Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-2243

Reliable and Replaceable Monitoring Systems for Ground Support Applications

Florian Hude
DSI Underground Austria GmbH, Austria, Florian.Hude@Sandvik.com

Harald Gundelwein
Enertec Engineering AG, Switzerland

ABSTRACT: Monitoring systems are essential tools in geotechnical engineering, operating as the silent guardians of critical infrastructure. In environments where direct access is restricted and subsurface conditions are continuously evolving, accurate and real-time data becomes indispensable. This paper presents the integration of modern, replaceable monitoring systems—with a focus on splitable load cells—within ground support applications such as soil anchors. Additional technologies, including optical fiber sensors, are discussed for their distributed measurement capabilities, even though they cannot typically be replaced without dismantling the structural elements.

Splitable load cells enable precise measurement of axial loads without disrupting the existing installation, offering a practical solution for both new constructions and retrofit scenarios. Optical fiber sensors allow detailed strain and temperature profiling along the length of embedded supports, complementing point-based systems like load cells. Together with other instrumentation such as inclinometers and piezometers, these tools provide a multi-dimensional perspective on structural performance.

Case studies from Austrian infrastructure projects demonstrate how these systems perform under real-world conditions—capturing seasonal load shifts and long-term deformation trends. The value of resilient and intelligent monitoring strategies becomes increasingly apparent in maintaining asset integrity and safety.

Looking ahead, the field of geotechnical monitoring is rapidly evolving. Wireless connectivity, AI-driven interpretation, and energy-autonomous sensors will transform monitoring from a passive activity into a proactive asset management strategy. Combining traditional engineering principles with cutting-edge innovation paves the way for smarter, safer, and more sustainable infrastructure.

KEYWORDS: Geotechnical Monitoring, Load Cells, Optical Fiber Sensors, Ground Support Systems, Soil Anchors

1 INTRODUCTION

In geotechnical engineering, knowing how ground support systems behave under real-world conditions is essential (Cheng et al., 2022). Whether we're talking about soil anchors, micropiles, or other embedded support structures, their performance can't be taken for granted. These systems operate in hidden, often hostile environments, facing varying loads, water intrusion, shifting soils, and temperature changes. That's where monitoring steps in.

Monitoring technologies give engineers the tools to understand how systems are performing over time. Traditional visual inspections or periodic checks fall short in complex geotechnical settings. Today, with the advancement of rugged, high-precision, and easily replaceable monitoring systems, we can gather real-time, actionable data from deep below the surface. This paper explores the technologies making that possible – splitable load cells, fiber optics, and other key systems – and how they're helping us build safer, longer-lasting infrastructure.

Monitoring systems for ground support systems must be tailored to their fundamentally different load transfer mechanisms. In soil and rock anchors, load is primarily transferred through the anchor head into the tendon and then into the grouted bonded length. Monitoring efforts typically focus on the anchor head, where splitable load cells are ideal for capturing axial force without disrupting pre-tensioned systems. Optical fiber sensors or strain gages may also be integrated along the whole length to detect elongation and redistribution of stress, especially to explore the load transfer in the bonded section. In contrast, forces and elongation in micropiles are more difficult to measure and require special structural methods to be able to measure the force at the head or over the full length. Unlike anchors, micropiles rarely offer convenient access points post-installation, making durability and permanence of sensors even more critical. The differing mechanics – head-dominated tension in anchors versus distributed compression and friction in micropiles – demand distinct monitoring strategies to effectively track performance, detect anomalies, and guide maintenance decisions. In this paper ground anchors only are considered.

2 IMPORTANCE OF MONITORING IN GEOTECHNICAL SYSTEMS

Subsurface structures interact with soils and rock in complex, often unpredictable ways. Unlike superstructures, they're hidden from view and subject to variables that can shift over time: moisture, temperature, loads, seismic activity, and more. That makes real-time, long-term monitoring not just beneficial - but essential.

Monitoring provides:

- Safety and Risk Reduction: Monitoring helps detect issues before they become failures - preventing collapses, landslides, and costly damage.
- Performance Validation: Live data confirms whether systems behave as modeled, particularly during initial loading and seasonal cycles.
- Maintenance Planning: Predictive insights based on actual load and strain trends can inform timely interventions.
- Design Optimization: Knowing the performance will help to optimize future design and increases the safety for existing and future structures.

