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MODERN DEVELOPMENT OF STRONG GROUND MOTION MONITORING SYSTEMS FOR BUILDINGS IN SEISMIC REGIONS (BASED ON FOREIGN EXPERIENCE)

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Abstract. This paper analyzes the modern development stages of strong ground motion monitoring systems, which play an important role in assessing the technical condition of buildings and structures in seismic regions. The study examines foreign experience, particularly the monitoring systems implemented by the Building Research Institute (BRI) in Japan, as well as the operation of K-NET and KiK-net networks and data obtained from real earthquake observations. The role of monitoring systems in ensuring structural safety, determining dynamic parameters, and predicting seismic impacts is scientifically substantiated. In addition, the effectiveness of sensor technologies, accelerometers, and digital data processing methods is evaluated. The obtained results highlight the necessity of implementing monitoring systems and developing sustainable construction policies in seismic regions.

Keywords: seismic monitoring, ground motion, accelerometer, structural health monitoring (SHM), dynamic analysis, IoT, seismic safety.

Annotatsiya. Mazkur maqolada seysmik faol hududlarda binolar va inshootlarning texnik holatini baholashda muhim ahamiyatga ega bo‘lgan kuchli grunt harakatlarini monitoring qilish tizimlarining zamonaviy rivojlanish bosqichlari tahlil qilinadi. Tadqiqot davomida Yaponiya tajribasi, xususan Building Research Institute (BRI) tomonidan amalga oshirilayotgan monitoring tizimlari, K-NET va KiK-net tarmoqlari faoliyati hamda real zilzila kuzatuvlari asosida olingan ma’lumotlar o‘rganildi. Monitoring tizimlarining konstruktiv xavfsizlikni ta’minlash, dinamik parametrlarni aniqlash va seysmik ta’sirlarni prognozlashdagi roli ilmiy jihatdan asoslandi. Shuningdek, sensor texnologiyalari, akselerometrlar va raqamli ma’lumotlarni qayta ishlash usullarining samaradorligi baholandi. Olingan natijalar seysmik hududlarda barqaror qurilish siyosatini shakllantirish va monitoring tizimlarini joriy etish zarurligini ko‘rsatadi.

Kalit so‘zlar: seysmik monitoring, grunt harakati, akselerometr, strukturaviy sog‘liq monitoringi, dinamik tahlil, IoT, seysmik xavfsizlik.

Аннотация. В данной статье анализируются современные этапы развития систем мониторинга сильных грунтовых движений, имеющих важное значение для оценки технического состояния зданий и сооружений в сейсмических районах. В ходе исследования рассмотрен зарубежный опыт, в частности системы мониторинга, реализуемые Building Research Institute (BRI) в Японии, а также функционирование сетей K-NET и KiK-net и данные, полученные на основе реальных наблюдений землетрясений. Научно обоснована роль систем мониторинга в обеспечении конструктивной безопасности, определении динамических параметров и прогнозировании сейсмических воздействий. Кроме того, оценена эффективность сенсорных технологий, акселерометров и методов цифровой обработки данных. Полученные результаты подтверждают необходимость внедрения мониторинговых систем и формирования устойчивой строительной политики в сейсмических районах.

Ключевые слова: сейсмический мониторинг, грунтовые движения, акселерометр, структурный мониторинг (SHM), динамический анализ, IoT, сейсмическая безопасность.

INTRODUCTION.

In recent years, ensuring the structural safety of buildings and structures located in seismic regions has become one of the most pressing scientific and practical challenges on a global scale. The rapid pace of urbanization, the increasing number of multi-storey buildings, and the extension of their service life have intensified the need for continuous monitoring of the reliability of structural elements. Dynamic loads generated during earthquakes can lead to hidden damage in structures, including microcracks and stiffness degradation, which negatively affect the overall stability of buildings.

Traditional visual inspections and periodic technical assessments often fail to provide a complete and reliable evaluation of the internal condition of structures. In particular, deformation processes caused by dynamic effects related to ground motion can only be effectively identified through instrumental monitoring. Therefore, in modern civil engineering, technologies for monitoring strong ground motions are emerging as an important scientific direction. These technologies enable real-time recording of acceleration, displacement, and vibration parameters, allowing for the assessment of structural safety and early detection of potentially hazardous conditions.

