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GEOTECHNICAL MONITORING OF THE IM-7 EXPRESSWAY, POŽAREVAC – VELIKO GRADIŠTE - GOLUBAC

Abstract:

Geotechnical monitoring represents a key component in preserving the stability and safety of structures and the route of an expressway, especially in complex terrain conditions such as peatlands and saturated soils. This paper analyzes an integrated monitoring system along such a route, which includes tracking settlements, pore pressures, and horizontal displacements in embankments, as well as deformations of retaining walls, bridges, and overpasses. The applied methods include piezometers, magnetic extensometers, settlement gauges, inclinometers and tiltmeters. Particular attention is given to system automation, real-time data acquisition, and alarm activation in the event of deviations from the design values.

Keywords: geotechnical monitoring, piezometers, settlement, inclinometers, “real-time” system.

ГЕОТЕХНИЧКИ МОНИТОРИНГ БРЗЕ САОБРАЋАЈНИЦЕ IM-7, ПОЖАРЕВАЦ – ВЕЛИКО ГРАДИШТЕ - ГОЛУБАЦ

Сажетак:

Геотехнички мониторинг представља кључну компоненту очувања стабилности и сигурности пратећих објеката и трасе брзе саобраћајнице, посебно у условима сложених терена као што су тресетишта и засићена тла. Овај рад анализира интегрисани систем мониторинга дуж једне такве трасе, који обухвата праћење слегања, порних притисака и хоризонталних померања код насипа, као и деформације потпорних зидова, мостова и надвожњака. Коришћене методе укључују пијезометре, магнетне екстензометре, слегомере, инклинометре и тилтметре. Посебна пажња посвећена је аутоматизацији система, „real-time“ аквизицији података и алармирању у случају одступања од пројектованих вредности.

Кључне ријечи:геотехнички мониторинг,пијезометар,слегање, инклинометар,“real-time”систем.

1. INTRODUCTION

Expressways represent a key component of modern road infrastructure and significantly contribute to regional connectivity, acceleration of transport, and regional economic development. However, their construction and long-term operation are often associated with significant geotechnical challenges, especially when the alignment passes through geologically unstable and heterogeneous terrains such as peatlands, deposits of poorly compacted clays, or areas with pronounced groundwater conditions, which was also the case for this high-speed road due to its proximity to the Danube River.

Settlement of the soil, horizontal movements of slopes, pore water pressures, and structural deformations can have a serious impact on the stability and safety of the alignment and associated structures, including in particular embankments, retaining walls, bridges, and overpasses [1]. Therefore, during the design and construction of such facilities, it is necessary to implement systematic geotechnical monitoring, both during construction and throughout the service life, which enables timely detection of deviations in the behavior of structures relative to the design values [2], [3].

Geotechnical monitoring includes the installation of various types of sensors and instruments used to monitor the behavior and deformation of soil and structures during construction and throughout the service life [4]. The data obtained from measurements enable validation of design solutions, the making of technically and economically justified decisions regarding subsequent construction phases, as well as the implementation of remedial measures in the event of deviations from permissible limits, and the improvement of regular and emergency maintenance plans.

This paper presents the most significant aspects of geotechnical monitoring along the route of the expressway IM7, motorway E-75 Niš–Belgrade (Požarevac interchange) – Požarevac bypass – Veliko Gradište – Golubac, with special emphasis on:

- monitoring of embankments and subsoil (piezometers, extensometers, settlement gauges, inclinometers),
- monitoring of retaining walls and bridges (in-place inclinometers, digital tiltmeters),
- as well as an automated system for data acquisition, processing, and alarming based on the obtained data.

The aim of this paper is to demonstrate how properly designed and implemented monitoring can contribute to safer, more durable, and more efficient operation of transport infrastructure.

1.1. ADVANTAGES AND CHALLENGES

The advantages of monitoring are numerous – it increases safety, reduces uncertainty, and enables better cost control. Challenges arise in the form of installation and maintenance costs, the need for specialized personnel, and potential delays in construction works while awaiting ground stabilization.

The collected data are compared with the threshold values defined in the design documentation. In the event of exceedance, engineers implement appropriate measures, which may include changes in construction technology, modification of materials, additional ground reinforcement, or temporary suspension of works until stability is achieved.

