THE EVALUATION OF HARDENED, CONVENTIONAL, DENSE, REINFORCED CONCRETE

There seems recently to have developed a barrage of complex instrumentation to do simple things. Here, **Simon Bladon** of **CRL Surveys** says that whereas one can see the benefit of replacing a couple of twigs with a box of matches or (non-disposable) lighter, replacing them with a thermal camera is missing the point. Nothing wrong with a thermal camera, at the right time and place. Visual inspection and (delamination) hammer testing, on the face of it, are the simplest and in many instances the most useful tools in the box. However, labelled as 'simple', they are, if done properly, time-consuming and therefore often delegated to the inexperienced and therefore cheapest operatives on-site.

MAIN IMAGE: Hammer testing and removal ('make-safe') of loose material.

The reliability of any pair of eyes depends upon the experience and thoroughness behind them. Lighting conditions change seasonally and throughout the day, and are especially challenging during night shifts. Cracks can be 'closed' in colder conditions, or when the structure (eg, a car park) is unloaded. However, when it warms up, and/or becomes loaded, cracks can open. So be aware and record when your 'snapshot' was taken and all the conditions pertaining.

(Lump) hammer testing is probably the most misunderstood and abused test, with the common assumption that hitting the surface every 300mm, on an orthogonal grid, will do (or is all that lump hammers can do). Not so. The hammer is used to impart energy in the form of vibrations, like seismic waves, with the response of the substrate monitored audibly. Hitting or 'rubbing' surfaces induces vibrations with varying energies and penetration, and similarly to seismic waves, they reflect off discontinuities, such as cracks and voids, or dissipate into sound concrete. Hitting picks up defects at greater depth, rubbing at shallower depth, with the latter allowing use on thin precast panels or cavity brickwork, where hitting just confirms the presence of the cavity behind.

Although 'simple', the importance of visual inspection and hammer testing cannot be underestimated, whether being used to monitor a structure, assess the significance or

TOP LEFT:
A close quarters visual inspection and recording onto drawings.

TOP RIGHT:
Assessments of previous repairs are needed to evaluate failures and promote better practice.

ABOVE:
A detailed covermeter survey to detail the reinforcement.

ABOVE RIGHT:
Structures can be very complex, multi-faceted with many surfaces out of site remotely.

Hammer testing can be undertaken on thin panels, using the right methodology.

NEAR RIGHT:
Structures in remote locations need special attention to construction faults.

FAR RIGHT:
Key infrastructure such as substations also need Inspection, Maintenance and Repair, but may not be seen as 'sexy' enough by some.

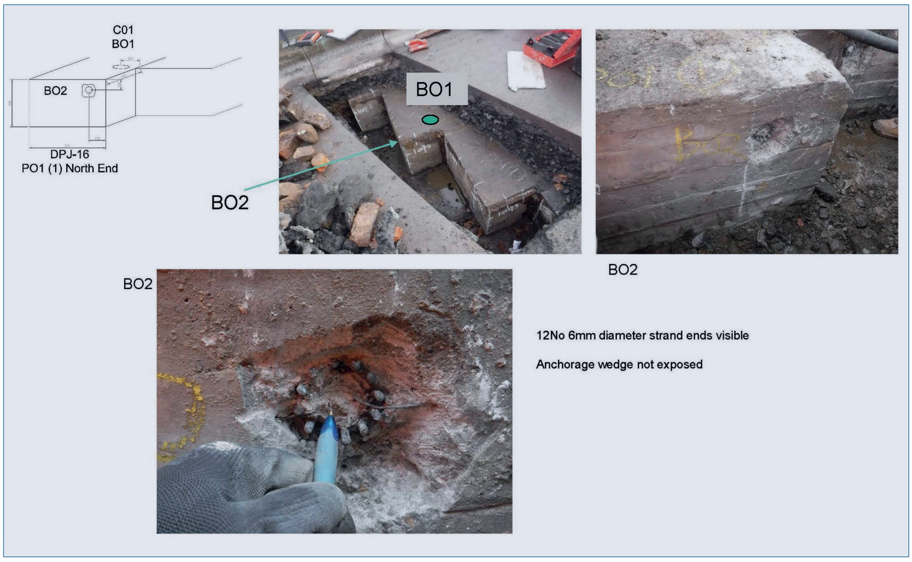
severity of damage, or put together a Schedule of Patina, Dilapidations and Defects, with the latter for a repair Bill of Quantities.

