ПРОМЫШЛЕННОЕ И ГРАЖДАНСКОЕ СТРОИТЕЛЬСТВО И ЭКОНОМИКА

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Zlobin Ya. A.[1], *Kashtanova K. D.*[2], *Mironova L. I.*[3], *Belyaeva Z. V.*[4]
[1-4] Ural Federal University, Yekaterinburg, Russia
e-mail: [1] yaroslav_zlobin@mail.ru, [2] kseniya.kashtanova.98@mail.ru, [3] mirmila@mail.ru, [4] z.v.beliaeva@urfu.ru

ANALYSIS OF THE INFLUENCE OF SEISMIC IMPACTS ON THE STATE OF STRUCTURES AND ROCKS. OVERVIEW OF THE REGULATORY FRAMEWORK

Abstract. The relevance of the article is due to the low awareness of the population about the possible consequences of an earthquake, as well as ways to prevent and prevent it already at the stage of designing a construction site. The article provides a comparative analysis of Russian and European design standards, which made it possible to identify their advantages and disadvantages. In addition, as a result of a review of Russian and foreign literature, an analysis was made of the development of scientific ideas about the stress-strain state of the geological environment as a result of seismic impacts. Based on the prerequisites set out in the text of the article, options for adjusting the maps of seismic activity of the territories are proposed. As a result of the analysis of the scientific literature, it was concluded that the behavior of soils and structures of buildings and structures during strong earthquakes remains poorly understood and is not always well described by existing mathematical models.

Keywords: earthquake, seismic impact, building structure, damage, voltage, seismic wave, seismic design, priming, building.

Злобин Я. А.[1], *Каштанова К. Д.*[2], *Миронова Л. И.*[3], *Беляева З. В.*[4]
[1-4] Уральский федеральный университет, г. Екатеринбург, Россия
e-mail: [1] yaroslav_zlobin@mail.ru, [2] kseniya.kashtanova.98@mail.ru, [3] mirmila@mail.ru, [4] z.v.beliaeva@urfu.ru

АНАЛИЗ ВЛИЯНИЯ СЕЙСМИЧЕСКИХ ВОЗДЕЙСТВИЙ НА СОСТОЯНИЕ СООРУЖЕНИЙ И ГОРНЫХ ПОРОД. ОБЗОР НОРМАТИВНОЙ БАЗЫ

Аннотация. Актуальность статьи обусловлена низкой осведомленностью населения о возможных последствиях землетрясения, а также способах его предупреждения и предотвращения уже на стадии проектирования строительного объекта. В статье проведен сравнительный анализ российских и европейских норм проектирования, который позволил выявить их достоинства и недостатки. Кроме этого, в результате обзора российской и зарубежной литературы проведен анализ развития научных представлений о напряженно-деформированном состоянии геологической среды в результате сейсмических воздействий. Исходя из предпосылок, изложенных в тексте статьи, предложены варианты корректировок карт сейсмической активности территорий. В результате проведенного анализа научной литературы сделан вывод о том, что поведение грунтов и конструкций зданий и сооружений при сильных землетрясениях остается малоизученным и не всегда хорошо описывается существующими математическими моделями.

Ключевые слова: землетрясение, сейсмическое воздействие, строительная конструкция, повреждения, напряжения, сейсмическая волна, сейсмостойкое проектирование, грунт, здание.

1. Introduction

For a long time, the danger of earthquakes was considered natural. It was assumed that the consequences of ground movements for buildings simply needed to be reconciled. Accordingly, measures to prevent earthquakes were mainly limited to preparations for the elimination of the consequences of a natural disaster, but already at the beginning of the 20th century, preventive measures also began to be proposed. In recent decades, intensive research on this topic has been carried out, and measures have been taken to reduce the vulnerability of buildings to earthquakes.

Earthquake risk (earthquake strength/probability of occurrence and local ground conditions) is a hazard and vulnerability factor for building structures. New structures are constantly being added to existing structures, which can be extremely vulnerable to careless or erroneous design. One of the reasons for this may be the fact that the design of new buildings does not always follow the important principles of seismic design, as well as the provisions of earthquake standards. This happens either out of ignorance or on purpose. This circumstance unnecessarily increases the risk of extremely destructive consequences of earthquakes.

