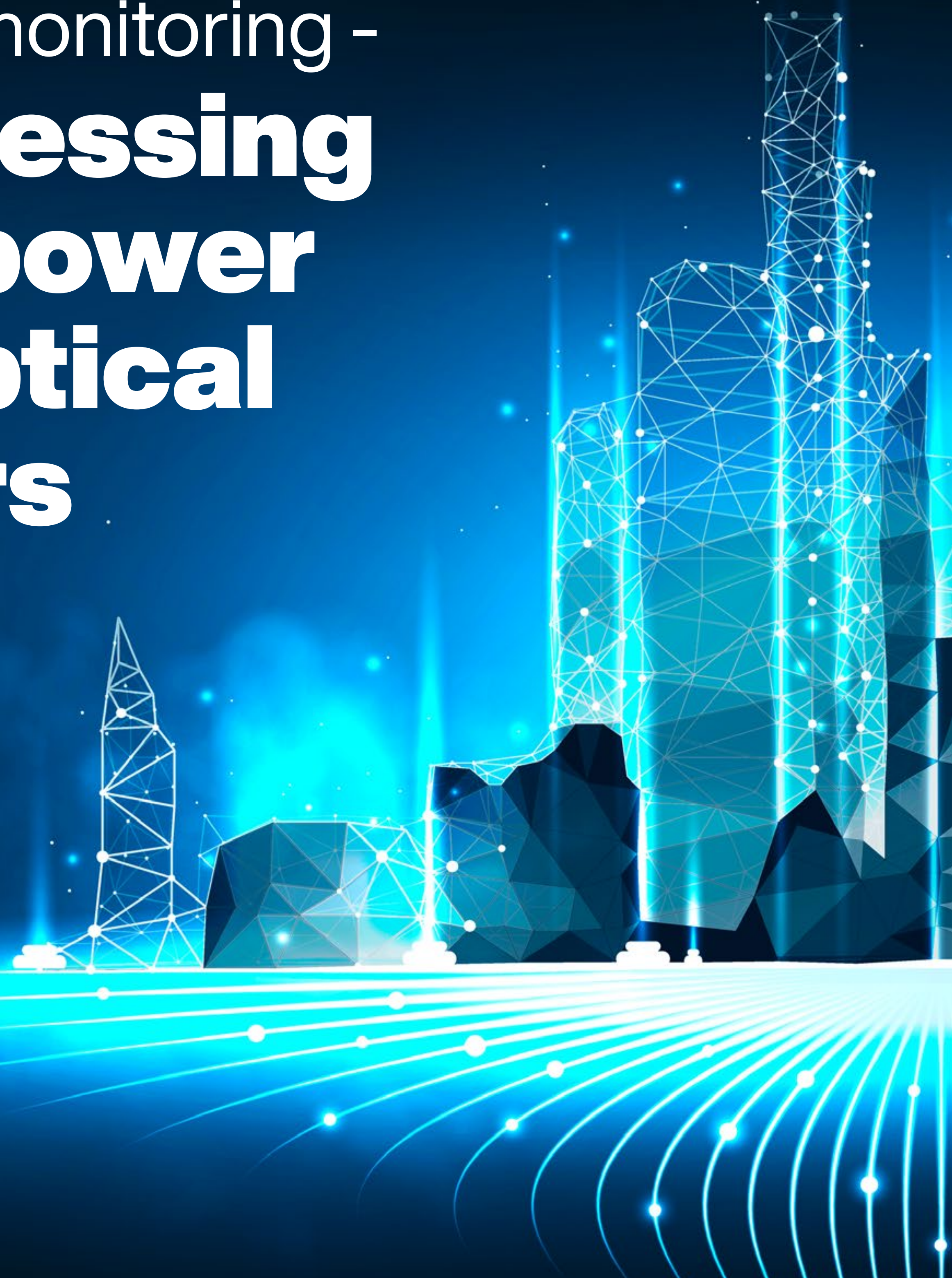
FIBRAIN

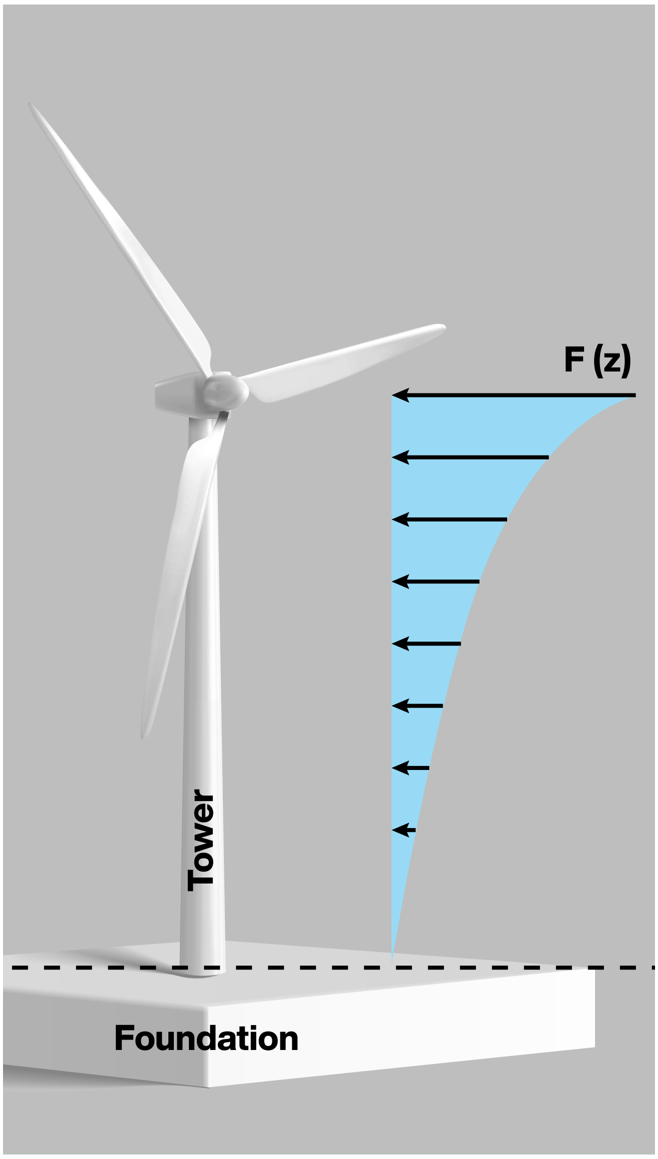
The future of structural health monitoring - **harnessing the power of optical fibers**



A Danish case-study

Low cost, safety and quick and easy construction, all simultaneously – the classic devil's triangle faced by any construction company. As investors' expectations grow, so is the pressure put on the contractors. Whether it is a wind farm, a bridge or a high-rise building **the investors and contractors alike have to carefully choose the technologies they use, to make sure their choice results in safety and efficiency,** not only during the construction phase but also (and perhaps more importantly) during operation, over tens of years down the line.

