Л.Н. Гумилев атындағы Еуразия ұлттық университетінің ХАБАРШЫСЫ.
ISSN: 2616-7263. eISSN: 2663-1261
ТЕХНИКАЛЫҚ ҒЫЛЫМДАР ЖӘНЕ ТЕХНОЛОГИЯЛАР СЕРИЯСЫ / TECHNICAL SCIENCES AND TECHNOLOGY SERIES/ СЕРИЯ ТЕХНИЧЕСКИЕ НАУКИ И ТЕХНОЛОГИИ

IRSTI 67.11.03
Article
https://doi.org/10.32523/2616-7263-2025-151-2-262-280

# Innovative solutions of geotechnical seismic isolation with application of ground rubber for protection ofarchitectural monuments

**S. Niyetbay[1], Y. Bessimbayev[2], I. Tashmukhanbetova*[1], Sh. Toleubayeva[1], A. Tleubayeva *[1]**

[1]*International Educational Corporation, Almaty, Kazakhstan*
[2]*Kazakh National Research Technical University named after K. I. Satpayev, Almaty, Kazakhstan*

***E mail: akmaral_alim@mail.ru, indiraberkinbaykyzy@gmail.com***

**Abstract.** This study investigates the application of geotechnical seismic isolation as a feasible and effective strategy for safeguarding architectural heritage sites against seismic hazards. Particular attention is given to the advantages of this approach, including the preservation of structural integrity and historical authenticity, minimal intrusion into existing constructions, and the use of durable, long-lasting materials. The paper examines various seismic mitigation techniques, such as the integration of isolation layers, damping interfaces, shock-absorbing elements, and specialized foundation systems. Case studies of successful applications in culturally valuable structures are presented to support the practical relevance of the proposed methods. The research further emphasizes the importance of advanced engineering solutions in reducing seismic vulnerability, especially in tectonically active regions. A central focus is placed on the use of soil–rubber composite layers as a seismic isolation medium. Experimental results demonstrate a substantial reduction in ground motion amplitudes, thereby enhancing both the resilience and service life of protected buildings. Overall, the findings establish geotechnical seismic isolation as a promising component of modern earthquake-resistant design, requiring a multidisciplinary approach that accounts for engineering, geological, and economic considerations.

**Key words:** geotechnical seismic isolation; soil–rubber composite; cultural heritage preservation; experimental testing; compaction device; accelerometric evaluation; seismic vibration amplitude.

Received 21.05.2025. Revised 11.06.2025. Accepted 13.06.2025. Available online 31.06.2025

* the corresponding author

## Introduction

The protection of architectural heritage from seismic hazards remains a critical and evolving concern in the broader context of cultural preservation and structural resilience. Historic structures, often characterized by unique construction techniques, rare materials, and age-related degradation, are inherently more susceptible to damage from seismic activity. Unlike modern buildings, these monuments typically lack standardized reinforcements or seismic-resistant features, which amplifies their vulnerability to earthquake-induced forces. In light of the growing frequency and intensity of seismic events in many regions of the world, there is an urgent need for advanced engineering solutions that are both effective and respectful of the historical value of these structures.

Among the emerging strategies addressing this issue, geotechnical seismic isolation has proven particularly promising. This method involves the installation of subsurface energy-dissipating systems that interrupt or attenuate seismic waves before they reach the superstructure. By reducing the amplitude and transmission of ground vibrations, such systems effectively limit the internal stresses experienced by heritage buildings during earthquakes. A major advantage of geotechnical isolation is its non-intrusive nature: it does not require extensive modification to the visible parts of a monument, thereby helping to preserve the authenticity, form, and aesthetic integrity of historically significant architecture.

Over the past decade, various configurations of geotechnical seismic isolation have been examined through computational modeling and laboratory experiments. These investigations have covered a wide range of materials and structural setups. For example, Forcellini and Chiaro [1] conducted parametric studies using the OpenSees platform to simulate the dynamic response of gravel–rubber composite layers under cyclic loading. Their work highlighted how the inclusion of different percentages of crumb rubber (10%, 25%, 40%) could significantly influence energy dissipation capacity, with higher rubber content generally yielding better damping performance.

In parallel, sustainable and eco-friendly solutions have gained prominence, particularly in the context of green construction. Several studies have explored the use of layered systems combining gravel and recycled rubber—materials that are not only readily available but also environmentally responsible. When placed beneath reinforced concrete foundations, these composite layers act as passive isolation mechanisms, effectively filtering seismic energy before it propagates upward. Empirical results from shake table tests and numerical models consistently demonstrate that such systems contribute to a measurable reduction in peak ground acceleration, lateral displacement, and base shear forces [2], all of which are critical parameters in maintaining the structural safety of heritage assets.

Banović [3] conducted a series of shake-table experiments aimed at evaluating the performance of geotechnical isolation layers under controlled seismic conditions. These experiments specifically focused on the influence of critical parameters—such as the thickness of the isolation layer, the degree of compaction, and the moisture content—on the seismic behavior of overlying structures. By systematically varying these parameters and subjecting the scaled models to different levels of peak ground acceleration (PGA), the study was able to provide detailed insight into how these factors affect the damping characteristics and overall effectiveness of the isolation system. The results demonstrated that optimal layer design—particularly with respect to compaction and thickness—can significantly enhance seismic energy dissipation.

Similarly, Jing [4] introduced an innovative multilayered seismic isolation configuration that utilized alternating layers of sand and glass beads. This composite system aimed to leverage the granular mechanics and frictional behavior of dissimilar materials to attenuate seismic energy more effectively. Through scaled vibration testing, including scenarios simulating real seismic events such as the 1940 El Centro earthquake, the proposed system was shown to perform well under various input intensities. The multilayer arrangement helped to decouple seismic waves and reduce transmission to the superstructure, validating the concept as a feasible seismic mitigation technique.

In a complementary line of investigation, Zhang [5] explored the mechanical properties of gravel-based isolation layers modified with recycled rubber particles. The study focused on how the inclusion of rubber affects the shear modulus and damping ratio of the soil matrix. Findings indicated that while the composite exhibited a reduction in shear stiffness, it gained enhanced damping capabilities—a trade-off that, in seismic contexts, favors energy absorption and reduced force transmission. This confirmed the potential of recycled materials not only as sustainable construction components but also as effective elements in seismic protection systems.

Building upon these foundations, numerous other studies [6–11] have confirmed the effectiveness of low-cost and accessible materials in seismic isolation. Approaches involving sand cushions, glass-enhanced granular layers, and other geotechnically modified fills have been shown to substantially decrease the dynamic response of structures when applied thoughtfully. Such strategies are particularly valuable in regions with limited financial resources or where minimal intervention is preferred due to the cultural value of heritage sites.

