3 REINFORCED AND PRESTRESSED CONCRETE

3.1 GENERAL

The durability of a reinforced or prestressed concrete structure is defined as its ability to withstand the expected wear and deterioration throughout its intended life without the need for undue maintenance. The principal factors affecting durability include:

- Attention to design details, including reinforcement layout, appropriate cover and provision for shedding of water from exposed surfaces;
- Good mix design;
- Correct construction practices, including adequate fixing of reinforcement and the placing, compacting and curing of the concrete.

Deficiencies in one or more of these factors can lead to premature deterioration of a structure. The most common form of deterioration is reinforcement corrosion.

NZS 3101 provides guidelines for detailing and specifying reinforced and prestressed concrete structures with a specified intended life of 50 years. The standard considers the effects of concrete quality and curing, chemical content, concrete cover, alkali aggregate reaction (AAR), abrasion from traffic and freeze-thaw cycles and exposure conditions. The increased risk of reinforcement corrosion due to salt contamination is allowed for in Table 5.5 of the Standard, which requires greater depths of cover concrete in exposed coastal environments.

Transit's "Bridge Manual" (SP/M/014) requires a bridge design life of 100 years in normal circumstances. To achieve this increased life expectancy the Manual includes a modified version of NZS3101: Table 5.5 with increased concrete cover depths.

Concrete bridge structures will deteriorate where the combination of design details and construction quality have provided insufficient durability for the environmental conditions. Where deterioration has occurred it is important to identify its nature and its cause to allow the effects on the performance of the bridge to be assessed and appropriate remedial options to be developed.

More detailed information on concrete bridge durability is given in Appendix 13.1.

3.2 VISIBLE DEFECTS

3.2.1 General

A bridge is affected by microclimates which control the nature of deterioration and hence the type of defects that develop in certain elements. The superstructure is the most exposed part and is susceptible to moisture sensitive deterioration such as freeze-thaw, AAR and reinforcement corrosion, as well as to traffic effects such as abrasion and impact. Although less exposed, the substructure of the bridge is still susceptible to reinforcement corrosion, particularly where exposed to salt-laden winds in coastal environments and where the concrete is wetted by driving rain or water leakage through the deck. Shrinkage cracking in concrete bridge decks commonly provides a passage for water leakage, and reinforcement corrosion may result. Bridge piers, piles and abutments may be exposed to soft water attack and to abrasion caused by aggregate movement in the river bed.

The defects that commonly affect concrete bridges are described in Sections 3.2.2 to 3.2.10.

3.2.2 Cracking

Fine cracks often become visible as a wet concrete surface dries, but generally they are not significant unless visible on the dry surface. Cracks visible to the naked eye, i.e. about 0.1 mm or wider, and which are continuous or form a pattern should be mapped, and their size, distribution and penetration recorded. This allows their cause to be identified.

Demec gauges or other devices (e.g. Tell-tales) will indicate whether cracks are progressively opening. Cracks can be outlined with chalk or paint, and by using different colours on successive inspections, crack growth can be accurately recorded. Photographic records should be kept for easy comparison.

Cracks do not always jeopardise the performance of a structure. Concrete will crack in tension zones before the steel can take up the tension, and design limits for crack width are given in NZS 3101. For cracks wider than these limits it is assumed that the cover concrete will no longer provide adequate protection to the reinforcing steel.

Spalling, staining, efflorescence or water leakage through cracks may be associated with reinforcement corrosion and should be investigated.

Excessive movement under traffic loads may pump water through the crack and/or widen the crack by abrading the sides.

