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Long term monitoring of ground anchors using distributed fiber optic sensing

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ABSTRACT: 10 years ago we proved that distributed fiber optic monitoring of ground anchors is feasible and provides very detailed strain information along the entire anchor length. Thus, we started a dedicated research project for the in-situ investigation of the load transfer mechanism between tendon, grout and surrounding ground in different soil conditions. Valuable information was gathered within the field experiments and used to optimise numerical models. This was already published in some publications and presented to the professional audience. In the meantime, this new technology has got well accepted in the geotechnical community. However, for long term monitoring of ground anchors, there is only little information available. Thus, we try to close this gap with this paper and report about our experiences with the long term monitoring which we gathered in various practical projects. Reported case describes monitoring of a permanent ground anchor, which we installed in 2018 on highway A10 in Austria. The monitoring concept is discussed as well as practical issues during the installation of the fiber optic sensing cables, which might help other users to set up robust monitoring systems. Since 2018, 9 repetitive measurements were carried out, both at the tendon and in the grout. The shown data gives further insights into how it works and proves feasibility of long term monitoring with fiber optics systems on ground anchors.

KEYWORDS: ground anchor behaviour, monitoring anchor, distributed fiber optic sensing, long term monitoring.

1 INTRODUCTION

At the Institute of Engineering Geodesy and Measurement Systems (IGMS) we started with fiber-optic sensing (FOS) 25 years ago. Since then, we carried out several research and industrial projects using different FOS technologies, mainly for strain and temperature sensing, most of them in civil engineering under harsh conditions. For instrument testing and data reliability, we set up several testing facilities in our metrology laboratory (Woschitz et al., 2015).

Since 2014, the authors work together on geotechnical applications on driven-piles with attached distribute fiber-optic sensing (DFOS) cables, see e.g. Woschitz et al. (2016). Based on these experiences and both, the very high spatial resolution (some centimetres within a range of about 70 m), and the high precision of strain data (some µm/m), we designed and realised in 2015 a first field-experiment with vertically aligned ground anchor in Söding, Austria (Račanský et al., 2016). By this, we could get first very detailed insights about the load transfer mechanism from the anchor to the soil. With this experiment we also proved, that the optical fibers can withstand the construction process in harsh environments, which are typical for a construction sites, as well as that they can withstand the large strains on the tendons, which arise during stressing the anchor and the more during testing the anchor until it fails.

Subsequently, we set up a dedicated research project in order to study the load transfer mechanism in more detail and different soils. As existing numerical models should be verified resp. improved by our experimental data in different soil, we collaborated with H. Schweiger (Graz Univ.of Technology) and his group (see, e.g., Fabris et al., 2021).

In the meantime, this new sensing technology is well accepted in the geotechnical community, and also other groups and already some companies started with it, e.g. Imai et al. (2019), Nakaue (2021) or Jasiak et al. (2025).

As there is still only little information available for the long term monitoring of anchors, we decided to set-up one of our anchors as a monitoring anchor in order to gather experience about the durability of the sensing fibers and their sensing characteristics in harsh environments over a much longer time-span. In this paper, we report about this monitoring anchor, show the results of 7 years monitoring, and summarize our experiences with more than 10 fiber-optically equipped ground anchors with length of up to 50 m.

2 DISTRIBUTED FIBER OPTIC SENSING

DFOS allows strain or temperature measurement along the entire fibre length, thus enabling measurements in a truly distributed way. For example, strain measurements at several thousand positions along the optical fiber are possible within few seconds. Using a single lead in fiber, makes installation more easy and reduces cabling related issues (like back-influencing the object and thus falsifying the results) to a minimum.

