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THE QUANTITATIVE EVALUTION OF SEISMIC HAZARD ON THE BASE OF THE LIMIT OF PLASTO-ELASTIC STAGE OF DEFORMATION

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ABSTRACT

In the paper we consider the quantitative seismic hazard. It is shown that a potential seismic hazard of strong earthquakes for fixed adduced hypocentral distances is constant in the first approximation and does not depend on an energetic class and R of radiator for earthquakes $M > 5$. It is shown that the calculated (and experimentally determined) maximum level of accelerations of building and construction motions does not in general allow to predict a real seismic hazard. Strength properties of elastic mediums at dynamic loads adequately determine relative deformations and oscillating velocities.

KEYWORDS

Earthquake hazard; linear and non-linear deformations; strength properties.

INTRODUCTION

The dynamic theory of the foci (Aki & Richards, 1983), which prevails at present, allows to conduct only a relative energetic (and magnitude) calibration by brining of actual foci to some fixed sphere. The assessment of dynamic stability of soils and soil-construction systems as the measure of seismic vulnerability is also relative on this ground. A conditional seismic hazard and earthquake magnitude are correlated. But such conditional characteristics can not provide seismic safety. Magnitude and energetic characteristics determines only elastic waves. Hazard of earthquakes depends on non-linear deformations.

Identical methodic approaches to focal zones of strong earthquakes and zones effected by moderate transite earthquakes are usually used in the analysis of the parameters of ground motions and seismic hazard. If at moderate transite earthquakes the grounds undergo elastic deformation caused by seismic waves propagation, then at strong earthquakes they are considerably or irreversibly deformed. But existing seismic zoning of all the levels states that relative amplitudes of ground motions at elastic and elasto-plastic deformations are identical. In this paper we consider only the effect of transite earthquakes. It is obvious that a new level of the prediction of earthquake consequences will require not only further improvement of multi-dimensional and not always physically justified relative characteristics of seismic hazard. To substantiate physical criteria of the practicality of existing empirical relationships between earthquake intensity and its parameters, one had to work out some engineering-seismological model of focal zones.

We worked out the main aspects of such a model. A similarity of earthquakes emerged (Potapov, 1992). A particle velocity at the transition from plasto-elastic deformations to elastic ones is a quasi-invariant of the similarity at equally strong crystalline connections in particle clusters of the rocks, irrespective of the extent they are decomposed to. A focal area of an earthquake is determined as an area of brittle and plasto-elastic decomposition of the rocks at the release of accumulated energy. The existence of energetic quasi-invariant is responsible for the same seismic hazard irrespective of an energetic class at the boundary of focal area. Naturally, we mean here the earthquakes with $M > 5$, the lengths of radiated waves of those are hazardous for constructions, but not microearthquakes.

QUANTITATIVE ASSESSMENT OF SEISMIC HAZARD

We showed (Potapov, 1992) that an initial seismic hazard can be quantitatively preassigned in a form of integral amplitudes

$$\dot{u}_H = \dot{u}_{max} R_R / R_H, \quad (1)$$

where $\dot{u}_H$ is an amplitude of oscillating velocity at the preassigned hypocentral distance, $\dot{u}_{\max} = 0.7$ m/s is a peakvelocity at elastic deformations (at the boundary of elastic radiator), and R_R is an effective radius of the radiator (of a strong earthquake). In accordance with traditional MSK-78 scale, we have from (1):

$$I = I_0 + 3.3 \lg(R_R / R_H), \quad (2)$$

where I_0 corresponds to $\dot{u}_{\max} \sim 0.7$ m/s (Medvedev, 1962; 1978). These relationships are obtained for idealized averaged cases. It is expeditious to compare with experimental data. It was V.V. Steinberg (Steinberg, 1988) who performed the most thorough study of the attenuation of integral amplitudes of velocities and accelerations depending on the distance in near zones of earthquakes of different magnitudes. In the analysis the author used a traditional approach. The relationship between amplitudes and absolute (not relative) distances was found. Relying on these results (Fig. 1), we shall study the correspondence of our model of the radiator of elastic waves to experimental generalized data.

