

Technical Report No. 69

Repair of concrete structures with reference to BS EN 1504

Report of a Joint Working Party of The Concrete Society, the Corrosion Prevention Association and the Institute of Corrosion



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Repair of concrete structures with reference to BS EN 1504

Contents

List of figures	iv
List of tables	iv
Foreword	v
1. Introduction	1
1.1 Overview of BS EN 1504	1
1.2 Scope and structure of this report	3
2. Deterioration processes	4
2.1 Background	4
2.2 Design and construction defects	5
2.3 Corrosion of steel in concrete resulting from carbonation and chlorides	5
2.4 The principles of repairing and controlling corrosion	9
2.5 Concrete degradation	10
2.6 Environmental influences	12
2.7 Structural damage	13
3. Repair of concrete	15
3.1 Introduction	15
3.2 Arresting degradation	16
3.3 Minimum requirements before work begins	16
3.4 Treating exposed steel	18
3.5 Filling holes	18
3.6 Preventing further degradation	19
3.7 Strengthening of weakened structures	19

4. General principles (Part 9)	20
4.1 Scope of Part 9	20
4.2 Overview	20
4.3 Application, product testing and CE marking	22
5. Surface protection systems	23
5.1 Surface treatments for concrete	23
5.2 Surface protection systems	24
6. Repair mortars, structural bonding and reinforcement protection	27
6.1 Repair mortars	27
6.2 Structural bonding	29
6.3 Reinforcement protection	30
7. Concrete injection	31
7.1 Introduction	31
7.2 Design considerations	32
7.3 Scope	33
7.4 Terms and definitions	34
7.5 Performance characteristics	34
7.6 Annexes	35
8. Anchoring of reinforcing steel	36
8.1 Application	36
8.2 Design considerations	36
8.3 Terms and definitions	36
8.4 Performance characteristics and requirements	37
8.5 Installation requirements	37
9. Achieving successful repairs	40
9.1 Content	40
9.2 Implementing the sections	40
10. Performance-based rehabilitation of reinforced concrete structures	43
10.1 The CONREPNET project	43
10.2 Lessons learnt from past repairs and current industry practices	43
10.3 A look to the future	46
10.4 Summary	48

11. Assessment of structures and ongoing monitoring of concrete repairs	49
11.1 Records	49
11.2 Concrete repair management	49
11.3 Testing	50
11.4 Assessment	51
11.5 Routine maintenance	51
References	53
Appendix A. Case studies illustrating the application of BS EN 1504	56
A1 Mayorhold multi-storey car park	56
A1.1 Description of the structure	56
A1.2 Problems that prompted repair	57
A1.3 Inspection and evaluation methods	58
A1.4 Repair and protection system selection	59
A1.5 Preview of corrosion management scheme	60
A1.6 Project installation and compliance with BS EN 1504 Part 9	60
A1.7 Special features	62
A2 University campus structures	63
A2.1 The structures	63
A2.2 The condition and situation of the structures	63
A2.3 Applying the Principles of BS EN 1504 to the rehabilitation process	65
A2.4 Design and specification of the work	66
A2.5 Site tests	67
A2.6 Conclusions	68
Appendix B. CE marking	60
Appendix C. Standards relevant to protection and repair of concrete and standard test methods for BS EN 1504 Parts 2 to 7	71

List of figures

- Figure 1 Steps in the repair process.
- Figure 2 The corrosion mechanism for steel in concrete.
- Figure 3 The two stages of the corrosion process for steel in concrete.
- Figure 4 Surface coating applied to repaired structure.
- Figure 5 Surface protection systems.
- Figure 6 Comparison of EN 1504-compliant labelling for Class R4 and Class R2 cementitious repair products (courtesy of BASF).
- Figure 7 Two-part acrylic injection of basement floor slab – Principle 1, Protection against ingress.
- Figure 8 Epoxy resin injection of overhead crack – Principle 4, Structural strengthening.
- Figure 9 Hole drilling using rotary percussive air flush drill bit.
- Figure 10 Resin being poured into prepared hole.
- Figure 11 Bar being inserted into resin.
- Figure 12 Completed installation.
- Figure 13 Anchorage assembly test equipment.
- Figure 14 Concrete failure possibly due to shallow fixing depth or cracking to concrete. This is an unreinforced slab.
- Figure 15 Reactive and proactive approaches to the maintenance of structures.
- Figure 16 Alternative approaches to the management and maintenance of structures.
- Figure A1 Spalling of concrete on downstand beams.
- Figure A2 Area of spalling on the deck.
- Figure A3 Half-cell potential mapping.
- Figure A4 Installation of anodes in deck.
- Figure A5 Typical termination box.
- Figure A6 Completed and repaired car park.
- Figure A7 The Teaching Wall and adjacent walkways.
- Figure A8 Walkway showing Teaching Wall behind.
- Figure A9 Incipient anode formation.

List of tables

- Table 1 The Parts of BS EN 1504.
- Table 2 Repair principles in BS EN 1504 Part 9.
- Table 3 Repair principles requiring mortars and concretes.
- Table 4 Sections in BS EN 1504 Part 10.
- Table 5 Advantages and disadvantages of the prescriptive and performance-based approaches.
- Table A1 Results from driving lane on Level B.
- Table A2 BS EN 1504 Part 9 Principles applied to the structure.
- Table A3 Selection of treatments for different elements.
- Table C1 Standards relevant to protection and repair of concrete.
- Table C2 European standard test methods for protection and repair materials.

Foreword

The suite of Parts that make up BS EN 1504, *Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity*⁽¹⁾, provides an integrated framework for the concrete repair industry. Although it is principally a product standard, it also aims to assist specifiers, clients and contractors. The Standard addresses all stages of the repair process, from initial awareness that a problem exists, to the handover of a structure to a satisfied client where the repairs have been properly designed and executed. The Standard embodies the use of products and systems which meet minimum performance requirements for a range of repair applications. The tests required to demonstrate compliance with the performance requirements are not given in BS EN 1504 but in separate Standards.

The Standard is not a specification. Rather, it should be seen as a framework around which clients and/or their designers can build a specification.

The material in this Report was prepared by members of the Joint Liaison Committee of The Concrete Society, the Corrosion Prevention Association and the Institute of Corrosion, and was originally published as a series of Repair Guidance Notes in The Concrete Society's magazine *CONCRETE*⁽²⁻¹²⁾. The aim of the Report is to guide consultants and contractors through the application of BS EN 1504, and other related concrete repair and protection standards for the evaluation, design specification and concrete repair process so that they develop appropriate solutions and specify and apply the appropriate materials.

1. Introduction

The various Parts of BS EN 1504 were developed over a period of 20 years. The requirements of the Standard are specification/performance based rather than prescriptive and therefore allow direct comparison of materials and selection based on required performance.

1.1 Overview of BS EN 1504

The titles of the ten parts of BS EN 1504, *Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity*⁽¹⁾, are given in Table 1.

Table 1
The Parts of BS EN 1504.

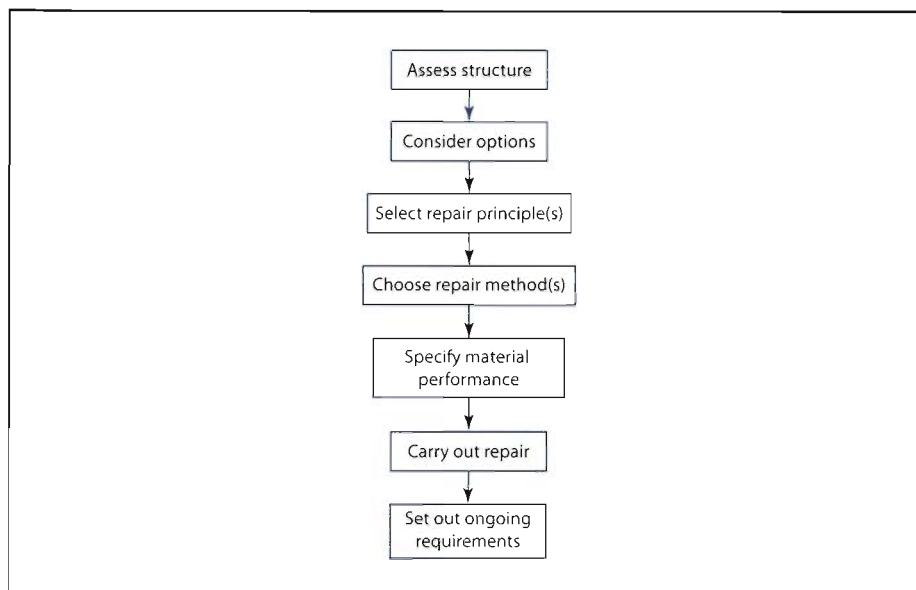
Part 1	Definitions
Part 2	Surface protection systems for concrete
Part 3	Structural and non-structural repair
Part 4	Structural bonding
Part 5	Concrete injection
Part 6	Anchoring of reinforcing bars
Part 7	Reinforcement corrosion protection
Part 8	Quality control and evaluation of conformity
Part 9	General principles for the use of products and systems
Part 10	Site application of products and systems, and quality control of the works

Part 9 is the key document for the specifier/engineer as it provides a structured approach to the investigation of the cause of deterioration as well as outlining the 11 Principles of remedial action. (Note that at the time of preparation of the report, Part 9 was still at the ENV stage; there may be some changes when Part 9 is finally published.)

The process set out in Part 9 is illustrated in Figure 1. The need for a formal assessment of the structure's condition and the causes of deterioration are key stages of the specification process. The process in Part 9 should result in logical and consistent repair decisions which allow the client to exercise economic choices based on whole-life costing when considering options and selecting principles. The approach should help to reduce the adoption of short-term, superficially less expensive, repairs which may be significantly more expensive in the long term. For example, the use of sacrificial anodes in a repair zone, though initially more costly, can significantly increase the life expectancy of the repair by reducing the tendency for new areas of damage to develop around the repairs.

The various parts of BS EN 1504 are comprehensive and provide information and guidance to all groups involved in the concrete repair process, namely specifier, contractor and material manufacturer. A series of complementary test methods has been developed for use in the evaluation and classification of the materials. These are set out in separate Standards outside BS EN 1504.

Figure 1
Steps in the repair process.



Details of the different product types are discussed in Parts 2–7. For the manufacturer, the challenge is to produce a range of products that **satisfy** the repair principles and perform according to the specification.

Site application and the associated quality control are covered in Part 10 of the Standard, which gives general guidance for the preparation, application, and quality control of the selected systems. However, it is essential that any additional product-specific information, supplied by the manufacturer, is also incorporated into the procedures prior to starting work.

BS EN 1504 governs the anticipated performance and testing regimes required for the repair materials used. Within the Standard there are a number of categories that need to be considered from a specification point of view, and informative Annexes are included. The repair has the best chance of being successful if the system has been designed, specified and applied properly. The Standard provides a framework that can help to achieve this. However, conformance to the relevant parts of the Standard does not and cannot guarantee the required level of enhancement. If it is the right procedure, it does not guarantee that the right material has been specified such that it is reasonable to expect the material to be properly applied on site. If it is the right procedure and the right material is being used, it does not guarantee a successful repair will be achieved. It is one element as part of an overall package required in achieving a successful repair. An engineer qualified and experienced in corrosion control techniques and coatings for concrete should be engaged to ensure that the appropriate materials and application procedures are used to achieve the desired result.

BS EN 1504 offers no guidance or restrictions on the techniques and methods to be used in carrying out the works on site, nor regarding the site quality control of the processes. Part 10: *Site applications of products and systems and quality control of the works* does offer some useful guidance but there is insufficient information to enable a specifier or designer to draw up a detailed specification. It will be necessary to consult with material manufacturers and specialist contractors, such as members of the Concrete Repair Association (CRA) or the Corrosion Prevention Association (CPA), for advice and guidance on how best to carry out the works on site.

1.2 Scope and structure of this report

This Report is not intended to be a handbook to BS EN 1504, explaining the background to requirements of the Standard, nor does it deal specifically with the mechanics of repairs and repair techniques. Rather, its aim is to guide repair consultants and contractors through the application of the Standard, and other related guidance, through the various stages from initial evaluation to the repair process and beyond. Following initial chapters (Chapters 1 to 3), which provide background on the main causes of deterioration and how they can be repaired, the main discussion of BS EN 1504 is provided in Chapters 4 to 8. Because Part 9 of the Standard underpins the whole of the process and is the basis for the use of the other sections, this is discussed in the first of these chapters (namely Chapter 4).

The Report concludes with three appendices. Appendix A contains two Case Studies, describing the repair of a multi-storey car park and structures on a university campus respectively, which illustrate the application of the principles of BS EN 1504. Appendix B briefly describes CE marking and Appendix C lists the many Standards dealing with the testing, protection and repair of concrete.

2. Deterioration processes

There are a number of causes of deterioration in concrete buildings and structures. Even when they are adequately built, properly used and well maintained, the environment will affect structures of all kinds and components will degrade or wear out and require repair or protection. The processes behind different types of deterioration are outlined below. Principles governing repair of deteriorated concrete structures are set out in Part 9 of BS EN 1504, *General principles for the use of products and systems*, and are listed here in Table 2. For each of the types of deterioration discussed below, a suitable repair principle (or principles) from the list is suggested.

Table 2
Repair principles in BS EN 1504 Part 9.

Principles related to defects in concrete	
Principle 1	Protection against ingress
Principle 2	Moisture control
Principle 3	Concrete restoration
Principle 4	Structural strengthening
Principle 5	Increasing physical resistance
Principle 6	Increasing resistance to chemicals
Principles related to reinforcement corrosion	
Principle 7	Preserving or restoring passivity
Principle 8	Increasing resistivity
Principle 9	Cathodic control
Principle 10	Cathodic protection
Principle 11	Control of anodic areas

2.1 Background

The largest single cause of deterioration in reinforced-concrete structures is corrosion of the reinforcing steel. In addition, there are a number of deterioration processes that attack the concrete directly, some from within, such as alkali–silica reaction, and some from external sources, such as freeze–thaw damage. Some are related to initial construction problems while others are due to subsequent use or lack of maintenance of the structure.

This chapter summarises the primary causes of defects, damage and decay in concrete buildings and structures. They are described in detail in Concrete Society Technical Report 54, *Diagnosis of deterioration in concrete structures*⁽¹³⁾. Any attempt to remedy problems must start with a thorough understanding of the cause and extent of the deterioration. It is essential that a detailed investigation is carried out as part of the appraisal process, the results are interpreted, and the repair options fully evaluated to ensure that the right repair option is selected. This is discussed in Section 5 of Part 9 of BS EN 1504.

2.2 Design and construction defects

The performance of reinforced concrete can be severely reduced by poor design and construction techniques. These may significantly increase the risk of reinforcement corrosion or degradation of the concrete itself which may in turn lead to reinforcement corrosion.

Insufficient cover to the reinforcement is a major negative influence on the durability of reinforced concrete. A number of problems, particularly with older structures, occur because of deficiencies at the design stage. Some of these problems are outlined in the following list.

- Older codes did not specify adequate cover or sufficiently impermeable concrete, especially in saline environments.
- Design codes used to specify cover to the main steel, which meant that there was inadequate cover to stirrups, etc.
- Details such as drips, grooving of surfaces, and so on, reduced overall cover, often to vulnerable steel at corners and in areas of water runoff.
- Poor detailing made it difficult to achieve the specified cover; problems could occur where congested steel made it difficult for concrete to flow into all of the spaces and completely encapsulate the steel.
- Reconstituted stone mullion and cill units have inherently poor durability and carbonate easily.

During construction a number of problems may arise, including:

- high water/cement ratio, leading to a more porous concrete, which is then more susceptible to carbonation and chloride ingress
- cast-in chlorides, from aggregates or admixtures
- choice of inappropriate aggregate and cement types leading to alkali–aggregate reaction, see Section 2.5.1
- incorrect reinforcement placing
- movement of reinforcement within shutters leading to reduction from the specified cover
- insufficient compaction of concrete
- plastic cracking.

Treatment comes under Principle 1, *Protection against ingress*, and Principle 2, *Moisture control*, as well as Principle 3, *Concrete restoration*, all in Part 9 of BS EN 1504.

2.3 Corrosion of steel in concrete resulting from carbonation and chlorides

There are two major contributing factors which can lead to corrosion of steel in concrete and that do not require damage to the concrete before the steel is attacked. These factors are carbonation and the presence of chlorides. Any prior damage or defects such as cracking or low cover are likely to further exacerbate the problem.

2 Deterioration processes

2.3.1 Carbonation

The alkali content of concrete protects the reinforcement from corrosion. During the cement hydration process which takes place as concrete sets and gains strength, calcium, sodium and potassium hydroxides are formed. These dissolve in the pore water of the concrete to form a very alkaline solution with a pH of around 12.5–13.5. At this pH, a very thin, protective oxide known as a passive layer forms on the surface of the reinforcement. This is a durable film that is far better than synthetic or metallic coatings that may deteriorate or be consumed. The passive layer also sustains and maintains itself indefinitely provided that the concrete stays highly alkaline and remains free from contamination.

The alkalinity of concrete can be reduced by the process of carbonation. This is due to the ingress of atmospheric carbon dioxide which then dissolves in the pore water in the concrete cover to form carbonic acid. The result is a reduction in the alkalinity of the concrete. This reduction occurs progressively from the concrete surface and a carbonation front moves through the concrete. If it reaches the steel, the passive layer on its surface breaks down as the pH drops from over 12 to around 8. Once the passive layer has broken down, corrosion can start if oxygen and water are present.

It should be appreciated that the carbonation front is not a distinct line, but a zone with a width of perhaps 10 mm or more where the pH drops from around 13 down to 8. Phenolphthalein, commonly used to determine the depth of carbonation, changes colour at pH 9.2, whereas full passivity is not achieved until the pH rises above about pH 11.5. There can therefore be a zone behind the apparently uncarbonated front where there is still a risk of corrosion.

The carbonation front moves into the concrete approximately according to the following parabolic relationship:

$$\text{Carbonation depth} = \text{Constant} \times \text{Square root of time}$$

A typical Portland cement concrete may have a carbonation depth of 5–8 mm after ten years, rising to 10–15 mm after 50 years (see BRE Digest 444⁽¹⁴⁾). Therefore structures with low concrete cover over the reinforcing steel will show carbonation-induced corrosion more quickly than those with good cover. A method for determination of carbonation depth is given in BS EN 14630:2006⁽¹⁵⁾.

The rate at which carbonation progresses is affected by the concrete quality. Concretes made with a high water/cement ratio and with a low cementitious content will carbonate more quickly than other concretes because they are more porous and have lower reserves of alkali to resist the neutralisation process. Concretes made with fly ash, ground granulated blastfurnace slag or other cement replacement materials have lower reserves of alkalinity, because some of the alkali material is used up in the hydration reaction. However, this is usually counterbalanced by the increase in concrete quality when compared with an equivalent Portland cement, except at high replacement levels in dry conditions (see BRE Digest 444⁽¹⁴⁾). The rate of carbonation is also affected by environmental conditions. Carbonation is more rapid in fairly dry and wet-dry cycling environments. It may therefore occur more rapidly in bathrooms and kitchens in blocks of flats than in other rooms in the building. The rate can also be higher in multi-storey car parks where the carbon dioxide concentrations are high due to exhaust fumes.

2.3.2 Chloride attack

The second major cause of reinforcement corrosion is chloride contamination. This is usually due to one of the following causes:

- ingress of de-icing salt from roads and vehicles
- ingress of sea salt in marine environments
- cast-in salt from contaminated mix components
- cast-in calcium chloride as a set accelerator.

