ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

№2
2026

ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

2 (476)

MARCH – APRIL 2026

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, 2026

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«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық рефеҏативтік және ғылымиметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық рефеҏативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

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News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: «Central Asian Academic Research Center» LLP (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Communications of the Republic of Kazakhstan Nº KZ50VPY00121155, issued on 05.06.2025
Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*
Periodicity: 6 times a year.
http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Меншіктеуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).
Қазақстан Республикасының Ақпарат және коммуникациялар министрлігінің Ақпарат комитетінде 05.06.2025 ж. берілген № KZ50VPY00121155 мерзімдік басылым тіркеуіне қойылу туралы куәлік.
Тақырыптық бағыты: *геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*
Мерзімділігі: жылына 6 рет.
http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Собственник: ТОО «Центрально-Азиатский академический научный центр» (г. Алматы).
Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и коммуникаций и Республики Казахстан № KZ50VPY00121155, выданное 05.06.2025 г.
Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*
Периодичность: 6 раз в год.
http://www.geolog-technical.kz/index.php/en/

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NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 2.
Number 476 (2026), 74–91

https://doi.org/10.32014/2026.2518-170X.616

UDC: 550.34:624.042.7
IRSTI: 38.33.21

©Avazov Sh.B.*, Yodgorov Sh.I., Mukhammadkulov N.M., Aktamov B.U., Khayriddinov B.B., 2026.
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INSTRUMENTAL SEISMOMETRIC ASSESSMENT OF THE IMPACT OF TECHNOGENIC SEISMIC VIBRATIONS ON THE STRUCTURAL STABILITY OF HISTORICAL OBJECTS

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Abstract. *Relevance.* Active urban construction near cultural heritage sites may generate persistent technogenic vibrations that threaten structurally sensitive historic buildings. Museum structures are especially vulnerable to repeated dynamic loads because even moderate vibration levels may affect fragile architectural and structural elements. Therefore, assessing construction-induced vibration impact is essential for ensuring structural safety and developing effective protection measures in heritage zones. *Purpose.* This study aims to assess the influence of construction-induced technogenic vibrations on the structural safety of a museum building located in the immediate vicinity of an active construction site. *Methods.* A detailed seismic and vibration monitoring program was implemented to record responses both in the ground and within the museum structure. Continuous instrumental observations captured dynamic effects generated by heavy freight vehicles, soil compaction equipment, and earthmoving machinery. The recorded data were analyzed in terms of temporal behavior, spectral characteristics, vibration amplitude, dominant frequency ranges, attenuation patterns, and vibration propagation from the construction zone toward the building. Comparative analysis of records obtained outside the structure and in different structural elements was carried out to quantify vibration transmission and identify possible resonance and amplification effects. The observed vibration levels were also evaluated using engineering-seismology-based vibration intensity approaches. *Results.* The results show that construction-related vibrations may reach levels capable of affecting sensitive architectural and structural components of the museum building if not properly controlled. The analysis revealed measurable vibration transmission from the construction site to the building structure, with local amplification effects observed in certain elements and frequency ranges.

Key words: museum, technogenic vibrations, seismic monitoring, ground vibrations, vibrational load, seismometer, PGV, seismic intensity

Funding. *This research was supported by the Academy of Sciences of the Republic of Uzbekistan under the applied funding "Development of a scientific basis for assessing various levels of seismic risk in seismically active areas and reducing losses from earthquakes" and the Agency for Innovation Development, #AL8924073457 "Development of a macroseismic database platform for damage to buildings and structures in epicentral zones during strong earthquakes".*

For citations: *Avazov Sh.B., Yodgorov Sh.I., Mukhammadkulov N.M., Aktamov B.U., Khayriddinov B.B. Instrumental Seismometric Assessment of the Impact of Technogenic Seismic Vibrations on the Structural Stability of Historical Objects. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. 2026. No.2. Pp. 74–91. DOI: https://doi.org/10.32014/2026.2518-170X.616*

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ТАРИХИ ОБЪЕКТІЛЕРДІҢ КОНСТРУКТИВТІ ТҰРАҚТЫЛЫҒЫНА ТЕХНОГЕНДІК СЕЙСМИКАЛЫҚ ТЕРБЕЛІСТЕРДІҢ ӘСЕРІН АСПАПТЫҚ СЕЙСМОМЕТРИЯЛЫҚ БАҒАЛАУ