In short, monitoring turns hidden behaviors into visible trends, helping engineers make better decisions across the life of a structure. From a production point of view, critically, monitoring systems must be rugged enough to endure extreme environments, yet precise enough to capture meaningful change. They must also be easy to replace or upgrade without dismantling the surrounding structure - especially in operational or hazardous settings.

3 MONITORING SYSTEMS

3.1 *Splitable Load Cell "DemiCell (DC)" – Replaceable Monitoring for Permanent Anchor Systems*

Load cells are a go-to choice for measuring axial loads in ground anchors and micropiles (see also Eusebio et al 2024). These sensors translate mechanical force into electrical signals, letting engineers know exactly how much tension or compression a system is experiencing.

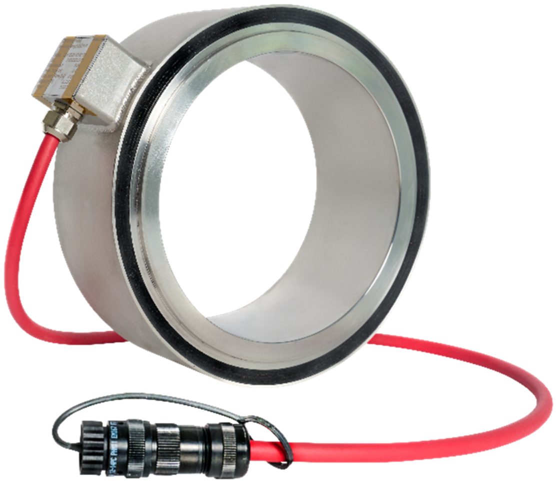

Figure 1. (Conventional) Load Cell

Splitable load cells have taken this a step further. Designed to be:

- Replaceable, as the actual service life of monitoring systems is usually less than the actual service life of the anchors itself
- Installed around existing anchor rods without removing the hardware, they allow for monitoring upgrades in live systems - ideal for retrofit projects.

Their main benefits include:

- Quick field installation and replacement
- High accuracy, even under variable temperatures
- Durability in wet and corrosive environments

With options for wireless telemetry and data logging, modern load cells provide continuous, dependable performance insights.

Figure 2. "Demi-Cell" - Load Cell, detached

3.1.1 *Motivation and Regulatory Background*

Long-term monitoring of anchor forces is essential for the durability and safety of geotechnical structures. Especially for semi-permanent or permanent anchors with service lives of several decades, standards like ÖNORM B 4456 explicitly require system designs that ensure accessibility for inspection and sensor replacement throughout the service life.

The SIA 267 (Sec. 7.2.2) further reinforces this requirement:

"Anchored structures must be monitored over the whole of their working life. Devices for measuring the forces in the anchors must be replaceable."

Traditional cylindrical load cells often fail to meet this criterion, as their replacement typically involves major disassembly or anchor modification. The DemiCell (DC) overcomes this limitation with a novel, splitable two-part design.

3.1.2 *Design and Operating Principle*

The DemiCell consists of two semi-circular sensor elements made of high-strength stainless steel that are radially inserted beneath the anchor head. The force is transmitted through the ring halves, which are precisely adapted to the geometry of the anchor head. Integrated strain gauges, arranged in a temperature-compensated configuration, ensure reliable performance under variable environmental conditions.

For initial installation, the anchor head (e.g., the nut) must be lifted by a distance equal to the minimum installation height of the DemiCell plus a few tenths of a millimeter. For replacement, only a slight lift of a few tenths of a millimeter is required - e.g., by temporary load release or hydraulic tensioning. Removal is completely non-destructive, making the system particularly suited for recalibration, sensor upgrades, or maintenance in critical infrastructure.

3.1.3 *Technical Specifications*

DemiCells hold following technical specifications:

- Installation height: from 20 mm, depending on force and geometry
- Minimum clearance for retrofit: ≥ 20 mm
- Force range: application-specific
- Accuracy: ≤ 1% F.S.
- Protection class: IP66
- Temperature range: −30 °C to +70 °C
- Signal outputs: mV/V, 4–20 mA, 0–5 V, RS485, SDI-12
- Optional features: integrated temperature sensor, lightning protection, on-site display

To extend the mechanical adjustment range, splitable spacer rings can be added, allowing for targeted pre- or post-tensioning and more flexible adaptation to field conditions.

