Monitoring performance of reinforced concrete piles

Benefit to
Designers, piling contractors

Impact and value
- cost-effective
- provides multi-metric distributed monitoring
- enables better understanding of performance of as-built pile

Distributed fibre optic sensing for pile monitoring

Traditionally strain gauges and extensometers have been used to monitor reinforced concrete piles. However, the information that they can provide is limited as they only return measurements at discrete points rather than along the entire length of the pile. The University of Cambridge and CSIC have been developing distributed fibre optic sensor (DFOS) systems for monitoring different types of infrastructure over the past 10 years. DFOS is ideal for monitoring strain or temperature over distance or area, and particularly useful for detecting phenomena such as cracks, material anomalies or embedded defects that cannot be observed with point sensors.

The advantages of monitoring piles with DFOS is that, with a single instrumentation, one can measure the concrete curing temperature as well as strain and displacement during pile testing or during the operational phase of a working pile. DFOS provides a complete profile along several sides and down the entire depth of the pile, thus delivering more information than strain gauges or extensometers that provide measurements only at single points.

Better smarter monitoring

Figure 1a demonstrates the importance of obtaining a continuous measurement profile along the whole depth of a pile – an advantage of using DFOS. Here, data from a compression test pile show the concrete curing temperature at regular intervals. The concrete reached peak temperature after about 34 hours. Normally the temperature profile would be fairly uniform along the whole depth. However, in this case, there is a clear rise in peak temperature at about 17m depth. This is indicative of an anomaly; for example a larger pile diameter due to a localised overbreak, or a soil inclusion or air void that is preventing the heat of hydration from dissipating. This pile was also tested with cross-hole sonic logging by an independent contractor, which confirmed the presence of an anomaly at the same location.