A dashed line in Fig. 1 divides the area of elastic and elasto-plastic deformations (at oscillating velocity of 70 cm/s). It is clear that at earthquakes with $M = 5.6$ a zone of non-elastic deformations exceeds the dimensions of destruction area (of the fault) in ~2 km, and at earthquakes with $M = 6.6$ a zone of non-elastic deformation exceeds the dimensions of destruction area in ~5 km. Thus, the area of plasto-elastic deformations is $l = (0.2 - 0.3)\ R_{focal}$ (it is 20 - 30 per cent of the radius of the radiator of elastic waves). Experimental data (Fig. 1) also indicate that the acceleration at the boundary of the radiator of elastic waves is ~0.4g. Fig. 1 shows a direct correspondence between velocities and accelerations at commensurable distances for the same earthquakes magnitudes. Now, on the basis of Fig. 1 curves, considering (1) and using R_R according to Yu.V. Riznitchenko (Riznitchenko, 1985), we shall set plots of

$$\dot{u} = f_1\left(\frac{R + R_R}{R_R}\right); \quad \ddot{u} = f_2\left(\frac{R + R_R}{R_R}\right),$$

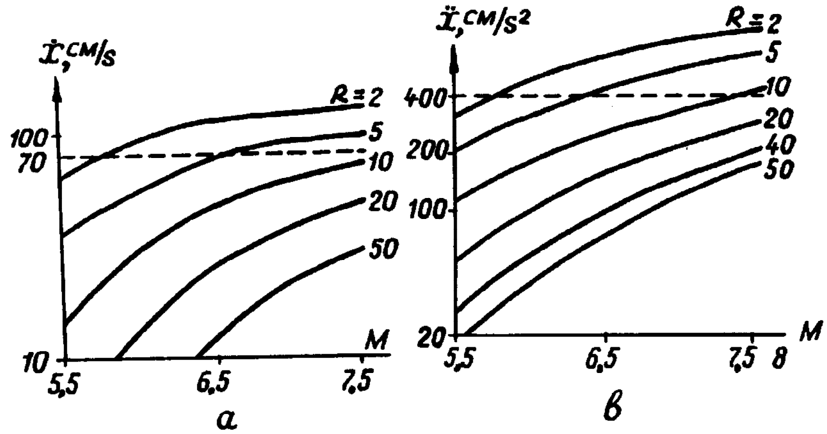

Fig.1. The attenuation of integral amplitudes of velocities and accelerations of earthquakes of different magnitudes depending on distance [Steinberg, 1988]. R - distance, km.

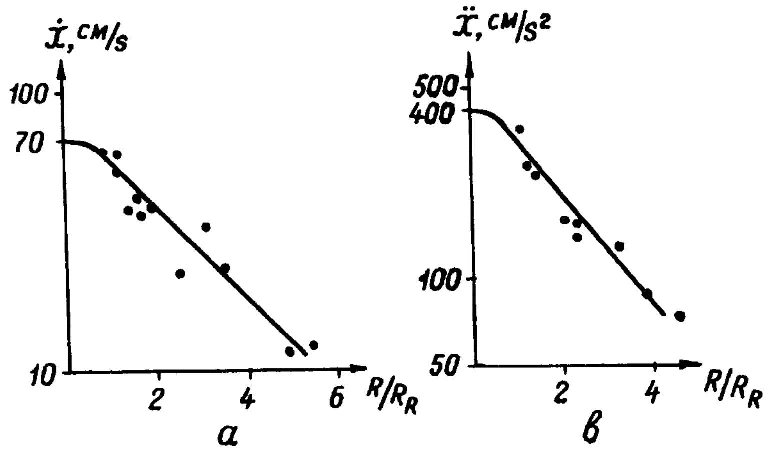

Fig.2. The attenuation of integral amplitudes of earthquakes depending on adduced (relative) distance.

