

Abstract

on the dissertation by Shadkam Asylbek Safaraliuly entitled “Modelling the interaction of a structure with a seismically isolated foundation under seismic actions”, submitted for the degree of Doctor of Philosophy (PhD) in the specialty 8D07303 – Construction and Production of Building Materials and Structures.

Relevance of the research: Modern earthquakes occurring in various regions of the world, including the seismically hazardous areas of Kazakhstan (Almaty, Shymkent, Taldykorgan, etc.), clearly demonstrate the high vulnerability of buildings and structures to seismic actions. Damage and destruction of constructed facilities lead not only to significant economic losses, but also pose a threat to human life and health. In this regard, the search for and implementation of new, more effective seismic protection technologies is a priority task of construction science and practice.

The aspects of the theory of earthquake resistance have been comprehensively developed in the works of Ya.M. Ayzenberg, T.Zh. Zhunusov, T.D. Abakanova, U.T. Begaliev, I.I. Goldenblat, S.V. Polyakov, G.A. Dzhinchvelashvili, O.V. Mkrttychev, B.G. Korenev, N.A. Nikolaenko, T.R. Radishidov, S.V. Kuznetsov, A.M. Uzdin, Yu.D. Cherepinsky, as well as N. Newmark, Sh. Okamoto, E. Rosenblueth, A.K. Chopra and others.

Studies on accounting for the interaction between a structure and the soil foundation are presented in the publications of Zh.S. Erzhanov, Sh.M. Aytaliev, B.B. Teltaev, E.A. Isakhanov, A.Zh. Zhusipbekov, V.A. Khomyakov, V.A. Ilyichev, D.D. Barkan, I.T. Mirsayapov, Z.G. Ter-Martirosyan, A.G. Tyapin, L.V. Nuzhdin, as well as J. Housner, Calvi P.M., Zhang J.S., Dhanya J.S., and other authors.

Traditional seismic isolation methods, based mainly on structural solutions in the superstructure of a building or in foundation systems, do not always provide a sufficient level of protection under complex engineering and geological conditions and strong seismic shaking. In this regard, the development of geotechnical seismic isolation (GSI) technologies, which involve the use of protective barriers and layers in the soil foundation to reduce the intensity of seismic wave propagation, is of particular importance.

However, according to the assessments of P.N. Abovsky, G.A. Dzhinchvelashvili, O.V. Mkrttychev and others, the field of active seismic isolation remains methodologically unformed and requires strict scientific and technical justification to ensure an objective verification of its effectiveness.

One of the promising directions is the use of geotechnical seismic isolation (GSI) technologies, which make it possible to attenuate seismic waves at the stage of their propagation in the soil foundation. Modelling the interaction of a structure with a seismically isolated foundation under seismic actions provides a scientific basis for evaluating the effectiveness of GSI and for developing practical recommendations for design.

Some results of numerical modelling of the propagation of seismic waves and their interaction with seismic barriers are presented in the works of S.V. Kuznetsov, G.A. Dzhinchvelashvili, O.A. Makovetsky, O.V. Mkrttychev, A.E. Nafasov, Kh.M.

Saparliev, V.V. Orekhov, E.T. Besimbaev, S.E. Nietbay, Kh. Negahdar, P. Douglas, R. Haupt, V. Liberman, M. Rothschild and others.

Studies in this field show that the use of geotechnical seismic isolation makes it possible to significantly reduce the amplitude of seismic vibrations acting on a building due to the damping properties of special materials and engineering solutions (trenches, barriers, layers made of rubber–soil mixtures, etc.). This approach opens up new possibilities for ensuring the stability of structures, including in construction in regions with increased seismic activity.

Thus, the relevance of the research is determined by the need to develop scientific and technical foundations and practical methods for the application of GSI under the conditions of Kazakhstan and other seismically hazardous regions. The results obtained will contribute to the formation of new design solutions, an increase in the level of seismic safety, and a reduction in the risk of damage and collapse during earthquakes.

Object of the research: reinforced concrete buildings and structures, as well as systems of various structural schemes located on soil foundations with geotechnical seismic isolation (GSI), subjected to intense seismic actions.

Subject of the research: the stress–strain state of the foundation during an earthquake (intensity of strains and stresses); models of geotechnical seismic isolation (GSI) in the form of V-shaped and vertical seismic barriers; and the assessment of the effectiveness of geotechnical seismic isolation.

Aim of the dissertation: numerical and experimental modelling of the interaction between a structure and a seismically isolated foundation, and evaluation of the effectiveness of geotechnical seismic isolation (GSI) in reducing the impact of earthquakes.

