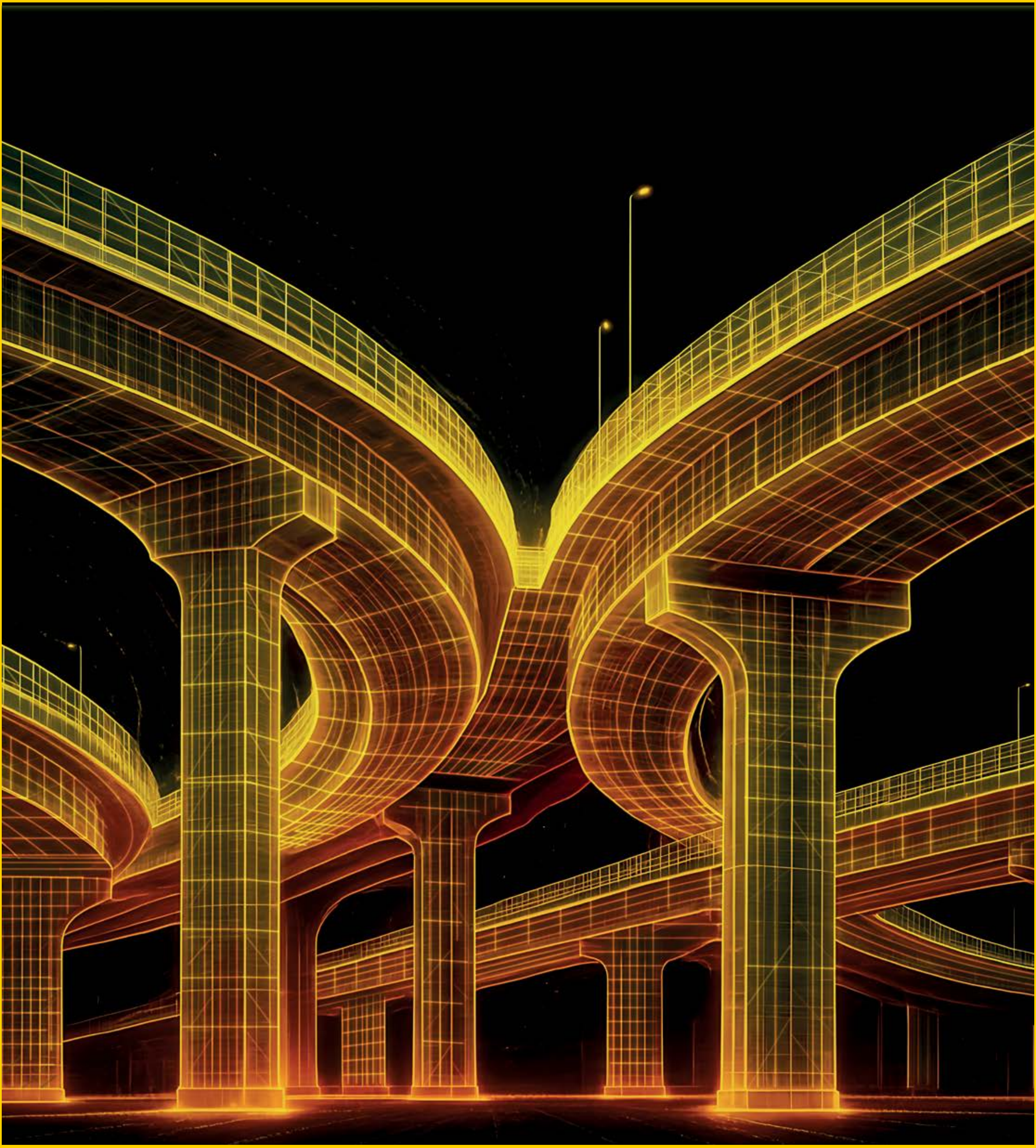


HEADING FOR COLLAPSE?

ADDRESSING THE GROWING RISKS POSED BY AGEING CONCRETE STRUCTURES

BUILDING TRUST

CONTENTS

A SPECIALIST REPORT BY SIKA

FOREWORD

Exploring a logical and effective approach to the life extension of reinforced concrete structures

In an ideal world, every reinforced concrete structure that we build would be designed for ultimate durability, constructed using the highest quality materials, placed by prodigious craftsmen and maintained like the gardens of Versailles. Unfortunately though, this world doesn't exist. Structural design approaches and standards have evolved over time, as has our understanding of materials, corrosion and the interplay of all three. As with all learning curves, mistakes have been made along the way. This fact, when coupled with shortfalls in awareness, understanding, focus and budgets, means that engineers are perpetually paying for the sins of our forefathers and being asked to do more with less, both in terms of money, time and (in recent years), skilled labour.

It's not all doom and gloom however. With necessity being the mother of invention, research institutions and materials manufacturers have kept pace with the challenges facing our structures, adopting technologies from other industries and developing new materials and systems to address their developing needs. Examples include cathodic protection, migrating corrosion inhibitors, spray applied waterproofing and ultra-high-performance concrete. The correct specification of these materials, based on a deeper understanding of corrosion, its causes and influences, allows us to tackle it in the most cost-effective way possible. This brings benefits to the businesses we work for and the public we ultimately serve.

Through the lens of **Assess, Specify, Repair** and **Maintain,** the aim of this report is to present a logical and effective approach to the life extension of reinforced concrete structures at risk of, or suffering from reinforcement corrosion. We use real world examples and illustrated approaches to discuss the nature of corrosion, its cost and how to identify and quantify the risk that it poses, whilst ensuring that both time and budgets are allocated to effective treatments and enduring protection. It's no coincidence that the approach laid out in this document broadly follows those contained in Building Research Establishment Digest 444 and BS EN 1504 – important texts to anyone involved in the repair, protection and strengthening of reinforced concrete.

This report has been prepared in collaboration with engineers, contractors and industry specialists in the hope that it will be a useful tool to those with a vested interest in maintaining our ageing concrete assets. I hope you find this document both interesting and informative. If you would like to learn more about Sika's collaborative approach to specification please find our contact details at the end of this report.

Dr. Steve Holmes
Head of Technical, Engineered Refurbishment, Sika

CHAPTER 1

WHAT IS CORROSION?

To understand how to tackle a corrosion problem, we need a basic understanding of what it is, why it occurs and what influences it.

Humans put a lot of energy into metal oxides (ore) to create steel and other metals. Through extraction, refining, melting and forming, we increase the extracted materials' energy state and in doing so, make it less stable, albeit way more useful. All materials naturally strive for their lowest energy state, and in the case of metals that means reverting back to ore.

Reinforcement corrosion occurs because we expose steel to an environment which allows it to release energy and start the process of becoming ore once more.

Steel corrosion (rusting) is an electrochemical reaction in which iron corrodes in the presence of oxygen and water to form iron oxides, which we see as a brown flaking or orange on metal surfaces. When we encase steel reinforcement in concrete, this process is not inevitable. In normal conditions, the naturally high alkalinity (pH 12-13) of the concrete generates a passive oxide layer on the reinforcement within hours of it being cast. This thin oxide layer prevents corrosion so long as the steel is kept above pH 10-11. However, when this passive layer is damaged due to the concrete acidification caused by carbonation or chlorides, corrosion can quickly establish and cause significant damage.

As steel corrosion is an electrochemical reaction it requires an anode, a cathode and a way of passing both ions and electrons between them. The basic corrosion reaction affecting steel in concrete can be seen in Figure 1 below. Water in the capillaries and pores of concrete acts as the electrolyte, allowing ionic current to pass between the anode and cathode. The steel itself acts as the route for electrons (electronic current). At the anode, iron is oxidised and that's where we see material loss, (rust), cracking and staining.

Once established, the rate at which corrosion progresses and therefore damage occurs is influenced by temperature, oxygen availability and concrete moisture content. This means that wet, but not saturated concrete in hot environments will result in higher corrosion rates, whereas dry and cold climates result in lower rates.

WHAT CAUSES CORROSION?

The two most common processes that lead to de-passivation of steel in concrete and corrosion of reinforcement are carbonation and chloride ingress.

Carbonation is a natural process whereby carbon dioxide is absorbed into concrete from the air. As it enters the concrete it reacts with calcium hydroxide to form calcium carbonate. This acidification reaction is progressive and moves into the concrete as a 'front', causing the pH to decrease to pH 10 or 11. Once the front reaches the reinforcement it destabilises and destroys the passive layer formed on the steel surface. This passive layer degradation allows corrosion to begin.

Carbonation does not change the mechanical properties of the concrete and only presents a corrosion risk once it reaches the reinforcement. In most structures made with good quality concrete and sufficient cover depth, carbonation will take decades to reach the reinforcement. However, carbonation progresses faster in porous, poor quality and damaged concrete, meaning that in older structures built poorly, to less stringent design codes we have a growing problem.

As a general rule, carbonation-induced corrosion tends to be found in drier (not regularly wetted) concrete. The optimal conditions for carbonation to progress are at a relative humidity of 50-75%, which means that progress is generally slow in dry, indoor environments. As carbonation typically progresses into the concrete from the exposed face at a similar rate, corrosion of the outermost reinforcement layer occurs first. This can mean isolated areas of damage and spalling where the cover is lowest, which grows over the years as the carbonation front reaches deeper bars.

Happily for engineers, although carbonation creates a mess and looks terrible, the general nature of the corrosion reaction means that it doesn't typically lead to focused reinforcement section loss. Determining the carbonation depth using a pH indicator solution (Figure 2) is straightforward, but without detailed cover depth information it is impossible to predict where damage will occur next.

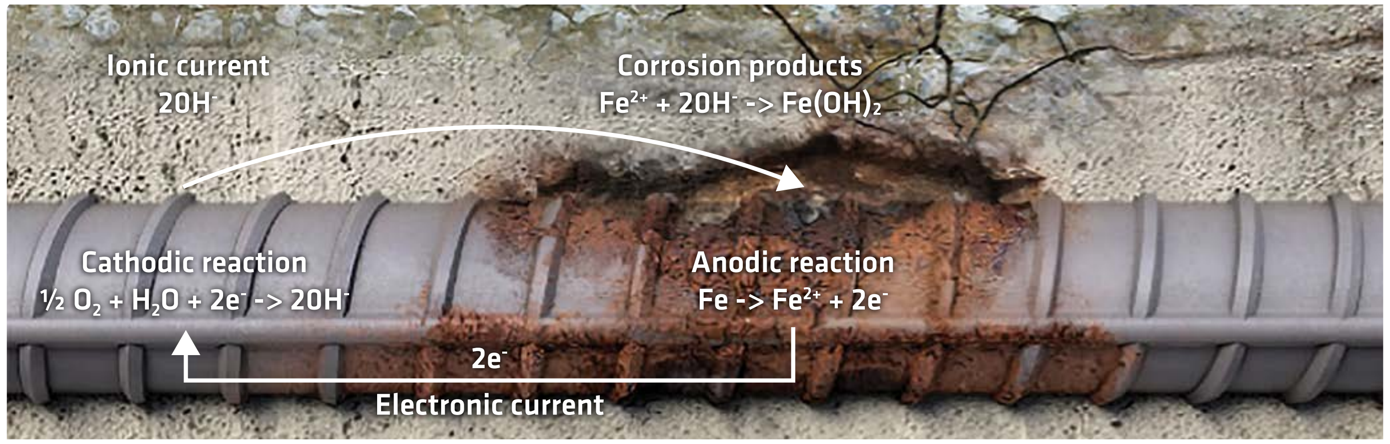


Figure 1. Diagram shows the electrochemical process of reinforcement corrosion in concrete

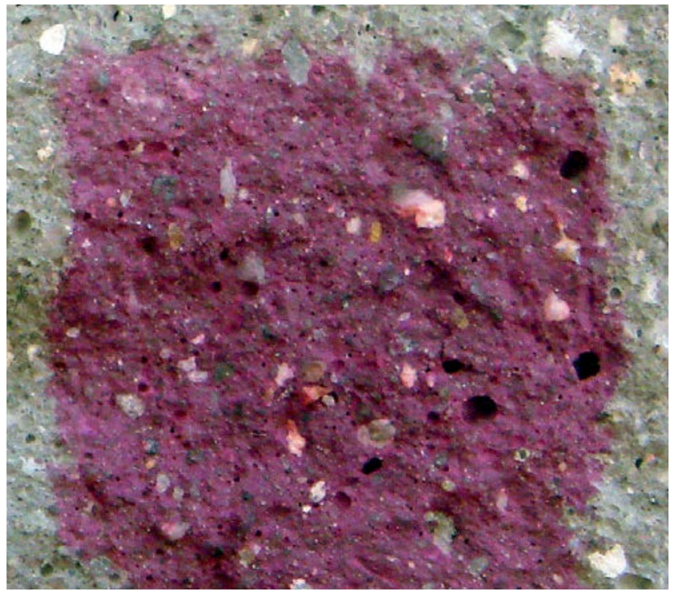
WHAT CAUSES CORROSION? (CONT)

Chloride-induced corrosion is caused by chloride ions passing through the concrete cover and reaching a high enough concentration at the reinforcement that they lead to the localised destruction of the passive oxide layer.