where $R = R_H - l$, where R_H is a distance from the fault. The relationship between amplitude and adduced (relative) distances R/R_R is given in Fig. 2. It is obvious, that generalized experimental relationships are in satisfactory accordance with (1). But at adduced distances which exceed 5 - 6, i.e.

at $\dot{u} < 10$ cm/s, an ideal elastic approximation becomes non-acceptable. At distances $R/R_R > 6$ there is a considerable dissipation of energy at heterogeneities of the medium. Owing to non-ideal elasticity, the attenuation at these distances also becomes considerable. The maximum amplitude level of the spectra of velocities of strong earthquakes relates to frequences of ~ 1 Hz (Medvedev, 1978). The dissipation of spectral components of signals in the vicinity of the main (bearing) frequencies is small (dissipated amplitude does not exceed 10 per cent) (Ivanov, 1983). This circumstance allows ideally elastic approximation to be objective in equation (1). Seismic intensity variations, caused by local grounds, are determined by high-frequency components of the spectra. Theoretically it is important to refine the spectra of oscillations radiated within focal zones of strong earthquakes. But the dissipation of high-frequency components of the signals results in such fluctuations of dynamic level (~ 40 per cent according to the amplitude), that, for these tasks to be solved, one have to obtain a considerable statistical material and to apply special methods of investigation. Since the prediction of seismic hazard objectively relates to some averaged statistical earthquake and geological cross-section, heterogeneous at random, then a theoretical prediction with regard to objective ambiquity is sufficient. The accepted model of a sphere source (but not its real configuration) to some extent compensates the ambiquity of prediction of earthquake focus position in space. Regional, refined and

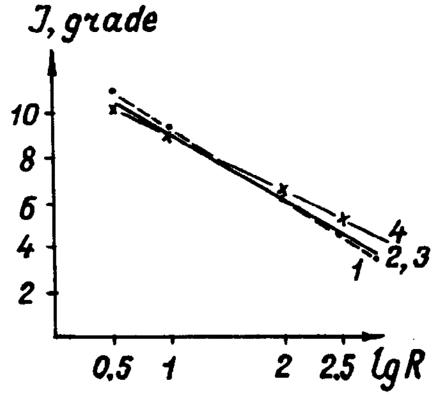

Fig.3.Relationships between seismic intensity of earthquakes M=6,7 and distance: 1- everaged relationship [Shebalin, 1975], 2, 3 - for Kazakstan (Nurmagambetov, 1993], 4 - relationship, describe by equation (2).

other equations of macroseismic field without a set of sufficient statistical data are random realizations of equation (2). Fig. 3 shows relationship between seismic intensity and distance, described by equation of (2) and experimental relationship for Kazakstan and averaged relationship by N.V. Shebalin (Shebalin, 1975). It is clear that the discrepancy between results does not exceed 10 per cent. The relationships between seismic intensity and distance along and across fault zones, obtained for Kazakhstan, are practically indistinguishable up to the relative distance of R/R_R= 6 : 10, which is compatible with the above-mentioned assessments [Nurmagambetov, 1993].

Along with it, the dissipation at high frequencies results in the variations of seismic intensity, which, owing to heterogeneity of the medium (half-space), achieves 0.5 in the observation point (Ivanov, 1983).

Our methodic approach does not relate to some new methods (formulae) of seismic intensity calculation. We showed that a potential seismic hazard of strong earthquakes is constant for fixed hypocentral relative distances (R_H /R_R = *const*) and does not depend on an energetic class of earthquakes (M>5).

But the equation of macroseismic field, for example, by N.V. Shebalin (Shebalin,1975)

$$I = 1.5 M - 3.5 lg R_H + 3 \qquad (3)$$

provides seismic intensity I, which is not concordant with an actual seismic hazard. Let us consider this discrepancy in more detail. Actually, according to equation (2), at R_R =0 (at the boundary of focal zones) we have I_o = $I(M)$ (Table 1, I-values presented in the numerator). And, for example, at magnitude M=8, I_o =15, and at M=4 we have I_o =9. At the assessment of potential hazard by traditional methods some limitation of I~10 is formally introduced for the boundaries of focal zones of earthquakes with the maximum M~8. In Table 1 we summarized initial seismic intensities in the vicinity of focal zones of strong earthquakes, calculated according to formula by N.V. Shebalin (in the numerator) and our formula (in the denominator).