The purpose of this article is to review scientific articles devoted to the analysis of the results of research in the field of earthquakes published by researchers of this problem in Russia, Germany, Switzerland and China.

For example, the Swiss public sector spends about 600 million Swiss francs a year on disaster management. The pie chart (Figure 1) on the right shows the distribution of various natural disasters. Relatively little money is spent on earthquake protection measures. This is because not every generation experiences a major earthquake. Despite this, the total consequences and damage to property from earthquakes can be orders of magnitude higher than from floods, avalanches, etc.

This example is just one of thousands around the world, but it also clearly shows that there are serious shortcomings in terms of measures taken to prevent earthquakes, as well as an underestimation of their possible consequences.

The search in the framework of this review of the literature on the topics of the influence of seismic impacts included familiarization with the already studied aspects of the chosen problem. 17 original scientific sources related to the research topic were found. The search was carried out using ResearchGate, eLibrary and other information retrieval services. The following will be a description of the results of the analysis of these sources. The review within the framework of this article is intended to raise awareness of the existing scientific developments related to the research topic, as well as to detect "blind spots" in the study of this topic, to assess the possibility of their improvement.

To achieve the goal of the article, it is necessary to solve the following tasks:

- to find out the causes of earthquakes and assess the possible damage from them;
- to study developments in the field of seismic resistance of building structures

and their maintainability after an earthquake;
- to analyze the applicability of existing regulatory documents and outline the prospects for their possible development;
- to analyze the stress-strain state of rocks and soils subjected to seismic impacts.

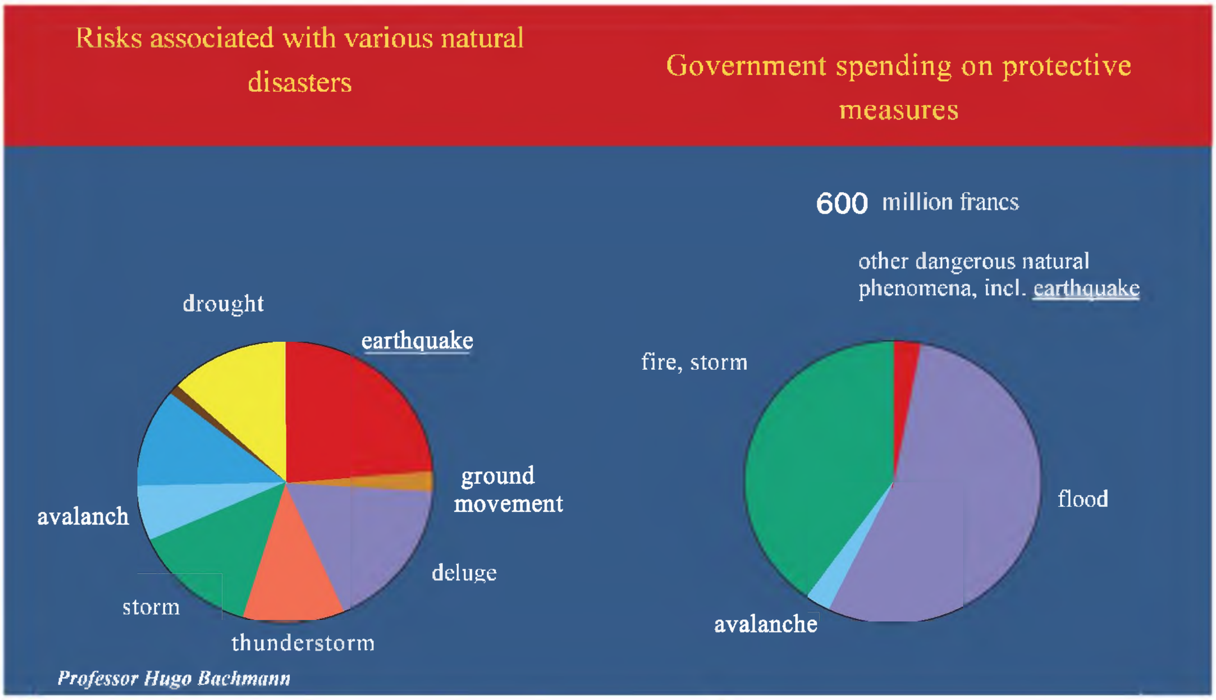

Figure 1. Diagrams of the probability of occurrence of a destructive impact and the amount spent by Switzerland on their elimination [1]