DFOS are based on different backscattering phenomena in the optical fibre. Systems based on Brillouin backscattering became available for the monitoring of geotechnical structures more than 15 years ago (e.g., Iten et al., 2008, Mohamad et al., 2011). They allow distributed sensing with a spatial resolution of about 1 m over long distances (several 10th of km). However, due to the small scattering effects, integration and thus measuring times of at least several minutes are needed. About 10 years ago, these drawbacks were overcome by sensing systems based on Rayleigh scattering, which gives much stronger signals compared to the Brillouin signal, and thus allows faster measurements. Such systems based on optical backscatter reflectometry (OBR) can reach a spatial resolution in the centimeter range, or even below, with scan rates of a few seconds, together with a better measuring precision. But their sensing length is often limited to the short range (e.g. less than 100 m.

Barrias et al. (2016) give more details on DFOS and thus is referred to. But there is one property that must be considered, for applications with changing temperature, this is the cross-sensitivity of strain and temperature due to the dispersive characteristics of the optical glass. There are just few systems, which are insensitive for this.

2.1 *Fiber optic instruments used*

As a main sensing instrument, a Luna OBR 4600 was used. There are also other optical backscatter reflectometers available, but the one we use is available at the institute. The OBR is capable to record sensing information with a very high precision of about 1 µm/m for strain measurements, and about 0,1°C for temperture measurements (Luna, 2014). Such a reading unit for distributed fibre optic sensing emits a laser light into a passive optical sensing fibre and analyses the backscattered light, which is arises along the sensing fiber due to Rayleigh backscattering. Typical spatial resolutions are 10 mm, but this depends on the quality of the signal and on the strain profile along the fiber.

Aside this, a Brillouin optical time domain analyser (FibrisTerre ftb5020) is used, which provides a spatial resolution of 0,5 m, and a repeatability of 20µm/m for strain and 1°C for temperature measurements. But as acquisition time is rather high because of the small signal level of Brillouin backscattering, we do not report about these measurements in this paper.

2.2 *Fiber optical sensing cables used*

For geotechnical field measurements under harsh field conditions, robust sensing cables are essential in order to protect the sensible optical fiber inside and allow their embedment into different structures. Furthermore, the sensing cables should have acceptable properties for the strain transfer from the structure to the optical fibre. Based on positive experiences in geotechnical applications (e.g. Iten, 2012) and on our own investigations, sensing cables from Solifos, Switzerland (formerly Brugg Cables) were used for more than 15 years. Iten (2012) also tested various strain sensing cables in the laboratory in advance to his field applications and thus valuably contributed to the availability of distributed strain sensing cables. In the meanwhile, several manufacturers offer robust sensing cables for DFOS, but information about their performance and testing is rare results, especially hardly at the long-term time scale.

Figure 1 shows the setup of the different types of sensor cables used within this project.

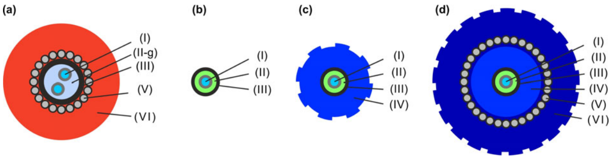

Figure 1. Different types of strain and temperature sensing cables from Solifos GmbH and their set-up: (a) Temp.85, (b) FiMT, (c) V9 and (d) V3. (I) single mode fibre (Ø250 µm), (II) multi-layer buffer with strain transfer layer, (III) metal tube, (IV) polyimide protection layer, (V) special steel armouring and (VI) polyimide outer sheath.

A standard single mode fiber of 250 µm is the common sensing element of all of these sensing cables. In case of the temperature sensing cable, two optical fibers are loosely guided inside a gel-filled stainless steel 316L pipe, which then is protected by an PA outer sheath (cable diameter 4,8 mm). A typical overlength of 0,2% separates the sensing fiber within this strain range from the strain at the structure. The cable may be used in between -40°C and +85°.

Contrary, for strain sensing, a good coupling of the optical fiber is needed to all its structural elements. The inner part of the shown strain sensing cables is the same, connecting the optical fiber to an ~0,9 mm thick stainless metallic tube (SS316L) by a special “interlock system”. This so called FIMT (fiber in metal tube) might already be used in situations, where its protection is achieved differently during the installation. In order to achieve a good composite with concrete, a structured polyamide layer is added (V9), and in case of harsh conditions, further layers are added (V3), making the sensing cable robust, but less sensitive. Thus choosing the right sensing cable is a compromise of durability and sensitivity. The strain sensors shown are intended for strains up to 10.000 µm/m within an operating temperature of -30°C to +70°C (Solifos, 2025).