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Аннотация. *Өзектілігі.* Мәдени мұра нысандарының маңындағы белсенді қалалық құрылыс құрылымдық тұрғыдан осал тарихи ғимараттарға қауіп төндіретін тұрақты техногендік дірілдерді тудыруы мүмкін. Музей ғимараттары қайталанатын динамикалық жүктемелерге ерекше сезімтал, өйткені тіпті орташа деңгейдегі дірілдің өзі нәзік сәулеттік және конструкциялық элементтерге әсер етуі ықтимал. Осыған байланысты құрылыс жұмыстары туындататын діріл әсерін бағалау құрылымдық қауіпсіздікті қамтамасыз ету және мәдени мұра аймақтарында тиімді қорғаныс шараларын әзірлеу үшін аса маңызды. *Мақсаты.* Осы зерттеудің мақсаты белсенді құрылыс алаңына тікелей жақын орналасқан музей ғимаратының құрылымдық қауіпсіздігіне құрылыс жұмыстары туындататын техногендік дірілдердің әсерін бағалау. *Әдістері.* Зерттеу аясында топырақта да, музей ғимаратының өзінде де пайда болатын тербеліс жауаптарын тіркеу үшін сейсмикалық және дірілдік мониторингтің егжей-тегжейлі бағдарламасы жүзеге асырылды. Үздіксіз аспаптық бақылаулар ауыр жүк көліктері, топырақты тығыздау жабдықтары және жер қазу техникасы тудыратын динамикалық әсерлерді тіркеді. Алынған деректер уақыттық мінез-құлқы, спектрлік сипаттамалары, діріл амплитудасы, басым жиілік диапазондары, әлсіреу заңдылықтары және дірілдің құрылыс аймағынан ғимаратқа қарай таралуы тұрғысынан талданды. Ғимарат сыртында және оның әртүрлі конструкциялық элементтерінде алынған жазбаларды салыстырмалы талдау дірілдің берілуін сандық бағалауға, сондай-ақ ықтимал резонанстық және жергілікті күшею әсерлерін анықтауға мүмкіндік берді. Сонымен қатар, тіркелген діріл деңгейлері инженерлік сейсмологияға негізделген діріл қарқындылығын бағалау тәсілдері арқылы қарастырылды. *Нәтижелері.* Нәтижелер көрсеткендей, құрылыс жұмыстарына байланысты дірілдер тиісті бақылау болмаған жағдайда музей ғимаратының сезімтал сәулеттік және конструкциялық элементтеріне әсер ете алатын деңгейлерге жетуі мүмкін. Талдау құрылыс алаңынан ғимарат құрылымына дірілдің өлшенетін түрде берілетінін, сондай-ақ жекелеген элементтер мен белгілі бір жиілік диапазондарында жергілікті күшею әсерлерінің байқалатынын көрсетті.

Түйін сөздер: мұражай, техногендік тербелістер, сейсмикалық мониторинг, топырақ тербелістері, вибрациялық жүктеме, сейсмометр, PGV, сейсмикалық қарқындылық

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ИНСТРУМЕНТАЛЬНАЯ СЕЙСМОМЕТРИЧЕСКАЯ ОЦЕНКА ВЛИЯНИЯ ТЕХНОГЕННЫХ СЕЙСМИЧЕСКИХ КОЛЕБАНИЙ НА КОНСТРУКТИВНУЮ УСТОЙЧИВОСТЬ ИСТОРИЧЕСКИХ ОБЪЕКТОВ

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Аннотация: *Актуальность.* Активное городское строительство вблизи объектов культурного наследия может вызывать устойчивые техногенные вибрации, представляющие угрозу для конструктивно уязвимых исторических зданий. Музейные сооружения особенно чувствительны к многократным динамическим нагрузкам, поскольку даже умеренные уровни вибрации способны оказывать негативное воздействие на хрупкие архитектурные и конструктивные элементы. В этой связи оценка влияния вибраций, вызванных строительными работами, имеет важное значение для обеспечения конструктивной безопасности и разработки эффективных мер защиты в охранных зонах культурного наследия. *Цель.* Оценить влияние техногенных вибраций, обусловленных строительными работами, на конструктивную безопасность здания музея, расположенного в непосредственной близости от активной строительной площадки. *Методы.* Для решения поставленной задачи реализована программа сейсмического и вибрационного мониторинга, направленная на регистрацию откликов как в грунтовом массиве, так и в конструкциях здания музея. Непрерывные инструментальные наблюдения позволили зафиксировать динамические воздействия, создаваемые тяжёлыми грузовыми транспортными средствами, оборудованием для уплотнения грунта и землеройной техникой. Зарегистрированные данные анализировались по временным характеристикам, спектральным особенностям, амплитуде колебаний, преобладающим частотным диапазонам, закономерностям затухания и особенностям распространения вибраций от зоны строительства к зданию. Сравнительный анализ записей, полученных вне сооружения и в различных его конструктивных элементах, позволил количественно оценить передачу вибраций, а также выявить возможные эффекты резонанса и локального усиления. Дополнительно уровни вибрации оценивались с использованием методов инженерной сейсмологии на основе определения интенсивности вибрационного воздействия. *Результаты.* Установлено, что вибрации, обусловленные строительными работами, при отсутствии надлежащего контроля могут достигать уровней, способных оказывать воздействие на чувствительные архитектурные и конструктивные элементы здания музея. Анализ выявил измеримую передачу вибраций от строительной площадки к конструкциям здания, а также локальные эффекты усиления в отдельных конструктивных элементах и частотных диапазонах.

Ключевые слова: музей, техногенные колебания, сейсмический мониторинг, колебания грунта, вибрационная нагрузка, сейсмометр, PGV, сейсмическая интенсивность

Introduction. Modern urbanization processes, especially large-scale construction and reconstruction work in large urban centers, are causing an increase in technogenic seismic impacts on cultural heritage sites (Ismailov et al., 2023; Ismailov et al., 2024). Historical buildings, in particular museums, are sensitive to external dynamic influences due to the structural properties formed over centuries, the physical and mechanical properties of materials, and the relative decrease in strength limits (Kishkina, 2001). Their location in areas directly adjacent to modern construction activities necessitates a comprehensive assessment of the impact of technogenic seismic vibrations arising during the construction of new structures on the structural system.

On construction sites, the movement of heavy trucks, sealing mechanisms, excavators, drilling operations, and other technological processes create vibrations with a certain frequency range. These vibrations, spreading through the soil layers, can lead to the emergence of local stresses in the structural elements of nearby historical objects, the formation of microcracks, and a decrease in overall stability in the long term (Steinberg et al., 1993). Especially for cultural heritage sites located in seismically active areas, there is an additional risk of technogenic vibrations, which may serve as a factor that strengthens natural seismic impacts in a synergistic way (Ismailov et al., 2022; Ismailov et al., 2023).