Geotechnical seismic isolation technologies have progressed beyond experimental validation and are now increasingly being implemented in real-world conservation and structural retrofitting projects. These solutions have proven their viability through successful applications in the protection of culturally significant buildings. For instance, vibration-isolating layers were integrated during the structural reinforcement of the Romanov Chamber in Moscow. This intervention contributed significantly to the building's improved seismic performance while maintaining the integrity of its historical and architectural elements. Notably, no invasive alterations were made to the building's original masonry or decorative components, demonstrating the compatibility of geotechnical isolation with the requirements of heritage conservation. Similarly, a comprehensive geotechnical isolation system was installed beneath the Belém Tower in Lisbon, a prominent UNESCO World Heritage Site. The system included custom-designed subsurface isolation elements that were installed with minimal disruption to the structure. Long-term monitoring of seismic behavior following the intervention confirmed a marked reduction in dynamic response, validating the effectiveness of this technology under field conditions. These case studies highlight the capacity of geotechnical isolation to deliver targeted, minimally invasive, and context-sensitive seismic protection for historically important structures. The integration of such systems into cultural preservation efforts marks a significant step forward in harmonizing engineering innovation with conservation ethics.

Given the increasing seismic risks faced by architectural heritage worldwide, especially in tectonically active regions, geotechnical seismic isolation (GSI) is emerging as one of the most adaptable and promising strategies for structural protection. Unlike traditional retrofitting methods that often require intrusive interventions—such as reinforcement of walls, installation of dampers, or structural bracing—GSI focuses on modifying the dynamic interaction between the structure and its foundation soil. By implementing isolation systems below ground level, it of becomes possible to preserve the original facades, load-bearing components, and artistic elements heritage buildings. This subsurface approach is especially valuable in conservation contexts where aesthetic, historical, and material authenticity must be maintained. Furthermore, the modular and scalable nature of GSI makes it suitable for a wide range of foundation types, soil profiles, and urban settings, including locations with strict regulatory or spatial constraints.

Within this innovative framework, the present study investigates the performance of engineered soil–rubber composites as a viable seismic isolation material. These composites, produced by blending natural granular soils with rubber particulates—typically derived from recycled automotive tires—exhibit enhanced damping properties and high energy absorption capacity. These characteristics are critical for mitigating seismic vibrations before they reach the building's superstructure. The rubber inclusions confer viscoelastic behavior to the soil matrix, enabling greater dissipation of vibrational energy through internal friction and deformation. The goal of the research is to evaluate how effectively these materials reduce seismic impact, especially when applied beneath foundations of heritage buildings located in seismically active zones, where structural vulnerabilities are often pronounced.

To achieve a comprehensive assessment, the study employs a dual-method approach that integrates experimental testing with numerical simulations. Controlled laboratory tests allow for the observation of dynamic behavior under standardized conditions, while computational modeling facilitates the analysis of complex soil-structure interactions and the extrapolation of results to full-scale scenarios. Through this methodology, the study aims to validate the soil–rubber composite as a cost-effective, sustainable, and minimally invasive alternative to conventional seismic isolation systems. The research contributes to the growing body of literature focused on sustainable seismic mitigation and seeks to support interdisciplinary collaboration between geotechnical engineers, structural preservationists, and policymakers in the domain of cultural heritage protection [12–17].

One notable recent advancement in the field of geotechnical seismic isolation (GSI) involves the development and application of non-invasive soil modification techniques, particularly the injection of polyurethane into subsoil layers. This innovative method is designed to enhance the seismic performance of foundations without requiring alterations to the aboveground structure, making it highly compatible with aging infrastructure and historically significant buildings. The technique is especially advantageous for heritage preservation, as it minimizes physical interference with the structure's visible and cultural elements. In a comprehensive study by Zhang et al. (2025), a refined approach to non-intrusive GSI was introduced, wherein carefully controlled injections of polyurethane altered the mechanical properties of the soil, shifting the natural vibration period of the site away from the dominant frequencies of seismic input. This strategic decoupling effectively reduced resonance risks. The methodology was validated through a combination of laboratory resonance column tests and nonlinear dynamic time-history analyses using the OpenSees platform. Results confirmed a substantial decrease in seismic response, particularly in deteriorated and corrosion-affected bridge piers. By extending the natural period of the soil-structure system and redistributing seismic energy more evenly, this method provides long-term protection throughout a structure's service life. While originally developed for bridge foundations, the underlying principles and benefits of this technique may be readily adapted to heritage structures, offering a minimally invasive, sustainable, and lifecycle-effective seismic mitigation solution that fully respects the constraints of conservation practice [18].

Expanding the scope of non-intrusive GSI solutions, recent research has also explored the use of engineered granular damping layers composed of recycled and composite materials. These systems aim to attenuate seismic waves within the subsurface before they impact the structure. For example, Yang et al. (2024) proposed a multi-layered soil system integrating lightweight expanded aggregates and polymeric inclusions. Their findings, supported by shake-table experiments and finite element simulations, showed that such configurations effectively reduce peak ground acceleration and limit stress wave propagation through the soil column. Due to their modularity and ease of installation, these layered damping systems are particularly suited for deployment beneath existing foundations with minimal excavation or disruption to the superstructure. This makes them attractive options for the seismic retrofitting of historically sensitive buildings, where reversibility and non-invasiveness are core conservation principles [19].

In parallel, continued innovation in geotechnical seismic isolation has led to the exploration of hybrid systems that combine soil reinforcement with layered energy-dissipating barriers. For instance, researchers have investigated the strategic placement of geosynthetic-reinforced granular soils with variable stiffness across depth profiles. These hybrid systems alter the impedance profile of the soil and introduce controlled interfaces that reflect or absorb seismic energy. The result is a delay in wave transmission and a reduction in peak ground motion intensity. Such systems, by tailoring the mechanical impedance across layers, enable efficient control of vibration paths without compromising the surrounding built environment. These advancements reinforce the role of geotechnical seismic isolation as a sustainable and adaptable solution for seismic resilience, particularly in urban zones where heritage structures coexist with modern infrastructure and where direct structural intervention is either undesirable or restricted [20].

Taken together, these advancements underscore a growing consensus within the engineering and conservation communities: geotechnical seismic isolation offers a compelling balance between structural safety and cultural preservation. Whether implemented through layered damping systems or in-situ soil modification, these techniques provide effective mitigation of seismic forces while maintaining the physical and aesthetic integrity of heritage buildings. Against this backdrop, the present study contributes to this evolving field by evaluating the performance of soil–rubber composite layers as a geotechnical isolation solution. Through carefully designed laboratory experiments and quantitative analysis of seismic response, the research aims to demonstrate the material’s effectiveness in reducing vibrational transmission. The outcomes are expected to inform future applications of sustainable and minimally invasive seismic protection strategies, particularly in the context of safeguarding irreplaceable architectural heritage.

## The methodology

The application of geotechnical seismic isolation represents a scientifically grounded and practically efficient approach to mitigating both vibrational effects and structural deformations resulting from seismic activity. This methodology has gained increasing relevance in the field of structural preservation, particularly when it comes to safeguarding cultural heritage buildings. In such contexts, any intervention must carefully balance the goals of enhancing structural resilience with the imperative to preserve historical authenticity and cultural significance. Many monuments are constructed from age-sensitive materials or using traditional construction techniques that are highly susceptible to damage from conventional retrofitting methods. Therefore, the selection of


*ISSN: 2616-7263. eISSN: 2663-1261*

non-intrusive isolation solutions becomes not only preferable but often essential for long-term conservation.

