Case Study:

Ground Movement and Structural Deformation Monitoring using Distributed Fiber Optic Sensing

Longsgraben disposal site during the Semmering Base Tunnel excavation (photo courtesy Austrian Federal Railways © ÖBB/Ebner)

Background

The Longsgraben valley provided the central disposal site for the 27.3 km Semmering Base Tunnel. Excavated material was transported to the 20 ha site on a 2 km conveyor belt and by truck.

The extensive preparation work included relocating a stream and building the retaining structure. In line with the project‘s overall sustainability goals, these measures and strict procedures during the disposal ensure a secure structure, which will blend into the region in the coming years. Monitoring ground movement during and after construction was crucial given the geological and hydrogeological challenges.

Rerouting the stream

The stream at the base of the existing valley was rerouted to run along the bottom of the 'new' valley, formed from the excavated material, requiring a 25 m high reinforced retaining wall with slopes of up to 75^{0}.

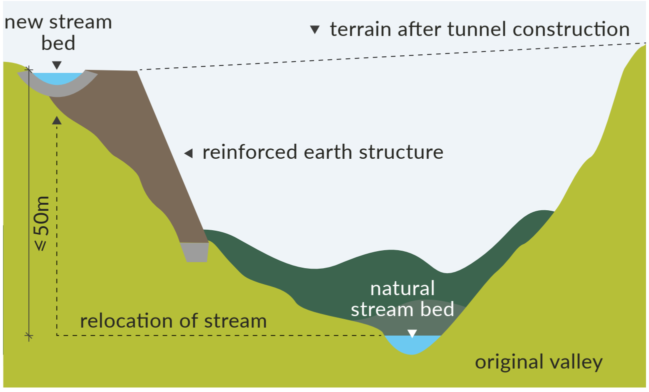

Figure 2: The stream is relocated using a reinforced earth structure (after a diagram courtesy of Engineering Geodesy and Measurement Systems, Graz University of Technology)

Strain monitoring of the reinforced earth structure

Conventional geodetic techniques, a total station and bi-reflex targets were used to measure the structure's surface displacement. Fiber optic distributed sensing was deployed to provide insight into the structure's internal strain evolution.

The fibrisTerre interrogator unit (based on Brillouin Optical Frequency Domain Analysis, BOFDA) provided continuous monitoring of the structure during and after construction. Detecting ground movement, creep and long-term erosion, the system reports strain and temperature changes and met the required strain measurement accuracy of 100 με.


Figure 3: Attaching the fiber optic sensing cable to the geogrid

Fiber optic cable installation

The fiber optic sensing cables were attached to geogrids using anchors and deployed at four cross-sections of the structure, at different height levels. The strain sensing cable length was pretensioned to detect strain; the same sensing cable was used without tensioning to provide temperature compensation.

At each level, a fiber optic sensing cable loop of about 2.5 km detects strain on the outward path, and temperature on the return, providing temperature compensation for the strain measurements.

Figure 4: The geogrid and sensing cables were deployed within the earth retaining structure

Results

Measurements were made weekly during the September 2013 construction phase to capture the strain development in the geogrids.

The safety management plan defined the actions to be taken if measurement thresholds were exceeded.

None of the threshold values were exceeded. Strain developed in three distinct phases (Figure 5), as observed in level 2, cross-section 1 (Figure 6). Phase A corresponds to the construction period of the retaining structure. The load increased as more earth layers were added. The extra weight resulted in positive strain of up to 0.4%, most of it seen in the section closest to the surface.

As expected, after construction, creep occurred as seen in phases B.