The development of the fields of seismology and engineering seismology in recent years, as well as the significant expansion of the instrumental base of leading scientific institutions under the Academy of Sciences of Uzbekistan, allows for high-precision measurement and assessment of technogenic impacts on cultural heritage sites. Conducting seismic monitoring in the internal structures of buildings and adjacent construction areas using modern seismometric instruments (Ibragimov, 2021; Ibragimov, 2022; Yemanov et al., 2018; Sadovsky et al., 1999;

Verholantsev et al., 2019; Nadyojka et al., 2009) allows comparing the intensity, frequency, and propagation characteristics of oscillations in real time (Ismailov et al., 2020). Monitoring results allow for the assessment of vibrations from various technical sources based on velocity amplitude using a special scoring system and the identification of the most dangerous dynamic sources (Sadovsky, 1999).

In the scientific literature, a number of studies on the protection of cultural heritage sites from man-made vibrations remain relevant. From this point of view, the results of this study are of great practical importance in increasing the seismic safety of cultural heritage sites, regulating construction processes, and developing scientifically based recommendations (Ismailov et al., 2022).

Data and methods. An important stage of the research involves preliminary visual analysis of the architectural features, structural design, and historical layers of the object where seismic surveys were conducted. Therefore, Figure 1 shows the exterior view of the museum complex where the study was carried out. This image reflects the combined architectural composition of the building's historical part and modern reconstructed wing, forming an initial impression for subsequent seismic analyses (Figure 1).

Figure 1. General exterior view of the museum building where the research was conducted.

The architectural and structural characteristics of the museum building shown in the image are of great importance in determining its seismic resistance. Specifically, the heavy decorative structures in the historical section, wooden columns, tiled facade elements, and lightweight structures of the modern block have different physical and mechanical properties (Ismailov et al., 2024; Ismailov et al., 2025; Aktamov et al., 2025; Yodgorov et al., 2025). Consequently, seismic vibration monitoring was conducted covering both structural zones of the object. Modern construction processes near the museum building necessitate accurate recording of the intensity, frequency, and distribution characteristics of man-made dynamic loads transmitted to the structures. Therefore, in this study, a seismic monitoring system aimed at assessing the structural stability of the museum building is developed and implemented based on a consistent methodological approach. The general research methodology comprises three main stages: (1) selection and placement of seismometric equipment; (2) classification of vibration sources and instrumental seismometric records; (3) assessment of vibration intensity on a point scale based on measured seismic records.

Function, classification and placement methodology of seismometer

The seismometers used in monitoring allow for high-precision recording of various types of oscillations, velocity and acceleration components of earthquakes. These instruments were selected to compare the strength and spectral characteristics of vibrations in different areas of the structure. During the monitoring process, a seismometer (Güralp: CMG-6TD) with high sensitivity and capable of recording reliable data across a wide dynamic range was used to record oscillations (Ismailov et al., 2020; Khusomiddinov et al., 2022; Ismailov et al., 2025).

Velocimeter (Güralp: CMG-6TD).

The CMG-6TD velocimeter is a three-component digital seismometer that registers ground vibrations with high accuracy in the frequency range of 0.033-50 Hz. It features three-directional measurement, accurate time synchronization via GPS, autonomous operation, and a robust waterproof housing (Figure 2).

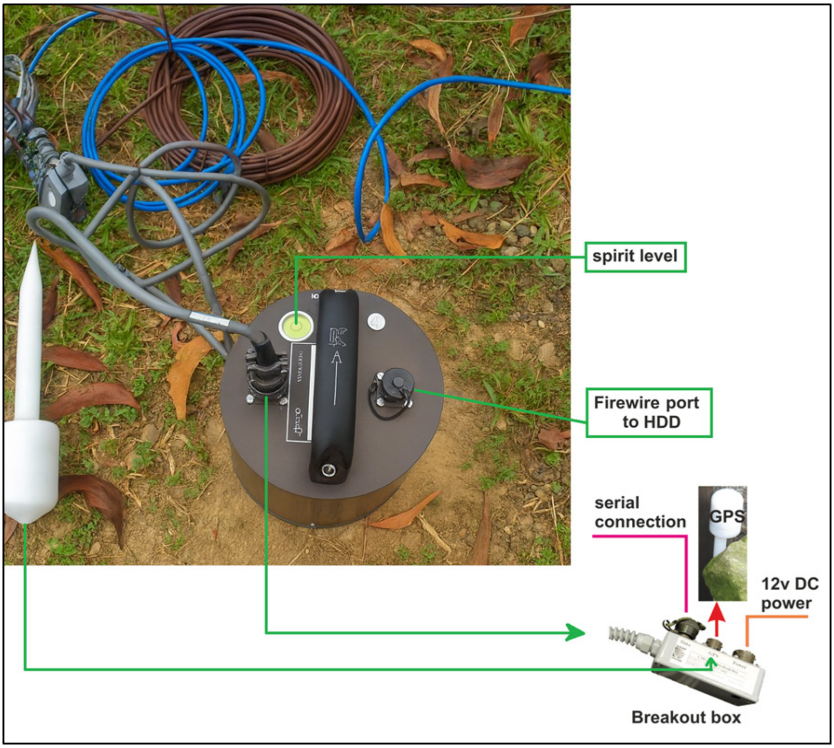

Figure 2. Guralp 6TD broadband seismometer, break-out cable, GPS antenna, and battery for power supply.

