

# The Paradigm of the Seismic Zonation Continuity

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## Abstract

Basic concepts of seismic zonation in Russia are the degree of intensity and soil categories that correspond to discrete structure in the ratio “seismic impact-ground reaction”. Meanwhile, the parameters of seismic effects, and the parameters of soil properties are continuous in the space. The report expounds the basic theory, adequately representing the above mentioned continuity. Thus, many the concepts of seismic zonation, used now, become either more correct, or unnecessary.

## Keywords

Seismic Microzonation, Intensity, Site Class, Referent Soil, Seismic Impact, Response Spectra, Site Coefficient, Dynamics Coefficient, Model, Continuity

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## 1. Introduction

The method of seismic zoning developed in Russia in the second half of the last century is preserved in the building codes to date. There are two basic concepts, connecting soil properties with seismic impact parameters, respectively the soil categories (or site classes) and the macroseismic intensity scores (or the increment of the scores). Thus, the diversity of seismic effects is divided into groups according to the scores, and the variety of soil properties grouped by soil categories. These two concepts, despite their perfect accordance, crudely characterize the properties of seismic effects and soil properties. Such a rough representation of seismic loads do not currently meet the requirements of practice, especially for unique technical projects. The transition in several countries (USA, China, etc.) to the use of other more physically meaningful quantities such as the maximum peak accelerations did not do away completely these contradictions between the continuous structure of natural objects and their discrete representation by using the concepts of soil categories. There is needed more radical transformation of all the most important concepts of seismic zoning, based on the concept of continuity.

## 2. The Continuity of Seismic Impacts

There are two extreme solutions to the question of a rational choice of parameters adequately describing the seismic action: use the ensemble of all possible accelerograms or represent the impact by one parameter, for example, the maximum accelerations. Representation of seismic effects by the set of constants that define type

of the generalized spectra of the reaction is in interval between these extreme situations. This way of representing seismic effects was selected by the seismologists of USA when at the end of the last century for mapping the seismic hazard there have switched to the use in the quality characteristics of seismic impacts to physically measured values: the amplitudes of the accelerations and periods [1].

Seismic hazard of the territory of the USA is defined by three parameters:  $S_s$ ,  $S_l$  and  $T_l$ . The first two parameters characterize respectively the values of response spectrum on short period ( $T = 0.2$  s) and long period ( $T = 1$  s),  $T_l$ —the value of extra-long period. The choice of these parameters is due to the fact that the seismic impacts at different frequencies is characterized either by the acceleration—on periods shorter than 0.6 s, or velocities in the interval of periods from 0.6 s to 4 s, or displacements for very long periods—more than 4 seconds.

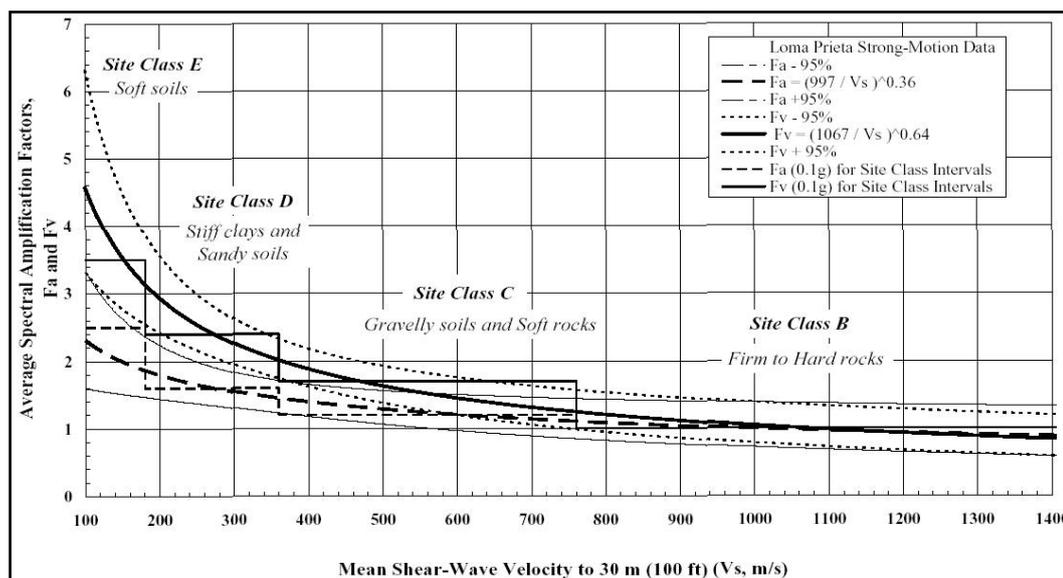
The values of these parameters are taking from the respective maps drawn to all regions of the United States. On the basis of these three parameters can be constructed the response spectrum and be calculated the accelerograms of seismic effects.