3.1.4 *Applications and Limitations*

The DemiCell is ideal for retrofitting monitoring systems into existing anchor installations or for new projects where future sensor replacement must be ensured. A temporary clearance of at least 20 mm is required during installation. The system is built for demanding conditions - moisture, frost, and dirt - and withstands long-term mechanical loading.

Typical applications include:

- Excavation support and retaining structures
- Tunnel linings and diaphragm walls
- Slope stabilization and rock bolts
- Anchor retrofitting in existing infrastructure

3.1.5 *System Integration*

The DemiCell can be operated as a standalone unit with a local data logger or be integrated into larger monitoring networks. Analog and digital output options allow seamless connection to remote telemetry platforms via cellular, LoRaWAN, or IP networks. In combination with complementary sensors - such as inclinometers, piezometers, and extensometers - the system forms a scalable, high-resolution monitoring solution for ground support systems.

Figure 3. Cellular Solar Panel for a grid-independent data-transfer solution

3.2 *Optical Fiber Sensors Based on Fibre Bragg Gratings*

3.2.1 *Measurement Principle and Comparison to Distributed Systems*

Fiber Bragg Grating (FBG) sensors are pointwise optical sensors that detect strain and temperature changes by monitoring shifts in the Bragg wavelength. A periodic modulation of the refractive index is inscribed into the fibre core, reflecting specific wavelengths depending on local strain or thermal expansion. These wavelength shifts can be accurately measured using an optical interrogator, enabling precise, long-term monitoring of structural responses.

Unlike distributed fibre-optic sensing systems based on Rayleigh or Brillouin scattering, which provide continuous data over the entire fibre length, FBGs operate as discrete sensors. Each grating acts as an independent sensing node, enabling multiplexing of dozens of sensors along a single fibre with high spatial resolution. FBG systems are passive and do not require power at the sensor location, making them ideal for harsh or electromagnetically noisy environments such as tunnel linings or deep anchor installations.

Further detailed description of the different systems can be found in several proceedings (e.g. Ma et al. 2024, Caldas et al. 2024).

3.2.2 *Technological Implementations in Structural Applications*

FBG sensors can be integrated into structural elements using various approaches, depending on the material, geometry, and monitoring goals:

- Embedded strain sensors are cast directly into concrete or grout. These sensors can be designed to mimic the mechanical behavior of reinforcement steel, allowing accurate measurement of internal strain fields in foundations, retaining walls, or structural slabs.
- Surface-mounted or bonded FBGs are applied to existing structures using adhesive or mechanical clamps. They are commonly used for retrofitting on structural steel, tunnel linings, or exposed concrete surfaces to detect cracks, displacements, or long-term deformations.
- Instrumented bolts or anchors incorporate optical fibers within the reinforcement itself. FBGs can be factory-installed along the axis of anchor rods, cables, or micropiles, enabling distributed measurement of axial force, slip, or damage within the element over time.
- Composite tape or flexible fiber arrays allow for surface deployment over curved or irregular geometries. These implementations are particularly suitable for monitoring strain distribution across masonry arches, tunnel crowns, or bridge decks.

All sensor types can include temperature compensation (either through dedicated reference gratings or dual-parameter calibration), ensuring reliable strain readings under varying environmental conditions.