To ensure the accuracy and reliability of monitoring during seismometer placement, several scientific and technical principles were applied. These principles include considering the sensitivity of structural elements inside the building, optimal identification of vibration sources in the external area, phase synchronization of measurement points, and ensuring maximum sensitivity of instruments. Additionally, the coordination of internal and external measurement points is taken into account to analyze the building's stability and determine the transmission of external influences to the structure. Soil conditions are assessed according to Kuzmenko's methodology (Kuzmenko et al., 1990; Kishkina., 1999).

In the internal zone of the building: the foundation and the main load-bearing structures were selected as the most sensitive vibration-receiving elements.

In the external area: points close to the source of vibrations from construction equipment, but reflecting local soil conditions, were identified in the construction pit adjacent to the museum

(Figure 3).

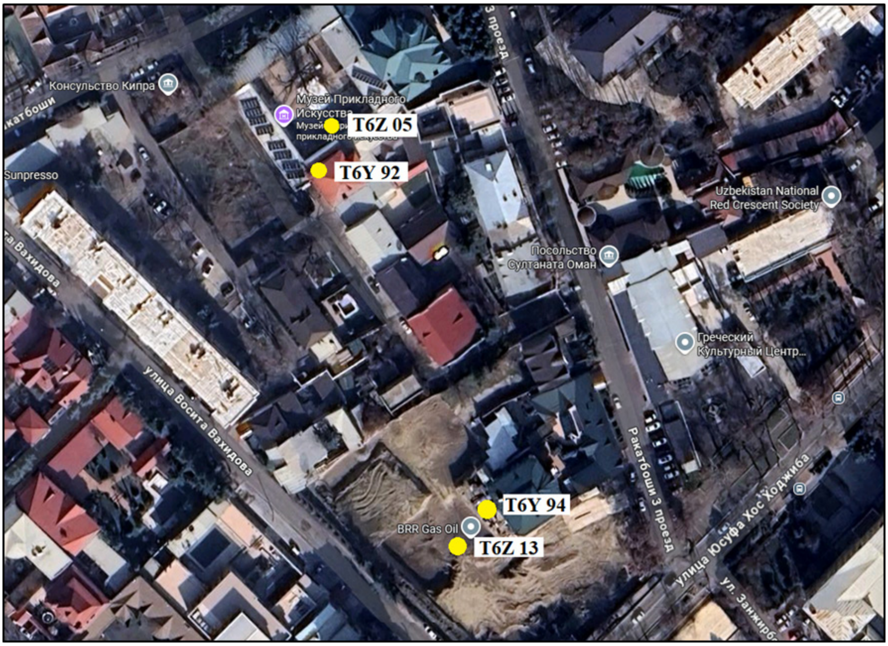

Figure 3. Schematic layout of measurement points in the museum and construction area.

The synchronous operation of seismometers enables precise temporal alignment of oscillatory processes at measurement points, allowing for highly accurate assessment of their phase differences, propagation speeds, and transmission mechanisms through the structure. This approach facilitates the determination of the spectral composition of oscillatory waves, their attenuation levels, and potential hazardous seismic effects on structural elements. Furthermore, such functional placement of measurement points enables systematic comparison of vibration fields inside and outside the building, evaluating the actual impact of dynamic loads from external sources. This enhances the reliability of monitoring results and aids in establishing safety criteria for the museum building's structural elements that are sensitive to technogenic seismic vibrations.

Classification of vibration sources and instrumental seismometric records. To characterize the nature of vibrations during construction work near the museum building, all major dynamic sources were sequentially recorded over time, with each individually classified according to its type of activity and technological regime. This approach allows for the analysis of the spectral composition of vibrations generated by various mechanical processes, their amplitude variability, and the conditions of their transmission to the building (Figure 4).

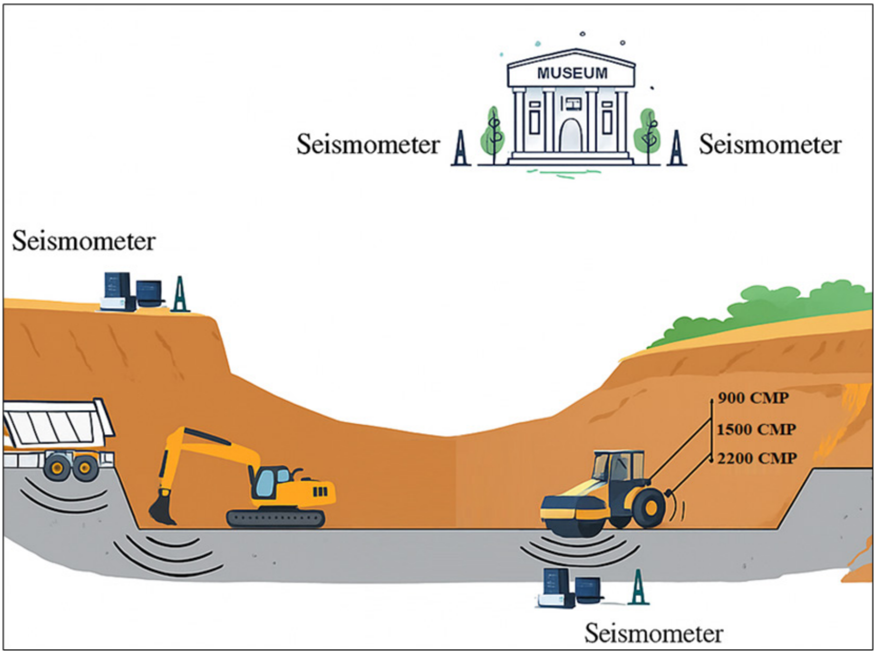

Figure 4. Diagram of the location of wave excitation sources and receiving seismometers.