The primary sources of chlorides for reinforced concrete structures are seawater and de-icing salts. As chlorides require water to pass through the concrete, the rate of penetration is increased in line with exposure to chloride-laden water at the outer face. This is why coastal structures exposed to sea spray/tidal ranges, bridges exposed to vehicle spray, and car parks are particularly risky environments for buried reinforcement.

As with carbonation, damaged and poor-quality concrete along with low cover depth increase the rate of chloride penetration. Unlike carbonation, however, chloride ions simply reaching the reinforcement isn't enough to cause corrosion propagation. A sufficient concentration of chloride ions is required to propagate a chemical reaction which leads to localised acidification and pitting corrosion (Figure 3). Pitting can lead to significant, or even total reinforcement section loss and structural weakening. What is worse is that in certain conditions this damage can take place with little visual indication that there is any cause for concern.

Figure 2. Photograph shows a section of a concrete block sprayed with a pH indicator solution. The magenta colour indicates high pH, while the carbonated outer surfaces do not change colour.



WHAT INFLUENCES WHERE AND WHEN CORROSION OCCURS?

There are many factors that dictate the location of corrosion damage, but the primary ones are:

Exposure to chlorides. Areas of a structure that are more frequently wetted with chloride-laden water than others are more likely to suffer from corrosion. For example, the lower levels of a car park are more likely to be contaminated by de-icing salts being tracked in from the road network.

Cover depth. Simply put, the thicker the cover the longer it takes for chlorides to amass at the reinforcement or progressive carbonation to reach it.

Existing damage. This can provide a quick route into the concrete for chlorides and carbon dioxide. For example, honeycombing or cracking associated with Alkali Silica Reaction or shrinkage cracking can provide direct access to the reinforcement, or remove half of the protection that good cover depth offers.

Concrete quality and strength. In general, high-strength, well-compacted concrete has a lower water:cement ratio, meaning fewer, smaller pores and reduced permeability.

Features of the structure. Features such as drainage design, falls and more fundamental things like the position of joints above bearing shelves will all determine where chloride contaminated water will contact the concrete or dwell on the surface.

Figure 3. The photo shows exposed rusting reinforcement in a concrete slab that has lost significant section due to pitting corrosion

CHAPTER 2

WHY DO WE CARE ABOUT REINFORCEMENT CORROSION?

So metal rusts, big deal? At the less serious end of the spectrum, corrosion damage to our reinforced concrete buildings and infrastructure is an eyesore and contributes to a feeling of degradation and decay. At the other end of the spectrum it causes serious injury and death.

As corrosion propagates on the reinforcement it generates various forms of iron oxide. These species occupy between seven and ten times the volume of steel, meaning that they exert increasingly large forces on the surrounding concrete. It's these forces which result in first delamination and then spalling of the cover concrete.

If spalling occurs on a horizontal surface it may introduce a trip hazard and a generator for loose aggregate, which can lead to chips on vehicle paintwork for example. If this delamination occurs at height, however, we have a falling object risk which might endanger the lives of motorists or pedestrians.

In July 2014 a chunk of concrete fell from a bridge spanning the M6 near Sandbach in Cheshire. The driver was taken to hospital after his windscreen shattered, and the road was closed for over three hours to allow make-safe work to be completed[1].

The bigger risk, however, comes when chloride-induced corrosion goes unaddressed and pitting corrosion results in reduced structural capacity. In some environments, pitting does not result in tell-tale delamination and spalling, meaning that corrosion can progress unnoticed until a structure fails under loading, with potentially tragic consequences.

In 2021, a 12-story condominium partially collapsed in Florida, USA, killing 98 people. Investigators identified long-term degradation of reinforced-concrete structural supports, especially the basement parking garage and pool-deck columns, where water infiltration led to corrosion of the reinforcing steel. This corrosion weakened concrete support elements and contributed significantly to progressive failure[2].

Thankfully many structural failures don't have tragic consequences and many weakened structures can be brought back to capacity, but completing the necessary work or even condemning a structure brings us round to another reason that we care about corrosion; the cost.

THE COST OF CORROSION IS ESTIMATED TO COST THE UK ECONOMY BILLIONS.

A 2013 study by NACE estimated the cost of corrosion at the time as $2.3 trillion, 3% of global GDP[3]. Several other assessments over the last 75 years have consistently estimated the cost of corrosion to a country's economy as between 1% and 5% of GDP. If we take 2023 as an example, then 3% of the UK's GDP was ~£76 billion.

The 2013 NACE report also concluded that if available corrosion control practices were adopted savings of between 15% and 35% of the cost of corrosion could be realised.

Sector-specific data is inevitably extrapolated but remains useful. An earlier 2002 NACE report[4] suggested that approximately 15% of the US bridge stock was structurally deficient because of corroded steel and steel reinforcement. The annual direct cost estimates totalled $8.3 billion and are broken down on the next page. Indirect costs to the user, such as traffic delays and lost productivity, were estimated to be as high as 10 times that of direct corrosion costs.

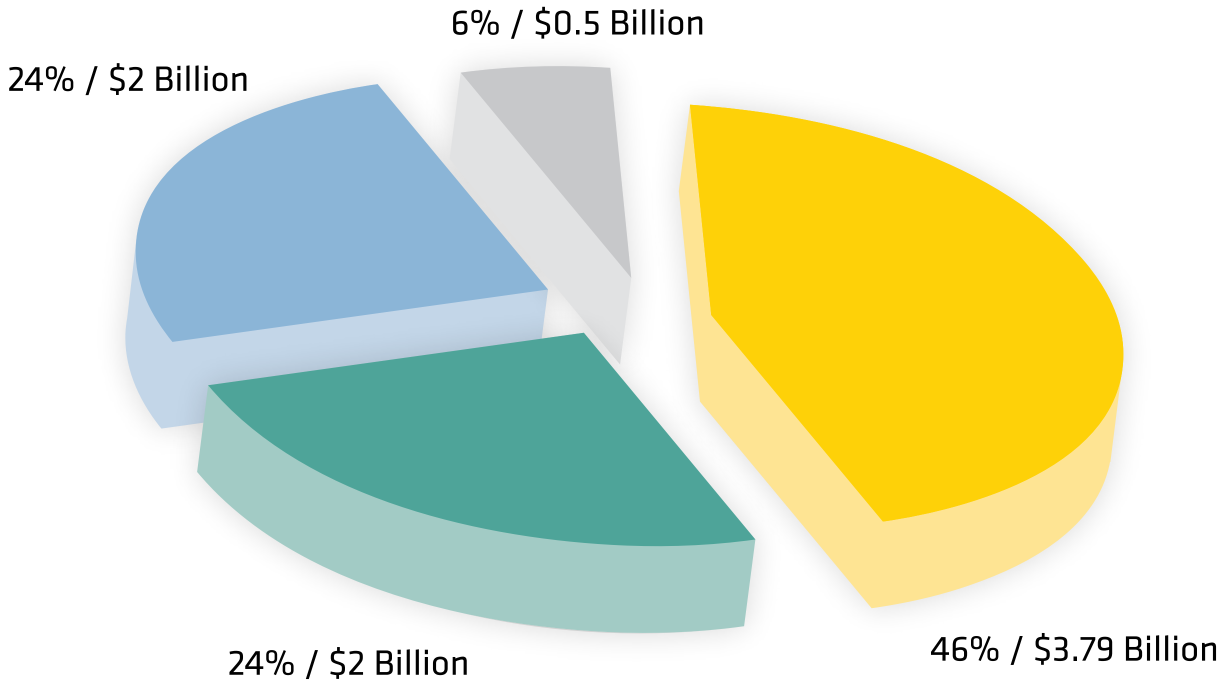
To give a UK example of how costs can mount, the M5 Oldbury Viaduct repairs cost upwards of £100 million. The works included removal and replacement of chloride-contaminated concrete, replacement of damaged steel reinforcement, installation of galvanic anodes, re-waterproofing and finishing the deck.

Even simple road closures to complete minor concrete repairs could cost tens of thousands of pounds, once the specialist contractor, access and traffic management companies have put in their invoices. A permit to close the road could cost more than £3,000 alone.

WHY DO WE CARE ABOUT REINFORCEMENT CORROSION? (CONT)

It's not just the direct costs of corrosion that mount up either. The knock-on costs of, congestion due to road or lane closures, re-routing traffic or closing bridges and car parks can have a significant impact on the profits of businesses, footfall in retail areas and by extension the national economy.

Corrosion Cost of Highway Bridge - Total: $8.29 Billion per year



🟨 Bridge replacement

🟩 Maintenance of concrete bridge decks

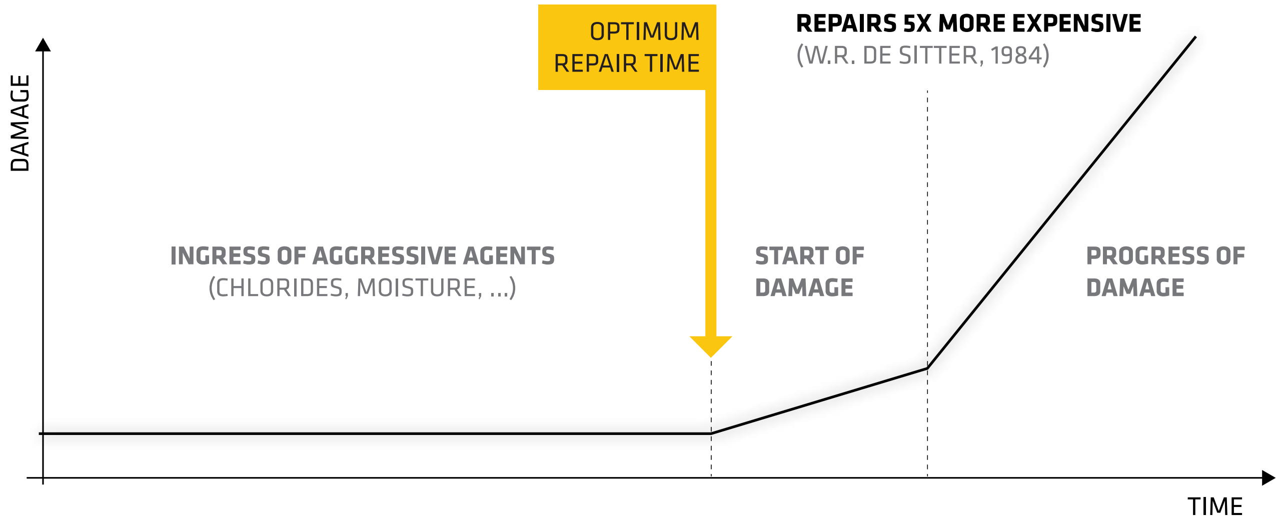
🟦 Maintenance of concrete sub and superstructures

⬜ Painting maintenance of steel bridges

Direct costs of steel and reinforcement corrosion on US highway bridge stock. (NACE Report, 2022)

In almost all cases, the cost of early intervention, preventative maintenance and incremental repairs is less than major mobilisations.