One of the principal advantages of geotechnical seismic isolation lies in its subsurface implementation, which allows for the strategic placement of isolation layers beneath the foundation or base slab without necessitating physical alteration to the existing superstructure. This non-invasive characteristic is of paramount importance in heritage conservation efforts, as it enables the retention of original architectural elements, including load-bearing components, decorative façades, and interior artistic finishes that contribute significantly to the historical and cultural value of the structure. Furthermore, the use of engineered composite materials—such as soil–rubber mixtures formed from granular soils and recycled elastomeric particles—enhances the durability, elasticity, and energy dissipation capacity of the isolation system. These materials are specifically designed to perform under cyclic loading conditions typical of seismic events, ensuring long-term functionality and reliability under both moderate and extreme seismic influences.

To rigorously assess the performance of the proposed seismic isolation strategy, a comprehensive series of controlled laboratory experiments was undertaken. The experimental design was centered around evaluating the dynamic response behavior of a custom-formulated soil–rubber composite, prepared by integrating granular soil with shredded rubber particles sourced from recycled tires. This specific composition was selected based on its advantageous viscoelastic properties, which are known to offer significantly higher damping ratios and energy absorption capacity compared to conventional or untreated soil matrices.

The physical test setup featured a scaled structural model placed atop a layered foundation, with two key configurations being systematically examined: a reference model with no isolation layer and an experimental model incorporating the composite isolation layer. Both setups were subjected to simulated seismic excitations using a calibrated vibration platform, replicating ground motions of varying intensity and frequency content. Key parameters, such as vibration amplitude, acceleration response, and frequency-domain characteristics, were monitored using a network of high-precision sensors and data acquisition systems. Figure 1 provides a schematic representation of the experimental layout, indicating the positioning of the soil–rubber composite layer and instrumentation used for real-time data collection.

The central objective of this investigation was to quantify the degree of vibration reduction and energy attenuation afforded by the composite isolation layer. By systematically comparing the seismic responses of the two configurations under identical loading conditions, the study sought to isolate the effectiveness of the engineered material in filtering and dissipating seismic energy before it could reach the superstructure. The collected experimental data were analyzed using both time-domain and frequency-domain techniques to evaluate not only the damping efficiency and deformation control characteristics of the material, but also to assess its practical viability for deployment in actual heritage preservation projects located in active seismic regions. The results obtained from these tests provide valuable empirical evidence supporting the adoption of geotechnical isolation as a feasible, minimally invasive, and sustainable method for enhancing seismic resilience in culturally significant structures.

During the laboratory testing phase, the soil–rubber composite material was prepared and compacted using a standardized laboratory compaction method, following technical guidelines and procedural specifications derived from the SOYUZDORNII Research Institute, which is recognized for its protocols in geotechnical and road construction materials testing. The composite mixture was composed of pre-weighed proportions of granular soil and crumb rubber, ensuring consistency in particle size distribution and homogeneity across samples.

**Figure 1. Engineering composite consisting of soil and shredded rubber (ground rubber)**

To simulate realistic installation conditions and to achieve reproducible results, the prepared material was introduced into a custom-fabricated cylindrical mold, designed specifically for the purpose of this study. This mold differed from conventional Proctor compaction molds in both diameter and depth, allowing for the accommodation of layered placement and measurement instrumentation. The mold's dimensions were selected to comply with the scaling requirements of the experiment and to facilitate observation of vertical and lateral compaction behavior.

The experimental procedure was executed in a multi-stage format to control compaction quality and material consistency. During the initial phase, the cylindrical container—exceeding the diameter of traditional compaction molds—was carefully set up on a vibration-isolated platform. The composite material was then placed into the container in three to five equal lifts, each approximately 3–5 cm thick. After each lift, the material was compacted using a mechanical rammer, applying uniform energy across the surface to eliminate air voids and achieve targeted density levels consistent with field conditions.

Particular attention was paid to achieving uniform compaction across the entire volume of the sample, as inconsistencies in density could influence the dynamic response characteristics during vibration testing. Instrumentation was embedded at designated depths to monitor compaction progress and to collect data during subsequent seismic simulation phases. Figure 2 shows the mold assembly and the layer-wise compaction process.

This rigorous approach ensured that the physical properties of the test specimens, such as bulk density, moisture content, and rubber dispersion, remained within predefined tolerance limits, providing a solid foundation for reliable interpretation of the dynamic testing results.

To accurately record the dynamic behavior of the composite specimen under simulated seismic excitation, a precision acceleration sensor of model VS 111 was employed. This sensor is equipped with integrated electronics and operates according to the ICP (Integrated Circuit Piezoelectric, also known as IEPE) standard, which ensures compatibility with a wide range of signal conditioning and acquisition systems. The VS 111 model offers a sensitivity of 10 mV/g, enabling detection of subtle changes in acceleration, and functions effectively across a broad frequency range of 0.5 to 15,000 Hz, making it suitable for capturing both low-frequency tremors and high-frequency components of seismic events.

Prior to testing, the accelerometer was carefully calibrated in accordance with the manufacturer's specifications, and its output was verified using a reference vibration source.

**Figure 2. Sample compaction device made according to the typical design developed by the Research Institute "SOYUZDORNII"**

The sensor was then securely affixed to the surface of the compacted soil–rubber composite, ensuring tight coupling and minimizing any potential signal distortion due to slippage or misalignment during impact events.

To simulate a seismic-like event in a controlled laboratory environment, a mechanical impact method was used. An impulsive load was generated by dropping a 450-gram steel weight from a height of 25 centimeters directly onto the surface of the compacted specimen. This loading technique was selected due to its simplicity, repeatability, and its ability to generate short-duration high-energy impulses, which are representative of the transient forces observed during the early phases of an earthquake.

The vertical impact induced a stress wave propagation through the composite layer, triggering vibrational responses akin to those experienced during seismic excitation. By maintaining consistent drop height and mass, it was possible to generate comparable input energy across all test cycles, thus ensuring the repeatability and reliability of the experimental results.

The analog output from the VS 111 accelerometer, representing the real-time vibration response of the sample, was transmitted via shielded coaxial cable to a ZET 017-U8 spectrum analyzer. This high-precision data acquisition system is capable of capturing vibrational signals with a frequency resolution of up to 20 kHz and features a dynamic range of 80 dB, allowing it to detect both minor fluctuations and more significant acceleration spikes with high accuracy.

The analyzer digitized the incoming signals and recorded them over a duration of approximately one second per impulse, which encompassed the full decay period of the induced vibration. The recorded waveforms were then exported for further processing, including Fourier transform analysis, peak amplitude extraction, and comparison across different specimen configurations. Figure 3 provides a schematic overview of the instrumentation setup, highlighting the sensor placement, impact mechanism, and signal transmission path.

This comprehensive instrumentation and data acquisition protocol ensured high fidelity in capturing the seismic isolation behavior of the soil–rubber composite and laid the foundation for a robust interpretation of the isolation system's performance characteristics.