Measurement points were selected to cover both the interior and exterior areas of the building, as well as to fully encompass the actual propagation zones of vibrations resulting from the movement and operation of heavy machinery. The seismometers are precisely oriented in north-south, east-west, and vertical directions and are mounted on a solid, non-deformable foundation. This allows for phase-accurate comparison of oscillations from various sources.

During the monitoring process, the following main vibration sources were recorded:

1) Movement of trucks. Vibrations generated during the passage of heavy

trucks through the construction site were recorded. This process allows for the assessment of the nature of background dynamic loads on the museum building, low-frequency oscillations caused by wheel pressure, and the extent of their propagation (Figure 5).

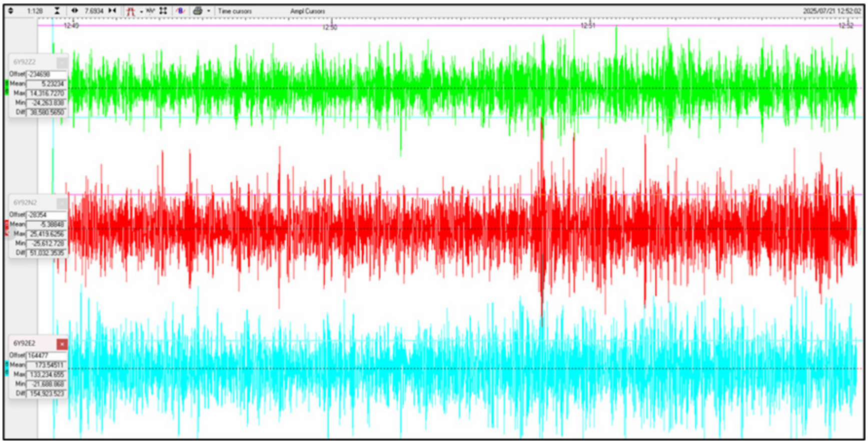

Figure 5. Seismogram of recorded vibrations at the location of the T6Y92 seismometer (in the building): Mode-1; truck movement (time: 17:49-17:52).

2) Vibration seal (roller) with different operating modes. The vibrating compactor was tested at three different rotational speeds:

900 CPM - low-frequency mode: mainly characteristic of the surface compaction process of soft soils (Figure 6).

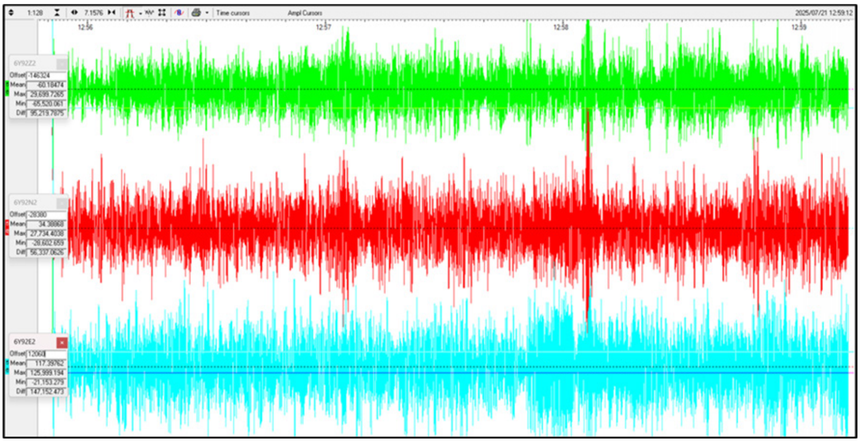

Figure 6. Seismogram of recorded vibrations at the location of the T6Y92 seismometer (in the building): Mode-2; operating mode of the vibrating roller at 900 CPM (time: 17:56-17:59).

1500 CPM - medium-frequency operating mode: represents the standard compaction process, which is widely used in construction (Figure 7).

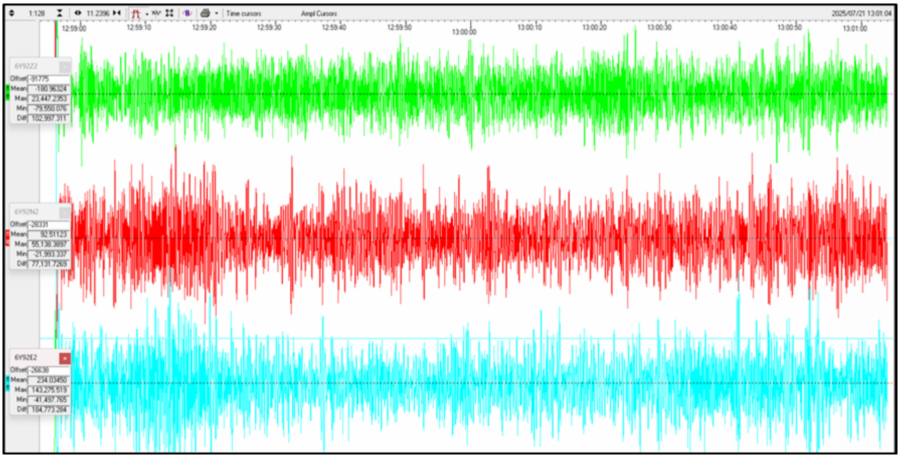

Figure 7. Seismogram of recorded vibrations at the location point of the T6Y92 seismometer (in the building): Mode-3; operating mode of the vibrating roller at 1500 CPM (time: 17:59-18:01).

