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Review paper

# Issues of seismic risk assessment of Vladikavkaz city

**V. B. Zaalishvili[1], A. Pinar[2], M. Erdik[2], O. G. Burdzieva[1], D. A. Melkov[1]**

[1]Geophysical Institute, Vladikavkaz Scientific Center, Russian Academy of Sciences, 93a Markova Str., Vladikavkaz 362002, Russian Federation, e-mail: cgi_ras@mail. ru;

[2]Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, Istanbul 34342, Turkey, e-mail: 4alipinar@gmail. com

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**Abstract**: **Relevance.** The last decades in Russia have been characterized by high growth rates of population, industry, infrastructure in large cities and industrial centers located in seismically active regions. The construction did not always take into account the characteristics of local soils and the level of seismic hazard. The study of the consequences of strong and destructive earthquakes created the conditions for new scientific developments in engineering seismology and earthquake-engineering. Seismic zoning of urbanized territories makes it possible to assess the seismic risk of the territory, take measures to strengthen existing buildings and carry out the construction of buildings and structures with a given seismic resistance. This problem is especially relevant for the regions of the Caucasus. The Republic of North Ossetia-Alania is located in a fairly high seismically active zone. It seems natural to assess the seismic risk in the capital of the republic – the city of Vladikavkaz. **Aim.** The aim of the work is to develop and implement modern methodology for the expected seismic risk assessment of a city on the example of Vladikavkaz city. **Methods**. The methods associated with the assessment (probabilistic or deterministic) of ground motion include consideration a number of processes: earthquake source, disaggregation of probabilistic hazard, empirical relationships of seismic attenuation, site effects, and construction mechanics. All of this demands regularization of Construction Norms parameters with different methodologies and corresponding methodology development based on GIS technology. **Results.** Previous test area assessment results are presented and tips for improvement and regularization are given. Consideration of specific types of soils and types of building stock with estimated intensities and vulnerabilities of building types caused a different level of expected economic losses.

**Keywords:** seismic hazard, intensity, soil conditions, seismic risk, economic and social losses.

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ГЕОФИЗИКА

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Обзорная статья

# К вопросу сейсмического риска территории г. Владикавказа

**В. Б. Заалишвили[1], А. Пинар[2], М. Эрдик[2], О. Г. Бурдзиева[1], Д. А. Мельков[1]**

[1]Геофизический институт Владикавказского научного центра Российской академии наук, Россия, 362002, РСО-Алания, г. Владикавказ, ул. Маркова, 93а, e-mail: cgi_ras@mail. ru;

[2]Университет Богазичи, Обсерватория Кандилли и институт Исследования землетрясений, Турция, Стамбул, 34342, e-mail: 4alipinar@gmail. com

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**Аннотация: Актуальность работы.** Последние десятилетия в России отмечены высокими темпами роста населения, промышленности и инфраструктуры в крупных городах и промышленных центрах, расположенных в сейсмически активных регионах. При строительстве не всегда учитывались местные грунтовые условия и уровень сейсмической опасности. Изучение последствий сильных и разрушительных землетрясений создало условия для новых научных разработок в инженерной сейсмологии и сейсмостойком строительстве. Сейсмическое районирование урбанизированных территорий дает возможность оценить сейсмический риск территории, принять меры по усилению существующих построек и осуществить строительство зданий и сооружений с заданной сейсмостойкостью. Эта проблема особенно актуальна для регионов Кавказа. Республика Северная Осетия-Алания расположена в зоне достаточно высокой сейсмической активности. Оценка сейсмического риска в столице Республики – городе Владикавказ становится очевидной. **Цель работы.** Целью работы является разработка и внедрение современной методологии оценки ожидаемого сейсмического риска города на примере города Владикавказ. **Методы исследований.** Методы, связанные с оценкой (вероятностной или детерминистической) движений грунта, включают рассмотрение ряда процессов: очага землетрясения, отделения вероятностной опасности, эмпирических соотношений затухания сейсмических волн, влияния площадки и строительной механики. Все это требует упорядочения параметров строительных норм с использованием различных методологий и разработки соответствующей методики на основе ГИС-технологий. **Результаты работ.** Представлены результаты предыдущей оценки тестовой области и даны советы по улучшению и регуляризации. Рассмотрение конкретных типов грунтов и типов застройки с оценкой интенсивности и уязвимости типов зданий дало разный уровень ожидаемых экономических потерь.

**Ключевые слова:** сейсмическая опасность, интенсивность, грунтовые условия, сейсмический риск, экономические и социальные потери.

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## 1. Introduction

An important problem of the modern seismic risk assessment methodology is the lack of a still reliable account of the features of seismic impact and the response of the existing building stock in their relationship. It is enough to recall the consequences of the Spitak earthquake (1988), the unexpected colossal losses of which were caused by the coincidence of the prevailing period of seismic impact, formed by the influence of a thick stratum of soft sedimentary deposits overlain by a layer of rock, on the initial seismic signal, with the period of natural or predominant vibration of high-rise buildings that were either destroyed or critically damaged. An important aspect of the methodology is the dependence between the effect of the amplitude-frequency characteristics of a seismic signal on the foundation soils and building stock and the level of the impact itself and its spectral composition, which is often caused by significant nonlinear phenomena (up to soil liquefaction). In fact, the duration of the incoming seismic signal also has a decisive influence on the earthquake effect. The noticeable influence of the relationship between the direction of incoming seismic waves and the orientation of a building stock on the severity of its destruction and damage, as well as the effect of multiple earthquakes and various dynamic effects on the state of building stock and its seismic resistance are well known. Finally, despite the development of a number of modern methods for seismic risk assessment insufficient attention is paid to the results of seismic microzonation with a changing level of seismic impact, which causes a variation in the calculated intensity increments. A full accounting of seismic effects and their relationship with the features of a building stock and foundation soils on the basis of the latest achievements will make it possible to develop a new methodology for state assessment and forecasting the behavior of the "soil-building stock" system during strong earthquakes.

