Application of automated monitoring using hydrostatic leveling sensors in the Moscow metro

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Abstract. The article discusses the experience of using a domestically manufactured «Monitron» automated hydrostatic leveling system for monitoring nearby structures during the construction of the Moscow Metro. Based on the real-time settlement measurements, the tunneling parameters and protective measures for existing buildings were optimized.

Keywords: Automated monitoring, hydrostatic leveling, digital twin.

1 Introduction

The main purpose of geotechnical monitoring [1] is to ensure the safety and safe operation of existing structures when they are affected by external factors, such as new construction. The most common method is the geodetic method.[2] It can be manual or automated:
Disadvantages of the manual method:
- human factor;
- Minimum number of measurement cycles
Disadvantages of the automated method:
- high cost of the total station
- Inaccessible in densely built-up and inaccessible areas.
The analogue of geodetic methods is the Method of hydrostatic levelling.

2 Hydrostatic levelling sensors

Automated hydrostatic leveling [3] is a technology for measuring [4] quasi-static settlements, which is used for geotechnical monitoring of buildings and structures of various types. [5-6] «Monitron» hydrostatic leveling system (Figure 1) includes a system of interconnected vessels with liquid level sensors installed on them. [7-9]

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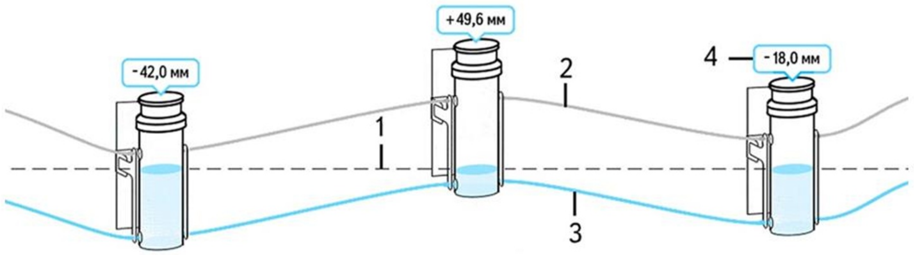

Fig. 1. The principle of operation of the hydrostatic leveling system:01) the level of the working fluid in the hydraulic system, 2) airwayline hose, 3) hydraulic line hose, 4) change in the high-altitude position of the measuring vessel from the baseline.

The advantages of this system over optical levels and tacheometers (manual and automated) are the following:
− cyclical measurements (data are obtained from sensors once in a minute);
− independence of measurement results on weather conditions and human factors;
− absence of the direct line of sight between sensors;
− fixed measurement accuracy of 0.1 mm, regardless of the distance between the sensors and their number (Figure 2).

A data-collecting computer and an internet portal https://»Monitron».xyz provide access to observation data. A feature of «Monitron» system is the use of innovative optical-electronic liquid level sensors. The system has the ability to self-diagnose for damage during operation. The Internet service allows us to configure the automatic generation and distribution of reports to authorized persons, informing via SMS notifications about reaching the threshold deformations.
The system software allows the integration of information from virtually any measurement tool, supplementing the readings of the OSG with data from other types of monitoring, such as:
- Geodetic monitoring;
- Groundwater level monitoring using piezometers;
- Vibration measurements [10];
- Video monitoring of facilities.

Monitoring method	Human factor	Measurement frequency	Data processing and output speed	Measurement accuracy	Monitoring of structures inside the building	Cost of monitoring	Influence of weather conditions on measurement accuracy
Manual geodetic measurements	Yes	Low	Low	Medium	Yes	Medium	Medium
Automated geodetic measurements	No	High	High	Medium	No	High	Medium
Automated hydrostatic levelling	No	High	High	High	Yes	Low	Low

Fig. 2. Comparison of monitoring methods

Tunnel advance rate is about 250 m per month or 8.3 m per day. At the same time, constant observation of the deformations of the monitored objects allows us to promptly change the tunneling parameters, ensuring the safety of existing structures.[11].