2. Research methods

To achieve the goal of the article, the essential-logical and comparative-comparative methods of theoretical analysis were used, which made it possible to comprehensively consider various scientific views on the subject of the article, reflected in scientific sources, as well as in comprehending practical experience; in addition, a system-structural method was applied, which made it possible to consider the studied phenomena in all their diversity, interconnection and integral unity of their components.

3. Results and discussion

H. G. Schmidt and S. Weissenburg in the publication "Determination of frequency-dependent coefficients of increase in rock movement due to local ground conditions" [2] showed how much influence the site conditions have on the stability and safety of structures in seismically active areas. The authors refer to the provisions of Eurocode No. 8 [3] and point to areas of possible supplementation of normative acts. As a result of the study for different classes of the terrain, an envelope of the spectral ratio was obtained, which can be given as a frequency- and soil-dependent magnification function for normalized spectral values of rock movement. The dependence of the soil factor (soil coefficient) S on the magnitude of the acceleration amplitudes and, consequently, on the resulting deformations was also noted. The authors point out that the implementation of generally applicable values for the ground conditions of construction sites, which should be set out in regulatory acts, requires interdisciplinary cooperation between seismologists, engineers and geotechnicians, namely it represents a promising direction for the development of activities.

Tuskaeva Z. R., Kulov M. E. in the article "Comparative analysis of Eurocode No. 8 [2]" and SNiP "Construction in seismic areas"" [4], [5] present an overview of the regulatory seismic framework of documents. The main idea of the authors was the possibility of introducing "Eurostandards" and "Euro-codes" into Russian production in order to reduce the material intensity and cost of design and construction and installation works, as well as to ensure interaction with foreign partners on the basis of one or similar regulatory and technical framework.

Improving the safety of construction of buildings and structures and bringing into line the Russian system of building codes and regulations (SNiP) without the embodiment of national ideas, as well as without the participation of domestic designers, structural engineers, architects and builders is impossible. Therefore, the authors see an opportunity to use some points of the Eurocode No. 8 as part of the Russian seismic standard only after processing and adjusting the points of the European standard according to the local conditions of Russia. It is possible to talk about the reliability of construction on the basis of such a "comprehensive" regulatory document only after the integration of Eurocodes into the Russian system of standards, norms and rules. To do this, it is necessary to conduct comparative calculations for each of the standards and analyze them.

J. Able and E. Keintzel also consider in detail the comparison of design standards in seismic areas, but on the example of Eurocode No. 8 [3] and DIN4149 [6]. The answer to the question "What are the advantages of Eurocode No.8 for the earthquake-resistant design of massive buildings in earthquake-prone areas of Germany?" can be found in their study [7]. This article presents comparative calculations that were carried out as part of a research project that examines the practical impact of the application of Eurocode No. 8 on the calculation and design of massive buildings in the event of earthquakes in Germany. Four standard buildings were designed in accordance with DIN 4149 and Eurocode No. 8. In particular, these include:

- a single-storey structure with reinforced concrete supports,
- multi-storey frame structure made of reinforced concrete,
- multi-storey wall panel structure made of reinforced concrete,
- two-storey stone building.

The seismic data required for comparative calculations have been identified for three site options:

- accommodation option 1: seismic zone 1 according to DIN 4149, hard ground as the most favorable option;
- accommodation option 2: earthquake zone 3 according to DIN 4149, solid ground;
- accommodation option 3: earthquake zone 4 according to DIN 4149, loose soil as the most unfavorable option.

The seismic loads included in the calculations were determined in accordance with the ratios specified in DIN 4149 and in Eurocode No. 8 with a limitation of the basic component of vibration.