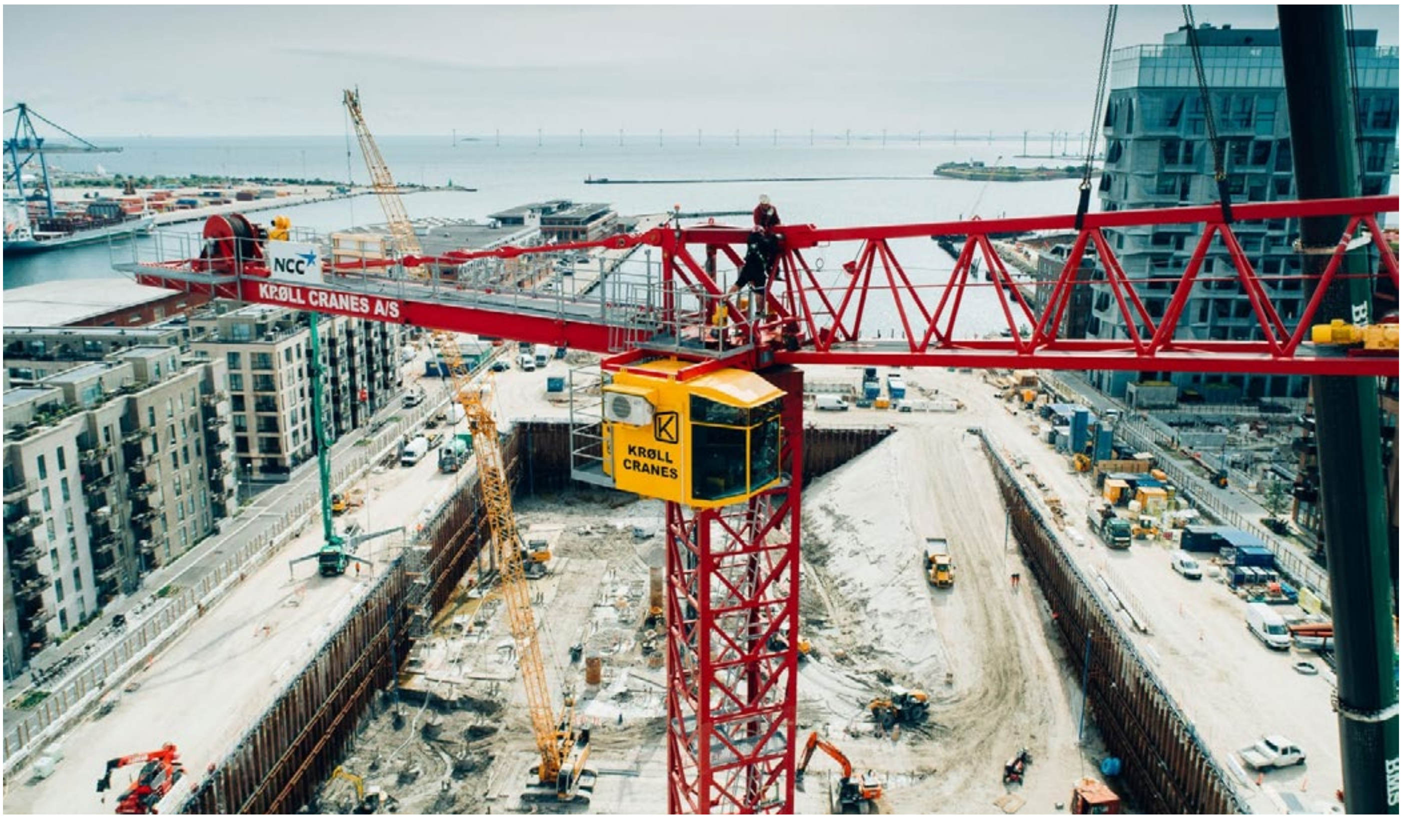
To this end, in any demanding construction project the choice of an adequate monitoring system becomes of paramount importance. For most structures, the critical parameter to monitor is the strain – think of dams, bridges, sky-scrapers and their foundations or windmills, which all have to maintain structural stability under widely varying load. That's why structural health monitoring (SHM) is so important. The traditional methods to monitor strain in such structures were to use wire strain gauges or tensometers, which (although tried-and-tested) suffer from several limitations, chiefly among them a limited spatial resolution (being discrete) or constraints on their dynamic response. Such limitations always mean compromises – if the measurement device is discrete how to make sure the gauge sits directly over the future crack location? If the device is slow how to monitor response to sudden wind gusts? How many measurement channels one would have to implement in order to try to achieve at least an approximate real-time monitoring with sensible spatial resolution?



