RESPONSE SPECTRA FOR CALCULATING SEISMIC LOADS

V.T. Rasskazovsky I)

SYNOPSYS

Response spectrum technique for aseismic design of structures is widely used but a theoretical approach to the definition of the real shape of response curve meets with difficulties, because spectral densities of separate realizations are random functions which can not represent the seismic process on the whole. In this paper a probabilistic approach is presented to the derivation of the upper estimate of response spectra for design purposes. If an additional information about predominant earthquake frequency in a given site is available, regional response curves can be plotted, leading to more precise and more economic design. Some examples of such curves are given.

The researches [1] show that a steady upper estimate of seismic acceleration spectrum gives the envelope of spectral density functions i.e. the curve passing through the points of their maxima.

On the base of exponential-cosine approximation of autocorrelation functions of accelerograms a semi-empirical formula for the envelope of normalized spectral density functions had been obtained [1] .

$$S(\omega)=\frac{2\,(0.28\,\omega^3+1.62\,\omega^2+0.27\,\omega+0.512)}{(1.98\,\omega^2+0.224\,\omega+0.64)^2-3.84\,\omega^4} \qquad (1)$$

Seismic response spectrum of an undamped system can be defined from the relation

$$|S_x(i\omega)|=\omega\,|S(i\omega)| \qquad (2)$$

I) V.T. Rasskazovsky - Sc.D., Manager of a Laboratory, Research Institute of Mechanics and Earthquake Engineering, Tashkent, UzSSR.

where $|S(i\omega)|$ - input amplitude spectrum - can be approximately expressed by spectral density function $S(\omega^2)$

$$| S(i\omega)| \doteq \sqrt{t_n S(\omega^2)} \qquad (3)$$

t_n - the duration of process.

The dynamic coefficient β is the ratio of the maximum absolute acceleration of the system to the maximum absolute acceleration of the ground

$$\beta = \frac{\sigma / S_x /_{max}}{/ W_0 /_{max}} \qquad (4)$$

By means of numerical analysis the mathematical expectation of the ratio of the maximum absolute acceleration $/W_0/_{max}$ to the standard of accelerogram had been found to be equal to 4,4 [1].

From (1), taking into account (2,3 and 4), the following expression for the coefficient β had been derived, which has the sense of the envelope of values of β corresponding to a set of realizations

$$\beta_0(\omega) = 1.07\omega \sqrt{\frac{0.28\omega^3 + 1.62\omega^2 + 0.27\omega + 0.512}{(1.98\omega^2 + 0.224\omega + 0.64)^2 - 3.84\omega^4}} \qquad (5)$$

An empirical relation of the maximum seismic response and the damping ratio of the system had been found by averaging the corresponding data of many real, as well as of D.E. Hudson's eight simulated accelerograms [2] , what led to the following approximate expression

$$\mathcal{K}(T,\delta) = \frac{/S_x(\delta)/_{max}}{/S_x(0)/_{max}} = a - b e^{-cT} \qquad (6)$$

$S_x(\delta)$ - seismic response of a system with logarithmic decrement of damping δ (damping ratio $n = \delta : 2\pi$).

$S_x(0)$ - seismic response of an undamped system.
The constants are given in the table below

For damped systems

$$\beta(\omega;\delta) = \mathcal{K}(T,\delta)\,\beta_0(\omega) \qquad (7)$$

Curves of $\beta(\omega;\delta)$ are plotted on Fig. 1 for three values of δ: 0.15; 0.30 and 0.5. The design curve of β of the USSR building code is given for comparison as well as $\hat{C}'$ curve which is the USA building code coefficient $\hat{C}$ [3] reduced to eight degree earthquake intensity of USSR scale:

$$\hat{C}' = \hat{C} : 0.05 = (\sqrt[3]{T})^{-1}$$

The formula (7) corresponds to the complete absence of information of earthquake properties in a given region, i.e. to the assumption of equal probability of earthquakes with different frequency characteristics and intensities.

If an additional information of the probability of fifferent kinds of earthquakes be available the formula (7) must be changed so as to decrease the design dynamic coefficient for the earthquakes of small probability. Let us consider the case of a given probability density function of spectral density maxima of regional earthquakes within the frequency range.

It is obvious that the design response value can not be proportional to the probability because of a great danger of buildings collapse in case of earthquake of small or zero probability.

On the other hand the small probability must be taken into account by corresponding reduction of seismic protection within safe limits.

Many observations lead to the conclusion that if the seismic protection of a building is one degree less than the intensity of the occured earthquake, the building does not fail and can be restored by the application of the well known technique (one degree of intensity means a two-fold reduction of design seismic load).

