DSST CABLES

DISTRIBUTED STRAIN SENSING CABLES

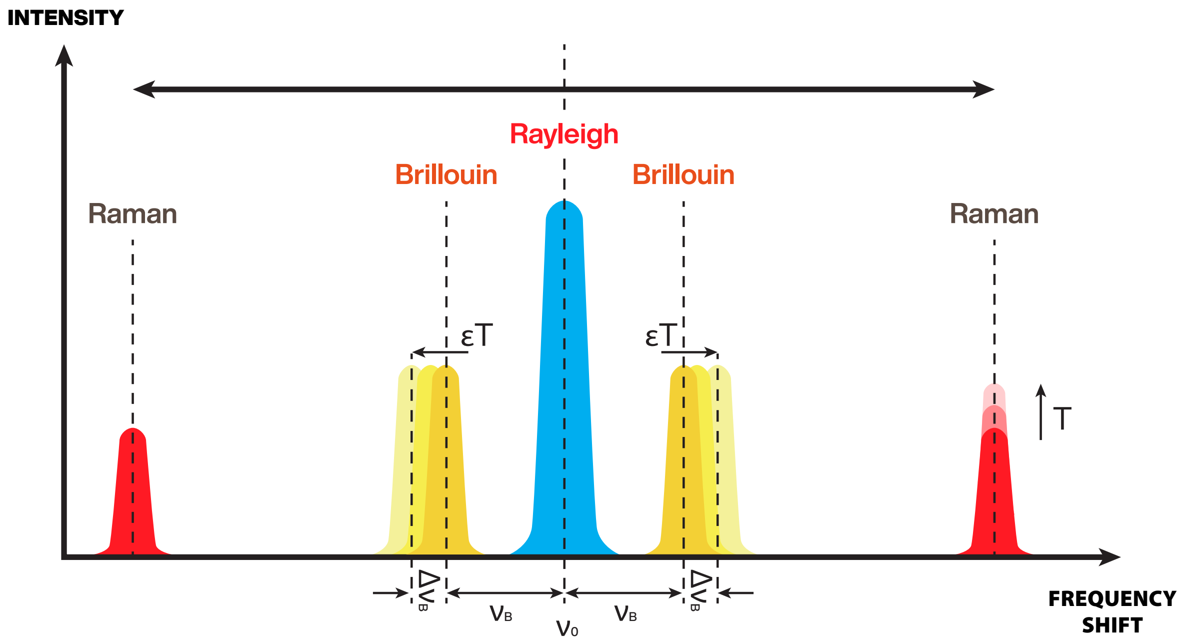
Fiber optic cables are commonly known as a telecommunication medium that permits transmission over longer distances. By introducing new solutions FIBRAIN proves that they have also other applications. This whitepaper introduces **new constructions - FIBRAIN DSST - Distributed strain sensing cable.**

Higher strength requirements that concern construction sector and even closer attention to civil safety regulations for both construction and ground structures have contributed to the significant development of monitoring methods. **Fiber optic sensors** are a relatively new, but intensively developing system to support this type of monitoring. This technology along with the truly innovative cable design is an attractive solution for the control of building and construction in real time.

Operating principle

The technology of optical sensors uses the effect that accompanies the signal transmission by a fiber optic medium. When the light impulse goes through the optical fiber, then the part of the light is scattered backwards (with no change of a wavelength) towards the source on the Rayleigh's scattering principle.

This is how OTDR optical reflectometers of work, which measure the intensity and return time of the transmitted pulse, creating the attenuation characteristics of the optical fiber line. However, apart from the Rayleigh's scattering, we can also see the scattering shifted in the wavelength range as regards the transmitted wavelength which is Raman and Brillouin scattering.



