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SPECIFICATION OF DESIGN SEISMIC EFFECT LEVEL AT EVALUATION OF SEISMIC STABILITY OF RESPONSIBLE STRUCTURES

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ABSTRACT

The goal of this study is to develop methods of definition of design amplitude of accelerogramms, which are used at evaluation of seismic stability of responsible structures, first and foremost NPS. The level of amplitude is established depending on the degree of structure responsibility and prevailing period of seismic input on the construction site.

The investigation strategy is based on statistical analysis of 310 earthquakes of magnitude 6-9. As a result of this analysis the dependence of peak amplitudes of seismic accelerations on the prevailing period of effects is constructed. In the basis of this dependence recommendations for rate setting of design accelerogramm amplitudes were developed for calculation of NPS structures and equipment of various degrees of responsibility for three modes of design effect definition: - using a package of real accelerogramms for calculation; - simulating the effect with random processes; - using the synthetic accelerogramm as short time process;

At the first phase of statistical processing there was installed the correlation dependence of mean value $\overline{A}$ and root-mean-square deviation σ of maximum earthquake acceleration from its prevailing period.

At the second phase there was specified the law of acceleration A distribution around mean value. In the investigation performed there were used Weibull and Pirson's distribution laws.

At the third phase the dependencies of design amplitude with preset probability of design value excess on the prevailing period of seismic effects are established.

The results of these investigations allowed to recommend the level of the safe-shutdown and operating basis earthquakes for objects of different responsibility categories when designing the NPS.

KEYWORDS

Seismic input, amplitude, period, dependence, distribution law, short time process, responsible structures (NPS).

INTRODUCTION

For designing the special responsibility structures, i.e. NPS, taking into account the possible excess of design level of seismic input is of special importance.

The main problem is to select the distribution law of seismic accelerations peaks. Thus for responsible structures behavior of distribution function at large values of argument (effect amplitude) is especially important. Earlier the normal probability law as a function of distribution was widely used. But when designing the specially responsible structures, such as NPS, if the excess of amplitude of design value 10^{-4} is allowed the usage of such a law follows in impractical value of design accelerations exceeding several g.

To neutralize this paradox [Beliaev et al., 1995] there had been proposed to use restricted statistical laws, thus, limitation of peak accelerations of seismic input was specified taking into account the seismological conditions of a construction site.

MODES OF DESIGN EFFECT DETERMINATION

As there was noted already, there exist three design effect determination modes, which in one or other form ensure the conformity of design and real accelerogramms,accurate use of which should lead to identical results.

Under the first two modes when creating the accelerogramm package a set of real (mode 1) or synthetic (mode 2) accelerogramms is taken as base, spectral-composition representative set for which the level of design effect (acceleration peak for each design accelerogramm) should be preset.

The problem of design effect level determination is reduced to determination of maximum conceivable acceleration of earthquake A_p at prevailing period Teq and preset probability of excess e.

As is known, the value of design acceleration A_p an be specified on the basis of the condition:

$$P(A_p) = \int_0^{A_p} p(A)dA = 1 - \varepsilon \qquad (1)$$

where P - distribution function (DF) of random value A,
p - distribution density function (DDF) of random value A,
e - allowable probability of design value excess.

When analyzing the equation (1) the dependence of peak amplitude of earthquake accelerations on its prevailing period is of fundamental importance. The Norms and Standards determine the upper boundary of accelerations of specified intensity value. For example, for magnitude 9 this boundary is - 4 m/c^2, and for 8 - 2 m/c^2. As a result, the structures are designed for upper boundary of the scale, i.e. for the areas of magnitude 9 it is 4 m/c^2. Nevertheless the actual acceleration for the earthquakes of magnitude 9 can be considerably less, for example, disastrous earthquake in Bucharest (1977) had peak acceleration of about 2 m/c^2. In literature there repeatedly was noted the fact of peak accelerations decrease with the increase of prevailing period of seismic effect. This laws served as a base for further studies (A.A.Dolgaya et al., 1993; A.M.Uzdin et al., 1993). To do it we had conducted gathering and processing of information on the amplitudes and prevailing periods of destructive earthquakes. All in all there were processed about 300 accelerogramms. As a result of such processing the there was calculated the regressive dependence of seismic accelerations amplitude on the prevailing period of effect which is as follows:

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

where I - rate of earthquake as per MSK-64 scale;

T_{eq} - prevailing period of seismic input;

A, C, B, ε_1 and ε_2- regression coefficients, dependent on the degree of the structure responsibility and designed by the least squares method. Dependence (2) had been received for mathematical expectation $\overline{A}$ and root-mean-square deviation σ_A. Regression coefficients are the values:

for mathematical expectation $\overline{A}$ (T_{eq})

$A = 0.171619$, $B = 0.06008$, $C = 0.19$, $\alpha_1 = 1.8$, $\alpha_2 = 4.1$;

for root-mean-square deviation

$A = 0.095206$, $B = 0.018025$, $C = 0.15$, $\alpha_1 = 1.7$, $\alpha_2 = 1.65$.