To achieve this aim, the following tasks have been set in the dissertation:

1. Analysis of theoretical and experimental studies of the interaction between a structure and a seismically isolated foundation during earthquakes, and the scientific and technical justification of geotechnical seismic isolation as a new scientific direction.
2. Development of a methodology for modelling the interaction of a structure with geotechnical seismic isolation (GSI), reflecting the joint behaviour of the “structure – seismically isolated foundation” system.
3. Development of a geotechnical seismic isolation (GSI) model in the form of seismic barriers that reduce seismic actions in the protected zone.
4. Numerical and experimental modelling of the shape, materials, and geometric dimensions of geotechnical seismic isolation in the form of vertical seismic barriers that provide a reduction of seismic actions.
5. Assessment of the effectiveness of geotechnical seismic isolation (GSI) for specific engineering–geological conditions and a design-level seismic action of an earthquake.

In the studies, numerical and experimental modelling was carried out to investigate the operating principle of geotechnical seismic isolation (GSI) in the form of seismic barriers, regarded as elements that reduce the transformation of surface seismic vibrations.

Research methods: Using PLAXIS 2D, numerical and experimental modelling of the interaction between the structure and the seismically isolated foundation was carried out, a comprehensive analysis of the response of buildings and structures to seismic loads was performed, and a set of engineering and technical solutions for their protection was developed.

The following methods were used in the dissertation.

- **analytical methods** – to generalize the theoretical foundations for the development of geotechnical seismic isolation (GSI) technologies;
- **numerical modelling methods** – to assess the stress–strain state of structures and the seismically isolated foundation under seismic actions;
- **methods of comparative analysis and expert evaluation** – to verify the developed geotechnical seismic isolation (GSI) model and to formulate practical recommendations.

The scientific novelty of the work lies in the development of the concept of geotechnical seismic isolation (GSI) as a design alternative to traditional seismic isolation systems, characterized by its efficiency in reducing seismic actions and by the reliability of its implementation during both construction and operation periods:

1. A methodology for the scientific and technical justification of geotechnical seismic isolation (GSI) as a new scientific field that contributes to improving the seismic resistance of buildings and structures has been systematized and developed.
2. A methodology has been developed for modelling the interaction of a structure with geotechnical seismic isolation (GSI), reflecting the joint behaviour of the “structure – seismically isolated foundation” system.
3. Geotechnical seismic isolation (GSI) models have been proposed in the form of V-shaped and vertical seismic barriers, which are characterized by high efficiency in reducing seismic actions and by reliability in implementation.
4. An optimal shape of seismic barriers, barrier materials with damping properties, and the main geometric parameters that govern the reduction of seismic actions in the protected zone have been proposed.
5. Numerical modelling of the joint performance of a seismically isolated foundation with the superstructure has been carried out, and the effectiveness of geotechnical seismic isolation (GSI) has been determined for specific engineering–geological conditions.
6. The reliability of a reinforced concrete building and a chimney has been assessed with due regard for the joint behaviour of the foundation with geotechnical seismic isolation (GSI).

A recommendation has been developed on ensuring the organisational and technological reliability of geotechnical seismic isolation (GSI) systems during both the construction and operational periods.

Main points submitted for defense:

1. Results of analytical and theoretical studies providing the scientific and technical justification of geotechnical seismic isolation as a new scientific

direction that contributes to increasing the seismic resistance of buildings and structures..

2. Results of numerical modelling of the interaction between a building and surface seismic waves, used to develop a methodology for modelling geotechnical seismic isolation (GSI) that reflects the joint behaviour of the “structure – seismically isolated foundation” system.
3. Results of numerical and experimental modelling of the shapes of seismic barriers made of various materials with good damping properties, aimed at reducing the impact of earthquakes.
4. Results of the reliability assessment of the “structure – geotechnical seismic isolation” system for a multi-storey building and a chimney under an earthquake with an intensity of 9 points.
5. Results of the assessment of the effectiveness of geotechnical seismic isolation (GSI) technologies and recommendations for their application under specific engineering–geological conditions.

Field of application – geotechnics, earthquake-resistant construction, and seismic protection of existing buildings.

The practical significance of the work is as follows:

the developed scientific and technical justification of geotechnical seismic isolation can be applied in the design and construction of buildings and structures. The use of the obtained results makes it possible to increase the seismic resistance of facilities, reduce earthquake-induced damage, and ensure reliable operation in seismically hazardous areas.

- The results of numerical modelling of the interaction between a building and surface seismic waves made it possible to develop a methodology for modelling geotechnical seismic isolation (GSI) that accounts for the joint behaviour of the structure and the seismically isolated foundation. This provides an opportunity for a more accurate assessment of the effectiveness of protective measures in the design of buildings in seismically hazardous areas.