Figure 4. Timeline of a corrosion problem
A graph showing how damage accelerates over time in concrete structures if repairs and maintenance are not carried out



This is illustrated by Figure 4 above, which clearly shows how taking preventative action and acting at the right time can have a huge impact on the cost of the repairs. This is especially true when we consider that a corrosion problem can put some structures beyond economic repair and lead to demolition and replacement, resulting in a significant cost increase both in terms of required investment and carbon.

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CHAPTER 3

ASSESS: IDENTIFY CORROSION ON SITE

In the previous section we discussed what reinforcement corrosion is caused and influenced by, along with the costs of managing corrosion; but how do we identify a corrosion issue on site, determine its **cause**(s) and **extent**, **rate**, the influencing factors and the **future risk** it poses to be able to specify a cost-effective solution?

In this section we'll explore a logical approach to the assessment of a reinforced concrete structure that is showing signs of corrosion damage or that you suspect may require a corrosion prevention strategy due to its exposure conditions. We'll also introduce some techniques that can be used to achieve each of the above objectives and explain how they can be combined and interpreted to allow for cost effective remediation.

STAGE 1 – LEARN FROM HISTORY

This stage can be invaluable but is often overlooked on structures which are not subject to mandatory inspections.

If the structure is decades old, it is likely that repairs and maintenance will have been carried out in the past and there may be records of these works.

- What was the nature of the repairs?
- Were they to the same areas subject to current investigation?
- Was any investigation or materials testing completed at the time?
- What was the repair specification and have the repairs endured?
- Were wider works completed to address the cause of the problem?
- Photos can be invaluable – comparing then and now tell you a lot about the nature of deterioration and help focus efforts

If you are lucky there may be an existing BIM file for the structure, although at this stage in the evolution of BIM, this is less likely for aged structures.

Any and all information should be gathered and studied in the context of the present issues facing the structure as it could influence the extent of testing required (and its budget) and ensure that the mistakes of past interventions are not repeated.

STAGE 2 – USE YOUR EYES

Although it can be tempting to jump headlong into hitting things with hammers, drilling and using hi-tech gadgetry, the basis of any well considered corrosion testing and investigation effort should be a visual survey of all the in-scope areas of the structure.

Where to start? In most cases the best approach will be to identify areas of obvious physical damage or that appear to be at high risk (e.g., wet or water-stained) and then work backwards to allow us to speculate as to the cause and mitigating factors. At best, this first step will allow us to make informed decisions about where to carry out sampling or testing which will confirm the cause of the damage, it's extent and the risk of future damage if nothing is done.

Table 1 presents an example of how a visual survey can help us narrow down the likely cause of damage, prior to using focused testing to confirm it. It may be useful to review *Chapter 2: Why do we care about reinforcement corrosion?* before reading the below.

Table 1. Visual survey and analysis

Visual clues	Thought process
Cracking and spalling noted on a bridge pier below a dual carriageway. There is a deck expansion joint above the bearing shelf. The reinforcement is exposed in some areas. The cover appears to be sufficient and there is no honeycombing etc.	Road surfaces in UK and other temperate climates are regularly 'gritted' in winter, meaning that chloride contaminated water is readily available to be sprayed onto bridge piers by vehicles, passed onto the concrete surface because of leaking bridge deck joints or wicked up from the earth at the pier base. Carbonation could be the cause, but with good cover depth and sound, good quality bridge concrete, on balance, chloride-induced corrosion is a more likely cause.
The damage sits in an area that is damp/wet and discoloured by algal growth. There is red rust staining coming from some of the cracks. This wet area extends from the bearing shelf to ground level and tapers inwards as it goes.	It looks like the area in which the damage sits has been wet on-and-off for a good while, judging by all that staining. It tapers from top to bottom, so the water must be coming from above. Chloride-induced corrosion likes damp, but not saturated concrete. The red rust staining tells us that there is corrosion in a damp environment. Carbonation in a damp environment is less likely without other factors like low cover or poor quality concrete as the process favours drier conditions (RH of 50-70%).
This wet area only affects ¼ of the bridge pier. There are three previous repairs in the wet area but there are no other repairs or visible corrosion damage elsewhere.	If the water staining/damp area is localised, perhaps the deck expansion joint is leaking water onto the bearing shelf which is then running down the pier face. In winter this water will be chloride-contaminated. Over time, helped by wetting and drying cycles throughout the year, this has penetrated into the concrete and reached a concentration which has propagated corrosion and damage. The fact that there are previous repairs that are found in this area and no repairs elsewhere suggests that this scenario has led to damage before.

STAGE 3: QUANTIFY THE DAMAGE

With a visual survey complete, the findings will typically be recorded in photos, sketches and notes. We may also have compared and contrasted this new data with any historic records we have from Stage 1.

Stage 3 will allow us to quantify the extent of current damage to the structure and is the first step in narrowing down a scope for the eventual repair works. Note, this Stage will only identify areas of the structure where corrosion has led to failure or deterioration of the surrounding concrete. It's important to perform a tactile survey of as much of the concrete surface area as possible to build up and accurate picture and so planning access is crucial.

Sketch out each element of the structure and add dimensions as accurately as possible.

Sketch the **visible damage** on the structure, it's position and size. This will typically include exposed reinforcement/spalling and cracking. It may be useful to note wet areas, water staining, efflorescence etc.

To quantify as-yet **invisible damage** carry out a hammer-tap (delamination) survey to identify hollow sounding areas which indicate delamination. Mark out the delaminated areas in chalk before noting them on your sketch.

This exercise should result in something that looks like the image in Figure 5. As you can see only a full delamination survey will reveal the true extent of the present damage to the structure.

Another incredibly useful (yet often overlooked) activity is to closely examine the steel reinforcement. This may have been exposed by delamination or spalling, or it may be necessary to locally expose the reinforcement using a drill/breaker. Examination can help determine the cause, extent and risk posed by future corrosion. Once exposed and if necessary, remove any corrosion products by gentle tapping or wire brushing so that the structural steel can be inspected.

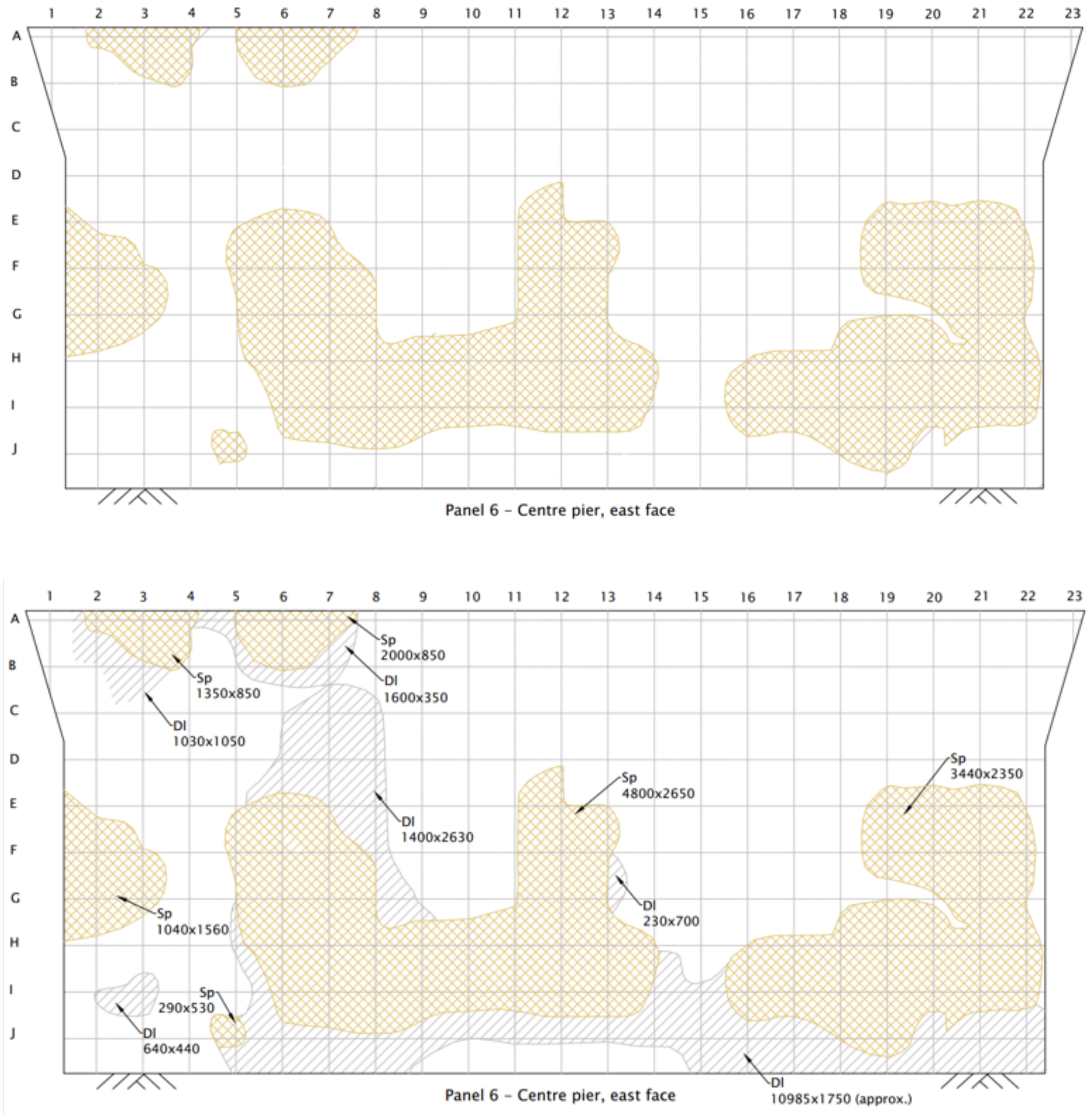
Are the bars 'pitted' or have they suffered significant section loss? Are these pitted areas adjacent to larger areas of undamaged or 'clean' steel. If so, this indicates that chloride-induced corrosion is the primary cause of damage.

Is the corrosion product evenly distributed over the bars, dry and flaky with minimal section loss? If so, this indicates carbonation-induced corrosion.

With a set of callipers, reinforcement section loss can be measured to determine whether supplementary bars are required as part of the future repair programme.

STAGE 3 – QUANTIFY THE DAMAGE (CONT)

Figure 5. Visual damage (top drawing) with added delamination damage (bottom drawing)



STAGE 4 – CONFIRM THE CAUSE AND ASSESS THE RISK

As discussed in the previous section, the primary causes of reinforcement corrosion in concrete structures are chloride ions and carbonation. Stages 1-3 have allowed us to quantify the damage and speculate as to the chemical cause of corrosion by both detailed examination and standing back and taking a look. In Stage 4 we will look at ways to confirm the cause of corrosion and assess the future risks if nothing is done.

CONFIRMING THE CAUSE

The only ways of confirming the chemical cause of reinforcement corrosion are by determining the presence and concentration of chloride ions by the weight of cement in the concrete, or by determining the depth of carbonation.

Chlorides
The most common way to collect concrete samples for chloride content analysis is to extract dust samples. This is done by drilling into the concrete and collecting the resulting concrete powder (dust). The dust is then sent to a UKAS Accredited laboratory where the chloride content by weight of cement is determined by titration. It is common to extract incremental samples from the concrete cover, i.e., 5-30, 30-55, 55-80mm to confirm ingress (concentration reducing with depth) or cast-in chlorides (similar concentrations in all samples). The concentration at the depth of the reinforcement indicates the current risk of corrosion and this is commonly assessed against the guidance in BRE Digest 444-2.

