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From Surface to Subsurface: Advancing Infrastructure Monitoring with Fiber Optics

L. Urmantseva[1]

[1] AP Sensing GmbH

Summary

Distributed Fiber Optic Sensing (DFOS) technologies are transforming infrastructure monitoring by providing continuous, high-resolution data through techniques such as Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS). These systems enhance real-time assessment of structural integrity, operational performance, and environmental conditions in both offshore and onshore applications. Beyond asset protection, DFOS also serves as a powerful tool for geoscience, enabling seismic monitoring and subsurface analysis in previously inaccessible areas. A key advantage of DFOS is its ability to generate valuable geoscience data alongside infrastructure monitoring. Fiber networks originally installed for communications and operational needs can also serve as seismic sensors, providing insights into subsurface dynamics, seismic events, and environmental changes in areas that were previously difficult to monitor. By repurposing fiber networks for sensing, DFOS enables a cost-effective expansion of geophysical data collection while enhancing infrastructure resilience.

Introduction

The integration of Distributed Fiber Optic Sensing (DFOS) technologies in infrastructure monitoring has revolutionized the ability to capture real-time, high-resolution data. Techniques such as Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) provide continuous, wide-area monitoring of both onshore and offshore assets, offering critical insights into real-time operational performance, structural integrity, and environmental conditions. While DAS excels in detecting vibrations and seismic events, DTS enhances temperature-based monitoring for applications ranging from fire detection to energy efficiency.

A key advantage of DFOS is its ability to generate valuable geoscience data alongside infrastructure monitoring. The same installation that safeguards critical assets can also provide insights into subsurface dynamics, seismic activity, and environmental changes. This dual-use capability connects engineering and geosciences, offering a unified data source that serves multiple disciplines. By leveraging a single DFOS deployment, stakeholders—including geoscientists, engineers, and decision-makers—can extract actionable insights to enhance safety, optimize maintenance, and advance scientific research.

Methodology

DFOS technology operates through the deployment of fiber optic cables along critical infrastructure, allowing for real-time detection and analysis of temperature variations, strain distribution, and acoustic signals. This capability enhances predictive maintenance by identifying anomalies before they escalate into critical failures.

At the same time, DFOS serves as a valuable input for geoscience research, providing data from areas previously uncovered by traditional sensors—often in remote or difficult-to-reach locations. This capability enables new opportunities to study subsurface dynamics, seismic activity, and environmental changes.

Examples

The versatility of DFOS is evident in both offshore and onshore infrastructure monitoring projects, demonstrating its value across multiple sectors.

One notable offshore application is the monitoring of subsea power cables, where DFOS enables fault detection, third-party interference (TPI) protection, and depth-of-burial assessments. Beyond structural integrity, these fiber-equipped cables serve as environmental monitoring tools. For instance, DFOS enables fatigue assessment by tracking periodic strain variations that align precisely with tidal cycles (Figure 1). Moreover, DAS deployed on offshore cables enables real-time seismic monitoring, effectively transforming infrastructure networks into large-scale earthquake observation systems. Given that many subsea cables are located in seismically active regions, this approach provides a cost-effective means to improve earthquake detection.

On land, railway fiber optic infrastructure presents another compelling use case. Existing fiber optic cables along rail corridors can be repurposed for DFOS applications, enabling continuous traffic flow monitoring, early detection of rail integrity issues, and seismic event tracking. Additionally, DFOS can contribute to broader public safety measures by detecting earthquake-induced ground movements (Figure 2), identifying underground instabilities, and monitoring transportation patterns in real time. This integration not only improves railway safety and efficiency but also expands the use of infrastructure networks for seismic and environmental monitoring.

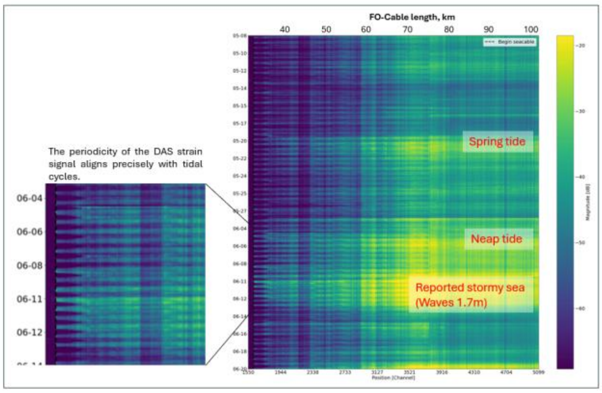

__Figure 1__ Offshore wind farm installation: Example of subsea cable fatigue monitoring using DAS. The correlation between the DAS signal and tidal cycles is shown.

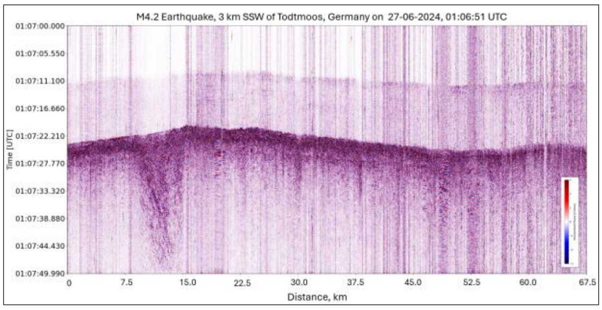

__Figure 2__ Example earthquake observed on June 27, 2024 along the train line ~70 km length monitored with DAS

Conclusions

These examples show how a single DFOS installation enhances both infrastructure resilience and geoscience research, fostering proactive monitoring and interdisciplinary collaboration. DFOS transforms existing infrastructure into vast sensor networks, providing real-time data on seismic, structural, and environmental conditions.

This dual capability bridges engineering and geoscience, offering insights into subsurface dynamics and infrastructure performance. As DFOS technology advances, collaboration across sectors will unlock new applications, with future data analytics further enhancing its impact.

DFOS is changing how we monitor and maintain critical infrastructure, leading to a future where we have a better understanding of both man-made systems and the natural world, and how they are connected.

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