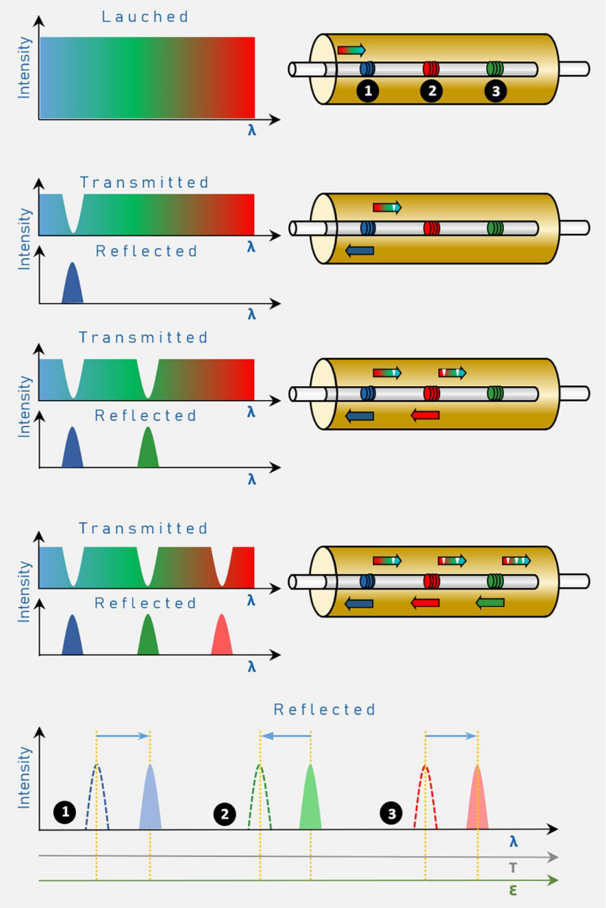

Figure 4. Function of FBG-Sensors

3.2.3 *Applications in Anchors and Micropiles*

FBG technology enables detailed insight into the load transfer behavior and mechanical integrity of ground anchors and micropiles:

- In post-tensioned anchors, sensors placed near the head can monitor long-term tension loss, corrosion effects, or mechanical overload.
- Along the shaft of micropiles or nails, FBGs can help assess load distribution, bond degradation, or ground-structure interaction.

- The technique is also well suited for time-dependent effects such as creep, shrinkage-induced stress redistributions, or frost-heave-induced displacements.

Thanks to their immunity to electromagnetic interference and their durability in aggressive environments, FBG sensors are increasingly used in challenging applications such as slope stabilization, urban tunnelling, or deep excavation support.

3.2.4 *System Integration and Data Visualization*

FBG sensors are compatible with a wide range of modern data acquisition systems. Optical interrogators convert wavelength shifts into engineering units (strain, temperature) and transmit data via standard protocols (Modbus, RS485, Ethernet) for further analysis.

These sensors can be seamlessly integrated into multi-sensor monitoring systems, enabling combined evaluation with conventional sensors, such as load cells or displacement transducers. The fused data can be processed in real time, visualized via cloud-based platforms, and used to trigger alerts or support predictive maintenance strategies.

Due to their multiplexing capability, dozens of measurement points can be monitored using a single fiber-optic line, reducing cabling complexity and installation cost. This makes FBG systems scalable and well-suited for large infrastructure projects.

3.3 *Complementary systems*

Other monitoring tools round out the picture:
- Strain gages: Good for targeted measurements on steel components.
- Inclinometers: Detect lateral ground movement.
- Extensometers: Measure changes in spacing between fixed reference points.
- Piezometers: Track pore water pressure and drainage effectiveness.
- MEMS sensors: Combine small size with wireless capability for hard-to-access areas.

Together, these systems help build a high-resolution view of what’s happening underground.

4 CASE STUDIES

4.1 *Splitable Load Cells in Active Railroad Slopes*

The Muehltobelgalerie in Dalaas, located adjacent to an active rail corridor, required a critical upgrade to its ground anchor monitoring system. The gallery structure, which protects the railway line from rockfall and slope instability, relies on a network of permanent anchors to maintain slope stability above the portal area.

Figure 5. Muehltobelgalerie in Austria

4.1.1 *Challenge: Unreliable Hydraulic Monitoring*

Originally, the monitoring system utilized conventional hydraulic load cells to measure anchor loads. Over time, however, these sensors exhibited significant inconsistencies in pressure readings, caused by temperature sensitivity, oil leakage, and long-term drift. These reliability issues impaired the ability to make confident assessments about anchor performance and long-term safety.

Moreover, due to physical constraints and embedment behind structural shotcrete and anchor heads, complete removal of the hydraulic load cells was deemed infeasible.

4.1.2 *Solution: Splitable Load Cell Retrofit with DemiCell*

To address this, a retrofit solution using DemiCell splitable load cells was implemented. A total of 31 hydraulic load cells were decommissioned by draining the oil (effectively disabling them), but left mechanically in place. The DemiCell units were then clamped directly onto the exposed anchor tendons, enabling force measurement without the need to dismantle anchor terminations.