Corrosion does not occur until a particular concentration (known as the threshold concentration) is exceeded at the reinforcement surface. This threshold can range from about 0.1 to 1.0% chloride by mass of cement, but the most commonly used thresholds are 0.3% (used by the Highways Agency) or 0.4%, found in much of the European literature. Once the chloride concentration at the reinforcement exceeds this threshold there is a significant risk of corrosion, especially in the presence of moisture. If cast-in chlorides exceed 0.4%, then the corrosion risk rises (see BRE Digest 444⁽¹⁴⁾). A test method for determination of the chloride content of hardened concrete is given in BS EN 14629:2007⁽¹⁶⁾.

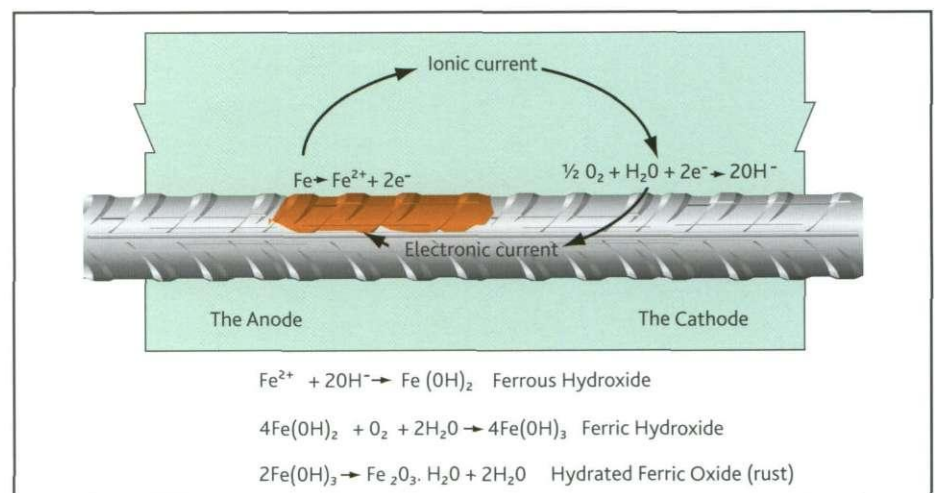
As with carbonation, the rate at which chlorides penetrate concrete is a function of concrete quality and environment. Chlorides can be transported rapidly in poor-quality concrete exposed to chloride-laden water by wetting and drying absorption and by capillary action. In good-quality concrete with good cover to the reinforcement and little cracking, diffusion processes predominate.

2.3.3 The corrosion process

Irrespective of the cause of corrosion, once the passive layer on the steel has broken down, corrosion proceeds by the process illustrated in Figure 2.

Corrosion (oxidation) of steel exposed to moisture and the atmosphere is a normal chemical process that nonetheless requires a reaction at an anode and a reaction at a cathode to occur in balance. Corrosion of steel in concrete is an electrochemical reaction in which the major constituent of steel (iron) goes into solution as positively charged ions, releasing electrons (electrical flow). The site at which this occurs is called the anode and hosts the oxidation process.

Figure 2
The corrosion mechanism for steel in concrete.



2 Deterioration processes

The electrons flow through the reinforcement towards sites on the steel surface where they react with oxygen and water from outside to produce additional hydroxyl ions. These sites are called cathodes and host the reduction process.

In a passive (highly alkaline) environment the reduction–oxidation reaction sustains and maintains the passive layer and from this point of view is beneficial. When depassivation has occurred, corrosion can begin and is accelerated by the presence of chloride ions.

As can be seen in Figure 2, the normal cathodic reaction requires water and oxygen. The initial anodic reaction does not require any reactants until the iron has been transformed into soluble ferrous ions. These can react with the hydroxide ions (the alkalinity in the concrete) and then with oxygen and water to create the solid rust. The volume increase associated with the deposition of rust can crack and spall the concrete.

The fact that oxygen is not required at the anode is important because the exclusion of oxygen from anodic areas without stifling the cathodic reaction can lead to dissolution of the reinforcement without cracking and spalling of the concrete, i.e. the structure is weakened without there being any external evidence of deterioration. This can happen in conditions of local saturation where the concrete is very wet and therefore sufficiently conductive to permit good spatial separation between anodes and cathodes. This condition is known as differential aeration where the lack of oxygen at the anode leads to formation of H^+ ions that are free to react with chloride to form hydrochloric acid within, for example, pits and crevices on the steel surface. Further oxygen starvation within the pit or crevice accelerates the process and leads to rapid failure.

The conditions necessary for corrosion are therefore:

- carbonation or sufficient chloride at reinforcement depth to depassivate the steel
- oxygen to fuel the cathodic reaction and to create the expansive oxide at the anode (in its absence at the anode, corrosion may occur without spalling and delamination); note that complete exclusion of oxygen from both anode *and* cathode will stop the corrosion process
- water to fuel the cathodic reaction and to create the expansive oxide.

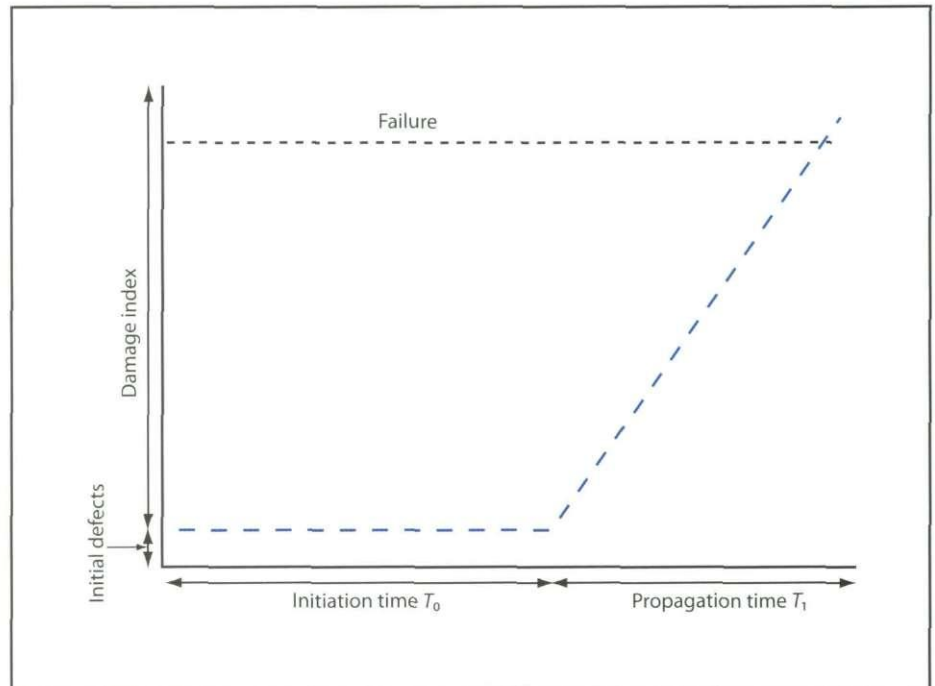
Note that chloride-induced depassivation produces pitting whether or not the rust is soluble.

These conditions, along with the electrical/electrochemical nature of the reactions, can therefore be used to assess the corrosion condition. Methods for corrosion assessment of reinforced concrete are given in Concrete Society Technical Report 60, *Electrochemical tests for reinforcement corrosion*⁽¹⁷⁾.

Repairs are formulated according to approaches based on Principle 7, *Preserving or restoring passivity*, in Part 9 of BS EN 1504, which includes electrochemical realkalization to CEN/TS 14038-1⁽¹⁸⁾ for the case where corrosion is the result of carbonation and electrochemical chloride extraction for the case where corrosion results from chlorides. Additional approaches might be Principle 8, *Increasing resistivity* or Principle 10, *Cathodic protection* (covered in BS EN 12696⁽¹⁹⁾). There will also be a requirement for Principle 3 on concrete restoration.

2.4 The principles of repairing and controlling corrosion

Figure 3
The two stages of the corrosion process for steel in concrete.



The two tables of principles in BS EN 1504 Part 9 can be considered to address the two-stage process. Table 1 Principle 1 is concerned with protection against ingress, T_0 , the corrosion initiation phase:

- 1.1 Impregnation
- 1.2 Surface coating with and without crack bridging
- 1.3 Local bandaging of cracks
- 1.4 Crack filling
- 1.5 Transferring cracks into joints
- 1.6 Enclosure
- 1.7 Membranes.

These processes can help to keep out contaminants such as chlorides and moisture. However, once corrosion has initiated, experience indicates that they are not very successful in controlling active corrosion.

Principle 2, *Moisture control*, overlaps with Principle 1. Principle 3, *Concrete restoration*, will be required once the propagation phase has started, but again, unless all contamination or carbonated concrete can be removed, it will not control corrosion outside the repaired areas. Principle 4 is concerned with structural strengthening, Principle 5 with physical resistance to physical or chemical attack of the concrete and Principle 6 to chemical attack.

2 Deterioration processes

Table 2 in Part 9 relates specifically to reinforcement corrosion, i.e. T_1 , the propagation phase in Figure 3. It covers the following techniques in Principles 7 to 11:

- Principle 7, *Preserving or restoring passivity*
 - Increasing the concrete cover
 - Replacing carbonated or chloride-contaminated concrete
 - Electrochemical realkalisation
 - Electrochemical chloride extraction
- Principle 8, *Increasing resistivity*
 - Limiting moisture ingress by coatings, surface treatments or sheltering
- Principle 9, *Cathodic control*
 - Limiting oxygen ingress by saturation or surface coating
- Principle 10, *Cathodic protection*
 - Galvanic or impressed current cathodic protection
- Principle 11, *Control of anodic areas*
 - Painting reinforcement with coatings with active pigments
 - Painting reinforcement with barrier coatings
 - Applying chemical corrosion inhibitors.

It is therefore important that the investigation of a structure divides it into those areas which require active corrosion control as reinforcement corrosion has initiated or will do so soon and those areas where it is possible to control ingress of CO_2 and chlorides to prevent depassivation.

It is also important to realise that some of the techniques in Tables 1 and 2 in Part 9 are difficult if not impossible to apply in practice and are unproven, particularly for steel in concrete, or as stated in the notes to the tables:

'Inclusions of methods in this [pre]standard does not imply their approval. An engineer experienced and qualified in corrosion control techniques should be engaged to advise on appropriate and proven techniques.'

2.5 Concrete degradation

There are a number of deterioration processes which can lead to the premature deterioration of concrete itself rather than corrosion of reinforcement (which then can result in cracking and spalling of the concrete). These are discussed in the following sections.

2.5.1 Alkali–aggregate reactivity

The pore solution within concrete is highly alkaline. Some aggregates may react with the alkalis to form products that swell by taking up water and can damage the concrete. The most common alkali–aggregate reaction is alkali–silica reaction (ASR). Silicates in the aggregates react to form silica gels. If sufficient moisture is present, these gels can absorb water and expand and crack the concrete. The result is often a 'map cracking' effect and exudation of the gel from the cracks at the surface of the concrete. The crack patterns may be modified by reinforcement and loading.

Many aggregates exhibit ASR to a greater or lesser extent. This reaction can be detected by microscopic examination of concrete but does not usually lead to any significant problems when the aggregates are used in appropriately designed concrete. A more limited number of aggregates show serious problems on a macroscopic scale. These aggregates are now well characterised in terms of type and source in the UK. In some cases ASR will occur in a structure or part of a structure, the alkalis or susceptible aggregates will react and be depleted and the situation will stabilise. The problem is often one of appearance rather than a major durability issue, but the structural performance may be affected; the Institution of Structural Engineers has published guidance⁽²⁰⁾. Further information on ASR can be found in BRE Digest 330⁽²¹⁾ and Concrete Society Technical Report 30, *Alkali-silica reaction: minimising the risk of damage to concrete*⁽²²⁾. In principle, it may be possible to slow ASR by reducing or eliminating moisture either by deflecting runoff, or by the application of coatings or sealers covered under Principle 2, *Moisture control*, in Part 9 of BS EN 1504. However, this is not well proven in practice.

2.5.2 Sulfate attack

Sulfates of sodium, calcium, potassium and aluminium are found in groundwater and soils in some locations. They can cause degradation of the concrete matrix by expansive attack on the calcium hydroxide and calcium aluminates in the concrete. Wet-dry cycling causes salts to be accumulated on the concrete surface, resulting in degradation. Sulfates can attack a part of the hydrated cement paste to form ettringite. It should be noted that some sulfate is always present in cement, and some ettringite is similarly present. Analysis of sulfate content should consider this and look for excess sulfates or ettringite. Delayed ettringite formation and thaumasite formation are also forms of sulfate attack. A simplistic analysis suggests that more than 0.1% water-soluble sulfate in soil or 150 ppm in water is moderate exposure to sulfate attack; more than 2% in water or 1% (10 000 ppm) in soil is severe exposure. However, a more sophisticated analysis is often required and guidance for design purposes is provided in BRE Special Digest 1, *Concrete in aggressive ground*⁽²³⁾. Treatment of the problem will require concrete repair under Principle 3, *Concrete restoration* and approaches based on Principle 1, *Protection against ingress*, and Principle 2, *Moisture control*, all in Part 9 of BS EN 1504.

2.5.3 High-alumina cement concretes

High-alumina cement (HAC) was used extensively in the 1960s and 1970s to achieve very high early-strength concrete. HAC concrete also has higher resistance to acids and sulfates. Under certain conditions during its curing (high water/cement ratio and high temperatures during curing) and particular environmental conditions after construction (high temperatures and/or high humidity levels), it undergoes a mineralogical change leading to substantial loss of strength and increase in porosity. This process is known as conversion. Once conversion has occurred, the cement paste may be attacked by some chemicals, such as calcium sulfate found in gypsum plasters and alkalis derived from Portland cements, which can cause alkaline hydrolysis. A number of structural failures occurred in which components made from HAC concrete were involved, although some of these were partly due to design and detailing issues as well as HAC failure. Conversion is ultimately inevitable in all HAC concrete

2 Deterioration processes

structures or components, which must therefore be monitored in all cases – see *An overview of the BRAC guidance in relation to current guidance on high alumina cement concrete*^[24]. It is likely that conversion will already have occurred in the vast majority, if not all, HAC structures built prior to the ban in 1972.

Repair approaches may be based on Principle 1, *Protection against ingress*, and Principle 2, *Moisture control*, in Part 9 of BS EN 1504. In most cases, even after conversion, HAC concrete members retain sufficient strength to continue to provide adequate factors of safety and a monitoring approach is adopted. In some cases, structural repair or even replacement may be needed. Most structures in the UK containing HAC have been identified and structurally evaluated to demonstrate that any conversion can be accommodated or the structure has been upgraded, i.e. strengthened or the structural HAC elements replaced. Care should be taken if repairing HAC as the use of highly alkaline repair mortars can cause further degradation due to alkaline hydrolysis.

2.6 Environmental influences

In addition to the corrosion of reinforcement which can result from exposure to carbon dioxide in the atmosphere or saline conditions, there are a number of other environmental factors that can cause deterioration.

2.6.1 Staining

Water-staining of unpainted concrete can be a problem in the UK. The porosity and water-absorption characteristics of concrete seem to make it more susceptible than brick and stone to this type of soiling. Like natural stone or brickwork, concrete can be cleaned, but removing concrete surface laitance can render the concrete more susceptible to future staining. Maintenance of and improvements to drainage may reduce the recurrence of the problem. Suitable coatings would come under Principle 2, *Moisture control*, in Part 9 of BS EN 1504.

2.6.2 Erosion

Continuous passage of water across a concrete surface, particularly of water containing suspended solids, can erode concrete with time. Aggressive solutions can etch concrete. Erosion control comes under Principle 2, *Moisture control*, Principle 3, *Concrete restoration* and Principle 5, *Increasing physical resistance*, in Part 9 of BS EN 1504. The source of the problem should also be addressed. As with staining, maintenance of and improvements to drainage may reduce the recurrence of the problem.

2.6.3 Efflorescence/salt recrystallisation

Efflorescence can occur due to moisture movements within concrete towards a surface or the passage of water through a member. Soluble calcium salts from the concrete dissolve in the water, which then carbonates and causes calcium carbonate to form on the surface.

In addition, other soluble salts may precipitate as the water evaporates. The effect is mainly cosmetic although there may be some erosion of the surface if significantly concentrated salts are formed in the near surface. However, long-term passage of water through concrete due to porosity or cracking can significantly weaken it. Control of efflorescence comes under Principle 2, *Moisture control*, in Part 9 of BS EN 1504.

2.6.4 Freeze–thaw damage

Freeze–thaw damage occurs where water-saturated concrete is exposed to cycles of freezing and thawing. The expansion of the freezing water can crack the concrete and cause scaling of the surface. Repair would come under Table 1 Principle 3, *Concrete restoration* and Principle 2, *Moisture control*, in Part 9 of BS EN 1504.

2.6.5 Chemical attack

A number of chemicals, particularly acids with pH <5, will attack the cement paste. Some aggregates are also vulnerable to attack. This leads to the loss of cement paste and/or aggregates with time. Its control comes under Principle 2, *Moisture control*, Principle 3, *Concrete restoration* and Principle 6, *Resistance to chemicals*, in Part 9 of BS EN 1504. If possible, the source of the problem should also be addressed.

2.6.6 Abrasion

Abrasion is the wearing away of the surface of the concrete, resulting in localised or general depressions in the surface. A common problem is the abrasion of slabs by the wheels of vehicles and mechanical handling plant. Abrasion may be caused by waterborne particles, such as the action of sand and pebbles carried by the waves on coastal structures. Repair would come under Principle 3, *Concrete restoration*.

2.7 Structural damage

Structural damage can result from a number of causes, including:

- inadequate design or construction
- settlement or other ground movement
- overloading or change of use
- fire
- impact
- seismic effects
- wind
- ASR and DEF (delayed ettringite formation)
- HAC conversion (see Section 2.5.3).

2 Deterioration processes

It is necessary to identify these using a qualified engineer and there are well-proven methods to rectify these problems. Structural strengthening is covered under approaches based on Principle 4 in Part 9 of BS EN 1504. See also Concrete Society Technical Report 55, *Design guidance for strengthening concrete structures using fibre composite materials*⁽²⁵⁾ and Technical Report 68, *Assessment, design and repair of fire-damaged concrete structures*⁽²⁶⁾.

3. Repair of concrete

The various deterioration processes that can affect plain, reinforced and prestressed concrete structures have been outlined in Chapter 2 and have been well documented elsewhere. Repair strategies and techniques are equally well covered but nonetheless it is worth giving a broad overview to set the scene and context for BS EN 1504.

3.1 Introduction

Deterioration of the structure will be in one or more forms:

- Corrosion of reinforcement or unsheathed prestressing strands:
 - visible damage (concrete cracking, spalling, rust staining)
 - hidden damage (concrete delamination, reduction in cross-section of reinforcement)
 - non-visible and potential defects.
- Corrosion of post-tensioning bars or strands within ducts:
 - hidden corrosion within the duct, unlikely to result in visible damage prior to structural failure.
- Damage to the concrete:
 - acid or sulfate attack of the cement matrix
 - abrasion or impact damage
 - fire
 - cracks.

The first step should always be an investigation to determine the cause of the deterioration. Once the diagnosis and quantification of the extent of damage have been completed, it is often found that repairs are required. Guidance on the general principles of concrete repair can be found in several publications (see for example Concrete Society Technical Report 38, *Patch repair of reinforced concrete subject to reinforcement corrosion*⁽²⁷⁾ and Technical Report 68, *Assessment, design and repair of fire-damaged concrete structures*⁽²⁶⁾) and in Part 9 of BS EN 1504. These general principles of repair include:

- treating exposed steel
- filling holes left by the removal of spalled or damaged concrete
- arresting and preventing further degradation
- strengthening of weakened structures.