Piccolo et al. (2020) tested some of these sensors and mention in their paper, with one of the manufacturer as one of the co-authors, that like “any other sensor, an optical fiber cable is designed to operate in the elastic domain, i.e., for strain levels often less than [...] 2000 µm/m.“ They also state that a high curvature resistant standard fiber is used, with an SMF G657 acrylate coating. Solifos solely notes for the temperature cable used, that a dual layer acrylate coating is used. This gets important to if sensor related effects are to be studied.

Schenato et al. (2024) investigated and confirmed the persistence of the fiber’s Rayleigh’s signature based on their own data derived over more than 6 years, even in the harshest conditions. They also proved, that the signature measured by different interrogators is still usable for data evaluation, which is crucial for long-term monitoring, especially if the interrogator hast to be replaced or repaired. However, when using different setups or interrogators over the lifetime of a monitoring installation, it is necessary to correlate the Rayleigh signal by an individual software.

3 MONITORING ANCHOR: ADVANTAGES AND CONCEPT FOR LONG TERM MONITORING

Traditionally, some individual anchors are equipped with load cells and thus allow basic anchor monitoring. But this single values corresponds to the integrated strain along the whole anchor, and cannot show strain distribution or its possible redistribution over time by e.g. a sliding area, an aquifer layer or another geological fault layer.

Thus, monitoring anchors using distributed fiber optic sensing are advantageous. Their standardised use in the beginning of an anchor project, in the geologically most critical section, would give in-situ information about the soil behaviour and thus allow to optimise the anchor lengths, giving either economically benefit or a higher safety level.

Our experiments intend to enhance this development and give information about the long-term behaviour of anchors.

Based on our experiences on prior ground anchor projects, we propose to use distributed fiber optic strain sensing cables on two tendons, and at least one – a robust one – in the grout, as well as a temperature sensing fiber for the temperature correction of the measured strain data.

Rayleigh based systems with a superior spatial resolution show more details, especially when a sensitive fiber is used. When using more robust fibers with a larger strain transition zone, also Brillouin based systems might be used, especially for for long anchors. Then loop configuration of the fiber sensors is recommended in order to get a better strain resolution.

4 INSTALLATION OF A STRAND ANCHOR AT THE A10 HIGHWAY

4.1 *Description of the construction site*

At the Austrian highway A10 from Villach to Salzburg, the Egger wall (built in the 1970) had to be renovated. The wall is located close to Eben im Pongau, is about 230m long and up to 22 m high, has an inclination of about 75° and a thickness of 0,5 m, Figure 2.

At the top of the wall there is a small forest road allowing maintenance works, and an adjacent forest on steep terrain. The wall is oriented to SSW and thus exposed to the sun from the late morning till sunset.

The strengthening of the wall was done in 2018 by massive vertical in-situ concrete beams (2,5 m wide, 1,1 m thick, up to

20 m high) and 262 permanent strand anchors (4 - 8 tendons, up to 26 m long). The anchors were manufactured by ANP-Systems Austria and installed by Keller Grundbau GmbH.

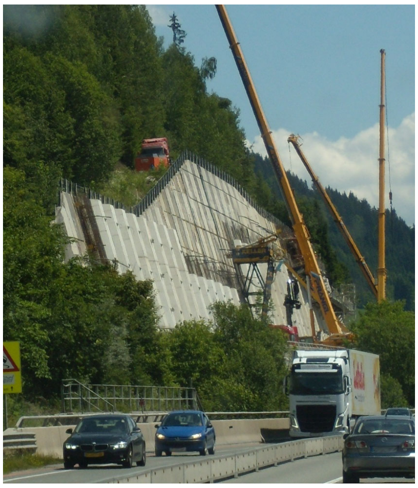

Figure 2. Egger wall at the A10 highway during its strengthening.