As it comes from Table 1, seismic intensity predicted according to N.V.Shebalin's formula in the vicinity of the foci of considerably slight earthquakes (M~4) is understated, but it is overstated as far as strong earthquakes are consermed, in comparison with an actual seismic hazard. We emphasize that unlike traditional methods, our approach allows to abandon the use of grade as a measure of seismic hazard.

We shall compare calculated and actual seismic hazard for the territory of Irkutsk. The macroconsequences of earthquakes from different focal zones were previously analyzed by

Table 1

Seismic intensity I calculated according to formula (2) (in the denominator) and N.V. Shebalin's equation for macroseismic field (in the numerator).

M	R , km	$I_{R_{H=0}}$	$I_{R_{H=5km}}$
4	1	9/10	6.5/7.5
5	2.7	10.5/10	8/9
6	7.3	12/10	9.5/10
7	19	13.5/10	11/10
8	51	15/10	12.5/10

S.I. Golenetsky (Golenetsky, 1990). The results of these analysis are summarized in Table 2. Focal dimensions (R_R) of the analyzed earthquakes according to Yu.V. Riznitchenko (Riznitchenko, 1985) are also presented here. I_c presented in the table are determined in accordance with formulae (1) and (2), considering $\dot{u}_{max} = 0.7$ m/s.

The variations of actually observed seismic intensities can be explained by the influence of local grounds (see the next part). In general calculated seismic intensities correspond actual seismic hazard.

Table 2

The comparison of actually observed seismic hazards (I) and calculated seismic intensities (I_c) for the territory of Irkutsk

K	M	Δ, km	I	R_R, km	I_c
18	8.1-8.2	650-870	5-6	40	5 grades
17	7.2-7.8	160	7-8	23	7 grades
16	6.4-7.2	65-100	7	14	7 grades
15	5.8-6.4	60-100	6-7	7.9	6 grades

The influence of a layered structure of the upper cross-section on seismic hazard variation is usually determined by the two main factors. Integral oscillation amplitudes can be intensified by interference phenomena in the layers of loose deposits. At the effect of oscillations with dynamic level exceeding the limit of strength of soils, a seismic hazard is determined by the loss of bearing capacity of the latters at comparatively low relative oscillation amplitudes (Potapov, 1992).

TO THE PROBLEM OF PREDETERMINED SEISMIC EFFECTS

Let us consider the particle motion elements (deformations, velocities and accelerations) which determine the characteristics of strength.

The relationship between deformations and stresses is direct and linear one at any weak loads (static or dynamic). Thus, for the shear deformations we have

$$\sigma = \mu\varepsilon ,$$

where μ is a shear modulus, σ is a stress and ε is a deformation. The effect, which breaks a linear connection between stresses and deformations, generally characterizes the ultimate strength. If an external pressure (a wave or a static force) in relation to some surface of the medium exceeds $\mu\varepsilon_{lim}$, then there is an occurence of elasto-plastic deformation or complete decomposition of the connections in particle clusters of crystalline bodies.

At quasi-static loads (at f proper >> f) on some surface of medium S we shall have

$$F/S = \mu\varepsilon = \rho b^2 \varepsilon , \tag{4}$$

where ρ is a medium density and b is a wave velocity. At $\varepsilon < \varepsilon_{lim}$ an elastic wave of the deformation is propagating in the medium. At $\varepsilon > \varepsilon_{lim}$ we have a non-elastic wave of the deformation. Its duration is determined by the moduli of elasticito of the medium, peculiarities and extent of a quasi-static loading. At dynamic loads (for example, at wave effect) the relationship between stresses and deformations looks like that:

$$\sigma = \rho b \dot{u} , \tag{5}$$

where $\dot{u}$ is a deformation velocity.