This chapter gives guidance on these principles of repair. All repair works should be carried out with repair products and systems specifically formulated for the intended purpose, with appropriate quality control and performance certification in place, such as compliance with BS EN 1504 or EOTA (European Organisation for Technical Approvals) certification until the Standard comes fully into force.

It should be noted that Part 9 does not cover repair works relating to all of the above mechanisms and associated principles of concrete repair. It is therefore important to appreciate what is and is not covered by the Standard.

3 Repair of concrete

3.2 Arresting degradation

The purpose of the repair will be to ensure that significant deterioration does not occur in the future. Sometimes this is simply the removal of the cause and replacement of damaged concrete. Where corrosion of reinforcement is involved, the planning process requires significantly more consideration.

The two main initiators of reinforcement corrosion are carbonation and chloride ion. To arrest deterioration, these must be removed or neutralised.

- **Carbonation.** In all areas of concrete where the depth of carbonation approaches or exceeds the depth of cover, reinforcement will potentially corrode in the presence of moisture and oxygen. The repair strategy must include breakout and removal of all carbonated concrete in contact with the reinforcement, or provide an alternative strategy where corrosion of the reinforcement is prevented (e.g. moisture-excluding surface coatings, electrochemical realkalisation of the cover concrete).
- **Chloride.** In all areas of concrete that are chloride contaminated, reinforcement will potentially corrode in the presence of moisture and oxygen. The repair strategy must include breakout and removal of all chloride-contaminated concrete in contact with the reinforcement, or provide an alternative strategy where corrosion of the reinforcement is prevented (e.g. cathodic protection, electrochemical chloride extraction of the cover concrete).
- **Combined carbonation and chloride.** It is rare for carbonation and penetrating chloride to occur coincidentally. However, it is more common to find carbonation of older buildings where the concrete contains cast-in calcium chloride. The process of carbonation releases more free chloride ions which can form an elevated ramp of chloride ahead of the carbonation front and can push the free chloride ion content above the limit of 0.2%, initiating corrosion over time. The repair strategy is the same as for chloride above.

3.3 Minimum requirements before work begins

3.3.1 Options for repair

Once the problem is clearly defined and the extent of current and future deterioration is known, the client (or the client's advisors) can assess the options for repair, their potential costs and timescales. Six options for effective concrete repair are commonly used, singly or more often in combination:

1. do nothing, but monitor
2. reanalyse the structural capacity of the weakened element
3. prevent or reduce further deterioration
4. improve, strengthen or refurbish all or part of the structure
5. replace all or part of the structure
6. demolish, completely or partially.

The pre-repair assessment should include a review of the following:

- original design approach
- condition during construction
- history of the structure
- client's current requirements and any proposed future change of use
- approximate extent and likely rate of increase of defects (without repair)
- importance of whole-life costing of the works, which is strongly recommended as the basis for selecting the final repair strategy, looking at the value over the intended remaining life of the structure, rather than just the capital costs of the works.

In addition, consideration can be given to the sustainability of the repair at this stage. As part of this assessment, full consideration is required of the safety and structural implications arising from the present and future condition of the substandard structures in need of repair.

3.3.2 Health and safety

Risks such as falling concrete should be assessed and appropriate actions specified to mitigate any identified events that could arise either before or during the repair work. Special consideration is needed if the structure is to be left to deteriorate further before works are carried out. The importance of this cannot be underestimated; there have been examples of structures allowed to deteriorate to the point where they form a significant danger to the public.

3.3.3 Residual structural capacity

Structural weakening needs very careful consideration by engineers experienced in the repair process.

- Weakening at the point of repair (e.g. due to loss of concrete section in a compression member, or loss in cross-section of reinforcing bar due to corrosion) can be calculated through a standard structural appraisal to give the residual structural capacity. In a structure that has been damaged by fire, the strength of both the concrete and the reinforcing steel can be significantly reduced, see Concrete Society Technical Report 68, *Assessment, design and repair of fire-damaged concrete structures*⁽²⁶⁾.
- Weakening post-repair is less obvious and the following factors must be considered:
 - The physical and structural properties of the repair products and systems to be used at the applicable service temperatures, in particular the elastic modulus, creep and shrinkage of the materials. Where the repair is to take compressive loads, consider the effects of creep at elevated service temperatures.
 - 'Locked-out stress' occurs where tensioned reinforcement is broken out and repaired, thereby losing its tensioned state. This weakening effect can only be reduced by removing load from the structure prior to repair (e.g. propping and load restrictions) and/or minimising the area of concrete to be broken out, even if new bar is added to replace the bar sectional area lost due to corrosion. Even then it is doubtful that the repaired area will fully adopt the initial structural capacity of the undamaged structure.

- Maximum service temperature of structural repair materials. Some organic materials, such as epoxy resin and other adhesives, may have a glass transition temperature of less than 60°C, meaning that they are unsuitable for structural use if service temperatures exceed this value. (The 'glass transition temperature' of a polymer is the approximate temperature at which it changes from a relatively stiff and brittle material to a viscous material.)
- Treatment of prestressed structures needs particular care, as the repair work will need to ensure the full structural capacity of the element is maintained following works. While post-tensioned elements may be able to be de-stressed and then re-stressed, pre-tensioned elements are often replaced owing to the difficulty of providing a repaired element with the same structural capacity as the original.

3.4 Treating exposed steel

Corroded steel must be carefully assessed for loss of cross-sectional area. In the case of conventional reinforcement, significant corrosion can occur without significant weakening of the structure, but in the case of prestressed strand, even slight pitting corrosion can cause significant weakening. Preparation by grit blasting or high-pressure water jetting (at least 700 bar) is preferred as this will remove all corrosion product and contaminants. Generally, further treatment of the bar is not necessary where it is to be surrounded by a strongly alkaline repair material. However, many repair products are not comparable to the concrete initially used (e.g. materials are often formulated to be stiff, suitable for trowel application, rather than a free-flowing concrete, and may not fully encapsulate the reinforcement). Also, the matrix may not be cementitious at all, but be based on an epoxy or other resin system, that will not passivate the reinforcement. It may be necessary to include a primer for the reinforcement and many concrete repair products and systems include these.

Where chloride-induced corrosion has occurred, it is important to ensure that all of the chloride-contaminated concrete is removed, not just where the concrete has spalled. Attempting this type of repair can lead to the formation of anodes on either side of the repair (the incipient anode effect) and can cause rapid failure of the repair. For this reason, methods such as cathodic protection or chloride removal are preferred to patch repair, where chlorides are involved. However, these methods may be unsuitable where prestressed concrete is involved.

3.5 Filling holes

It is strongly recommended that the holes left following removal of defective concrete are filled using materials that are of similar physical and chemical properties to those they are replacing, particularly where the material is in contact with the reinforcement. Therefore, cementitious concrete repair products should normally be used unless there are overriding technical reasons to use other binder formulations (e.g. epoxy or polyester resin).

Repair materials fall into three basic categories:

1. **Structural** – where the repaired element is to be under compressive load. Materials are usually based on normal-density cementitious products, modified with additives to reduce shrinkage and improve adhesion, but still retaining comparable elastic modulus, creep and shrinkage to that of the concrete it replaces. Note that while the laboratory tests for a product may suggest suitability for structural applications, each specific repair situation must be considered on its merit (e.g. compare the properties of old concrete, that has completed full shrinkage and creep under compression, with new material that will undergo shrinkage and creep in the repair situation).
2. **Semi-structural** – where the repair product is in contact with reinforcement but is under no direct compressive load, such as repair to a beam soffit. Materials are usually based on lightweight cementitious products that are unlikely to have the same elastic modulus, creep and shrinkage as concrete.
3. **Cosmetic** – where the hole does not extend to the depth of the reinforcement. Materials are usually based on lightweight products, with either cementitious or polymer binder, and are unlikely to have the same elastic modulus, creep and shrinkage as concrete.

Most repair products and systems in this category will include a priming system to promote adhesion with the existing concrete. Such 'bonding aids' must be used strictly in accordance with the manufacturer's instructions and in particular the recommended time between applying the bonding aid and applying the repair mortar must be strictly adhered to, taking into account the ambient temperature, humidity and wind conditions.

3.6 Preventing further degradation

To prevent future degradation, measures must be put in place to stop the initiator of degradation. In most repair situations, the durability of the concrete can be significantly enhanced by use of a surface protection system. The exact performance requirements of the surface protection system will depend on the conditions of exposure and mechanisms at work. Further information is given in Chapter 5.

3.7 Strengthening of weakened structures

Strengthening may be required where structures are assessed to be below their original structural capacity or require an increase in capacity due to a change in use or change in applicable standards. Methods include:

- adding extra reinforcement and casting additional concrete
- adding externally bonded reinforcement to increase tensile and/or shear capacity; see Concrete Society Technical Report 55, *Design guidance for strengthening concrete structures using fibre composite materials*⁽²⁵⁾
- adding external post-tensioning.

Where structures are strengthened, the ambient service temperature and possible fire effects need to be carefully considered, along with the design principles of the strengthening. As mentioned above, the glass transition temperature of resins used to bond steel or synthetic fibres to concrete may be relevant, particularly in a fire situation.

4. General principles (Part 9)

The overall approaches to concrete repair are set out in BS EN 1504 Part 9, *General principles for the use of products and systems*.

4.1 Scope of Part 9

Part 9 is the starting-point and is considered in this Report out of its natural numerical order, as it puts the other Parts of BS EN 1504 into context and refers to other European and ISO Standards covering special methods of concrete repair. It provides the framework and approach, providing:

- a logical structure to the steps in the repair process, particularly in the processes of developing repair solutions
- a technical standard structured so as to allow the client to make economic choices
- a framework for the specification of repair products.

The scope of Part 9 specifically excludes fire-damaged structures or those containing tensioned reinforcement (pre-tensioned or post-tensioned). In the UK, there is no reason why the principles of Part 9 and the associated product performance standards (Parts 2–6) and site application (Part 10) would not apply to these repair situations provided that particular care is taken over structural aspects. Other issues such as repair of historic listed structures may have project-specific requirements such as aesthetics, minimising the removal of original material, and which modify the application of the principles in Part 9. Appendix A includes a case history of the application of BS EN 1504 to listed buildings on a university campus.

4.2 Overview

Part 9 is not intended to be a code of practice, but a framework for the whole repair process. It covers the need for repair, suggested methods to assess the extent of the problem and deliver a repair package using products and systems tested to European Standard methods and approved (CE marked) as meeting minimum requirements.

Part 9 is intentionally flexible, so it can be used in the various regulatory and contractual environments within Europe. Because of this, there is an absence of specific direction in many instances and requirements are given in very general terms, with few topics covered in any detail. This chapter is intended to provide the necessary interpretation needed for users of the Standard in the UK. The style of the document leaves unanswered questions as to who provides the information and to whom. In the UK, this is covered by the *Construction (Design and Management) Regulations*⁽²⁸⁾, commonly known as the CDM Regulations.

The various steps in the process of assessment, design, specification, site execution and maintenance and monitoring of structures described in Part 9 are illustrated in Figure 1 and may be summarised as follows, with examples of the aspects considered:

- Step 1: Assess structure.** Consider what has caused the damage, the present condition of the structure, its environment and its future use.
- Step 2: Choose options.** These range from doing nothing to partial or complete demolition and replacement. Consider aspects such as the likely long-term performance of protection or repair works, the acceptable number and cost of future repair cycles and the costs of alternative protection or repair options, including future maintenance and access.
- Step 3: Select repair principles.** Select appropriate principles, such as concrete restoration, structural strengthening and cathodic protection as described in more detail below.
- Step 4: Choose repair methods.** Choose methods appropriate to selected repair principles in the light of available products and systems.
- Step 5: Specify material performance.** Select materials with the performance characteristics required for the chosen application.
- Step 6: Carry out repair.**
- Step 7: Set out ongoing requirements.** Develop instructions on inspection and maintenance to be undertaken during the remaining life of the structure.

Part 9 sets out the repair principles and methods of protection and repair that can be adopted. The principles and methods are divided into two groups: the first deals with defects in the concrete as a material; the second addresses defects caused by corrosion of reinforcement. The principles have been listed earlier, in Table 2. Tables in Part 9 also list the repair principles, along with examples of methods complying with each principle, such as:

- Principle 1, *Protection against ingress*
 - impregnation
 - coating
 - filling cracks.
- Principle 3, *Concrete restoration*
 - hand-applied mortar
 - sprayed or recast concrete.
- Principle 4, *Structural strengthening*
 - added reinforcement
 - plate bonding.
- Principle 6, *Increasing resistance to chemicals*
 - coating
 - impregnation.
- Principle 10, *Cathodic protection*
 - see BS EN 12696⁽¹⁹⁾.

The tables refer to the relevant Parts of BS EN 1504 covering the minimum performance requirements for products and systems suitable for use in concrete protection and repair. Note that not all methods are within the scope of products and systems covered by Parts of BS EN 1504.

4.3 Application, product testing and CE marking

As noted above, while Part 9 gives general principles for repair, the main purpose of BS EN 1504 is as a product standard leading to CE marking of products and systems suitable for the protection and repair of concrete structures. The introduction of CE marking across Europe is now underway. All conflicting Standards for both products and test methods will be withdrawn in due course and CE marking will become mandatory in many parts of Europe. Further information on CE marking is given in Appendix B.

A comprehensive list of the test methods specified in BS EN 1504 Parts 2 to 7 is given in Appendix C. Most of these are laboratory test methods but notably the tests for carbonation depth and chloride content of hardened concrete can be used on site.

BS EN 1504 Parts 2 to 7 refer to a large number of Standards that are used to characterise the repair or treatment systems, many of which govern the factory production control systems such as ensuring the product that is received on site is consistent. These are termed identification requirements (the material is what it claims to be) and performance requirements (the material does what it claims to do). It would not be expected that every bag or tin of product would have been subject to every test, but the manufacturer should have an appropriate testing regime and quality control measures in place to ensure that the products are consistent. Note that they are laboratory tests, i.e. would not be appropriate for quality assurance (QA) purposes on site.

Products and systems intended for use in structural applications must be manufactured under a third-party certified QA system. An approved system under BS EN ISO 9000⁽²⁹⁾ will satisfy this requirement.

5. Surface protection systems

Very few new concrete structures in the UK receive a coating. Concrete is assumed to be a dense impermeable material that will provide a very long life. However, when concrete is to be exposed to aggressive chemicals or chloride-laden environments, surface treatment is often applied. Bridge decks are routinely waterproofed, and the visible concrete is often treated with hydrophobic impregnations, typically silanes or siloxanes. These products help shed water and therefore reduce the rate of penetration of chloride ions that cause corrosion. In addition, the use of coatings and waterproofing systems as part of a repair strategy is becoming increasingly common. These can provide an enhanced appearance (see Figure 4) and an enhanced durability. This chapter presents a brief introduction to coating concrete including a review of the relevant requirements in Part 2 of BS EN 1504.

Figure 4
Surface coating applied to repaired structure.



5.1 Surface treatments for concrete

Anti-carbonation coatings are a widely used and relatively well-known means of enhancing the durability of reinforced concrete. Historically there have been two basic figures expressed for such coatings: an R value denotes the resistance to carbon dioxide and an S_D value denotes the vapour permeability. As concrete is a porous material, vapour permeability can prevent some types of coating failure. Silanes are also fairly commonplace as surface treatments for concrete, as are waterproofing systems that either coat the surface of the concrete or soak into the concrete and block the pores. These are the commonest types of treatments, and are technically termed coatings, hydrophobic impregnations and impregnations.

In applying surface treatments to concrete it is necessary to remember a number of key elements. Concrete is a porous material. The pores may contain air or moisture and the surface treatment will have to be able to address this. The moisture may be present near to the surface but will also be present at depth into the concrete. It is likely that the concrete to be treated will be exposed to the external environment and therefore may be exposed to water just before, during or after the application of a coating. Some surface treatments are more able to cope with the presence of moisture than others. Urethanes have excellent adhesion and crack-bridging properties but can turn into expanding foam if applied in the presence of moisture. As a result, these are often used in conjunction with a water-borne epoxy primer that will be applied to the surface as a sealant.

5 Surface protection systems

The moisture may also contain significant quantities of soluble salts. Coatings and surface treatments are therefore often termed 'breathable' where they will allow the passage of water vapour out of the concrete, but will restrict the penetration of water into the concrete.

This breathability characteristic is needed to prevent blistering due to water pressure and can allow the concrete to dry out. Where significant amounts of soluble salts are present in the concrete, the salts can crystallise and break up the surface of the concrete under the coating system.

Concrete also contains cracks. These can be a consequence of its structural behaviour, can be a result of thermal stresses during the original casting, or can be as a result of long-term shrinkage of the concrete. They can be subject to short-term or long-term movements and an originally uncracked area can develop cracks as time progresses. Technically, any coating covering concrete where cracks can appear is subject to infinite strain. In order to cope with this, the coating will either crack or remain intact, but locally debond from the concrete.

Finally, as with any surface treatment to any substrate, the condition of the surface needs to be considered. For any structure, surface preparation will be required before applying a coating. Almost all coating failures are due to inadequate surface preparation. The type and nature of what is required depend on the material to be applied and manufacturers typically make specific recommendations for their products that must be followed. The suitability of the material depends on the practicality of achieving this required level of surface preparation as well as the process of applying and curing the material.

5.2 Surface protection systems

There are three basic approaches used in applying surface protection to concrete. The first is to apply a hydrophobic impregnation. These materials penetrate the outer few millimetres of concrete and leave a water-repellent lining on the surface of the pores. They encourage the concrete surface to repel water but do not prevent water ingress under significant pressure. Materials can also be applied that impregnate the concrete and block up the pores. Finally, coating systems are those that adhere to the outer surface of the concrete. Within BS EN 1504 these are designated as repair methods and are split into:

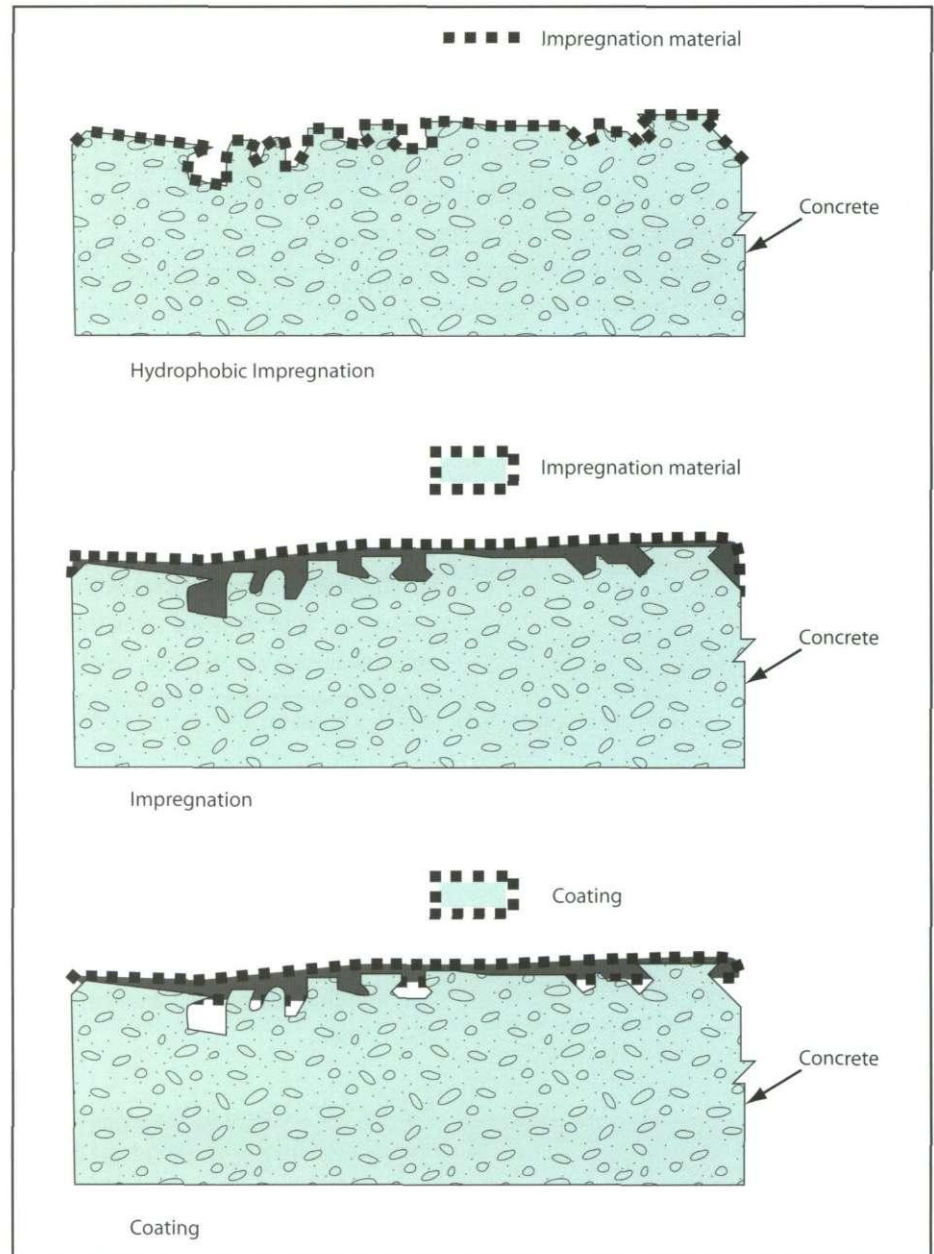
- hydrophobic impregnation (H)
- impregnation (I)
- coatings (C)

and are shown schematically in Figure 5.