Photogrammetry and other technologies have developed to the point where extremely detailed and accurate models can now be prepared. Using drones and other remotes, data for detailed models can be collected on-site rapidly and, in some cases, without putting personnel in harm's way – all great and worthwhile positives.

However, interrogation and interpretation of the models must remain thorough and therefore time-consuming (although someone will, or may be already has, recruited AI to speed things up).

Regardless, those undertaking such remote inspection(s) still need to be trained and experienced, ie, knowing what they're looking at, where to drill deeper into the models and what it all means. If not, as an industry, we're no further forward and even more vulnerable to the charlatans.

The development of technology always seems to go hand in hand with the development of computer-generated imaging – the pretty pictures, the 'wow' factor – but we should also ask how these are put together. Do the programmers etc know what we're looking for? The author once discussed with a physicist what the output from his scanners meant. He described, precisely, lapped bars, enabling accurate measurements of lap lengths. "What are lapped bars?" was his response.



Conventional optical camera, LiDAR, thermal imaging and radar can all be used to collect useful data, but the more remote we become and the wider the separation from face-to-face interactions, the more we need to question and interrogate. Unfortunately, this is not always easy, as manufacturers of the kit seek to maintain trade secrets.

Once we have established the general form and condition, we need to develop a sampling and testing plan, selecting areas of interest, spread equally across the structure and in terms of condition, representative of the 'good', the 'bad' and the 'indifferent'. We would then variously undertake the following:

ASSESSMENTS OF CONCRETE MATERIAL CONDITION

This fundamentally remains the same as it always was, ie, in-situ evaluations of cover to reinforcement and testing for depths of carbonation, with sampling for chemical analysis, eg, for chloride, sulfate, alkali-metals and/or other potentially aggressive agents, with selection driven by structure/building type and environments of exposure.

In this context, generally, the covermeter still does not need to be overly complicated, nor produce images of reinforcement distribution and detailing. If it has been calibrated, and its limitations, precision and accuracy are understood, it will be sufficient for use by a trained operative. It is important to directly measure and record the original 'as-cast' depths of cover at spalled locations, assess any repeating patterns or locations of spalling and include those locations elsewhere on the structure in your sampling and testing plan.

Sampling of the concrete for chemical analysis will mostly comprise the collection of drilled dust. Points to consider are the size of drill bit to be used. As most concrete will have a relatively large/coarse aggregate, eg, up to 25mm, the drill bit should be at least 25mm diameter and the holes drilled to depths greater than 25mm and multiple holes drilled at each location. This ensures that the dust sampled is representative of the concrete, not just the aggregate, as well as ensuring that sufficient dust is collected.

If exposure conditions dictate, drilled dust sampling can be done incrementally, ie, taking separate subsamples at different depths, to evaluate penetration of externally derived agents.

Testing for depths of carbonation, to minimise damage elsewhere, should be done on the drilled holes. This is normally done by producing a freshly broken edge, breaking out the 'bridge' between neighbouring holes and, after blowing clear of dust, spraying with a solution of phenolphthalein indicator. Do not spray the dust or the holes 'as drilled'. Hardened concrete always contains unhydrated cement grains, which become hydrated by the water in the solution of phenolphthalein, releasing 'new' alkalis so everything goes 'pink'. If you find that the depths of carbonation are initially deeper and the 'pink' discolouration recovers to a shallower depth over a few seconds or minutes, this again probably indicates test-driven hydration of unhydrated cement. Also, you don't need biblical floods of solution running everywhere to hide the true picture: it may dry out and fade, but it comes back in full colour for years afterwards, when it rains.