Comparative calculations for the three selected reinforced concrete buildings show that the application of Eurocode No. 8 to reinforced concrete structures of structures in earthquake-prone areas of Germany with increased seismic loads compared to DIN 4149 on the lower floors of multi-storey buildings is decisive only for design in zone 2 of Eurocode No. 8 and unfavorable ground conditions. In the most adverse cases, compared to DIN 4149, we can expect an increase in steel consumption in components subject to seismic loads (frames, wall panels) by a maximum of 20 %.

In his publication, Doctor of Technical Sciences F. Mayer considers "Experimental repair studies of severely damaged reinforced concrete supports after a dynamic load" [8]. The research program presented in the article has two goals:

- classification of the damage index;
- investigation of the effectiveness of various repair measures and materials for reinforced concrete columns under static and earthquake-like loads.

Tests have shown that a mathematically determined degree of damage for different levels of damage can be very well classified visually based on the nature of the damage (cracking, condition of concrete and reinforcement). The classification of damages can be used as a first approximation in order to draw conclusions about the degree of damage and related repair measures based on the damage pattern of the corresponding reinforced concrete columns.

Restoration of the bearing capacity and deformation behavior of load-bearing elements, such as supports, severely damaged or destroyed by high loads (earthquake, collision of vehicles, etc.), is of great economic importance. For countries in regions with high seismicity, the economic damage would be immeasurable if every serious damage to a structure as a result of a medium-strength earthquake led to complete destruction.

The author notes that a small number of researchers are engaged in the discussion of the problem of the article. His article proposes approaches to the classification of damage to reinforced concrete columns as a result of dynamic loads, the implementation of appropriate repair measures and the development of the influence of various repair materials (cement mortar, polymer cement concrete PCC and steel fiber concrete).

In addition, it is concluded that for purely static loads it is preferable to use cheaper monolithic concrete. At dynamic, and, in particular, earthquake-like stresses, test poles with various repair materials behave in proportion to the price of these materials. An expensive steel fiber sealant has shown the best test results and is recommended from a technical point of view for high requirements.

In conclusion, it is noted that it is possible to restore the original bearing capacity and deformation behavior of severely damaged and destroyed reinforced concrete columns with the help of appropriate repair measures and materials. However, special care should be taken in the selection of measures and materials and attention should be paid to precise execution.

G. Grünthal and V. Minkley in the article "Seismic activity caused by mining as a source of seismic stress" [9] share the results of their study. The authors recall that seismic events caused by mining have repeatedly reached structurally destructive proportions in the past in the territory of the Federal Republic of Germany in villages above the affected mining areas. Consequently, in the subsequent version of DIN4149, the relevant areas near Cali Verra were designated as earthquake hazardous areas.

Probabilistic consideration of seismic hazard, as required by the new version of DIN 4149:2005-04, induced seismic events, according to the authors, is insufficient or not available at all. They argue that the map of earthquake zones of the standard does not contain information about man-made events.

In this paper, the types of non-tectonic induced seismic events are considered on a national scale. Of particular importance to German conditions are induced events in the mining areas with the strongest seismic events in the Saale Cali area and in the Cali Verra area. For the latter, a detailed description of the strongest events that have occurred so far is given, and the danger of future events with devastating consequences is assessed.

In the article "Seismic Risk Mapping based on EMS-98: A Practical Example of Eastern Thuringia", J. Schwarz, M. Raschke and H. Maiwald formulate methodological principles for assessing realistic potential damage based on the

European macroseismic scale EMS-98 for the testing area in Eastern Thuringia on the example of the city of Schmölln [10]. The authors note that the quality of seismic risk mapping depends to a large extent on the available baseline data, which should be processed in a form suitable for GIS, to the extent that models are available to characterize the potential of local fortifications and the actual stock of buildings. Based on the available geological maps and borehole data, a spatial depth profile is created. By modeling on depth profiles, spectral accelerations are determined for the period ranges in which the major periods of the building groups prevailing in the target area are located.

On the basis of aerial photographs and cadastral data, the actual stock of buildings is updated and mapped using on-site records. At the test site itself, about 3,000 objects were sorted by building type, purpose, condition, etc. and classified by vulnerability class according to EMS-98. Based on this data, earthquake scenarios are simulated, which imply a "normal case" (a repetition period of about 500 years) and other, "optimistic" or "pessimistic" events with a very low probability of occurrence. Results are available for a variety of earthquake scenarios that are based on both intensity and location-specific magnitude-distance conditions. A perspective on current work has been developed in which local expected ground movements can be directly taken into account, and the behaviour of the structure can be predicted depending on the local stress level.