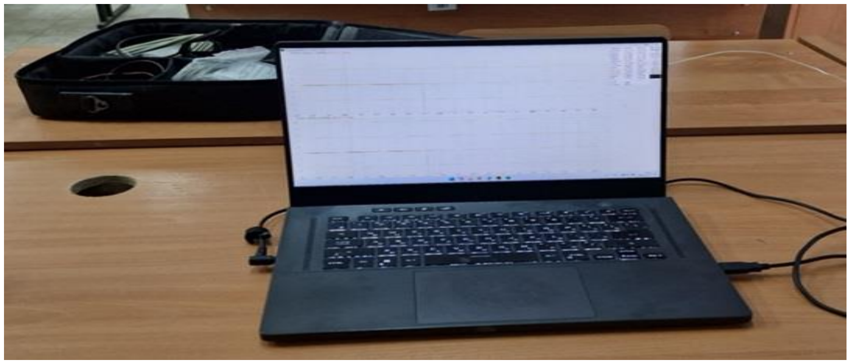

**Figure 3. Zetlab program designed for vibration signal analysis**

The impact of impulse vibration was assessed by analyzing the recorded peak acceleration value.

## Findings/Discussion

The results of the dynamic testing are graphically presented in Figures 4 and 5, which depict the recorded acceleration amplitude profiles for two experimental configurations: one using unmodified natural soil, and the other incorporating the engineered soil–rubber composite layer. The time histories span an observation window of 0.5 seconds, which adequately captures the initial impact event and the subsequent attenuation behavior of the materials.

In the case of the natural soil specimen, the measured peak ground acceleration (PGA) reached a maximum value of 13.85 $m/s^2$, indicating a relatively low damping capacity and minimal energy dissipation following the applied impulsive load. The acceleration curve for this configuration shows a sharp peak followed by a gradual decay, characteristic of systems with limited internal energy absorption mechanisms. This suggests that seismic energy is more readily transmitted through the unmodified soil medium, posing greater risk to overlying structures.

Conversely, the sample that incorporated the soil–rubber composite layer demonstrated a markedly different response. The peak acceleration was significantly reduced to 8.75 $m/s^2$, representing a 36.83% decrease compared to the natural soil configuration. This notable reduction in amplitude clearly illustrates the damping effectiveness of the composite material, which absorbs and disperses seismic energy more efficiently due to the viscoelastic behavior of the rubber component.

The observed attenuation is attributed to several factors: (1) the increased hysteretic damping introduced by the rubber particles, (2) the disruption of wave propagation paths through heterogeneous interfaces within the composite, and (3) the frictional energy loss resulting from particle movement under dynamic stress. These mechanisms act synergistically to lower the amplitude and duration of transmitted vibrations.

Taken together, the experimental findings validate the hypothesis that soil–rubber composites can serve as effective geotechnical seismic isolation layers, particularly in scenarios where traditional structural interventions are either infeasible or undesirable due to cultural preservation constraints. The reduced acceleration response translates into lower inertial forces acting on the foundations of heritage structures, thereby improving their seismic resilience without compromising architectural authenticity.

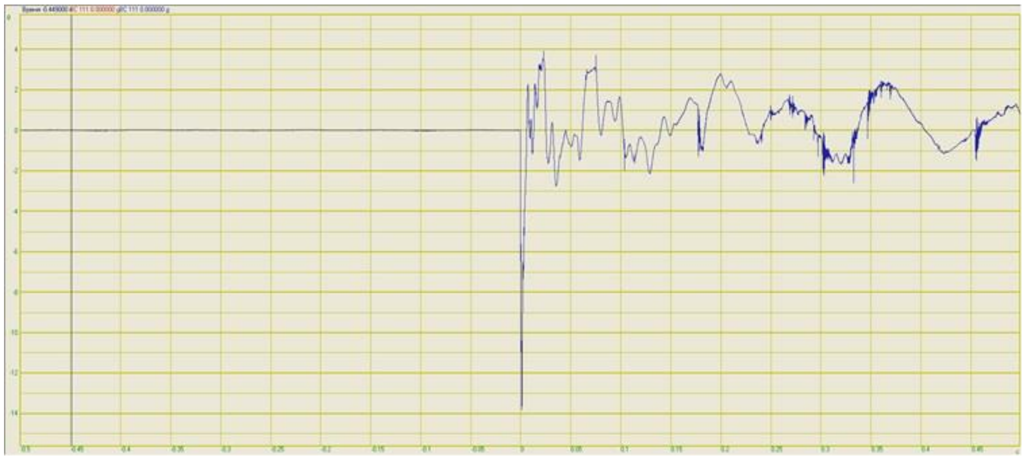

**Figure 4. Graph of accelerations recorded on natural soil**

Figure 5 provides a comparative visualization of the peak vibrational amplitude recorded for two different foundation materials: untreated natural soil and the soil–rubber composite (gruntoresina).

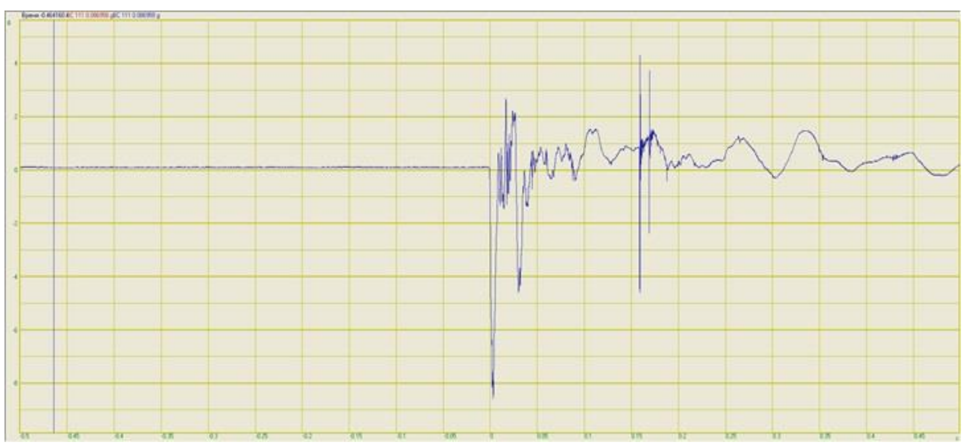

**Figure 5. Acceleration diagram obtained during the testing of ground rubber**

The horizontal axis indicates the six experimental runs, while the vertical axis reflects the maximum acceleration values (in m/s$^2$) observed during each trial. For each configuration, the displayed values represent the average of four individual measurements, ensuring statistical consistency and reducing the influence of random deviations.

The results reveal a clear and consistent trend: across all six experiments, the samples composed of natural soil demonstrated higher peak acceleration values, ranging between 13.45 and 14.3, with an average near 13.87 m/s$^2$. In contrast, the specimens containing rubber-modified soil exhibited significantly reduced acceleration amplitudes, falling within the 8.21 to 9.28 range, with a mean value of approximately 8.75 m/s$^2$.

This substantial reduction — on the order of 35–40%, depending on the experimental run — illustrates the superior damping capacity of the composite material. The incorporation of crumb rubber introduces viscoelastic properties into the soil matrix, which effectively transforms part of the vibrational energy into heat and internal friction, rather than allowing it to propagate through the medium.

Additionally, the low error margins indicated atop the bars suggest that the measurements are both precise and repeatable, lending further credibility to the conclusion that soil–rubber composites function as reliable seismic mitigation layers. The overall downward shift in amplitude observed for the modified samples underscores their capacity to attenuate input motion, which is essential for protecting structures—particularly those of historical or architectural significance—against dynamic seismic forces.

