations during their transmission from the earth to the foundation, i.e. to take into account their interaction. Thus a study of the factor of interaction is of topmost significance in determining the genuine values of seismic forces transmitted to the structure. From this viewpoint it is apparently more proper to study the vibrations of structures in nature during the earthquakes.

G.W.Housner was the first to take notice of the reduction of seismic effect during an earthquake resulting from the interaction of the foundation of the structure and its base [7] . Subsequently this problem was highlighted in numerous theoretical and experimental studies, which regrettably we cannot refer to through lack of space. However it should be noted that despite a number of interesting results obtained, the matter is not cleared completely as yet.

As distinct from the studies carried out so far, aimed at revealing the factor of interaction between the base and the foundation of the structure, when some particular building or structure comes under consideration, we suggest to conduct the investigation on a site where a vast number of buildings and structures are erected. This will provide us not only with an interaction between the base and the foundation of particular buildings and structures but also their mutual effect; worded differently, a complicated picture of mutual effect will emerge. We believe in addition that a number of other factors should also be considered such as the effect of particular waves and the direction from the source of vibrations, the condition of the resonance, intensity, the spectral composition of the vibrations, etc.

We have studied the vibrations of a site containing 4-5 storey buildings with a period of the fundamental tone of free vibrations 0.25–0.40 sec. The layer of the earth underlying the base was made up of sand and pebble depositions with a bearing capacity of 2.5 kg/cm^2. The instruments were installed at a distance of 0.5; 2 and 20 m from buildings variously oriented to action (parallel, perpendicular and under the angle of action) as well as to the foundations of those buildings. Four seismic effects have been analysed: those effects were of Intensity III–V with their epicentral distance over 100 km.

Now let us analyse the experimental data obtained and point out some of the regular features that have been established.

During the first action the measurements were made at building No 1 on the earth in two points at a distance of 20 and 2 metres and also on the foundation of the building along a line perpendicular to the direction of the action. Thus the devices recorded vibrations in three points along two mutually perpendicular components (in the direction of the main axes of the building). It has been revealed that the maximum displacements differ but slightly along the longitudinal and transverse waves both on the earth (at various distances) and in the building (on the foundation).

During the second action the devices were installed in two mutually perpendicular directions along the line of explosion (from the butt of building No 1) and perpendicular (from the façade of the same building). The records were made along two horizontal components parallel to the main axes of the building. A consideration of the values of maximum displacements shows that on the earth they reduce as we draw close to the building from variously remote points. This is particularly noticeable when we analyse the data of the devices installed along the line of the action (along both longitudinal and transverse waves). The difference for vibrations in two mutually perpendicular directions is essential – the great values were obtained along the line of the action. As to the results derived with the help of devices installed across the line of action, no difference in two mutually perpendicular directions was to be noticed for the same points. No differences in the values of maximum displacements on the earth at and within the building have virtually been observed.

The third action is distinctive inasmuch as the devices were installed on the earth, unlike the two preceding cases, close to three buildings variously located in respect of the action and variously remote from them. Around two buildings (Nos 1 and 2) the measurements were made along the line of action while around building No 2 – under an angle of approximately 45°.This action was incomparably weaker than the two previous ones and therefore no appreciable difference was observed in the recordings of the devices installed at various distances from each building. However, it has been established on the other hand that the values of maximum displacements reduce as the buildings under study move farther away from the spot of action. But in this case the distance from the focus could exert no influence since it was quite remote from the building (over 100 km) while the distance between the extreme buildings is 0.4 km in all. Evidently the influence of the buildings themselves is making itself felt in this case which accounts for a reduction of the seismic action.

During the fourth action the devices were set up in front of and behind building No 1 and also in both butt-ends of the building. Prominent was the role of the building as a barrier to the propagation of the seismic waves, viz.getting closer to the building a reduction of the seismic effect occurred at the nearest butt-end. Further, within the building itself the seismic effect remained constant both in the nearest and farthest butt-ends, while it was reduced again on the earth behind the building. It should be pointed out that the values of maximum displacements along the transverse waves came to be much greater (about 2.5 times) than along the longitudinal values.

In this way a complete picture of the mutual effect[1] of buildings is derived, their influence as barriers to the propagation of seismic waves and the increase of the mutual effect with the growth of intensity vibrations has been established.