## 2. Seismic risk concepts

To assess seismic hazard, a probabilistic approach is currently used in the world. The approach is caused by the probabilistic nature of an earthquake itself. The seismic resistance of a building stock is determined not only by the strength of its elements (construction, material, etc.) but also by the conditions which occur during operational loads. During strong earthquakes, the strength characteristics of building stock will be determined by various features of the seismic load. Seismic effects are characterized by the load level and the range of periods or frequencies of the incoming vibrations. Under intense loads, soils exhibit significant physical nonlinearity, characterized by a change in their amplitude and vibration frequency. Numerous experimental studies show that constructions usually vibrate with the frequency or period of their natural vibrations regardless of the frequency of the external influences. In this case, the prevailing periods of natural or free vibrations of most buildings and structures are in the range T = 0.1-2.0 s. Thus, the vibration frequency of the dynamic load experienced by a structure during earthquakes, as a rule, is in the range of 0.5-10 Hz. On the other hand, as a result of the interaction of the system "foundation soils – structure", during intense loads under the conditions of noticeable physical nonlinearity of soils, the prevailing or resulting vibrations will differ significantly from the frequency of free vibrations.

Despite the development of a large number of adaptive systems for the protection of buildings and structures, this fact makes the forecasting of building stock behavior during strong earthquakes rather uncertain. Currently, techniques and methods for seismic hazard and risk assessment of territory have been developed; new data on the soil layer behavior under intense seismic loads and its influence on the transformation of vibration frequencies during the passage of waves excited by strong earthquakes have been obtained. At the same time, there is still no single information and technical system that allows performing the entire range of work in the format of structural-dynamic, kinematic, physical and mathematical models of the spatial data infrastructure and realizing calculations in a single information field. The absence of reliable accounting of resonance phenomena in the "soil-structure" system associated with their interaction is one of such problems of modern methods of the expected seismic risk assessment.

In this regard, it is useful enough to recall the consequences of the Spitak earthquake of 1988, the colossal losses in which were caused by the coincidence of the frequency of seismic impact, distorted by the initial signal passage through a thick layer of weak lacustrine sediments, covered with rocks, and the natural frequencies of buildings of the so-called 111 series. These were buildings on the territory of the city of Leninakan, that were all destroyed or critically damaged, in contrast to the similar buildings in the city of Kirovokan. So establishment of the various sides of the complex diversity of the interaction of seismic impact and the urbanized environment is of a high importance. Analysis and subsequent adequate consideration of the features of seismic impacts on the designed and the existing construction site will significantly reduce both economic and social damage through a preliminary or subsequent regulation of the hazardous characteristics of a construction site in an urbanized area.

The term "seismic risk" was first identified as a special concept, different from the actual term "seismic hazard" in the foundational work of Cornell [Cornell, 1968]. In Russia, the issues of seismic zoning were considered by I.E. Gubin, S.V. Medvedev, Yu.V. Riznichenko. [Gubin, 1950; Medvedev, 1960; Riznichenko, 1965]. The influence of soil conditions was investigated in the works of Egorov, Popov V. V. (1945), A. N. Safaryan (1963). Further development of the methods of long-term forecasting was obtained in the works of G.A. Sobolev, V.I. Ulomov, M.I. Bogdanov. [Sobolev, 1992; Ulomov et al., 1993; Ulomov, 1994; Balassanian et al., 1999; Ulomov et al., 2015].

At present, a large number of studies are concerned with seismic hazard [Pinar et al., 2001, 2016; Zaalishvili, Rogozhin, 2011; Yamamoto et al., 2020] and seismic risk assessments [Shah, 1995, 2009; Shah, et al., 1987, 1992; Balassanian et al., 1999; Erdik, 2005, 2013, 2017; Erdik et al., 2000, 2018; Durulkal et al., 2008; Chan et al., 1998; Davidson et al., 1999; Dong et al., 1994; Yuchang and Kemon, 1991; Zaalishvili et al., 2001]. The following works of Trifunac [Trifunac, Todorovska, 1998], Bazurro and Cornell [Bazzurro, Cornell, 2004] and many other foreign researchers` works [Yang et al., 2000; 2018; Campbell & Bozorgnia, 2003; Bolisetti et al., 2018; Chandra, Gueguen, 2019; Dammala, 2019; Das, Chakrabortty, 2020; Kwok et al., 2007; Phillips & Hashash, 2009; Rathje et al., 2010; Riga et al., 2018; Sonmezer et al., 2018] are devoted to the study of nonlinear properties. The works analyze the consequences of strong earthquakes [Hartzell et al., 1999; Kaklamanos et all., 2013, 2015]. Sometimes, the analysis is done using strong motion databases [Mahani & Kazemian, 2018; Kaklamanos & Bradley, 2018; Afshari & Stewart, 2019; Pagliaroli et al., 2018; Pavel et al., 2019; Wang et al., 2019; Zeghal et al., 1995] or with the help of mathematical modeling [Poul et al., 2018; Stupazzini et al., 2009; Terziv & Ignatakis, 2018; Thebian et al., 2018; Tsiapas & Bouckovalas, 2019]. In the works of A.V. Nikolaev and V.B. Zaalishvili [Zaalishvili, Kanukov, 2013; Zaalishvili, 2016; Zaalishvili et al., 2014, 2018, 2019a, b, 2020], the experiments have been described and the methods have been developed to assess the nonlinear behavior of soils using the in situ instrumental method directly in the investigated area.

