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EARTHQUAKE ACCELERATIONS ESTIMATION FOR CONSTRUCTION CALCULATING WITH DIFFERENT RESPONSIBILITY DEGREES

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ABSTRACT: The investigation object is the design amplitude of accelerograms, which are used in the evaluation of seismic stability of responsible structures, first and foremost, NPS. The amplitude level is established depending on the degree of responsibility of the structure and on the prevailing period of earthquake action on the construction site.

The investigation procedure is based on statistical analysis of 310 earthquakes. At the first stage of statistical data-processing we established the correlation dependence of both the mathematical expectation and root-mean-square deviation of peak acceleration of the earthquake on its prevailing period. At the second stage the most suitable law of acceleration distribution about the mean was chosen. To determine of this distribution parameters, we specified the maximum conceivable acceleration, the excess of which is not allowed. Other parameters of distribution are determined according to statistical data. At the third stage the dependencies of design amplitude on the prevailing period of seismic effect for different structures and equipment were established.

The obtained data made it possible to recommend to fix the level of safe-shutdown (SSB) and operating basis earthquakes (OBE) for objects of various responsibility categories when designing NPS .

1. INTRODUCTION

The analysis of the research of earthquake stability of different structures shows that the results of this research are mostly determined by the type of the expected seismic action used by the author. Most essentially the method of choosing the seismic action influences the expected parameters of the base earthquake isolation.

Three methods of presenting earthquake action are used in the research of earthquake structures stability:

- the set of real acceleration records;
- the collection of synthetic acceleration records;
- the short-time duration process.

The correct usage of all above-maintained methods is to result in identical effects. The analysis of these methods was made by the authors. The recommendations for improving the above mentioned methods of presenting are given in the report. A special emphasis is laid on base isolation structures.

2. THE PECULIARITIES OF EARTHQUAKE ACTION PRESENTING FOR BASE ISOLATION STRUCTURES

When calculating the construction for the package of accelerograms the latter is to meet a diversity of requirements. In the most general case among them are the following:

a) representativeness of the package accelerograms;

b) danger of each accelerogram of the package for the structure class being under consideration;

c) absence of serious distortions in the design accelerograms;

d) an account must be taken of the correlation between the design seismicity, amplitude and prevailing frequency of impact.

The last two requirements are very important for seismoisolation system.

Representativeness of the design package is ensured by selecting accelerograms so that their prevailing periods would closely and evenly cover the range of changing the possible periods of seismic impact. If the range is not known, the prevailing periods must be close to the possible periods of the main tone of the structure oscillations.

The requirement to use only dangerous accelerograms for the constructions of the class under consideration allows to decrease the number of calculations. But when the construction is operating beyond the limits of elasticity the term "dangerous" cannot be clearly formulated. The prolonged one-sided impact is dangerous as regards the progressive destruction, and a great amount of cycles is dangerous with respect to the low-cycle fatigue. The problem of criteria of "dangerous" is most easily solved in linear calculation. If the spectrum of reaction of the accelerogram under consideration is below the envelope of other accelerograms spectra, there is no sense using this accelerogram because its "safety".

Distortions of accelerograms which appear during their recording and quantization may play an important role in calculations of structures. The problem of correct reception of accelerograms has recently been the focus of attention. Ones the seismogram of impact has been specified the accelerogram can be obtained by numerical integration. In this case, the errors of impact for the high frequency component usually occur. The occurrence of these errors is obvious from the design accelerogram which eliminates the possibility of using accelerograms with serious defects. If there is a record of an accelerogram, it is often used in calculations without any corrections. At the same time it is necessary to note the existence of errors in the long-period range in the majority of recorded accelerograms. Among the simplest errors are the shift and rotation of the zero line of the accelerogram. Even small mistakes of such kind may distort the picture of displacement of the object being calculated. Displacements play the principal role when estimating the seismic stability of the seismoisolated structures. That is why it is important to provide the correspondence of real and expected spectra. To estimate the kinematics of base soil isolating foundations it is necessary for remaining displacements of expected seismograms to correspond to real ones. If the real acceleration is absent, an essential criterion which the design accelerograms must satisfy is the following:

$$\frac{\ddot{Y}_{\max}\,\tau^2}{Y_{res}} \geq 0.005 , \qquad (2.1)$$

where $\ddot{Y}_{\max}$ - maximum of acceleration; Y_{res} - residual displacement on the design seismogram; τ - earthquake duration.

