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Geodetic Monitoring of Vertical Deformations in the City Cardiology Hospital Building in the Town of Bryukhovychi During Reconstruction

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SUMMARY

This research presents the results of comprehensive geodetic monitoring of vertical deformations in a three-story building of the city cardiology hospital, which is being renovated as part of the UNBROKEN project. The monitoring was conducted over a 12-month period (April 2025–April 2026) and included six cycles of high-precision geometric leveling and crack monitoring using biaxial mechanical crack gauges. The monitoring network included 25 wall deformation marks, a reference point, and 9 crack gauges. The study identified three distinct deformation zones: a zone of localized settlement in the western part of the building with displacements of up to –3.8 mm, a zone of maximum settlement in the northern part with a cumulative displacement of up to –6.1 mm, and a zone of localized uplift in the northern part with displacements of up to +2.5 mm. Data from the crack gauges confirmed the localized nature of the deformations and the absence of intensive crack development. The results obtained demonstrate the effectiveness of combining geometric leveling and crack gauge measurements for the operational monitoring of the technical condition of buildings during major reconstruction.

Keywords: Geodetic monitoring; Geometric leveling; Building deformations; Wall marks; Crack gauges; Crack deformation; Vertical settlement.

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Introduction

In 2023, reconstruction began on the municipal cardiology hospital in the town of Bryukhovychi (Lviv Oblast, Ukraine) as part of the UNBROKEN project – the creation of a next-generation rehabilitation center that will become part of the national rehabilitation ecosystem. The project involves a comprehensive modernization of the medical facility, an addition to the existing building, the construction of new wings, the creation of a barrier-free environment, and the expansion of functional infrastructure. Construction work began in 2024 and involves significant changes to the structural scheme and the load on the building's foundation.

The renovation project involves a three-story hospital building constructed in the second half of the 20th century. According to the project, plans call for the addition of an extra floor, the construction of two new three-story sections, and the integration of the existing buildings into a single rehabilitation complex with a total area of over 9,000 m². These structural changes will result in a redistribution of loads on the foundations and may cause uneven deformations of the foundation.

The renovation of buildings involving the addition of new stories falls into the category of work with elevated geotechnical risk, as it can cause foundation settlement, structural tilting, and the development of cracks in load-bearing elements. According to recent studies, the main factors contributing to deformations are soil compaction, changes in the stress-strain state of the foundation, fluctuations in the groundwater level, and vibrations from construction work, which underscores the importance of geodetic monitoring of such buildings (Voitenko et al., 2021; Celms et al., 2022). A monitoring method based on data obtained from geodetic monitoring of control and measurement networks installed on the building's above-ground structural elements has also been proposed and tested at the Bydgoszcz University of Science and Technology (Sztubecki & Mrówczyńska, 2023). Therefore, systematic geodetic monitoring is an essential element in ensuring structural safety during the reconstruction of such structures.

To monitor the spatial position of the building at the site, high-precision geodetic monitoring was organized using the geometric leveling method. Observations were carried out along closed leveling traverses, referenced to the Ukrainian height network benchmark and a system of deformation markers affixed to the structural elements of the building. Additionally, the development of local deformations was monitored using biaxial crack gauges, which allowed for a comprehensive assessment of both the vertical displacements of the foundations and the dynamics of crack propagation.

The main objective of this research is to evaluate the vertical deformations of the building's structural elements and to analyze the dynamics of crack propagation based on the results of six cycles of geodetic observations conducted between April 2025 and April 2026.

Method

To monitor building deformations, modern engineering geodesy uses GNSS measurements (Tretyak et al., 2021), terrestrial laser scanning (Savchyn et al., 2023; Danyliv et. al., 2026), electronic total stations, and high-precision geometric leveling (Serant et al., 2022). The choice of method is determined by the nature of the expected deformations, the required accuracy, and the structural characteristics of the object (Pirti & Hoşbaş, 2019). For monitoring vertical settlements during building reconstruction, geometric leveling remains the most accurate and normatively sound method, as it allows for the determination of displacements at the millimeter level (Erol et al., 2004; Dzhuman & Shkvarok, 2026).