The seismic risk maps obtained in this way show the degree of damage to existing structures and allow a realistic assessment of potential damage. However, the results can be presented with varying degrees of detail (for example, in the form of the degree of damage to individual objects or the average degree of damage to the boundaries of specific sites). The related need for coordination with local authorities is being discussed.

The article "Earthquake-resistant buildings" [11], published by the Frauhofer Society in the journal "Research compact" (06.2017, issue 3), deals with the use of innovative torque converters to ensure the seismic stability of buildings.

Experts attribute the fact that earthquakes lead to numerous deaths, with the lack of precautions, but above all - with the construction of houses with non-compliance with the standards of earthquake-resistant design. Representatives of the Center for Easy and Environmentally Friendly Construction of the Institute for Wood Research named after that decided to influence this situation. Fraunhofer, Wilhelm-Kloditz-Institut (WCI). Together with the Department of Organic Building and Wood-Based Materials of the Institute of Building Materials, Capital Construction and Fire Protection at the Technical University of Braunschweig, as well as with entrepreneurial partners such as Pitzel Metallbau from Altheim, researchers are developing solutions for the construction industry that could protect thousands of lives from the devastating effects of earthquakes. The article says that Fraunhofer VKI engineers are currently working on high-performance torque converters that help make tall buildings earthquake-resistant: sensor-controlled steel joints are highly rigid and at the same time elastic enough to hold the house under strong fluctuations. In numerous tests, the flawless functioning of torque converters has been confirmed. Among other things, the researchers studied the type of stress state in static, cyclic and dynamic application of forces; the service life of the structure was tested using simulated environmental tests.

The article "Damage to non-load-bearing building elements and structures caused by storms and earthquakes" by G. Berz and A. Smolka [12] draws attention to the fact that numerous natural disasters in recent decades, damage by storms and earthquakes to non-load-bearing components, the contents of buildings, as well as installations and machines are becoming increasingly important compared to other damage to the structure of the building and increasingly exceed the total damage. The authors note that despite this, measures to prevent damage have so far been largely ignored, although in general they can be implemented with a much more favorable cost-benefit ratio. They argue that damage from earthquakes and storms is often associated with secondary effects, such as debris flying away, fires, rainwater ingress and disruption of production and services because of it, which can drastically increase the damage. On the basis of a typical case of destruction, particularly frequent or critical weak points of buildings are presented and appropriate precautions for damage are discussed. The authors believe that much more attention needs to be paid to measures to protect against earthquakes and destructive effects, which has not yet been done. With extensive experience in the field of losses, the insurance industry can provide disaster assessment engineers with the basic information needed to develop effective measures to reduce the level of destruction.

In the article by Y. V. Semenova "Modeling of soil reaction in seismic microzoning of construction sites" [13] approaches to determining the resonant properties of the upper part of the geological medium section under the construction site for earthquake-resistant design are considered. The development of scientific ideas about linear and nonlinear models of the geological environment is analyzed. The author concludes that there is no program that works well in all situations. In cases of manifestations of strong nonlinearity, there is sometimes a discrepancy between the registered and calculated accelerationograms due to the fact that the behavior of soils during strong earthquakes remains poorly understood and is not always well described by existing models. However, with very intense seismic influences, the most acceptable results can be obtained by nonlinear modeling.

The article presents and analyzes the results of linear, equivalent linear and nonlinear modeling of the reaction of a real soil stratum under a real construction site in Kiev to earthquakes of different levels. Based on the comparison, the author concludes that with seismic microzoning in weakly seismic areas, it is permissible to use both nonlinear and equivalent linear modeling of the reaction of soils to seismic influences, because with relatively small deformations, the results of these methods give comparable results.