The implementation of monitoring systems has become a standard practice in modern construction, as it significantly enhances the reliability and long-term safety of infrastructure facilities, while also contributing to more rational project management, cost optimization, and the protection of human lives [5].

2. GENERAL OVERVIEW OF GEOTECHNICAL MONITORING OF EMBANKMENTS AND ASSOCIATED STRUCTURES ON ROADWAYS

Geotechnical monitoring represents a set of activities aimed at measuring, analyzing, and interpreting the behavior of soil, embankments, and structures under real conditions during the construction and operation of transport infrastructure. In modern infrastructure projects, particularly on expressways that traverse geotechnically complex terrains, monitoring is used as a tool for verifying design solutions, risk control, and the timely decision-making regarding potential corrective and maintenance measures.

Within the road alignment, the key elements subject to geotechnical monitoring include:

- Embankments and subsoils;
- Bridges, overpasses and culverts;
- Retaining structures;
- Slopes and cut slopes

Geotechnical monitoring can be classified as:

- **Passive monitoring**, which relies on periodic measurements of selected parameters using standard instruments,
- **Active monitoring**, which involves continuous observation and automatic real-time data transmission [6], [7].

The most commonly used methods include the application of the following equipment:

- **Piezometers** – for measuring pore water pressures and groundwater levels,
- **Inclinometers** – for monitoring horizontal displacements at depth,
- **Settlement gauges** – for measuring vertical deformations of embankments and subsoil,
- **Extensometers** – for measuring deformations within soil layers and structural elements [8].

Geotechnical risks, such as settlements, landslides, the occurrence of pore pressures, changes in groundwater regime, or lateral displacements, can significantly affect the safety and functionality of road infrastructure [9]. Inadequate monitoring and neglect of geotechnical signals may lead to severe damage, construction delays, and even total structural failure.

Monitoring has several key roles:

- Verification of design solutions (e.g., settlement magnitude compared to the calculated value),
- Warning of early signs of instability (e.g., horizontal displacements in slopes),
- Optimization of construction works (e.g., determining the appropriate time to resume works after consolidation),
- Real-time decision-making based on accurate and reliable data,
- Documentation of ground behavior as a basis for future projects and database development [10], [11].

2.1. EMBANKMENT MONITORING

Road embankments, particularly those constructed on weak subgrades (e.g., alluvial sediments, peat, clayey layers), are prone to settlements and instabilities. Geotechnical monitoring of embankments includes:

- Settlement plates – horizontal plates installed in different layers of the embankment and subsoil to measure vertical displacements,
- Vacuum tubes or leveling points – for monitoring overall settlement,
- Piezometers – for measuring pore pressures and monitoring the drainage behavior of soil during consolidation,
- Extensometers – for detecting local deformations in layer contact zones,
- Inclinometers – for tracking potential slip surfaces [12].

The role of monitoring is crucial for determining the appropriate time to apply additional loads on the embankment (e.g., installation of the final pavement layer) without risking destabilization, or for implementing preventive corrective measures to avoid failure [13].

2.2. MONITORING OF BRIDGES AND RETAINING STRUCTURES

Bridges, overpasses, culverts, and retaining walls must be carefully monitored in foundation zones, as soil deformations can directly affect their stability. The following parameters are most commonly monitored:

- Vertical and horizontal displacements of abutments and piers,
- Changes in groundwater level that may induce additional forces or foundation flooding,
- Micro-displacements in piles (in weak ground conditions),
- Forces in anchors and prestressed elements, in the case of retaining walls [14].

The use of fibre-optic sensors, vibrating wire gauges, and automated total stations enables continuous, high-precision monitoring of structures [14].

2.3. MONITORING OF SLOPES AND CUTS

Slopes, both artificial (cut slopes) and natural, require special attention, as they are often in equilibrium under their own weight. Adverse factors such as rainfall, seismic activity, or traffic loading can destabilize the ground. Slope monitoring includes:

- Inclinometer boreholes – for monitoring deep-seated ground movements,
- GPR (Ground Penetrating Radar) and radar interferometry (InSAR) – for detecting surface displacements over large areas,
- Surface markers and reflective prisms – monitored using total stations [15].