To predict the expected consequences of strong earthquakes, as well as other disasters, a detailed study of the features of urbanized territories is required. At the end of the 20th century, different approaches for assessing the seismic risk of already existing buildings and structures were developed in Russia. They took into account various factors that, with varying accuracy, determine the level of an expected seismic risk. One of the first such techniques, considering world experience, was developed by S. Yu. Balasanyan. in 1991. Aizenberg Ya. M., Klyachko M. A., Koff G. L. [Klyachko, 1994; Klyachko, Polovinchik, 1994; Polovinchik, Klyachko, Koff, 1995] laid the foundation and made a significant contribution to the formation and subsequent development of domestic approaches of risk assessment. Developed by Zaalishvili V. B. in 2000 method of rating assessment of soil conditions and seismic risk of the territory seems to be a more complete and, apparently, more adequate forecasting technique. This method was first applied for the allocated territory of Tbilisi during the process of implementing the international project of the INTAS Program "Seismic hazard assessment for big cities in Georgia using the modern concept of seismic microzonation with consideration of soil non-linearity" (1999-2001). Later, in 2004, a rating assessment of the complex of engineering-geological, hydrogeological, geomorphological and other features of soil conditions was for the first time successfully implemented in Russia for the capital of North Ossetia under the next international NATO "Science for Peace" Program Project "Seismic Risk of Large Cities of Caucasus: Tools for Risk Management. Azerbaijani, Armenian, Georgian and Russian (North-Ossetian) scientists took part in the realization of this project. In this case, a rather extensive area of the city of Vladikavkaz (Kuibyshev street and the adjacent quarters) was chosen as the object of the study. It is known, that the vulnerability of building stock during strong earthquakes depends significantly on its type and infrastructure characteristics. Different types of construction of buildings are characterized by the different seismic vulnerability. The traditional use of the letters to denote different types of buildings derives from the Modified Mercalli-Richter Scale of 1956 (MM1). This classification characterizes different levels of vulnerability quite roughly. Similarly, the current MSK-64 seismic scale directly identifies building classes by type of construction and resulting differences in the vulnerability or building exposure to seismic effects. The vulnerability curves do not take into account resonance phenomena; it necessitates a set of curves for each vibration frequency. Assessment of buildings` resonant frequencies, which, first of all, depend on the type of structure and number of storeys must be carried out. And microseismic method could be used.

The aim of the work is to develop the existing methodology of a building stock seismic risk assessment and to work out new approaches for taking into account the interaction of building stock and foundations in the urbanized territories based on the use of modern knowledge and technologies. To achieve this goal, the following tasks are required:

– Creation of a data infrastructure that allows carrying out the modeling and various calculations of seismic effects (including the influence of the location of faults and the influence of local soil conditions), data on the building stock and its interrelationships, which together make it possible to simulate scenarios (with the help of modern computational power)

– Development of computational algorithms for modeling the initial seismic impacts for different recurrence periods, the response of the soil strata and building stock to these effects, with support for the possibility of multivariate calculations and the use of the Monte Carlo method.

– Modeling based on known and developed methods for seismic risk assessment, comparing the results and choosing the most optimal methodology for the conditions of the North Caucasus.

The considered and the other tasks are the methodological basis and are included in each stage of work (detailed zoning – seismic microzonation – risk assessment)

## 3. Seismic hazard assessment

Seismic hazard assessment carried out in connection with the analysis of the risks of urbanized areas can be realized using probabilistic or deterministic approaches. A probabilistic approach would be relevant for probable losses estimation in a given area or geocell. However, since all probable losses in a given geocell cannot manifest themselves simultaneously, the integral effect of individual (single) losses will give an overestimation of the total losses in the urban area. In addition, a spatial-system approach is required for the assessment of the life cycles` disruption. As general, estimates of earthquake losses in urban areas have traditionally been deterministically associated with an earthquake scenario (or the set of scenarios).

An earthquake scenario can be assessed by disaggregating the probabilistic hazard to find the source that contributes the most to the formation of the integral hazard (Thenhaus and Campbell 2003; Somerville and Moriwaki 2003; Faccioli and Pessina 2003).

The methods associated with the assessment (probabilistic or deterministic) of ground motion include consideration of the following processes:

- Process at the source of the earthquake
- Disaggregation of probabilistic hazard
- Empirical relationships of seismic attenuation
- Effects close to faults (directivity graph and radiation directivity)
- Influence of soil conditions

Nowadays reliable empirical models exist in terms of peak acceleration, velocity and displacement (PGA, PGV, and PGD) and pseudospectral velocity (PSV) at the specific frequencies and damping factors for a given earthquake intensity, distance, fault mechanism, and local geology [e. g. Boore et al. 1993; Campbell and Bozorognia 1994; Gregor, 1995; Fukushima and Tanaka, 1990; Ambraseis and Bommer 1995; Campbell 2003a, 2003b]. Although the statistical results were obtained for the territories which are fully equipped with monitoring systems (for example, California and Japan), the comparison shows that with identical definitions of the input parameters, the difference between the attenuation ratios in the western United States, Japan and Europe is less than the actual dispersion in any of them. [Fukushima and Tanaka 1990; Ambraseys and Bommer 1995]. This substantiates the use of the data for the territory of Turkey and the Greater Caucasus. We will also consider numerical modeling procedures for determining ground motion based on the mechanism of fracture disruption and wave propagation. At shorter distances, the phenomena associated with the finite dimensions of the fault become significant. These phenomena are primarily caused by the final velocity of disruption propagation, as a result of which some parts of the fault emit energy earlier than others; thus, waves emitted with delays then interfere, causing significant directivity effects. The modeling method used, for example, in the FINSIM program [Beresnev, Atkinson, 1997, 1998], is described in works and previous publications devoted to the basics of the stochastic technique. The time series for the sub-faults are generated using the Boore procedure, which assumes a baseline $\omega^2$ spectrum and takes into account the propagation of seismic waves to the observation point, using defined duration and attenuation operators. The program uses the standard stacking operation, in which the rupture from the hypocenter propagates radially, initiating secondary sources during its passage. The random component enters at the moment of the sub-source starting, etc. Analysis and consequent account of initial accelerograms transformation will become the basis for site effect analysis at strong seismic loadings (Figure 1) [Zaalishvili et al., 2010].