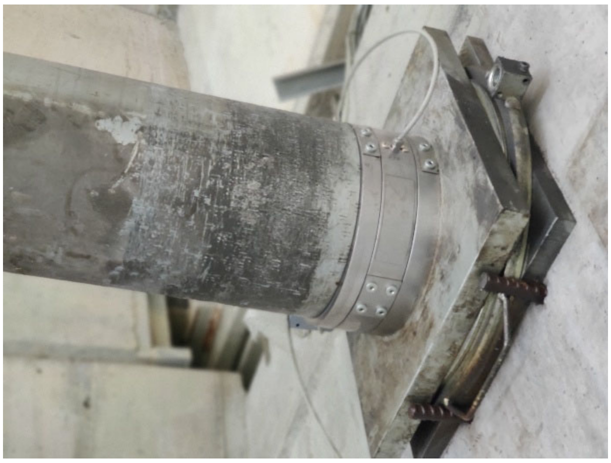

Figure 6. Splitable Load Cell installed between wedge plate and anchor plate

Each splitable load cell was individually calibrated on-site, ensuring consistent baseline values. The load cells were included in an existing monitoring system so that all sensors (including inclinometers, piezometers, …) feed the data into one central point.

4.1.3 *Outcome and Benefits*

The retrofit restored confidence in the monitoring data, offering stable, precise, and maintenance-friendly measurements. Unlike their hydraulic predecessors, the DemiCell sensors proved to be unaffected by ambient temperature fluctuations or mechanical hysteresis. The integration of the LoRa-WAN system further enabled streamlined condition monitoring, with anchor loads now available remotely in near real time.

This project highlights the practicality and performance benefits of splitable load cells in geotechnical retrofits, especially where existing infrastructure restricts conventional sensor installation. The proximity to the rail line made the need for non-invasive, fast-installation solutions even more critical - demonstrating how modern instrumentation can be adapted to demanding environments without compromising structural integrity or safety monitoring capabilities.

4.2 *Selection of monitoring system for a suspension bridge*

The A26 bridge project in Linz, Austria, (see also Bach et al., 2023; Sempelmann et al., 2023) is a critical component of the city's infrastructure development, designed to span the Danube River and relieve urban traffic congestion. As a suspension bridge, the structure relies heavily on high-capacity ground anchors to safely transfer massive tensile forces from the main cables into the abutments and surrounding ground. Accurate and long-term monitoring of these anchors is essential to ensure structural safety and performance throughout the bridge's lifecycle.

4.2.1 *Evaluation of Monitoring Options in the Design Phase*

During the engineering phase, several instrumentation strategies were evaluated to monitor anchor forces both during construction and over the bridge's operational life. The goal was to identify a system that provided reliable force measurements, allowed verification of load transfer into the bonded section, and supported future maintenance strategies. Three main technologies were considered:

- Conventional Electronic Load Cells: These sensors measure axial force at the anchor head. They are well-established and deliver precise point-load data but are limited to monitoring at the surface and do not capture load distribution along the anchor length.

Figure 7. Test anchor using conventional electronical load cell

- Splitable Load Cells – DemiCell: Offering a flexible retrofit and installation solution, these load cells can be clamped around already tensioned tendons without requiring structural disassembly. Their modular nature supports easier long-term maintenance but came with higher unit costs.
- Magnetoferric-Based Elongation Measurement – Dynaforce: This technology enables distributed strain measurement along the entire anchor, including the bonded section - a unique advantage for verifying the actual load transfer profile. The system uses magnetically reactive inserts and external readers to measure elongation over time.

4.2.2 *Final Monitoring Concept and Rationale*

After a thorough technical and economic review, the final monitoring strategy combined conventional electronic load cells with elongation-based measurement using the Dynaforce system:

During initial load transfer and verification, Dynaforce sensors were installed along the anchor free and bonded lengths to gain a complete picture of load distribution. This data was critical for validating load transfer assumptions and checking that post-tensioning procedures achieved uniform load transfer into the rock mass.

For the permanent monitoring phase, only the conventional electronic load cells remained in use. Positioned at the anchor head, these load cells continue to provide long-term monitoring of anchor force levels, sufficient for operational safety checks and lifetime structural assessment.

The selection was driven by a balance between technical benefit and lifecycle cost. While splitable load cells offered advantages in ease of replacement and installation, their higher cost compared to standard electronic systems - combined with the successful verification achieved through Dynaforce - meant they were ultimately not selected for this project.