2200 CPM - high-frequency mode: reflects the intensive oscillations generated during the compaction of deep layers (Figure 8).

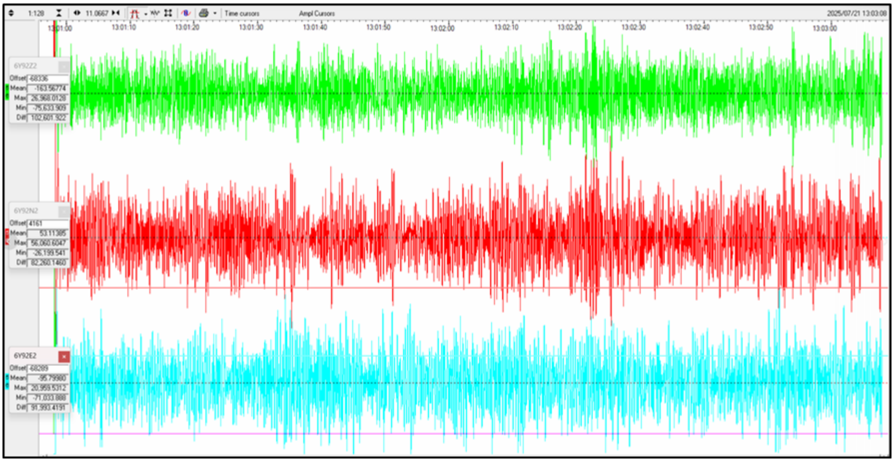

Figure 8. Seismogram of recorded vibrations at the location point of the T6Y92 seismometer (in the building): Mode-4; operating mode of the vibrating roller 2200 CPM (time: 18:01-18:03).

Each mode is characterized by different vibration amplitudes, spectral composition, and duration, which allow us to determine the specific mechanisms of influence of construction technology.

3) No-vibrator mode of the roller. It was especially noted that the compactor moves only due to its own weight. This process, unlike vibrational mode, helps to isolate only the effects of static load and mass oscillations. Thus, the differences between the translational motion of the mass and the dynamic action in the vibrator-activated state are determined (Figure 9).

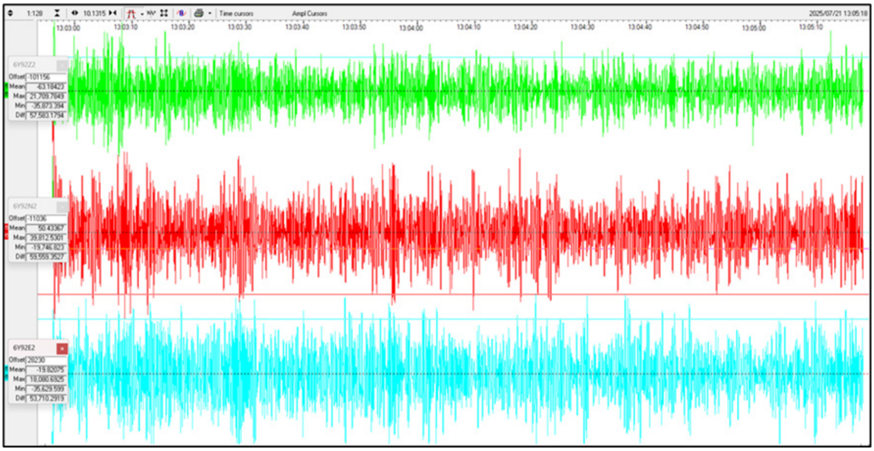

Figure 9. Seismogram of vibrations recorded at the location point of the T6Y92 seismometer (in the building): Mode-5; non-vibrational state (time: 18:03-18:05).

4) Excavator work. Various excavator operations, such as the impact of the bucket on the ground, soil lifting, displacement of equipment, and mechanical interaction with the ground, were recorded as separate sources of vibration. These processes are often characterized by impulsive, short-duration, but high-amplitude oscillations (Figure 10).

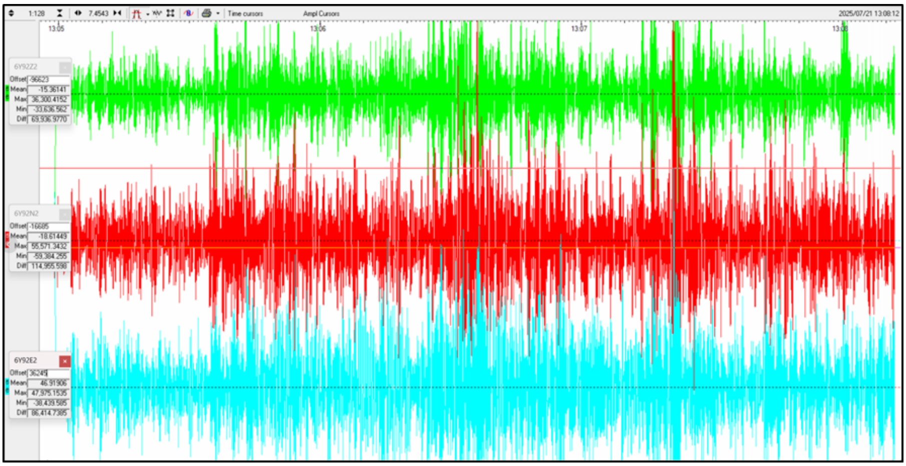

Figure 10. Seismogram of recorded vibrations at the location of the T6Y92 seismometer (in the building): Mode-6; excavator movement (time: 18:05-18:10).