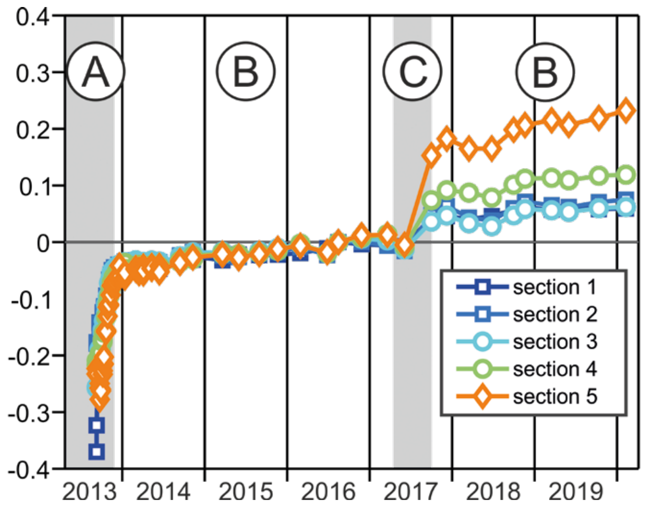

Figure 5: Strain evolution of the geogrid within the reinforced earth structure of level 2 of cross-section 1, with phases A, B and C shown

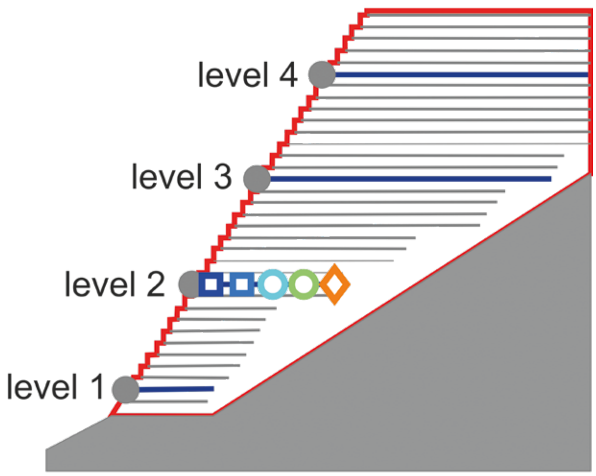

Figure 6: Location of sections within level 2

In 2017, all strain readings suddenly increased in phase C (Figure 5). An investigation revealed that to accommodate larger dump trucks, the road had been widened using extra earth (Figure 7).

The timing of the work coincided with the strain increase and the affected section was observed closely so that appropriate action could be taken if the strain development did not stabilize.

Subsequently, the deformation reverted to creep (Figure 5).

The strain evolution of level 3, cross section 2, mirrors the continuing creep deformation across all levels over the four years post-construction. The highest strain occurs in the middle of level 3 (about 1%) and the lowest in the rear of the structure.

Conclusion

Geohazards can be monitored and mitigated, reducing the risk of structural failure.

Distributed fiber optic sensing contributes to construction safety by detecting both anticipated and unexpected strain events.

Such monitoring systems increase safety, enable more efficient construction and can be incorporated into condition-based maintenance programs. Fiber optic sensing is a valuable monitoring tool complementing conventional methods.

Figure 7: Adding quantities of soil to widen the access road resulted in a sudden rise in strain behind the structure

Contact fibrisTerre to discuss your project's requirements with a specialist.

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Figure 8: A fibrisTerre distributed fiber optic sensing interrogator unit

References

- Lienhart W, Buchmayer F, Klug F and Monsberger CM **Distributed fibre-optic sensing applications at the Semmering Base Tunnel, Austria.** Proceedings of the Institution of Civil Engineers – Smart Infrastructure and Construction, https://doi.org/10.1680/jsmic.20.00006
- Lienhart W, Buchmayer F, Klug F and Monsberger CM **Distributed fiber optic sensing on a large tunnel construction site: increased safety, more efficient construction and basis for condition based maintenance.** International Conference on Smart Infrastructure and Construction 2019 (ICSIC): Driving data-informed decision-making
- Semmering Base Tunnel- Wikipedia (https://en.wikipedia.org/wiki/Semmering_Base_Tunnel)
- fibrisTerre **fTB 5020 – Fiber-optic sensing System for distributed strain and temperature monitoring.**

All diagrams and pictures courtesy of **Engineering Geodesy and Measurement Systems, Graz University of Technology**, unless otherwise noted.