ON THE PROBLEM OF DETERMINING LOSS VALUE DUE TO EARTHQUAKES

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The problems associated with earthquake-proof construction economics and, consequently, with seismic risk acquire more urgent importance.

Under the notion "seismic risk" we understand the probability of damages, losses connected with seismic hazard - over a certain period of time.

It should be noted that studies connected with seismic risk arouse growing interest and find wide application. This seems to be facilitated by:

1) widespread recognition of statistical outcomes based on probability assessment of certain outcomes in engineering directions, and particularly, in earthquake-proof constructions;

2) damage associated with earthqukes is not reduced with time though safety of occupants in modern buildings constructed according to the earthquake-proof buildings codes is much higher than in the old ones.

3) development of statistical seismology with accumulation of facts and generalizations concerning reiteration, shakeability and other probability characteristics of seismic activity. It is natural that availability of such data though not very accurate and reliable provides prerequisites though not for their immediate consideration in engineering design but at least for studying such a possibility.

Usually in comparison and selection of structural solution variants for agricultural projects in seismic areas the expenses only for initial aseismic measures are compared while post-earthquake rehabilitation costs are not taken into account. Such estimates of economic factors seem to be insufficient. Design of building structures for seismic actions with regard to economic assessment is complicated due to unavailability of the necessary data both on losses due to damage of structures as well as due to the change in the bearing capacity with time and on losses due to temporal interruption of production and loss of capacity for labour by a part of population.

In spite of the above dificculties the application of economic analysis in design of structures for seismic areas appears to be promissing.

For this purpose the projects are usually subdivided into:

- projects with non-econimic resposibility, the destruction of which is not assessed by economic factors;
- projects with purely economic responsibility.

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These are rural buildings among which the share of structures with purely economic responsibility is the greatest, i.e. those projects that already permit to use the results of studies connected with seismic risk in design and construction.

Above we have given the definition of structures with purely economic responsibility. Now we shall specify this notion and give the list of buildings and structures that should be considered as projects with purely economic responsibility. Of course, neither the below notion nor the list of projects are exhaustive and should be regarded as preliminary initial materials that will be specified as additional data would appear.

The notion of a structure with purely economic responsibility may be formulated in the following way. "Structures where there is no necessity for a long occupancy", i.e. the probability of people staying inside becomes compatible with their staying outside, for example, near "dilapidated" buildings.

In a number of papers, for example the method of determining the optimum preliminary costs for aseismic strengthening of buildings is proposed.

The method is based on minimization of the purpose function of total costs for aseismic strengthening made up of the value of primary costs for aseismic strengthening and additional expenses for rehabilitation of the damaged buildings.

Let ρ - total cost for aseismic reinforcement, X - preliminary costs for aseismic reinforcement (total and preliminary costs are expressed in per cent of building cost), B_S - long-term mean frequency of occurence at the given point of the earth's surface of seismic shaking of any intensity S or seismic shakeability, $R(X,S)$ - matrix of average probable losses at an earthquake of S points intensity and initial costs X.

Then

$$\rho = X + \mu \sum_{S=6}^{S=9} B_S R(X,S) \qquad (1)$$

If the matrix $R(X,S)$ is given, the problem is reduced to determination of X, minimizing the function ρ. Matrix $R(X,S)$ is obtained of the basis of experimental data.

On the basis of inspection results of Tashkent (1966) and Gazli (1976) earthquakes we have specified the distribution of buildings according to the degree of damage.

The data obtained were used to specify the loss value due to earthquakes depending on the value of preliminary costs for aseismic strengthening (Table I).

With the known approximate expenditure cost for aseismic strengthening of buildings in per cent of their cost it is possible to establish earthquake losses for various types of buildings. For example, for school and other types of public buildings with brick walls and a rare grid of transversal walls the cost of aseismic strengthening varies and of the whole equals: 4% of the building estimate cost tor 7 point-seismicity, 8% - for 8-point-seismicity and 12% - for 9 point-seismicity. We consider it possible to use the following data given in Table I and obtained after Tashkent earthquake (1966); these data somewhat exceed the known data

In paper /I/ an approximation is suggested

$$R(X,S) = C_1\left[1 - \exp\left(-\frac{C_2 S^2 - C_3}{1 + C_4 X}\right)\right] \quad (2)$$

where C_I, C_2, C_3 and C_4 equal to 1,07; 30; 0,005; 50, respectively.

Losses due to earthquakes in parts of the building estimate cost

Table I

Cost of aseismic strengthening related to the building estimate cost	Earthquake intensity in points			
	9	8	7	6
0,12	0,22 1/	0,08 1/	-	0,00
0,08	-	0,16	0,06	0,02
0,04	-	-	0,09 2/	0,05
0	1,03 1/	0,53	0,32	

Note: 1/ Based on data of Medvedev,

2/ Average from data Zakaev, the res from our data.