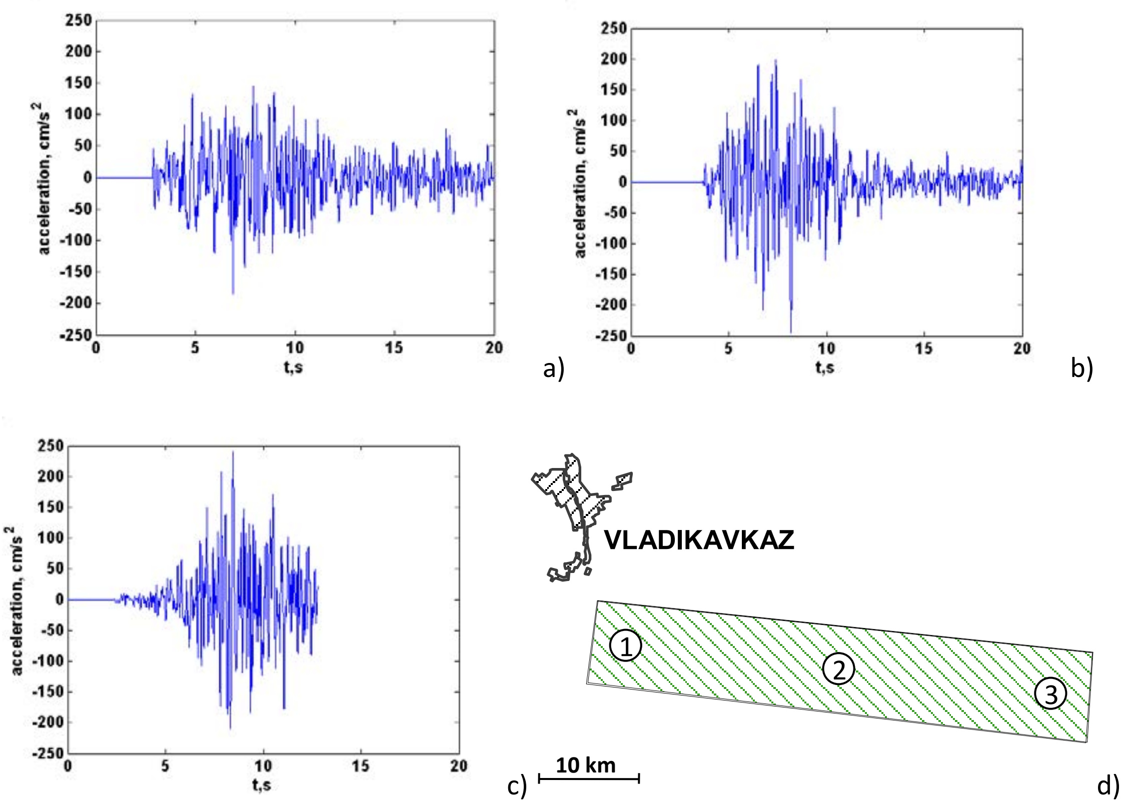


*Fig. 1. Synthetical accelerograms for different source locations:*
*a – western part of fault; b – middle part of fault; c – eastern part of fault; d – scheme of sources of scenarios earthquakes*

Seismic microzonation (SMZ) can be viewed as a method of zoning of a city or a large construction site in areas with the same ground response for standard seismic effect of a certain level and assessment of the relative changes in the characteristics of vibrations on the surface relative to the characteristics of vibrations of so-called reference site to which the initial intensity is attributed. In Russia the reference sites are sites with average seismic properties of ground conditions of certain territory. In Armenia and Georgia sites with the worst ground conditions are generally considered as reference, although in some cases they can be averages. In the United States the reference sites are Rock sites. In former USSR sites with standard ground conditions traditionally were chosen after macroseismic investigation of historical strong earthquakes.

Sites with the same intensity are combined in different seismic zones. Engineering-geological, hydrogeological and geomorphological conditions are taken into account. On the other hand, the target of seismic microzonation is development of initial data of various levels of seismic impacts for structural engineering and urban planning. The territory is divided into a grid with equal cells. Further the parameters of the forming characteristics of ground conditions in each of these cells are defined, which requires active use of GIS technology [Zaalishvili, Berezko, 1999]. In particular, such studies have been carried out in 2000, in the process of implementation of the international project for a large area of Tbilisi, with various types of soils, in different physical conditions [Zaalishvili et al., 2001].

In general, the process of seismic microzonation can be divided into three phases. In the first phase, initial regional seismic characteristics of the earthquake at rock level are determined for each cell. In the second stage, the site profiles are modeled on the basis of the results of the drilling and field testing. The third phase includes an analysis of the expected response of sites to evaluate characteristic of earthquake on the surface and interpreting the results of microzonation [Ansal et al., 2004, 2010]. When the available data of engineering geological zoning (usually the results of surveys of past years) do not correspond to modern requirements (for example, insufficient data on fill content in gravels), the instrumental studies based on some selected grounds in the territory is essential for the reliability of the final result.

In the paper approaches used abroad is combined with techniques of Russian-Georgian school of seismic microzonation, especially instrumental method which is the primary method of SMZ. Seismic process is a complex multifactor process, so final maps of seismic microzonation are based on the results of integrated use of instrumental, calculational and recently developed instrumental-calculation methods. On the basis of this approach in 2010 SMZ Map of Vladikavkaz city was developed (Figure 2).