International experience shows that seismic monitoring systems are highly developed, especially in countries with high seismic activity such as Japan. In this country, monitoring systems developed by the Building Research Institute (BRI), as well as strong ground motion observation networks such as K-NET and KiK-

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net, allow for high-precision analysis of earthquake processes through thousands of observation stations. These systems not only record ground motion but also capture the dynamic response of buildings, providing essential data for evaluating the actual behavior of structural systems.

Data obtained from strong ground motion monitoring systems make it possible to assess the real effects of seismic loading, determine the frequency characteristics of structures, and evaluate deformation parameters. This enables forecasting of degradation processes in structural elements, improvement of design solutions, and enhancement of seismic safety levels. Moreover, modern monitoring systems are increasingly integrated with IoT technologies, cloud computing, and digital modeling, advancing structural health monitoring (SHM) systems to a new level [2].

The aim of this paper is to analyze the development stages of strong ground motion monitoring systems based on international experience, evaluate their technical capabilities, and scientifically substantiate their role in ensuring the structural safety of buildings.

METHODOLOGY. This study is aimed at analyzing the modern development of strong ground motion monitoring systems in seismic regions and was conducted based on a literature review and systematic analysis approach. During the research process, foreign scientific publications, technical reports, and practical data related to seismic monitoring systems were comprehensively studied and synthesized. Particular emphasis was placed on the experience of Japan, as this country possesses advanced scientific and technological solutions in the field of seismic monitoring. Specifically, the activities of the Building Research Institute (BRI), as well as real observational data obtained from the K-NET and KiK-net monitoring networks, were analyzed. The characteristics of recorded ground motion parameters, their accuracy, and their impact on structural elements were scientifically evaluated [5].

The research methodology consisted of several main stages. In the first stage, the theoretical foundations of seismic monitoring and scientific sources related to ground motion parameters were analyzed. In the second stage, foreign monitoring systems, including sensor networks and accelerometric measurement techniques, were examined. In the third stage, based on real observational data, the patterns of variation in dynamic parameters were identified, and their influence on structural safety was assessed. During the monitoring analysis, primary attention was given to key physical parameters such as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), spectral acceleration, and vibration amplitudes. These parameters were considered as the main diagnostic

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indicators for evaluating seismic intensity and determining the dynamic response of structures.

Comparative analysis, graphical interpretation, and scientific generalization methods were applied to process and interpret the data. Differences between various monitoring systems, their technical capabilities, and their effectiveness were analyzed to identify optimal approaches.

The main advantage of this methodology lies in the integration of scientific and practical data from diverse sources, enabling a comprehensive evaluation of the development trends of seismic monitoring systems. This approach provides a solid scientific basis for the future implementation of advanced monitoring systems in national construction practice.

RESULTS. The conducted literature review and analysis of international experience made it possible to determine the level of development of strong ground motion monitoring systems in seismic regions and to assess their effectiveness in ensuring structural safety. The analysis showed that modern monitoring systems are capable of recording high-precision data in real time, which allows for a comprehensive evaluation of the dynamic behavior of structures. The spatial distribution of global seismic activity is presented in the following figure [3].