For Russian seismic building codes inertial tendencies hold prevailing evaluation and using of intensities maintained its position, although has undergone a noticeable change in the adoption of fractional values. Developed and gradually entering into the practice of seismic zoning, seismic intensity scale [2] establishes a reliable connection between the seismic intensity and the accelerations and durations, and thus removes the contradictions in the choice of method for mapping seismic hazard.

### 3. Continuity of Soil Properties

To account for the soil properties in the US standards acceleration characterizing the incoming seismic motion multiplied on soil coefficients of the two species, respectively, for short-period  $F_a$  and long-period part of the spectrum  $F_v$ . Pay attention to the fact that as a seismic impacts and the properties of the soil are defined in tabular form, *i.e.* discretely in terms of soil classes, from A to E, and the transition from one class to other (like increasing the power of the source of impacts) is accompanied by a jump. This form of presentation is contrary to the nature of the objects that are continuous.

The power of seismic incoming motion is characterized by a continuous value of the maximum acceleration. In **Figure 1** shows graphs of site coefficients identified by survey earthquake Loma Prieta 1989, depending on the magnitude of shear wave velocity. The shear wave velocity is the most important characteristic of the seismic properties of the soil class, as in the US standards and domestic standards. Chart **Figure 1** shows the continuous dependence of the properties of seismic impacts (in form of site coefficients) and of soil properties in the form of values of average shear wave velocity in the soil mass of 30-meter thickness. And there are not any reason for using the concept of site classes. They are absolutely not needed.



**Figure 1.** The dependence of site coefficients from shear wave velocities (by BSSC, 2001).

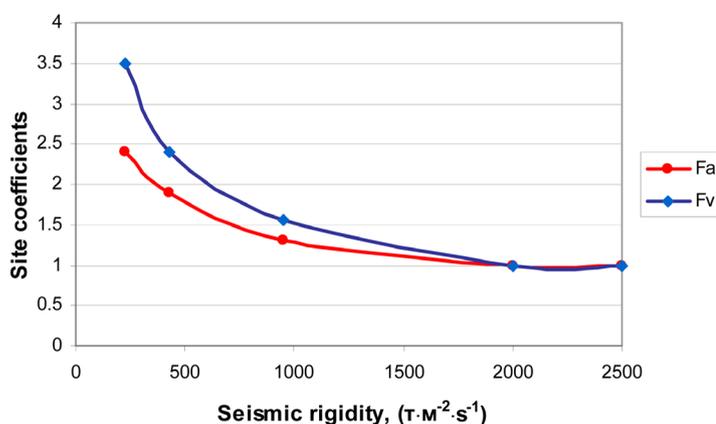
It should be noted that the shear wave velocity is not the only value determining seismic properties of the soil. The reaction of soil on seismic impacts, is also determined by the density, or more precisely the seismic rigidity, that is the product of density on the shear wave velocity. It is appropriate to note that this value appears as the main quantitative characteristics of soil properties in **Table 1** of the building regulations [3]. Graph of relation of site coefficients and seismic rigidity of soils is shown in **Figure 2**.

Chart **Figure 2** can be expressed in analytical form by the formula:  $\lg F_a = -0.4 \lg R + 1.32$ .

In a similar way one can obtain the expression for the connection of low-frequency coefficients  $F_v$ :  $\lg F_v = -0.6 \lg R + 2$ . In both expressions the dimension of  $R$  [ $t \cdot m^{-2} \cdot s^{-1}$ ].

Using these expressions for the value of the seismic rigidity you can get the value of the site coefficient. For that enough to know the seismic rigidity of the 30-meter depth of soil. Thus the use of the notion of category becomes redundant. Continuous seismic properties of the environment adequately described by a continuous value—seismic rigidity.

The multiplicative unit of site coefficients, as shown **Figure 2**, corresponds the soil with seismic rigidity of  $2000 t \cdot m^{-2} \cdot s^{-1}$ , that simultaneously addresses noted in the literature drawback [4] when the properties of an “medium” soil depend on the intensity of seismic effects. This view should be used to also when mapping the general and detail seismic zonation [5], otherwise, as it is easy to show, it are inevitable not remarkable but significant errors.