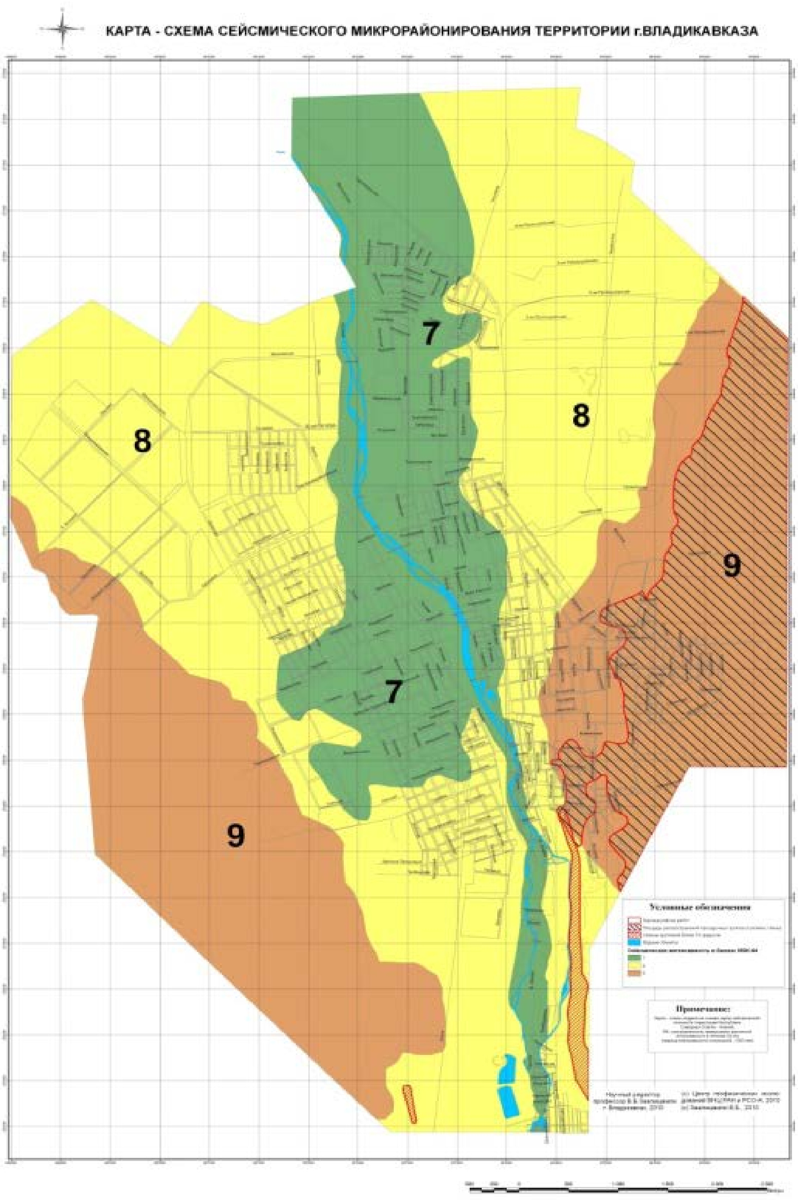


*Fig. 2. Seismic microzonation Map of the territory of Vladikavkaz city*

## 4. Vulnerability of buildings and structures

Tables 1-2 show number of damaged buildings, degree of damage d and the corresponding values of the damage coefficient DR for different intensity levels I.

The value of the damage coefficient above 30% from an economic point of view should be considered as very high for repair and, therefore, can be considered 100% loss for functioning in certain cases.

Each intensity level in the macroseismic scale represents a certain number of buildings that must be exposed to a certain extent within the range of damage levels from 1 to 5.

Vulnerability value for a building of types A, B, C, D, taking into account the data in Table 1 and Table 2 at various levels of macroseismic intensity can be calculated using the following expression:

$$V_i = \sum_{i=0}^{5} N_i (DR)_I \qquad (1)$$

It must be noted that "averaged" express assessment technique based on MSK-64 scale concept is applied. It is applicable for the most of the buildings of the investigated area and allowed to make assessment in a short time. Specifics of new building types as for the site 1 are considered in section 8. Life-cycle cost and seismic reliability analysis could give more precise and detailed result.

*Table 1.*

**Number of damaged buildings N (% of total) with corresponding degree of damage d at different intensity levels on the MSK – 64 scale [Sobolev, 1997].**

| Seismic intensity I, MSK-64 scale | Building type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | | B | | C | | D | |
| | Number of damaged buildings, N (%) | Degree of damage d | Number of damaged buildings, N (%) | Degree of damage d | Number of damaged buildings, N (%) | Degree of damage d | Number of damaged buildings, N (%) | Degree of damage d |
| 7 | 10<br>35<br>50<br>5 | 1<br>2<br>3<br>4 | 15<br>35<br>50 | 0<br>1<br>2 | 50<br>50 | 0<br>1 | 65<br>35 | 0<br>1 |
| 8 | 10<br>35<br>50<br>5 | 2<br>3<br>4<br>5 | 10<br>35<br>50<br>5 | 1<br>2<br>3<br>4 | 10<br>35<br>50<br>5 | 0<br>1<br>2 | 45<br>50<br>5 | 0<br>1<br>2 |
| 9 | 15<br>35<br>50 | 3<br>4<br>5 | 10<br>35<br>50<br>5 | 2<br>3<br>4<br>5 | 10<br>35<br>50<br>5 | 1<br>2<br>3<br>4 | 15<br>50<br>35 | 0<br>1<br>2 |

*Table 2.*

**Degree of damage d and the corresponding values of the damage coefficient DR [Sobolev, 1997]**

| Degree of damage d | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Damage coefficient DR | 0.02 | 0.10 | 0.30 | 0.80 | 1.00 |

In the study area, four structural types of buildings were identified. For each type, a seismic vulnerability was calculated. The value of the degree of vulnerability lies in the range $0 \le V \le 1$. The closer V is to unity, the higher the vulnerability of the building. A value of 1 corresponds to the complete collapse of the building. The results are presented in Table 3 and in Fig. 3.

*Table 3*

**Vulnerability $V_i$, corresponding to four types of buildings on the MSK-64 [Sobolev, 1997]**

| Building type | Macroseismic intensity on MSK-64 scale | | | | | |
|---|---|---|---|---|---|---|
| | V | VI | VII | VIII | IX | XII |
| **A** | 0.001 | 0.015 | 0.227 | 0.565 | 0.825 | 1 |
| **B** | 0 | 0.001 | 0.057 | 0.227 | 0.565 | 1 |
| **C** | 0 | 0 | 0.010 | 0.072 | 0.227 | 1 |
| **D** | 0 | 0 | 0.002 | 0.015 | 0.06 | 1 |