If the condition (2.1) for the accelerogram under consideration is not satisfied the latter cannot be directly used for calculations.

There exist some methods which allow to correct the distorted accelerogams. The problems of correction of accelerograms are given in details in the monograph by V.M.Grayzer (1984), where one can find a method of correction which provides the best results according to our own experience.

Consideration of correlation between the amplitude and the prevailing period of impact is as important as other requirements upon the package when selecting the design accelerograms. The more the predominant actions period, the less the amplitude. This question is considered below.

3. ESTIMATION OF CORRELATION BETWEEN THE EARTHQUAKE ACCELERATION AND PREDOMINANT PERIOD

The existence of such correlation is unquestionable and can be found in the works by S.V.Medvedev (1962), Y.M.Eizenberg (1988) and other authors. But in dynamic calculations this correlation is not taken into account.

In the majority of works the design accelerograms are to be rated according to the upper boundary of the magnitude scale or adopted with the accelerations which took place in reality. Such situation is sure to influence the results of calculation. When standardizing the accelerogram of the Bucharest earthquake according to the upper boundary of the magnitude scale, the design accelerations A_{calc} equal to 4,0 m/sec² but in fact they are about 2,2 m/sec². For example, when calculating the seismoisolated non-linear systems the design displacements u in the seismoisolation level are $u = 0{,}8$ m if $A_{calc} = 4$ m/sec² and $u = 0{,}12$ m if $\omega = 2{,}2$ m/sec². It is clear, that standardization for the upper boundary of the seismicity scale provides certain reserves of reliability when calculating structures. Being the individual realization of the random process, the use of separate record with its actual accelerations, cannot be a reliable estimation of the expected impact.

To eliminate the existing contradiction the authors carried out a statistical data processing of more than 300 records of earthquake accelerations and on this basis proposed the following connection between the average amplitudes $\overline{A}$ and the prevailing period of impact:

$$\overline{A} = \left[A\left(e^{-\varepsilon_1 T_{eq}} + C\,e^{-\varepsilon_2 T_{eq}}\right) + B\right] \cdot 2^{I-8} \quad , \tag{3.1}$$

where I - intensity of earthquake on MSK scale; T_{eq} - predominant period of earthquake action; A, C, B, and ε_1 , ε_2 - ratios have been calculated by least square method.

Such dependence has been obtained for the root-mean-square deviation σ_A(fig. 1) with corresponding ratios regression.