Geological exploration (15-25 m long boreholes) has shown three main layers,

a) slope debris (thickness 0,5-3 m)
b) weathered rock below (thickness 5-15 m, alternation of claystone and marlstone with stratified water flows at some positions, moderate strength)
c) compact rock below (alternation of claystone and marlstone, moderately high to high strength)

with cataclastic fault rocks of 1-2 m size (sandy to gravelly) in layers b) and c).

4.2 *Measuring anchor and sensor installation*

The location for the measuring is approximately in the middle of the wall, in the highest anchor row, about 20 m above the highway, which was partially closed during construction.

During drilling works (borehole 150 mm, aligned 15° downwards) it was found, that upper 13 m (resp. 14,1 m after placement of a concrete beam) consists of weathered rock where the borehole needed to be protected by casing.

The strand anchor consists of 8 corrosion-protected standard tendons (15,7 mm, 7 wires) with a breaking strength of 2232 kN, has a total length of 27 m with a free length of 16 m and a fixed length of 10 m.

We were manually glued the FIMT sensing cables to the tendons in a factory building of ANP. There, we helically bonded it to the tendon by placing it in the gap between the outer wires of the tendon. Testing different epoxies and application techniques, we found this a good solution. We use only one sensing fiber per tendon in order to disturb the later tendon-grout interaction as little as possible. We fully bond the sensing fiber it in the fixed length, but also in the free length in order to allow studying strain behaviour in this section too. Later, when setting the anchor to its design load, we guide the FIMT through the wedge plate, which presses the monitoring anchor against the abutment, and lead it through the anchor cap to a sensing box. As there are many steps during anchor installation, stressing, testing, locking-off where fragile fiber might easily get damaged, two of the eight tendons were instrumented with a sensing fiber for redundancy.

After some days, which were given to the straight lying tendons to allow the adhesive to fully cure, the anchor was assembled, wound to a spool and transported to the construction site. There, at the forest road above the wall, it was rolled out and when laying almost straight, the outer sensing cables were attached to the corrugated pipe using an adhesive tape, Figure 3.

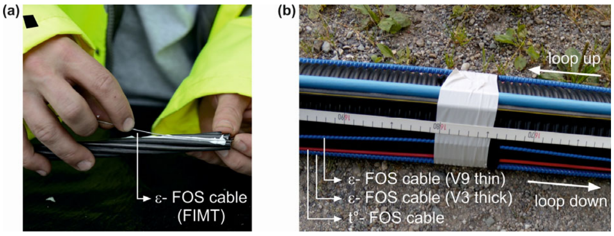

Figure 3. Outer sensing fibers attached to the corrugated pipe.

The different cable types shown before were used for strain (V3 and V9, the one with a higher robustness, the other more fragile but more sensitive), and temperature sensing. Loop configuration with opposite location on the anchor was used for all of them, in order to allow Brillouin (BOTDR) measurements too and reveal possible bending effects.

The assembled anchor was lifted up by a crane, and then slowly inserted into the borehole. Afterwards grout was injected, the casing tubes pulled out. The outer sensing cables were lead along the old wall, up to a sensing box, where the splices and patch-cords are well protected. The construction of the concrete beam followed, thus the remaining sensing cables of the tendon had to be well protected to survive mechanical works. After the approval of the loading capacity of the new structure by concrete testing, the anchor test was prepared, by leading the FIMT cables of the tendon to the sensor box and splicing patch-cords to all sensor cables.

5 MEASUREMENTS AND RESULTS OF THE TESTS

5.1 *Anchor testing*

In July 2018, the anchor was tested in accordance with EN ISO 22477-5, and subsequently locked off. We used the OBR for measurements before, during stressing and after locking off the anchor to its load of 810 kN, and all later measurements. Results were already shown and briefly discussed, e.g. in Račanský (2022).