It is essential that concrete from the depth of the reinforcement is sampled and tested. If it's not, then the present risk of corrosion cannot be known and the results are somewhat meaningless.

A large diameter drill bit (>15mm) is also required to ensure sufficient sample is collected and reduce the influence of aggregates.

Carbonation depth
To confirm whether carbonation is the cause of the damage, phenolphthalein indicator is sprayed onto freshly broken concrete to determine the depth of carbonation. This solution remains colourless when brought into contact with concrete with a pH of less than 8.5 (acidic) and turns pink when the pH is greater than 8.5. This test can therefore tell us how deep the carbonation front has penetrated into the concrete. If its depth is greater than the reinforcement cover depth, then it may be the cause of corrosion seen.

ASSESSING THE RISK

There are myriad of different techniques that are used to assess the risk and rate of corrosion – a non-exhaustive list can be found in Table 2, and it is beyond the scope of this report to go into detail of these.

Each technique has its own unique benefits and limitations, as a result it is essential to combine these techniques to gather a true assessment of corrosion risk. A worked example can be seen on the next pages in Figure 6.

Table 2. Testing techniques and what they can tell you about the corrosion process

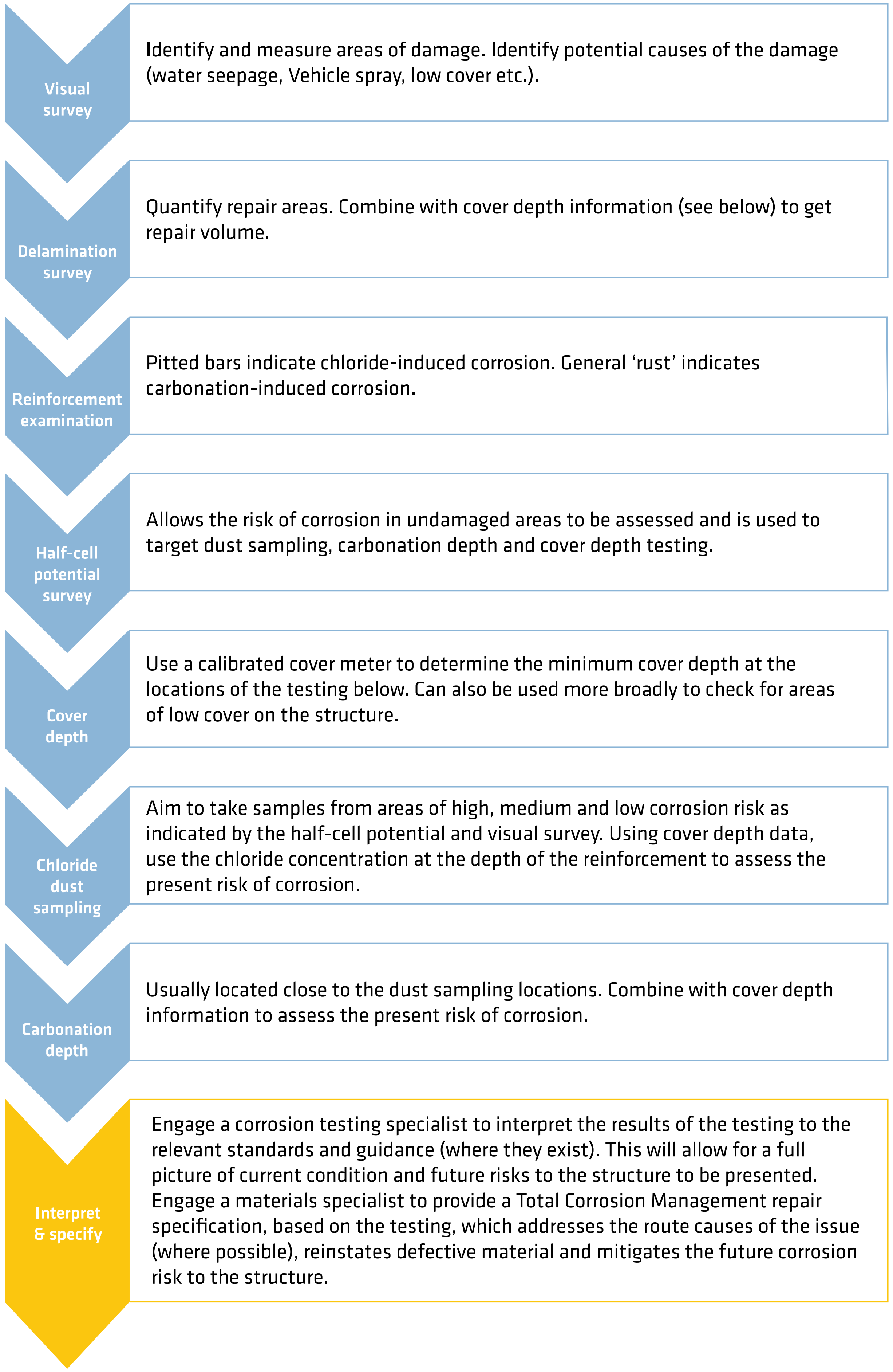
Test method	Corrosion cause identification	Corrosion risk	Corrosion damage	Corrosion rate	Destructive?	Relevant guidance
Determination of chloride concentration	■	■			■	BS 1881-124 BRE Digest 444
Carbonation depth	■	■			■	BS EN 14630
Cement content of the concrete		■			■	
Half-cell corrosion potential survey		■				ASTM C876
Concrete resistivity survey		■				BS EN 12390-19
Reinforcement examination	■	■	■		■	–
Cover depth*		■				–
Visual survey		■	■			–
Ground Penetrating Radar		■	■			–
Linear Polarisation Resistance				■		–
Hammer-tap/ delamination survey			■		■	–
Concrete compressive strength		■			■	BS EN 12504-1
Review of historic records	■	■				–

*When combined with chloride profiles and carbonation depth

For example:

- To assess the risk posed by chloride concentration in the concrete, or carbonation depth we need to know the cover depth. There may be a high concentration of chlorides at the surface, but little corrosion risk posed by the present concentration at the depth of the reinforcement.
- In order to confirm the corrosion that is indicated by negative half-cell potential readings, we need to examine the reinforcement. Half-cell potentials are only ever an indicator of corrosion risk – verification at discrete locations is always recommended.
- A visual survey will tell you where the visible corrosion damage is, but only when combined with a delamination and cover depth survey will it allow for accurate quantification of the repairs.

Figure 6. A logical approach to corrosion testing



Visual survey

Identify and measure areas of damage. Identify potential causes of the damage (water seepage, Vehicle spray, low cover etc.).

Delamination survey

Quantify repair areas. Combine with cover depth information (see below) to get repair volume.

Reinforcement examination

Pitted bars indicate chloride-induced corrosion. General ‘rust’ indicates carbonation-induced corrosion.

Half-cell potential survey

Allows the risk of corrosion in undamaged areas to be assessed and is used to target dust sampling, carbonation depth and cover depth testing.

Cover depth

Use a calibrated cover meter to determine the minimum cover depth at the locations of the testing below. Can also be used more broadly to check for areas of low cover on the structure.

Chloride dust sampling

Aim to take samples from areas of high, medium and low corrosion risk as indicated by the half-cell potential and visual survey. Using cover depth data, use the chloride concentration at the depth of the reinforcement to assess the present risk of corrosion.

Carbonation depth

Usually located close to the dust sampling locations. Combine with cover depth information to assess the present risk of corrosion.

Interpret & specify

Engage a corrosion testing specialist to interpret the results of the testing to the relevant standards and guidance (where they exist). This will allow for a full picture of current condition and future risks to the structure to be presented. Engage a materials specialist to provide a Total Corrosion Management repair specification, based on the testing, which addresses the route causes of the issue (where possible), reinstates defective material and mitigates the future corrosion risk to the structure.

A NOTE ON CORROSION RISK

The corrosion risk, as determined by any of the techniques mentioned in this report can be assessed by referencing available guidance, such as BRE Digest 444-2 for chloride concentration or ASTM C876-2015 for half-cell potential.

The fact is that none of the guidance pertaining to corrosion risk can say for certain that your reinforcement will or will not corrode. There are too many variables affecting the structure and in the concrete itself for there to be any degree of certainty and the collective guidance on corrosion risk has been assembled over time thanks to the efforts of academics and experts working in the field.

It is ever more important then, that multiple techniques are used and the results overlayed to build up as complete a picture as possible on which a repair approach can be based.

GETTING THE JOB DONE

It's always best to go into the planning of a corrosion assessment with a clear idea of what you want to achieve from the works and to engage a specialist. There are a number of highly experienced and reputable testing companies operating in the UK and many can interpret the results of testing and recommend repair approaches. They will also be able to guide you as to what testing techniques are most suitable and the extent of the testing required to build up a full picture.

Corrosion inspection and testing needn't cost a fortune, but the cost of specifying a repair solution which does not address the cause of the corrosion and future risk is likely to fail early, costing much more in the long term.

Well thought out inspection and testing can potentially save thousands of pounds as it may tell you that 80% of the structure requires little or no action, and that interventions can be targeted to 20% with little risk of future damage.

Without the results of testing to act upon, a well-considered but risk averse repair and protection specification is the likely outcome, based on the available visual and historic data. This almost inevitably costs more.

Further reading:

Concrete Society Technical Report 54 – **Diagnosis of deterioration in concrete structures**

Concrete Society Technical Report 60 - **Electrochemical tests for reinforcement corrosion**

Building Research Establishment (BRE) Digest 444 - **Corrosion of steel in concrete: Protection and remediation**

CHAPTER 4

SPECIFY: A COLLABORATIVE EFFORT

In Chapter 3: Assess, we presented a model approach to identifying the cause(s), extent and rate of corrosion, as well as the site factors that influence it. We have also weighed up the future risk posed to the structure. We now have the information required to tackle the corrosion problem, but how do we make sure that we use this information to employ the correct strategies, materials and systems to address the factors above to extend the life of the structure?

This section covers the approach to materials specification for reinforced concrete refurbishment more broadly, before focusing on the four approaches of Sika's Total Corrosion Management approach.

SPECIFICATION IS A TEAM SPORT

The arc of refurbishment projects differs wildly depending on procurement processes, urgency and client preference. However, in an ideal world, materials selection and specification should be collaborative effort between the client, material manufacturer, designer/specifier and the specialist contractor. This is because the priorities of the various parties are different but must pay heed to each other to ensure the smooth running and successful outcome of a refurbishment scheme.

For example, a client's focus is on return to service, minimising disruption to residents and extracting long term value from their investment. A specifier may be focused on the performance aspects of the materials and systems to meet the clients' needs. The specialist contractor will be focused on what is required for him to deliver a high-quality application and finish. The material manufacturer will want to specify materials which balance the expectations of the three other parties, whilst performing for the required design life.

Without collaboration and understanding, these different focuses could result in a scenario like this:

- The designer favours the ease of installation and protection offered by a surface applied migrating corrosion inhibitor (MCI), but how can the contractor apply the surface applied MCI when parts of the structure are coated with approximately four layers of masonry paint?
- The client doesn't want the masonry paint to be removed due to the noise, dust and delay it presents.
- The manufacturer may have a solution, in the form of vapour-phase inhibitors placed in drilled holes, but neither the contractor or specifier have heard of this product.

A discussion between the different parties on site could result in multiple different specification options being discussed before an approach that suits the structure is selected. Site visits will also highlight noise, dust and access issues based on the application techniques required and allow realistic programmes to be discussed.

From here, if required, a specification document can be produced which will cover all of the products and systems discussed along with salient details that cover substrate preparation, site conditions and application.