These in turn relate to the repair principles in BS EN 1504 Part 9:

- Principle 1: Protection against ingress
- Principle 2: Moisture control (MC)
- Principle 5: Physical resistance/surface improvement (PR)
- Principle 6: Resistance to chemicals (RC)
- Principle 8: Increasing resistivity by limiting moisture content (IR)

Figure 5
Surface protection systems.



It may be considered that these are all relatively self-explanatory and mainly involve keeping aggressive species out of concrete. Basically, there are pore liners that repel water (e.g. silanes and siloxanes), pore blockers that soak into the surface and seal the porosity (e.g. resins) and conventional coatings that sit on the surface of the concrete.

While there are a large number of tests listed that could be considered to be the manufacturer's remit, there are number of requirements that should be taken into account by the specifiers. For hydrophobic impregnations there are two classes that relate to the depth the material penetrates into the concrete on standard test blocks; Class I is <10 mm and Class II is ≥ 10 mm. Similarly there are two classes for drying rate coefficients. There is a performance characteristic for resistance to diffusion of chloride ions, but the test method is subject to national standards and regulations.

5 Surface protection systems

BS EN 1062^[30] addresses coating materials and coating systems for exterior masonry and concrete and gives tests for carbon dioxide and water vapour penetration. Part 3 covers methods of determining liquid-water transmission rate, w , and gives high, medium and low classifications that are reported to relate to lime mortars and masonry rather than protection of concrete. Tables 4 and 5 of BS EN 1504 Part 2 require $w < 0.1 \text{ kg}/(\text{m}^2 \cdot \text{h}^{0.5})$.

Part 6 of BS EN 1062 covers carbonation resistance. The test method requires calculation of the permeability I in $\text{g}/(\text{m}^2 \cdot \text{d})$ while Part 2 of BS EN 1504 requires an anti-carbonation coating to have an S_D value $> 50 \text{ m}$ air layer thickness equivalent; S_D is calculated in the process of determining I . Note that the Standard now describes both water vapour permeability and carbon dioxide resistance in terms of an S_D value. To avoid confusion, it is obviously important to be clear which is being referred to.

For impregnations there are three classes of permeability to water vapour (Class I, *Permeable*, Class III, *Dense against water vapour*, and Class II falling between these). Similarly for impact loading there are three classes, with Class I being the lowest impact resistance and Class III the highest. Also there are three classes for slip and skid resistance dependent on the exposure (inside wet surfaces, inside dry and outside), although these contain caveats with a requirement to meet national regulations.

For coatings there are two strength classes for traffic with either polyamide or steel wheels. Three classes for water vapour are also present, similar to impregnations. Thermal compatibility is split into trafficked or untrafficked adhesion figures after various cycles: this split is further subdivided into flexible crack-bridging systems or rigid systems. For crack-bridging systems the required crack-bridging ability should be selected by the designer with respect to local conditions, with no failures allowed. The impact resistance is again split into three categories, and there are two classes for antistatic coatings dependent on environment.

The last half of the standard consists of informative annexes. Annex A gives an example of minimum frequencies of manufacturer's testing. Annex B gives useful examples of what designers need to specify for three separate cases. Annex C relates to the release of dangerous substances and Annex Z, which occupies over 30% of the document, relates to the Construction Products Directive and certification of conformity.

6. Repair mortars, structural bonding and reinforcement protection

Repair mortars, structural bonding and reinforcement protection are covered respectively by Parts 3, 4 and 7 of BS EN 1504 which adopt a common structure and approach. Each Part addresses the requirements for identification, performance (which includes durability) and safety of the products. The sections below set out the main characteristics of each of the product groups in turn.

The performance characteristics are described in detail in Table 3 of each Part, along with the test methods to be used to assess product performance. The test methods themselves are published as separate Standards. Each Part also sets out the quality control and conformity evaluation requirements which materials producers need to follow when producing products to meet the Standard or for CE marking.

6.1 Repair mortars

BS EN 1504 Part 3, *Structural and non-structural repair*, covers repair mortars and concretes for the structural or non-structural repair of concrete, to replace defective concrete and to protect reinforcement, in order to extend the service life of a concrete structure exhibiting deterioration. The mortars and concretes may be used in conjunction with other products such as coatings.

6.1.1 Application

Repair mortars and concretes are used for several of the repair principles, as shown in Table 3.

Table 3
Repair principles requiring mortars and concretes.

Principle 3 Concrete restoration	Method 3.1: Applying mortar by hand
	Method 3.2: Recasting with concrete
	Method 3.3: Spraying mortar or concrete
Principle 4 Structural strengthening	Method 4.4: Adding mortar or concrete
Principle 7 Preserving or restoring passivity	Method 7.1: Increasing cover to reinforcement with mortar or concrete
	Method 7.2: Replacing contaminated concrete

6.1.2 Overview of requirements

The performance requirements for repair mortars and concretes are:

- compressive strength
- chloride ion content
- adhesive bond
- restrained shrinkage/expansion
- carbonation resistance
- thermal compatibility
- elastic modulus
- skid resistance
- coefficient of thermal expansion
- capillary absorption (water permeability).

Repair mortars and concretes are categorised into four classes: Class R4 and R3 are suitable for structural repair, while Class R2 and R1 are suitable for non-structural work. Structural mortars and concretes are distinguished by having a high compressive strength, stronger adhesion to the substrate (before and after thermal cycling and shrinkage tests) and requirements for the elastic modulus of greater than 20 GPa for Class R4 and greater than 15 GPa for Class R3. However, it is likely that manufacturers will only produce pre-bagged formulated mortars for the two strongest grades.

6.1.3 Carbonation resistance

Carbonation resistance applies to the carbonation of a patch repair material, which is different from the testing of an anti-carbonation coating. There is no requirement for carbonation testing of BS EN 1504 Part 2 Class R1 and R2 (non-structural) repair materials. In Table 3 of Part 2 they are noted as 'not suitable for protection against carbonation unless an anti-carbonation coating is used'. Figure 6 shows an example of a Class R4 concrete repair product which passes the BS EN 13295⁽³¹⁾ test threshold under BS EN 1766⁽³²⁾.

Figure 6
Comparison of EN 1504-compliant labelling for Class R4 and Class R2 cementitious repair products.
Photo: BASF

	
0749	
BASF Construction Chemicals Belgium NV Nijverheidsweg 89, B-3945 Ham	
06	
0749 - CPD BC2-563-0013-0002-001	
EN 1504-3 Concrete repair product for structural repair CC mortar (based on hydraulic cement)	
Compressive strength	class R4
Chloride ion content	≤ 0,05 %
Adhesive bond	≥ 2,0 MPa
Restrained shrinkage	≥ 2,0 MPa
Carbonation resistance	passes
Elastic modulus	≥ 25 GPa
Thermal compatibility	
- Freeze-Thaw	≥ 2,0 MPa
- Thunder Shower	≥ 2,0 MPa
- Dry cycling	≥ 2,0 MPa
Capillary Absorption	≤ 0,5 kg m ⁻² h ^{0,5}
Reaction to fire (MPA Dresden)	A1
Dangerous substances	complies with 5.4

	
0749	
BASF Construction Chemicals Belgium NV Nijverheidsweg 89, B3945 Ham	
06	
0749 - CPD BC2-563-0013-0002-001	
EN 1504-3 Concrete repair product for non-structural repair PCC mortar (based on hydraulic cement, polymer modified)	
Compressive strength	class R2
Chloride ion content	≤ 0,05 %
Adhesive bond	≥ 0,8 MPa
Restrained shrinkage	≥ 0,8 MPa
Thermal compatibility	
- Freeze-Thaw	≥ 0,8 MPa
- Thunder Shower	≥ 0,8 MPa
- Dry cycling	≥ 0,8 MPa
Capillary absorption	≤ 0,5 kg m ⁻² h ^{0,5}
Reaction to fire	A1
Dangerous substances	complies with 5.4

However, in conformity with the Standard, there is no mention of carbonation resistance for the Class R2 product. Designers should therefore be aware that using Class R1 or R2 repair mortars could lead to more rapid carbonation of the repair than using Class R3 or R4.

6.2 Structural bonding

BS EN 1504 Part 4, *Structural bonding*, covers products intended for application to concrete to provide a durable structural bond to an additional applied material, including:

- bonding external plates to the surface of concrete for strengthening purposes (such as fibre composite plates, see Concrete Society Technical Report 55, *Design guidance for strengthening concrete structures using fibre composite materials*⁽²⁵⁾)
- bonding hardened concrete to hardened concrete in repair and strengthening situations
- casting of fresh concrete to hardened concrete using an adhesive bonded joint where it forms a part of the structure and is required to act in a composite manner.

6.2.1 Application

Structural bonding products are used for structural strengthening (Principle 4), in particular for bonded plate reinforcement (Method 4.3) and for bonding mortar or concrete (Method 4.3).

6.2.2 Overview of requirements

The requirements of the Standard address the following performance aspects of the materials:

- suitability for application, including to vertical surfaces and soffits, horizontal surfaces and by injection
- temperature range of suitability for application and curing
- suitability for application to a wet substrate
- adhesion of plates to plates, concrete and corrosion protected steel and of hardened or fresh concrete to hardened concrete
- durability of the complete system under thermal or moisture cycling.

The Standard also addresses the following characteristics of the bonding material for the designer:

- open time and workable life
- modulus of elasticity in compression and in flexure
- compressive and shear strength
- glass transition temperature
- coefficient of thermal expansion
- shrinkage.

The Standard contains detailed performance requirements, specifies test methods to be used, and sets out the quality control and conformity evaluation requirements which materials producers need to follow when producing products to meet the Standard.

6.3 Reinforcement protection

BS EN 1504 Part 7, *Reinforcement corrosion protection*, covers active coatings and barrier coatings for protection of existing steel reinforcement in concrete structures under repair. The coating may provide protection or provide a base layer to which repair mortar or concrete can subsequently be applied or both.

6.3.1 Application

Reinforcement protection is covered by Principle 11, *Control of anodic areas*:

- active coating of the reinforcement (method 11.1)
- barrier coating of the reinforcement (method 11.2).

6.3.2 Overview of requirements

The primary performance characteristics of anchoring products are:

- corrosion protection
- glass transition temperature
- shear adhesion (of coated steel to concrete).

7. Concrete injection

BS EN 1504 Part 5, *Concrete injection*, covers products intended for filling of cracks, voids and interstices in concrete. Injection products may be based on either a hydraulic binder or a polymer binder, and different product characteristics are specified for the different materials.

7.1 Introduction

Generally, there are two main reasons why cracks or voids in concrete need to be repaired. They are to re-establish structural integrity (i.e. 'glue the concrete together') or to fill the cracks in order to stop water from entering or leaving a structure. In BS EN 1504 terms, injection can satisfy:

- protection against ingress and waterproofing by filling cracks (method 1.4)
- structural strengthening by injecting cracks, voids or interstices (method 4.5)
- filling cracks, voids or interstices (method 4.6).

When considering injection, it is necessary to consider why a crack has formed and what is hoped to be achieved by injecting it. If the crack has formed due to thermal movement in service and the structure contains insufficient movement joints, there is little point in injecting with an epoxy resin to re-establish structural integrity and not creating new movement joints. The structure will simply form its own 'joint' by forming a new crack, which may be in a more problematic location than the original.

It is important to understand that the formation of fine cracks in water-retaining structures is not unusual and, in the majority of cases, these cracks will self-heal. Time should be allowed for this to occur before resorting to crack injection.

Cracks that are formed by corrosion and expansion of reinforcement (or other embedded ferrous objects) should not be repaired by injection techniques unless a short-term (one to two years) solution is acceptable. Such problems are better dealt with by using traditional concrete repair techniques combined with suitable corrosion control measures.

Injection techniques can sometimes also be used to re-bond areas of screeds and renders which have become detached from their concrete substrate. This requires a high level of skill on the part of the operative. Very low viscosity resins with a long open time are used so that the pressure employed does not cause the injected resin to act like a wedge and detach more of the adjacent render or screed. Vacuum injection techniques which do not suffer from this potential drawback may prove to be more reliable for this particular application.

7 Concrete injection

7.2 Design considerations

The basic considerations are why injection is needed and what it is hoped will be achieved. Part 5 of BS EN 1504 defines two principles for concrete injection:

- Principle 1 (IP), *Protection against ingress*. This is relatively self-explanatory, e.g. where there is a crack in a concrete structure with water leaking through that could cause damage either directly (such as water leaking into a basement) or indirectly (such as water containing chlorides causing corrosion of the reinforcement).
- Principle 4 (SS), *Structural strengthening*. This is sometimes referred to as 'crack bonding', where the concrete is 'glued' back together.

Figures 7 and 8 show applications of injection being carried out in accordance with these two Principles.

Below **Figure 7**

Two-part acrylic injection of basement floor slab – Principle 1, *Protection against ingress*.

Right **Figure 8**

Epoxy resin injection of overhead crack – Principle 4, *Structural strengthening*.



In fulfilling Principle 4, Principle 1 may also be satisfied, although the specifier will need to examine the cracks and note:

- the crack width
- whether or not the crack is live
- whether there is any water present (or likely to be present at the time of injection).

The specifier or designer should also consider how the injection will be carried out, as a narrow crack of, say, less than 0.2 mm will need high injection pressures to ensure that the entire crack is filled. In itself, this may lead to further fracturing of the concrete, especially if the original crack is close to an unconfined edge.

Consideration should also be given to preparation of the cracks, e.g. cleaning out of any contaminants that will affect the performance of the injected material.

7.3 Scope

The Standard covers the injection of cracks, voids and interstices in concrete using three generic material types:

1. those capable of transmitting forces (F), generally cement-based materials, epoxies and polyesters
2. those capable of remaining ductile (D), i.e. flexible to accommodate future movement – generally polyurethanes
3. those capable of swelling to fill the crack (S); these are generally polyurethanes and acrylics.

It does not cover:

- chasing out cracks and filling with elastomeric sealant
- filling of voids outside of the concrete structure (e.g. grouting behind tunnel linings)
- injecting into any other materials, e.g. brickwork, masonry.

While these appear straightforward, there will be circumstances, such as injecting a water-reactive grout through a basement wall so that the grout forms a 'membrane' on the back of the wall in the space between the concrete and the backfill, where the injection process is covered by the Standard, but not when the grout leaves the concrete structure.

The Standard may not cover performance requirements for some highly specialised applications in extreme environmental conditions, such as cryogenic use; neither may it cover repair of damage due to accidental impact by traffic or ice, nor earthquake loading, where specific properties will be needed. It does not address the treatment of cracks by widening them and sealing them with an elastomeric sealing compound, external filling of cavities, or preliminary injection or grouting works to temporarily stop passage of water during waterproofing.

7.4 Terms and definitions

This Section of Part 5 of BS EN 1504 provides specific definitions for injection products with polymer binders (P) and hydraulic binders (H). It also defines pot life; workable time; crack width; injectability (i.e. the minimum crack width in mm into which the product is injectable); the moisture state of the crack (dry, damp, wet, water flowing); and crack movement, e.g. due to traffic or temperature.

7.5 Performance characteristics

The primary performance characteristics of injection products are as follows:

- basic characteristics, related to adhesion, shrinkage, compatibility with steel and concrete, glass transition temperature and watertightness; these are essential for any intended use
- workability characteristics, which indicate the conditions in which the product can be used (width, moisture state of the crack)
- reactivity characteristics including the workable life and strength development
- durability of the hardened product under the prevailing climatic conditions.

Other characteristics may need to be considered for certain intended uses of the product, such as:

- glass transition temperature, where the temperature of the hardened product in the crack may be higher than 21°C and the product is formulated with reactive polymer binder
- chloride content and corrosion behaviour for injection of reinforced concrete
- watertightness for waterproofing applications.

These are covered in tables in the Standard. A reference to a test method is provided for each of the characteristics. These tests will be carried out by the material manufacturers and the results quoted on their data sheets (and CE marking where appropriate) to show compliance with the Standard. Unfortunately, the extensive testing required by material manufacturers, to demonstrate compliance of their products against the various requirements of the Standard, may lead to less choice for the specifier and installer. It is likely that many of the smaller manufacturers will decide that the high costs associated with compliance testing cannot be justified, in what is a relatively small niche market. At best, the range of resins tested will be limited to the 'best sellers', which will restrict the contractor's choice when carrying out the works. This will also mean that any change in formulation, to meet a specific site requirement, is unlikely to be supported by compliance testing, which will prove to be a barrier to innovation and ongoing product development.

The remaining Sections of Part 5 of BS EN 1504 deal with *Sampling, Evaluation of conformity* and *Marking and labelling*, all of which affect the manufacturing process.

7.6 Annexes

Part 5 of BS EN 1504 contains five Annexes as follows:

- Annex A: *Classification of injection products*
- Annex B: *Special applications*
- Annex C: *Release of dangerous substances*
- Annex D: *Minimum frequency of testing for factory production control*
- Annex ZA: *Clauses addressing the provisions of EU Construction Products Directive.*

8. Anchoring of reinforcing steel

BS EN 1504 Part 6, *Anchoring of reinforcing bars*, deals with the performance criteria and compliance testing for materials suitable to grout (anchor) reinforcing bars into concrete.

8.1 Application

Anchoring is used as a repair method under Principle 4: *Structural strengthening*, Method 4.2, *Adding reinforcement anchored in pre-formed or drilled holes*. Part 6 is not intended to cover anchoring of threaded bars, which comes under the scope of European Technical Approvals.

8.2 Design considerations

A note in Section 1, *Scope*, of Part 6 states:

'It is assumed that a proper structural assessment of the structural elements to be subjected to repairs will be carried out by qualified engineers and that the choice of the products and systems to be used, as well as the design, are based on this assessment.'

