Making visible the invisible

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Using distributed fibre optics sensors to visualise underground concrete structures

A TEAM at the University of Cambridge's Centre for Smart Infrastructure (CSIC) is embedding networks of fibre optic temperature and strain sensors into subsurface concrete structures such as piles and diaphragm walls during their construction. These sensors enable engineers to measure the strain field and temperature in multi-dimensional space and visualise the condition of the underground structure in a manner which would otherwise not be possible. Such a technique provides the engineer with insights in how the structure has engaged with its surrounding ground, and whether during the construction of the structure any defects have formed which might impact on its function.

What consultants want to know

The construction of cast in-situ foundation elements relies heavily on a contractor's workmanship and its experience with the ground conditions encountered. This makes these elements particularly vulnerable to structural defects and variables in construction quality.

It is therefore vital to verify the construction quality of individual elements, as each can affect the performance of a whole foundation system. However, direct visual inspection of these buried elements is impossible in most cases — if not impractical — and also unsafe.

Temperature and strain measurements can provide especially useful information for design and quality assurance of foundation elements. By measuring the heat of hydration generated during concrete curing, it is possible to evaluate the structural integrity of these elements.

During pile load tests, monitoring the development of strain provides critical information on the structural performance of a particular foundation design. Where it is impractical or uneconomical to test full-scale piles, load tests may be carried out on smaller piles. Test results and strain measurements can then be extrapolated as permitted by design codes.

For close to a decade, researchers at the University of Cambridge have been working to develop embedded distributed fibre optic sensing (DFOS) techniques for concrete construction. Now driven by CSIC, the promising research boasts a growing portfolio of laboratory tests and on-site installations.

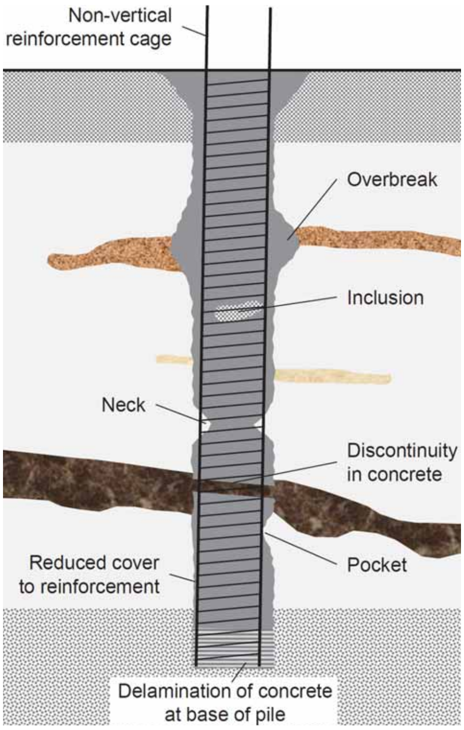

Figure 1: Possible defects in piles.

DFOS

DFOS can capture strain and temperature data from within a concrete structure, effectively allowing engineers to 'see from within'. Fibre optic cables are embedded into the concrete and the entire cable effectively acts as a sensor — a little like the nerves in our bodies. As the name suggests, the nature of the information produced is distributed continuously along a given length of fibre, rather than focused at discrete points. As light travels through the cable a small fraction is reflected (backscattered). The properties of this reflected light are sensitive to changes in strain and temperature in the cable. When a portion of cable is exposed to a change, the light reflected from that region is

Figure 2: Lowering the cage segment. Engineers have pre-instrumented the rebar cage of a pile about to be constructed. The fibre optic sensors (two are deployed, one for temperature measurement and one for strain measurement) are attached to the steel rebar in a mesh pattern, allowing strain and temperature to be measured at multiple points in a 2D array surrounding the pile itself.

There is potential to paint a complete story of a pile's behaviour from very early to advanced stages of its life.

Figure 3: Rebar and sensor network in place. The rebar cage is now in place in the excavated pile cavity. It is now ready for the pouring of concrete which will fully surround the sensors attached to the rebar, which will then become part of the completed foundation structure.

altered and the changes can be located and quantified. What is observed in the cable can then be used to infer the behaviour of the structure in which it is embedded.

DFOS has been successfully implemented on several piling load tests to capture strain development. The technology is also being implemented in studies on geothermal piling and their behaviour under temperature loads.

The capability to use either strain, temperature or both to give a picture of the integrity (geometry and quality of construction) of a pile is currently being investigated by researchers. With a single unified data capture system such as DFOS there is potential to paint a complete story of a pile's behaviour from very early to advanced stages of its life and operation. The key advantages to using DFOS are:

- Strain and temperature data can be measured over a wide area and develop a mesh layer of sensor data.
- One system may be used to measure structural integrity and load capability.
- The sensors offer a low level of intrusion in the structure when in use.
- The entire cable itself is the sensor.

Conclusions

Distributed fibre optic temperature and strain sensors are providing a new approach to the assessment of structures. By instrumenting a wide area of a structure, they allow a multidimensional 'picture' of the measurand to be visualised, in a manner that would be difficult to do in any other way.

The research team is expecting to be able to deliver better insights into subsurface structural performance and integrity, and able to provide a better understanding of structures above and beyond what is possible with current measurement techniques.

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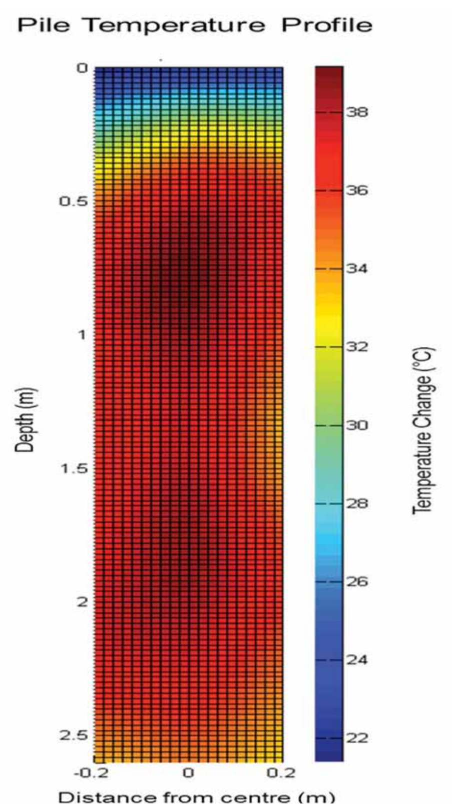

Figure 5: Temperature distribution within a pile. The chart shows a plot of the temperature field inside an as-cast pile from the centre of the pile to its outer boundaries.

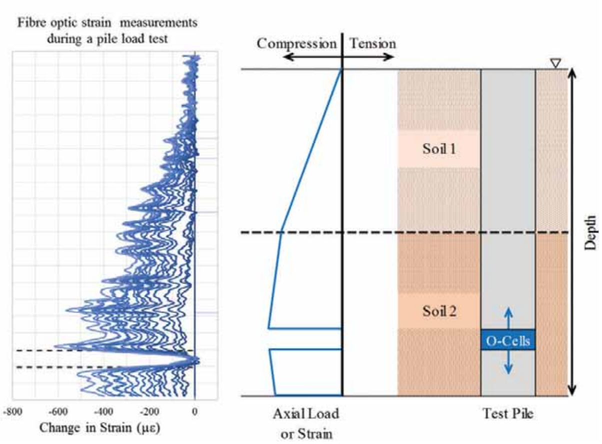

Figure 4: Distributed strain data in the pile.