INFORMED DECISION-MAKING

Aside from the practical aspects discussed above, it is critical that the client is well-informed and understands the full implications of the work being undertaken. This is both in terms of the extent of the protection offered by the specified products and their lifespan.

For example, the specialist contractor and manufacturer understand the results of the testing and specify a range of products to address the issues uncovered. The justification for each product in the specification should be communicated to the client, along with the anticipated protective lifespan and the extent of the protection offered by that specification. The client should also understand the impact that value-engineering and optioneering can have on the extent and lifespan of the protection.

For an example of what is meant by the protection extent, imagine we have a chloride contaminated car park deck with some delamination and spalling due to corrosion:

A basic concrete patch repair will reinstate structural continuity and provide corrosion protection for the reinforcement within. The same patch repair with galvanic anodes installed around its periphery will extend corrosion protection to the reinforcement in adjacent concrete. Replacing galvanic anodes with a grid of two-stage anodes placed over the entire area will provide global protection to the wider at-risk area. Installation of a crack-bridging waterproof coating system offers a degree of protection to the whole deck by preventing the ingress of chloride-laden water and increasing concrete resistivity.

Each of the above options have a corresponding anticipated repair and protection lifespan. These lifespans will depend on what was discovered in the Assess phase in terms of present level of risk, use of the structure and other influencing factors. They also have corresponding costs which, unsurprisingly, increase with the protection lifespans offered. The client must have all of this information and understand the implications of each option in order to make an informed decision about their investment.

TOTAL CORROSION MANAGEMENT SPECIFICATION

Sika's Total Corrosion Management (TCM) approach is the concept of specifying materials and technologies to address the root cause of reinforcement corrosion, disrupt the corrosion process and provide long term protection against future damage.

The TCM approach addresses the causes and factors which influence the corrosion rate occurring on the steel which are separated into four 'actions':

Increase resistivity – Specifying materials to dry out the concrete and prevent moisture from increasing or maintaining the rate of corrosion.

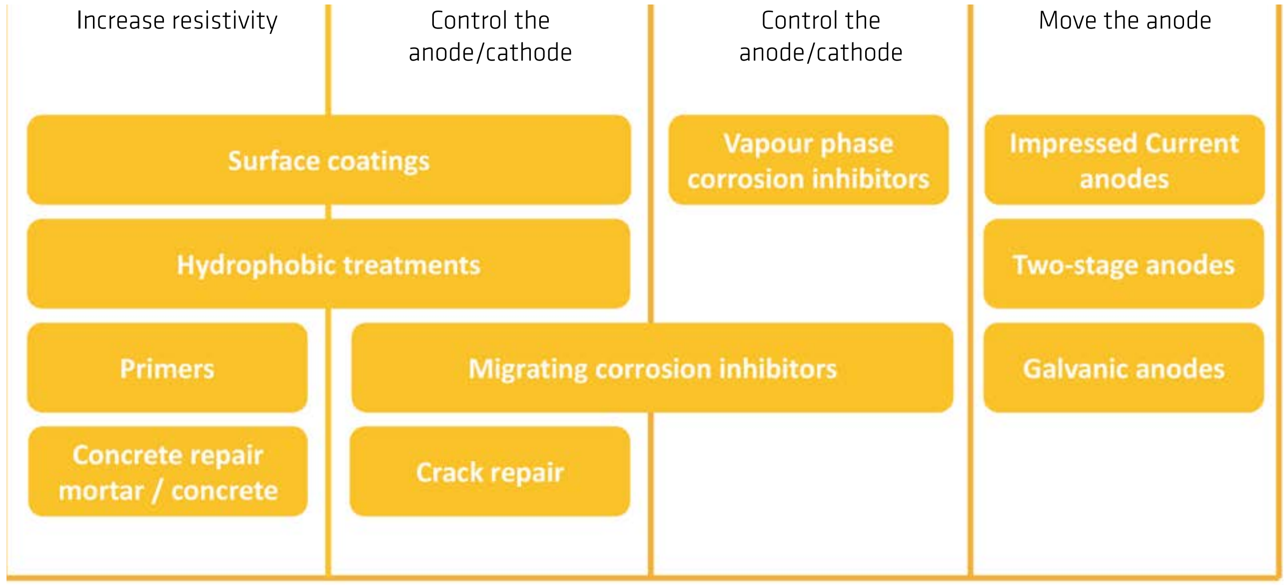
Prevent ingress – Using materials to prevent aggressive agents entering the concrete and initiating corrosion and/or contributing to its rate.

Move the anode – Relocation of the damaging anodic reaction to prevent future damage. This action covers the various forms of cathodic protection.

Control the anode/cathode – Using advanced chemicals to interrupt the corrosion reaction on the steel and prevent damage from occurring.

Each action is explained in the section below. These actions can be delivered using a number of different product groups which are often combined to exploit synergies and provide a robust protective solution (see Figure 7).

Figure 7. Sika's Total Corrosion Management approach



INCREASE RESISTIVITY

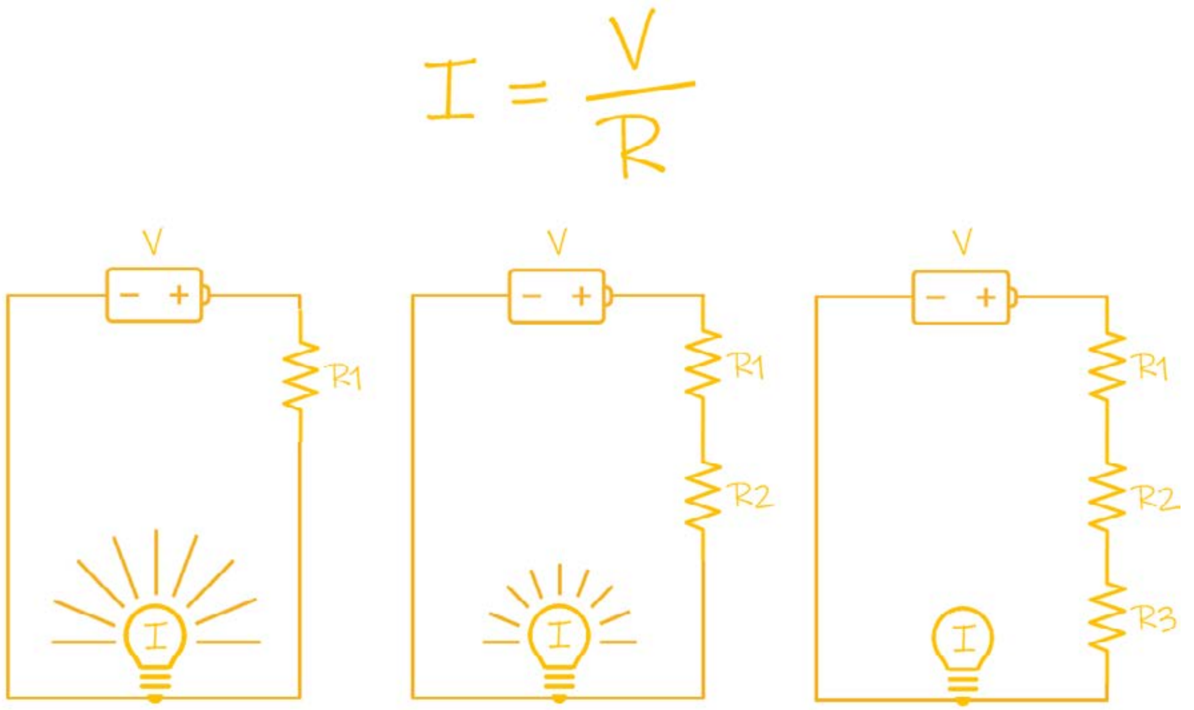
TCM is a complimentary corrosion-focused take on the Repair Work phase of BS EN 1504. Its main purpose is to ensure consistent quality, durability, and safety when dealing with deteriorated or damaged concrete.

In a nutshell, specifying materials to increase the resistance to corrosion current flow, thus reducing the opportunity for corrosion to start and limit its rate if ongoing.

The main ways in which we can increase the electrical resistivity of the concrete are to reduce the amount of water in the pore network or replace low resistivity concrete.

Reduce moisture
If we think of corrosion as a simple electrical circuit (Figure 8), then reducing the moisture content is like adding a resistor and reducing the current. The current is our corrosion reaction, and so as per Ohm's Law (Current = Voltage/Resistance) anything we can do to increase the resistivity of the concrete will limit the corrosion rate. This is not true in saturated conditions.

Figure 8. The effect of concrete resistivity (R) on corrosion current (I)



INCREASE RESISTIVITY (CONT)

The simplest way to reduce moisture in the concrete is to prevent it from entering in the first place. Specialist surface coatings are available for all aspects of RC structures and are formulated and designed to ensure that they prevent water ingress in their specific service environments. For example, car park deck waterproofing systems need to provide excellent crack-bridging capabilities whilst also being slip and UV resistant. Protective coatings for concrete and masonry need to protect against spray and driving rain, whilst also allowing water vapour to escape the structure.

Hydrophobic impregnations (silanes or siloxanes) are another class of material which prevent liquid water from entering the concrete but allow water vapour to escape. This allows concrete sub-surface concrete to remain dry and surface concrete to dry more quickly when it gets wet. These materials are applied using similar techniques to a coating, but aren't film forming and have no impact on the appearance of the concrete.

Replace damaged low-resistivity materials

Old, poor quality, cracked, porous and/or chloride contaminated concrete is likely to have lower resistivity than new, high-strength, dense repair mortars or micro-concretes. This means that simply by completing concrete repairs, we are reducing the likelihood of future corrosion in the patch repair.

PREVENT INGRESS

Using materials to prevent aggressive agents entering the concrete and causing corrosion.

Surface coatings and hydrophobic impregnations are an excellent way to prevent moisture ingress and therefore increase concrete resistivity (see above). However, coatings can also be specifically designed to prevent aggressive elements from penetrating the concrete and contributing to corrosion. In the case of chloride penetration into the concrete, waterproof/water-resistant coatings and hydrophobic impregnations exclude chlorides from the concrete by excluding the water they rely on to move.

In the case of carbonation, specifically formulated coatings stop the penetration of CO2 into the concrete. This halts it's resultant acidification and therefore de-passivation and corrosion of the steel. These coatings can be applied to new or old concrete to halt the natural progress of carbonation and the potential for future damage.

Another way of preventing ingress is to repair cracks in the concrete. Cracks arise for a number of reasons, including concrete curing conditions, structural movements or overloading and repair strategies will differ. The one thing that they all have in common, however, is that they provide an easy route into the concrete for both chloride ions and CO^2 by effectively reducing the cover to the reinforcement (see Figure 9).

Crack repair techniques are tailored to the requirements of the structure; for example does the solution need to provide waterproofing and/or structural continuity, or just fill and flatten? The main product groupings for crack repair are:

- Crack injection resins – low viscosity two-part resins which can be injected into cracks under pressure using specialist equipment (see Figure 10), or gravity poured. Can fill cracks ~0.1mm or wider.
- Thixotropic adhesives – two-part epoxy adhesives used to fill and re-profile larger cracks and also seal cracks prior to injection.

