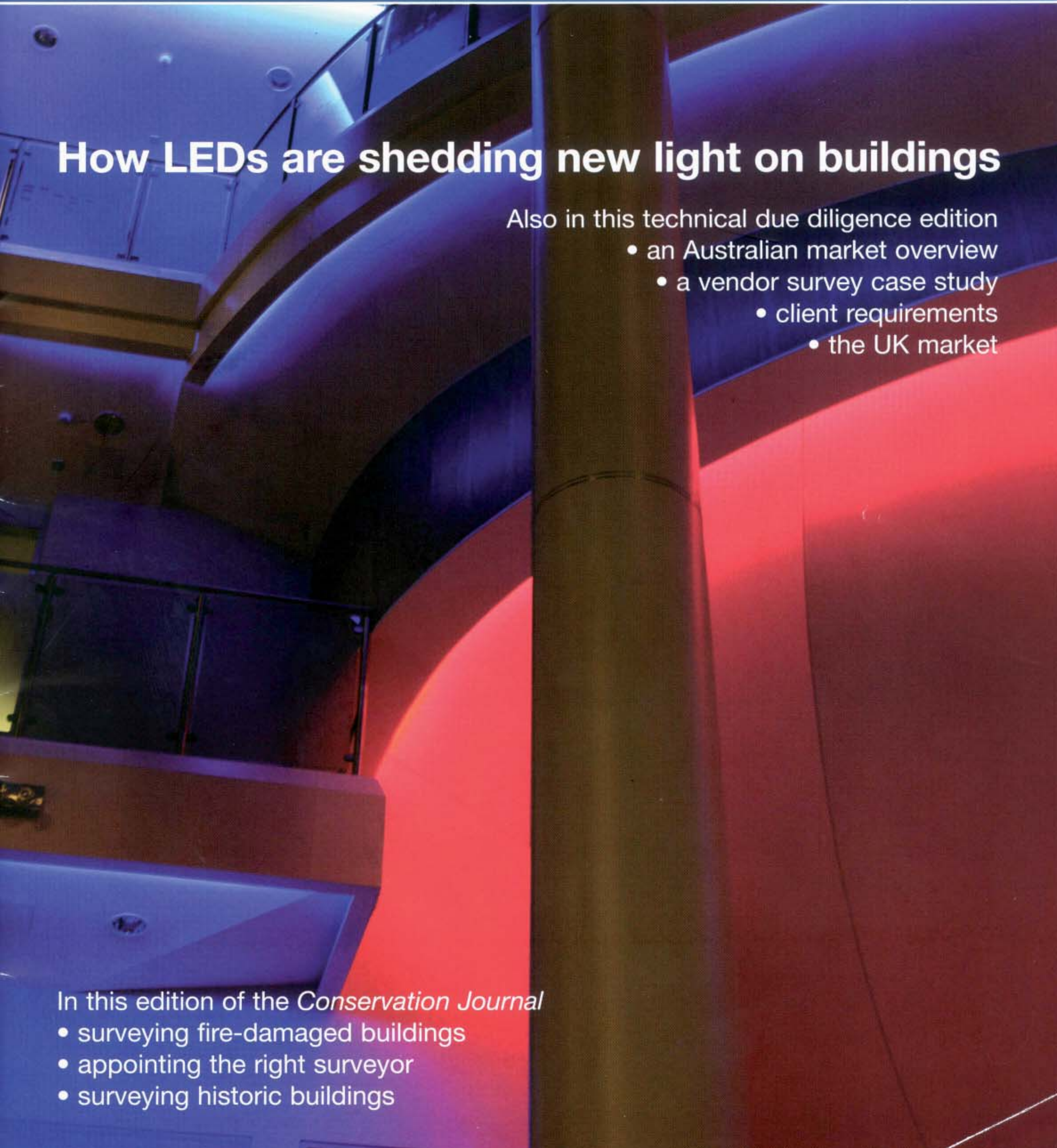
RICS
the mark of property professionalism worldwide