Now, in order to gives some more insights, Figure 4 shows the arising strains during a standardised load test (prestressing to 100 kN, then loading and unloading from 100 – 600 – 100 kN, 100 – 800 – 100 kN, 100 – 1000 – 100 kN, 100 – 1250 – 100 kN, 100 – 1500 – 100 kN) and the strain after locking-off the anchor to 810 kN. All 510 single measurements are plotted. The upper surface of the concrete beam (25 cm below the wedge plate) is used as a zero-point within the graphics. For computation, a gage length of 3 cm and a spatial resolution of 1 cm were chosen. Shown data of anchor testing is not filtered. The strain values of the tendon and their corresponding positions were corrected due to helically bonding.

At the repeated load-steps, there are some offsets between the strain-curves do not perfectly fit together, as there is little variation in the applied force due to the manual regulating of the hydraulic jack. Clearly, three sections can be seen in Figure 5: (a) the grey section in the wall, where the fiber is loose in the beginning and thus shows no strain, followed by a short section of increasing strain (0,5 -1,2 m), until the full strain of the tendon is transferred to the fiber. The end of this section remains at 1,2 m over all loads, which is an important indicator that shows onsite, that the sensing fiber is properly connected to the fiber. (b) The second section shows the strain behaviour in the free length, where the tendons should be ideally uniformly strained over their length. This is the case down to 5,75 m, but further downwards, there seems to be a significant friction, which reduces part of the load applied at anchor head. Stressing the anchor, the tension in this section is lower, compared to the upper part of the free length. Contrary, the load remains on a higher strain level, when the anchor is unloaded. All tendons are guided in the free length inside standard debonding hoses (plastic sheating), which were properly sealed at the end. Thus, only small friction should come from this part. A curvature of a borehole axis, together with the rather stiff soil, which avoids straightening the anchor during loading, might be a reason for this significant friction in a free length, which we have also seen at other anchors in similar soil. Additionally, a cyclic pattern shapes on the tendon strain measurements, which might originate from the helical winding of the cable around the tendon, in case of a bend anchor. We have investigated this in detail but have to discuss it somewhere else due to a limited page number. (c) At the end of the free length, a vertical black line at 15,81 m depth (tape measurements in the factory were used to determine this position; precision less than 5 cm) indicates the beginning of the fixed length. Below this line, the load is transferred to the soil, and the larger the applied load gets, the longer this load transferring section is. For the highest applied load, the length of the transferring section was 2,95 m. The remaining 7 m of anchor bond length were not activated. Thus, this anchor has a high safety margin with respect to its ultimate bearing capacity. Optimisation of required fixed length is easily possible, when such measurements are available.

Figure 5 shows the emerging strain in the grout. Shown is the data with the robust cable V3, but data of the more sensitive V9 is alike. With increasing load, the strain in the grout gets larger at the beginning of the fixed length, increasing the length of affected section. Some differences in this region are attributed to the different soil layers. The two main tensioned sections are at about 16,6 m and 17,8 m. The latter is activated not before the highest load step, and when locking-off the anchor, part of the strain induced there remains visible. When zooming in, small strains are visible down to 19,7 m, further down, the appearing strain gets smaller than 10 µm/m.

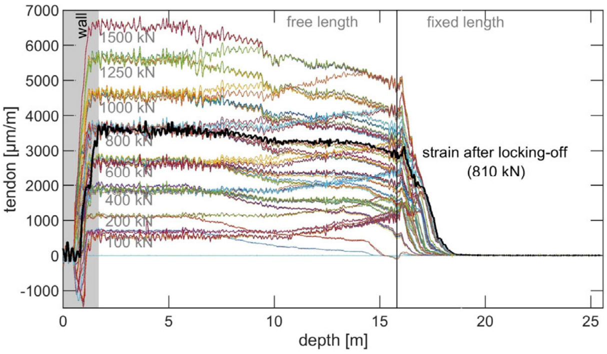

Figure 4. Emerging strain at the tendon during the load test.