The regressive dependencies received confirm the noted relation between the acceleration amplitude and the prevailing period of effect and permit to take this relation into consideration when constructing the proposed DDF. For taking into account the limitation of peak acceleration DDF there was developed two approaches to determination of design acceleration level for foundations of NPS and other responsible structures:

- Usage of quickly attenuated distributions;
- Usage of restricted distributions.

The first approach is based on the theorem V.V. Bolotin (1961) on the distribution of peaks, in accordance with which the random values peaks (in our case the acceleration peaks) are distributed as per the distribution law of first order maxima (under the Weibull's law). Thus, the DDF of peak acceleration A around its mean is described with the following equation:

$$p(A) = \frac{\beta}{b}\left(\frac{A-\overline{A}}{b}\right)^{\beta-1} P(A), \tag{3}$$

here P(A) - is Weibull's DF, which is as follows:

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

β - parameter of shape; b - parameter of scale.

This law is two-parametrized one and its parameters β and b are uniquely determined with values $\overline{A}$ and σ, which are calculated according to the formula (2).

Condition (1) for determination of required amplitude with the use of Weibull's distribution law assumes the form:

$$\exp\left[-\left(\frac{A-\overline{A}}{b}\right)^{\beta}\right] = \varepsilon \tag{4}$$

Main peculiarity of the DDF accepted is its high-speed attenuation with the increase of A, that permits to consider the given law as a restricted one. At the same time the extreme possible acceleration values are not specified a priori and are derived automatically.

The second approach is based on the use of Pirson's three-parametrized DF, which requires additional a priori setting of extreme value of peak accelerations A_{lim}. Parameters of such function distribution can be found on the values $\overline{A}$, σ_A and A_{lim}.

For realization of the second approach there was used the Pirson's distribution law of the first order (Beta-distribution), for which DDF is presented as follows:

$$p(x)=\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\,\Gamma(\beta)}x^{\alpha-1}\cdot(1-x)^{\beta-1} \qquad (5)$$

Here $\Gamma(x)$ - is a gamma-function; $x = A(T_{eq}) / A_{lim}(T_{eq})$ - dimensionless amplitude of accelerations. Transition to dimensionless variable permits to cut down the number of parameters of DDF up to two, as in this very case $x_{lim} = 1$ for all values T_{eq}.
Condition (1) for determination of required amplitude with the use the Pirson's distribution law receives the form:

$$\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\,\Gamma(\beta)}\int_0^{x_p} x^{\alpha-1}\cdot(1-x)^{\beta-1}dx=1-\varepsilon \qquad (6)$$

where $x_p=\dfrac{A_p}{A_{lim}}$.

For determination of A_p of the solution of equations (4) and (6) is required. These equations had been resolved with numerical methods. Calculations were performed in cycle within the range of prevailing periods of earthquakes from 0 up to 3 in steps 0.1s.

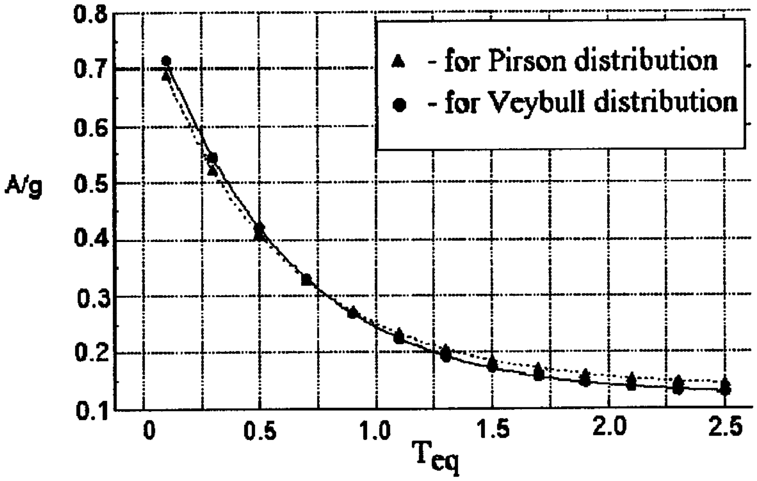

Fig.1. Dependence A_{sse} on T_{eq}

As a result of calculations for various values of prevailing periods T_{eq} there were received the parameters of DDF of acceleration peaks and design acceleration for two values ε - 0.01 (OBE) and 0.0001 (SSE). For comparison of results on Fig.1 there are given the dependencies $A_{sse}(T_{eq})$, corresponding to the distribution laws under consideration. From the figures one can see, hat a priori determination of value A_{lim} affects insignificantly the acceleration range of safe-shutdown earthquake (SSE).