Taking into account that experimental data of the basis of wchich (2) is suggested are extremely limited and will be constantly corrected in the course of earthquake consequences inspection and are different for various building types it seems advisable to approximate $R(X,S)$ by a simpler relationship, for example, by a second (or third) power polynom:

$$R(X,S) = a_0(S)X^2 + a_1(S)X + a_2(S) \quad (3)$$

Coefficients $a_0(S)$, $a_1(S)$, $a_2(S)$ are proposed to be selected at each S from the condition of the best approximation (for example, in the mean square sense) of experimentally obtained matrix entries $R(X,S)$. Coefficients $a_{js} = a_j(S)$, included in the approximation formula (3) at $S = 6,7,8,9$ points and $j = 0,1,2$ are selected so as to minimize the error:

$$\Delta_S = \sum_i \left[r_{is} - \left(\sum_{j=0}^{2} a_{js} X_i^{2-j} \right) \right]^2 \qquad (4)$$

Here r_{is} - known elements of Table I (index "i" designates the line number). Then coefficients a_{js} will be obtained from condition:

$$\frac{d\Delta_S}{da_j} = 0; \qquad j = 0,1,2; \qquad S = 6,7,8,9. \qquad (5)$$

At $S = 6,7,8$ the presented experimental data are sufficient to determine coefficients a_{js}. To obtain a_{j9} we extrapolate the missing experimental value (for example $r_{2,9}$), drawing the parabola through points r_{2S} ($S = 6,7,8$) and expecting that $r_{2,9}$ lies on this parabola. Using (4) and (5) the set of equations for determination of a_{js} at any S may be written as follows:

$$\begin{cases} a_{0s}\sum_i X_i^4 + a_{1s}\sum_i X_i^3 + a_{2s}\sum_i X_i^2 = \sum_i r_{is} X_i^2 \\ a_{0s}\sum_i X_i^3 + a_{1s}\sum_i X_i^2 + a_{2s}\sum_i X_i = \sum_i r_{is} X_i \\ a_{0s}\sum_i X_i^2 + a_{1s}\sum_i X_i + a_{2s} n = \sum_i r_{is} \end{cases} \qquad (6)$$

Here n - quantity of the known experimental data in the columns of Table I. The solution of the system (6) may be written using known Kramer formula:

$$a_{0s} = \frac{\Delta a_0}{\Delta}; \quad a_{1s} = \frac{\Delta a_1}{\Delta}; \quad a_{2s} = \frac{\Delta a_2}{\Delta} \qquad (7)$$

where Δ - determinant of system (6); Δa_0, Δa_1, Δa_2 - determinants appearing with substitution in Δ of the respective column for the column from aggregated terms of the system.

Extreme conditions (1) are:

$$\frac{d\rho}{dX} = 0 \qquad (8)$$

Using (1) and (3) let us put down (8) as follows:

$$1 + M \sum_{S=6}^{S=9} B_S \left[2a_0(S)X + a_1(S) \right] = 0 \qquad (9)$$

From (9) it is easy to find extreme value $X = \bar{X}$:

$$\bar{X} = -\frac{1}{2} \frac{\frac{1}{M} + \sum_{S=6}^{S=9} B_S a_1(S)}{\sum_{S=6}^{S=9} B_S a_0(S)} \qquad (10)$$

Computations by formula (10) are recommended to be performed for buildings with economic responsibility.

It is required to determine value $X = X_{min}$, minimizing function $\rho(X)$ in the interval $0 \leq X < \infty$. As is known the continuous function reaches the minimum value in a certain area or points of extremum ($\frac{d\rho}{dX} = 0$), or at the ends of this area. Suppose that fuction $\rho(X) \to +\infty$, at $|X| \to \infty$ (the opposite $\rho(X) \to -\infty$, at $|X| \to \infty$ is physically impossible). This proposition is realized*/ if

$$\sum_{s=6}^{s=9} a_o(s)\, B_s > 0 \tag{11}$$

Then $X = \bar{X}$ will minimize function $\rho(X)$ along the whole number axis. In this case value X_{min} is obtained from the following condition:

$$X_{min} = \bar{X}, \quad \text{if} \quad \bar{X} > 0 \tag{12}$$

If $\bar{X} \leq 0$, then $X_{min} = 0$; it means economic unadvisability of initial aseismic reinforcement.

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*/ If $\sum_{s=6}^{s=9} B_s a_o(s) = 0$, $1 + \sum_{s=6}^{s=9} B_s a_1(s) > 0$ and $\sum_{s=6}^{s=9} B_s a_2(s) > 0$, then $X_{min} = 0$ case $\sum_{s=6}^{s=9} a_o(s) = 0$, $1 + \sum_{s=6}^{s=9} B_s a_1(s) < 0$ and $\sum_{s=6}^{s=9} B_s a_2(s) < 0$ is physically impossible.

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