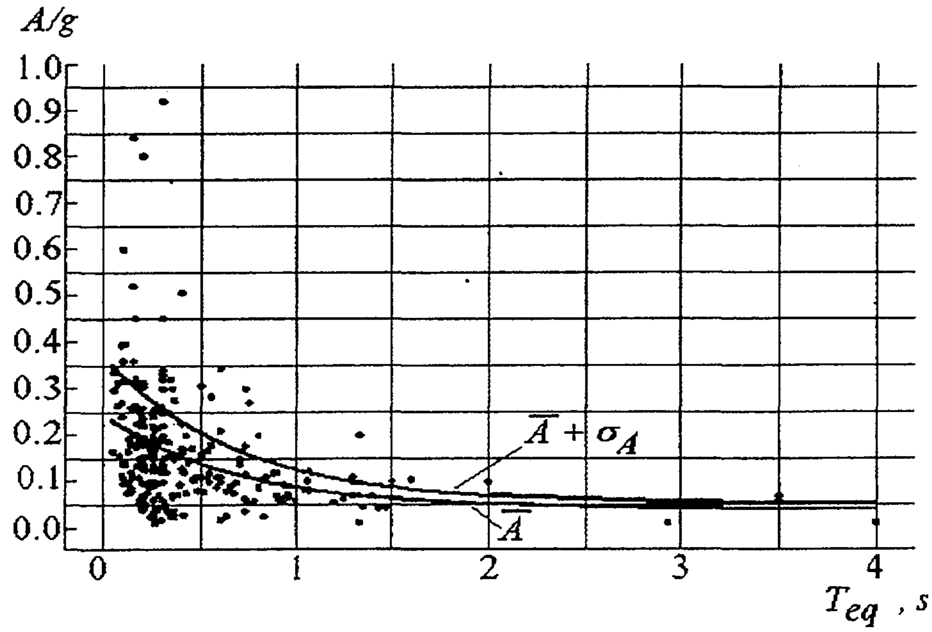

Fig. 1. Dependence amplitude A on period T_{eq}

4. ESTIMATION OF EXPECTED AMPLITUDE OF ACCELERATION

Dependence (3.1) determines the average dependence $\overline{A}(T_{eq})$. To calculate the structures, the value of expected action amplitude is to be taken with a certain margin of safety and is given by $A_{calc} = \overline{A}K$, where $K > 1$. The value K is to be fixed depending on the degree of the structure responsibility, proceeding from the equation:

$$\int_0^{A_{calc}} p(A)dA = 1 - \varepsilon_{calc} \ , \qquad (4.1)$$

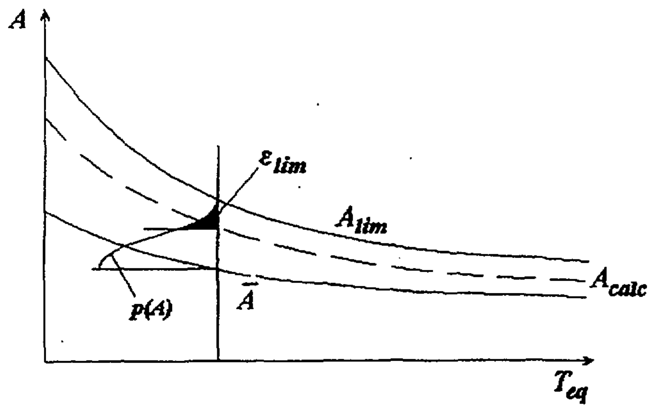

Fig.2. Illustration of A_{calc} definition

where ε_{lim} is the admissible probability of the amplitude exceeding the calculated value by the amplitude and $p(A)$ is the law of amplitude distribution (Fig.2).

Two kinds of the probability density functions were used to analyze the equation (4.1):

1. Veybull probability density function;
2. Pirson probability density function (Beta-distribution).

The first density function is a fast decreasing one and defines the limit amplitude A_{lim} from the equation:

$$\int_0^{A_{\lim}} p(A)dA = 1 - \varepsilon_{\lim} \ , \qquad (4.2)$$

where $\varepsilon_{lim} = 10^{-6}$,

$$p(A) = \frac{\beta}{b}\left(\frac{A-\overline{A}}{b}\right)^{\beta-1}\left[1-\exp\left(-\left(\frac{A-\overline{A}}{b}\right)^{\beta}\right)\right], \qquad (4.3)$$

β and b are distribution parameters.