3 Objects

Consider a number of objects where this system has been applied «Monitron» hydrostatic leveling system was used in the tunneling under an already operating section of the Moscow metro (Figure 3).
The length of the collector tunnel in the metro technical zone is 50 m. The actual rate of tunneling was 5.6 m/day. The clear distance from the lining of the collector under construction to the metro structures is 6.0 m Application of «Monitron» hydrostatic leveling system Taking into account that the actual deformations during tunneling may differ from the design ones, it is advisable to have a digital twin of the structures, which is a sufficiently detailed FEM model of the designed structure, soil and existing structures. Due to the calculation of the digital twin, taking into account the data of hydrostatic levels, it becomes possible to estimate the actual safety factor and predict further changes in the stress-strain state of both structures and soil.[12]
The effect of controlled compensation [13] grouting was monitored according to the readings of
automated hydrostatic levels. Grouting was stopped while the settlement of the sensor, which previously had a maximum value of 12.4 mm, was compensated to 2.6 mm. The subsequent process of stress relaxation, shrinkage and fluid loss of the grouting compound led to the stabilization of the settlement within 8 days.

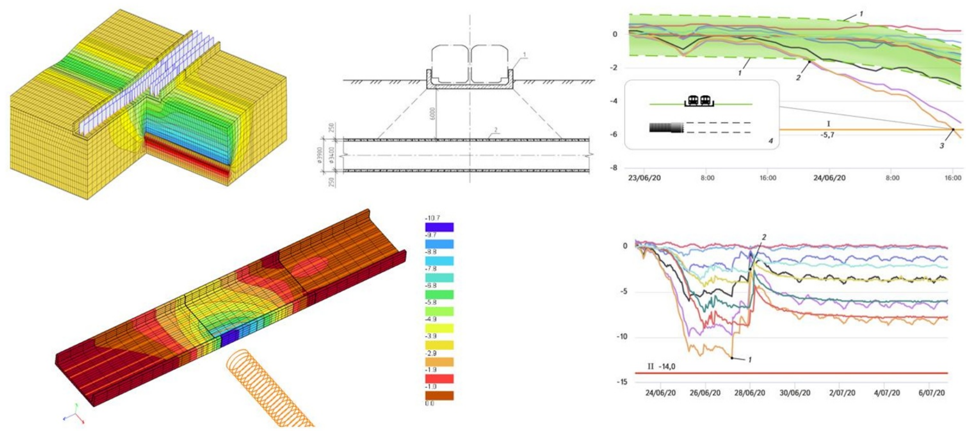

Fig. 3. Results of automated monitoring of the open section of the metro

The «Monitron» system was used in the construction of a large building near an underground station. (Figure 4) The geodetic method is only applicable at night when there is no traffic.[14] This is why the hydrostatic levelling system was able to detect, practically in real time, a sudden change in the height of the underground station. Construction was halted, construction was corrected and then the building resumed again, avoiding an emergency situation. In comparison to the geodetic measurements, which were taken once a day, there was a high degree of convergence with the «Monitron» system.