Figure 9. Photo shows how a crack in the concrete cover can lead to deeper penetration of carbonation

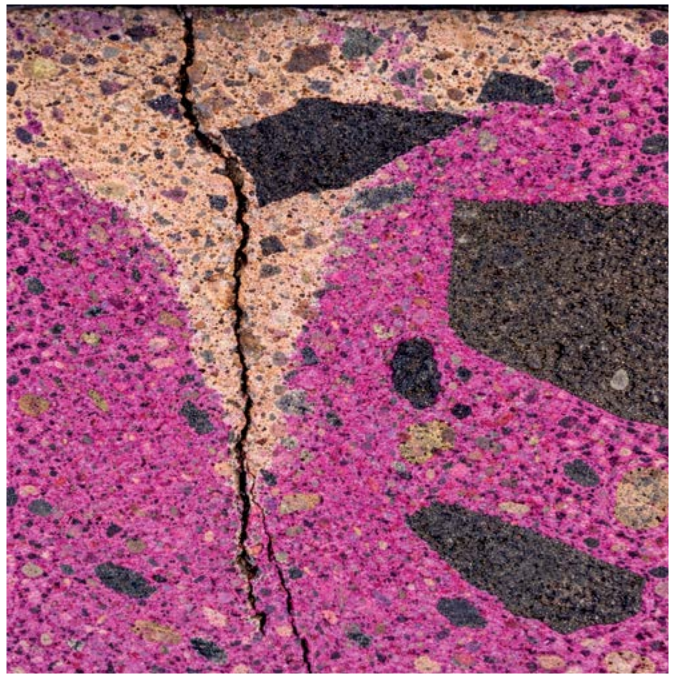
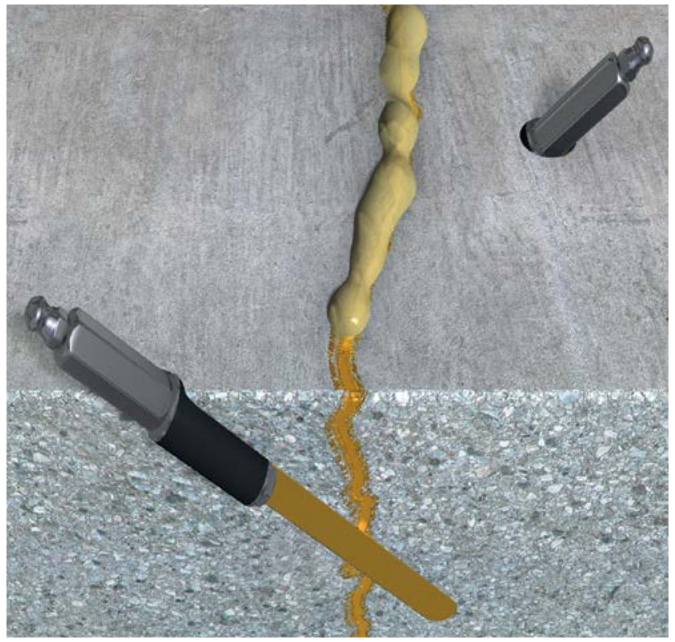


Figure 10. Digital image showing a sectional view of high pressure crack injection



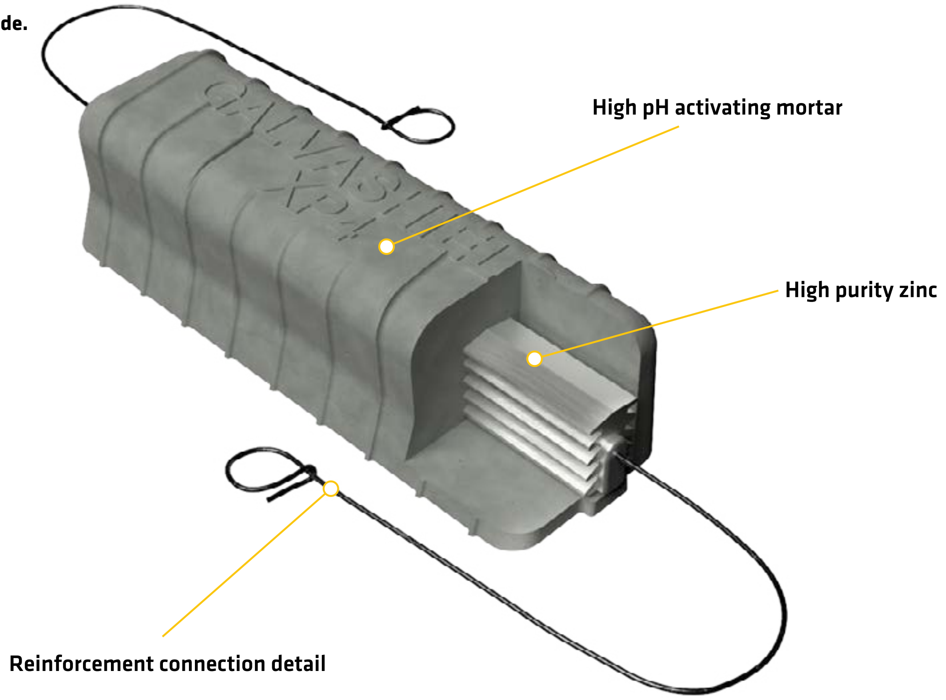
MOVE THE ANODE - CATHODIC PROTECTION

Cathodic protection in a nutshell: The aim of cathodic protection is to make the steel reinforcement a cathode and make another, separate material into an anode. To do this, we pass a current from an installed anode through the concrete to the steel surface. There are two ways of creating a current – by connecting the reinforcement to a different, more reactive metal or by introducing a power supply.

Cathodic protection is used to protect against chloride-induced corrosion of buildings, bridges, industrial and coastal structures.

Galvanic Cathodic Protection (GCP)
The simplest form of cathodic protection. Although galvanic anodes come in all different shapes and sizes, they all share the same anatomy (Figure 11). They work in the same way as a household battery in that when two different metals are connected in a common electrolyte a voltage difference exists and so a current flows from the more reactive metal to the less reactive metal. In our case the more reactive metal is zinc and the less reactive steel; the electrolyte is mortar or concrete and the voltage is about 0.3V. It is essential that concrete from the depth of the reinforcement is sampled and tested. If it's not, then the present risk of corrosion cannot be known and the results are somewhat meaningless.

Figure 11. The anatomy of a galvanic anode.



Galvanic anodes are installed in patch repairs to protect the surrounding reinforcement which sits in chloride contaminated concrete. They can also be placed in drilled holes in a grid arrangement to protect reinforcement in sound concrete that has been identified as being at risk from ingressed chlorides. Novel surface mounted variants are now available for when drilling is undesirable or impossible, and galvanic anodes can also be installed in new concrete structures that are exposed in high-risk environments.

The current passed to the reinforcement will vary depending on the temperature and moisture content of the electrolyte, meaning they naturally respond to the corrosion risk facing the reinforcement. As a result, monitoring of galvanic anodes is not necessarily required but can be implemented where necessary.

As the zinc anode is consumed by the current it passes, galvanic anodes have a finite life but if correctly designed and installed they can have a functional life of over 20 years.

Impressed Current Cathodic Protection (ICCP)
Instead of relying on a voltage difference between two metals to drive a protective current, ICCP inserts a power supply into the circuit to allow the voltage and therefore the protective current to be controlled. The current is delivered and monitored using a transformer-rectifier which all of the anodes are wired back to. This unit requires a permanent AC power source. ICCP systems come in a variety of forms, from drilled-in anodes to mesh and cementitious overlay to sprayed conductive mortars or coatings.

As with galvanic anodes we use the concrete or a mortar as our electrolyte, but a key difference is that impressed anodes are not consumed by the reaction on their surface. Instead they generate gases, and monitoring and control software is used to ensure the right amount of current is delivered. ICCP systems can also be used on masonry-clad steel structures.

Two-stage or hybrid cathodic protection
Two-stage anodes are a combination of ICCP and GCP, where the same anode unit is used to deliver both stages:

In **Stage 1** a voltage is introduced to drive a high current density to the reinforcement and halt active corrosion. This stage lasts for ~2 months.

In **Stage 2** a galvanic anode is employed to deliver protective current and prevent corrosion long term.

As with GCP, no permanent power supply or monitoring is required to ensure proper function of the anodes as they respond to their environment, although simple monitoring arrangements can be put in place. As the initial burst of current in Stage 1 re-builds the passive oxide layer on the steel and re-alkalises the surrounding concrete, only a small galvanic anode is required to give a life time of up to 30 years.

CONTROL THE ANODE / CATHODE – CORROSION INHIBITORS

Corrosion inhibitors use advanced chemicals to interrupt both the anodic and cathodic parts of the steel corrosion reaction. To do this, they need to pass through the cover concrete and reach the reinforcement surface.

There are two main forms of corrosion inhibitor:

- Migrating – liquid applied onto an exposed concrete surface which then penetrates through the cover to the reinforcement and forms a film on its surface. This can take a number of weeks to complete, but penetration can be confirmed by an established technique.
- Vapour phase – pellets are placed in drilled holes set out in a grid. The active agents then penetrate through the concrete in a vapour phase before forming a mono-molecular layer on the reinforcement which inhibits the corrosion reaction. This technique allows for treatment with corrosion inhibitors even when the concrete has coatings which cannot be removed.

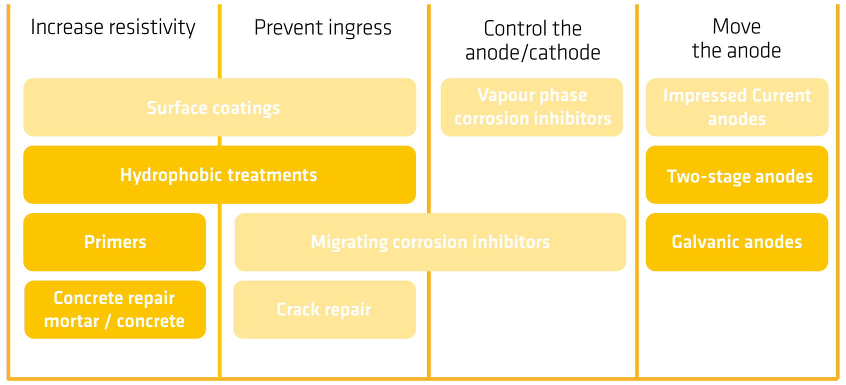
Corrosion inhibitors are generally used for corrosion prevention and not for high-risk environments. They are well suited to buildings where carbonation, or a low to moderate risk of chloride-induced corrosion has been identified, and are not a replacement for cathodic protection techniques.

Worked examples
The following project studies show how products can be combined to address the four actions of TCM.

AQUATICS CENTRE

Challenges:

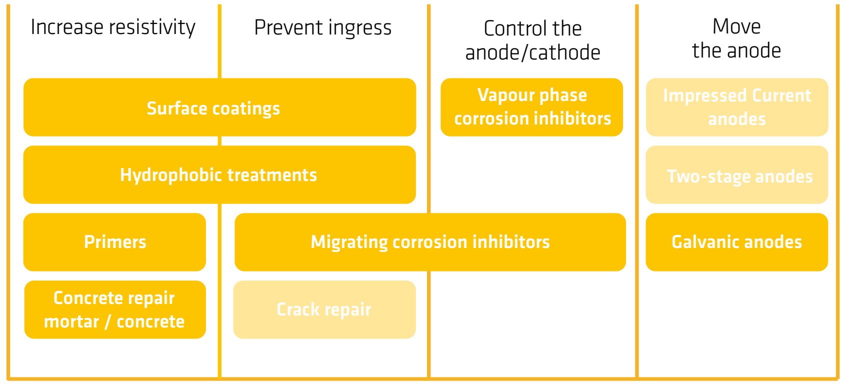
- Exposure to chlorinated pool water
- Warm and humid environment
- High concrete chloride content
- Active corrosion



GOLDFINGER HOUSE

Challenges:

- Poor quality concrete
- Carbonation of cover concrete
- High chloride levels on gritted areas as well as cast-in chlorides
- Grade II listed structure, aesthetic demands



Further reading
The repair and protection of reinforced concrete with Sika – Click Here
Concrete repair and protection case studies – Click Here

CHAPTER 5

REPAIR: ENSURE LONG-LASTING PROTECTION

Informed by an assessment of the structure's current condition and future risks, a materials specification will be produced for the project and agreed upon by the client or their engineer.