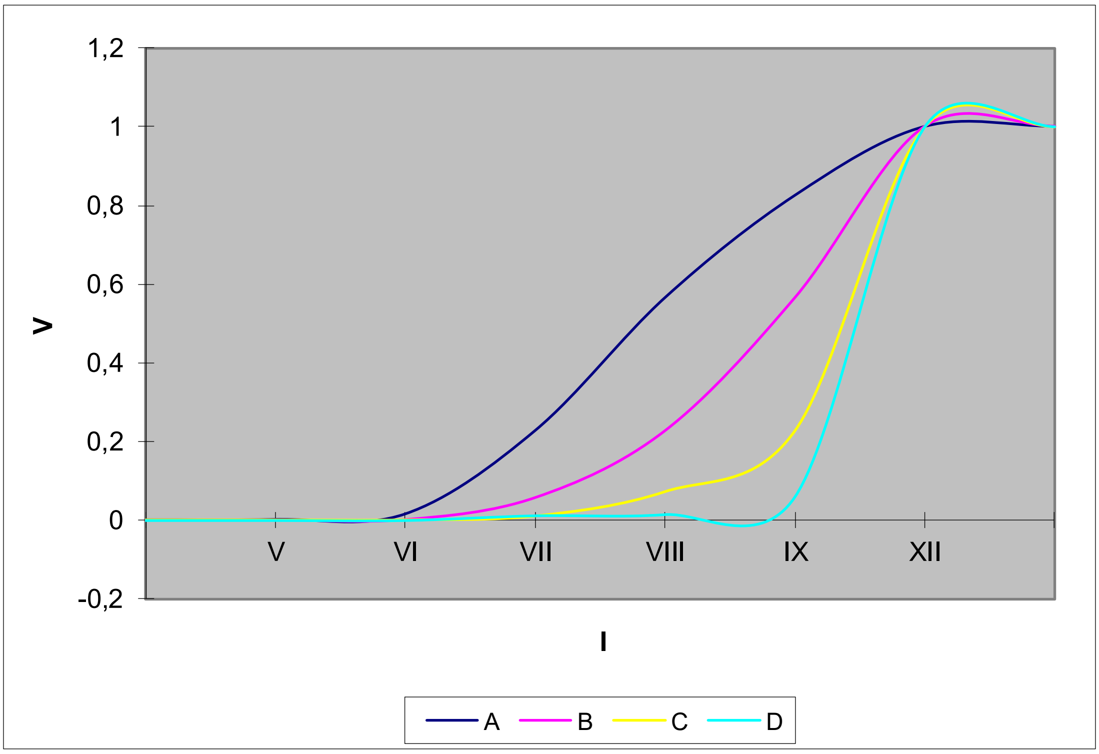


*Fig. 3. The dependence of the vulnerability of buildings V from the intensity I*

## 5. Seismic risk assessment

On one or another urbanized area, the population, buildings and structures, various communications and socio-economic activities are considered as the "elements of risk". Buildings and life support systems form an "artificial environment". Physical losses of the elements of risk, which may result from a particular earthquake scenario, require an extensive and comprehensive collection of "inventory" or initial data, i. e. the collection of the following information: demographic distribution at different times of the day; building stock and its typification; life support systems and infrastructure (main roads, railways, bridges, overpasses, public transport, distribution of electricity, water supply, sewerage, gas supply, telephone communications, including cell towers and the possibility of their operation at maximum loads), including their nodal points (stations, pumps, switchgears, storage systems, power transmission towers, sewage treatment plants, airports, seaports, etc.); main and critical facilities (dams, power plants, large chemical and fuel storage tanks) in the form of GIS databases. In fact, the issue is to develop the main elements of the domestic HAZUS system [HAZUS, 1999, 2014]. The vulnerability functions of the elements at risk represent the possibility of its response to an earthquake exceed its various limit states based on physical and socio-economic impacts. Vulnerability assessments are usually based on the analysis of the previous earthquake data (the observed vulnerability) and on the analytical studies (predicted vulnerability). The main physical vulnerability is associated with buildings, infrastructure and life support. Secondary physical vulnerability is associated with consequential losses. Socio-economic factors of vulnerability include accidents, social disruption and injuries, as well as economic consequences, not only associated with damage to the facilities but also production downtime, supply disruptions, etc.

To construct scenarios of losses, caused by earthquakes, vulnerability matrices, which link damage classes to impact intensity, must be used. The principles, underlying the MSK-64 scales and the new developed domestic seismic scale of the MSK type, will be used for the territory of the North Caucasus. Several approaches will be used to assess the losses directly under the conditions of various earthquake scenarios and average losses (for the different probability of nonexceedance) and a comparative analysis will be performed.

HAZUS is a standardized methodology for estimating earthquake losses implemented in GIS [Whitman and Lagorio, 1999]. HAZUS provides a quantitative estimate of losses in terms of direct costs to repair and replace damaged buildings and life support components; direct costs associated with the loss of function (for example, loss of business income); victims; people who have lost their homes; expenses for the elimination of blockages; regional economic implications; loss of functionality in terms of loss of function and recovery time for buildings, critical facilities such as hospitals and life support systems.

KOERILoss is a software developed by Earthquake Engineering, Bogadishi University (Kandilli Observatory and Earthquake Research Institute (KOERI)). The software uses a loss estimation methodology (probabilistic or deterministic) developed by KOERI to perform the analysis for estimation of potential losses from earthquakes. The Code or Norms for the assessment of seismic scenarios was developed by the Italian National Seismic Service (SSN) [Di Pasquale and Orsini, 1997]. This model uses seismic intensity, which supposes its adaptation to the Russian MSK scale.

According to the definition, the risk is the probability of economic and social damage for a given territory over a certain period of time.

It is possible to assess risks, expressed as a percentage of losses for individual elements of risk or in monetary terms of these losses. The percentage of seismic risk is more convenient because such expression is more stable for certain elements of risk. The percentage ratio of losses does not depend on inflation and makes it possible to compare the results of assessments according to the materials of different countries, regardless of the ratio of the currency rate.