The detection of initial movements (often in millimeters or fractions of a millimeters) enables timely slope stabilization before the occurrence of landslides [16].

2.4. METHODOLOGY AND ORGANIZATION OF THE MONITORING SYSTEM

An effective geotechnical monitoring system involves:

- Defining key measurement points – in zones where changes are expected,
- Selection of appropriate instruments and methods – in accordance with geological conditions and the type of structure,
- Automation of measurements – where feasible, including the use of GSM/GPRS systems for data transmission,
- Installation of alarm systems – to notify responsible persons in the event of threshold exceedance,
- Data analysis and interpretation – using software for processing measurement series (e.g., GeoStudio, PLAXIS Monopile, Vista Data Vision),
- Preparation of reports and documentation – for evaluation of structural behaviour in relation to design assumptions [17].

2.5. LEGAL FRAMEWORK AND STANDARDS

Within the European Union and many other countries, monitoring forms an integral part of legal and design requirements. In Serbia, geotechnical monitoring is regulated by the Rulebook on Technical Standards for the Design and Construction of Civil Engineering Structures (SRPS EN ISO 18674), which is applied in accordance with EN ISO 18674 – Geotechnical investigation and testing – Monitoring, as well as Eurocode 7 – Geotechnical Design and the ITA Guidelines for tunnels and underground structures [18, 19, 20].

3. EXPRESSWAY POŽAREVAC – VELIKO GRADIŠTE – GOLUBAC: ROUTE CHARACTERISTICS AND GEOTECHNICAL CHALLENGES

The expressway Požarevac – Veliko Gradište – Golubac represents an important infrastructure project, whose objective is to improve traffic connectivity of eastern Serbia with the rest of the country (connection to the E-75 motorway), as well as to stimulate the development of tourism and the economy along the right bank of the Danube [21].

The route of the expressway passes through complex geotechnical conditions that require careful design and continuous monitoring in order to preserve stability and safety, with sections characterized by challenging terrain conditions identified, including:

- presence of peat and weak-bearing soil layers,
- elevated groundwater levels,
- the need for construction of high embankments and retaining structures,
- unstable slopes potentially prone to landslides and horizontal deformations [21].

Due to such conditions, the route was divided into several critical zones, mainly within Subsection 2, which require the implementation of geotechnical monitoring during all phases of realization, from earthworks execution to the operational period [21].

In the most vulnerable sections, especially in peatland areas and in the vicinity of structures such as bridges, retaining walls, and high embankments, a comprehensive monitoring system was designed. This system includes instruments for measuring:

- vertical settlements of soil and embankments,
- pore water pressures in groundwater,
- horizontal displacements of the ground and structures,
- tilting of bridges head beams and retaining wall capping beams [21].

3.1. PEATLAND AND WEAK-BEARING LAYERS

Sections with the presence of peatlands and poorly compacted clays require special measures due to the high risk of large settlements and uneven soil behavior. Consolidation of these layers is slow, which prolongs the stabilization time of embankments.

3.2. ELEVATED GROUNDWATER LEVEL

Due to the proximity of the Danube, increased groundwater saturation is present in certain areas, which may cause excess pore water pressures and a reduction in effective soil strength, endangering the stability of slopes and foundations [21].

3.3. HIGH EMBANKMENTS AND SLOPES

The construction of high embankments under unfavorable conditions leads to increased risks of lateral displacements and landslides, especially at transitions between different soil types. Retaining walls and slopes require additional reinforcement and precise monitoring [22].

3.4. DYNAMIC INFLUENCES

Traffic and seismic activities can further affect the stability of structures, especially bridges and overpasses, where it is necessary to monitor deformations and inclinations in order to respond in a timely manner to potential hazards [21], [23].

3.5. LOGISTICAL CHALLENGES AND IMPLEMENTATION OF MONITORING

The installation of instruments in areas with difficult access, system maintenance, and ensuring continuous data transmission represent additional challenges. In this regard, the selection of automated and wireless systems with solar power supply has proven to be an effective solution.