These findings validate the use of engineered fill materials in geotechnical seismic isolation systems, particularly in cases where traditional structural retrofitting is not feasible. By substantially reducing vibrational transfer from the ground to the structure, such composites contribute to enhanced seismic safety and resilience while maintaining compatibility with heritage preservation requirements.

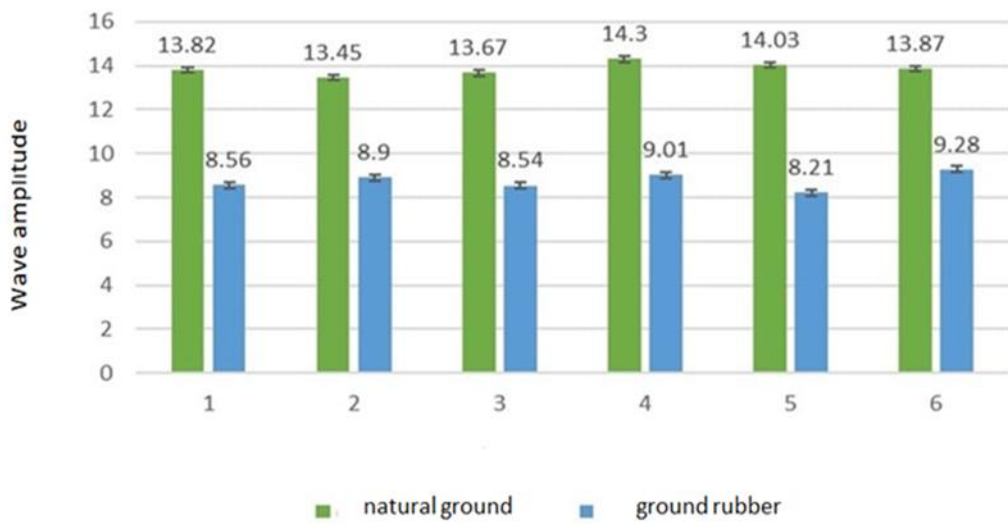


**Figure 6. Vibration amplitude values for natural soil and rubber-based composite**

Figure 6 presents a quantitative comparison of the average peak acceleration values recorded during six independent tests, clearly illustrating the performance difference between natural soil and the soil–crumb rubber composite. As shown in the graph, the average peak acceleration for samples with the composite layer was 8.75 m/s$^2$, compared to 13.85 m/s$^2$ for untreated soil. This represents a 36.83% reduction in seismic vibration amplitude, underscoring the composite material's superior ability to attenuate dynamic ground motion.

Such a significant decrease in vibrational response confirms the high damping efficiency of the soil–rubber mixture. The result can be attributed to the inherent viscoelastic behavior of the rubber inclusions, which absorb and dissipate seismic energy through internal friction and hysteresis. Additionally, the heterogeneity introduced by the composite structure contributes to scattering and diffusing wave energy, thereby reducing its impact on the overlying structure.

These findings are particularly relevant for the seismic protection of architecturally and culturally valuable heritage sites, where minimal intervention and preservation of original materials are paramount. The demonstrated effectiveness of the composite material provides a compelling argument for its real-world implementation in geotechnical seismic isolation systems, especially in scenarios where traditional retrofitting may be invasive, cost-prohibitive, or structurally incompatible.

Furthermore, the consistency of the results across all six experiments indicates that the material behavior is stable and reproducible, which is a crucial prerequisite for field application. The evidence presented lays a robust foundation for future studies, including scaled physical modeling, long-term field performance monitoring, and the optimization of material ratios for specific soil types and seismic profiles.

In conclusion, the soil–crumb rubber composite not only enhances seismic resilience but also represents a sustainable, cost-effective, and minimally invasive solution for protecting vulnerable structures in seismically active regions. Its integration into modern geotechnical design frameworks holds considerable promise for advancing earthquake-resistant construction practices.

## Conclusion

The outcomes of this experimental study provide strong evidence in support of using soil–rubber composite materials as an effective geotechnical seismic isolation solution. The findings are of particular importance in the context of heritage preservation, where conventional retrofitting techniques may be either technically infeasible or undesirable due to their invasive nature. By leveraging the damping properties of crumb rubber, the proposed approach offers a sustainable, low-cost, and minimally disruptive alternative to enhance the seismic resilience of critical structures.

Laboratory simulations under controlled dynamic loading revealed a consistent and significant reduction in peak ground acceleration when soil–rubber composites were employed. The recorded data showed that the average vibration amplitude was reduced by 36.83%, indicating a marked improvement in energy dissipation capacity. This reduction is not only statistically significant but also practically meaningful, as it translates into lower seismic loads transferred to superstructures, which can mitigate structural damage and preserve serviceability during seismic events.

From a materials science perspective, the improved performance of the composite is attributable to the viscoelastic behavior of rubber, which introduces hysteretic damping and internal friction mechanisms into the soil matrix. These characteristics allow the composite to absorb and disperse seismic energy more efficiently than natural soil alone. Additionally, the heterogeneity of the material, resulting from the presence of rubber particles, alters wave propagation paths and increases scattering, further contributing to its attenuation capacity.

The advantages of this technique extend beyond performance metrics. The approach is also environmentally responsible, as it encourages the reuse of waste rubber materials, such as shredded tires, thus addressing both seismic safety and ecological concerns. Moreover, the method non-invasive nature means it can be implemented without altering the original design, appearance, or materials of heritage buildings—an essential requirement in restoration and conservation practice.

These results lay the groundwork for a new generation of foundation isolation strategies, particularly suitable for historically valuable structures, public buildings, museums, and cultural landmarks situated in seismic zones. However, to translate these laboratory-scale findings into field-ready applications, further research is required. This includes:

- Long-term monitoring of full-scale systems under real seismic events;
- Evaluation of performance under varied environmental and geological conditions;
- Study of the effects of different rubber content ratios, particle sizes, and soil types;
- Development of design guidelines and standards for practitioners;
- Numerical modeling and simulation using advanced finite element tools to complement physical testing.

In addition, interdisciplinary collaboration among civil engineers, material scientists, seismologists, and heritage conservation specialists will be essential to develop implementation protocols that align with both structural performance requirements and conservation ethics.

In conclusion, the integration of soil–rubber composites into seismic isolation practice represents a technically sound, environmentally friendly, and culturally sensitive innovation. As climate change and urbanization continue to increase the vulnerability of existing structures to natural hazards, the need for such forward-looking and adaptable solutions becomes more urgent. The present study not only validates the concept at the laboratory scale but also opens up a promising avenue for future implementation and standardization within the broader field of resilient infrastructure development.

**Authors' contribution**

Niyetbay S.E., Besimbayev E.T. - concept, methodology, data analysis, writing the text, approval of the final version.
Tashmukhanbetova I.B. - conducting experiments, writing the text, technical revision.
Tleubaeva A.K. - data collection, calculation part, technical revision.
Toleubaeva Sh.B. - data analysis, interpretation of results.