**Figure 2.** The dependence of site coefficients from seismic rigidities.

**Table 1.** By the Russian building Codes (SP.14.1330).

Site Class	Description of soils (in reduced form)	Characterization of seismic properties of soils		The estimated seismic intensity of the site under seismic region			
		Seismic rigidity $\rho \cdot V_s$ ( $g/cm^3 \cdot m/s$ )	Shear wave $V_s$ , m/s Ratio $V_p/V_s$	VI	VII	VIII	IX
I	Rocky ground (including permafrost eternally frozen); coarse soils are dense, slightly wet	>1500	>700 1.7 - 2.2	-	VI	VII	VIII
II	Rocky soils weathered; the coarse-grained soils, with the exception referred to the first category, sand gravel, large and medium size dense and the average density slightly wet and moist	350 - 1500	250-700 1.7 - 2.2(dry) 2.2 - 3.5 (wet)	-	VII	VIII	IX
III	Sand dense and medium density water-saturated	200 - 350	150 - 250 3.5 - 7	VII	VIII	IX	>IX
IV	The most dynamically unstable sandy-clay soils are prone to liquefaction under seismic loads	<200	60 - 150 7-15	VII*	VIII*	IX*	>IX*

\*Soils are more likely prone to liquefaction and loss of bearing capacity when earthquake intensity more than VI.

#### 4. The Continuity of the Spectral Characteristics

In addition to marked effect on the intensity, the concept of soil classes used in accounting for the spectral characteristics of seismic vibrations by means of response spectra or its normalized form of the dynamic coefficient  $\beta_i$ . The type of dependence  $\beta_i$  from the period oscillations  $T_i$  of buildings or structures in Russian building rules is different for different soil classes.

In the U.S. regulations, the dependence of the spectral characteristics from the soil classes shows through the values of soil coefficients. As has been shown, soil coefficients are uniquely determined by the value of the seismic rigidity, spectral characteristics can also be expressed using the value of the seismic rigidity in the form of continuous dependence:

$$S_{DS} = 14 \times 10^{-0.4 \lg R} \cdot S_S \quad S_{DI} = 158 \times 10^{-0.67 \lg R} \cdot S_I$$

The calculations showed that the dynamic coefficients of real soil massif are in the range from 2 to 6.

Generally the resonance phenomena in the practice of the seismic microzonation are considered bad. The regulations contain only general recommendations, there is little help in practice.

Critics of the seismic rigidity method fair point to a drawback of this method consisting in underestimation of resonance phenomena. The use of microseisms for the account of the resonances, theoretically justified, in practice also involves a lot of errors due to the influence of anthropogenic interference. Without claiming to solve this issue in detail, let us point out some features, the implementation of which may be useful in the determination of resonance phenomena in underground strata. For example, the values of the dynamic coefficient of more than 2.5 are a sign of resonance phenomena.

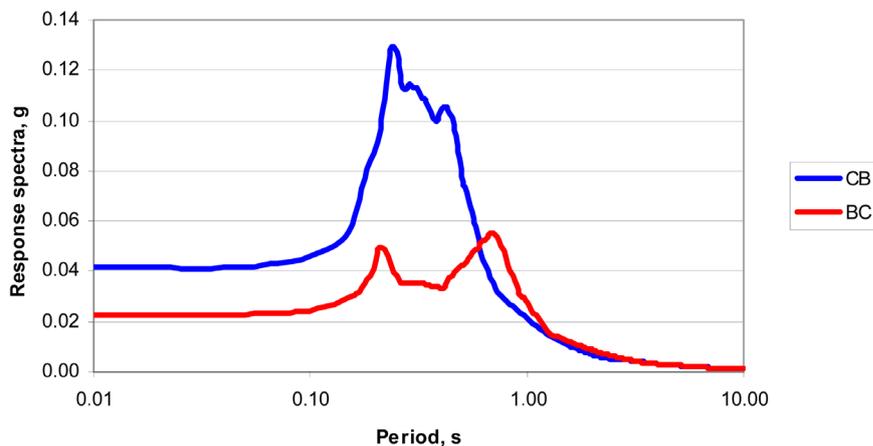
There is another reason why site class not well describe of a soil massif properties associated with resonance phenomena. Indeed, the site class, as mentioned, is determined by the average values of velocity  $V_s$  and density in the upper 30 m layer of soil. But in the soil the sequence of the layers can be arbitrary, although the average values are the same ones. For example, consider two models comprising two layers with high B and low C values of velocities and densities. The parameters of the models: the layer B  $V_s = 750$  m/s,  $\rho = 1.95$  g/cm<sup>3</sup>; layer C –  $V_s = 375$  m/s,  $\rho = 1.85$  g/cm<sup>3</sup>. The thickness of both layers is 15 m, and they are underlain by an elastic half-space with  $V_s = 1000$  m/s and  $\rho = 2.3$  g/cm<sup>3</sup>. The calculations were performed using the program *NERA*. The input impact is the delta-pulse. The amplitude of the input pulse is equal to 0.2 g, which corresponds to an VIII intensity *MSK*. As is known, the system response to such exposure represents the frequency response of the system layers. The output in the calculations are the Fourier spectrum, response spectrum and the dynamic coefficient. For simplicity, let us give in **Figure 3** response spectra, since they display both a frequency and amplitude characteristics of the spectrum.