Geotechnical instrumentation, combined with automated systems for data acquisition and analysis, enables engineers and supervisory teams to monitor the behavior of structures in real time and to respond in a timely and appropriate manner in the event of deviations from the designed threshold values [21].

4. GEOTECHNICAL MONITORING OF EMBANKMENTS AND SOIL

The construction of embankments along the route of the Požarevac – Veliko Gradište – Golubac expressway is carried out through zones with unfavorable geotechnical conditions, particularly along the Požarevac – Veliko Gradište section, including peatlands, weak-bearing layers, and a high groundwater level, which poses a high risk of differential settlements, lateral displacements, and slower soil consolidation [21].

In order to ensure the stability of the embankments and associated structures, a complex geotechnical monitoring system was implemented, encompassing multiple types of instruments and methods.

4.1. PIEZOMETERS

Piezometers are used for measuring pore (interstitial) water pressures in saturated soil strata. They are installed at the base of the embankment at 100-m intervals along the alignment, with the objective of monitoring the variation of excess pore water pressures during both the construction and operation [21].

The following types were implemented:

- Open standpipe piezometers with manual readings – requiring daily monitoring during the embankment construction phase.
- Automated piezometers – equipped with “diver” sensors or vibrating wire systems, enabling measurements at predefined time intervals and digital data storage [21].

Upon completion of embankment construction, continued monitoring of piezometers is required until the complete dissipation of excess pore water pressures, i.e. the end of the consolidation process. The monitoring frequency after construction may be reduced, however, it should not be less frequent than once per week. All piezometers, regardless of type, must be adequately protected to ensure their functionality throughout construction activities.

4.2. MAGNETIC EXTENSOMETERS

Magnetic extensometers are used for monitoring vertical settlements at different depths, both within the embankment and in the subsoil [21], [24].

The system consists of:

- a corrugated flexible plastic pipe,
- magnetic rings installed at different depths,
- a protective cap,
- a manual reading device capable of detecting the displacement of the rings relative to their initial positions.

Extensometers are installed prior to the start of embankment construction and monitored throughout the construction phase, with regular readings performed on a weekly basis. This method enables the analysis of stratified settlement, which is essential for understanding the behavior of the foundation soil and the embankment itself [21], [24].

Figures 1, 2 and 3 show the main components of a magnetic extensometer.

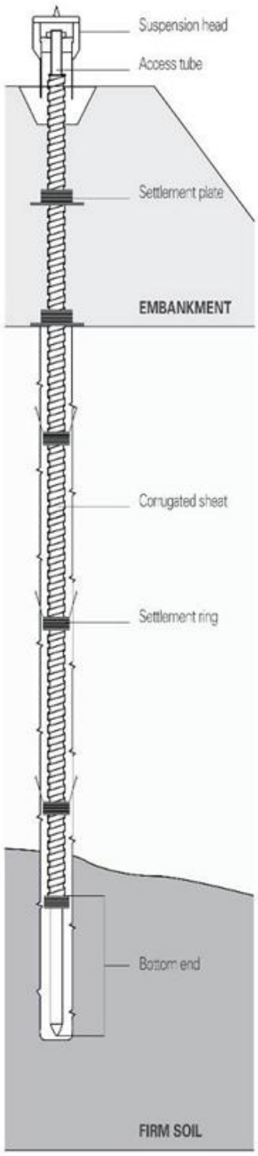

Figure 1. System installation [21].

Figure 2. Corrugated pipe, lead column and "spider" spacer [21].

Figure 3. Data reading device [21].

Figure 4 shows in detail the installation procedure within the first layer of the embankment, while Figure 5 illustrates the installation in the final embankment layer.