Value β and b are connected with the average amplitude $\overline{A}$ and root-mean-square deviation σ:

$$\begin{cases} \sigma_A^2 = b\sqrt{\Gamma\left(\frac{\beta+2}{\beta}\right) - \left[\Gamma\left(\frac{\beta+2}{\beta}\right)\right]^2} \\ \overline{A} = b\Gamma\left(1+\frac{1}{\beta}\right) \end{cases}, \qquad (4.4)$$

where $\Gamma(x)$ is gamma-function. The average amplitude $\overline{A}$ and root-mean-square deviation σ_A of the Veybull distribution law are in the right part of the equation (4.4). In this case the equation (4.1) has been obtained as follows:

$$\exp\left[-\left(\frac{A-\overline{A}}{b}\right)^{\beta}\right] = \varepsilon \ . \qquad (4.5)$$

The second density function is limited by the *a priori* fixed value of A_{lim}:

$$p(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}x^{\alpha-1}(1-x)^{\beta-1} \ , \qquad (4.6)$$

where α and β are distribution parameters.

Value A_{lim} is based on the seismological conditions of the site and the results of numerous seismic observations.

It is convenient to use dimensionless accelerations $x = \frac{A(T_{eq})}{A_{\lim}(T_{eq})}$. In this case $x_{lim} = 1$, $\sigma_x(T_{eq}) = \frac{\sigma_A(T_{eq})}{A_{\lim}(T_{eq})}$ and $\bar{x} = 0.25$.

The distribution parameters α and β are calculated from the following equations system:

$$\begin{cases} \bar{x} = \dfrac{\alpha+1}{\alpha+\beta+1} \\ \sigma_x^2 = \dfrac{\alpha\,\beta}{(\alpha+\beta)^2(\alpha+\beta+1)} \end{cases} \tag{4.7}$$

According to (4.7)

$$\alpha = \frac{3\bar{x}^2}{4\sigma_x^2} - 0.25 \quad \text{and} \quad \beta = 3\,\alpha .$$

In this case equation (4.1) has been obtained as follows:

$$\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\,\Gamma(\beta)} \int_o^{x_{calc}} x^{\alpha-1}(1-x)^{\beta-1}\,dx = 1-\varepsilon\ , \tag{4.8}$$

where $x_{calc} = \frac{A_{calc}}{A_{\lim} A}$.

As a result of the above calculations we obtained the dependencies of distribution parameters and value A,~. on the predominant period T.". These dependencies are illustrated in fig.3 for Veybull law distribution.

It is necessary to stress the difference between the dependencies of $A_{lim}(T_{eq})$ for Veybull and Pirson distributions (Fig.4). But these differences don't affect the A_{calc} value. It can be

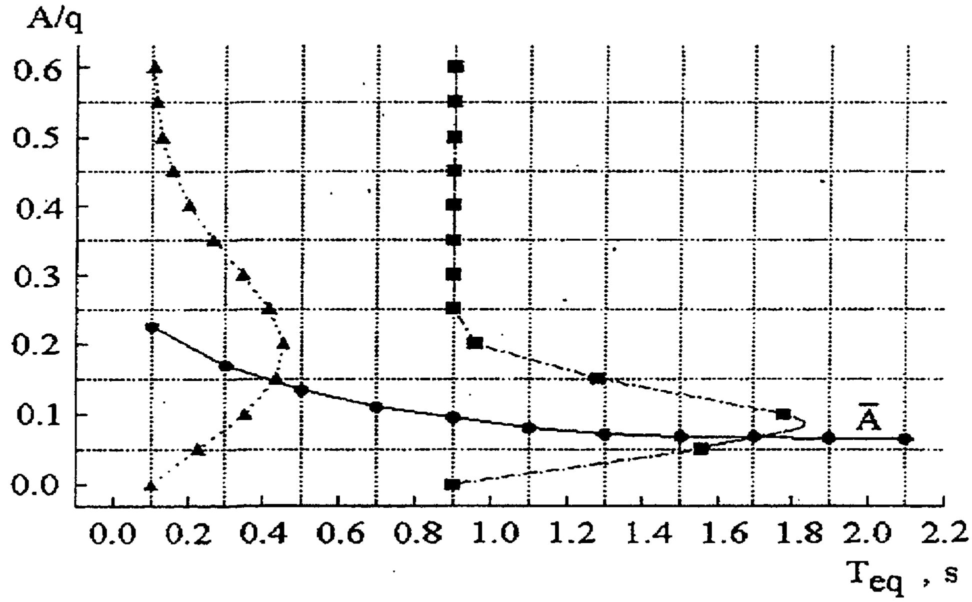

Fig. 3. Veybull distribution function for value of T_{eq}
▲ - for $T_{eq} = 0.1$ s ; ■ - for $T_{eq} = 0.9$ s