- Numerical and experimental modelling of the shapes of seismic barriers made of materials with high damping properties makes it possible to substantiate their effectiveness in reducing earthquake impacts and can be used in the design of protective systems for buildings and structures.

- The practical significance of the work lies in the fact that the effectiveness of geotechnical seismic isolation (GSI) technologies has been assessed and recommendations have been developed for their application depending on specific engineering and geological conditions. This ensures a well-founded choice of optimal solutions to improve the seismic resistance of buildings and structures.

The author’s personal contribution consists in formulating the aim and objectives of the dissertation, collecting and systematising research materials, performing numerical calculations for the seismically isolated foundation, analysing and interpreting the obtained results, as well as preparing the conclusions and main

provisions submitted for defence. In addition, the author has written scientific papers and conference reports on the topic of the research.

The author participated as a researcher in the programme-targeted funding project BR21882292 “Integrated development of a sustainable construction industry: innovative technologies, optimisation of production, efficient use of resources, and creation of a technology park.”

Publication and approbation of the work. The main results of the dissertation were discussed and validated at international and national scientific conferences:

1. D. Serikbayev East Kazakhstan Technical University “Engineering Education: Challenges, Trends, Best Practices” (2024).

2. II Eurasian Innovation Forum “Current Issues of Development and Safety of Large Cities” (2024).

3. International conference at Razzakov KSUSTA University dedicated to the 80th anniversary of the Kyrgyz Republic statesman Nasirdin Isanov (2024).

The main results of the dissertation are presented in 7 published works of scientific value, including 2 publications in Scopus-indexed journals (Q2 and Q4), 2 papers in journals recommended by the Committee for Quality Assurance in Science and Higher Education (KOKSNVO), and 2 patents for inventions:

1. Bessimbayev Y.T., Shadkam A.S., Begaliev U.T., Begentayev M.M., Suleyev D.K., Zhumadilova Z.O., Igribayev T.I., Ussipbekov Y.Y. Development of Geotechnical Seismic Isolation System in the Form of Vertical Barriers: Effectiveness and Perspective. Buildings, 2024, Vol 14, I 9, 2736

<https://doi.org/10.3390/buildings14092736>

2. Alenov K.T., Bessimbayev Y.T., Shadkam A.S., Bissenov K.A., Niyetbay S.E., Z.N. Moldamuratov Z.N. Modelling and efficiency assessment of vertically reinforced slab foundation of multi-storey building. Nanotechnologies in Construction. 2025. T 17. No. 2. P 151-172. Scopus Building and Construction – 43 процентиљ <https://doi.org/10.15828/2075-8545-2025-17-2-151-172>

3. Besimbayev E.T., Asylbekov D., Niyetbay S.E., Shadkam A.S. Geotechnical method for ensuring the seismic resistance of ancient historical architectural monuments. Bulletin of Kazakh Leading Academy of Architecture and Construction, No. 4 (86), 2022, pp. 147–154. ISSN 1680-080X. <https://doi.org/10.51488/1680-080X/2022.4-14>

4. Bessimbayev Y.T., Shadkam A.S., Begaliev U.T., Niyetbay S.E. The Comparison of Deformation Calculation Results of Structures under Seismic Impact Using Mohr-Coulomb and Hardening Soil Small (HSS) Soil Models. Вестник КазГАСА. №4 (94), 2024. Құрылыс. <https://doi.org/10.51488/1680-080X/2024.4-16>

5. Besimbaev E.T., Kuldeev E.I., Zhumadilova Zh.O., Begaliyev U.T. Specific features of designing a vertically reinforced base of a slab foundation. Bulletin of D. Serikbayev EKTU, No. 4 (228), 2024. https://doi.org/10.51885/1561-4212_2024_4_228

6. Besimbaev E.T., Irgebayev T.I., Zhambakina Z.M., Shadkam A.S., Nashiraliyev

Zh.T., Kuatbayeva T.K., Kusbekova M.B., Maselbekov D.M. Screen for protecting buildings and structures from seismic shocks during earthquakes and from the effects of technogenic sources of vibrations. No. 36539, bulletin dated 05.01.2024.

7. Besimbaev E.T., Irgebayev T.I., Zhambakina Z.M., Nashiraliyev Zh.T., Shadkam A.S., Kuatbayeva T.K., Kusbekova M.B., Maselbekov D.M., Begaliyev U.T., Nietbay S.E., Zhirenbayeva N.O., Kadyrov Zh.N. Screen for protecting buildings and structures from seismic shocks during earthquakes and from the effects of technogenic sources of vibrations. No. 36543, bulletin dated 05.01.2024..

Structure and scope of the work. The dissertation includes an introduction, four chapters and a conclusion, and comprises 121 pages. The work is illustrated with 65 figures, contains 3 tables, and is accompanied by a list of references consisting of 88 titles..