The interaction of buildings and the earth of the base has likewise been studied by comparing the amplitude spectra of vibrations of the earth with the reaction spectra (with the reduced seismic accelerations) when the damping decrement equals zero; actually those are the vibration spectra of the foundation. To this end amplitude spectra of seismo-explosive vibrations have been derived in various soils and seismic waves in nearby earthquakes. The spectra of the reduced seismic accelerations habe been obtained analytically, using the records of explosions and seismograms of earth - quakes as well as instruments, with the help of multi-pendulum seismometers.

A comparison of the amplitude spectra of seismic waves in earthquakes with respective reaction spectra shows that peaks of amplitude spectra occur over a wider range of

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1 We have introduced the term 'mutual effect' as distinct from 'interaction' which we believe to be more general.

periods than at reaction spectra. However, peaks at reaction spectra are of a more pronounced nature. In explosions a somewhat different picture prevails. The reaction spectra look more like a hyperbole, with quite negligible or without peaks, while strikingly distinct peaks are to be seen at amplitude spectra.

The regular features discovered in this way are accountable in terms of the varying nature of the interaction of buildings and the earth of their foundations in earthquakes and explosions and the difference of the mechanism of their focii.

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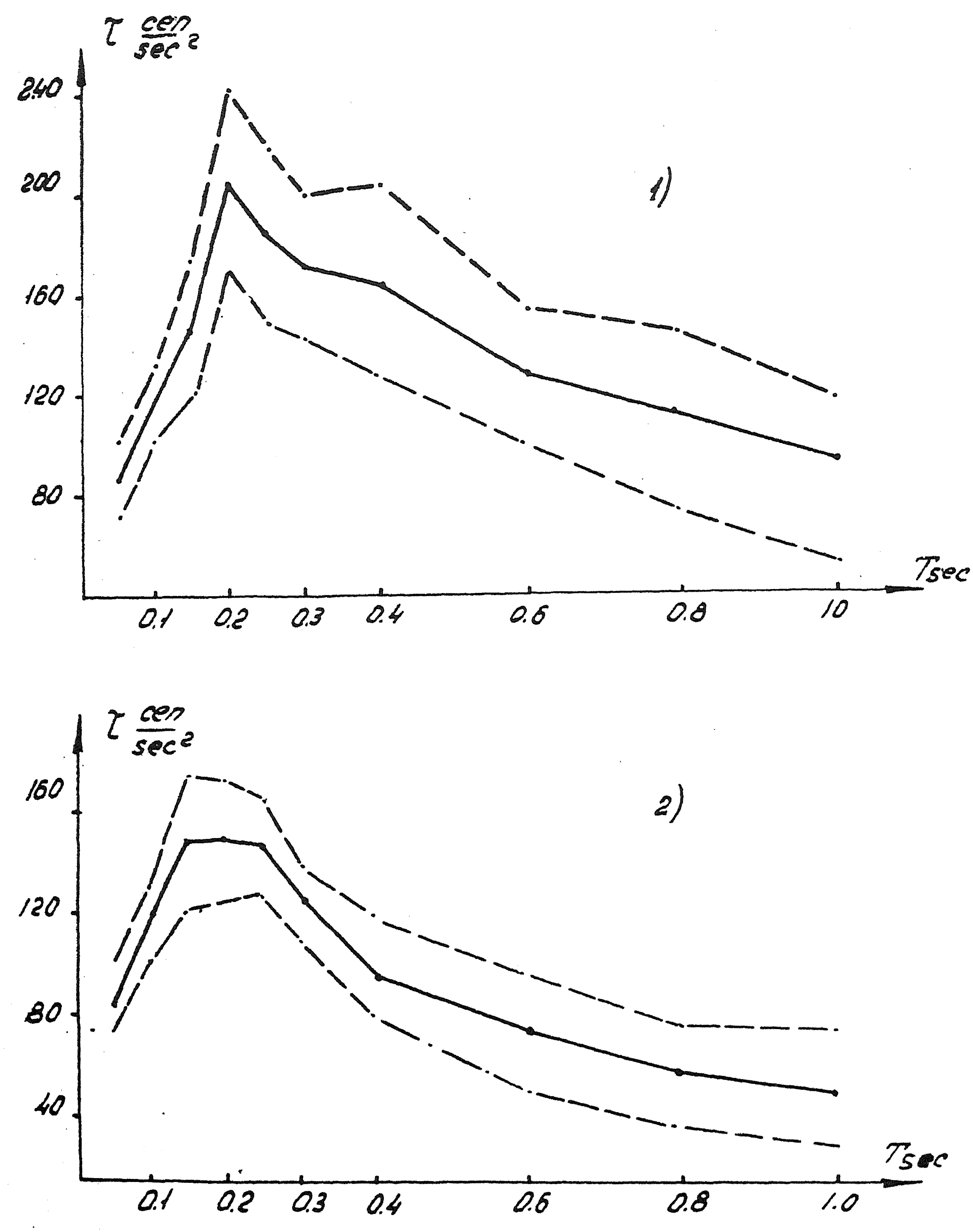

Fig.1 Average spectra of accelerations with 95 % confidence limits:
a) in an elastic solution;
b) in an elastic-plastic solution.