This document presents the high-quality products to be used and details how and where they are to be applied to the structure. The project is finally scheduled to start, and so the next stage is to make sure that the repairs are completed to a high standard to ensure return on investment and long-lasting protection. This means ensuring that the specification is still fit for purpose and that the operatives carrying out the work are competent.

ENSURE THE SPECIFICATION IS STILL FIT FOR PURPOSE

Anyone who has worked in the refurbishment of structures will know how long some projects can take to come to site. Some projects start almost immediately after specification, however, it's not uncommon for projects specified by a manufacturer to start 3 or 4 years after the initial documents were issued.

If the issue date on the product specification is more than year ago, it is essential that it is reviewed by all parties to ensure it is fit for purpose, for several reasons.

Firstly, the condition of the structure may have deteriorated. If a corrosion problem goes unchecked it can quickly lead to further damage and may have spread to other areas as the structure deteriorates. A fresh assessment or survey of the structure may find that a different approach would now be more economical or effective.

For example:

- Hand placed concrete repair mortars replaced with spray-applied micro-concrete for a larger repair area.
- Patch repair galvanic anodes replaced with embedded galvanic anodes in a grid as the corrosion risk and repair area has expanded.
- Higher chloride concentration now rules out migrating corrosion inhibitors.

Secondly, the availability of the specified products may have changed. Manufacturers are always improving the performance and sustainability aspects of their range which usually means predecessor products are retired. At the same time new, innovative products and technologies are being launched which may be a better fit for the structure than those previously proposed.

Thirdly, the access, phasing and site provisions that were proposed at the time of specification may have changed. The work may now have to be done from an access platform, at night or in short shifts before a road or railway re-opens, meaning that the requirements of the materials have changed. For example, rapid-setting or rapid strength gain materials allow trafficked surfaces to be re-opened sooner, sprayed concrete can be placed in higher volumes than by hand and surface-applied galvanic anodes can be fitted much more quickly than those installed in cored holes.

Finally, the one item that causes more headaches for programmes and budgets than anything else is the good old British weather. A project delay resulting in winter rather than summer working can mean shorter working hours and more instances of rain stopping play, but often the biggest issue for specified materials is the lower temperatures. It is a fact of life that to gain strength at a reasonable rate and fully cure, Ordinary Portland Cement (OPC) based concretes and repair mortars need a temperature of +5°C. There are also minimum temperature requirements for resin-based products such as structural adhesives or liquid-applied flooring. These two classes of material account for the vast proportion of structural repair products and so a move to winter working can be problematic.

There are specialist variants of the products above that can be applied at lower temperatures. Examples include magnesia phosphate cements, which allow for placement at -20°C, PMMA floor coatings which can be applied at 0°C and boosters which can be added to resins to reduce the minimum working temperature and decrease the cure time. Another option is to create an environment which meets the temperature requirements of the material. This can be easy for small, sheltered areas but is more of a challenge (and cost) for exposed structures like bridges.

Conversely, high temperatures can lead to shorter pot-lives and working times for resinous materials. Cementitious materials can also cure too quickly in hot conditions, leading to cracking and expansion not seen at regular temperatures.

In summary, carrying out the required work at a time of year that suits the specified materials is likely to mean more control over programmes, less complicated applications and lower overall costs.

COMPETENCE

Throughout this report we use the phrase specialist contractor because to deliver high quality concrete repair and protection work requires real expertise, craftsmanship and experience. Specifying the right high-performance materials is one aspect of a successful project, but ensuring they are applied correctly following the correct preparation, preliminary steps and in the right site conditions is even more important.

So, who to trust with your project? There is no doubt that specialist concrete repair sector has not been spared by the growing skills shortage facing UK construction. A report published by the CPA (Construction Products Association) in October 2024[5] stated that over the previous five years, UK construction lost an average of 70,000 workers a year. At the same time, apprenticeship starts averaged 31,000 per year, with a dropout rate of 40%. That means every year saw a net loss of 50,000 people from the labour pool. It also concluded that the labour force is ageing, with the average age of a UK born construction worker now being over 50.

Finding and retaining talent in this environment is challenging to say the least, as the labour market is competitive and its workers mobile. There are incredibly talented people spread across the whole gamut of specialist contractors, meaning that smaller businesses have just as much, or significantly more experience and talent than the bigger players.

As with many construction sectors, competency frameworks are lacking or in their infancy, so, how do you ensure you employ a competent specialist to undertake the specified works? The list below is not exhaustive, but forms a useful guide:

- The specialist contractor should be able to prove organisational competence with examples of the same or similar work they have carried out, with similar materials, preferably on a similar type of site (e.g., road, rail, residential).
- They should be accredited for relevant management and improvement standards such as ISO 9001:2015 for Quality Management Systems, ISO 45001 for Health and Safety Management and ISO 14001 for Environmental Management Systems.
- Where qualifications exist for specialist operations, the specialist contractor should have staff who are qualified to the correct level or be willing to put their staff through the training. Examples include ISO 15257:2017 competence for those working in cathodic protection. A broader commitment to staff development and training should also be in evidence.
- Related to the point above, the contractor should also be able to point to individuals who are competent in certain operations and who will be responsible for oversight and sign-off.
- The specialist contractor should also be able to produce or significantly contribute to Inspection and Test Plans (ITPs) or method statements for the works to ensure quality.
- Although not essential, membership of a trade association such as the Concrete Repair Association (CRA) or Corrosion Prevention Association (CPA) will ensure that the company has a proven track record and conforms to a code of practice and relevant standards such as BS EN 1504. Trade associations also offer training such as NVQs and an opportunity to keep abreast and influence standards and guidance.

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[5] ***UK Construction's Demographic Timebomb. Accessed March 2026: https://www.theconstructionindex.co.uk/news/view/uk-constructions-demographic-timebomb***

CHAPTER 6

MAINTAIN: LIFE CARE PLANNING

Once the project is completed there is a natural tendency to breathe a sigh of relief, congratulate ourselves and move on to the next job. Unfortunately, however, few repair solutions will achieve their desired longevity if the structure isn't periodically inspected, maintained or monitored. This section discusses life care planning for repaired structures which ensures the investment made in the repair and protection works delivers value over their design life.

Getting a life care plan or something akin to one in place up front, renewing shorter service-life products when required and identifying small issues before they grow into costly failures can significantly delay the requirement for future major works.

WHAT IS LIFE CARE PLANNING?

Life care planning takes many forms and has different names across different sectors, but the term simply describes a documented, managed approach to the inspection, maintenance and management of structure for its remaining design life.

The term has risen to prominence for the management of multi-storey car parks, but is applicable in its scope to almost any reinforced concrete structure, whether new-build or refurbished.

Life care plans, in whatever form they take, are normally prepared by the responsible engineer or competent professional and agreed with the end client. Although cost and disruptions are key drivers, the main focus of life care planning should be safety of the public whilst they use the structure.

WHAT IS INVOLVED?

Keep records
We discussed the usefulness of historic data in Stage 1 of Chapter 3: Assess and it goes without saying that collating and securely storing all relevant documentation and data about the current works is crucial to decision making and planning for future maintenance.
This typically includes:

- Results of previous testing/ investigation works.
- As-built and other drawings.
- Specifications and material warranties.
- Operation and maintenance manuals.
- Contractor details and works done.

If it doesn't already exist, this information could form the start of a BIM file for the structure. Although establishing this can be more complex and costly than for a new structure, it is likely to lead to cost savings and efficiencies in future.

Take stock
Along with forming an enduring and complete record of the current works and what informed them, this step should also record any learnings from the project which will inform how future upkeep and monitoring is planned.

For example, was there something omitted from the present works for cost reasons that will need to be addressed/prioritised when funds become available? Are there watch-outs, for example a drainage system that easily blocks, which could impact the performance or longevity of a protective system?

WHAT IS INVOLVED? (CONT)

Get a plan together
Critical industries or sectors may mandate regular inspection and testing of a structure along with obligatory reporting which presents recommended or compulsory actions. However, for sectors such as housing and industrial this may be less formal.

Paying heed to the two sections directly above, a calendarised month by month, year by year plan which details the actions required for each event, the reporting required and who shall receive it, will ensure that:

- Small maintenance or repair issues are identified early, raised to the responsible party and addressed.
- Any manufacturer inspections required to retain validity of the materials guarantee or warranty are undertaken.
- Any deterioration in the wider structure can be logged and monitored over time.
- Any specialist installations such as ICCP systems are monitored and maintained to ensure performance.
- Any cleaning operations which prolong the life of the repaired structure such as specialist cleaning of car park deck coatings, drainage jetting etc. are carried out.

The collation and review of the data generated by these works:

- Allows for the prioritisation of budget allocations in current and future years.
- Informs future planning for the structure (change of use, end of life etc.).
- Builds a case for future works/improvements.
- Keeps the interested parties and stakeholders involved close to the project.

Monitoring corrosion
The entire section up to this point has considered the ongoing inspection and maintenance of the repaired structure more broadly, but what about the initial cause of all the trouble – reinforcement corrosion? Shouldn't we be keeping an eye on that?

If everything so far has gone to plan and we have a properly specified and executed repair solution which is being looked after well, then arguably no. However, in some cases, through necessity of budgets, access or time, specified repairs are not the full solution to a corrosion problem.

They may act to put the structure in a holding pattern until further budget can be found, offer a limited period of protection or may have only been carried out to a part of the structure. In these cases, and/or when the structure is a piece of critical infrastructure or difficult and costly to access, it may be worth installing a corrosion monitoring system.

These systems employ one or more of the techniques covered in Chapter 3: Assess to make an ongoing assessment of corrosion risk and in some cases, corrosion rate. They are typically embedded in the structure at the time of repair or shortly afterwards and should target areas identified as being of high structural importance or that are most at risk of future corrosion.

In its most simplistic form, a corrosion risk monitoring solution might comprise an embedded half-cell potential probe in the area of interest and a connection to the reinforcement close by. Wires will then be placed in concrete chases/ducts to connect the sensor and reinforcement connection to a junction box which is located somewhere easy to access.

The necessary half-cell potential readings can then be taken manually using a voltmeter, typically a few times a year.

One step up from this may be a box with a battery or mains-powered data-logger which automatically records data daily or hourly for download and interrogation at a convenient time. A further improvement would be to build in telematics so that data can be interrogated remotely on demand without site presence. Multiple areas of a structure could be monitored by installing multiple half-cell potential probes and wiring them back to the same enclosure and data-logger.

As discussed in Chapter 3: Assess, ideally multiple assessment techniques should be employed to fully understand the cause and severity of a corrosion issue.

The same is true when it comes to embedded monitoring.

Over time, half-cell potential monitoring will tell you if there is an increase in the corrosion risk to the reinforcement, but it won't tell you what is causing it. Combining half-cell potential data with concrete resistivity and/or relative humidity probe data from the same location will indicate whether moisture ingress is to blame for the change. It won't, however, confirm that chlorides are present, or confirm them as the cause of the increased corrosion risk. A pH probe will monitor the risk from carbonation, but it won't tell you if the reinforcement is corroding and at what rate.

WHAT IS INVOLVED? (CONT)

Often, this doesn't mean that huge numbers of different sensors need to be installed. Instead, we can rely on previous testing/monitoring data and what we know about the structure's primary maintenance issues or deterioration risks to target areas for monitoring, before selecting the most appropriate types of measurement. We may also want to target monitoring in areas that are difficult to access and where regular inspections would be challenging or impossible. The generated monitoring data can then be used to prompt further interventions such as detailed inspections and/or further confirmatory testing such as break-outs for reinforcement inspection, dust sampling or corrosion rate testing.

This approach presents the primary benefit of monitoring the condition of a structure. It offers a cost-efficient way of building a body of evidence for acting at the right time – before corrosion problems present a risk to safety or a huge repair cost.