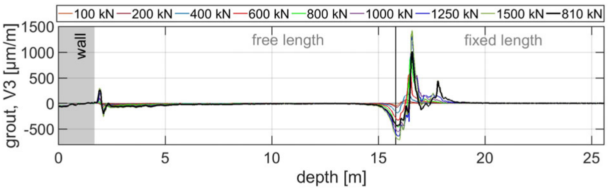

Figure 5. Emerging strain in the grout during the load test.

At the same time of loading, the soil in the free length, and thus also the grout of the anchor, gets more and more compressed. Maximum compression is found in a depth of 2,7 m with -85 µm/m, which decreases with depth and gets smaller than -10 µm/m at 10,0 m depth. But there is also a short section close below the wall (1,9 -2,3 m) which shows both, compression (-200 µm/m) and tension (300 µm/m). We assume that bending might be responsible for this effect, as the anchor is not perfectly orthogonal aligned to the concrete wall direction. We also analysed the second part of the sensor loop (placed at the opposite side of the anchor), and there appears almost the same pattern, but with a different sign, which also indicates a bending effect.

5.2 *Long term measurements*

Since anchor testing and locking-off in 2018, further measurements were taken at 9 epochs until 2025, rather sporadically and just for our own research interests to contribute to the clarification of long-term stability. The presented measurements were taken, again, with the OBR

In order to find possible creep effects and further rearrangement of the load transfer to the ground, we used a measurement taken about 15 min after locking-off the anchor as a reference. For data evaluation and computation, a gage length of 3 cm and a spatial resolution of 1 cm were chosen. Additionally, strain data at tendon was low pass filtered (MAV, 25 samples) in order to reduce the aforementioned parasitic oscillations at the tendon. Other data was also slightly filtered (MAV, 5 samples) for noise reduction.

Strain data was temperature compensated using the temperature measurements shown in Figure 6. The same figure shows the topography above the anchor for interpretation issues. As the anchor is in the highest anchor row of the wall, the overburden to the forest road is just a few meters. This obviously explains the temperature changes of about 15°C, down to about 12 m, between summer and winter. Air temperatures (summer about 20°C to 30°C, winter about -10°C to 0°C), are transferred to the soil with delay, but the sporadic measurements do not allow deeper investigation. One also has to consider, that steel tendons are a good conductor for heat, and some measurements taken at the late afternoon already show small temperature changes compared to the measurements at noon, which is very unlikely to originate from the soil. Anyway, there are 3 different measurements over the years in winter time, 2 in late spring, and 4 in summer time, which match well to each other.

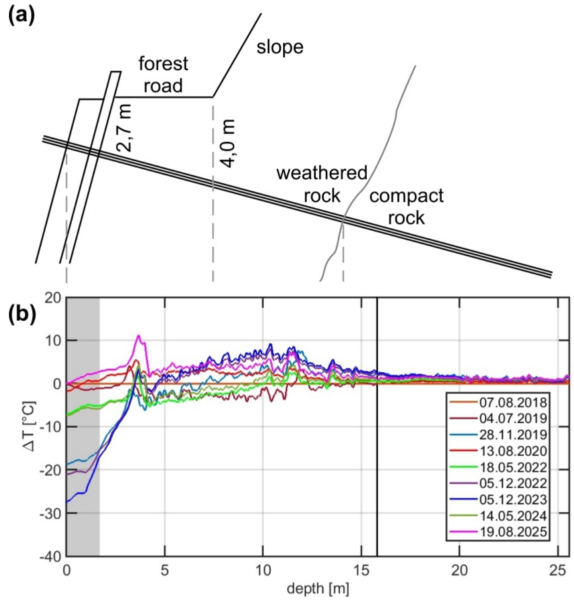

Figure 6. (a) Topography above the anchor and (b) temperature changes along the anchor measured in the grout.

Figure 7 shows the corresponding additional strain values at the tendon and in the grout, arising after locking-off the anchor. Additionally, the measured strain after locking-off the anchor (already shown in Figure 4) is plotted as a black dotted line, for better comparison of these emerging additional strains since locking-off.