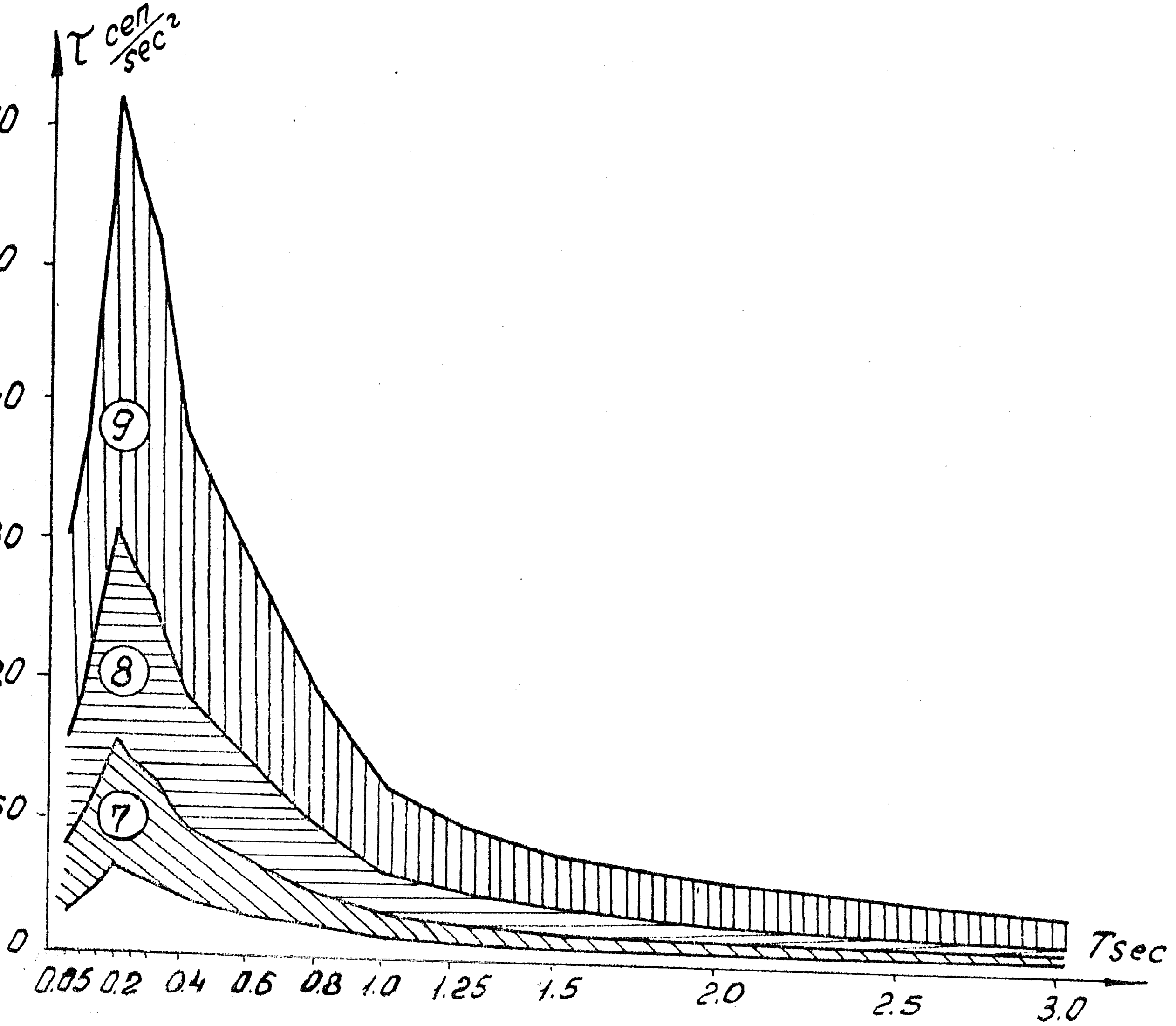

Fig.2 Seismic scale of intensity compiled according to 12-accelerogram earthquakes.