The difference between static (E_S) and dynamic (E_D) moduli of elasticity of the rocks within E_S= 2-12 MPa does not exceed 10-15%. In our consideration we shall disregard the difference between E_S and E_D. In practice it is also true to disregard the difference between static (σ_S) and dynamic (σ_D) ultimate strengths at loading cycles of $n=1:10^2$. Then from (4) and (5) for the limit of proportionality we shall obtain

$$b\varepsilon_{\lim} \approx \dot{u}_{\lim} . \tag{6}$$

As it comes from (6), relative deformations and velocities of displacements directly characterize the properties of strength. Acceleration ($\ddot{u}$) does not have any constraints. Moreover, irrespective of the reliability of elastic system, the amplitudes of its forced oscillations at frequencies f, which exceed its own f_S in 1.4 times, become lower than an amplitude level at quasi-static loading of the same force (Yablonsky & Noreiko, 1975). And relative amplitudes of the overcritically deformed systems become less than 1 already at frequencies $f=f_S$. Relative deformations may actually possess zero values at high frequency effects. At high frequiency effects, even at rather large accelerations, a body (medium) can undergo only a liner deformation. There are many examples from techniquies and engineering seismology which confirm these regularities.

Hence, strength properties of elastic mediums at dynamic loads adequately determine relative deformations and oscillating velocities.

It is obvious, that integral amplitudes of wide-band signals can be intensified by elastic systems, the durability of which exceeds a unit, and their self frequencies are with in the frequencies of the maxima of signal spectra. In comparison with a frequency range of velocities, a significant amplitude level of the accelerations of wide-band signals will be displaced in more high frequency area. Though rigid elastic systems with small period of oscillations will be effected by large "force" loads, the deformations of their elements and oscillation velocities may generally not approximate to the limit values which determine different stages of rigidity (the limit of proportionality and others).

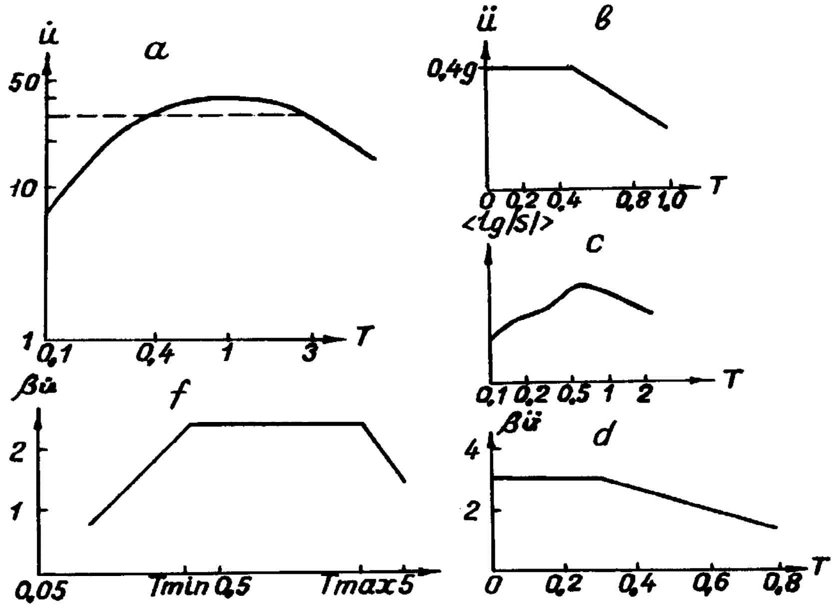

Fig.4. Spectra of strong earthquakes and coefficients β of buildings. a - spectrum of velocity [Medvedev, 1978] b - spectrum of acceleration [Medvedev, 1962] c - spectrum of acceleration [Steinberg, 1988] d - spectral dynamic coefficients, used in Building Code of Russia. f - spectral dynamic coefficients, obtained with spectrum of velocity.