**References**

1. Forcellini, D., Chiaro, G., Palermo, A., Banasiak, L., Tsang, H.H. Energy Dissipation Efficiency of Geotechnical Seismic Isolation with Gravel-Rubber Mixtures: Insights from FE Non-Linear Numerical Analysis // Journal of Earthquake Engineering 2024,
2. Ниетбай С.Е. диссертация Обеспечение сейсмостойкости памятников архитектуры устройством систем геотехнической сейсмоизоляции /2024/ https://official.satbayev.university/download/documentPhd/41180/Dissertation%20by %20Niyetbay%20S.E..pdf.
3. Banović, I., Radnić, J., Grgić, N. Geotechnical Seismic Isolation System Based on Sliding Mechanism Using Stone Pebble Layer: Shake-Table Experiments // Shock and Vibration 2019, 2019, doi:10.1155/2019/9346232.
4. Jing, L., Yin, Z., Sun, H., Dong, R., Xu, K., Cheng, X. Shaking Table Test of Geotechnical Seismic

Isolation System Based on Glass Bead-Sand Cushions // Yanshilixue Yu Gongcheng Xuebao/Chinese Journal of Rock Mechanics and Engineering 2020, 39, doi:10.13722/j.cnki.jrme.2019.1138.

5. Pitilakis, D., Anastasiadis, A., Vratsikidis, A., Kapouniaris, A. Configuration of a Gravel-Rubber Geotechnical Seismic Isolation System from Laboratory and Field Tests // Soil Dynamics and Earthquake Engineering 2024, 178, doi:10.1016/j.soildyn.2024.108463.
6. Jing, L.P., Yin, Z.Y., Sun, H.F., Dong, R., Xu, K.P., Li, Y.Q. Shaking Table Tests on Two Geotechnical Seismic Isolation Systems // Yantu Gongcheng Xuebao/Chinese Journal of Geotechnical Engineering 2020, 42, doi:10.11779/CJGE202011001.
7. Dhanya, J.S., Fouzul, M.A., Banerjee, S., Boominathan, A., Zhussupbekov, A. Shaking Table Experiments on Framed Structure Resting on Geogrid Reinforced Geotechnical Seismic Isolation System // Bulletin of Earthquake Engineering 2023, 21, doi:10.1007/s10518-023-01687-x.
8. Zhang, H., Song, C., Wang, M., Cheng, Y.; Yue, S., Wu, C. A Geotechnical Seismic Isolation System Based on Marine Sand Cushion for Attenuating Ground Shock Effect: Experimental Investigation // Soil Dynamics and Earthquake Engineering 2023, 168, doi:10.1016/j.soildyn.2023.107854.
9. Sun, Q., Xue, Y., Hou, M. Geotechnical Seismic Isolation System to Protect Cut-and-Cover Utility Tunnels Using Tire-Derived Aggregates // Soil Dynamics and Earthquake Engineering 2024, 176, doi:10.1016/j.soildyn.2023.108354.
10. Tsang, H.H., Tran, D.P., Hung, W.Y., Pitilakis, K., Gad, E.F. Performance of Geotechnical Seismic Isolation System Using Rubber-Soil Mixtures in Centrifuge Testing // Earthq Eng Struct Dyn 2021, 50, doi:10.1002/eqe.3398.
11. Golestani Ranjbar, E., Seyedi Hosseininia, E. Seismic Performance of Rubber-Sand Mixture as a Geotechnical Seismic Isolation System Using Shaking Table Test // Soil Dynamics and Earthquake Engineering 2024, 177, doi:10.1016/j.soildyn.2023.108395.
12. Degli Abbati, S., Sivori, D., Cattari, S.; Lagomarsino, S. Ambient Vibrations-Supported Seismic Assessment of the Saint Lawrence Cathedral's Bell Tower in Genoa, Italy // J Civ Struct Health Monit 2024, 14, doi:10.1007/s13349-023-00709-1.
13. Kilic, G. Assessment of Historic Buildings after an Earthquake Using Various Advanced Techniques // Structures 2023, 50, doi:10.1016/j.istruc.2023.02.033.
14. Requena-Garcia-Cruz, M. V., Romero-Sánchez, E., López-Piña, M.P., Morales-Esteban, A. Preliminary Structural and Seismic Performance Assessment of the Mosque-Cathedral of Cordoba: The Abd al-Rahman I Sector // Eng Struct 2023, 291, doi:10.1016/j.engstruct.2023.116465.
15. Hoseynzadeh, H., Mortezaei, A. Seismic Vulnerability and Rehabilitation of One of the World's Oldest Masonry Minaret under the Different Earthquake Frequency Content // Journal of Rehabilitation in Civil Engineering 2021, 9, doi:10.22075/JRCE.2021.21251.1441.
16. Alekseenko, V.N., Zhilenko, O.B. Seismic Stability of the Restored Architectural Monument // Magazine of Civil Engineering 2016, 67, doi:10.5862/MCE.67.4.
17. Bessimbayev E.T., Niyetbay S.E., Awwad T. The prospect of using geotechnical seismic insulation for the protection of architectural monuments. Second Eurasian innovation forum «Current problems of development and safety of large cities».

https://gradoresurs.ru/grado/wp-content/uploads/sites/2/2024/07/The-prospect-of-using-geotechnical-seismic-insulation-for-the-protection-of-architectural-monuments.pdf
18. Ma Z., Li Y., Wang D. Seismic fragility assessment of non-invasive geotechnical seismic isolation for existing bridges // Soil Dynamics and Earthquake Engineering. Elsevier, 2025. Vol. 192. P. 109266. doi:10.1016/J.ISTRUC.2024.107020.
19. Liu Y., Li J., Lin G. Nonlinear seismic assessment for nuclear power plants with structural-geotechnical hybrid isolation strategy // Structures. Elsevier, 2024. Vol. 67. P. 107020.C. 109266. doi:10.1016/J.SOILDYN.2025.109266.
20. Sun Q., Xue Y., Hou M. Geotechnical seismic isolation system to protect cut-and-cover utility tunnels using tire-derived aggregates // Soil Dynamics and Earthquake Engineering. Elsevier, 2024. Vol. 176. P. 108354. doi:10.1016/J.SOILDYN.2023.108354.

**С.Е.Ниетбай[1], Е.Т.Бесимбаев[2], И.Б. Ташмуханбетова *[1], А.К.Тлеубаева *[1], Ш.Б.Толеубаева [1]**

*[1]Халықаралық білім беру корпорациясы, Алматы, Қазақстан*
*[2]Сәтбаев атындағы ҚазҰТЗУ, Алматы, Қазақстан*

## Сәулет ескерткіштерін қорғау үшін резеңке топырақты қолдана отырып геотехникалық сейсмикалық оқшаулаудың инновациялық шешімдері

**Аңдатпа.** Мақалада сәулеттік ескерткіштерді сейсмикалық әсерлерден қорғау мақсатында геотехникалық сейсмооқшаулау әдістерін қолданудың шешімдері қарастырылады. Бұл тәсілдің артықшылықтарына ерекше назар аударылған, атап айтқанда тарихи ғимараттардың конструкциялық тұтастығын сақтау және олардың түпнұсқалығын жоғалтпау, конструкциялық жүйеге араласуды барынша азайту, сондай-ақ қолданылатын материалдардың ұзақ мерзімді тұрақтылығы. Сейсмооқшаулау бойынша негізгі әдістер мен технологиялар талданған, соның ішінде оқшаулаушы қабаттарды, демпферлік элементтерді, амортизациялық жүйелер мен іргетас төсеніштерін орнату тәсілдері. Тарихи- сәулеттік маңызы бар нысандарда сейсмооқшаулау технологияларын сәтті қолдану мысалдары келтірілген. Сейсмикалық белсенділігі жоғары өңірлерде мәдени мұраны сақтау үшін заманауи технологиялық шешімдердің маңыздылығы ерекше атап өтіледі.