Obviously, for models CB and BC vary as the shape of the spectral curve and that is especially clearly the level of spectra. For CB models, it is approximately 2 times higher, owing to the structure of the soil massif: in structure of the model BC there is an inverse low-velocity layer and the uppermost part of the section in BC is represented by a layer of increased seismic rigidity.

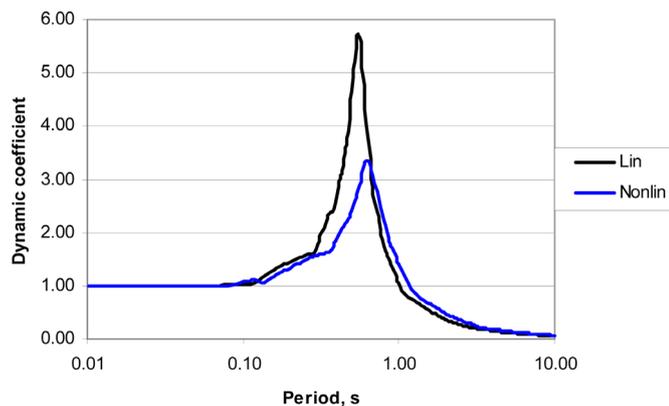
We note that given the dynamic coefficient are obtained under the assumption of linearity of soil properties and parameters of seismic effects. Significant influence of nonlinear processes on the values of the dynamic coefficient shown in **Figure 4**, which shows the dynamic coefficients of linear and nonlinear dynamic models. The seismic parameters of the models and the layer thickness are the same. Vary the coefficients of nonlinearity and intensity of input seismic impacts. In the linear case, the magnitude of the excitation pulse of 0.1 g, and in the nonlinear case, the pulse amplitude of 0.4 g. Despite this, the amplitude of the response spectrum in the nonlinear case is much lower. The dynamic coefficient in the nonlinear case, does not exceed 3.5, while for the linear case it is slightly below 6.0. Markedly changed spectral composition: in the spectrum of the linear model presents high-frequency components (with shorter periods).

Thus, in the accounting for resonance phenomena in soils the seismic building regulations need substantial improvements. In particular, there is a significant difference obtained on the models values of the dynamic coefficient from the proposed standard [3] values (not more than 2.5 for all types of soils). One of the vital suggestions on this issue is the rejection of the normative values of the dynamic coefficient and using the values determined on the basis of calculations with real soil massif models.

Concluding this section we note that instead of site classes we propose use of *model seismic ground conditions* as the fundamental concept of the seismic microzonation, determining the peculiarities of the engineering-



**Figure 3.** The response spectra for CB and BC models.



**Figure 4.** The dynamic coefficients for linear and nonlinear models.

seismological surveys in the study area. This includes all local features of the geological environment, which determine the specificity of seismic effects—their amplitude and spectral composition. Thus, it is desirable to investigate a seismic cross-section to a depth of up to a rock foundation or to the regional horizon soils with a sufficient high seismic rigidity.

## 5. Final Proposals for Regulations

It remains to consider the question how the considerations will affect the content of normative documents? What from the above considerations can obtain a place in future regulations?

The general considerations in a thesis form can be summarized as follows.

1) Instrumental characteristics of seismic effects make optional the use of seismic intensity, instead of which it is proposed to use continuously distributed physical quantity accelerations, periods and durations of seismic vibrations. This does not mean that the notion of intensity in general should be removed from use in any seismic problems. For example, in matters of paleoseismology using intensity is often the only way to solve practically important problems.

2) Becomes optional the use of the notion of site classes. Instead, when describing the properties of the soil massif is proposed to use seismic rigidity, which adequately characterizes the continuity properties of the soil massif. Again it is possible in this case to repeat: site classes can be used if the task is not accurate, adequate description of the seismic properties of the soil.

3) Instead of the notion of a “medium” soil introduces the concept of “reference” soil, against which to assess the reaction of the studied soils for the seismic effects.

4) As a reference soil is recommended to put the soils of high seismic rigidity, thus avoiding the influence of

nonlinearity of soil properties by the strong (over VII MSK) seismic intensities.

5) To determine the soil coefficients  $F_a$  and  $F_v$  by the value of the seismic rigidity  $R$  ( $\text{t}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ ), it should use the expressions:  $\lg F_a = -0.4\lg R + 1.32$  and  $\lg F_v = -0.6\lg R + 2$ .

6) It is proposed to abandon the normative values of the dynamic coefficient and to use the values that determined on the basis of real soil massif models calculations.

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