We shall deal with strong earthquake spectra. In Fig. 4a there is an averaged spectrum of earthquakes with the intensity of 9, obtained by S.V. Medvedev (Medvedev, 1978). The maximum level relates to the periods of ~1 s. The spectrum at the level of 0.7 from $\dot{u}_{max}$ may be considered as a constant within the periods of 0.3 : 0.4 s. For the comparison Fig. 4b and 4c show acceleration spectra of the earthquakes with the intensity of 9, obtained by S.V. Medvedev (Medvedev, 1962) and V.V. Steinberg (Steinberg, 1988). We notice that acceleration spectra are displaced in more high frequency area. The maximum level of the spectrum shown in Fig. 4b and Fig. 4c is confined within the frequency range of 2-10 Hz. It is reflected in the plots of spectral dynamic coefficients $\beta_{\ddot{u}}$, used in Russia (Fig. 4d) (Building Code, 1982). The level of spectral plots in the USA Building Code is close to the forgoing one. The range of periods of relative maximum amplitudes also agreed satisfactorily.

The maximum analogues of the plots of β coefficients according to oscillation velocities are enclosed in the interval of 0.4 : 0.3 s (Fig. 4f). To set a dynamic plot according to the velocities, we used Table 3 at Q - factor of elastic systems ~10, i. e. D ~ 0.05 (Potapov, 92). Here we note that at Q - factor change in 2 times (Table 3) the level will change only by 20 per cent. By analogy with the plot of $\beta_{\ddot{u}}$, descending parts of $\beta_{\dot{u}}$ are accepted as inversly proportional to T in the area of large periods ($T > T_{max}$), and as proportional to T in the area of small periods ($T < T_{min}$). Calculated dynamic loads from earthquakes, determined according to accelerations, do not allow to provide the limits of strength of the materials for the constructions (buildings) with the periods of 0.4 : 0.3 s of their own (Fig. 4d). Dynamical loads according to the limits of strength are at the same time unwarrantedly overestimated for high frequency systems ($f >$ 2:3 Hz) on the basis of accelerations.

We do not pretend to an absolute adequacy of the plot of a real seismic hazard shown in Fig. 4f. It requires a more refined form of descending branches, "frequency ranges" and maximum levels for

Table 3

Calculated dynamic coefficients γ of elastic systems with one degree of freedom

k	D	$\gamma = K/K_0$
0.9659	0.259	1.77
0.9848	0.174	2.00
0.9962	0.087	2.44
0.9976	0.069	2.58
0.9986	0.053	2.80

ground-construction systems. It is very important to state energetic limits ($\dot{u}_{max}$) of strength (limit of proportionality, limit of bearing capacity and others) for different constructional materials. It is undeniable that the calculated (and experimentally determined) maximum level of accelerations of building and construction motions does not in general allow to predict a real seismic hazard, i. e. a degree of damage and destruction.

CONCLUSION

A similarity of earthquakes was stated. At equally strong crystalline links in rock particle clusters, irrespective of the degree they are decomposed to, a particle velocity is a quasi-invariant of the similarity at the transition of plasto-elastic deformations into elastic ones. An earthquake focal zone is determined as a zone of brittle and plasto- elastic decomposition of rocks at the release of accumulated energy. The existence of quasi-invariant stipulates equal seismic hazard of earthquakes irrespective of an energetic class at a focal zone interface. It is shown that a potential seismic hazard of strong earthquakes for fixed adduced hypocentral distances ($R_H / R_R = const$) is constant in the first approximation and does not depend on an energetic class and R_R of radiator of earthquakes M>5. Quantitative characteristics, which determine a potential seismic hazard, objectively correspond to the grounds of a half-space. A level of influence, which breaks a linear connection between stresses and deformations, is a general characteristic of the limit of strength. As far as the calculations according to seismic loads are concerned, the use of accelerations, the maximum level of which relates at earthquakes to frequency ranges exceeding self frequencies of the most wide-spread types of buildings, results in the understating of calculated deformations and deformation velocities in comparison with the actual ones.

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