Sedov B. M. in the author's abstract to the dissertation for the degree of Doctor of Geological and Mineralogical Sciences on the topic "Seismic properties of the cryolithozone" [14] gave a solution to the fundamental problems of the complex scientific problem of seismic properties of the cryolithozone, establishing the relationship of seismic characteristics with geocryological parameters, and their display in the wave fields of elastic oscillations. In particular, the author obtained the characteristics of the seismic properties of the cryolithozone, established their dependence on geocryological parameters; it has been established that the wave fields of elastic oscillations reflect the horizontal and vertical heterogeneity of the cryolithozone, and with surface and close-surface sources on the permafrost, the main carriers of energy are Rayleigh waves. Typical multidimensional seismoheocriological models have been developed for the most characteristic permafrost sites. The practical significance of the work also lies in improving the geological efficiency of seismic exploration, including by expanding the range of geocryological problems to be solved on the basis of new methods using exchange and reflected Rayleigh waves, reverberation oscillations. In addition, the result of the study was an increase in the geological and economic efficiency of seismic exploration in permafrost areas.

Aleshin A. S. in the article "Macroseismic foundations of seismic microzoning" [15] considers the current norms of earthquake-resistant construction in Russia, based on macroseismic assessments using the concept of "seismic score". The author describes various aspects of seismic microzoning, in which the use of a macroseismic approach has led to advances in anti-seismic construction. Emphasis is placed on the practice of Western countries, primarily the United States, where new approaches based on mass instrumental measurements of the parameters of strong movements were intensively developed, which was due to the rapid development of microelectronics, means of obtaining and processing seismic signals. A. Aleshin notes the lag in this respect of domestic engineering seismology and believes that the analysis of the achievements of foreign engineering seismology, based on an instrumental approach, and ways to overcome the lag of domestic science should be the content of further work of Russian scientists in this direction.

The results of unique measurements of the reaction of rock massifs to the passage of seismic waves initiated by high-intensity and weak influences are investigated by E. Gorbunova in the article "Changes in the properties of a rock mass under the influence of seismic oscillations" [16]. In this paper, variations in geophysical and hydrogeological parameters (values of longitudinal wave velocities, depth of the structural boundary, level and intensity of water inflows) confirmed the change in the mechanical properties of the mountain range under intense exposure. As an example of the intense impact of seismic waves on the geological environment, one of the sites of the Semipalatinsk test site was chosen, within which a large-scale explosion was carried out in the experimental well. The results of unique full-scale measurements demonstrate that irreversible changes in rock massifs associated with the passage of seismic waves can occur not only under intense influences, as in the above example of a large-scale explosion, but also with relatively weak disturbances. The considered examples of registration of deformations in field experiments and under the influence of earthquakes in the range of soil displacement velocities from 0.1 to 100 mm/s show that irreversible changes can occur in this range of oscillation amplitudes, of course, if the array is ready to "react" to such a disturbance. Given that with repeated exposures, small deformations can accumulate, as a result, there may be a significant increase in the fissile permeability of the array with the accumulation of the effect with prolonged exposure. Changing the number of open cracks and increasing their effective permeability can lead to migration of fluids, variations in pore pressure, and, consequently, the entire range of mechanical characteristics of the local section of the array – E. Gorbunova comes to this conclusion.

Chinese researchers Zhongxian Liu, Jiaqiao Liu, Qiang Pei, Haitao Yu, Chengcheng Li, Chengqing Wu in their study "Seismic reaction of the tunnel near the fault zone under the waves SV" [17] studied the influence of deformation factors on the dynamic reaction of a nearby linear tunnel during the fall of plane reflected transverse waves SV using the method of indirect boundary elements. The study examined the effect of a number of critical parameters, such as the frequency of collisions, the degree of inclination of the fault, the distance between the fault and the tunnel on the voltage of the hoop of the aligned inner and outer walls. Numerical results showed that the malfunction can significantly change the stress distribution on the inner and outer surfaces of the tunnels. In general, for vertically acting seismic waves, when the tunnel was located in the wall of the foot (under the fault), the voltage inside the tunnel was significantly greater than that of tunnels in the half-space without a closure, with a gain of up to 117 %. The amplification effect became more pronounced as the angle of incidence increased. However, when the tunnel was located above the fault, the fault could have a significant shielding effect on the dynamic response of the tunnel under the high-frequency impact of waves. At the same time, the voltage reduction was up to 81 %. However, low-frequency waves can cause the tunnel voltage to increase by up to 152 %. The results of the described studies can be a guide in the seismic design and protection of underground structures at fault sites.

