GeoTerrace-2025-079

Geodetic monitoring of the Chernobyl NPP shelter: research, analysis and forecast of structural stability

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SUMMARY

The paper presents a detailed analysis of geodetic observations of settlements and deformations of the Shelter Structure at the Chornobyl Nuclear Power Plant (ChNPP). Conducted in July 2024 as part of the second cycle of comprehensive monitoring, the study aimed to obtain precise data on the condition and stability of structures, essential for ensuring safety and enabling the facility's transformation into an environmentally secure system. Special attention was given to measurements of spatial and vertical displacements, which allow assessing structural conditions and potential risks to operational safety. The data were used to analyze the impact of detected changes on structural durability and environmental safety and to forecast further deformation trends. These forecasts support strategies for maintaining stability and minimizing environmental risks. The primary goal was to acquire reliable data on the Shelter's enclosure structures, focusing on deformation and settlement. Such data are crucial for monitoring displacement dynamics, evaluating stability, and predicting potential emergencies. This approach enables not only the prevention of structural failure but also the development of effective stabilization strategies during the Shelter's transformation. The study's results provide a clear assessment of risks associated with structural degradation and form the basis for informed decision-making regarding safe operation. They are essential for maintaining long-term stability, ensuring timely detection of threats, and preventing catastrophic scenarios. Overall, the findings offer critical insights for ensuring both structural integrity and environmental safety, supporting the ongoing transformation of the ChNPP Shelter into a secure and stable facility.

Keywords: Geodetic monitoring, Chernobyl NPP (ChNPP), Structural deformations, Structural stability, Stability risks.

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Introduction

The Shelter Structure (hereinafter referred to as the Shelter), located on the territory of the Chornobyl Nuclear Power Plant, is one of the most complex and risky engineering projects aimed at eliminating the consequences of nuclear disasters.

Given the extreme operating conditions, the Shelter is exposed to numerous negative factors, including environmental conditions, geotechnical loads and permanent structural deformations caused by both material aging and residual processes in the accident area. All these factors pose significant risks to the stability of structures and require regular geodetic monitoring.

Method and Theory

Monitoring of large industrial facilities, including nuclear facilities, is widely described in the engineering and geodetic literature. Standard techniques include geodetic networks, satellite positioning systems, and deformation analysis. According to Ukrainian standards and international recommendations, monitoring must meet strict accuracy criteria to ensure the reliability of the results. Previous studies on the Shelter (Baran, Sushko, & Chornokin, 2006) and the ChNPP New Safe Confinement (NSC) focused on the initial stages of stabilization and subsequent safety assessments. For example, the ChNPP monitoring program for 2018-2023 provides a basis for integrating geodetic methods with predictive models to assess structural risks.

ChNPP is located in the exclusion zone in the north of Kyiv region near the Pripyat River. The facility is located within the 10-kilometer zone of increased radiation hazard, surrounded by forests and water bodies (SSE «Chornobyl NPP», 2022). The geodetic monitoring program covered certain structural elements of the Shelter, including its foundations, the northern cascade wall, and metal reinforcements (MRs).

Results

For geodetic measurements, a Leica DNA03 digital level and invariance coding rails were used. A network of fixed geodetic references, calibrated according to state accuracy standards, served as the basis for all measurements. Spatial coordinates and vertical displacements were determined using methods of the second accuracy class.

The planned geodetic network of the NSC-Shelter complex was created to ensure control of horizontal and vertical deformations of the Shelter, NSC structures, including foundations, and the process building, monolithic reinforced concrete walls of the enclosing contour in the turbine hall along axes 39 and 65, as well as structures of the turbine hall of Unit 4 (axes 36-68, row A, and axis 68 in rows A-B), reinforced concrete frame of the deaerator stack (axes 42-53, rows B-C).

The NBC network includes:

✓ the basic GPS network, which consists of 9 points (GPS-4, GPS-5, GPS-12 new, GPS-22, GPS-10, ZRU, NP-6, Gl.Rp31, Gl.Rp34);

✓ linear-angular triangulation, which includes 16 points (ZRU, NP-6, B41, B42, T.113, T.114, B5, B6, B7, B8, NP-2 new, GPS-4, GPS-5, GPS-12 new, GPS-22, GPS-10, B25, B26, B27, S1, S2, S3, B33, B34).

The coordinates of depth references 31 and 34 were determined using the accuracy of the State Geodetic Network of the 1st class, and other points using the accuracy of the State Geodetic Network of the 2nd class. A catalog of coordinates of the points of the reference geodetic network in the State Geodetic Reference Coordinate System USC-2000 in the 6th standard six-degree and 10th three-degree zones of the Gauss-Kruger projection was compiled with an assessment of the accuracy of each point. A catalog of coordinates of points of the reference geodetic network in the World Geodetic System WGS-84, in the implementation of G1762, was compiled.