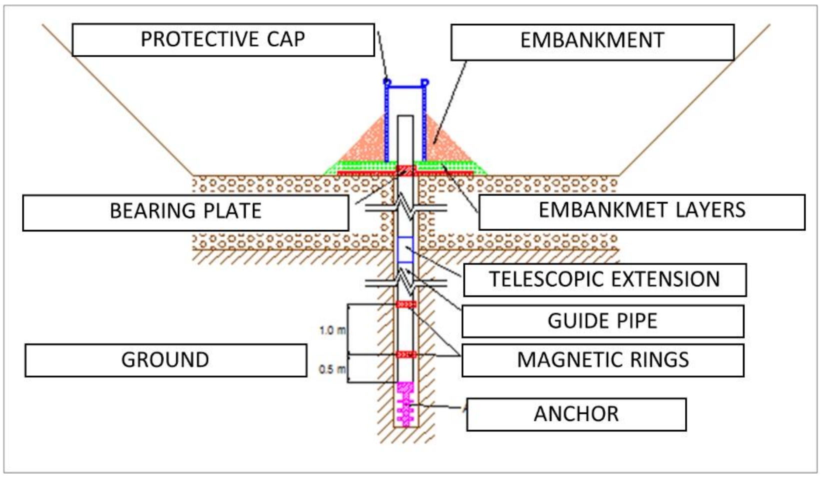

Figure 4. Installation of an extensometer in the first embankment layer [21].

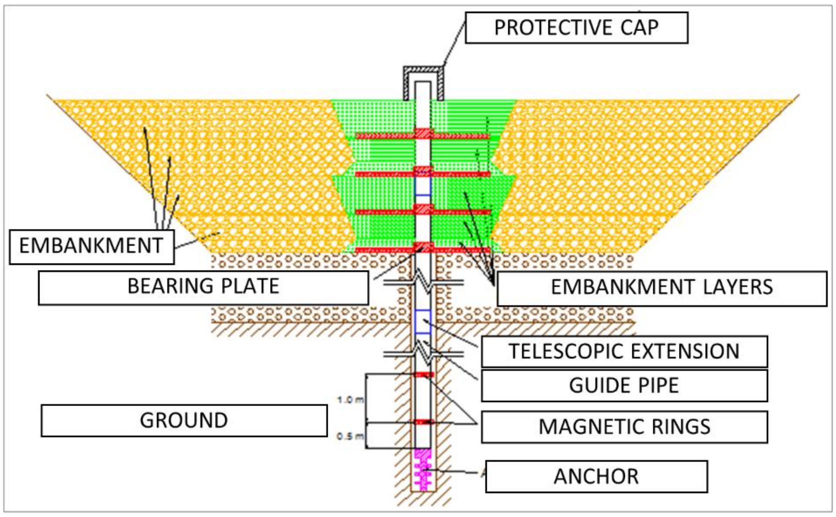

Figure 5. Installation of an extensometer in the final embankment layer [21].

4.3. SETTLEMENT PLATES

In sections of the alignment where higher design settlements are expected, or where material replacement has been performed, it is necessary to monitor settlements over time, i.e., settlement monitoring. Settlement plates are used to measure the total vertical settlement of the embankment [21], [25].

They consist of a telescopic metal rod with extensions, attached to a bearing plate (settlement plate), which is installed at the base of the embankment or on the subsoil prior to embankment construction [21], [25]. Settlement plates are positioned along the embankment axis, where the largest settlements are expected. The settlement plate must be clearly marked and protected against damage.

Figure 6 shows the installation of the settlement measurement rod. Figure 7 depicts a settlement plate, while Figure 8 presents an example of a settlement diagram during embankment construction.

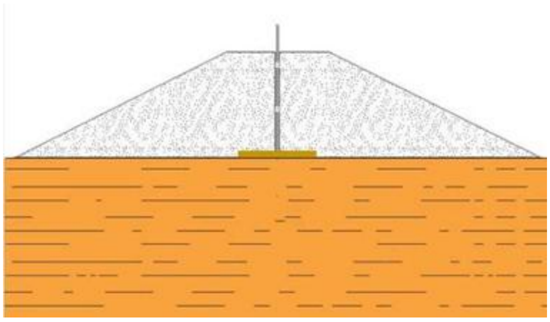

Figure 6. Layout of settlement measurement pipes installed within embankment cross-sections [21].