The area of the study was located on the territory of 1.35 km$^2$; Gorky Street was considered as its southern border, the northern boundary passed along the of Dzhanaev Str., Markov Str., Osipenko Lane and Shchukin Brothers Str.; in the west, the region stretched to the Terek River, and in the east it was limited by the corresponding line of the constructed Vesna district. The built-up part of the area was conditionally divided into six approximately equal sites, which are named from east to west: 1) Vesna, 2) Balkinsky passage – Pionerov Street, 3) Pionerov Street – Lermontovskaya Street, 4) Lermontovskaya Street – Frunze Street, 5) Frunze Street – Lenin Street 6) Lenin Street – Terek River. Within each of the site, on the vector graphic, various objects and their number of storeys (separate houses and their groups, schools, institutes, administrative and public buildings, markets, etc.) were allocated, for each of which constructional types of buildings (A, B, C, D) and their number of storeys were established (Fig. 4). Constructional types of buildings were chosen while considering the design estimation documentation, as well as during the inspection of structures in-situ. The researchers of the institute were involved for this purpose. In each of the above-mentioned sites, its total area was determined, as well as the total area occupied by various built-up objects.

Data for some types of damage calculation is necessary in order to estimate the total damage:

– $L_1$ is economic damage as a result of damage and (or) destruction of residential buildings and structures;

– $L_2$ is economic damage as a result of damage and (or) destruction of urban infrastructure (excluding indirect losses);

– $L_3$ is economic damage as a result of damage and (or) destruction of buildings for social welfare services (institutions of management, health care, etc.);

– $L_4$ is social damage.

Damage caused by the secondary effects of earthquakes is taken into account by introducing specially designed multiplying coefficients for additional costs associated with the mitigation of the consequences (caused by the soils deformation, landslides, mudflows, etc.) including those connected with the impact of additional engineering protection structures from hazardous processes.

The total economic losses L is calculated as the sum of individual types of losses for all zones of varying intensity [Balassanian et al., 1999]:

$$L_i = \sum_{j=1}^{j} S_{ij} \times V_{ij} \times C_{ij} \qquad (2)$$

where, $S_{ij}$ is building stock density of type j in the zone with intensity i; $V_{ij}$ is an average vulnerability of a single object; $C_{ij}$ is the average cost of a single object.

Distribution of economic losses during an intensity 8 earthquake is shown in Fig. 5, which clearly shows that the largest economic losses should be expected in areas 2 and 3, which, first of all, is due to soil conditions. At the same time, the risk of economic losses for site 1 ("Vesna" micro-district) is insignificant, due to the fact that the development of this area consists entirely of D-type buildings. At the same time, considering possible tilting of buildings caused by soil liquefaction, an economic risk will increase several times and according to our assessments will be about 400 million rubles (damage to about 30% of building stock).