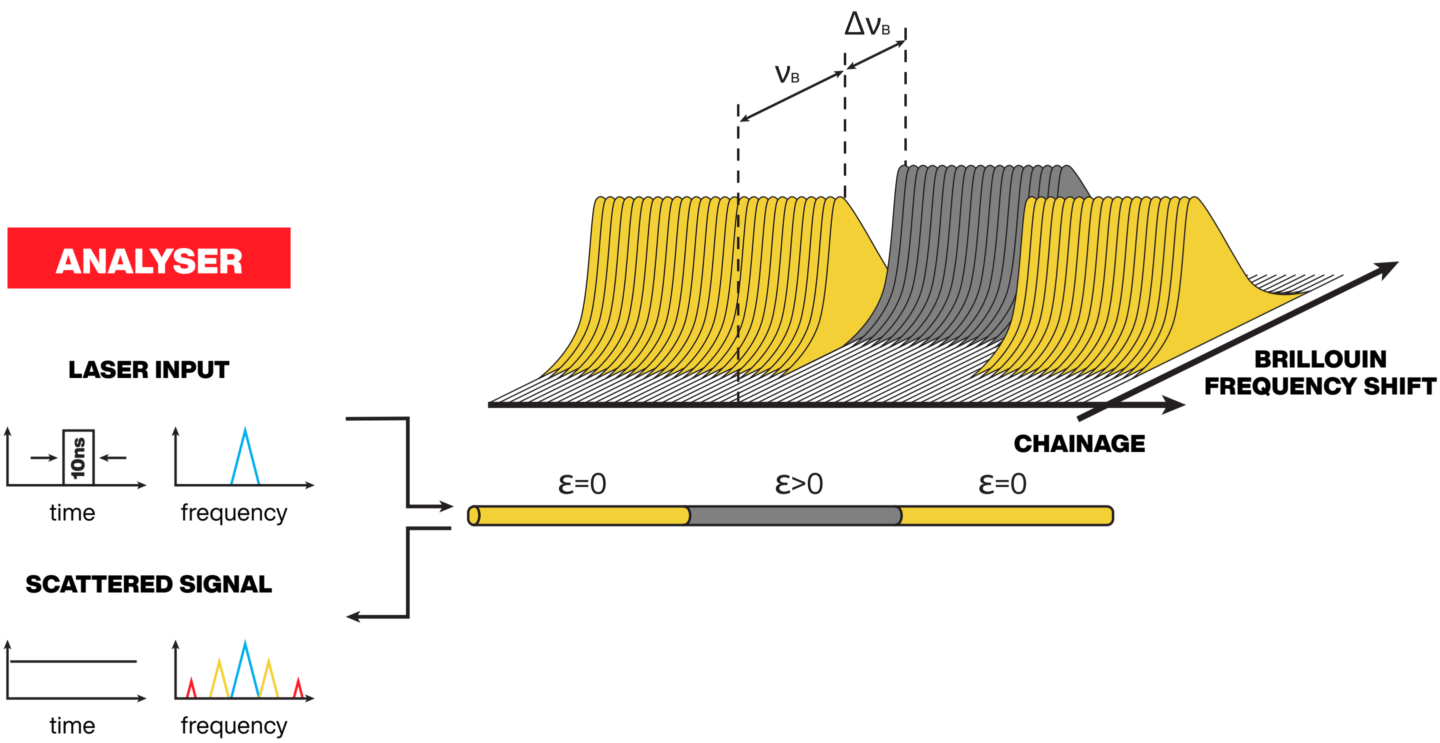
Brillouin and Raman scattering refer to the effect of interaction between the light impulse (photons) and an acoustic wave (phonons) propagating in the fiber core. This effect is characterised by a shift of frequencies compared to photons caused by the Doppler effect. As a result of Doppler effect (optical wave reflection on the acoustic wave) we observe a change in the frequency of reflected wavelength the same as in case of measurements by a speed camera. In Raman scattering, a change in the peak amplitude of a distributed signal is visible, which proportional to the temperature change. The characteristic feature of Brillouin scattering is the frequency shift of the distributed light in proportion to the change in the fiber density.

In turns, a change in density results from temperature changes in the fiber and its deformations that is caused by fiber stress. By installing the optical fiber along the monitored structure due to Brillouin's frequency of measurements in terms of transmitted wavelenght, we are able to measure a temperature change of the material as well as the relative shift of points in the measured construction.