The monitoring included the measurement of horizontal and vertical displacements of control points located on the structural elements of the Shelter. To ensure accuracy, measurements were repeated under similar conditions, and discrepancies were eliminated by additional observations (Dvulit, Dvulit, & Sidorov, 2019). Comparative analysis was conducted with the basic data of previous cycles.

The altitude coordinates of the points of the base GPS network and the linear-angular geodetic network of the NSC-Shelter complex were determined by the method of geometric leveling of classes I and II. For this purpose, a digital level Leica DNA 03 was used with the use of invariant code rails. The distances for the leveling stations were measured using a steel tape measure, with the transition points fixed with metal dowels. After marking, all transition points and device installation locations were marked with paint. A schematic representation of the leveling network is shown in Figures 1 and 2.

The leveling was performed both in the forward and reverse directions: with two positions of the tool horizon for class I and one position for class II (Chen et al., 2021). The length of the sighting beam from the level to the rail did not exceed 25 m for class I leveling and 30 m for class II, and the difference between these distances did not exceed 0.25 m.

The 2024 cycle revealed the ongoing deformation of the structural elements of the Shelter. The main results of the observations are the following:

✓ Northern cascade wall (Figure 3): horizontal displacements ranged from 6.0 to 14.6 mm, and vertical displacements - up to 2.3 mm.

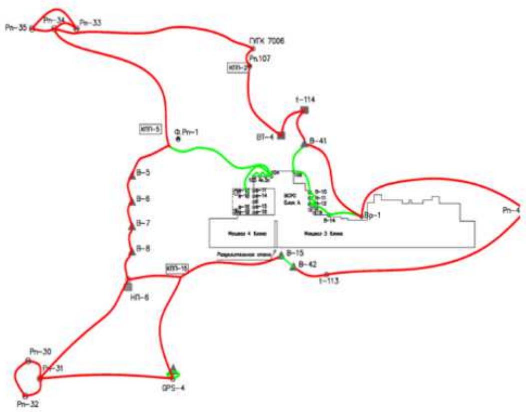

Figure.1. Scheme of class I leveling passages on the territory of the ChNPP for leveling class II sedimentary marks

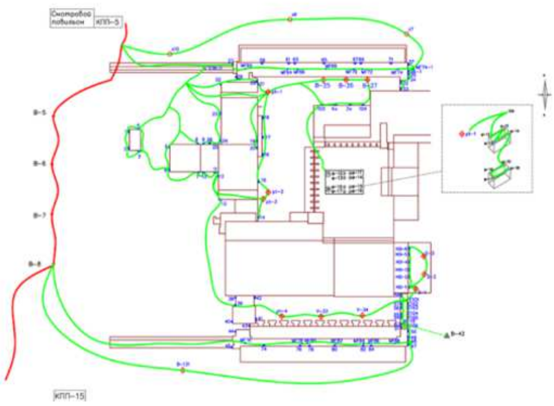

Figure. 2. Class II leveling scheme for sedimentary marks

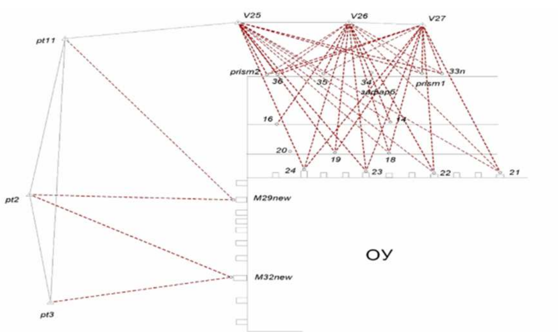

Figure. 3. Scheme for determining the coordinates of control marks of the northern cascade wall

These indicators indicate a stable, although slowed-down, process of structural settlement. Comparing to the previous cycle, the average horizontal displacement increased by 2-3 mm, indicating a gradual accumulation of stress in the foundation (Smoliy, 2015).

The main indicators are shown in Table 1:
- mark M-21: horizontal displacements are 14.6 mm and vertical displacements are 2.3 mm. These are the maximum recorded values for this mark;
- mark M-15: horizontal displacements vary within 10.2 mm, vertical displacements - up to 1.8 mm. The displacements show a stable trend since the previous observations in 2023;
- mark M-10: the smallest horizontal displacements are within 6.0 mm, and vertical displacements are 1.2 mm. These indicators indicate local stability in this area of the structure.