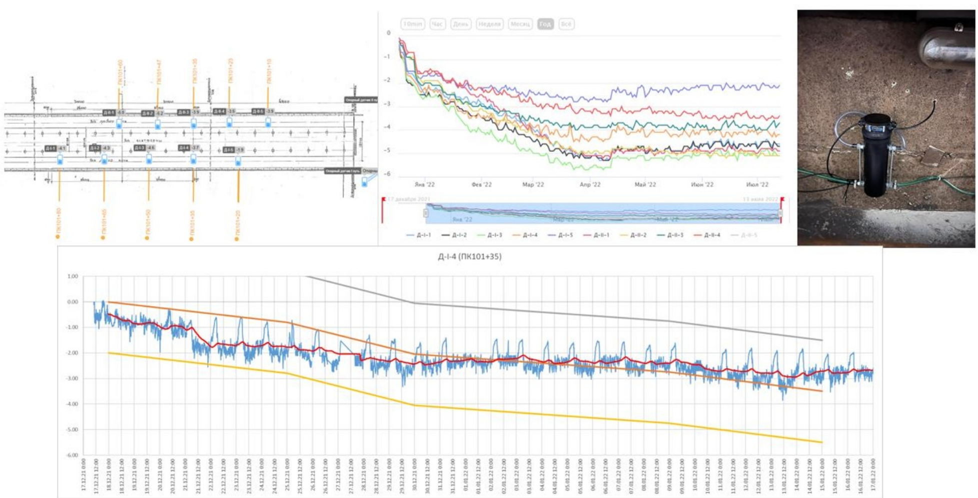

Fig. 4. Results of automated monitoring of the metro station

The construction of the two underground tunnels was carried out under the hydrostatic sluice to monitor the deformations of the sluice caused by tunneling (Figure 5), a «Monitron» hydrostatic levelling system and an automated total station with reflective prisms in the same locations as the hydrostatic levelling sensors were used simultaneously. The results of measurements by the automated [15-17] total station was received once every 6 hours, while the hydrostatic levelling sensor readings were received once every 4 minutes. The trenching was carried out in winter and the presence of precipitation prevented uninterrupted operation of the total station. Weather conditions had no effect on

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the performance of the «Monitron» system. The maximum discrepancy between the two measuring methods was 0.3 mm with an absolute value of the measured deformations not exceeding 2.5 mm.

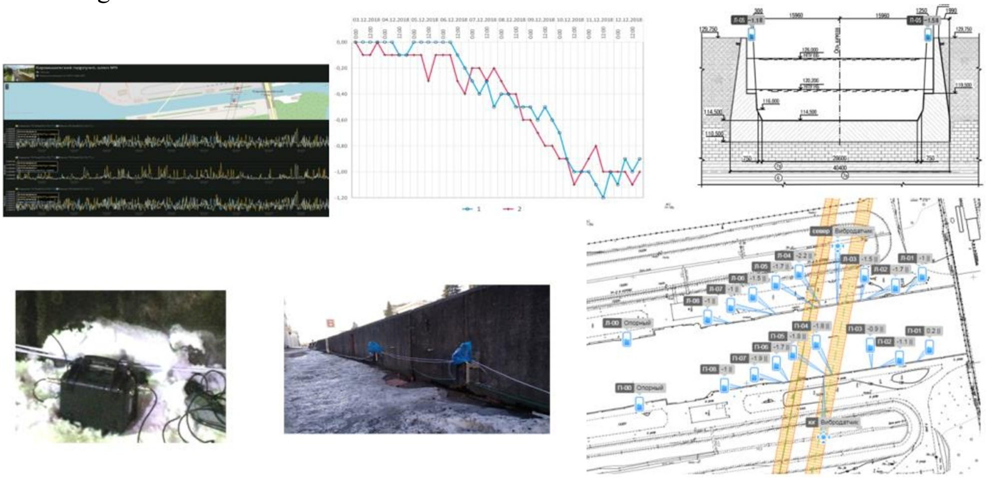

Fig. 5. Results of automated monitoring of hydraulic structures during metro construction

4 Conclusions

Real, proven in practice, preconditions have been created for integrated geotechnical monitoring on
the basis of «Monitron» modern automated hydrostatic levels together with software. This provides constant monitoring and control over the change in the stress-strain state of
buildings and structures under construction or operation during the development of underground space. [18-20]
When analyzing geotechnical monitoring data, it is necessary to compare the measurement results not with their calculated maximum value, but with the calculated values of deformation for each point of observation, taking into account the current stage of construction. [21-22] This allows the combined use of «Monitron» automated hydrostatic levels and the digital twin of the monitoring object.

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