We can enumarate two the most popular technologies for measuring the Brillouin scattering that is BOTDA and BOTDR. Brillouin Optical Time–Domain Reflectrometry is based on the detection of spontaneous scattering of the light pulse resulting from interference with the acoustic wave present in the fiber. The BOTDR generates an input pulse from one end to a single-mode optical fiber and records the Brillouin scattering generated by the pulse, at the same end of the optical fiber, thus an access to one end of the optical fiber is required. Therefore, this solution provides a possibility to measure also in the event of a failure of the optical fiber line.

In case of BOTDA Brillouin Optical Time--Domain Analysis access to both ends of the fiber line is required for measurements. From each side the light beams are transmitted to the fiber optic line through the activation of a short „pump" pulse at one end and the continuous „probe" signal at the second end of the fiber core. The imposed Brillouin scattering occurs when the difference of the pulse wavelength and the probe signal corresponds to the Brillouin frequency shift. This interaction leads to greater cattering efficiency, resulting in a transfer of energy from the pulse to the probe signal while at the same time strengthening it. Due to the high strength of a signal, deformation and temperature measurements are more accurate and the measurement range is longer than in the case of BOTDR technology.

Performing measurements on the basis of Rayleigh's scattering may be an optimal solution. Depending on the material each fiber has its own Rayleigh scattering characteristic, which causes the backscatter. As a result of stretching a fiber section, this characteristic changes (linearly with stretching or increasing temperature). Consequently, there is also a change in the intensity of the scattered signal, which can be easily detected by a suitable measuring device.



DSST cable construction

In order to achieve this groundbreaking monitoring system, it was necessary to design a new type of fiber optic cable. Standard transmission cables are designed to minimize mechanical loads directly on a fiber preventing data transmission disruption. In this case, the opposite situation is required and the most accurate load onto the fiber of the structure to which the cable is attached would be desirable.

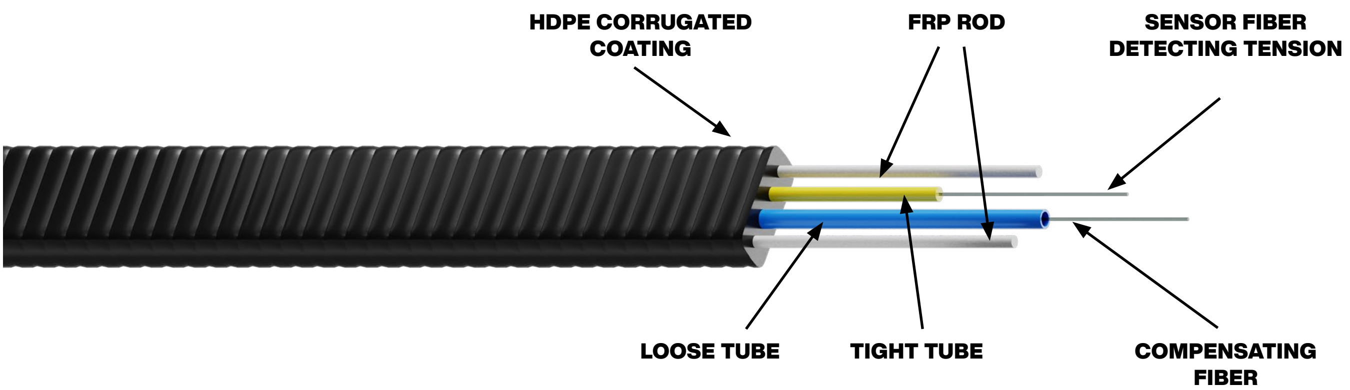
Theoretically, the ideal solution would be to apply non-insulated fibers, but then the level of protection against damage would be insufficient. There is a need for a compromise between the protection of fibers and preserving the capacity to detect deformations. In order to transfer external stresses onto fiber, it is necessary to use **a structure with the lowest slide effect between the different layers of internal cable.** It should be borne in mind that fibers are additionally protected and the stripping capacity required during installing cable is maintained.