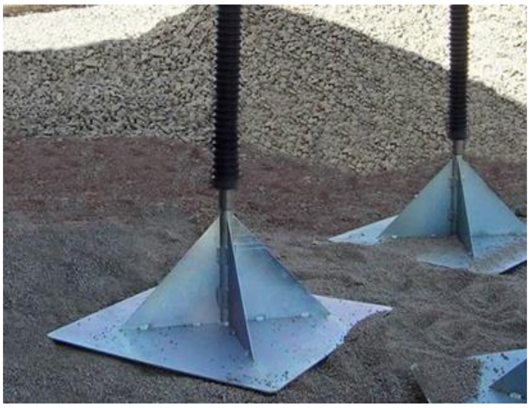

Figure 7. Typical configuration of a settlement gauge [21].

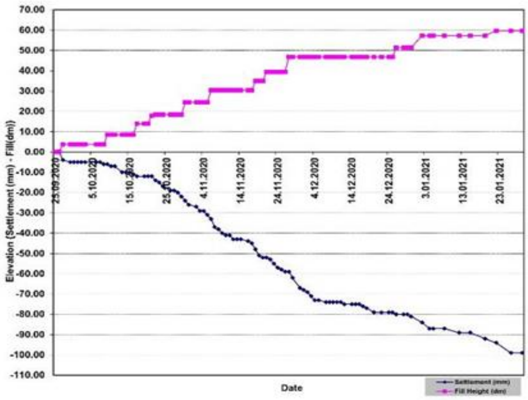

Figure 8. Example of a settlement diagram during embankment construction [21].

After installation, a geodetic survey should be carried out. Subsequently, the embankment is constructed in layers, fully in accordance with the project. As the embankment height increases, sections of the telescopic extensions are added up to the design elevation (embankment crest). Geodetic measurements of the settlement plates and embankment contours are performed daily during construction, while after the completion of embankment, measurements are conducted once a week. The results are compared with the design values. It is also recommended to install four additional geodetic control points in the cross-sections, allowing precise analysis of embankment settlement in space. The geodetic control points should be anchored in the embankment body with concrete to prevent displacement. Additionally, they should be clearly marked and protected against damage [21].

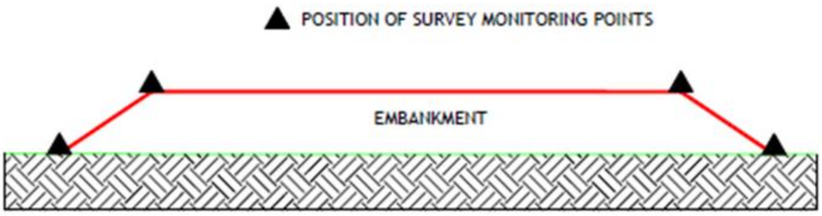

Figure 9. Location of settlement monitoring points in the embankment cross section [21].

In addition to the calculated values of the predicted consolidation settlement, another criterion should be introduced, based on which it can be considered that 90% of the consolidation settlement has occurred. This criterion is that, over a one-month observation period of the settlement monitoring benchmarks, the recorded settlement is less than 0.5 cm [21]. Once this condition is met, construction of the pavement structure can proceed. Based on the results, the designer will determine when the settlement process is complete, after which the pavement construction can commence.

4.4. INCLINOMETERS

For the purpose of detecting lateral (horizontal) displacements, particularly on embankment slopes and in the subsoil, inclinometers are installed. In high-risk sections, inclinometers are placed:

- at the embankment toe –at the beginning of construction, to monitor possible lateral extrusion during embankment construction
- at the embankment crest – after completion of embankment construction [21].

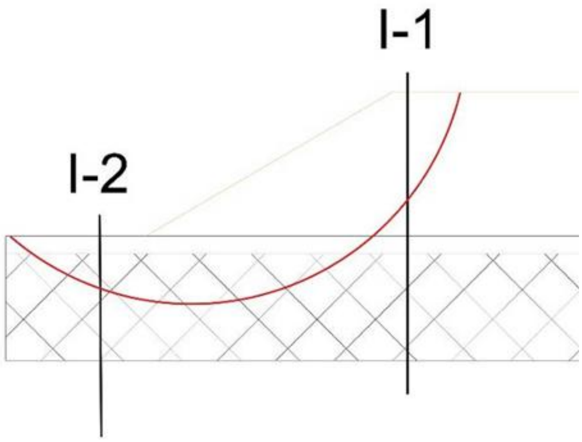

Figure 10. Location of inclinometers at the embankment toe and crest [21].