This means that a suitably qualified engineer will need to design the bond length of the anchor and the diameter of the hole, taking due consideration of the strength of the existing concrete, the type of anchor grout to be used and the maximum load to which the anchor will be subjected. The designer should also take account of the risk of fire within the structure and the likely temperatures resulting from any potential fire. Thus, the designer may choose to specify a cement-based grout, or even a mechanical anchor, in preference to synthetic resin based grout for high-risk structures such as bridge deck soffits, tunnels and petrochemical installations. Most material manufacturers advise against using resin anchors where structural load-bearing performance has to be maintained in temperatures exceeding 40°C.

8.3 Terms and definitions

Part 6 of BS EN 1504 confines itself to:

'Hydraulic binders or synthetic resins, or a mixture of these, installed at a fluid or paste consistency to grout reinforcing steel bars in hydraulic concrete structures.'

These will generally be cement-based grouts, or polyester or epoxy resins, which sometimes use cement powder as a filler. Mechanical fixings, or the anchoring of threaded bars and the like, are not covered by the Standard.

8.4 Performance characteristics and requirements

Table 3 in Part 6 lists four performance requirements for the anchor grouts:

1. pull-out: less than 0.6 mm displacement at a load of 75 kN
2. chloride ion content: less than 0.05%
3. glass transition temperature: greater than 45°C, or 20°C above maximum in-service ambient temperature
4. creep under tensile load: less than 0.6 mm displacement after a continuous loading of 50 kN for three months.

Items 3 and 4 are only required for synthetic resin grouts.

Other requirements are stated, such as not releasing dangerous substances from the hardened material and reaction to fire.

Manufacturers also have to test their products against a number of other parameters including compressive strength, stiffening time, workability and pot life.

8.5 Installation requirements

Part 6 of BS EN 1504 gives no guidance on installation and Part 10, which deals with site applications, gives very limited advice. However, most material manufacturers give good advice on how to install their products, including advice on drilling of the holes. Rotary percussion with air flush is the preferred method (see Figure 9), with diamond-cored holes being avoided as they are too smooth. Manufacturers will also advise on the optimum diameter of hole for any given bar diameter and most have a range of grouts to suit different site requirements, e.g. thixotropic grouts for overhead installations.

Figure 9
Hole drilling using rotary percussive air flush drill bit.



8 Anchoring of reinforcing steel

Manufacturers generally recommend that deformed reinforcing bar is used; one of the most common uses in a concrete repair scenario is where small-diameter link reinforcement needs partial replacement due to the effects of excessive corrosion. Designers may wish to consider alternative connections, such as welding for replacement of links, in areas of high shear stresses. However, welding of reinforcement should only be carried out in accordance with an approved quality assurance scheme, particularly where the bars may be highly stressed.

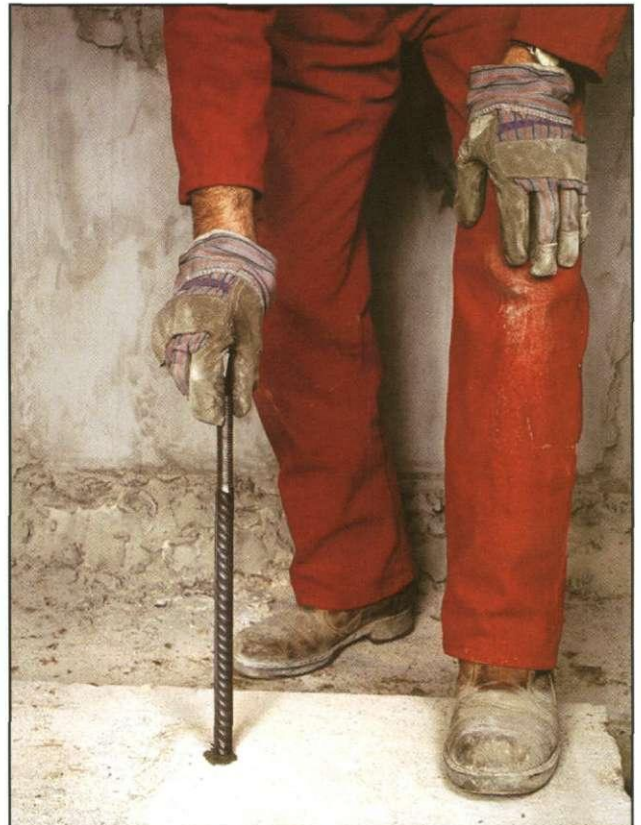
Anchor grouts come in a wide variety of forms. For some, two components are simply mixed together and the resultant mix either poured or injected into the holes (see Figure 10). Others use a spiral mixing nozzle which attaches to a cartridge containing the unmixed components. Where the grout is injected or pumped, the hole should be filled from the bottom outward to ensure that it is fully filled and any entrapped air is avoided.

Glass capsules or plastic 'sausages', containing unmixed components, can also be used. These are inserted into the holes and mixed by 'drilling-in' a length of reinforcing bar, although this technique is more appropriate for the installation of purpose-made anchor 'bolts'.

It is usual for the required amount of grout to be placed in the holes and the reinforcing bar pushed in (see Figure 11). Occasionally, however, it may be necessary to install the bar first, followed by the grout. If this is the case, extreme care must be taken to ensure that the holes are completely filled and no air is entrapped.

Below **Figure 10**
Resin being poured into prepared hole.

Below right **Figure 11**
Bar being inserted into resin.



Whichever method is chosen, it is obviously important that the holes are thoroughly cleaned out prior to installation and that the anchors are not disturbed, or subjected to loading, until the grout has achieved the design strength.

It is often impossible to dry out the holes. This is particularly so when faced with deep vertical holes that fill up with rainwater. In these circumstances a cement-based grout may be more suitable than a resin grout.

In summary, it is necessary to employ a competent engineer to design and specify the anchors and the anchor grout. Materials should be purchased from a manufacturer whose products comply with the specification and with Part 6 of BS EN 1504. An experienced contractor should be employed to install the anchors and, if necessary, carry out proof testing (see Figures 12 to 14).

Below **Figure 12**
Completed installation.

Below right **Figure 13**
Anchorage assembly test equipment.

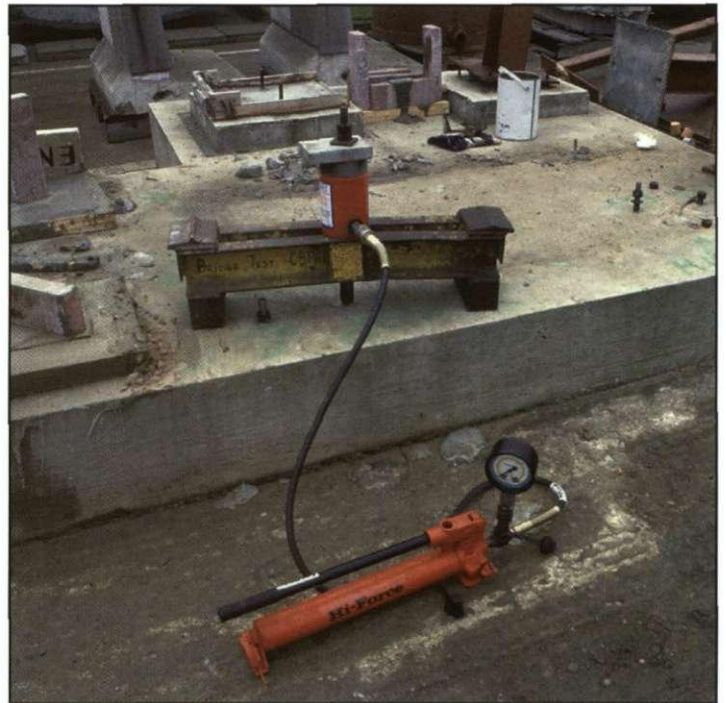


Figure 14
Concrete failure possibly due to shallow fixing depth or cracking to concrete. This is an unreinforced slab.



9. Achieving successful repairs

The objective of BS EN 1504 Part 10, *Site application of products and systems, and quality control of the works*, is to follow the standard approach to assessing concrete repair projects, determining appropriate material selections and executing the work, taking the whole-life cost of the scheme into account.

9.1 Content

Part 10 is often thought of as ‘the installer’s section’, since it deals with the installation of the repair scheme. This is only partially correct, in that it presents the preparation and repair process options. However, the selection of the preparation and repair process to be used usually rests with the designer, so there remains a crucial overlap between the parties to a contract when allocating who does what within this Part.

The sections that make up Part 10 are shown in Table 4. Each section details the considerations that must be taken into account in the execution of each stage of the work. Section 6, *Methods of protection and repair*, is where the Standard starts to get down to the basics of deciding the actual repair specification, and cross-references the protection and repair Principles from Part 9 with repair methods, preparation requirements, application requirements and the relevant quality control method. Section 7 correlates which preparation processes are relevant to each repair method, and the standards of preparation that must be met by each of the listed preparation processes.

Table 4
Sections in BS EN 1504 Part 10.

Sections 1–3	Scope, Normative references, and Terms and definitions
Section 4	Structural stability during preparation, protection and repair
Section 5	General requirements
Section 6	Methods of protection and repair
Section 7	Preparation of substrate
Section 8	Application of products and systems 8.1 General 8.2 Defects in concrete and structural strengthening 8.3 Defects caused by reinforcement corrosion
Section 9	Quality control 9.1 General 9.2 Quality control tests and observations
Section 10	Maintenance
Section 11	Health, safety and the environment
Annex	Informative

9.2 Implementing the sections

Having determined the objectives, scope and design of the scheme, Part 10 sets the standards that each part of the installation process must achieve in order for the scheme to be implemented safely, both for the structure and the operatives, and for it to achieve its durability objectives.

For example, surface texture is a significant component in the performance of many products. If it is too smooth, inadequate adhesion may result; if it is too rough, the product thickness may be inadequate for the desired durability. Part 10 gives guidance to the installers as to what they should be achieving. In many cases, this will be what the manufacturer of the product being used currently decrees, but as products become specified more generically, the Standard seeks to apply more uniformity to the assessment process.

While Part 10 specifically guides the work of the installer, the designer will need to specify and direct the repair scheme with reference to its provisions. Particularly relevant examples of this include:

- **Structural stability during repair works.** Installers need to have an awareness of structural stability, but assessing when a structure could become unstable will invariably be the remit of the structural engineer (unless specifically devolved to the installer in the contract).
- **Aesthetic performance of the repair.** Perfectly functional repairs need not look pretty! Designers will need to determine what the overall appearance must be. It is not uncommon for aesthetic considerations to override performance considerations. For example, where instances of low cover are encountered, it is unusual for a repair scheme to call for cover to be locally reinstated by building out a repair proud of the surface. More common is for a compromise solution involving other products such as MCI (migratory corrosion inhibitors), cementitious, or other protective coatings.
- **Concrete removal.** Specific technical, health and safety or environmental considerations may influence the selection of the concrete removal method. Hydrodemolition is fantastic from a technical and HAVS (hand-arm vibration syndrome) perspective, but environmentally may not measure up. Designers are usually charged with making this decision.

Producing satisfactory workmanship (Quality Management) is clearly the remit of the installer and Section 8 is a mix of instructions to the installer on how a product is to be applied, such as:

'Repair mortar shall be worked into the prepared substrate and shall be compacted without inclusion of entrapped air pockets and in such a way that the required strength is achieved and the reinforcement is protected against corrosion.'

and indications that the designer still has a responsibility, such as:

'The condition of the substrate shall be specified where a bonding primer is used.'

Clearly, both parties have a joint responsibility under the Standard.

Table 4 in Section 9 of Part 10 firmly ties down the responsibilities of the installer within a quality plan prepared for the project. (The Standard does not indicate who should prepare this quality plan.) It details the measures the installer must take to ensure that the designer's repair scheme is properly executed, as well as the tests that can (and should) be used to verify satisfactory installation.

9 Achieving successful repairs

Installers should retain records of each quality test carried out, in order to complete the audit trail, and to provide the information as to the future maintenance of the installed product required in Section 10.

The non-mandatory Annex is one of the most interesting and useful parts of the document. It is here that parameters for performance, indications of bond strengths, pressures suitable for water cleaning, etc. are given, as well as significant detail on implementing the quality tests in Section 9. This is useful information for specifiers and installers. The Annex also includes surface and substrate preparation and application data for repair methods that have not been included in the Standard, such as applying inhibitors to concrete.

10. Performance-based rehabilitation of reinforced concrete structures

It has been estimated that some 50% of Europe's annual construction budget is currently spent on refurbishment and remediation of existing structures. This figure is expected to increase as the major population of concrete structures built in the 1960s and 1970s, which not only form a key part of Europe's infrastructure but also account for a large percentage of existing expenditure upon protection, repair and refurbishment, are likely to require additional work as their age increases (see Matthews and Morlidge⁽³³⁾).

There are known problems in achieving the required levels of performance from repairs to concrete structures and increasing social, environmental and economic factors continue to extend the need for the limited resources available to be applied with greater efficiency. Accordingly, owners of buildings and infrastructure now require greater certainty in the performance of repaired concrete structures in order to manage their assets more effectively. This has generated a requirement for industry to deliver more durable and effective repairs to concrete structures.

10.1 The CONREPNET project

While BS EN 1504 is primarily concerned with the performance of repair materials, CONREPNET, a European thematic network on performance-based rehabilitation of concrete structures, sought to address the wider issues relating to the performance of repairs. Consultation with industry stakeholders indicated that the focus of the project work needed to be wider than just the so-called 'technical aspects' of concrete repair, and should include the associated 'softer' relationship factors between the stakeholders. It was perceived that the contractual/working relationship aspects are extremely important, and potentially the most influential factors, in determining the 'quality' of the outcome of a repair or preventative works intervention. This requires consideration of 'business' factors to achieve a satisfactory outcome in terms of the durability and longer-term performance of a repaired concrete structure.

10.2 Lessons learnt from past repairs and current industry practices

A review was undertaken of the performance of previously repaired concrete structures and current industry practices, with information on about 230 structures being obtained and analysed (see Tilly⁽³⁴⁾ and Tilly and Jacob⁽³⁵⁾). Overall, the review revealed that the repairs and interventions carried out performed disappointingly in terms of the planned rehabilitation strategy for the various structures. From the responses received it was estimated that almost 50% of repairs and interventions exhibited signs of failure within five years of application. For those between six and ten years old the situation appeared to improve, with some 40% exhibiting signs of failure. For those aged between 11 and 25 years, some 40% were judged to be successful, reducing to 25% when aged between 26 and 50 years. This level of performance was considered by many owners to be disappointing and probably not sustainable.

Investigation of the modes of failure of the repair (or intervention) showed that this typically was associated with continued corrosion, cracking, debonding or spalling of concrete.

Opinions offered by the reviewers suggested that the causes of failure related mainly to:

- wrong diagnosis of the cause of the initial damage or deterioration of the structure
- inappropriate design of the intervention works
- inappropriate specification or choice of the materials used
- poor workmanship.

It is clear that to achieve the goal of more durable repaired concrete structures, practitioners must use techniques and procedures that are appropriate for the deterioration mechanism(s), environmental conditions and structural circumstances which exist for the specific structure or part of the structure under consideration. There is also a need to take a wider and longer-term view of these matters.

Unfortunately, it is still highly likely that a short-term 'first' cost focus will be adopted by many owners of buildings and structures, rather than a longer-term 'remaining' life perspective which overall might be more efficient and effective from a wider financial and sustainability viewpoint. This is often done for well-understood, but unfortunate, reasons and is commonly in response to severe financial pressures and limitations on budgets available for maintenance and remedial works.

It is postulated that the management of concrete structures could be improved by:

- early intervention, before damage is visible
- proactive monitoring and maintenance in support of this
- correct diagnosis of the problem and mechanism(s) causing the deterioration
- effective intervention systems for preventative and remedial treatments.

Figure 15 illustrates the underlying concept, taking the situation of steel reinforcement embedded in the concrete and the circumstances leading to corrosion. This assumes that sufficient concentrations of both oxygen and moisture are present to facilitate corrosion. A very simple two-stage linear corrosion model has been adopted. In the early life of the structure (the initiation phase), the ingress of aggressive species occurs through the cover concrete (e.g. carbon dioxide, chlorides). After some time the surface of the reinforcement becomes depassivated, permitting corrosion to begin. The corrosion propagation phase is entered and corrosion products are produced, with cracking of the concrete and spalling following at some later time. The diagram also illustrates when visible damage is likely to occur in this process. It will be seen that this is relatively late, only becoming apparent some time after the fundamental deterioration (which leads eventually to damage, possibly years later) has taken place.

Reactive maintenance is likely to be instigated only when visible indications appear (e.g. cracking or spalling of concrete), with an intervention being made to slow the rate of deterioration and extend the length of the useful service life of the structure. Proactive maintenance, such as the early application of a coating to slow the ingress of the aggressive species, could potentially delay the onset of corrosion and extend the useful service life. The implementation of these concepts is illustrated in Figure 16, which presents a time-line representation of the two alternative philosophies and includes a notional indication of their respective costs.

Figure 15
Reactive and proactive approaches to the maintenance of structures.