When designing a new cable structure, it is also important to take into account the source variation of the characteristic change in the Brillouin scattering.

As mentioned before – it may be a change in the temperature and at the same time the longitudinal strain of the optical fiber. For clear identification of longitudinal stresses in a cable structure, the second fiber shall be applied that is subjected to deformations and mechanical forces at the minimal degree. As a result, these fibers may recompensate changes in temperature.

Responding to the requirements, FIBRAIN has developed an innovative design for a sensor-based DSST fiber cable. The main element protecting a fiber from external factors are two FRP rods. This cable has two optical fibers with different methods of coating and protection. The temperature compensation that was already mentioned is provided by a fiber which is in a loose tube. Such protection ensures the highest degree of independence against fiber deformations, from the stresses affecting a cable. In addition, the polyamide used for producing loose tubes guarantees a low coefficient of friction at the interface with another layer of cable structure. While, the second fiber is used to measure deformations, which is surrounded by a tight tube, so all deformations can be easily transffered on a fiber. Therefore, materials have high coefficient of friction and low coefficient of movement the individual layers towards each other.

The ratio of fiber deformation to the extension of the entire cable construction reaches 90%. The margin from 100% is required in this case, as the fiber should give the possibility of sliding to a certain extent in order to avoid early fiber breaking in case of the ideal connection between the fiber and the cable structure. This may happen in the event of excessive loading, especially cracks, which could exceed the permitted elongation for fiber breaking.



Another important thing in this respect concerns a type and shape of an outer coating to transfer external deflections directly onto fiber. This aspect is also important as the inadequate transfer of forces can degrade the entire measurement system at a large extent. In DSST construction there is a flat cross-section with a corrugated outer coating that will enable to achieve the highest degree of adhesion to the tested structure while minimising the possibility of sliding.

Testing FIBRAIN cables

The effectiveness of sensing cables was subjected to meticulous laboratory examination and tests. **The possibilities of measuring fiber deformations as well as the temperature of the compensating fibers have been checked.** At the same time, we have compared the quality tests with other leading manufacturers of sensor cables. Figure 1 shows the process of deformations in all samples which differ in the tensile force that has been applied. As a result of measurement, we can clearly identify a place where the deformation occurs -- which confirms one of the main functions of sensing cables - danger and damage location in the construction. In addition, the values obtained in the diagram are proportional to the strain that occurred, which makes it easy to assess the scale of the deformations.

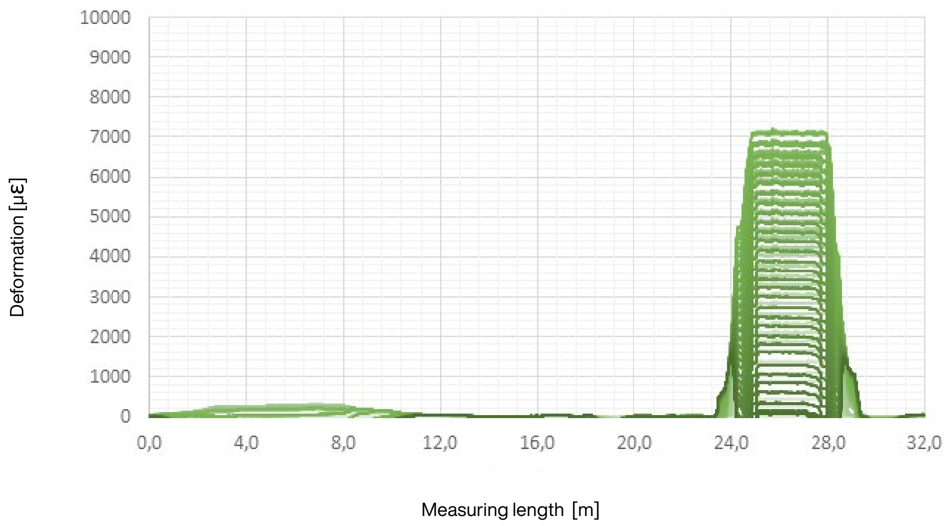
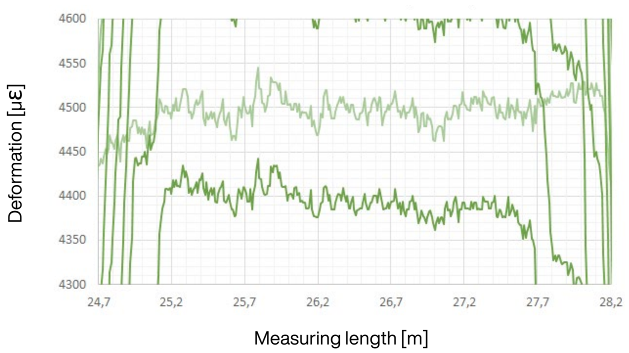