The base of the inclinometer should be installed in a layer of silty-sandy gravel (at a depth of approximately 15 m). Measurements are carried out every 5 days, and depending on the results, the frequency may be increased. Automated systems enable real-time data acquisition, storage, and alerting in case the design threshold values are exceeded [21].

For the purpose of monitoring horizontal ground displacements, inclinometers should be installed in the slope zones at km 37+825 – 38+225 and km 43+625 – 43+725 (Subsection 2, Požarevac – Veliko Gradište section). The design should define the expected and alarm displacement values separately for each structure.

5. STRUCTURAL MONITORING – RETAINING WALLS AND BRIDGES

Along the route in complex geotechnical conditions, the monitoring of associated structures such as retaining walls and bridges represents a key component in ensuring the stability and long-term performance of the roadway. Along the Požarevac–Veliko Gradište–Golubac expressway, in zones of extensive excavations and steep slopes, an integrated monitoring system was designed to include the observation of horizontal structural displacements and deformations of capping beams [21].

During construction, it is necessary to install geotechnical monitoring equipment in order to verify the effectiveness and stability of the designed structures. The locations of measurement points should be selected so as not to interfere with the continuous construction process. In addition to displacement measurements obtained from inclinometers, a system of monitoring points must be established on the constructed retaining structures, with displacements measured using geodetic methods.

The monitoring system is designed to enable a realistic assessment of displacements within the structure as well as in the terrain above the structure itself, and it should be implemented both during construction and after completion, throughout the operational phase.

5.1. TYPES OF MONITORING

The monitoring of deformations and displacements of structural elements, as well as of the entire slope, aims to compare the actual behavior with the designed values of individual parameters in real time, while also providing timely warning in the event of structural safety risks.

The following types of monitoring are planned:

- monitoring of horizontal ground displacements;
- monitoring of deformations of the newly designed retaining structure.

Monitoring should be carried out using an automated system that enables real-time data acquisition, storage, processing, and alarm triggering. The entire system consists of a series of sensors and a central unit powered by solar energy, enabling continuous operation and incorporating a modem for data transmission.

The installation of the following instruments is planned:

- automatic in-place inclinometers on the slopes above the structure;
- automatic in-place inclinometers within the structural piles;
- automatic digital tiltmeters [21].

5.2. INCLINOMETERS INSTALLED IN TERRAIN ABOVE STRUCTURES

On slopes located above retaining walls and bridges, automatic in-place inclinometers are installed. These instruments are used to monitor horizontal ground displacements that could affect the stability of the structures.

A complete inclinometer system includes:

- inclinometer casings installed in boreholes,
- inclinometer probes,
- a wireless data acquisition system,
- a central processing unit with solar power supply,
- a web-based platform for measurement visualization and monitoring [13], [21].

Data are collected at 30-minute intervals, with the possibility of more frequent readings in the event that threshold values are exceeded [21].

5.3. INCLINOMETERS INSTALLED IN PILES

For the purpose of monitoring potential displacements within the foundations of retaining structures and bridges, inclinometers are also installed inside piles. Typically, one inclinometer is installed at intervals of 50–60 m along the structure.

Unlike terrain-installed inclinometers, readings from inclinometers installed in piles are performed manually at controlled time intervals. These measurements enable the detection of undesired displacements within the foundation of the structure, which may indicate inadequate soil bearing capacity or issues related to pile integrity and continuity [21].

Figure 11. Inclinometers installed in piles (photography by author).

5.4. TILTMETERS INSTALLED ON CAPPING BEAMS

Digital tiltmeters are installed on the capping beams of bridges and retaining walls to detect inclination and rotation of the structure relative to its axis. Tiltmeters are installed between inclinometers, also at intervals of 50–60 m [21].

These instruments are part of a real-time monitoring system, featuring continuous data acquisition and automatic alerts in the event of deviations from allowable parameters. Together with inclinometers, they provide a three-dimensional insight into the structural behavior during construction as well as during the service life of the structures.