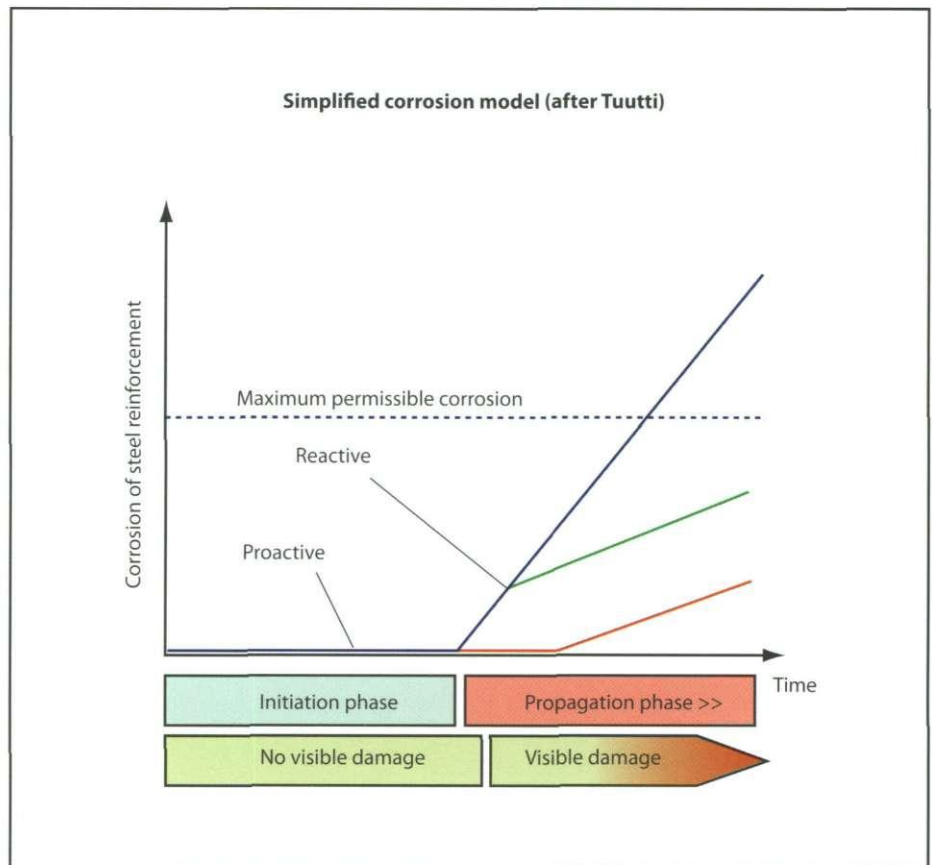
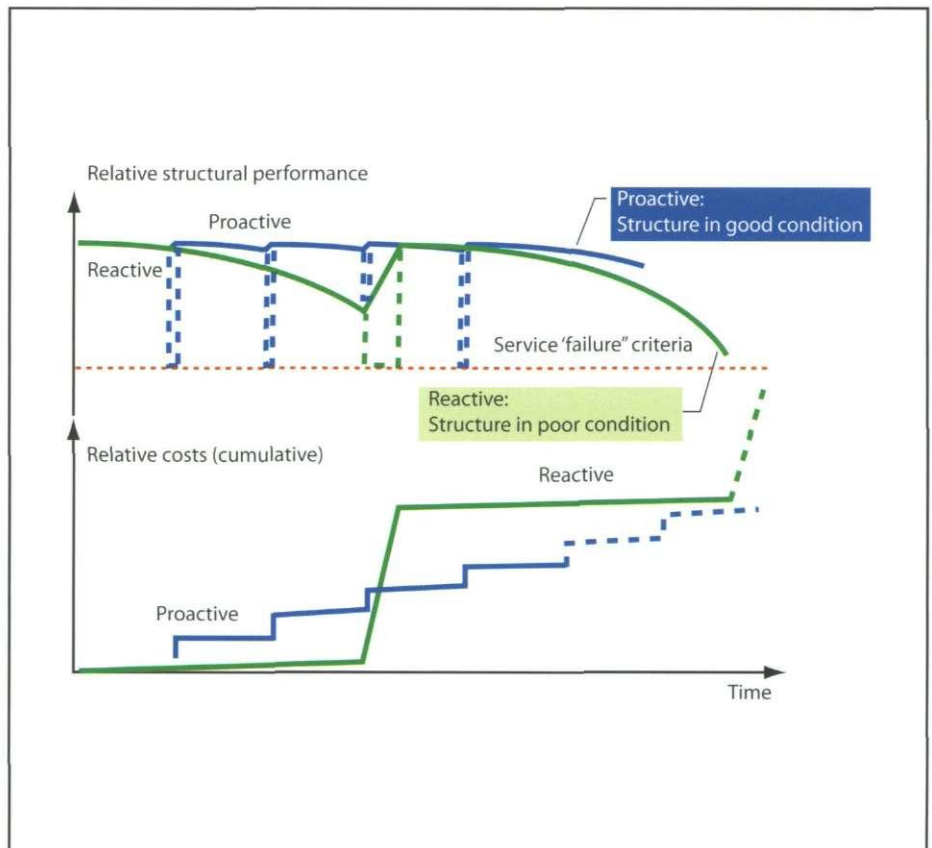


Figure 16
Alternative approaches to the management and maintenance of structures.



Proactive maintenance could:

- reduce the resources necessary to repair or remediate
- reduce the disruption time
- reduce the overall cost of ownership.

Recent changes in owner attitudes to construction are reflected by the increasing interest in through-life costs – that is, not only in the capital costs of construction but particularly in the operational costs associated with delivery of functional performance for a defined lifespan. This change is an important development in achieving a more balanced and holistic approach to extending the lifespan of existing buildings and structures. In addition it is closely aligned to society's increasing interest in sustainable construction, with the attendant greater consideration of environmental and societal factors.

10.3 A look to the future

10.3.1 The prescriptive approach

Over time, architects, builders etc. have developed experience of what forms of construction work satisfactorily and produce a durable building or structure, with their experience being expressed in terms of materials used and styles of building that suit the particular geographic region or the function of the building concerned. That experience gradually led to prescriptive codes and standards, which have the advantage that they are generally easy to understand and to control. There has been similar experience with respect to the repair of concrete structures, leading to the available contemporary guidance and recommendations.

If this approach has in general proved to be satisfactory and successful, why is there any desire or need to change from the prescriptive approach? Some of the difficulties encountered with the prescriptive approach include:

- the tendency to create a restrictive framework which can generate barriers to change that can limit the adoption of new, more effective, practices
- a poor match between true requirements of the user and/or owner and what has been delivered by the construction or repair process
- a perception that the construction industry has a poor ability to meet user/owner expectations and has provided poor value for money. The issue of snagging, i.e. work not done correctly or satisfactorily first time, is a symptom of some of the underlying problems and issues.

10.3.2 The performance-based approach

Performance concepts are not new. They have been applied for many years by international organisations dealing with the evaluation of innovative products and systems or those for which there are no classical prescriptive standards. In a performance-based approach, the most important aspect is defining the required function. From this it should be possible to identify a testing regime for the product, system or component with appropriate criteria to demonstrate performance compliance. Thus, products and systems are not evaluated for compliance with predetermined parameters (as in the prescriptive approach) but by their ability to fulfil a defined function.

The attraction of a performance-based approach for improving concrete repair is its ability to adapt to the evaluation of any material or materials constituting a structure, or part of a structure. This may be achieved by considering items or 'work packages' as systems and evaluating the performance of the most relevant characteristics of the system in relation to its required function. Thus, the approach focuses on evaluating how well functions are performed in the circumstances of use, reflecting actual behaviours in service.

Therefore performance-based methods can be applied to:

- products, methods and systems
- components of structures, entire structures and structure complexes
- services and processes.

CONREPNET sought to build on previous work relating to performance-based concepts. It explored ways of using these concepts for developing strategies, techniques and processes for delivering more durable and effective remediation of concrete structures.

The project outlined concepts for a Performance-Based Intervention (PBI) (see Matthews *et al.*⁽³⁶⁾) which recognises not only basic economic considerations, such as whole-life cost issues, but also associated social and environmental drivers which form the wider framework of sustainability-related issues which society now expects the construction industry to address. This has been done by:

- seeking to understand owner aspirations and needs
- developing an industry response for achieving them
- formulating a vision for performance concepts to achieve durable remediation of concrete structures.

These concepts were further developed to address the issues associated with the implementation of PBI for concrete structures under a series of subsequent activities concerned with:

- taking the concepts developed for PBI of concrete structures from vision into practice
- the research and technological development needed to help deliver PBI as a practical tool
- the interaction of PBI with issues such as the European rules for public procurement and the associated Construction Products Directive, as well as developments in European standardisation for the protection and repair of concrete structures.

As stated previously, the concept of a performance-based approach is not new and a number of the current materials and engineering Standards (such as BS EN 1504) contain tests to evaluate products or components by characteristics related to the function they perform. Although it is sometimes perceived as a more advanced and complete alternative for the evaluation of products, the PBI approach has various advantages and disadvantages. These are briefly summarised in Table 5.

10 Performance-based rehabilitation of ...

Principle	Advantages	Disadvantages
Prescriptive approach	Traditional and well known. Widely used by manufacturers and construction companies. The tests required already exist. Generally the testing procedures are conceptually straightforward and clearly defined in terms of specific measurable (material) parameters.	Can be very restrictive. Innovation and change are difficult. The tests are not related to the functional performance and final use of the work, product or component.
Performance-based approach	Can facilitate innovation. Adaptable to different work sites. Is related to the functional performance and final use of the work, product or component. Has the potential to better reflect user interests and requirements.	There is no tradition in its use. Many of the tests required have yet to be developed. The more complex specification and testing procedures may increase the cost of products.

Table 5
Advantages and disadvantages of the
pre-scriptive and performance-based
approaches.

10.4 Summary

In the context of the CONREPNET project, the application of a performance-based approach to the protection and repair of concrete structures was deemed feasible. There was the desire from stakeholders to adopt a PBI methodology which not only recognised the differences between the prescriptive and the performance-based approaches but was able to draw upon the two approaches as appropriate to achieve an integrated solution better able to assess the fitness for purpose for use in particular circumstances.

PBI is concerned with activities taken to modify or preserve the future performance of a structure during its intended or extended service life, using an approach which involves the practice of thinking and working in terms of the end goals rather than specifying the means by which the result can be achieved. By its very nature PBI implies a proactive approach to structure management and intervention strategies. This would need to take into account not only basic economic considerations, such as whole-life cost issues, but also recognise the social, economic and environmental drivers which form the wider framework of sustainability-related matters.

One of the basic goals of the CONREPNET project was to encourage industry stakeholders to communicate and better understand each other's needs and objectives. If current industry practices are to be influenced then a cultural change in the way the various stakeholders engage and work together will be required. From the embryonic developments identified and facilitated by the CONREPNET project, the required changes in working practices may take a long time to be recognised, accepted and be promulgated to all those concerned with the repair and extension of life of concrete structures. This will mean continued interaction, dialogue and engagement between owners, construction professionals, as well as the wider repair specialist industry and associated material suppliers.

The experiences and observations gained during the CONREPNET project have been brought together in a published report entitled *Achieving durable repaired concrete structures, Part 1: Observations on performance in service and current practice*⁽³⁵⁾ and *Part 2: Adopting a performance-based intervention strategy*⁽³⁶⁾.

11. Assessment of structures and ongoing monitoring of concrete repairs

In this chapter, no distinction is drawn between repairs to reinforced or prestressed (either pre-tensioned or post-tensioned) concrete construction, or between precast and in situ concrete. The principles are identical, although the practice may differ in detail. Additionally, many repairs may be non-structural while others are structurally significant and load-bearing.

11.1 Records

As with all construction works, the first essential is to ensure that all records of the concrete repair works have been provided. This is required under health and safety legislation in the UK, principally the Construction (Design and Management) Regulations⁽²⁸⁾. As a minimum, the records should consist of:

- as-built records of the concrete repairs
- details of the materials used
- construction method statement
- certificates of the materials used
- details of construction operations, environmental data and dates undertaken
- any problems during construction
- approval documentation and pertinent contract documentation.

Where concrete repairs are combined with other operations, the records should include details of all remedial works undertaken. If the concrete repairs are combined with the installation of cathodic protection systems then a full Operational and Maintenance manual is also required, which will include details of the arrangements for ongoing management of the cathodic protection system.

Information should be provided by the contractor and retained by the client in a secure system, either paper based or using electronic storage. In either case the records should be accurately referenced and located to allow easy retrieval. Many clients use electronic asset management systems which will allow retrieval and use of data to assist future infrastructure management.

11.2 Concrete repair management

Sometimes concrete repairs in structurally critical locations may have monitoring systems installed during the remedial operations, though most will not. Where systems such as crack, movement or corrosion measurement sensors have been installed, the client should ensure that there is an associated periodic monitoring regime in place. Where structurally necessary, it may be appropriate to develop an intervention strategy and contingency arrangements, should the monitoring reach pre-defined 'trigger points'.

In most cases where no monitoring is installed, clients should ensure that they have a management regime in place. All structures should have arrangements for inspection, although the intervals and details of the surveys will depend on the nature of the structure, location, usage and structural criticality. Larger clients, such as highway authorities which manage thousands of structures, will have well-documented regimes typically consisting of:

- superficial inspection (frequently)
- visual inspection (typically every two years)
- detailed inspection, often called principal inspection (typically every six to ten years), which is a close inspection at touching distance of all parts of the structure, using access equipment as required
- special inspection (as required to investigate particular defects).

While the above guidance is for bridges, similar regimes should be developed for other exposed structures, such as multi-storey car parks and marine/coastal structures. In many buildings only the cladding will be exposed; it is likely that it will only be practical to inspect the main frame during major refurbishment of the building.

The first inspection should be a detailed benchmark or handover inspection at the completion of the remedial works. Detailed inspections should also include basic non-destructive testing; a hammer tap test is often used to identify areas of delamination and spalling in concrete and repair materials. Where cracks are encountered they should be recorded in detail and measured. Occasionally clients also instigate some routine testing of concrete during the course of detailed inspections, such as coring and testing for chlorides and carbonation, and some half-cell testing to detect the onset of corrosion.

The inspection should be undertaken by suitably experienced staff, with appropriate knowledge and training in the performance of materials.

The inspection should include all the structure concerned, both original and repaired areas, and identify the extent and severity of any defects. When dealing with concrete repairs, inspectors should pay particular attention to the interface between the original and repaired concrete, and also the area surrounding the repair where corrosion may occur (incipient anode effects).

Where defects have been found during the course of the inspection, the engineer responsible for the inspection should attempt to diagnose the cause of the deterioration. Reference can be made to a number of publications to assist, such as Concrete Society Technical Report 54, *Diagnosis of deterioration in concrete structures*⁽¹³⁾.

11.3 Testing

Where defects have been found during an inspection, and the diagnosis of the cause is unknown or unclear, it is often necessary to undertake a Special Inspection. This will include a very detailed survey and some testing. To investigate poorly performing concrete repairs, tests may include cover surveys, sample coring, crack measurement, chloride sampling, half-cell and resistivity testing (see Concrete Society Technical Report 60, *Electrochemical tests for reinforcement corrosion*⁽¹⁷⁾) and carbonation testing. Site work may be followed

by other testing in the laboratory to determine the extent of chloride ingress, strength testing, petrographic examination to assess the constituents of repair and substrate concrete, and the examination of cores to detect loss of bond, and compaction issues. Other more specialised testing may also be necessary, and clients should seek specialist advice in such circumstances.

11.4 Assessment

When the results of the testing are available the client should assess the implications of the defects to determine the cause and significance, and whether there has been change over time. Previous inspections and construction records should be consulted. Actions will depend upon the extent and severity of the defects, whether the deterioration is continuing and at what rate, and the safety of the structure and its users. Other structural or environmental factors may also be implicated. In addition to engineering considerations, the client may need to consider contractual obligations regarding the repair. If the repairs are recent and implicated in the cause of the defect, the client should contact the contractor and commence discussion over the damage that has occurred. Where repairs have been very recently completed, clients should make immediate contact with the contractor regarding appropriate investigations to determine cause and remediation.

Typical actions are as follows:

- Undertake a structural assessment (if the concrete repair is structurally significant and damage is severe and extensive, and safety of the structure appears to be compromised).
- Instigate a regime of periodic monitoring of the defect by visual inspections and/or technical monitoring such as crack measurements, strain gauging or movement sensors.
- Instigate a programme of repairs.
- Install safety measures and temporary works to secure structure.

In terms of concrete repairs, a client will need to consider whether a defect has been caused in or by the repair material itself, by the method of the repair, the interaction of the repair with the surrounding concrete substrate or in fact has nothing to do with the repair and has been caused by external agents, e.g. vandalism, accident or environmental conditions, or is the result of some other structural, chemical or electrochemical effect.

11.5 Routine maintenance

Clients should have a regime of routine maintenance in place (good housekeeping) to keep the structure in good order. Clearance of drainage, mending leaks, and removal of detritus from and cleaning of concrete surfaces are typical examples. Such operations may save time and money by avoiding major remedial works in future. In addition, they may facilitate future inspections carried out as part of the ongoing management of the structure.

The Highways Agency and its equivalents in other parts of the UK and abroad have statutory inspection requirements for bridges. The Institution of Civil Engineers has published *Recommendations for the inspection, maintenance and management of car park structures*⁽³⁷⁾ following a series of failures. All repair works in the UK are subject to the CDM Regulations

and will require a Health and Safety File and, where relevant, an Operation and Maintenance Manual for repair systems. Those responsible for structures, particularly after they have been repaired, should have complete documentation of the work done and be aware of the structure's ongoing maintenance and monitoring needs. They should implement a programme of at least regular visual inspection and where this shows up problems, they should be acted upon before they lead to health and safety issues and to further expenditure on repairs.

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Appendix A. Case studies illustrating the application of BS EN 1504

The two Case Studies in this appendix describe the refurbishment of a multi-storey car park and repairs to parts of a university campus. They illustrate how many of the Principles in Part 9 of BS EN 1504 were used for the repair and protection of the reinforced concrete structures.

A1 Mayorhold multi-storey car park

Built in 1973, Mayorhold multi-storey car park in Nottingham is an important town centre parking facility. Owned by Nottingham Borough Council, it provides a key service to shoppers and businesses alike and underpins the livelihood of the town.

A1.1 Description of the structure

The complex consists of five parking levels – designated A (basement) through to E (roof) – with entry at level B, and provides spaces for 1100 cars. Access between levels is via flat ramps/decks leading upwards and spiral ramps leading downwards. The decks are conventionally reinforced trough slabs with light fabric reinforcement between downstand beams.

Over a period of years, the condition of the car park declined both visually and structurally. Spalling of concrete was evident on both the deck soffit and the downstand beams (see Figure A1), including incipient anode effects from previous emergency repairs. It received notoriety when the President of the Royal Institute of British Architects included the car park on a list of buildings 'worthy of demolition'. The aim was to identify buildings whose removal would enhance the environment; so-called 'X-listing' would give planners powers to refuse change of use and to grant permission for replacement, with a grant fund to 'tip the balance in favour of demolition and appropriate replacement in particularly deserving cases'.

Figure A1
Spalling of concrete on downstand beams.



Consequently the omens were not good for proposing a repair and enhancement programme for the structure. However, refurbishment has completely transformed both the external appearance and the internal functionality and ambience, as well as stabilising the structure for a further 25-year lifespan.

A1.2 Problems that prompted repair

Prior to 1999, localised repairs were carried out on the structure but these continued to fail as a result of ongoing corrosion. On an annual basis, new areas were identified that required repairs. It was clear that the structure was deteriorating and that failure would ultimately occur. However, it was noted that the repair areas were mainly associated with leaking expansion joints and construction joints. The downstand beams in these areas were in a more serious condition than other mid-span beams. There was also spalling of the deck surface over the beams associated with reinforcement corrosion (see Figure A2).

Moreover, the areas of heavy trafficking associated with Entry level B, Ramp B–C and Level C itself were worse than the Basement level A where traffic rarely descended and on Levels D and E where trafficking was much lighter. In addition, Roof level E was protected with a deck waterproofing system.

Therefore, the evidence of deterioration was more specific than general (although growing in scope) and this led to the client instigating testing to assess the feasibility of designing a corrosion management strategy that could meet the technical and economic needs of the structure.

Figure A2
Area of spalling on the deck.



A1.3 Inspection and evaluation methods

In 1999, the first phase of the investigation began on Levels B and C and revealed high levels of chloride and consequent corrosion of the reinforcement over a significant portion of these levels. The investigation was repeated in 2003 and it was determined that the problem had accelerated in the high-chloride areas over the four-year period.

The principal techniques used to determine the condition and the rate of deterioration were:

- chloride analysis at 25 mm increments to three depths
- carbonation testing with phenolphthalein on fresh concrete surfaces
- half-cell potential contour mapping (see Figure A3) and interpretation to ASTM C 876:99⁽³⁸⁾
- delamination sounding
- visual records.

Figure A3
Half-cell potential mapping.



The data in Table A1 were obtained in the driving lane on Level B and were representative of the corrosion condition of that level. Similar results were obtained for Level C. The increasing chloride at all depths and the more negative shift in corrosion potential clearly demonstrated the extent to which deterioration was accelerating. This acted as the basis for the type of corrosion mitigation techniques employed.

Table A1
Results from driving lane on Level B.

Year of testing	Chloride content % (by weight of cement)			Corrosion potential, mV CSE (copper/copper sulfate electrode)	
	25 mm	50 mm	75 mm	Most -ve	Most +ve
1999	1.82	2.32	1.28	-396	-206
2003	4.48	4.85	3.96	-560	-285

Chloride contents for Levels A and E were less than 1%, while on Level D contents varied from very low (<0.1%) to medium (<2%) with corrosion potentials reflecting this lower activity.

Carbonation levels were low throughout. Thus deterioration was attributed mainly to chloride contamination of the cover concrete.