Figure 1. Deformations on a mesuring path registered by DSST FIBRAIN cables.

Still, the accuracy of measurement remains important. If this graph is analyzed at a higher measurement resolution, it can be noted that the deformation for FIBRAIN SST is approximately 100 με over the length of the measurement section (Figure 2). It is interesting to mention that the same construction from our competition reached 500 με and even more.

FIBRAIN DSST



COMPETTITIVE CONSTRUCTION

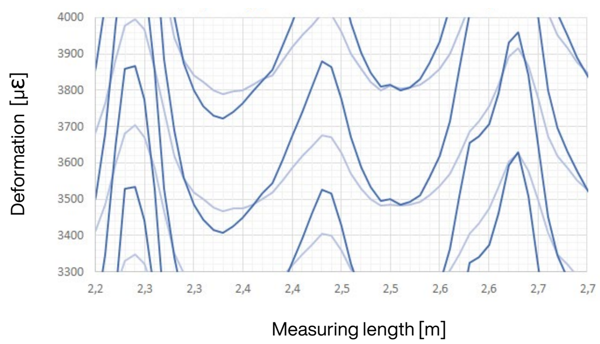


Figure 2. Spatial visualization of deformations for FIBRAIN DSST and competitive structure.

In a given test cycle in subsequent steps (P1, P2..) the applied force was increased proportionally for a half of the cycle to the preordained value, and then it was gradually decreased. According to Figure 3, averaging the values we can notice the expected linearity of the process relative to the subsequent deformation steps. It ensures an appropriate proportion between the deformation of the structure and the measurement values obtained with the aid of the sensor. It should be noted that the values obtained for FIBRAIN DSST provide smaller deviations from the expected value compared to a competitive solution.

At the same time, after taking the load from the cable, the value returned to the initial state and there was no „freeze" effect of the deformation in the second case, which could mistakenly point the continuation of the stresses in the tested structure.