The results of investigations had shown, that for specially responsible structures the SSE accelerations A_{sse} should correspond the accelerations which are maximum conceivable according to seismological conditions on the construction site A_{lim}. Depending on the degree of structure responsibility (values of permissible probability of excess are ε) the values A_{obe} and A_{sse} can be lowered.

The most substantial for design of seismic isolation foundations are the installed dependencies $A_{obe}(T_{eq})$ and $A_{sse}(T_{eq})$. These dependencies permit to lower the level of design loads on seismic isolated objects with low-frequency seismic isolation system.

Proposed dependencies $A_{obe}(T_{eq})$ and $A_{sse}(T_{eq})$ are based on statistical material which is wide enough and can be recommended for designing the conventional NPS structures, including those with seismic isolation foundations. When designing NPS on particular sites the level of design effect can be lowered due to the use "local" accelerogramms and reduction of data variation.

SIMULATION OF INPUT WITH SHORT-TIME PROCESS

For isolated structures designs the most convenient is the short-time process. For simulation of input with short-time process we has used velocigramm approximation with two or three attenuated sine lines:

$$\dot{Y} = \sum_{i=1}^{3} A_i e^{-\varepsilon_i t} \sin(\omega_i, t) \qquad (7)$$

The frequency of the first sine lines is accepted as equal to the prevailing frequency of effect, and the frequency of the second sine line - to the frequency of main structure tone. In such a manner, for each structure a synthetic design accelerogramm appears to be different. Besides, such approach takes into account simultaneity of the of base and structure operation.
In the process simulated the required onesare amplitudes A_i and attenuation parameters ε_i. These parameters should be specified as to ensure the conformity with real processes. To do it there had been formulated two groups of conditions, which are performed for real accelerogramms and should be performed for the process in question.

The first group of conditions - disparity conditions. 1.First disparity borders speed at the end of earthquake. This condition is recorded with the following disparity :

$$V\big|_{t>T} < \varepsilon \qquad (8)$$

where ε - small value, T - duration of active oscillations.
In the conducted calculations there is accepted T = 17.5 s., ε =0.0001 m/s.
2. The second disparity bounds the residual displacements Y_{res} on the model seismogram.

$$\frac{y_{res}}{\ddot{y}_{max}\tau_{eq}^{2}} \leq 0.005 \qquad (9)$$

here t_{eq}- duration of earthquake. The second group of conditions - equality conditions.

1. The first equality corresponds to the zero equality of accelerations speeds and displacements of the system in initial instant of time:

$$Y(0) = \dot{Y}(0) = \ddot{Y}(0) = 0, \qquad (10)$$

2. The second equality is the correlation relation installed between amplitude of the effect and prevailing period of earthquake A (T_{eq}).

The third equality is based on the american investigators data, according to which there is a correlation relation between the peaks of displacements, speeds and accelerations, expressed by the relation:

$$\frac{y_{max}\,\ddot{y}_{max}}{\dot{y}_{max}^{2}} \sim 6 \qquad (11)$$

This dependence is recommended to be used when selecting the synthetic accelerogramms in design standards of nuclear reactors USA.

4.The last, fourth equality is accepted according to the following reasons. For designing the structures the valid Norms and Standards of Russia determine the dynamic coefficient value. The condition is reduced to coincidence of the dynamic coefficient β bat the value of period T, which is equal to the period of structure T_s, with the standard value of dynamic coefficient βo. This requirement could be written as follows:

$$\beta(T_c) = \beta_o \qquad (14)$$

where $T_s = 2\pi / \omega^2$.

To solve this problem the test calculations were conducted.

CONCLUSION

Analysis of given results permits to determine the following:

1. Distribution parameters depend on substantially prevailing period of seismic input T_{eq}. With increase of T_{eq} not only the mean of acceleration peak $\overline{A}$, but also its root-mean-square deviation σ_A decreases. In accordance with variations of values $\overline{A}(T_{eq})$ and σA (T_{eq}) other parameters of DDF alter as well. This fact is rather important when designating the design level of seismic input.

2. The received values $A_{obe}(T_{eq})$ and $A_{sse}(T_{eq})$ make up respectively (1.7...2) $\overline{A}$ and (2 ...3) $\overline{A}$, and the value of coefficient of transition decreases with the growth of period. Comparison with the Norms and Standards which are actual in Russia, shows that OBE with prevailing period more than 0.5 s meet the requirements of the standards. For more high-frequency earthquakes the OBE level exceeds a standard. Relation of SSE and OBE level makes up to 1.7...1.9, which as a whole corresponds to domestic and foreign standard recommendations, where this relation is determined as two.

3. Proper taking into account the peculiarities of seismic input with observance of the proposed principles results in identical results independently of accepted peak acceleration DDF.

4. The offered model of short-time process permits to take into consideration both the regional peculiarities of construction site, and dynamic characteristics of the construction itself and permits to conduct large-scale designs of various structures at the initial stage of their parameters selection.

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