Important note – read the CoSHH Assessment Sheet; phenolphthalein is highly flammable, but also acts as a pretty good laxative, so remember to wash your hands after use.

Petrographical analysis can be used to evaluate carbonation but be aware that phenolphthalein is a pH indicator, which will pick up changes at depth where the potential for corrosion changes. It's a blunt tool, but it generally works. Petrographical analysis identifies the surface zones of recrystallisation, the results of surface absorption and reaction with carbon dioxide. Depths of carbonation determined by phenolphthalein indicator will commonly be less than those determined by petrographical analysis.

REINFORCEMENT CORROSION CONDITION

Traditionally, the potential for reinforcement corrosion has been assessed using the measurement of half-cell potential, with the rate of reinforcement corrosion assessed by the measurement of resistivity.

Modern half-cell kit uses silver–silver chloride electrodes, as older copper–copper sulfate electrodes are prone to contamination and need regular recharging.

Measurements of resistivity will generally be recorded using a four-probe Wenner array, which facilitates surface measurements, as opposed to two-probe devices that require holes to be drilled into the concrete.

The corrosion rate of the reinforcement can be measured

OPPOSITE PAGE, LEFT:
Details buried deeply in complex structures, where NDT couldn't find them.

OPPOSITE PAGE, RIGHT:
Evaluations of corrosion condition and losses in section need, hands on, close scrutiny.

RIGHT:
A Great structure, with lots of detail, needs everything in the toolbox.

BELOW:
In many cases, there is no substitute for getting the right pair of eyes close to the structure.

using linear polarisation resistance (LPR), but by comparison with taking half-cell potential measurements, the equipment is relatively expensive and testing at each location can take several minutes.

These methods and the science behind them are understood and time-served, with, more importantly, their limitations understood. They have become important additional tools in the box.

More recent developments with radar and various magnetic resonance techniques show promise and may one day replace, or more likely sit alongside, half-cell, resistivity and LPR.

However, at present, the developers and their partners seem to be holding their cards close. As we tend not to accept things at face value, trust needs to be earned; we need to know how these instruments work, what they're imparting, the responses and what programming is done to the data to produce the pretty pictures. We need to supply clients with results that we can believe in, trust and stand by, and not just to protect our reputations and insurance. Our reports allow clients to make important, costly and long-term decisions; they need to be right.

INTRUSIVE STRUCTURAL INVESTIGATIONS

CONCRETE STRENGTH

If possible, core specimens should always be the way forward. Specimens, or parts thereof, and the debris following testing can also be used for a variety of other procedures, with due regard for changes in sample condition.

However, where coring is not prudent or possible, the determination of rebound number can give a reasonable idea of possible strength.

REINFORCEMENT AND HIDDEN DETAILING

In many scenarios, this is where the high-tech equipment comes into its own, with NDT instrumentation including radar and ultrasonic tomography vastly improving the 'old school' consultation of limited as-built drawings, tape measure and 'X' marks the spot. These techniques can enable the accurate location and investigation of potentially sensitive details, potentially reducing the need for extensive and damaging breaking out, with the latter, depending on the making-good afterwards, becoming additional vulnerable points going forward.

However, be aware that these techniques are better where the target details are embedded within relatively uncomplicated structures, eg, long, straight duct/tendon runs, where access to surfaces is relatively straightforward. These newer techniques facilitate much greater penetration in these locations and enable carefully targeted intrusions, where needed. But the devil is in the detail, especially where compromised tendon runs have been identified, can become of even greater significance and could be hidden in more complex positions. Panel walls, diaphragms, reinforced infills and toppings, and more densely congested reinforcement can make some details difficult, if not impossible, to resolve. In these scenarios, we need to maintain our 'old school' skill sets but now using radar and tomography to greatly reduce the extent of breaking out. And it's worth pointing out that breaking out, regardless of the impressions given in some quarters, was always minimised and the author's experience was never undertaken by the implied Neanderthals. C