4. Conclusion

The analysis of foreign and domestic scientific publications carried out in the article showed what consequences may arise for structures and rocks as a result of seismic impacts. In addition, shortcomings, opportunities, boundaries and prospects for the development of the development of national design standards were identified while maintaining the current level of safety and increasing it. It is shown that there are some gaps related to the topic of seismic impacts on buildings and rocks. At the same time, in some of the sources under consideration, the authors give a direct indication of a promising direction for further research. These include the following:

- study of the feasibility of applying the points of seismic regulatory documents and proposals to reduce the safety factors incorporated in them;
- study of the possibilities for the restoration of building structures after earthquake damage and the choice of a restoration method depending on the degree of damage.

At the same time, the idea has been repeatedly expressed that the widespread introduction of seismic protection systems is currently constrained by the lack of data on the actual behavior of such systems during strong earthquakes, as well as the widespread myth that seismic protection included in the cost at the design stage will lead to a significant increase in construction costs. In fact, the increase in cost will be no more than 1-3 % of the cost of construction.

It should also be noted that there is still no map of seismic zones, compiled taking into account the likelihood of earthquakes as a result of "induced" activity - mining operations, which are a source of seismic stress along with natural causes. In addition, the results of a comparative analysis of the rationality of applying one or another method of seismic protection with reference to specific natural conditions and territories in terms of intensity have not been found. These questions are relevant from the point of view of labor costs applied when creating computational models in software systems at the design stage, and therefore are expressed in monetary terms.

Summing up the review article, it should be said that the goals set at the beginning of the study have been achieved, the tasks have been completed, and the result is the plurality of identified unexplored areas that take place in the study of topics of seismic impacts on buildings and rocks. Some of these gaps will be further explored by the authors of this article.

References

1. Bachmann, H. (2002). *Erdbebengerechter Entwurf von Hochbauten.* In: Erdbebensicherung von Bauwerken. Birkhäuser, Basel. https://doi.org/10.1007/978-3-0348-8143-2_4. (In German)

2. Schmidt, H.G. and Weisenburg, St. (1994). Ermittlung von frequenzabhängigen Vergrößerungsfaktoren der Felsbewegung durch lokale Baugrundverhältnisse [Determination of frequency-dependent magnification factors of rock movement due to local ground conditions]. *Seismische Einwirkungen auf Bauwerke unterschiedlichen Risikopotentials* [Seismic impacts on structures with different risk potential].

(pp. 97-110) German Society for Earthquake Engineering and Structural Dynamics. (In German)

3. BSI (British Standards Institution) (2004). Eurocode 8: Design of structures for earthquake resistance - Part 1 : General rules, seismic actions and rules for buildings. BSI, London, EN 1998-1 :2004:

4. FAU FCC (Federal Center for Rationing, Standardization and Technical Conformity Assessment in Construction) (2018). Code of rules SP 14.13330.2014 Stroitel'stvo v seysmicheskikh rayonakh [Construction in seismic areas]. FAU FCC, Moscow (In Russian)

5. Tuskaeva, Z. R., Kulov M. E. (2018). Sravnitel'nyy analiz Yevrokoda 8 i SNiP "Stroitel'stvo v seysmicheskikh rayonakh" [Comparative analysis of Eurocode 8 and SNiP "Construction in seismic areas"] *Fundamental'nyye i prikladnyye issledovaniya: gipotezy, problemy, rezul'taty [Fundamental and applied research: hypotheses, problems, results]* (pp. 77-82) Center for the Development of Scientific Cooperation. (In Russian)

6. NABau (DIN Standards Committee Building and Civil Engineering) DIN 4149: 2005-04: Bauten in deutschen Erdbebengebieten - Lastannahmen, Bemessung und Ausführung üblicher Hochbauten [Buildings in German earthquake areas. Design loads, analysis and structural design of buildings]. Berlin. (In German)