This made it possible to distinguish the spectral composition and amplitude characteristics of vibrations generated by various technical processes. Obtaining complete seismograms for each event provides a basis for conducting systematic analysis in subsequent stages of monitoring.

During the research, seismic recordings were obtained from equipment (trucks, rollers, excavators, etc.) operated in various modes inside the museum building and in the construction pit. In this article, one seismogram is presented as a representative example for each type of equipment, while the remaining data and detailed records are provided as an appendix.

Assessment of seismic intensity based on seismograms. The recorded vibration data were processed according to peak ground velocity (PGV) and the vibration intensity was assessed on a point scale used in current engineering practice. This assessment method allows for qualitative and quantitative determination of the potential risk of man-made vibrations to the structure. Corresponding score indicators of PGV and PGA values obtained from various sources serve to compare their risk levels, as well as to identify the technical process with the maximum impact. The use of instrumental seismic intensity in assessing the influence of vibrations recorded near the museum building on structural stability is a scientifically sound approach. Scientific sources note that V.B. Zaalishvili studied approaches to assessing seismic risk based on PGA, and also developed empirical regression relationships for converting instrumental indicators such as PGA and PGV into macroseismic intensity (points) in seismological studies.

This scale establishes ranges of maximum values for acceleration, velocity, and displacement for each intensity level, which are widely used in international practice for assessing artificial and natural seismic vibrations. In the study, the PGV values of the velocimetric records obtained inside and outside the museum were compared with this table, and the equivalent intensity scores of the vibrations affecting the building were determined.

This approach is important as a sensitive, digital, and reproducible method for assessing the structural safety of historical objects. Using instrumental intensity, the vibration zone, their propagation, and the force of impact on the structure are quantitatively expressed (Zaalishvili et al., 2024) (Table 1).

Table 1. Instrumental seismic intensity scale of V.B. Zaalishvili and other researchers: assessment criteria based on the maximum parameters of ground motion.

I, intensity (points)	PGA, sm/s²	PGV, sm/s	PGD, sm	PGA·PGV	PGA·$\sqrt{d}$
1	0.448	0.0167	0.0003	0.007	0.6
1.5	0.704	0.0289	0.0006	0.02	1
2	1.12	0.0501	0.0013	0.056	1.62
2.5	1.76	0.0867	0.0028	0.152	2.63
3	2.8	0.15	0.0062	0.42	4.27
3.5	4.4	0.25	0.014	1.1	7.08
4	7	0.44	0.03	3.08	11.7
4.5	11	0.75	0.063	8.25	19.5
5	17.5	1.3	0.14	22.75	32.4
5.5	28	2.2	0.3	61.6	53.7
6	44	3.8	0.66	167.2	89.1
6.5	70	6.5	1.4	455	151

7	110	11	3.2	1210	251
7.5	175	19	7	3325	416
8	280	33	15	9240	691
8.5	440	57	33	25080	1150
9	700	98	72	68600	1900
9.5	1100	170	160	187000	3160

In assessing vibrations recorded near the museum, PGV was selected as the primary diagnostic parameter, as it is considered an effective indicator for historical structures sensitive to low-frequency vibrations. The measured PGV values were equated to corresponding intensity scores according to V.B. Zaalishvili's instrumental intensity scale. This table presents typical values of PGA, PGV, and PGD observed at various intensity levels, which allowed for a quantitative assessment of dynamic loads affecting the museum structure.

Results and analysis. As a result of seismic monitoring, the maximum velocity values of vibrations generated during construction equipment operation were determined. During experimental observations, seismic signals were recorded in the following modes: movement of heavy trucks, vibrating rollers at various rotational speeds (900, 1500, and 2200 CPM), with the vibrator turned off, and during excavator operation. The maximum values recorded in each mode were evaluated according to the MSK-64 scale. This approach enabled quantitative assessment of vibrational load intensities and determination of their impact on the museum building structures.

Table 2. Intensity of seismic loads affecting the museum building under various operating modes of construction equipment.

Point of measurement - №1				
Guralp T6Z05	№	Vibration source (time)	PGV, nm/s	Intensity (points)
	1	17:49-17:52 (trucks)	77689	1
	2	17:56-17:59 (vibrating roller - 900 CPM)	180369	1.5
	3	17:59-18:01 (vibrating roller - 1500 CPM)	219898	1.5
	4	18:01-18:03 (vibrating roller - 2200 CPM)	591900	2.5
	5	18:05-18:08 (excavator)	130233	1.5
Point of measurement - №2				
Guralp T6Y92	№	Vibration source (time)	PGV, nm/s	Intensity (points)
	1	17:49-17:52 (trucks)	205731	1.5
	2	17:56-17:59 (vibrating roller - 900 CPM)	223932	1.5
	3	17:59-18:01 (vibrating roller - 1500 CPM)	135278	1
	4	18:01-18:03 (vibrating roller - 2200 CPM)	305622	1.5
	5	18:03-18:05 (roller - no vibrator)	86312	1
	6	18:05-18:10 (excavator)	32211	1
Point of measurement - №3				