A1.4 Repair and protection system selection

The corrosion management strategy was designed to arrest corrosion immediately with important control considerations that would avoid deterioration in the future. Concrete repairs were defined and carried out together with the significant use of electrochemical corrosion mitigation techniques, namely surface-applied corrosion inhibitors and impressed current cathodic protection methods to control the effects of corrosion.

Armed with the visual and electrochemical inspection results from the testing in 1999 and 2003, criteria were developed to identify the most appropriate corrosion mitigation techniques in specific circumstances. This had the intention of targeting the most appropriate technical solution while still being acutely aware of the most appropriate economic solution for the client.

The criteria were based in principle on the chloride depth and corrosion potential contour mapping information but with the underlying intention not to mix and match solutions on the same parking level but to use the most appropriate technique to achieve the 25-year life extension desired by the client.

The criteria and system package solutions applied were as follows:

- Half-cell potentials more positive than -200 mV CSE and chloride content less than 1% by weight of cement would receive no corrosion mitigation treatment.
- Half-cell potentials more negative than -200 mV CSE and chloride content less than 1% by weight of cement would receive surface-applied corrosion inhibitor throughout. This was also applied to support columns.
- Half-cell potentials more negative than -200 mV CSE and chloride content greater than 1% by weight of cement would receive a mixed metal oxide (MMO)-coated titanium ribbon anode impressed current cathodic protection (ICCP) system.
- In addition, the top deck (Level E) would receive a decking system (solvent-free elastic polyurethane overcoated with a flexible epoxy seal coat) on all top surfaces to provide a tough, crack-bridging, waterproof but flexible surface to the deck with good colour stability and weather, abrasion and slip resistance.
- Intermediate decks exposed to less weathering would receive a solvent-free epoxy resin decking system with all the stated exposure durability characteristics.
- A decorative and anti-carbonation coating system would be applied to soffits and downstand beams.

This yielded the following strategy on a level-by-level basis:

- Level A: Limited concrete repairs and deck waterproof coating.
- Levels B and C: Extensive concrete repairs, ICCP system and deck waterproof coating.
- Level D: Limited concrete repairs, surface-applied corrosion inhibitor and deck waterproof coating.
- Level E: No concrete repairs but new deck waterproof coating.

Levels B, C and D would be monitored for performance as well as selected early detection points to the downward spiral ramps.

The repairs were to the deck surfaces above the rib positions and at every fifth rib soffit position (including downstand beams) arising from the leaking of the construction joints.

A1.5 Preview of corrosion management scheme

Prior to proceeding with the full corrosion mitigation scheme, a preview was conducted to provide assurance that the use of the various techniques would provide the required level of protection to the structure. In the main, there was a concern for the ICCP system design as the ribbon anode was primarily intended to protect the steel in the deck and downstand beams, with the light reinforcing mesh between beams needing definition with respect to throwing power of the anode system.

An area was chosen that reflected 'best case' – that is, the chlorides were low as this was likely to reflect the worst case for conductance of the protection current. It was shown that not only did the ICCP protect the deck and downstand beam but that the mid-point of the trough mesh was also polarising and at low driving voltage.

A1.6 Project installation and compliance with BS EN 1504 Part 9

The approach taken with the repair and protection scheme can be related to one or more of the Principles contained in Part 9 of BS EN 1504. The only Principle not represented in the scheme is Principle 4 for structural strengthening that was not a requirement. These are summarised in Table A2.

Table A2
BS EN 1504 Part 9 Principles applied to the structure.

Part 9 Principle	Objective	Technique chosen	Area of structure
1	Protection against ingress	Waterproof membranes and anti-carbonation coatings	Throughout top surfaces and soffits
2	Moisture control	Waterproof membranes; new expansion joints	Throughout
3	Concrete restoration	Concrete repairs	Where delaminated
5	Increasing physical resistance	Coatings	Throughout
6	Increasing resistance to chemicals	Coatings	Throughout
7	Preserving or restoring passivity	ICCP and inhibitors	Levels B, C and D
9	Cathodic control	ICCP and inhibitors	Levels B, C and D
10	Cathodic protection	ICCP	Levels B and C
11	Control of anodic areas	ICCP and inhibitors	Levels B, C and D

Repairs were conducted with a proprietary pre-bagged rapid-setting mortar with high early strength characteristics.

Expansion joints were upgraded on both the top deck and intermediate decks with state-of-the-art technology with attention to finishing and sealing details.

The consideration of repair material resistivity was made with the decision to firstly provide robust concrete repairs and allow the ICCP to provide its protection to the unrepaired areas. Over time, as the steel within the repair patch requires additional protection, the resistivity change would allow passage of current and allow protection to proceed.

However, the MMO-coated titanium ribbon anode was set into slots in the deck (Figure A4) with a non-polymer modified, but rapid-setting, mortar to allow flow of current to occur from initial energisation.

Figure A4
Installation of anodes in deck.



A policy of using embedded monitoring of all system packages in a representative manner for the structure was also adopted. To achieve this, the half-cell contour plots were used to locate corrosion potential and corrosion rate devices to provide performance data for the decks, downstand beams and trough steel on the levels that received direct corrosion mitigation treatments.

All wiring associated with the ICCP and monitoring systems was hidden within the deck either in the anode slots or saw-cut into the deck and dropped through to the termination boxes (Figure A5) on the soffits. These were then transferred to zonal enclosures in two-compartment trunking that was also used to house the lighting cabling.

Figure A5
Typical termination box.



The installed system integrated all corrosion mitigation choices in a single controllable network management system. Boxes containing specific electronics for ICCP power, control and monitoring, as well detection of early onset of corrosion, were discreetly hidden within the trough ends.

A single network management access unit controls the whole installation and is conveniently sited in the parking management suite. Access and control is remote and accessible via a secure internet facility that will allow not only growth of the client's infrastructure management but also can integrate other features, such as lighting and security, on the same network. The internet corrosion management facility allows the owner to continually assess the performance of the structure.

A1.7 Special features

The appearance of the repaired parking facility was just as important as achieving structural integrity and ensuring the future condition. The deck coating systems were chosen not only for their durability and mechanical features but also for their aesthetic and safety features. Previously the car park was dark and dismal but with the ability to enhance the colour regime within the structure and upgrade the lighting system, the appearance of the structure has been transformed. The combination of an aesthetically pleasing new deck coating system and enhanced lighting has especially transformed the parking facility.

Colour-coding of the deck has allowed demarcation of disabled and standard parking bays and driving aisles, as well as clarifying entry and exit. Ramps were added to facilitate disabled access to the lifts. New lighting was installed along with new automated emergency lighting. New roller shutters have been installed to secure the parking facility at night. Fully interactive help points linked to a help desk have been added to newly installed pay-on-foot machines. Security has been increased with the installation of CCTV and patrols. Following completion of the refurbishment (Figure A6), the facility was assessed and was accredited with Park & Mark® secure parking status.

Figure A6
Completed and repaired car park.



A2 University campus structures

The University of East Anglia was founded in the 1960s and the main campus buildings, including the 'Teaching Wall' and the well-known 'Ziggurat' residential blocks (featured on the English Heritage website), were laid out by Sir Denys Lasdun. The university is proud of its architecture which has been supplemented by other famous architects.

A2.1 The structures

The 'Teaching Wall' consists of a shallow 'W' of reinforced concrete buildings approximately 500 m long. The runs of offices, laboratories and lecture rooms are interrupted by lift and stair 'towers' at intervals along its length, with water tanks and plant rooms above the main building roof level. The exposed concrete façades are a feature of the Teaching Wall and various parts of the campus which were given Grade II* and Grade II listing during the process of the works. Various sections of the Teaching Wall and other campus buildings are linked with elevated walkways (see Figure A7).

Figure A7
The Teaching Wall and adjacent walkways.



A2.2 The condition and situation of the structures

Broomfield Consultants were appointed as corrosion specialist consultants to Jacobs Babbie Consultants to conduct 'Forensic Structural Engineering' initially to the 'Biotower' (Phase 1) and then to all of the reinforced concrete structures with exposed concrete façades on the campus. Work was conducted in close collaboration with the university departments affected, as well as the Estates Department which ran the project, English Heritage and the Norwich City Planning Office which gave the planning consents for the work.

Phase 1 work was on the 'Biotower', a lift and stair tower with air-conditioning plant room and a water tower above. Detailed investigation showed low cover and carbonation to be prevalent with some admixed calcium chloride in some lifts of concrete, all leading to reinforcement corrosion. A number of options for repair were investigated, including the possibility of cladding the façade and 'air-conditioning' it to remove moisture and stop reinforcement corrosion according to Principle 8 in BS EN 1504 Part 9. However, this was untried technology and it was considered that no contractor would offer any warranties on such an installation. For that reason, ICCP was applied according to Principle 10, *Cathodic protection*, in BS EN 1504 Part 9. The specification was according to BS EN 12696: 2000, *Cathodic protection of steel in concrete*⁽¹⁹⁾.

The Phase 2 works were on the library walkway, a concrete stairway to another walkway showing severe corrosion damage and two further stair/lift towers in the Teaching Wall. Figure A8 shows the library walkway. Rundown of de-icing salts and leachate can be seen where the waterproofing and drainage had failed, allowing corrosion of the slim pier supports.

Figure A8
Walkway showing Teaching Wall behind.



A detailed quantitative condition survey revealed areas of concrete damage due to corrosion from carbonation. This was principally due to low cover, indifferent quality concrete and the age of the structure. Other areas were deteriorating due to de-icing salt ingress, particularly on the elevated walkways and access stairways. Using the survey data, calculations were made of ongoing chloride and carbonation ingress on a 30-year life projection, see Broomfield⁽³⁹⁾.

Corrosion modelling was carried out using Fick's law of diffusion calculations on cover depth measurements combined with carbonation depths and chloride depth profiles, see Broomfield⁽⁴⁰⁾. This showed that other than the areas showing immediate damage, few other areas were found to be susceptible to future corrosion.

A2.3 Applying the Principles of BS EN 1504 to the rehabilitation process

Under Section 5.2 of BS EN 1504 Part 9, the following options are given:

- a. do nothing for a certain time
- b. reanalysis of structural capacity
- c. prevention or reduction of further deterioration without improvement of the concrete structure
- d. improvement, strengthening or refurbishment
- e. reconstruction of all or part of the structure
- f. demolition.

Given that the structures are part of a listed site, that further deterioration could lead to health and safety problems in some areas and that the university has set aside a budget for its 'concrete preservation plan', options c and d were relevant.

The standard options given in Part 9 of BS EN 1504 for intervention on a reinforced-concrete structure suffering from reinforcement corrosion are:

- A. do nothing for a certain time
- B. complete or partial demolition and rebuild, Principle 3.4
- C. patch repair of local damaged areas, Principle 3
- D. ingress control via coatings, membranes, sealers, water stops, enclosures or other barriers, Principles 1, 2 and 8
- E. impressed current cathodic protection, Principle 10 (BS EN 12696⁽¹⁹⁾)
- F. galvanic cathodic protection, Principle 10
- G. electrochemical realkalisation, Principle 7.3 (CEN/TS 14038-1⁽¹⁸⁾)
- H. electrochemical chloride extraction (CEN/TS 14038-2⁽¹⁸⁾)
- I. corrosion inhibitors, Principle 11.3.

Being part of a listed building and suffering from corrosion damage, options A and B were not feasible. Option C was required in some areas. Option D was used but in some areas its use was constrained by the requirement to retain the board-marked finish to the concrete on the listed façades. However, control of ingress of CO₂ and chloride ions was required.

To this end, a proprietary architectural coating was trialled, for approval by the university and by the local authority conservation officer. This coating 'tones down' changes in concrete colour and finish and was considered ideal for minimising the visual impact of patch repairs on the board-marked finish on the concrete façades. The selected coating has anti-carbonation properties and is also compatible with a silane for control of moisture and chloride ingress.

In this phase of the works, ICCP, option E, was not required on a large enough area to be cost-effective. However, given the presence of active chloride-induced corrosion, an alternative was to use galvanic anodes installed in the patch repairs to minimise incipient anodes. Figure A9 shows incipient anode formation around an old repair on the Biotower plant room prior to Phase 1 repair and ICCP. The other electrochemical treatment techniques, options F, G and H, were not considered suitable for this project.

Figure A9
Incipient anode formation.



A2.4 Design and specification of the work

Techniques selected therefore included localised galvanic cathodic protection to minimise the incipient anode effect around patches in areas of high chloride (Principal 10, *Cathodic protection*, in Part 9 of BS EN 1504). Penetrating sealers were required as a barrier to further chloride ingress according to Principles 1.1 and 6.1 and to reduce moisture penetration (Principle 8). Anti-carbonation coatings were required to reduce the rate of carbonation (Principles 1.3c and 6) and a renewal of the waterproofing membrane on the walkway decks was specified to keep moisture and chlorides out of the deck concrete (Principle 1.1). The membrane and improvements of drainage provided reduction in water leakage, sheltering the walkway substructure from de-icing salt rundown. These techniques were used along with conventional patch repair where required (Principle 3).

Table A3
Selection of treatments for different elements.

Detailed analysis of the condition survey results allowed determination of treatments to different elements of the structures as shown in Table A3.

BS EN 1504 Part 9 Principles	Method/Principle	BS EN Standard	Elements treated	Materials used
1, Protection against ingress 8, Increasing resistivity	Hydrophobic impregnation, Principles 1.1 and 2.1	BS EN 1504 Part 2 BS EN 1062-3 ⁽³⁰⁾ Maximum value $w = 0.035 \text{ kg/m}^2 \cdot \text{h}^{0.5}$	Walkways below deck level where de-icing salts were applied and chloride level at reinforcement is below the threshold for corrosion	Silane compatible with cosmetic coating used to 'tone down' repairs
1, Protection against ingress	Anti-carbonation coating, Principle 1.3c	BS EN 1504 Part 2 BS EN 1062-6 ⁽³⁰⁾ Permeability to CO_2 $S_D > 50 \text{ m}$	Parapets on walkways above de-icing salts where chloride levels are very low	Cosmetic coating with anti-carbonation properties
1, Protection against ingress	Waterproofing membrane, Principle 1.7	Not listed in BS EN 1504	Walkway decks	Waterproofing system
3, Concrete restoration 7, Preserving or restoring passivity	Hand-applied mortar, Principle 3.1	BS EN 1504 Part 3 Class R4 Compressive strength $> 40 \text{ MPa}$ Adhesive bond $> 2 \text{ MPa}$	All damaged elements	Pre-bagged patch repair material
10, Cathodic protection	Local galvanic anodes, Principle 10	Galvanic anodes not covered yet	Patch repairs with chloride levels in excess of the corrosion threshold	Zinc anodes encapsulated in a proprietary activating mortar

The following specifications were written for the job, based on the relevant Parts and appendices of BS EN 1504:

1. Concrete repair specification:
 - materials according to Part 9 and Part 3 (Class R4 structural grade repair mortar)
 - patch repair preparation according to Part 10, Section 7 and Appendix A7
 - material application according to Part 10, Section 8 and Appendix A8
 - testing on site and of site samples using test methods and values in Part 10, Appendices A7, A8 and A9.
2. Coating specification for silane impregnation:
 - materials according to Part 9 and Part 2 (1.3c for anti-carbonation coating and 1.1(H) and 1.2(I) for silane impregnation for moisture/chloride ingress control)
 - manufacturer's literature for application
 - surface preparation according to Part 10, Sections 7 and 8 and Appendix A8
 - site testing according to Part 10, Appendices A8 and A9.
3. Application specification for a waterproofing membrane:
 - lifting paving slabs
 - conducting repairs
 - repairing an improving drainage
 - applying waterproofing system
 - replacing paving slabs.

A2.5 Site tests

After applying coatings, cores were taken and sent for testing. Carbon dioxide permeability tests (Part 6 of BS EN 1062⁽³⁰⁾) gave far better than the 50 m minimum values recommended in the specifications with uncoated concrete starting at 23 m and 30 m. So the improvement required by the coating was not as great as it might have been for a more permeable concrete.

The water permeability test results were:

■ Coated	0.03 and 0.04 kg/m ² .h ^{1/2}
■ Partial coated	0.05 kg/m ² .h ^{1/2}
■ Uncoated	0.11 and 0.12 kg/m ² .h ^{1/2}

Table 1 in Part 3 of BS EN 1062 states:

■ I High	>0.5 kg/m ² .h ^{1/2}
■ II Medium	0.1 to 0.5 kg/m ² .h ^{1/2}
■ III Low	<0.1 kg/m ² .h ^{1/2}

Given the requirements for a coating with architectural properties, and the fact that most areas of low cover were repaired, the coated values falling in the II Medium range were judged to be an acceptable performance. Also, renewal of the waterproofing and the drainage would reduce the amount of water rundown on the substructure, reducing further the rate of chloride ingress.

Pull-off tests on concrete patch repairs can be conducted according to BS EN 1542⁽⁴¹⁾, BS EN ISO 4624⁽⁴²⁾ and Parts 201 and 207 of BS 1881⁽⁴³⁾, as described in BS EN 1504 Part 10 Section A9.2, Test or observation No. 35, *Adhesion of coatings, adhesive and repair materials*. Recommended values are given in Table A2 of BS EN 1504 Part 10. In this project, pull-off tests achieved 0.8 MPa or better.

It should be noted that the specifications were written prior to full publication of all Parts of BS EN 1504 and the associated test methods. Not all testing on this project was compliant with the specific CEN test mentioned but used equivalent British Standards or other tests in use at the time.

A2.6 Conclusions

Work was successfully completed in 2007. There was minimal disruption to campus activities and both the university and the Listing Officer were pleased with the final finishes on the listed elevations.

In conclusion, it can be seen that concrete repair systems can be designed, performance specified and applied using BS EN 1504, along with the associated test methods, following the principles of corrosion engineering to ensure corrosion prevention before it initiates and corrosion control once damage has initiated.

The first critical part of any repair and refurbishment project is a condition survey, which quantifies the type and extent of damage to ensure that:

- only areas in need of treatment are treated
- appropriate treatments are selected
- the current and future requirements of the structure are fully considered in the repair design process.

Appropriate repair systems and materials can then be selected based on the Principles of BS EN 1504 and repair designs and specifications prepared using the product characteristics specified in the Standard and the associated test methods.

Appendix B. CE marking

As indicated in Section 4.3 of the main text, CE marking will shortly be mandatory in many parts of Europe. Even where CE marking is not mandatory, compliance with the six Essential Requirements of the Construction Products Directive is a legal requirement. This means that products must be demonstrably fit for purpose. In practice that is most readily demonstrated by compliance with the Standard. While nobody in the UK is going to be forced to comply with the Standards, specifiers are increasingly likely to expect compliance, and those producers that choose to ignore the Standards may find it increasingly difficult to win work. NBS (National Building Specification) has already published a revised specification for concrete repair, based on BS EN 1504, which subscribers will already be using. The Highways Agency is also amending its specifications to incorporate the new Standards. The performance basis of the Standards also means that specifiers are likely to want to see detailed information about the performance of the products in the standard tests. This will require the revision of technical literature and data sheets.

To achieve CE marking, products and systems will have to reach minimum performance standards for a range of engineering properties, related to the end use. For example, a surface protection system for concrete, such as a film-forming paint, will have different performance requirements depending on whether it is intended to protect against ingress of chloride ions, or reduce carbonation of the concrete, or control moisture penetration into the surface, and whether the paint is to be applied over active cracks in the concrete. CE marking is therefore intended to deliver products and systems certified to comply with one (or more) of the repair principles and methods listed in BS EN 1504 (e.g. a very high-performance coating may meet the minimum performance requirements of several categories, yet a lower-performance product may only pass one specific method category).