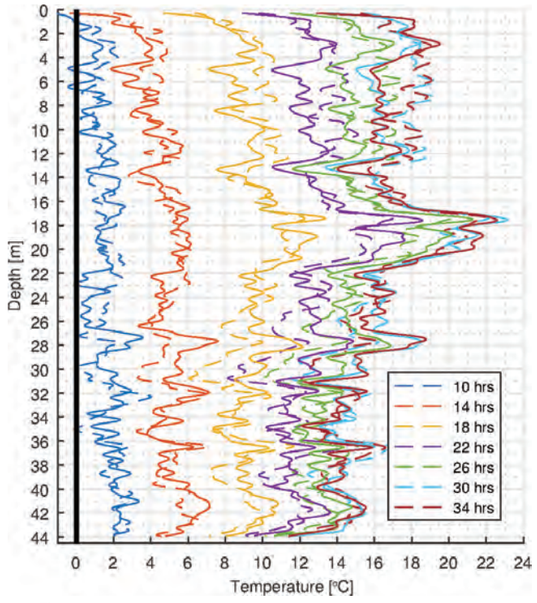

Figure 1a

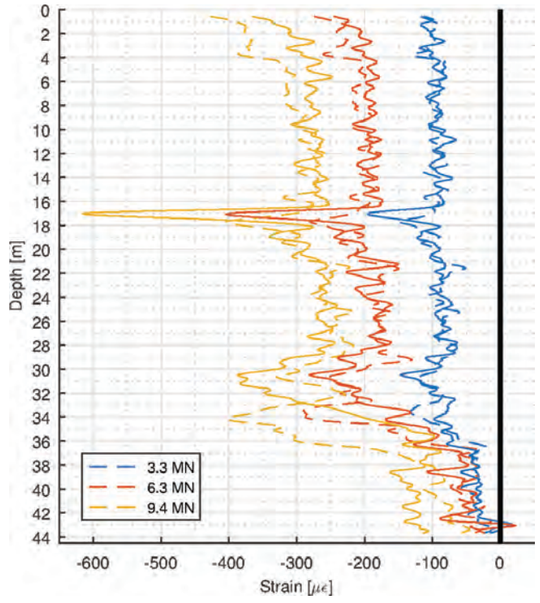

Figure 1b

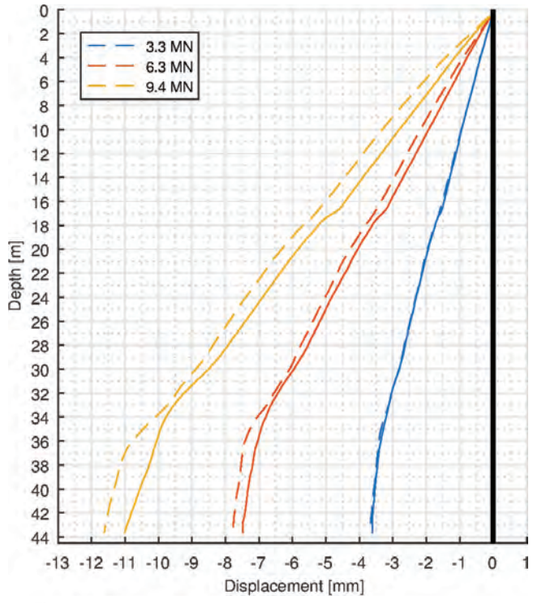

Figure 1c

Figure 1. Profiles of (1a) concrete curing temperature, (1b) load test strain and (1c) load test displacement obtained from two opposite sides (solid lines and dashed lines) of a test pile monitored with DFOS.

The pile was then tested using a standard static load test. The strain profile was plotted for every load step and a very distinctive spike in compressive strain was observed at the location of the suspected anomaly, mainly on one side of the pile, confirming the presence of a very localised weak spot in the pile (Figure 1b). This information could not have been acquired by an embedded vibrating wire strain gauge. Even if there was a gauge at this exact location, it is likely the gauge would be thought to be faulty and its readings ignored. An added bonus to the continuous strain profile is the ability to obtain a profile of the pile's displacement with depth, relative to the pile head, with an accuracy of around a tenth of a millimetre (Figure 1c).

> We have used DFOS provided by CSIC for both thermal integrity testing and instrumenting preliminary test piles. For both purposes, DFOS has been extremely valuable in confirming and correcting the data from traditional instrumentation. However, the real difference with DFOS is the provision of a continuous profile of data down the full pile length, not just at discrete locations. This is something traditional instrumentation just cannot do.
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Industry ready

After many field trials and incremental improvements, CSIC has developed the capability and processes to enable fast and easy installation of DFOS, which has led to rapid industry uptake in the past two years. DFOS monitoring is now specified in the 3rd edition of the *ICE Specification for piling and embedded retaining walls* (SPERW)[1] which CSIC contributed to. Following initial training on site by CSIC, the fibre optic cables can be installed by the piling contractor's operatives under the supervision of CSIC specialists. The cables are attached along the length of the pile cage, on two or more sides, and can also be installed on central rebar bundles. Monitoring can start from the moment the cage is inserted into the pile bore to be concreted. DFOS can be used to monitor sacrificial test piles or working piles, comprising one or more cages. It has been used in bored piles and continuous flight auger (CFA) piles, and in both tension and compression piles. CSIC provides DFOS pile monitoring as a commercial service in partnership with the spinout company, Epsimon Ltd. In the past year, the CSIC/Epsimon partnership has carried out pile monitoring projects at a number of major construction sites in London.

Cost effective

Since DFOS enables many measurement points per metre of cable, it is a cost effective technology for pile monitoring as the equivalent cost per sensing point is very low compared with traditional point measurement sensors. Most of the capital investment relates to the optical spectrum analyser, which can be used to monitor several piles simultaneously, or be shared across different sites. However, in the vast majority of projects it is the monitoring service provider, such as CSIC/Epsimon, that owns the analyser and provides it as part of the service, thus reducing the cost of the monitoring project significantly.

[1] ICE Specification for piling and embedded retaining walls, Third Edition, ICE Publishing, 2017. ISBN 9780-0-7277-6157-6

An instrumented CFA pile cage being inserted into the pile bore

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