To support those involved in managing structures make informed decisions about repair interventions, Sika partners with Duramon (, a Swiss spin off from ETH Zurich, to offer state of the art monitoring systems for both existing and new build structures. Their advanced multi-sensor pack allows for remote real-time monitoring of all relevant corrosion-related parameters – including pH and chloride concentrations – providing a complete picture of the corrosion status and its potential causes. To date, DuraMon has installed monitoring systems on more than 20 structures across Europe, including tunnels, parking structures, retaining walls, and bridges. These systems identify when, where, and why corrosion will start, giving peace of mind to their owners.

This long term monitoring solution will allow those responsible to act at the right time and in the right way to ensure safety and minimise cost.

Wait and see

Another use case for corrosion monitoring is to use it as part of a 'wait and see' approach. For example, testing and inspection works have revealed chloride ingress, but the present corrosion risk is low to moderate and there is no visible corrosion damage.

There is little budget for repairs at present and the client is keen to delay investment. It is decided that a hydrophobic impregnation should be applied to prevent ingress/increase resistivity, and a corrosion monitoring system installed to ensure that action is taken at the right time in the future.

Corrosion monitoring should always be specified by a competent professional, usually a Level 4 ISO 15257 Level 4 Cathodic Protection Specialist. They will be able to advise on the best monitoring option for your structure and also provide interpretive reports based on the data generated.

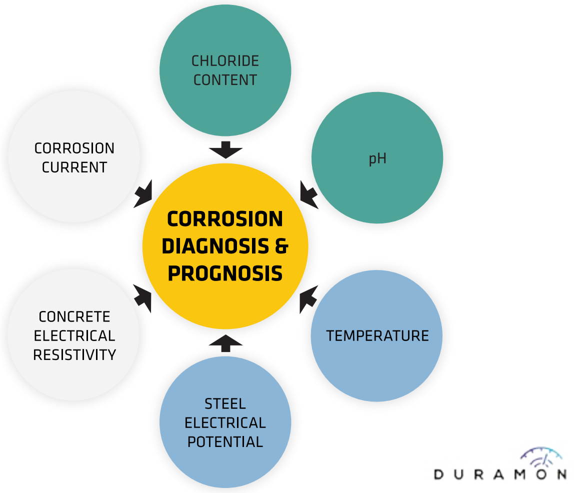
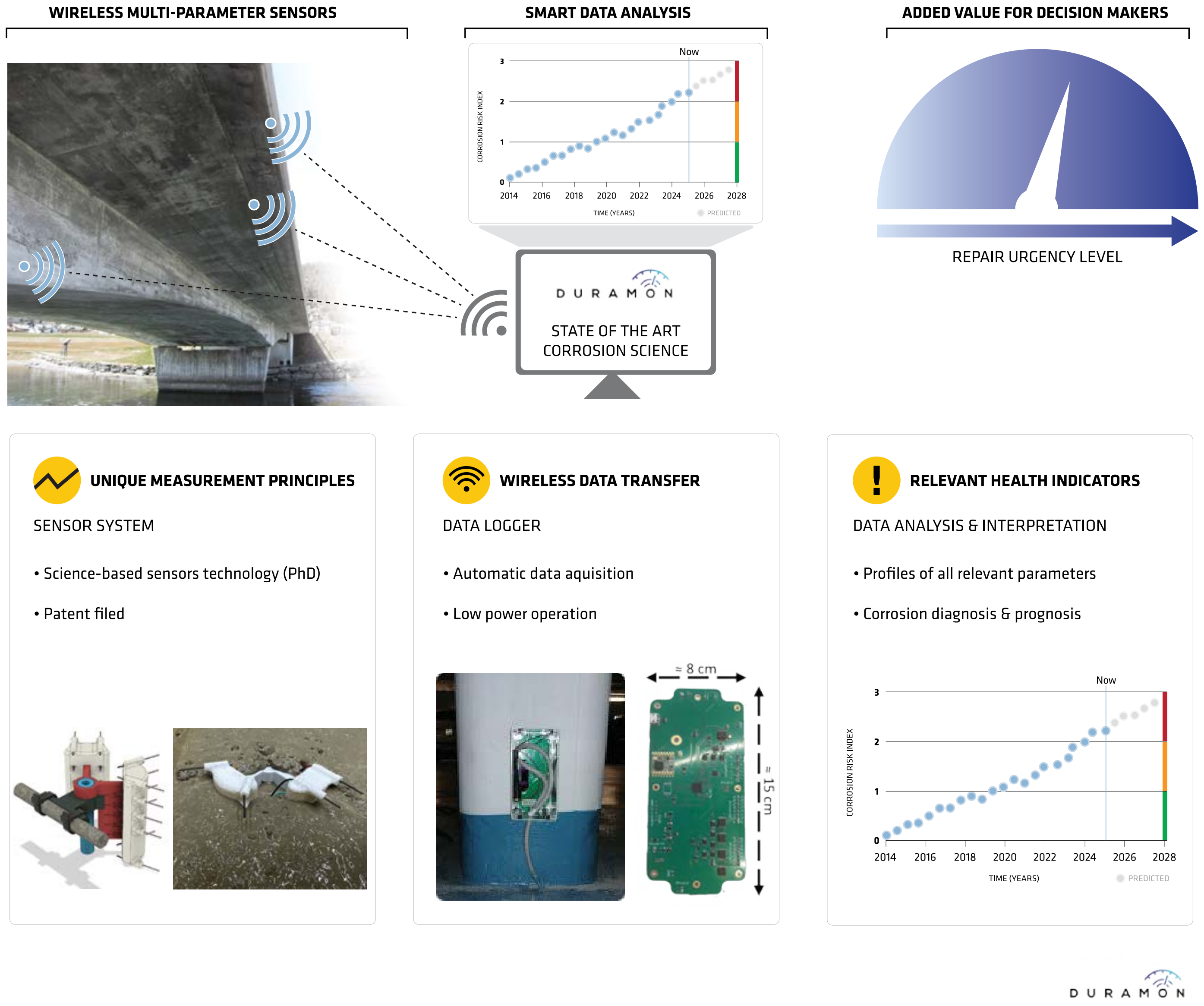


Figure 12. Graphic showing the capability of the Duramon embedded sensors

Figure 13. The Duramon corrosion monitoring system



Other uses

Another use case for corrosion monitoring is to use it as part of a 'wait and see' approach. For example, testing and inspection works have revealed chloride ingress, but the present corrosion risk is low to moderate and there is no visible corrosion damage. There is little budget for repairs at present and the client is keen to delay investment. It is decided that a hydrophobic impregnation should be applied to prevent ingress/increase resistivity, and a corrosion monitoring system installed to ensure that action is taken at the right time in the future.

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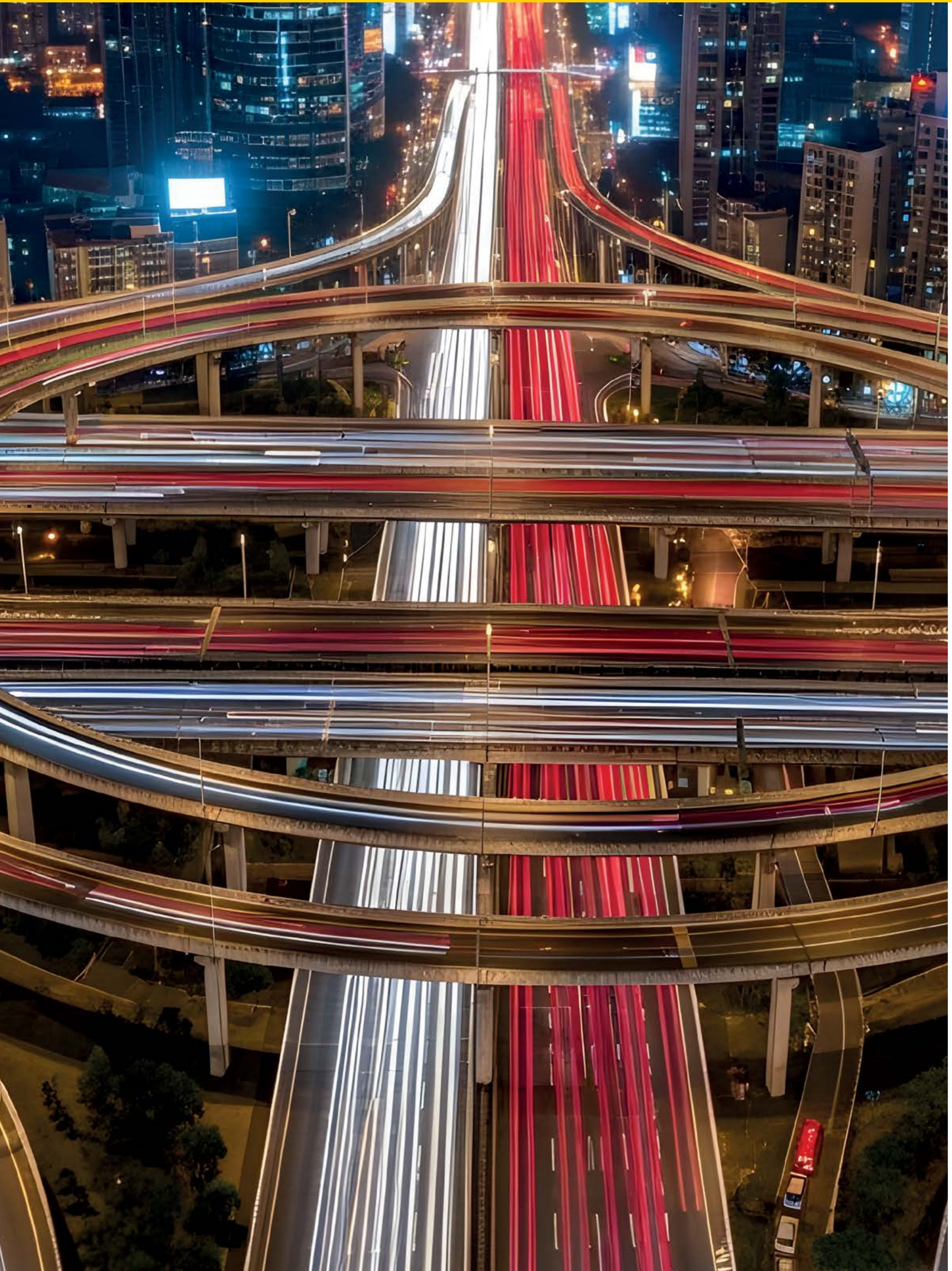

SUMMARY

Reinforcement corrosion remains one of the greatest threats to the safety, serviceability and value of our ageing concrete buildings and infrastructure. While the causes are well understood the consequences are far-reaching, from unsightly deterioration and disruption to costly repairs and, in the worst cases, structural failure. With billions spent each year on addressing avoidable damage, the industry can no longer afford reactive approaches or short-term fixes.

The most effective way to manage corrosion is through a structured, informed and preventative strategy. By first **assessing** the true condition of a structure and understanding both the causes and risks of deterioration, we can target interventions where and when they are needed most. Through collaborative **specification,** the right combination of materials and technologies can be selected to address the root causes of damage, disrupt corrosion mechanisms and provide durable protection. High-quality **repair,** delivered by competent specialists using appropriate products and methods, ensures these solutions perform as intended and insure return on investment. Finally, ongoing **maintenance** and life care planning safeguard the investment, allow for early intervention and extend service life, minimising whole-life costs.

Taken together, this systematic approach transforms corrosion management from a cycle of failure and patchwork reactive repairs into a proactive programme of preservation. By combining sound engineering judgement, modern materials and long-term planning, owners and engineers can extend the life of existing assets, improve safety, reduce disruption and deliver better value for both budgets and the environment. In doing so, we move from simply reacting to deterioration to actively managing durability - ensuring that today's structures continue to serve future generations with confidence.

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