CE marking also ensures that the products and systems are safe (i.e. in terms of release of dangerous substances and reaction to fire) and consistent (i.e. produced under a factory production control system to deliver a quality assured product). This is set out in Part 8 of BS EN 1504, covering quality control and evaluation of conformity for the products and systems.

The most important aspect for the specifier or end user is the performance of the product or system in service. The specifier must be aware that the performance Standards give a minimum level of performance, below which the product will not be 'fit for purpose' and therefore will not carry a CE mark for the repair method. While this minimum performance may be suitable for a 'general' intended purpose, it may not necessarily be adequate for all applications.

Materials producers supplying products to parts of Europe which require CE marking will need to test their products against the requirements of the relevant parts of the product Standard. These tests do not have to be carried out by third parties; manufacturers may choose to use test houses, but are not required to do so (except for some fire testing). Third-party testing may be the cost-effective option for some tests which require equipment that the manufacturer does not have, and which do not have to be carried out frequently.

For further information about CE marking and the Construction Products Directive, go to the Building Regulations section of the Department for Communities and Local Government website. The page dealing with the Construction Products Directive and CE marking, <http://www.communities.gov.uk/index.asp?id=1131335>, provides a frequently asked questions page, along with details about attestation of conformity and notified bodies.

Appendix C. Standards relevant to protection and repair of concrete and standard test methods for BS EN 1504 Parts 2 to 7

This appendix lists the Standards for the repair and protection of concrete which have been published or are being prepared by CEN TC 104 SC8, *Protection and repairs of concrete structures*. It was updated in September 2008. Table C1 lists Standards prepared by other committees and cited in BS EN 1504, although coverage is not comprehensive.

Table C2 lists supporting test methods in numerical order. It indicates which materials specifications for coatings, mortars, structural bonding, injection products, anchoring products and reinforcement coatings use the particular test method. Most of these are laboratory test methods but notably the tests for carbonation depth and chloride content of hardened concrete can be used on site.

Standards identified as BS EN or BS EN ISO are available from the British Standards Institution (BSI) as British Standards. For current information and to order published British, European and International standards see www.bsi-global.com.

Table C1
Standards relevant to protection and repair of concrete.

Standard	Title
BS EN 12696: 2000	<i>Cathodic protection of steel in concrete</i>
CEN/TS 14038-1: 2004	<i>Electrochemical realkalisation and chloride extraction treatments for reinforced concrete, Part 1: Realkalisation</i>
CEN/TS 14038-2	<i>Electrochemical realkalisation and chloride extraction treatments for reinforced concrete, Part 2: Chloride extraction (In preparation)</i>
BS EN 206-1: 2000	<i>Concrete, Part 1: Specification, performance, production and conformity</i>
BS 6270-2: 1985	<i>Code of practice for cleaning and surface repair of buildings. Concrete and precast concrete masonry</i>
BS 8221-1: 2000	<i>Code of practice for cleaning and surface repair of buildings. Cleaning natural stones, brick, terracotta and concrete</i>

Table C2
European standard test methods for protection and repair materials.

Standard	Title	1504-2	1504-3	1504-4	1504-5	1504-6	1504-7
BS EN 1015-3: 1999	<i>Methods of test for mortar or masonry, Part 3: Determination of consistency of fresh mortar (by flow table)</i>	✓					
BS EN 1015-6: 1999	<i>Methods of test for mortar or masonry, Part 6: Determination of bulk density of fresh mortar</i>	✓					
BS EN 1015-7: 1999	<i>Methods of test for mortar or masonry, Part 7: Determination of air content of fresh mortar</i>	✓					
BS EN 1015-17: 2000	<i>Methods of test for mortar or masonry, Part 17: Determination of water-soluble chloride content of fresh mortars</i>		✓			✓	
BS EN 1062-3: 2008	<i>Paints and varnishes. Coating materials and coating systems for exterior masonry and concrete, Part 3: Determination and classification of liquid-water transmission rate (permeability)</i>	✓					
BS EN 1062-6: 2002	<i>Paints and varnishes. Coating materials and coating systems for exterior masonry and concrete, Part 6: Determination of carbon dioxide permeability</i>	✓					

Continued...

Table C2 cont'd
European standard test methods for
protection and repair materials.

Standard	Title	1504-2	1504-3	1504-4	1504-5	1504-6	1504-7
BS EN 1062-7: 2004	Paints and varnishes. Coating materials and coating systems for exterior masonry and concrete, Part 7: Determination of crack bridging properties	✓					
BS EN 1062-11: 2002	Paints and varnishes. Coating materials and coating systems for exterior masonry and concrete, Part 11: Methods of conditioning before testing	✓					
BS EN ISO 1517: 1995	Paints and varnishes. Surface-drying test. Ballotini method	✓					
BS EN 1242	Adhesives. Determination of hydroxyl values and/or hydroxyl content				✓		
BS EN 1240: 1998	Adhesives. Determination of isocyanate content				✓		
BS EN 1542: 1999	Test methods. Measurement of bond strength by pull off	✓	✓				
BS EN 1543: 1998	Determination of tensile strength development for polymers				✓		
BS EN 1544: 2006	Determination of creep under sustained load for synthetic resin products (PC) for anchoring of reinforcing bars					✓	
BS EN 1766: 2000	Reference concretes for testing	✓	✓	✓	✓	✓	
BS EN 1767: 1999	Infrared analysis	✓	✓	✓	✓	✓	✓
BS EN 1770: 1998	Determination of the coefficient of thermal expansion	✓	✓	✓			
BS EN 1771: 2004	Determination of injectability and splitting test				✓	✓	
BS EN 1799: 1999	Tests to measure the suitability of structural bonding agents for application to concrete surface			✓			
BS EN 1877-1: 2000	Reactive functions related to epoxy resins. Determination of epoxy equivalent	✓	✓		✓	✓	✓
BS EN 1877-2: 2000	Reactive functions related to epoxy resins. Determination of amine functions using the total basicity number	✓	✓		✓	✓	✓
BS EN 1878	Thermogravimetric analysis					✓	
BS EN 1881: 2006	Testing of anchoring products by the pull-out method					✓	
BS EN 12188: 1999	Determination of adhesion steel-to-steel for characterisation of structural bonding agents			✓			
BS EN 12189: 1999	Determination of open time			✓			
BS EN 12190: 1999	Determination of compressive strength of repair mortar	✓	✓		✓	✓	
BS EN 12192-1: 2002	Granulometry analysis. Test method for dry components of premixed mortar	✓	✓			✓	
BS EN 12192-2: 1999	Granulometry analysis. Test methods for fillers for polymer bonding agents			✓			
BS EN 12614: 2004	Determination of glass transition temperatures of polymer			✓	✓	✓	✓
BS EN 12615: 1999	Determination of slant shear strength			✓			
BS EN 12617-1: 2003	Determination of linear shrinkage for polymers and surface protection systems (SPS)	✓		✓			
BS EN 12617-2: 2004	Shrinkage of crack injection products based on polymer binder: volumetric shrinkage				✓		✓
BS EN 12617-3: 2002	Determination of early age linear shrinkage for structural bonding agents			✓			
BS EN 12617-4: 2002	Determination of shrinkage and expansion		✓				
BS EN 12618-1 2003	Adhesion and elongation capacity of injection products with limited ductility				✓		✓
BS EN 12618-2: 2004	Determination of the adhesion of injection products, with or without thermal cycling. Adhesion by tensile bond strength			✓	✓		✓

Table C2 cont'd
European standard test methods for
protection and repair materials.

Standard	Title	1504-2	1504-3	1504-4	1504-5	1504-6	1504-7
BS EN 12618-3: 2004	Determination of the adhesion of injection products, with or without thermal cycling. Slant shear method				✓		✓
BS EN 12636: 1999	Determination of adhesion concrete to concrete			✓			✓
BS EN 12637-1: 2004	Compatibility of injection products. Compatibility with concrete				✓		
BS EN 12637-3: 2003	Compatibility of injection products. Effect of injection products on elastomers				✓		✓
BS EN 13036-4	Road and airfield surface characteristics. Test methods, Part 4: Method for measurement of slip/skid resistance of a surface – the pendulum test	✓	✓				
BS EN 13057: 2002	Determination of resistance of capillary absorption		✓				
BS EN 13062: 2003	Determination of thixotropy of products for protection of reinforcement	✓					✓
BS EN 13294: 2002	Determination of stiffening time		✓			✓	
BS EN 13295: 2004	Determination of resistance to carbonation		✓				
BS EN 13395-1: 2002	Determination of workability. Test for flow of thixotropic mortars		✓				
BS EN 13395-2: 2002	Determination of workability. Test for flow of grout or mortar	✓	✓			✓	
BS EN 13395-3: 2002	Determination of workability. Test for flow of repair concrete		✓				
BS EN 13395-4: 2002	Determination of workability. Application of repair mortar overhead		✓				
BS EN 13396: 2004	Measurement of chloride ingress		✓				
BS EN 13412: 2002	Determination of modulus of elasticity in compression		✓	✓			
BS EN 13501-1	Fire classification for construction products and building elements, Part 1: Classification using test data from reaction to fire tests			✓		✓	
BS EN 13529: 2003	Determination of resistance to severe chemical attack	✓					
BS EN 13578: 2003	Compatibility on wet concrete	✓					
BS EN 13579: 2002	Drying test for hydrophobic impregnation	✓					
BS EN 13580: 2002	Water absorption and resistance to alkali for hydrophobic impregnations	✓					
BS EN 13581: 2002	Determination of loss of mass of hydrophobic impregnated concrete after freeze–thaw salt stress	✓					
BS EN 13584: 2003	Determination of creep in compression for repair products		✓				
BS EN 13687-1: 2002	Determination of thermal compatibility. Freeze–thaw cycling with de-icing salt immersion	✓	✓				
BS EN 13687-2: 2002	Determination of thermal compatibility. Thunder-shower cycling (thermal shock)	✓	✓				
BS EN 13687-3: 2002	Determination of thermal compatibility. Thermal cycling without de-icing salt impact	✓	✓		✓		
BS EN 13687-4: 2002	Determination of thermal compatibility. Dry thermal cycling		✓				
BS EN 13687-5: 2002	Determination of thermal compatibility. Resistance to temperature shock	✓					
BS EN 13733: 2002	Determination of the durability of structural bonding agents			✓			
BS EN 13894-1: 2003	Determination of fatigue under dynamic loading. During cure			✓			
BS EN 13894-2: 2002	Determination of fatigue under dynamic loading. After hardening			✓			

Table C2 cont'd
European standard test methods for
protection and repair materials.

Standard	Title	1504-2	1504-3	1504-4	1504-5	1504-6	1504-7
BS EN 14068: 2003	Determination of watertightness of injected cracks without movement in concrete				✓		✓
BS EN 14117: 2004	Determination of time of efflux of cementitious injection products				✓		
BS EN 14406: 2004	Determination of the expansion ratio and expansion evolution				✓		
BS EN 14497: 2004	Determination of the filtration stability				✓		
BS EN 14498: 2004	Volume and weight changes of injection products after air drying and water storage cycles				✓		
BS EN 14629: 2007	Determination of chloride content in hardened concrete						✓
BS EN 14630: 2006	Determination of carbonation depth in hardened concrete by the phenolphthalein method	✓					✓
BS EN 15183: 2006	Corrosion protection test						✓
BS EN 15184: 2006	Shear adhesion of coated steel to concrete (pull-out test)						✓
EN ISO 178: 2001	Plastics – determination of flexural properties			✓			
EN ISO 868: 2003	Plastics and ebonite – determination of indentation hardness by means of a durometer (Shore hardness)	✓					✓
EN ISO 2409: 1992	Paints and varnishes – cross cut test	✓					
EN ISO 2431: 1993	Paints and varnishes – Determination of flow time by use of flow cups	✓					
EN ISO 2808: 1999	Paints and varnishes – Determination of film thickness	✓					
ISO 2811-1: 2001	Methods of test for paints. Determination of density by the pyknometer method (Also available as BS 3900-A19: 1998)	✓			✓		✓
ISO 2811-2: 2001	Methods of test for paints. Determination of density by the immersed body (plummet) method (Also available as BS 3900-A20: 1998)	✓			✓		✓
EN ISO 2812-1: 1993	Paints and varnishes – determination of resistance to liquids, Part 1: General methods	✓					
EN ISO 2815: 2003	Paints and varnishes – Buchholz indentation test	✓					
EN ISO 3219: 1995	Determination of viscosity using a rotational viscometer with defined shear rate	✓			✓		✓
EN ISO 3251: 2008	Paints and varnishes. Determination of non-volatile matter of paints, varnishes and binders for paints and varnishes	✓	✓		✓		✓
EN ISO 3451-1: 1997	Plastics. Determination of ash, Part 1: General methods	✓		✓			
EN ISO 4628-2: 2003	Paints and varnishes. Evaluation of degradation of coatings. Assessment of degree of blistering	✓					
EN ISO 4628-4: 2003	Paints and varnishes. Evaluation of degradation of coatings. Assessment of degrees of cracking	✓					
EN ISO 4628-5: 2003	Paints and varnishes. Evaluation of degradation of coatings. Assessment of degrees of flaking	✓					
BS EN ISO 6272: 1994	Paints and varnishes. Falling-weight test BS 3900-E13: 1993	✓					
EN ISO 7783-1: 1996	Determination of water-vapour transmission rate, Part 1: Dish method for free films + Corrigendum 1: 1998						
EN ISO 7783-2: 1999	Determination of water-vapour transmission rate, Part 2: Determination and classification of water-vapour transmission rate (permeability)						

Table C2 cont'd
European standard test methods for
protection and repair materials.

Standard	Title	1504-2	1504-3	1504-4	1504-5	1504-6	1504-7
EN ISO 9514: 2005	Paints and varnishes. Determination of the pot-life of liquid systems. Preparation and conditioning of samples and guidelines for testing	✓	✓	✓	✓	✓	✓
ISO 11357-3	Plastics. Differential scanning calorimetry (DSC), Part 3: Determination of temperature and enthalpy of melting and crystallization				✓		
EN ISO 11358: 1997	Plastics. Thermogravimetry (TG) of polymers. General principles	✓	✓	✓			✓
ISO 1332-1	Particle size analysis – laser diffraction methods, Part 1: General principles				✓		
ISO 2736-2	Concrete test. Test specimens, Part 2: Making and curing of test specimens for strength tests					✓	



Solutions with Substance



The new BS EN1504 standard is being adopted throughout Europe and must be applied in the UK for all forward projects. BS EN1504 details the performance criteria for the protection and repair of concrete structures and gives guidelines for repair and protection methodology.

The **weber.cem concrete repair system** complies with the new BS EN1504 standard:

- ☐ The **weber.cem concrete repair system** includes proven specialist mortars and a wide range of protective coatings. The system is used for repairs to concrete in building structures and civil engineering
- ☐ **Weber** offer a comprehensive advisory service to assist surveyors, structural engineers and architects to work within the new regulation
- ☐ A new RIBA approved CPD training module is already available from **Weber** to assist the understanding of this complex set of regulations



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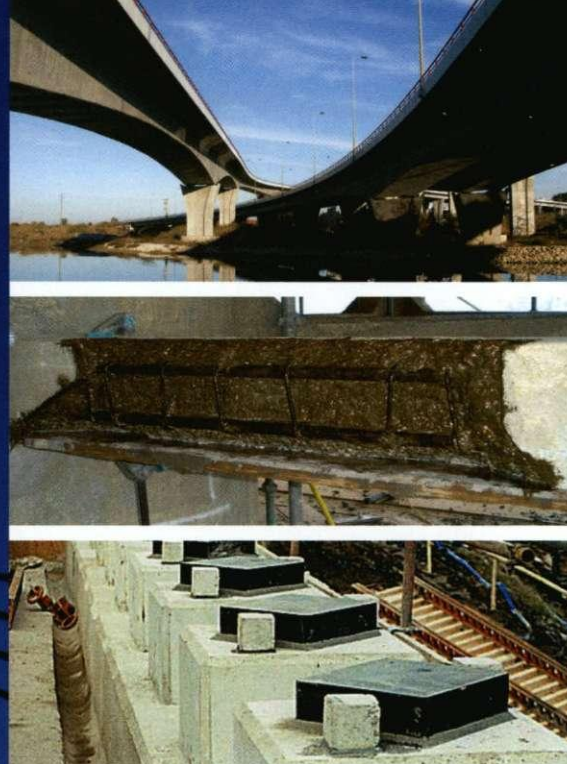
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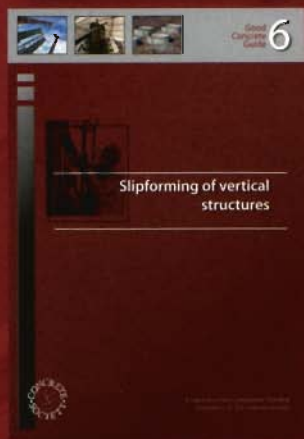
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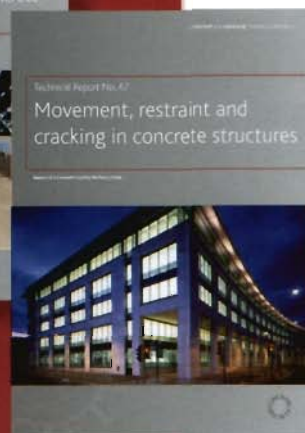
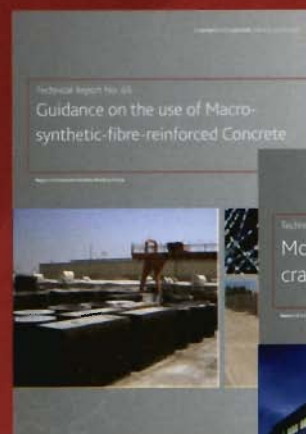
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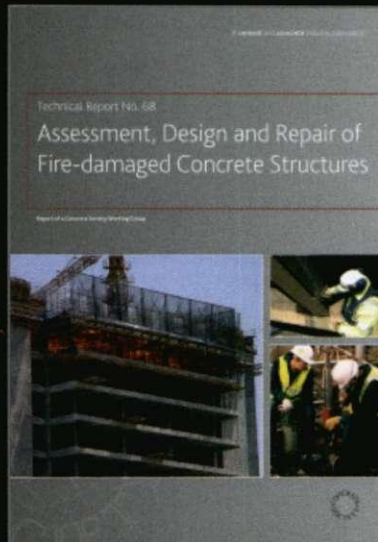
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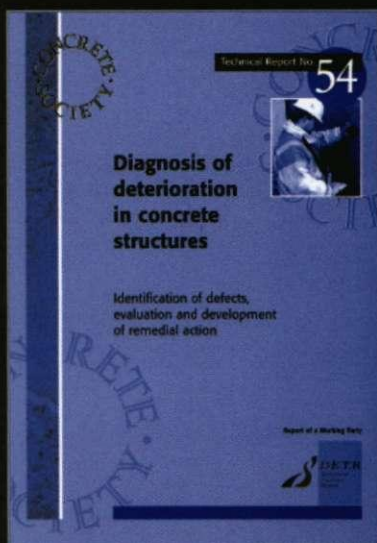


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This report is intended as a broad introduction to the subject of concrete deterioration and contains advice on identification of defects, evaluation and development of remedial strategies. The report may thus serve as a reference document in its own right or as a base for more specialised investigation.

Intended audience for this report is engineers or surveyors responsible for concrete structures, or for advising clients and owners. Useful also to those undertaking inspections and testing programmes, and interpret the results. Suppliers of specialist repair materials and systems, and repair contractors.



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The aim of this Report is to guide consultants and contractors through the application of BS EN 1504, and other related standards, so that they develop appropriate solutions and specify and apply the appropriate materials.

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