seen in fig.5, where dependencies $A_{sse}(T_{eq})$ for both distribution laws are shown. In fig.6. the dependencies of acceleration level on value T_{eq} for Veybull law are presented.

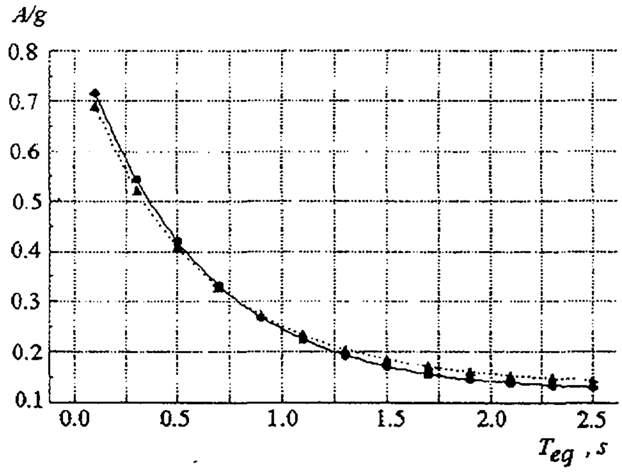

Fig.4. Dependencies A_{sse} on T_{ea}
▲ - *for Pirson low;* ● - *for Veybull law*