October-November 2010

rics.org/journals

Building Surveying Journal

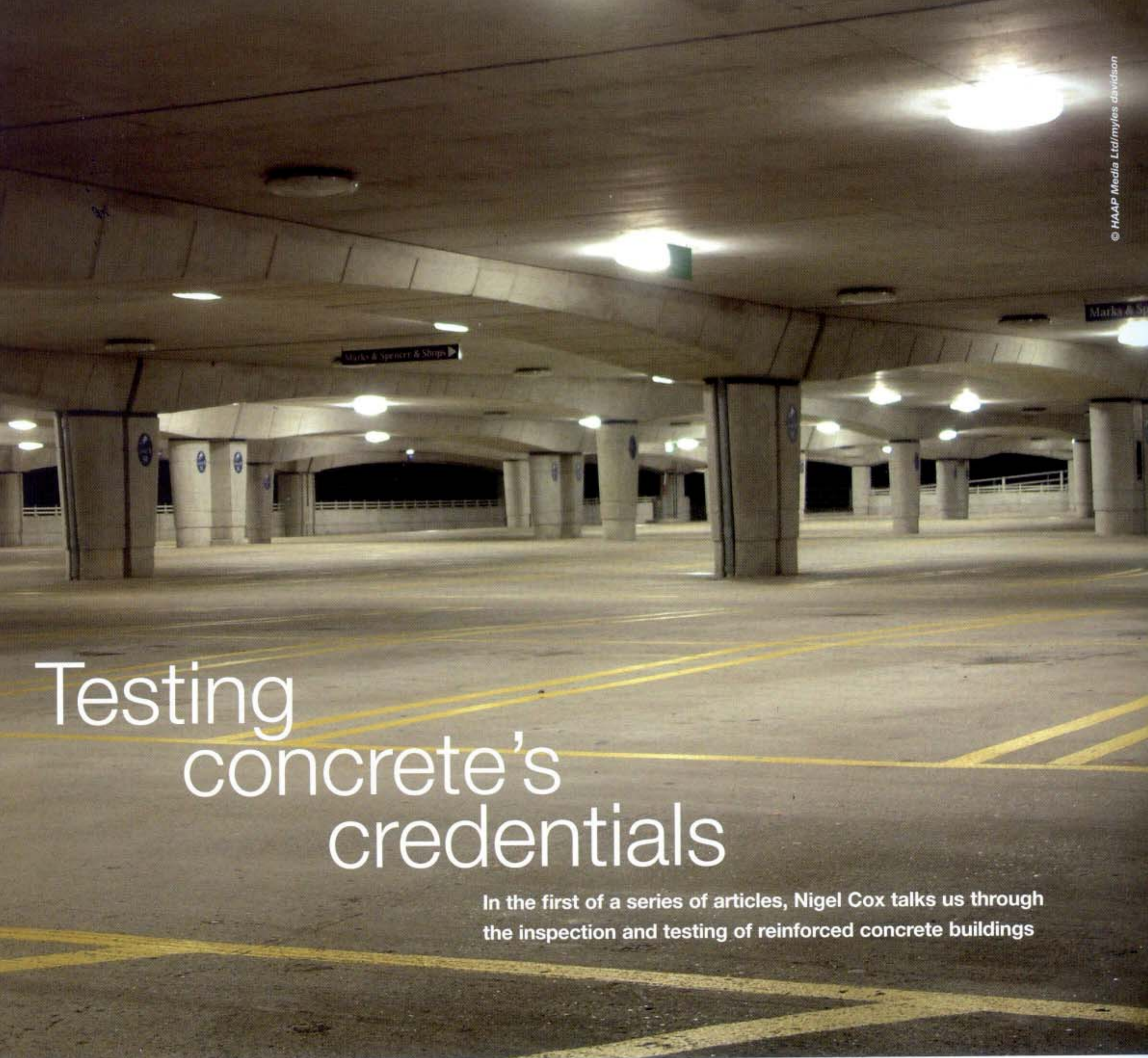
Incorporating the Building Conservation Journal