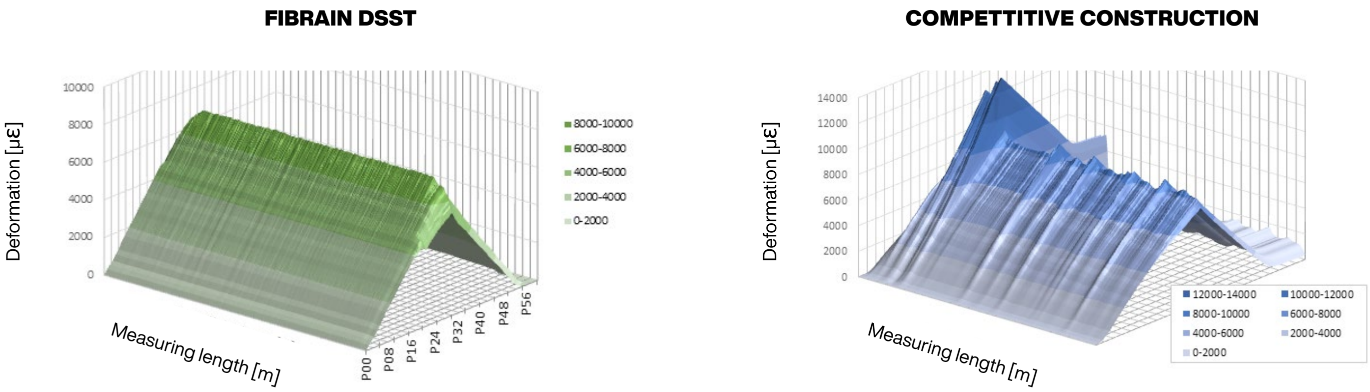


Figure 3. Spatial visualization of deformations for FIBRAIN DSST and competitive structure.

Applications

By means of a fiber optic detection system, which is spatially disposed, the conventional methods for measuring stress and deformations for a number of constructions and geotechnical structures may be substituted, including:

Landslides – – the movements of a soil initiated by crawling landslides can cause huge problems, including destroying infrastructure and buildings in the nearby area. Consequently, the assessment and monitoring of landslides is crucial, in particular for planning dams and water reservoirs, to ensure their safety during operation. At present the mapping and monitoring is based on traditional techniques such as measuring the area in geodesy. This technique requires a very dense network of markers near the landslide, which is very time-consuming for larger areas.

Flood banks – measurements are particularly important for the assessment of conditions of the flood banks during and after the floods. Fiber optic cables used in geosynthetics can provide information on the construction and also help to diagnose and support it.

Dams – Both the deformation of its structure and use of sensoring cables to locate the water leak are significant. By using a fiber that is adapted to measure the temperaturę, on the basis of the temperature change, caused by flowing water we can easily locate the water leaks.

Reinforced concrete structures – settling the ground, own weight and dynamic load are main causes of deformation. In addition, thermal reactions, disproportionate distribution of temperature and as a result various contraction in different parts of the structure causing, amongst others cracks on the surface. The use of sensing cables provides continuous monitoring of the deformation and cracks of the concrete.

Bridges – Buildings which require high accuracy measurements of deformations of elements – most common concrete and steel - both during the construction stage and using. By implementing a range of solutions related to connecting cable with the bridge structure, they can also be particularly useful for studying the current state of the older structures.

Tunnels – deformations in a tunnel can be a serious threat. It is absolutely necessary to verify the stability and reliability of construction continuously as well as to check the deformations that may appear in the-long term perspective.

Mines - the optical sensors guarantee the monitoring of the integrity of structures and production parameters at the same time, which provides early warning of possible danger. A clear advantage is the use of non-ignition material in the explosive environment.

Pipelines - Sensor cables provide continuous monitoring of the integrity of the line, locating leaks also on the basis of temperature changes. This gives the opportunity to detect critical deformation and cracks as soon as possible.

Why FIBRAIN DSST sensing cables?

In many cases, the measurement method based on sensing optical cables seems to be a more optimal approach than the standard solutions previously encountered. There are several advantages in this regard:

- A wide range of possibilities to collect data at the entire length of a measuring equipment line
- Automated and rapid data collection (replacing manual readings and operator assessment, continuous monitoring, remote measurements)
- The possibility of monitoring the structure spatially and not only single-points as in case of traditional solutions
- A possibility of integration optical sensors in geosynthetics
- Insensitivity to external factors - electrical systems, atmospheric discharges, strong electromagnetic field, moisture, chemically toxic environment
- No electrical power requirement at the points of measurement
- Small size of fiber optic cables
- A possibility to apply in hard-to-reach structures
- In some cases, the only acceptable solution
- Low cost of fiber optic cable compared to traditional devices of point measurement

Summary

Technology based on optical sensors has successfully entered the world of montoring constructions and buildings. A new FIBRAIN DSST cable fits perfectly into requirements set by this technology, demonstrating **a high quality of performed automatic readings in the laboratory measurement tests.** The use of a suitable cable structure and the system which detects deformations distributed spatially **may replace conventional methods of single-point measurement.** In many cases, the economic and social aspects support a number of technological advantages that have been described in this article.