Зерттеудің мақсаты – геотехникалық сейсмооқшаулаудың сәулеттік мұраны сақтаудағы тиімді құрал ретінде қолдану мүмкіндігін көрсету. Эксперименттік зерттеу нәтижелері көрсеткендей, оқшаулаушы қабат ретінде топырақ пен резеңке үгіндісінен тұратын композициялық материалды (грунторезина) пайдалану сейсмикалық тербелістердің амплитудасын айтарлықтай төмендетуге мүмкіндік береді, бұл өз кезегінде ғимараттардың тұрақтылығы мен пайдалану сенімділігін арттырады. Геотехникалық сейсмооқшаулау сейсмикалық тұрақты құрылыс саласындағы болашағы зор бағыт ретінде қарастырылады және техникалық, геологиялық және экономикалық факторларды ескеретін кешенді көзқарасты талап етеді.

**Түйін сөздер:** геотехникалық сейсмикалық оқшаулау; резеңке мен топырақтан тұратын композит; мәдени мұра нысандарын қорғау; зертханалық жағдайдағы эксперименттік сынақтар; стандартты тығыздау құрылғысы; акселерометр көмегімен вибрацияны талдау; сейсмикалық әсер кезіндегі үдеудің амплитудасы.

**С.Е.Ниетбай[1] , Е.Т.Бесимбаев[2] , И.Б.Ташмуханбетова*[1] , А.К. Тлеубаева*[1] , Ш.Б.Толеубаева[1]**

*[1]Международная образовательная корпорация, Алматы, Казахстан*
*[2]Казахский национальный исследовательский технический университет им. К. И. Сатпаева, Алматы, Казахстан*

## Инновационные решения геотехнической сейсмоизоляции с применением грунторезины для защиты памятников архитектуры

**Аннотация.** В данной работе рассматривается потенциал применения геотехнических сейсмоизолирующих технологий для защиты объектов архитектурного наследия от разрушительных последствий сейсмических воздействий. Подчёркивается ряд преимуществ данного метода, среди которых — сохранение конструктивной целостности зданий, обеспечение их исторической аутентичности за счёт минимального вмешательства в существующие несущие системы, а также устойчивость используемых материалов к длительной эксплуатации в сложных условиях. Осуществлён обзор ключевых инженерных решений в области сейсмоизоляции, включая устройство амортизирующих прослоек, демпфирующих слоёв, поглощающих вставок и специальных фундаментных оснований. Приведены примеры реализации подобных решений на памятниках культурного значения. Особое внимание уделено значению современных инженерных разработок для повышения сейсмической безопасности в регионах с повышенным риском землетрясений. Целью исследования является обоснование эффективности геотехнической сейсмоизоляции как средства защиты исторических сооружений. Экспериментальные данные показали, что применение грунторезиновых композитов в качестве прослойки способствует значительному снижению амплитуд вибрационных колебаний, тем самым улучшая устойчивость и надёжность зданий. Подобный подход рассматривается как перспективное направление в развитии технологий сейсмостойкого строительства, требующее междисциплинарного анализа с учётом инженерных, геологических и экономических условий.

**Ключевые слова:** геотехническая сейсмоизоляция; композит на основе резины и грунта; защита объектов культурного наследия; экспериментальные испытания в лабораторных условиях; прибор для стандартного уплотнения образцов; анализ вибраций с использованием акселерометра; величина колебательных ускорений при сейсмическом воздействии.

## References

1. Forcellini, D., Chiaro, G., Palermo, A., Banasiak, L., Tsang, H.H. Energy Dissipation Efficiency of Geotechnical Seismic Isolation with Gravel-Rubber Mixtures: Insights from FE Non-inear Numerical Analysis // Journal of Earthquake Engineering 2024

2. Ниетбай С.Е. диссертация Обеспечение сейсмостойкости памятников архитектуры устройством систем геотехнической сейсмоизоляции /2024/ https://official.satbayev.university/download/documentPhd/41180/Dissertation%20by%20Niyetbay%20S.E..pdf.
3. Banović, I., Radnić, J., Grgić, N. Geotechnical Seismic Isolation System Based on Sliding Mechanism Using Stone Pebble Layer: Shake-Table Experiments // Shock and Vibration 2019, 2019, doi:10.1155/2019/9346232.
4. Jing, L., Yin, Z., Sun, H., Dong, R., Xu, K., Cheng, X. Shaking Table Test of Geotechnical Seismic Isolation System Based on Glass Bead-Sand Cushions // Yanshilixue Yu Gongcheng Xuebao/Chinese Journal of Rock Mechanics and Engineering 2020, 39, doi:10.13722/j.cnki.jrme.2019.1138.
5. Pitilakis, D., Anastasiadis, A., Vratsikidis, A., Kapouniaris, A. Configuration of a Gravel-Rubber Geotechnical Seismic Isolation System from Laboratory and Field Tests // Soil Dynamics and Earthquake Engineering 2024, 178, doi:10.1016/j.soildyn.2024.108463.
6. Jing, L.P., Yin, Z.Y., Sun, H.F., Dong, R., Xu, K.P., Li, Y.Q. Shaking Table Tests on Two Geotechnical Seismic Isolation Systems // Yantu Gongcheng Xuebao/Chinese Journal of Geotechnical Engineering 2020, 42, doi:10.11779/CJGE202011001.
7. Dhanya, J.S., Fouzul, M.A., Banerjee, S., Boominathan, A., Zhussupbekov, A. Shaking Table Experiments on Framed Structure Resting on Geogrid Reinforced Geotechnical Seismic Isolation System // Bulletin of Earthquake Engineering 2023, 21, doi:10.1007/s10518-023-01687-x.
8. Zhang, H., Song, C., Wang, M., Cheng, Y.; Yue, S., Wu, C. A Geotechnical Seismic Isolation System Based on Marine Sand Cushion for Attenuating Ground Shock Effect: Experimental Investigation // Soil Dynamics and Earthquake Engineering 2023, 168, doi:10.1016/j.soildyn.2023.107854.
9. Sun, Q., Xue, Y., Hou, M. Geotechnical Seismic Isolation System to Protect Cut-and-Cover Utility Tunnels Using Tire-Derived Aggregates // Soil Dynamics and Earthquake Engineering 2024, 176, doi:10.1016/j.soildyn.2023.108354.
10. Tsang, H.H., Tran, D.P., Hung, W.Y., Pitilakis, K., Gad, E.F. Performance of Geotechnical Seismic Isolation System Using Rubber-Soil Mixtures in Centrifuge Testing // Earthq Eng Struct Dyn 2021, 50, doi:10.1002/eqe.3398.
11. Golestani Ranjbar, E., Seyedi Hosseininia, E. Seismic Performance of Rubber-Sand Mixture as a Geotechnical Seismic Isolation System Using Shaking Table Test // Soil Dynamics and Earthquake Engineering 2024, 177, doi:10.1016/j.soildyn.2023.108395.
12. Degli Abbati, S., Sivori, D., Cattari, S.; Lagomarsino, S. Ambient Vibrations-Supported Seismic Assessment of the Saint Lawrence Cathedral’s Bell Tower in Genoa, Italy // J Civ Struct Health Monit 2024, 14, doi:10.1007/s13349-023-00709-1.
13. Kilic, G. Assessment of Historic Buildings after an Earthquake Using Various Advanced Techniques // Structures 2023, 50, doi:10.1016/j.istruc.2023.02.033.
14. Requena-Garcia-Cruz, M. V., Romero-Sánchez, E., López-Piña, M.P., Morales-Esteban, A. Preliminary Structural and Seismic Performance Assessment of the Mosque-Cathedral of Cordoba: The Abd al-Rahman I Sector // Eng Struct 2023, 291, doi:10.1016/j.engstruct.2023.116465.
15. Hoseynzadeh, H., Mortezaei, A. Seismic Vulnerability and Rehabilitation of One of the World’s Oldest Masonry Minaret under the Different Earthquake Frequency Content //