Figure 8. Test anchor using splitable load cell

4.2.3 *Conclusion*

The A26 bridge project in Linz exemplifies a thoughtful, phase-oriented approach to ground anchor monitoring - combining targeted strain distribution analysis during commissioning with streamlined long-term load surveillance. The integration of *Dynaforce* elongation measurement during initial stages provided valuable insight into load transfer mechanisms, particularly within the bonded sections - critical for such a heavily loaded suspension system. Transitioning to conventional electronic load cells for long-term monitoring offered a practical and maintainable solution aligned with the project's operational requirements.

However, from a technical standpoint, it is important to acknowledge that more advanced solutions - such as splitable load cells (DemiCell) and distributed optical fiber sensors - would have offered superior diagnostic capabilities, easier sensor replacement, and a more comprehensive long-term dataset. These systems excel in capturing spatially resolved strain behavior and providing redundancy in high-risk infrastructure, particularly where post-installation access is limited.

It is therefore technically regrettable that such innovations are sometimes excluded from final implementation solely due to economic constraints, despite their engineering advantages. The A26 case highlights the need for broader lifecycle cost-benefit evaluations in infrastructure planning, where initial investment in advanced monitoring can yield greater long-term value through improved safety assurance, maintenance efficiency, and structural resilience.

5 CONCLUSION AND OUTLOOK

Monitoring systems play a pivotal role in the design, operation, and maintenance of geotechnical infrastructure. As structures are subjected to increasing loads, environmental stresses, and longer service lives, the ability to reliably measure performance becomes essential. This paper has highlighted the growing relevance of replaceable and high-resolution monitoring technologies - with a focus on splitable load cells like DemiCell, distributed optical fiber sensors, and complementary systems such as strain gages and elongation-based methods.

These technologies not only enhance safety and operational transparency but also reduce intervention costs through early detection and informed maintenance. Case studies, including the Mühltobelgalerie in Dalaas and the A26 bridge in Linz, have demonstrated practical applications where such systems have either significantly improved monitoring reliability or were evaluated during engineering phases.

However, these examples also underscore a key challenge: cost-driven decisions often lead to the exclusion of technically superior solutions. While splitable load cells and optical fibers offer long-term benefits in terms of precision, maintainability, and data quality, they are at times set aside in favor of conventional systems due to initial budget constraints. From an engineering perspective, this is a missed opportunity - especially in projects with long design lives or limited accessibility for future upgrades.

Looking forward, the future of geotechnical monitoring lies in intelligent, connected, and adaptive systems. Developments such as wireless data transmission (e.g., LoRaWAN), AI-based data interpretation, energy-harvesting sensors, and modular sensor architectures will transform how we monitor and maintain ground support systems. A shift toward lifecycle-based decision-making - considering not just initial installation cost but long-term performance, risk mitigation, and operational value - will be essential to fully leverage the capabilities of modern instrumentation.

To build more resilient and efficient infrastructure, geotechnical monitoring must evolve from a compliance-driven task to a strategic engineering function, enabling proactive asset management supported by rich, reliable data.

6 REFERENCES

Cheng S.-H., Chen S.-S., Yang K.-H., 2022. Self-inspection system for ground anchors monitoring on long-term load change. In: *Transportation Geotechnics, Volume 36*. 2022. ISSN 2214-3912

SIA 267. 2020. *Geotechnical Design – Soil and Rock Engineering*. Zürich: Swiss Society of Engineers and Architects (SIA).

OENORM B 4456. 2021. *Geotechnics – Durability of Anchorages*. Vienna: Austrian Standards International.

Bach, D., & Eder, M. 2023. Challenging projects in Austria. *Geomechanics and Tunnelling*, *16*(4), 338-339.

Sempelmann, F., Bartl, R., Edlmair, G., & Lang, M. 2023. A26 Linz Motorway–Challenges looking back and looking forward. *Geomechanics and Tunnelling*, *16*(4), 382-397.

Eusebio A. , Tony L., and Óscar P. 2024. Installation of load cells in ground anchors. In: *Proceedings of the 7th International Conference on Geotechnical and Geophysical Site Characterization*. Barcelona, 2024

Ma J., Pei H., Zhu H.-H., Shi B., Jianhua Y. 2022. A review of previous studies on the applications of fiber optic sensing technologies. In: *Geotechnical monitoring. Rock Mechanics Bulletin.* 2. 100021. 10.1016/j.rockmb. 2022.100021.

Caldas P., Laranjo M.L., 2024. Fiber optic sensors in geotechnical works – a review. In: *Proceedings of the XVIII ECSMGE 2024*. Lisbon, 2024.