	№	Vibration source (time)	PGV, nm/s	Intensity (points)
Guralp T6Y94	1	18:52-18:55 (trucks)	310065	1.5
	2	18:55-18:58 (vibrating roller - 900 CPM)	495672	2
	3	18:58-19:00 (vibrating roller - 1500 CPM)	946765	3
	4	19:00-19:01 (vibrating roller - 2200 CPM)	661407	2.5
	5	19:01-19:02 (roller - no vibrator)	832389	2.5
	6	19:02-19:05 (excavator)	770490	2.5
Point of measurement - №4				
Guralp T6Z13	№	Vibration source (time)	PGV, nm/s	Intensity (points)
	1	18:52-18:55 (trucks)	324924	1.5
	2	18:55-18:58 (vibrating roller - 900 CPM)	628715	2
	3	18:58-19:00 (vibrating roller - 1500 CPM)	593392	2
	4	19:00-19:01 (vibrating roller - 2200 CPM)	696099	2.5
	5	19:01-19:02 (roller - no vibrator)	505313	2
	6	19:02-19:05 (excavator)	585921	2

Analysis. The museum building is a historical object, and its structural system is more sensitive to vibrations than modern buildings. Such structures often have a complex structural scheme, and their load-bearing elements consist of worn-out materials. Therefore, the assessment of the intensity of anthropogenic vibrations arising during construction work near the museum is important from the point of view of ensuring the seismic safety of the structure. The conducted monitoring increases the likelihood of local resonance states and cumulative deformations in the museum structure due to vibration machines, heavy equipment movement, and vibrations generated during excavator operation.

Analysis of the results of seismic observations made it possible to identify the following important features of oscillations affecting the museum building:

1. The intensity of vibration during the movement of construction equipment differs significantly. The movement of trucks caused vibrations of the lowest intensity (1-1.5 points according to MSK-64). Such vibrations usually do not cause structural damage, but they can widen existing microcracks in museum walls.

2. As the rotational speed of the vibrating roller increases, the vibration intensifies. PGV values, recorded at frequencies of 900, 1500, and especially 2200 CPM, reached a range of 2-3 points. These vibrations can cause: delamination in the plaster layer of walls, fine destruction in decorative elements, micro-deformations in floor coverings. High-frequency oscillations are especially dangerous for historical buildings, as they impose frequently recurring dynamic loads on structural elements.

3. Although the vibrations from excavator operation are relatively low, the cumulative effect is strong. Although excavator vibrations are in the range of 1-2 points on average, due to the duration and frequency of work, accumulative deformations can occur in structural elements.

4. Comparison of internal and external measurement points showed an important result. The recorded vibrations were maximal in the pit area, i.e., in the area closest to the construction equipment. However, their partial extinction was observed as they spread into the interior of the museum building. Nevertheless: high-frequency oscillations are significantly reflected in the internal structural elements of the building; this indicates the possibility of a resonant state occurring in some local zones of the building.

5. The monitoring results have practical significance for the seismic protection of the museum. The collected data will allow:

- identification of structural zones most susceptible to vibrations;
- development of protective measures (for example, vibration isolation, temporary structural reinforcement);
- establishment of permitted operating modes of construction equipment;
- improvement of safety standards during construction near the museum.

The activity of construction equipment carried out near historical buildings can pose a certain danger through anthropogenic vibrations. Based on these monitoring data, it is necessary to develop measures for the protection of structures.

Conclusion. The results of seismic monitoring conducted in field conditions within the framework of this study made it possible to quantitatively assess the intensity of vibrations arising during the operation of various construction equipment in the museum building and the adjacent pit area. In the measurements, the highest values of vibrational speeds were recorded directly in the pit area, especially during the operation of the vibrating roller at a frequency of 1500 and 2200 CPM, as well as in the non-vibrating mode and during the operation of the excavator, the intensity reached 2.5-3 points. According to the MSK-64 scale, these values correspond to the range "from insignificant to insignificant" and increase the probability of the occurrence of local resonance phenomena in some structural elements.

Within the museum building, including in the foundation zone and upper structural parts, the recorded vibrations are relatively low, usually in the range of 1-1.5 points. Only in some high-frequency vibration modes, an increase in intensity up to 2.5 points was observed, however, this level does not pose a significant threat to the overall stability of the museum structure. The most noticeable oscillations, observed at a frequency of 1500 CPM of the vibrating roller and in non-vibrating mode, can be explained by the propagation of low-frequency waves and resonance effects in structural elements.

The high maximum PGV values recorded in the pit area indicate a significant level of load on engineering structures. These results indicate that they should be taken into account when designing protective measures to strengthen the foundation and reduce vibrations. Although the excavator's activity formed a relatively moderate seismic effect, it was found that the operation of heavy equipment in a limited area caused an increase in intensity in the pit zone by up to 2.5 points.

The form and spectral characteristics of the recorded oscillations are characteristic of seismic processes of technogenic origin, where the main part of the amplitude is observed along the horizontal components (X and Y), while the vertical component (Z) is expressed to a much lower degree. In general, the monitoring results show that the museum building is not at a critical risk of anthropogenic seismic impacts caused by construction equipment under current operating conditions. However, considering the constructive sensitivity of cultural heritage sites, the possibility of increased vibrations in the foundation zone should be assessed and monitored through continuous monitoring during nearby construction processes, particularly when using equipment with high vibrational loads.

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ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Managing Editor: *T. Apendiev*
Editors: *D.S. Alenov, A.Shormakova*
Computer layout: *G.D. Zhadyranova*

Signed for print: April 10, 2026
Format: 70×90 1/16. 26.5 printed sheets. Order No. 2.

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