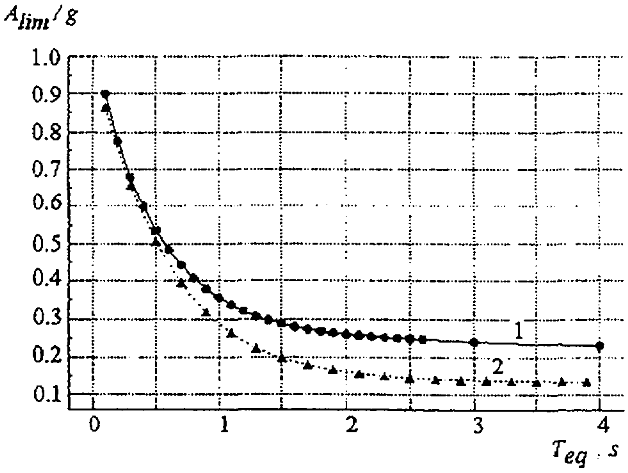

Fig.5. Dependencies A_{lim} on T_{ea}
1 - for Pirson law; 2 - for Veybull law

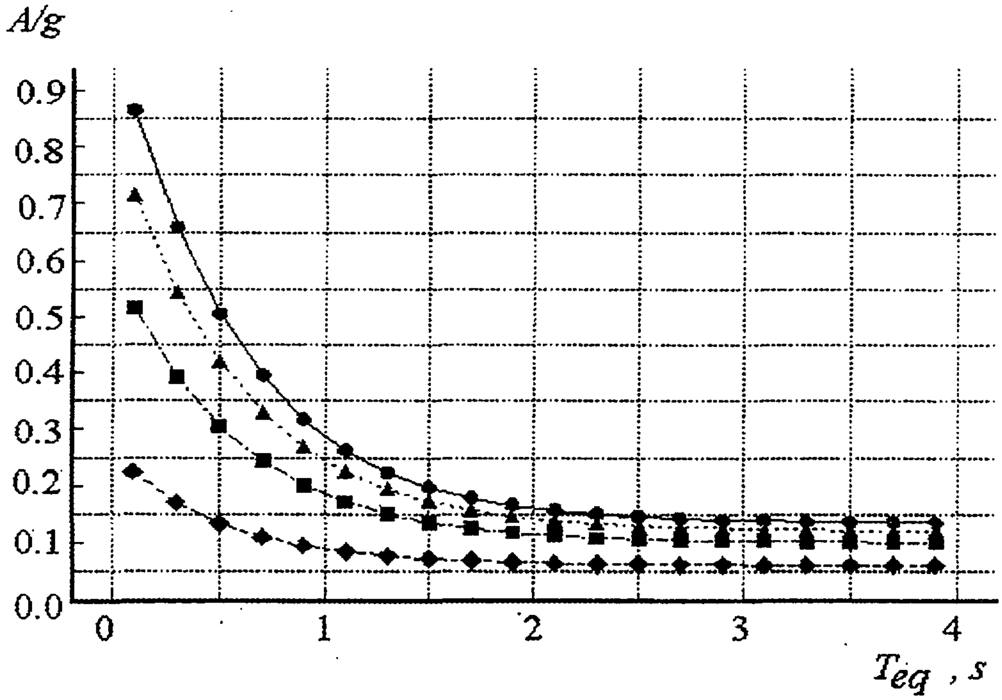

Fig.6. Dependencies of accelerations level on value Teq for Veybull law
● - A_{lim} ; ▲ - A_{sse} ; ■ - A_{obe} ; ◆ - $\overline{A}$

5. THE SHORT-TIME DURATION PROCESS FOR EARTHQUAKE MODELING

The superposition of three or two damping sinusoids are offered for modeling earthquake velocity:

$$\dot{Y} = \sum_{i=1}^{3} A_i \, e^{-\varepsilon_i t} \sin(\omega_i t) \; . \tag{5.1}$$

The frequency ω_1 is taken as equal to the main frequency of earthquake and ω_2 - as equal to the first, i.e. main, natural frequency of the structure. The frequency ω_3 is taken as equal to the frequency which is important for the structure element.

The values of A_i, ε_i are determined by using the following conditions:

$$Y(0) = \dot{Y}(0) = \ddot{Y}(0) = 0 \ , \qquad (5.2)$$

$$\ddot{Y}_{\max} = A(\omega_1) \ , \qquad (5.3)$$

$$\frac{Y_{\max} \dot{Y}_{\max}}{\ddot{Y}_{\max}} = 6 \ , \qquad (5.4)$$

$$\frac{\ddot{Y}_{\max} \tau^2}{Y_{rez}} \geq 0.005 \ , \qquad (5.5)$$

$$\dot{Y}(\tau) < 0.001 \ . \qquad (5.6)$$

Under these conditions $A(\omega)$ is the dependence of A_{calc} on ω_1 according to (5.2). $\ddot{Y}_{\max}$, $\dot{Y}_{\max}$, Y_{max} are the greatest values of the earthquake acceleration, velocity and displacement respectively; Y_{rez} - residual displacement; τ - earthquake duration . The condition (5.4) was taken according to USA standard. Our calculations indicate that it is possible to use only one of the conditions (5.3) or (5.4). The condition (5.5) was taken according to prof. O.A.Savinov proposals. It allows to exclude the acceleration records with unreal residual displacement. The condition (5.6) provides the equilibrium of acceleration records (the absence of movement after the earthquake is over).

The experience of using the presented short-time duration processes has shown that all structure forces were somewhat stronger than the similar forces which had been obtained while using natural earthquakes records.

6. CONCLUSION

As the result of this research the recommendations for calculating the base isolation structures for some regions of Russia, in particular, for Kamchatka for bridges and old buildings in operation and for base-isolation nuclear power plants located near St-Petersburg and on the Kolsky peninsula, have been worked out.

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