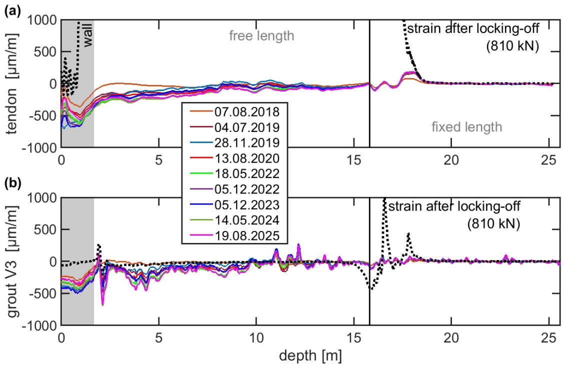

Figure 7. (a) Additional strain at the tendon and (b) in the grout since anchor locking-off.

In the bonded length of the anchor (Figure 7a), some rearrangement of the strain is visible, with a more strained section (17,3 m – 18,3m, +180µm/m), and left aside a compressed section (16,0 m – 17,3 m, -120 µm/m). This section was already activated during anchor testing at the highest loads, see Figure 4. A further activation downwards does not appear. In the free length, both sensing cables show an increasing compression with time. The closer to the wall the larger the compression (-450 µm/m in the grout; -300 µm/m at the tendon), see geology above. The anchor slowly compresses the weathered rock with time, and up to now, this compression has got about 7 times larger than the one during the anchor test! Additionally, the strains in the grout are more structured compared to those at the tendon, with stronger and less compressed sections, obviously related to the alternating soil layers or the 1 – 2 m faults. The more sensitive V9 shows in principal the same, but with little more detail (not shown here). Inside most parts of the wall, the sensing cables are loose due to the sensor protection hoses, thus data in these greyly marked sections cannot be interpreted.

6 GATHERED EXPERIENCES

6.1 *Practical issues*

Making an on-site experiment is always a delicate issue. Proper planning is needed to disturb the regular construction process as little as possible, and a site manager, who really supports these –often heard - “new, strange, and fragile technology”. Also, a specific amount of flexibility is needed, if the planned construction sequence needs suddenly to be changed.

Site conditions with dispersible dust are an issue for the instruments, but can be managed by protecting and cleaning the optical connectors more regularly.

The FIMT and the V9 have a rather fragile set-up due to their sensitiveness, and thus are not feasible for common workers at the construction site. But having a little experience, one can manage to guide the FIMT attached to the tendons through the wedges of the bearing plate, by this we never lost a fiber till yet.

Within our projects we also have teached interested personnel – far from being fiber-optic experts – how to successfully install the sensing cables on their own, even the fragile ones. However, the steel armoured V3 is robust enough, and in some of our further anchor installations, we managed to let site workers to attach these sensing cables on their own without damages. This only minimally disturbs the construction process and enhances acceptance. However, if detailed information is needed, the more sensitive and thus more fragile sensing cables have to be used.

6.2 *Sensing related issues*

There are still a few issues connected to the OBR, which still is the favourable instrument within its price class, due to its high precision and superior spatial resolution. Using the proper settings, even large strains up to several 1000 µm/m can be measured, allowing the instrument to be removed and conducting sporadic measurements. In case of too large strain, Brillouin data might help to connect the different time series. A little drawback is the limited sweep range (0,8 nm resp. 3 nm) in the 2 km mode, which would – if larger – allow measurements in different configurations, beneficial for monitoring purposes. We believe that the manufacturer could implement this today, but sensing people are only a minor group among their customers.

Some more issues are related to the sensing fibers, which usually are not designed for such large strains as they appear in geotechnical applications. We have already fixed some problems related to this and will report elsewhere in detail. It is also important to know about the sensing cables - as well as the auxiliary equipment (e.g., lead in fibers), as they might be exposed to high tempertures (in the case of direct sun exposure, or when filling the cap with petroplast for corrosion protection). Splices in these temperature exposed sections should be avoided, but larger overlengths of the sensing fibers are hard to handle within the anchor installation, testing and stressing process.