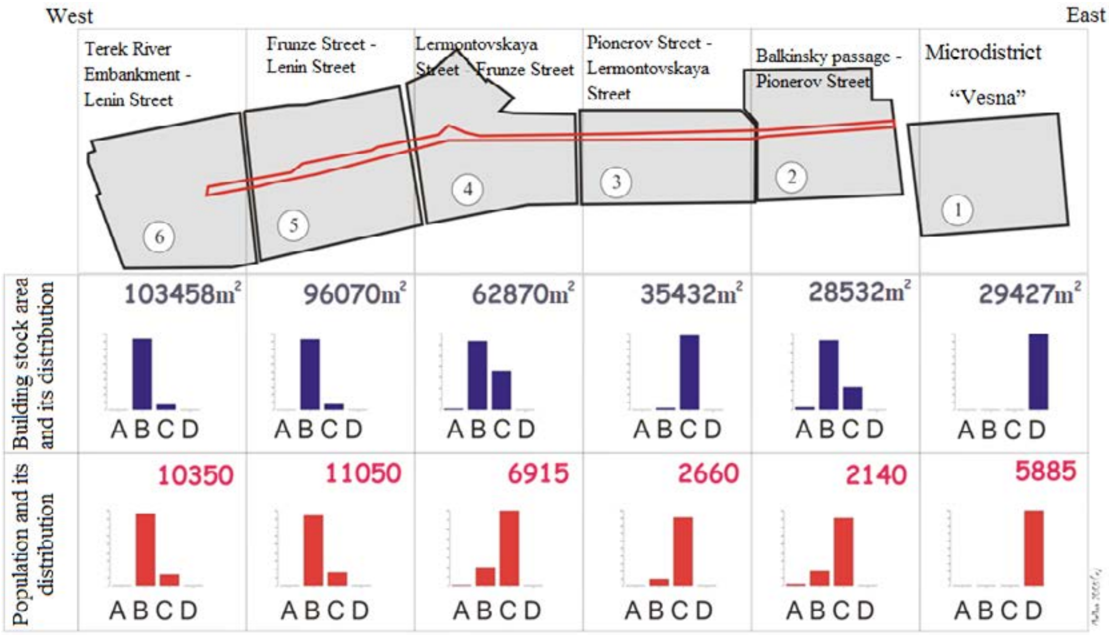


*Fig. 4. Initial data for seismic risk assessment*

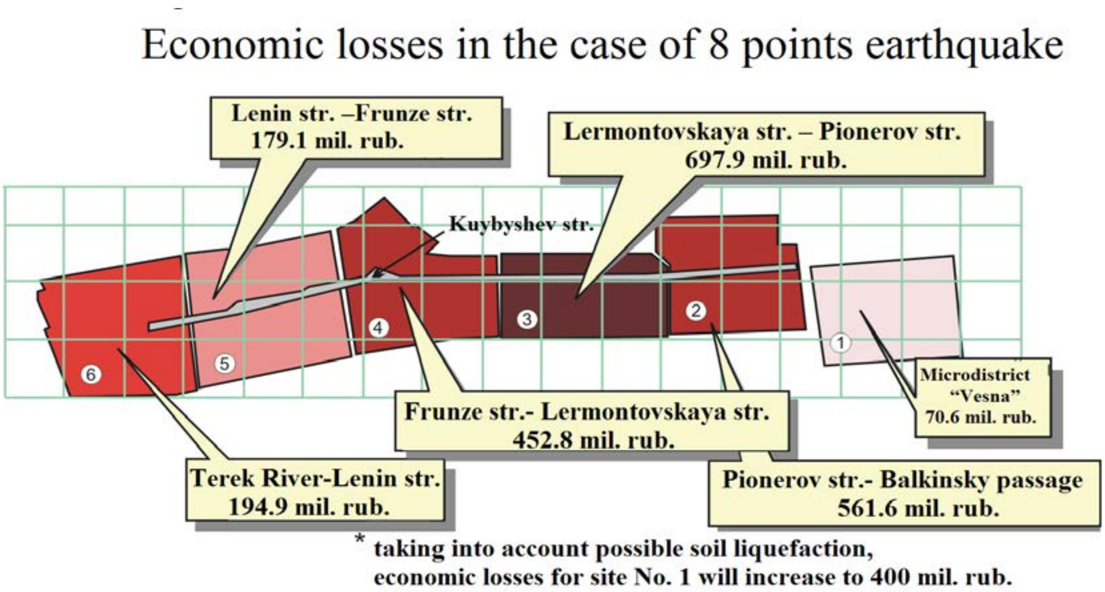


*Fig. 5. Expected economic losses in the case of 8 points earthquake for Vladikavkaz (for average soil conditions)*

## 5. Results and discussion

Based on the analysis of the results of geological surveys on Kuybyshev Street on the territory of Vladikavkaz six sites with different soil conditions were identified. Then, using the method of expert assessments, rating evaluations of the soils of the foundations

According to detailed seismic zoning and seismic microzonation data, the calculated intensity for the indicated site varies within 7-9 points.

Analysis of the calculation results shows that, depending on the type of buildings, the vulnerability varies widely. It can be well seen that the modern development of the "Vesna" micro-district is sharply distinguished by the minimality of the predicted vulnerability. Here it is almost zero at 6-9 points of impact. On the other hand, an analysis of the instrumental records of stations located in different soil conditions shows that this region is characterized by a significant seismic hazard due to the foundation soils in the form of a thick layer (20 meters or more) of clayey soils with a free-flowing consistency.

The results of the analysis of the worst effects of earthquakes show that the base plates, although they prevent the effect of the uneven settlement on the integrity of buildings,

*Fig. 6. Micro-district Vesna, Vladikavkaz*
$M_{max} = 7.1$. *Photo: T. V. Zaalishvili*

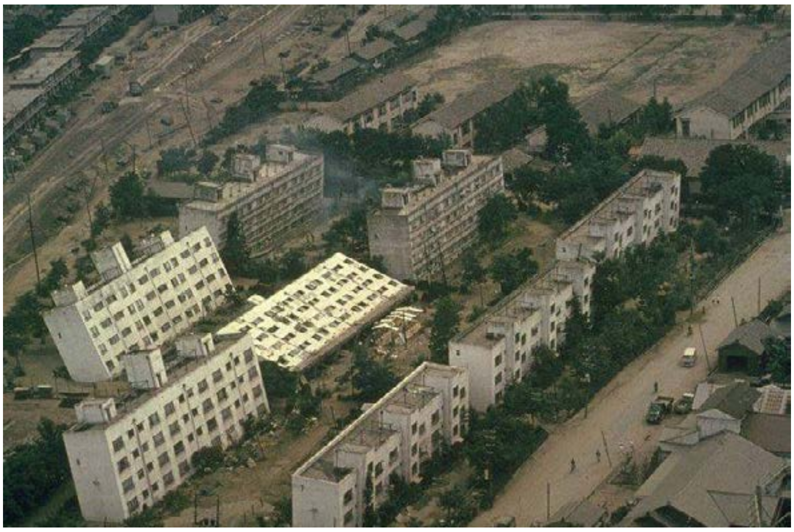

*Fig. 7. Soil liquefaction June 16, 1964, Niigata, Japan,*
$M_{max} = 7.5$. *Photo: Joseph Penzien*

with soft base soils make them very vulnerable to tipping. Examples of such accidents are well known (Niigata, 1964). In general, the question of the traditional increase in the intensity of a site in order to enhance them is still controversial, since even a second sagging of individual parts of a heavy building will lead to significant damage. Some authors believe that buildings are not recommended to be strengthened and believe that it is even harmful because, on soft soils, a heavy building may simply "sink" in the ground. Therefore, it is necessary to implement special measures to strengthen the soil itself.

When implementing the seismic impact of the expected level, and, as noted above this is the magnitude of M = 7 with an earthquake intensity of 9-10 points in the epicenter, an earthquake that is generated directly in the southern part of the city, will have the same intensity in the investigated site.

Considering that soil liquefaction usually takes place for flooded soils already with 8-point intensity, a very realistic manifestation of a seismic event similar to Niigata (Fig. 7.) seems quite feasible at the "Vesna" site (Fig. 6). It should be noted that during the Niigata earthquake (Japan, 1964), good quality houses simply lay on the ground almost undamaged. With minimal social losses, the economic damage was great. For site No. 1 (Vesna), represented by the ground layer, which contains a layer of soil of flowing consistency, the economic loss a priori will increase by 2.5 times and, according to calculations, will amount to 400 million rubles. (Fig. 5.). Due to the very high quality of buildings, by the way, designed for 8 points, social losses here will be minimal. Social losses during earthquakes are mainly determined by the level of damage to buildings and structures. At the same time, the so-called secondary effects in the form of landslides, soil liquefaction, floods can become defining and abnormally high at a certain confluence of negative factors. As noted above, it is necessary to note the problem of fires, which often accompany destructive earthquakes due to completely regular violations of gas pipelines, power lines, etc.

But the most of the buildings are masonry type, especially in historical regions, some of them are unique and needs special approach for vulnerability assessment and reinforcement techniques for risk mitigation.

## Conclusions

Finally the issue of seismic risk assessment implementation technique in the North Caucasus consists in adoption and developing the main elements for the analog of HAZUS system. To construct scenarios of losses, caused by earthquakes, vulnerability matrices, which link damage classes to impact intensity, must be used. The principles, underlying the MSK-64 scales and the new developed domestic seismic scale of the MSK type, will be used for the territory of the North Caucasus as it shown for the test area of Kuibisheva street in Vladikavkaz city. Several approaches will be used to assess the losses directly under the conditions of various earthquake scenarios and average losses (for the different probability of nonexceedance) and a comparative analysis must be performed.

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