How LEDs are shedding new light on buildings

Also in this technical due diligence edition
- an Australian market overview
- a vendor survey case study
- client requirements
- the UK market

In this edition of the *Conservation Journal*
- surveying fire-damaged buildings
- appointing the right surveyor
- surveying historic buildings



Testing concrete's credentials

In the first of a series of articles, Nigel Cox talks us through the inspection and testing of reinforced concrete buildings

Typical levels in decks of multi-storey car parks can often exceed 2.5% of chlorides by weight of cement, and are therefore at high risk of corrosion

Concrete is a very successful construction material and generally we think of it as modern. However, it has been used in various forms since before 5,000BC, with notable examples including the Great Pyramid at Giza. Concrete as we know it today dates from the mid-19th century with the introduction of Portland cement.

It is versatile, relatively low cost and readily available. Yet despite, or maybe because of this, we have witnessed many examples of its failure to perform. Concrete on its own (mass concrete) performs well in compression but it is in tension that it readily fails. In 1854, this led to William Wilkinson taking out a patent for a method of constructing fireproof buildings using strips of iron in mass concrete. This ultimately led to the widespread use of steel-reinforced concrete.

Many of us will be aware at how readily unprotected or exposed steel corrodes, unless it has some additional process applied to it, such as galvanising. It would seem reasonable to assume therefore that by placing plain steel inside a wet mix of concrete, the steel would soon corrode.

However, the ability of the steel to stay un-corroded within the concrete is a factor of the high alkalinity of Portland cement concrete. To create this environment, Portland cement is mixed with water and aggregate, which hardens to form concrete. The hardening or hydration process continues for many months. As the concrete dries, pores are created, and a mixture of water and calcium hydroxide will develop within them with an alkalinity of around pH12.

This high pH value creates a protective or passive layer of oxides and hydroxides on the surface of the steel reinforcement, inhibiting corrosion. Without this layer, the steel would be exposed to oxygen and moisture within the concrete pores, resulting in rapid corrosion.

The passive oxide layer is durable and self-repairing, and can last indefinitely if the highly alkaline environment is maintained. However, this layer can be broken down by attack from chloride salts, and the layer itself will break down if the highly alkaline environment is reduced below a critical level by the effects of carbon dioxide in the atmosphere, i.e. carbonation.

Concrete repairs are notoriously prone to increase in size and quantity once a scheme has been let due to inadequate surveys, and thus money spent at this stage… will limit your client's exposure

Carbonation

Carbon dioxide in the air is able to migrate as a gas into the pore structures of concrete buildings. Once inside, it dissolves into the pores' 'water' of alkaline calcium hydroxide to form a mildly acidic solution and insoluble calcium carbonate. As this process continues to migrate, the once highly alkaline concrete will start to acidify, resulting in pH levels falling from 12 to say 9. At or around pH10.5, the passive oxide layer surrounding the embedded steel will start to break down and the steel will become exposed to moisture and oxygen, causing corrosion to commence, which then in turn creates expansive 'rust' and causes the typical concrete spalling we see on many concrete buildings.

Generally, the effects of carbonation are most obvious on the external façade of a building, where corrosion of the embedded steel reinforcement is rapid and expansive, causing concrete to spall in numerous locations. However, carbonation can occur internally, without any obvious signs of deterioration, due to the concrete drying out and the steel only becoming exposed to oxygen and not moisture as well. Internal areas such as kitchens and bathrooms will likely provide this additional element of moisture and lead to the inevitable spalls.