7. Eibl J. and Keintzel E. (1994). Was bringt der Eurocode 8 für die Erdbebenauslegung von Massivbauten in deutschen Erdbebengebleten? [What is the benefit of Eurocode 8 for the seismic design of solid structures in German seismic areas?] *Seismische Einwirkungen auf Bauwerke unterschiedlichen Risikopotentials* [Seismic impacts on structures with different risk potential]. (pp. 137-150) German Society for Earthquake Engineering and Structural Dynamics. (In German)

8. Meyer F., (1991). Experimentelle Instandsetzungsuntersuchungen an, nach dynamischer Belastung, Stark geschädigten Stahlbetonstützen [Experimental repair studies on heavily damaged reinforced concrete columns after dynamic loading]. *Erdbebeneinwirkungen auf nichttragende Bauelemente* [Seismic actions on non-load-bearing components] (pp. 241-260) German Society for Earthquake Engineering and Structural Dynamics. (In German)

9. Grünthal, G. & Minkley, W. (2005). Bergbauinduzierte seismische Aktivität als Quelle seismischer Belastungen – Zur Notwendigkeit der Ergänzung der Karte der Erdbebenzonen der DIN 4149: 2005-04 [Mining-induced seismic activities as a source of seismic loads - The need to supplement the earthquake zone map of DIN 4149:2005-04]. *Bautechnik.* (82), 508–513. http://doi.org/10.1002/bate.200590167 (In German)

10. Schwarz J., Raschke M. and Maiwald H. (2001). Seismische Risikokartierung auf der Grundlage der EMS-98: Fallstudie Ostthüringen [Seismic risk mapping based on the EMS-98: case study East Thuringia]. *Forum Naturkatastrophen* [*Forum Natural Disasters*] (pp. 325-336). Leipzig. (In German)

11. Eitner, J. and S. Peist, (2017). Erdbebensichere Gebäude. Neuartige Momentenverbinder für unzerstörbare Hochbauten [Earthquake-proof buildings. Novel moment connectors for indestructible buildings]. https://www.fraunhofer.de/content/dam/zv/de/pressemedien/2017/Juli/ForschungKompakt/fk_06_2017_WKI_Erdbebensichere%20Geb%C3%A4ude.pdf (In German)

12. Berz, G. and Smolka A. (1991). Sturm- und Erdbebenschaden an nichttragenden Bauelementen und Gebaudeeinrichtungen [Storm and earthquake damage to non-load-bearing structural elements and building facilities]. *Erdbebeneinwirkungen auf nichttragende Bauelemente* [Seismic actions on non-load-bearing components] (pp. 7-16) German Society for Earthquake Engineering and Structural Dynamics. (In German)

13. Semenova, Yu. V. (2015). Modelirovaniye reaktsii grunta pri seysmicheskom mikrorayonirovanii stroitel'nykh uchastkov [Simulation of soil response during seismic microzoning of construction sites]. *Geofizicheskiy zhurnal* [*Geophysical Journal*]. 37 (6), 137-153. http://doi.org/10.24028/gzh.0203-3100.v37i6.2015.111181. (In Russian)

14. Sedov, B. M. (1992). Seysmicheskiye svoystva kriolitozony [Seismic properties of the cryolithozone] [Doctoral dissertation, Wilmington University]. St. Petersburg. (In Russian)

15. Aleshin, A. S. (2011). Makroseysmicheskiye osnovy seysmicheskogo mikrorayonirovaniya [Macroseismic foundations of seismic microzoning] *Voprosy inzhenernoy seysmologii* [*Problems of engineering seismology*]. 38(4) 15-28. (In Russian)

16. Gorbunova E. M., Pavlov D. V., Ruzhich V. V. (2015). Izmeneniye svoystv massiva gornykh porod pod deystviyem seysmicheskikh kolebaniy [Change in the properties of a rock mass under the influence of seismic vibrations] *Triggernyye effekty v geosistemakh* [*Trigger effects in geosystems*] (pp. 121-128). GEOS Publishing House, Moscow. (In Russian)

17. Zhongxian Liu, Jiaqiao Liu, Qiang Pei, Haitao Yu, Chengcheng Li, Chengqing Wu (2021). Seismic response of tunnel near fault fracture zone under incident SV waves. *Underground Space*. 6, 695-708. http://doi.org/10.1016/j.undsp.2021.03.007