Table 1. *List of spatial movements of control marks of the northern cascade and buttress wall of the Shelter*

№. mark	*Cycle №2 (07.2024) - №1 (03.2023)*						*Cycle №2 (07.2024)- №2 (07.2023)*						*№2 (07.2024) - Monitoring start№1 (08.2018)*					
	Δ X, mm	*Δ Y, mm*	*Δ H, mm*	*r, mm*	*l, mm*	*α°*	*Δ X, mm*	*Δ Y, mm*	*Δ H, mm*	*r, mm*	*l, mm*	*α°*	*Δ X, mm*	*Δ Y, mm*	*Δ H, mm*	*r, mm*	*l, mm*	*α°*
M-21	6.0	7.3	2.3	9.7	9.4	51	11.9	-7.2	-8.1	16.1	13.9	329	17.2	5.5	-37.8	41.9	18.1	18
M-22	8.3	7.1	-2.4	11.2	10.9	41	11.0	-2.4	-5.2	12.4	11.3	348	24.3	3.9	-38.1	45.4	24.6	9
M-23	14.6	7.7	1.9	16.6	16.5	28	8.0	0.8	-7.4	10.9	8.0	6	19.3	-1.7	-44.2	48.3	19.4	355
M-18	-1.3	11.8	1.9	12.0	11.9	96	4.8	4.9	-5.8	9.0	6.9	46	20.1	8.9	-45.8	50.8	22.0	24
M-19	13.3	11.8	-3.8	18.2	17.8	42	7.6	1.5	-10.8	13.3	7.7	11	25.4	1.2	-50.9	56.9	25.4	3
M-14	-26.5	2.0	24.6	36.2	26.6	176	15.7	-3.1	-8.0	17.9	16.0	349	18.5	-2.8	-41.9	45.9	18.7	351
M-33n*1	-4.7	2.4	5.2	7.4	5.3	153	-8.0	-3.9	-7.6	11.7	8.9	206	6.6	-1.6	-25.0	25.9	6.8	346
M-35	9.0	8.3	2.8	12.6	12.2	43	2.0	5.0	-5.5	7.7	5.4	68	14.2	4.6	-46.8	49.1	14.9	18
M-36	-3.2	7.5	7.1	10.8	8.2	113	0.0	13.2	-9.2	16.1	13.2	0	14.5	6.6	-46.8	49.4	15.9	24
M-29 new	-7.5	4.3	4.2	9.6	8.6	150	0.0	2.1	1.8	2.8	2.1	0	-13.7	9.6	1.2	16.8	16.7	145

✓ Metal reinforcements (MRs): annual displacements remained within the permissible values, but localized points of increased settlement were detected. In particular, the maximum displacement reached 5.3 mm in the area of peripheral fasteners, which may indicate uneven load distribution.

Comparison with the 2023 data indicates a gradual stabilization of the central part of the structures, but the peripheral zones show greater displacement dynamics. For example, the control marks of the northern cascade wall showed a total displacement of up to 18 mm since the start of observations in 2018, with most of this displacement occurring during periods of significant temperature changes. All this points to a gradual increase in displacements in the range of 1.5-2.0 mm for most grades. In particular, the areas near the mark M-21 show accelerated horizontal displacement, which may be caused by uneven loads on the foundation.

The main factors of deformation are:
1. Soil heterogeneity: areas with low bearing capacity under the foundations cause localized dips, which lead to uneven settlement;
2. Moisture and flooding: high soil moisture, especially after heavy rains, contributes to a decrease in soil stability;
3. Seasonal temperature fluctuations: sudden changes in temperature lead to stresses in structural materials, which accelerate the processes of shear and tension.

Based on the data obtained, the following trends are expected:
1. Taking into account the completion of the first phases of soil stabilization, deformation processes are expected to slow down;
2. Weaknesses in peripheral elements can become points of stress concentration that require additional reinforcement;
3. Expected droughts or increased rains may temporarily aggravate the situation, especially in unprotected areas of the foundation;
4. Horizontal displacements will remain active in the areas of highest stress, in particular near the M-21 mark;
5. Vertical settlements can be stabilized by implementing soil compaction measures;
6. Peripheral areas of the structure will remain at high risk due to uneven load distribution.

The following measures are proposed to minimize the impact of deformations and ensure the long-term stability of the facility:

1. Reinforcement of foundations: use of modern materials to reinforce soils in high-risk areas (near the mark M-21);
2. Modernization of drainage systems: ensuring effective drainage to avoid flooding;
3. Application of remote monitoring (Mohylnyi et al., 2023): the use of laser scanners and drones for detailed tracking of changes in real time.

Conclusions

The results obtained indicate a satisfactory condition of the Shelter structures, but they also indicate the need for constant monitoring to prevent possible risks. An integrated approach to geodetic observations makes it possible to:

1. Predict deformation processes: based on the data obtained, it is possible to predict the development of displacements and settlements of structures, which contributes to the preliminary planning of repair or stabilization measures;
2. Develop effective stabilization strategies: monitoring results allows identifying weaknesses and focusing on strengthening them, minimizing the risk of destruction;
3. Ensure environmental and industrial safety: controlling structural settlements prevents potential emergencies that could have a negative impact on the environment.

In the future, the research results will serve as a basis for developing new approaches to monitoring complex facilities such as the Shelter. This will also help to improve the reliability of structures and maintain safety in the process of their further operation and transformation into environmentally safe systems.

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