Chloride attack

Salt (present in marine environments and used to de-ice roads, bridges, multi-storey car parks, etc) attacks steel in a different way to carbonation. Dissolved in water, sodium chloride is highly corrosive, destroying the passive oxide layer around the steel. Unlike carbonation, which often leads to rapid and expansive rust formation, chlorides result in dissolution of the steel or 'pitting corrosion', causing loss of section of the steel and, in extreme cases, structural failure. The chloride ions in solution migrate around the concrete pore structure with ease, ultimately coming into contact with the embedded steel reinforcement. This can seriously affect the integrity of the structure and, in extreme examples, some car park decks have been known to collapse, e.g. Pipers Row in Wolverhampton in March 1997.

Chlorides are commonly introduced via two differing forms:

- de-icing salts and marine structures suffer from 'ingressed chlorides', i.e. they have entered from the outside. This is the more aggressive of the two forms
- 'cast-in chlorides', i.e. they were introduced by man when the concrete was being cast or formed. Pre-cast concrete panels on building façades are the most common form.

Calcium chloride was used as an accelerator until being banned in the mid-1970s. As the chlorides are bound into the matrix of the concrete when it hydrates or dries, the damage caused by the chlorides is often less pronounced until the pre-cast concrete panels carbonate, at which point the chlorides are no longer 'bound-in' to the concrete matrix and they become 'free' to act in the same way as ingressed chlorides.

Why does steel corrode?

Corrosion is an electrochemical process, which involves the exchange of electrons similar to that which occurs in a car battery. Differences in electrical potential cause the formation of anodic or positively charged areas of metal, and cathodes or negatively charged areas of metal. At the anodic site, metal oxidises and it forms the product we call rust. The rust expands and compresses the concrete until it splits and spalls. At the cathode, a harmless balancing reaction occurs meaning the steel here does not degrade.

Assessing the damage

It is imperative to establish the cause and extent of any problems with a reinforced concrete building or structure through the commissioning of a survey prior to the works being tendered. Concrete repairs are notoriously prone to increase in size and quantity once a scheme has been let due to inadequate surveys, and thus money spent at this stage in the process on a thorough survey will limit your client's exposure during the on-site phase.

In its simplest form, the survey should consist of a visual appraisal of the building façade by an experienced surveyor who will, even at this stage, have an idea of the main cause of the concrete deterioration, if not the extent. A visual survey will identify at the very least those areas of concrete that have already spalled or delaminated, assuming that access is not an issue. Visual inspection and suspicion, however, are not enough.

A survey should include some or all of the following procedures, the results of which should be interpreted together and not in isolation. Access will be an important consideration and can include mobile towers but in difficult access situations it may be more cost-effective to use abseil techniques or even specialist access netting, e.g. beneath bridges, etc.

Hammer test

A small sounding hammer is used across the whole surface of the structure to establish areas of hollow-sounding concrete. These may be adjacent to areas that have already spalled or they may be new independent areas that have corroding steel beneath the surface that hasn't yet caused spalling.

Hammer testing can also identify areas of honeycombed concrete beneath the surface. All defective areas identified should be presented on a defects drawing and, in some cases, also marked on the surface of the structure.

Carbonation test

As the protective passive oxide layer breaks down at pH levels of 10.5 or less, we are able to use this fact to allow us to determine if concrete is carbonated or not. At each test location, a small diameter hole (approx 12mm) is drilled into the concrete surface to at least the depth of the embedded steel (established using a covermeter) and a pH indicator (phenolphthalein) is sprayed down the hole. If any of the concrete is not carbonated (i.e. steel is still protected) the solution will turn pink. If any of the concrete is carbonated (i.e. steel is no longer protected) the solution will remain clear. We are thus able to measure the depth that the carbonation has penetrated.

»

Covermeter survey

A covermeter works on the principle that the steel reinforcement within the concrete will be affected by a magnetic field that is applied by the covermeter. When the magnetic field is forced through the embedded steel, it opposes this change with an eddy current, which produces its own magnetic field opposite in direction to the applied field. By assuming a set magnetic property for all steel reinforcing bars and using a given bar size (based on the likely bar size for the structure being inspected), the covermeter can predict the depth and location of the reinforcing bar. The varying depths in mm of the steel reinforcement can then be indicated on the structure as well as in the survey report.