In this research, vertical deformations were determined using the Class II geometric leveling method with a closed traverse (DSTU B V.2.1-30:2014). A wall benchmark (RP) located on a neighboring stone building outside the area affected by construction work served as the reference elevation. Closing the traverse at the reference point ensures control of discrepancies during the leveling process, since, theoretically, the sum of the excesses along the traverse should be zero. At the same time, the distribution of discrepancies allows for increased reliability in determining the heights of reference points in the conventional system and in the observation results.

The monitoring network at the municipal cardiology hospital in the town of Bryukhovychi consisted of 25 wall deformation marks (STM1–STM25), evenly spaced around the building's perimeter, and nine biaxial mechanical crack gauges (C1–C9) to monitor crack opening in the horizontal and vertical directions (Figure 1.), which were installed on various floors in the western part of the building at existing settlement cracks. Wall deformation marks were installed as temporary monitoring points on the building's facade, while the crack gauges were installed inside the building at locations with documented characteristic settlement cracks.

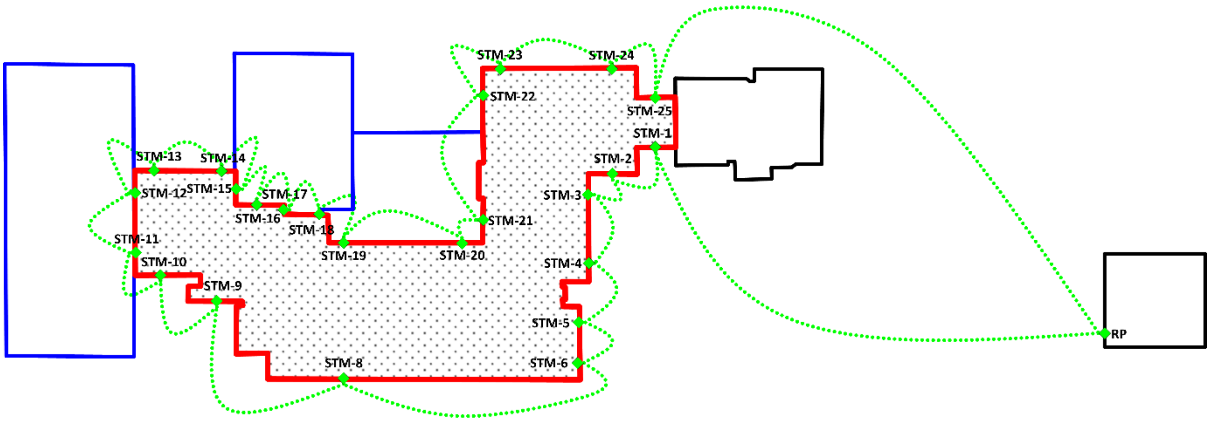

Figure 1. *Location of wall marks at the study object (red: monitoring building; black: existing buildings; blue: new buildings; green: Class II leveling survey)*

Geometric leveling was performed using a Trimble DiNi0.3 digital level with Trimble LD13 solid invar staffs. Before fieldwork began, the level and staffs were calibrated at the laboratory of Lviv Polytechnic National University using an "IP-1" linear displacement laser interferometer, which ensured the metrological traceability of the measurements (Gassner & Ruland, 2006).

Data

The geodetic monitoring lasted 12 months (April 2025–April 2026) and consisted of six consecutive observation cycles, the results of which were used to determine the temporal dynamics of vertical displacements and crack development. The first cycle served as the baseline, while the subsequent cycles were used to determine the dynamics of vertical displacements of deformation markers and changes in crack width. At the same time, the integrity of the monitoring network was assessed, as it gradually changed due to construction and installation work (Table 1).

Table 1. *Characteristics of Geodetic Monitoring Cycles*

Cycles	Date	Wall marks		Crack gauges	
		Quantity	Preservation	Quantity	Preservation
I	30.04.2025	25	100%	9	100%
II	05.05.2025	25	100%	9	100%
III	28.05.2025	25	100%	9	100%
IV	30.06.2025	23	92%	6	67%
V	25.09.2025	13	52%	2	22%
VI	17.04.2026	5	20%	1	11%

Table 1 shows a gradual decrease in the number of available monitoring points throughout the building's renovation. The first three cycles were carried out while the network remained fully intact, which ensured the creation of a high-quality set of observations. The greatest losses occurred between cycles IV and V due to facade and finishing work: the number of leveling marks decreased from 23 to 13, and the number of crack gauges from 6 to 2. By the final cycle, only 20% of the deformation markers and 11% of the crack gauges remained, which is typical for long-term geodetic monitoring of structures undergoing active reconstruction.