Due to the several investigations of the Solifos cables and their long experience in manufacturing fiber optic sensor cables, we still think, that these sensing cables are a good choice. Anyway, for any sensor there is a strong need for their investigation in order to find their capabilities and possible limits. Else, no reliable long-term installations are possible.

6.3 *Cost related aspects / Automation*

The installation of the sensing cables to the tendon was done manually up to now. This time-consuming operation requiring at least three persons is adding significantly to overall instrumentation costs.

We have tried - together with ANP - to automatically inlay the sensing fiber inside the single wires of the tendon, and performed specific test with these specimen, which have shown promising results. We also successfully used this technique at another anchor test. Results will be reported elsewhere.

But these trials have proved, that the development of a suitable machine for the automatic laying of the sensing cable inside the tendon would be very beneficial for our community. Automation would drop the instrumentation price and thus initiate an accelerated demand for monitoring anchors.

6.4 *Data interpretation*

Measurements during anchor stressing or testing are beneficial, to specify the mobilised length of the anchor’s bond length, which is useful for later interpretation. If long-term measurement is started after stressing, possible strain redistribution in the already activated sections might not be interpreted in a coherent manner.

From the sensorial point of view, measurements at the tendon should not be missed, as they allow the more accurate interpretation of data. They directly show the activated length of the anchor and a possible failure of one of the tendons, and thus give valuable insights. But from the financial aspect, people tend to avoid them, because of the costs arising with the effort to produce a monitoring anchor.

Contrary, also the sensing cables embedded into the grout should not be omitted, as they show the strain transition to the ground, with compressed and tensioned regions, not only in the transition zone between the bonded and the free length of the anchor, but also in case significant soil layers of different stiffness are present. Anyway, this does not come clearly out by the shown A10 data, due to the very stiff underground.

The way of attaching the outer fibers to the corrugated pipe by an adhesive tape might induce additional spikes in the signal, in the case the tape prevents the proper embedment of the sensing cable into the cement matrix. These spikes must not be falsely interpreted. Using fiber loops (also for the Brillouin measurements), and alternately attachment might help to identify these spikes. However, alternately attachment is not an easy task when the outer fibers are attached to the anchor during its inserting into the borehole, which is necessary in case of insufficient space at the site.

7 CONCLUSION AND VISION FOR THE FUTURE

Distributed fiber optic monitoring has become state of the art in geotechnical monitoring. Valuable information was gathered by various experiments of different groups. We contributed with our research to the better understanding of the strain transfer of ground anchors to the soil, and have shown that fiber optic sensors withstand harsh field conditions for several years. However, due to the large strains arising within geotechnical filed applications, sensor characteristics have to be considered to avoid misinterpretation, especially in long term monitoring.

But still, monitoring anchors are only used in critical projects, or if proper anchor installation must be proved, in order to guarantee safety, due to the extra costs. Decreasing the costs of a monitoring anchor (no fiber optic experts during anchor installation) would widen their usage in regular projects.

Using monitoring anchors within regular projects, installed in the beginning and at the geologically most critical position, would give in-situ information about the anchor behaviour and thus would allow optimising the anchor bond lengths. This either provides additional safety, or reduces costs and construction time.

An increased number of monitoring anchors would drive the automation process for the integration of the measuring fiber to the tendon. Thus, measuring anchors might be easily produced for minor extra costs and installed without any disturbance of the construction process. Slightly extended protective caps allow the sensing fiber to be stored inside, up to a moment in the future, when there is a need for monitoring and then the fiber could be activated. If accepted, each anchor might be equipped with a sensing fiber, for the costs of approx. an extra tendon, for later use, in case needed. Equipping the anchor manufacturer with a measuring instrument and providing data of a factory reference measurement, would even allow to determine the strain signal of the strained tendon by "reverse monitoring".

Anyway, for more detailed analysis, a minor number of anchors might be equipped with a strain and a temperature sensing cable for grout measurements. Sensing cables are robust enough to be installed by common workers at the construction site. Such installation is already now cost effective.

8 ACKNOWLEDGEMENTS

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