From this consideration the following method had been adopted. Let the value of the probability density of earthquake with frequency parameter $\hat{\beta}$ be $f(\hat{\beta})$(i.e. of earthquake having spectral density maximum at the period $T = 2\pi : \hat{\beta}$). A complex function $\varphi[f(\hat{\beta})] = g(\hat{\beta})$ is introduced, such that $g(\hat{\beta}) = 1$ for the maximum value of $f(\hat{\beta})$ and $g(\hat{\beta}) = 0.5$ for zero value of $f(\hat{\beta})$. Then the design spectrum of can be taken proportional to $g(\hat{\beta})$.

$$\beta(\delta, f) = g(\hat{\beta})\, \beta(\omega; \delta) \tag{8}$$

Two examples of regional dynamic coefficients β are shown on Fig. 2 and 3. A truncated normal probability distribution for $f(T)$ is adopted with maximum value at on the Fig. 2 and $T_0 = 0.6\,s$ on Fig. 3. The distribution standard σ is defined from the condition that the probability density decreases two-fold at $T = 2T_0$.

The function $g(\hat{\beta})$ is taken as

$$g(\hat{\beta}) = 0.5\left[1 + exp\left(1 - \frac{f_{max}}{f(\hat{\beta})}\right)\right]$$

Graphs are plotted in coordinates ($T = 2\pi : \hat{\beta}, \beta$).

The design curve of β in USSR building code does not encompass all possible kinds of earthquakes in low-frequency range and sufficiently conforms with the regional graph $T_0 = 0.3\,s$.

USA building code coefficient $\hat{C}$ is almost similar in shape to the general dynamic coefficient curve but its level is essentially lower.

The procedure above may vary accordingly to the additional information about regional earthquake properties.

The graphs on Fig. 1 can serve as an upper estimate of seismic response at design level of intensity. Fig. 2 and 3 show that even a minimum information about the properties of earthquakes leads to the essential change of the design response curve and affords the possibility of more economic design. The three graphs relative to different damping ratios of systems enable more precise definition of seismic loads.

BIBLIOGRAPHY

1) Rasskasovsky V.T., Principles of Physical Methods of Determination of Seismic Response, Publ. House "Fan" UzSSR, Tashkent, 1973.

2) Hudson D.E., Equivalent Viscous Friction for Hysteretic Systems with Earthquakelike Excitation, 3 WCEE, 1965.

3) Claugh R.W. and Penzien J., Dynamics of Structures, Mc. Grow-Hill Book Com., 1975.

The table

δ	a	b	c
0.15	0.75	0.40	2.32
0.30	0.65	0.47	2.10
0.5	0.52	0.41	2.60

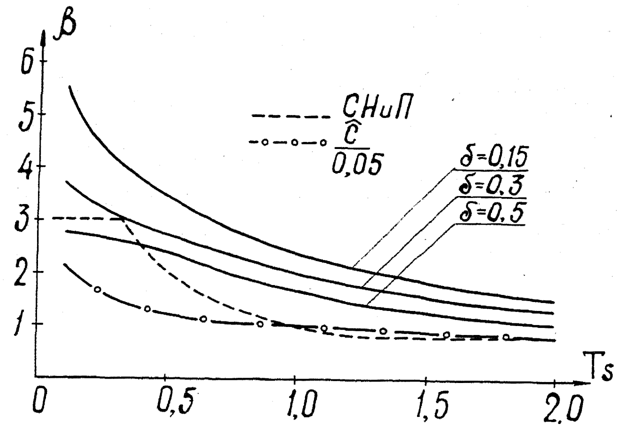

Fig. 1. General Response Curves.

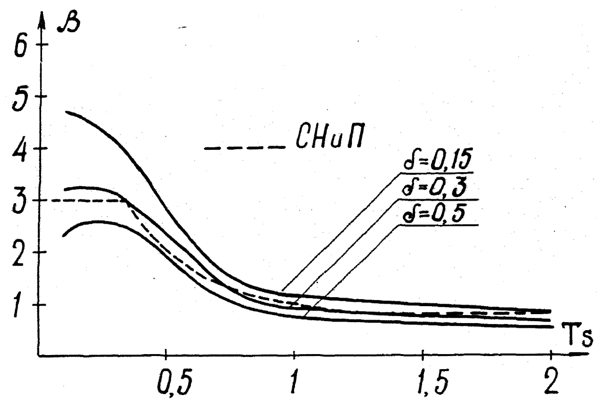

Fig. 2. Regional Response Curves, T_o = 0,3s.

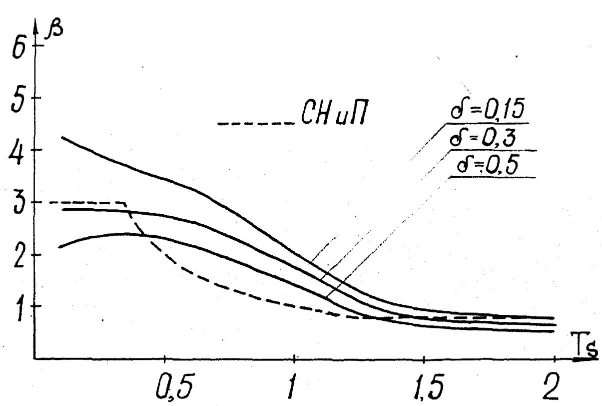

Fig.3. Regional Response Curves, T_o= 0,6 s.