Figure 12. Tiltmeters installed on capping beams

5.5. ALARM THRESHOLDS AND DATA INTERPRETATION

Table 1 presents the monitoring intervals for inclinometers and tiltmeters.

Table 1. Monitoring intervals

Instument type	Location	Monitoring frequency
Inclinometers	Slopes above structures	Continuous Real-Time Data Acquisition (Data collection every 30 minutes). Can be adjusted in case threshold values are exceeded. Monitoring should be carried out throughout the entire construction period. Reporting is performed via the web-based platform.
Inclinometers, tiltmeters	Piles and capping beams	

All data obtained from inclinometers and tiltmeters are collected via a web-based platform, which enables:

- automatic processing and visualization of results,
- comparison with design values,
- generation of reports and historical displacement charts.

The system is equipped with an alarm mechanism that, in the event of exceeding predefined threshold values, automatically sends notifications via e-mail and SMS to designated members of the Investor's, Contractor's, and Supervisory teams. Following the issuance of an alert, the Investor's expert team, in cooperation with the Designer, will define, as soon as possible, the measures and actions to be undertaken by the Contractor in order to prevent potential damage arising from any cause [21].

Based on the defined warning thresholds, three alert levels are distinguished:

- **Green** – all values within design limits,
- **Warning** – displacements approaching critical limits, increased attention required,
- **Alarm** – limit exceedance, immediate action required [21].

Table 2 presents indicative displacement values of pile-supported structures and the terrain above the structures for different alert levels. For each structure, the exact displacement thresholds must be defined within the monitoring design.

Table 2. Indicative displacement values for different alert levels

No.	Type of displacement	Unit	Green	Warning	Alarm
1	Pile displacement within the structure	mm/m	1.25	2	2.30
2	Horizontal ground displacement above the structure recorded bt inclinometers	mm	15	20	35

6. RECOMMENDATION FOR OPERATION AND FURTHER ROUTE MONITORING

After the completion of works on the Požarevac – Veliko Gradište – Golubac expressway, it is recommended to establish a long-term geotechnical monitoring system during the operation phase. Although all design requirements have been met and monitoring during construction demonstrated structural stability, certain subsoil characteristics and complex geotechnical conditions necessitate additional observation of key parameters.

To maintain a high level of safety and the long-term durability of the route, it is recommended to continue monitoring the following parameters:

- settlement of embankments and subsoil, particularly in areas with previously identified weak layers,
- pore pressures using piezometers, to detect potential changes in groundwater conditions,
- horizontal displacements, especially on slopes and near structures,
- displacement of piles and foundations in structural elements.

Monitoring can be conducted through periodic field inspections and automated readings from instruments via remote data acquisition and management systems.

7. CONCLUSION

Geotechnical monitoring represents an indispensable tool in modern civil engineering, particularly for the construction of infrastructure projects such as expressways and highways. Along the Požarevac – Veliko Gradište – Golubac route, which traverses complex geotechnical terrains, a comprehensive monitoring system was implemented encompassing earthworks (embankments) and associated structures (retaining walls, bridges, and slopes) to ensure the stability, safety, and long-term reliability of the roadway.

The application of advanced instruments—including piezometers, extensometers, settlement gauges, and inclinometers—enables detailed monitoring of soil consolidation, vertical and horizontal displacements, and pore pressures. Of particular importance is the use of inclinometers in piles and slopes, as well as tiltmeters on capping beams, which allow timely detection of potential deformations and stability disturbances. Coupled with automated data acquisition and analysis systems featuring real-time access and alarm functionality, this approach facilitates prompt responses to any potential risks.

The results obtained during construction allow the identification of deviations from design values and optimization of construction technologies, thereby reducing the risk of structural damage and extending the service life of the structures. The validation of design solutions under real conditions is further confirmed through the analysis of collected data. Moreover, it is essential to continue geotechnical monitoring during the operational phase, alongside the implementation of preventive maintenance and data management systems.

Based on the presented case study, it can be concluded that geotechnical monitoring should become a standard practice in all infrastructure projects with significant geotechnical challenges, in order to ensure maximum safety, functionality, and long-term sustainability of transportation infrastructure.

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