The higher the structure the more pressing need to monitor its load

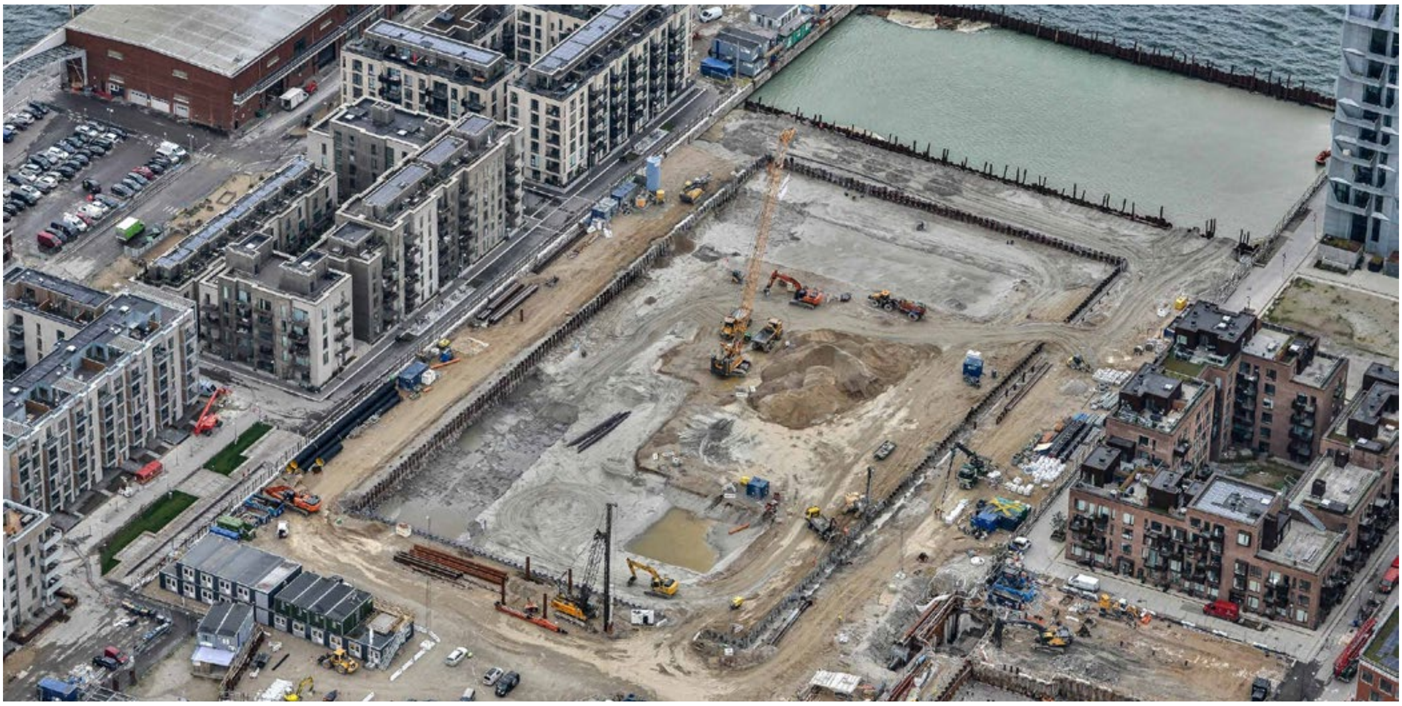
Fortunately, these problems are fairly easily overcome with the help of fiber-optic based monitoring.

In optical methods, the optical fiber itself becomes the sensing head placed in the environment or fixed on the element to be monitored. At the far end, an interrogator periodically, possibly with extremely high frequency, polls the fiber, to check for any changes in an observable optical property, as these changes directly encode information about the mechanical parameter of the actual interest. **Several different optical phenomena can be utilized for sensing, and the most important ones are stimulated Brillouin scattering (SBS), stimulated Raman scattering (SRS) or Rayleigh scattering.** All these methods allow obtaining truly distributed sensors and from the mechanical point of view their response is practically instantaneous. Additionally, optical sensors are fully passive and inherently immune to electromagnetic interference and can be made fully dielectric, therefore are well-suited to work in many difficult environments. **Not only strain, but also temperature can be monitored using the aforementioned approaches.**



source: www.kronlobsbassinet.dk

As optical sensing methods are becoming more widely known, more construction companies and investors willing to stay at the forefront of the technology employ them in the field. Here the results of a practical field implementation are reported. The construction project has been carried out by **NCC Denmark A/S** and the foundations were built by **Hercules Fundering,** a Nordic company specializing in geotechnical engineering. The construction was a residential and commercial builidng with a 4-storey underground parking located in Copenhagen.



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The deep foundation consisted of a few hundreds of bored piles installed from a working platform located 10 meters below the sea level. Obviously, boring in the ground below the sea level next to an open sea requires very specialistic know-how and equipment. **This underlines how non-trivial the described project was and why structural health monitoring was so important. To verify and potentially optimize the deep foundation design, test piles were instrumented with fiber optic cables and subjected to static loading tests.** The Rayleigh scattering-based optical approach has been used to monitor strain along the piles during the tests.