Result and Analysis

The results of six cycles of geometric leveling made it possible to identify three distinct zones of building deformation (Figure 2.), which reflect the different responses of the structures to the renovation and construction of new additions.

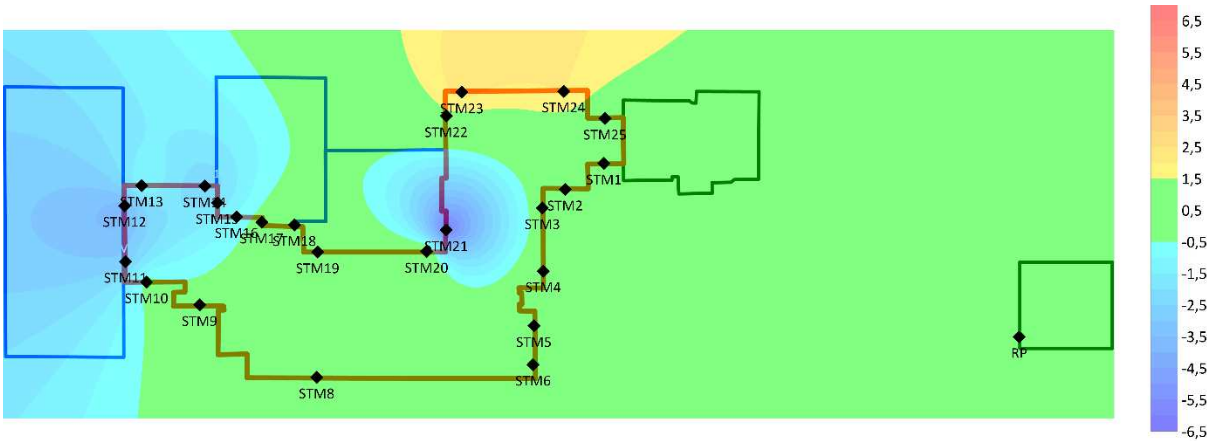

Figure 2. *Spatial Distribution of Deformations*

The stable zone encompasses the eastern and southern parts of the structure (marks STM1–STM10), where, throughout the entire observation period, the total vertical displacements did not exceed ±1.0 mm, which is within the measurement accuracy and indicates the absence of significant settlement.

The first zone of localized settlement formed in the western part of the building, which directly borders the excavation pits and foundations of the new wings. Here, settlements of –1.0 to –3.8 mm were recorded for sections STM11–STM15; specifically, for STM12 and STM14, they were –3.8 mm and –2.6 mm, respectively. Another zone of localized settlement was identified in section STM21, where the maximum accumulated settlement was –6.1 mm. A zone of local uplift was also identified in the northern part of the structure (sections STM23-STM24), where vertical displacements were positive and ranged from +1.5 to +2.5 mm. This pattern of changes may be associated with a local redistribution of stresses in the structure during reconstruction. Overall, the spatial distribution of deformations confirms that the recorded displacements are predominantly local in nature and are concentrated in the area of active construction work.

The measurement results from the two-axis crack gauges C1–C9 generally confirm the data from the geometric leveling. For most of the monitored cracks, changes in readings did not exceed 0–1 mm, indicating that the structures are stable. The largest horizontal displacements along the X-axis were recorded on crack gauges C5 and C6, where they reached –2…–3 mm by the fourth cycle, while crack gauge C7 showed a vertical displacement along the Y-axis of up to +2 mm. Despite the gradual loss of some crack gauges due to finishing work, the results obtained do not indicate intensive crack propagation but confirm the localized nature of the deformations, as established by leveling data.

Conclusions

Based on the results of six cycles of geodetic monitoring, it was determined that the building's reconstruction is accompanied by localized, rather than general, deformations. High-precision Class II geometric leveling (the misclosure in all cycles did not exceed 1.0 mm) ensured reliable detection of vertical displacements, and biaxial crack gauges confirmed the absence of significant crack development. The largest settlements (up to –6.1 mm) are concentrated in the western part of the building, adjacent to the new foundations, while the rest of the structure remains stable. The study confirms the effectiveness of combining geometric leveling and crack monitoring as a practical tool for monitoring building safety during major reconstruction.

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