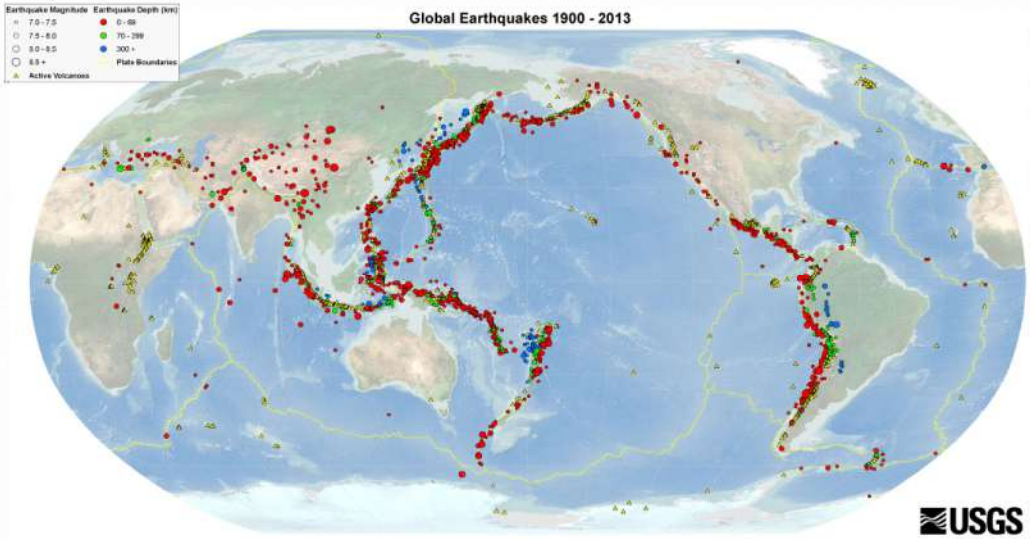


Figure 1. Global distribution of earthquakes and plate boundaries (1900-2013) [based on USGS data] [3]

Studies based on the experience of Japan have shown that the K-NET and KiK-net monitoring networks continuously record the main parameters of ground motion through thousands of seismic stations, including Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and spectral acceleration. The data obtained from these systems make it possible to determine the actual behavior of the ground during earthquakes and to evaluate the real response of

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structures. The results indicate that variations in soil conditions and geological layers significantly influence the intensity of seismic effects.

Based on data obtained from monitoring systems, the dynamic parameters of structures, including natural frequencies and vibration amplitudes, can be determined. Research findings show that over time, due to the reduction in structural stiffness, natural frequencies decrease while vibration amplitudes increase. This phenomenon indicates the presence of hidden damage and degradation processes within structural elements. One of the key historical events that stimulated the development of seismic monitoring systems was the Niigata earthquake that occurred in Japan in 1964. During this earthquake, soil liquefaction, strong ground shaking, and significant deformation of structural elements were observed. This event clearly demonstrated, for the first time, the necessity of instrumental recording of strong ground motions [1].

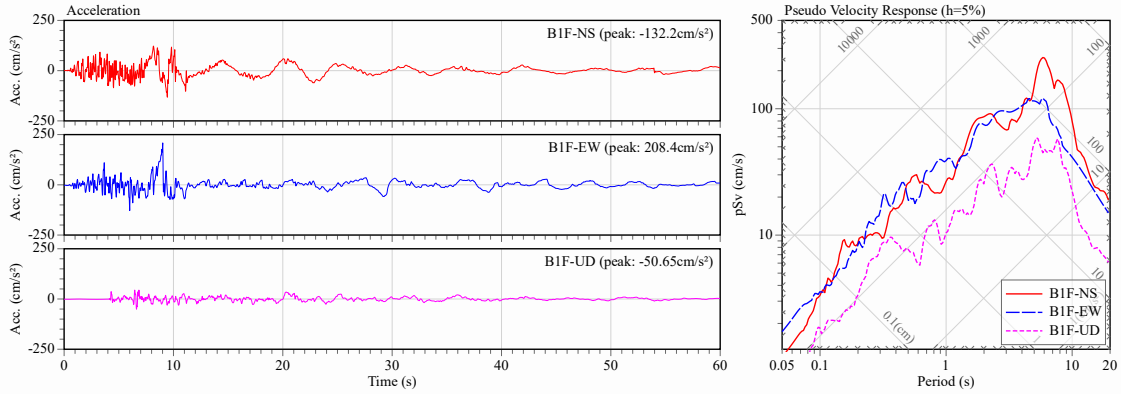


Figure 2. Ground motion records and accelerograms obtained during the 1964 Niigata earthquake (Japan, based on BRI data)



Figure 3. Residential building tilted due to soil liquefaction caused by the Niigata earthquake

On June 16, 1964, a magnitude 7.5 earthquake occurred, resulting in 26 fatalities and the destruction of approximately 1960 buildings. In addition, monitoring systems enable the determination of displacement and deformation

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parameters through sensors installed at different heights of buildings. The obtained results indicate that maximum displacements are typically observed at the upper levels and tend to increase compared to lower floors. This behavior is associated with the spatial performance characteristics of the structure and reflects the non-uniform distribution of deformations under loading conditions [1,6].