source: J. Kania, CP Test

source: A. B. Jørgensen, CP Test

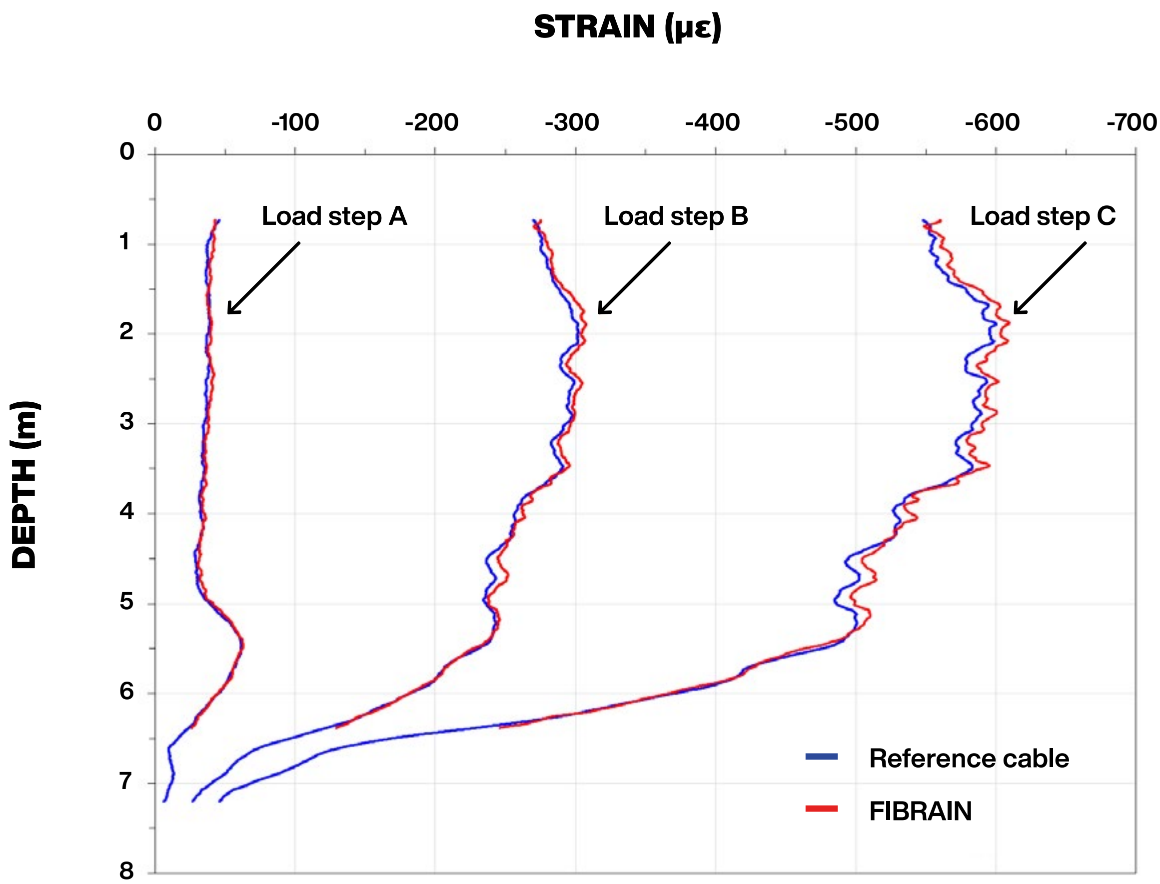
Special optical cables have been inserted vertically along the piles, next to the reinforcement bars to be able to monitor their load and deformation. The optical cables used for strain monitoring have a significantly different construction than the more standard cables used for transmission, where the typical design goal is to uncouple the optical fiber from the environment as much as possible. For the cable used for strain monitoring the tension or compression experienced by the outer cable sheath must be transferred in a linear and controlled fashion onto the fiber, so that changes in the external forces induce changes in the optical response. In the discussed project, two types of cables have been used; one was the widely-known strain cable used commonly in SHM monitoring and the other was the FIBRAIN strain and temperature sensing cable. The cables were encased in the concrete foundation piles, about 7 meters deep.

Cables from both manufactures have been fixed to the same rebar, to make sure they work in the same conditions. The first cable contains a single fiber, for strain sensing only. The FIBRAIN cable is a fully-dielectric design, with two fibers inside, one for strain monitoring, the other for temperature monitoring.

The instrumentation of the piles and static loading test campaign (involving planning, preparing, operating, logging, analysing and reporting) was performed by the pile testing specialists from **cp test A/S (Denmark)** and **DMT Gründungstechnik** GmbH (Germany) using a Luna ODiSI-B interrogation unit.

source: A. B. Jørgensen, CP Test

To check the performance of the two cables the strain data were recorded at each load step. Cables from both manufacturers were monitored sequentially, with short switching times, to reduce the effect of a possible soil creep. The graph below shows the results from three selected load steps.



source: J. Kania, CP Test

It can be seen that the responses of both cable types are virtually identical (and that the FIBRAIN cable is slightly shorter and doesn't reach the very bottom of the pile, where the strain is dissipated). It should be noted that no additional scaling or calibrating was required to obtain such agreement between the results, **which proves again the maturity of the optical monitoring technique, as well as compatibility of the sensing cables from the compared manufacturers.**