Journal of Rehabilitation in Civil Engineering 2021, 9, doi:10.22075/JRCE.2021.21251.1441.
16. Alekseenko, V.N., Zhilenko, O.B. Seismic Stability of the Restored Architectural Monument // Magazine of Civil Engineering 2016, 67, doi:10.5862/MCE.67.4.
17. Bessimbayev E.T., Niyetbay S.E., Awwad T. The prospect of using geotechnical seismic insulation for the protection of architectural monuments. Second Eurasian innovation forum «Current problems of development and safety of large cities». https://gradoresurs.ru/grado/wp-content/uploads/sites/2/2024/07/The-prospect-of-using-geotechnical-seismic-insulation-for-the-protection-of-architectural-monuments.pdf
18. Ma Z., Li Y., Wang D. Seismic fragility assessment of non-invasive geotechnical seismic isolation for existing bridges // Soil Dynamics and Earthquake Engineering. Elsevier, 2025. Vol. 192. P. 109266. doi:10.1016/J.ISTRUC.2024.107020.
19. Liu Y., Li J., Lin G. Nonlinear seismic assessment for nuclear power plants with structural-geotechnical hybrid isolation strategy // Structures. Elsevier, 2024. Vol. 67. P. 107020.C. 109266. doi:10.1016/J.SOILDYN.2025.109266.
20. Sun Q., Xue Y., Hou M. Geotechnical seismic isolation system to protect cut-and-cover utility tunnels using tire-derived aggregates // Soil Dynamics and Earthquake Engineering. Elsevier, 2024. Vol. 176. P. 108354. doi:10.1016/J.SOILDYN.2023.108354.

**Сведения об авторах:**

Ниетбай С.Е. – доктор PhD, ассоциированный профессор кафедры Проектирование зданий и сооружений, факультета общего строительства Международной образовательной корпорации, ул. Рыскулбекова 28, г. Алматы, 050043, Казахстан.
Бесимбаев Е.Т. – доктор технических наук, ассоциированный профессор кафедры строительства и строительных материалов, института архитектуры и строительства КазНИТУ им. Сатпаева, ул. Сатпаева 22а, 050013, г. Алматы, Казахстан.
Ташмуханбетова И.Б. – автор для корреспонденции, доктор PhD, ассоциированный профессор кафедры Проектирование зданий и сооружений, факультета общего строительства Международной образовательной корпорации, ул. Рыскулбекова 28, г. Алматы, 050043, Казахстан.
Тлеубаева А.К. – автор для корреспонденции, кандидат технических наук, и.о. доцента кафедры Проектирование зданий и сооружений, факультета общего строительства Международной образовательной корпорации, ул. Рыскулбекова 28, г. Алматы, 050043, Казахстан.
Толеубаева Ш.Б. – PhD доктор философии, и.о.доцента кафедры Проектирование зданий и сооружений, факультета общего строительства Международной образовательной корпорации, ул. Рыскулбекова 28, г. Алматы, 050043, Казахстан.

Ниетбай С.Е . – PhD докторы, Халықаралық білім беру корпорациясының жалпы құрылыс факультеті, Ғимараттар мен құрылыстарды жобалау кафедрасының қауымдастырылған профессоры, Рысқұлбеков к-сі 28, 050043, Алматы қ., Қазақстан.
Бесимбаев Е.Т. – техника ғылымдарының докторы, Сәтбаев атындағы ҚазҰТЗУ сәулет және құрылыс институтының құрылыс және құрылыс материалдары кафедрасының қауымдас-

тырылған профессоры, Сәтбаев көшесі 22а, 050013, Алматы қ., Қазақстан.
Ташмуханбетова И.Б. – хат-хабар авторы, PhD докторы, Халықаралық білім беру корпорациясының жалпы құрылыс факультеті, Ғимараттар мен құрылыстарды жобалау кафедрасының қауымдастырылған профессоры, Рысқұлбеков к-сі 28, 050043, Алматы қ., Қазақстан.
Тлеубаева А.К. – хат-хабар авторы, техника ғылымдарының кандидаты, Халықаралық білім беру корпорациясының жалпы құрылыс факультеті, Ғимараттар мен құрылыстарды жобалау кафедрасының доцент м.а., Рысқұлбеков к-сі 28, 050043, Алматы қ., Қазақстан.
Толеубаева Ш.Б. – PhD философия докторы, Халықаралық білім беру корпорациясының жалпы құрылыс факультеті, Ғимараттар мен құрылыстарды жобалау кафедрасының доцент м.а., Рысқұлбеков к-сі 28, 050043, Алматы қ., Қазақстан.

Niyetbay S. – PhD, Associate Professor of the Department of Building and Structure Design, Faculty of General Construction, International Educational Corporation, Ryskulbekov St. 28, 050043, Almaty, Kazakhstan
Bessimbayev Y. – Doctor of Technical Sciences, Associate Professor of the Department of Construction and Building Materials, Institute of Architecture and Construction, Satbayev University, Satpayev St. 22a, 050013, Almaty, Kazakhstan.
Tashmukhanbetova I. – corresponding author, Associate Professor of the Department of Building and Structure Design, Faculty of General Construction, International Educational Corporation, Ryskulbekov St. 28, 050043, Almaty, Kazakhstan.
Tleubayeva A. – corresponding author, Candidate of Technical Sciences, Acting Associate Professor of the Department of Building and Structure Design, Faculty of General Construction, International Educational Corporation, Ryskulbekov St. 28, 050043, Almaty, Kazakhstan.
Toleubayeva Sh. – PhD, Doctor of Philosophy, Acting Associate Professor of the Department of Building and Structure Design, Faculty of General Construction, International Educational Corporation, Ryskulbekov St. 28, 050043, Almaty, Kazakhstan.