Another important finding based on international experience is that monitoring systems allow for rapid post-earthquake assessment of structural conditions. Using real-time data, it is possible to determine the level of structural damage and significantly accelerate engineering decision-making processes in emergency situations. This highlights the importance of monitoring systems not only from a scientific perspective but also in practical applications.

The analysis also shows that modern monitoring systems achieve higher efficiency when integrated with IoT technologies, cloud computing, and digital modeling tools. This integration enables the rapid processing of large volumes of data, their visualization, and the evaluation of structural risk levels. In general, the obtained results confirm that strong ground motion monitoring systems are an essential tool for ensuring structural safety in seismic regions, identifying dynamic processes, and enabling early prediction of hazardous conditions.

DISCUSSION. The obtained results indicate that strong ground motion monitoring systems play a significant scientific and practical role in ensuring structural safety in seismic regions. In particular, high-precision data obtained in real time from systems such as K-NET and KiK-net in Japan enable in-depth analysis of seismic processes. Compared to traditional computational models, this approach allows for a more accurate assessment of the actual behavior of structures.

Changes in dynamic parameters identified through monitoring systems are considered important indicators for evaluating the degradation processes of structural elements. In particular, a decrease in natural frequencies and an increase in vibration amplitudes indicate a reduction in structural stiffness. This observation is fully consistent with the principles of structural health monitoring (SHM) and confirms the effectiveness of monitoring systems as non-destructive diagnostic tools [4,7]. At the same time, the influence of soil conditions on seismic effects has been identified as a critical factor. Even for earthquakes of the same magnitude, recorded acceleration values may vary significantly depending on local geological conditions. This highlights the necessity of considering site-specific soil characteristics in the design and implementation of seismic monitoring systems.

Another important advantage of monitoring systems is their ability to provide rapid post-earthquake assessment of structural conditions. Based on real-

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time data, it is possible to determine the level of structural damage and define appropriate engineering measures. This significantly accelerates decision-making processes in emergency situations and contributes to the protection of human life and material resources. However, monitoring systems also have certain limitations. First, their implementation requires substantial financial investment, including the cost of sensors, data transmission devices, and server infrastructure. In addition, continuous operation demands regular maintenance and calibration. The large volume of data generated by these systems also requires specialized software and qualified personnel for effective processing.

Nevertheless, modern technologies such as IoT, cloud computing, and artificial intelligence-based analytical methods significantly enhance the efficiency of monitoring systems. These technologies enable automated processing of large datasets, early detection of hazardous conditions, and the development of real-time warning systems [7]. Overall, the analysis confirms that strong ground motion monitoring systems are essential not only for scientific research but also for practical civil engineering applications. Their implementation in national construction practice can improve structural safety, reduce эксплуатation costs, and ensure more effective management of seismic risk.

CONCLUSION. Within the framework of this study, the modern development stages of strong ground motion monitoring systems in seismic regions and their role in ensuring structural safety were analyzed based on international experience. The reviewed materials demonstrate that modern monitoring systems are an essential tool for assessing the dynamic behavior of structures by recording high-precision data in real time. The K-NET and KiK-net monitoring networks developed in Japan have shown their effectiveness in comprehensive observation of strong ground motions, identification of seismic parameters, and evaluation of the actual performance of structural systems. Data obtained from these systems play a crucial role in determining the stiffness characteristics, deformation behavior, and seismic resistance of structures.

The analysis indicates that a decrease in natural frequencies, an increase in vibration amplitudes, and changes in deformation parameters can be considered key indicators of structural degradation. This confirms the practical significance of the structural health monitoring (SHM) concept and highlights the effectiveness of non-destructive diagnostic methods. Furthermore, monitoring systems enable rapid post-earthquake assessment of structural conditions, determination of risk levels, and optimization of engineering decision-making processes. This is particularly important for ensuring safety in emergency situations.

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Although the implementation of monitoring systems requires significant initial investment and ongoing maintenance, their long-term economic efficiency and contribution to safety are highly valuable. The integration of modern technologies such as IoT, artificial intelligence, and digital modeling further enhances the effectiveness of monitoring systems. In general, the implementation of strong ground motion monitoring systems in national construction practice represents an important scientific and practical direction for reducing seismic risk, improving structural safety, and developing sustainable construction policies. Future research should focus on integrating these systems with BIM technologies and AI-based predictive models.

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