Chloride content test

So as not to be too destructive when testing, the concrete dust from the small diameter hole drilled to carry out the carbonation depth test is collected and sent to a laboratory. The dust is taken at incremental depths, 10-15mm at a time, with a total depth of at least the known steel reinforcement depth (identified by a covermeter). The dust is dried in the laboratory and can then be tested for content of cement and also chloride. Assuming an average cement content of 14% (a good general 'yardstick'), the critical level of chlorides required within the sample of dust to initiate corrosion is 0.4% of chlorides by weight of cement. Typical levels in decks of multi-storey car parks, for example, can often exceed 2.5% of chlorides by weight of cement, and are therefore at high risk of corrosion. The results are then presented in a tabulated form, starting with the shallowest range e.g. 5-10mm deep.

A good quality report should also provide the client with a comparison table. For example, in any given area, if the covermeter has established that the steel reinforcement is at an average depth of 25mm and that carbonation has advanced to nearly 25mm, the passive oxide layer protecting the steel will soon be compromised. Comparisons such as these are helpful to a client that may be considering acquiring a building that on face value appears sound but in truth is only a few years away from needing considerable maintenance.

Comparisons of chloride levels in the differing depth increments will also give a surveyor the ability to determine whether the chlorides are 'ingressed' or 'cast-in'. Results that show chloride levels decreasing with depth suggest the former; similar chloride levels at all depths suggest the latter is true.

> This high pH value creates a protective or passive layer of oxides and hydroxides on the surface of the steel reinforcement, inhibiting corrosion

Half-cell potential test

This test assesses the condition of the steel embedded in concrete regarding varying levels of corrosion activity. The test is particularly suited to establishing corrosion activity in large expanses of reinforced concrete such as decks of multi-storey car parks. In this test, the electrical potential difference between the embedded steel reinforcement and a standard portable reference electrode in contact with the concrete surface is measured. The reference electrode is connected to the negative end of the voltmeter and the embedded steel reinforcement to the positive end.

A grid pattern is established on the structure, say at 1m or 0.5m centres and potential readings are then taken at each intersection of the grid pattern. To make interpretation easier, each potential reading is then plotted on a drawing of the structure as a contour map, coloured to show areas of similar or equal potential. The probability of corrosion of the embedded steel reinforcement is less than 10% if the potential is more positive than –200 mV, whereas potential values less positive than –350 mV indicate a high probability (90%+) that corrosion is active. Half-cell potential maps of the various levels of a multi-storey car park can often help a surveyor establish a Life Care Plan* for a client.

In summary, concrete can be a very versatile and relatively low-cost building material, but introducing mild steel reinforcement to increase its structural capability can in turn result in potentially catastrophic failures if the buildings are left unmaintained. Detailed surveys of a building's condition are a vital tool in maintaining a client's investment, not only at end of lease but also at pre-acquisition stage.

Further information

* Recommended in *Inspection, Maintenance and Management of Car Park Structures* (2002) published by The Institution of Civil Engineers. This was the result of the enquiry set up by the Institution and Mott MacDonald following the Pipers Row car park collapse in 1997.

Future articles will look at traditional and advanced concrete repair techniques

Nigel Cox MRICS specialises in the refurbishment of concrete buildings and is an Associate with the Concrete and Corrosion Consultancy Practice
ncox@concorr.co.uk

Investigating Hazardous and Deleterious Building Materials by Trevor Rushton is available from *www.ricsbooks.com*

2010

RICS Matrics London: Reinforced Concrete Buildings, 26 October 2010, RICS HQ, London, *www.rics.org/events*

Inspection Techniques for Surveyors, various dates and UK locations, *www.rics.org/events*

C

Related competencies include: T006, T044