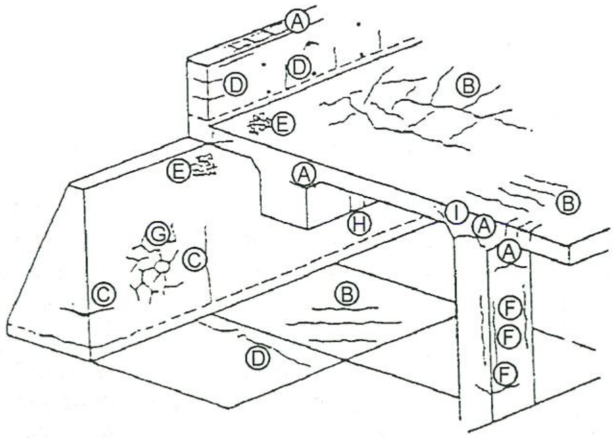

Figure 3.1: Characteristic crack patterns in a hypothetical structure.

A: Plastic settlement (after compaction, before initial set).
B: Plastic shrinkage (before initial set, before curing starts).
C: Early thermal contraction (forms 1 day to 2-3 weeks after casting).
D: Drying shrinkage (forms weeks or months after casting).
E: Crazing.
F: Reinforcement corrosion.
G: Alkali-aggregate reaction (cracks often discoloured, may follow reinforcement).
H: Tension bending cracks.
I: Shear cracks.

Characteristic concrete crack patterns are shown in Figure 3.1. In practice, several forces may contribute, simultaneously or successively, to the development of a crack, and may include loading (bending, tension, shear, torsion, bond failure or concentrated load), overloading, settlement, fire, impact or incorrect stressing.

The following is a summary of the most common causes of cracking and the characteristics of the cracks resulting from each:

- Plastic settlement cracks may be of any orientation and width, ranging from fine cracks above reinforcement and at changes in profile on a vertical surface, (which result from the settlement of the fresh concrete), to wide cracks in supporting members due to foundation settlement during setting of concrete;
- Plastic shrinkage cracks form in parallel lines or a grid and result from rapid drying of the concrete in its plastic state. Such cracks can be wide but are usually shallow. They develop on the top surface of the deck and can often be observed in deck soffits;
- Drying shrinkage cracks result from drying of the concrete after it has hardened. They are usually finer and deeper than plastic shrinkage cracks and have a random orientation;
- Early thermal cracking results from cooling and contraction of concrete after initial heat rise due to cement hydration. Cracking will only occur if the element is restrained;
- Crazing is fine cracking in the surface layers of concrete caused by shrinkage of the surface relative to the concrete mass due to differential moisture movement. Crazing is only a few millimetres deep and is unlikely to affect the integrity of the concrete;
- Reinforcement corrosion: See Section 3.2.3;
- Structural cracks usually result from the differences between assumed and actual stress distribution, except for those controlled by the provision of reinforcement. Width will vary, although orientation will often be well defined. Examples include diagonal cracks in the acute corners of severely skewed decks, wide longitudinal cracks opposite the voids in some post-tensioned structures and the classical bending and shear cracks;
- AAR cracking is usually depicted as map cracking (a closely spaced network of cracks) although it may be controlled by the presence of reinforcing steel. The cause is an expansive effect due to reaction between the aggregate and the alkalis in the cement.

3.2.3 Reinforcement Corrosion

Reinforcement will corrode when the passivation of the steel produced by the highly alkaline environment in concrete is disrupted by chloride ion contamination or carbonation, and when sufficient quantities of oxygen and moisture are available.

There is a greater risk of chloride contamination in coastal areas where the concrete is in contact with sea water, salt-laden winds or spray. Chlorides may also have been added to the original mix as a set accelerating admixture or in salt contaminated aggregate.

Carbonation is a reaction between the hydrated cement paste and atmospheric carbon dioxide. It reduces the concrete alkalinity. The rate of carbonation is controlled by the moisture condition of the concrete.

The most common manifestation of reinforcement corrosion is the production of orange-coloured corrosion products. The corrosion product occupies a greater volume than the steel, and its formation generates expansive forces which will crack and spall the cover concrete. This type of corrosion results in uniform section loss to the reinforcement.

In chloride-contaminated concrete, reinforcement corrosion may produce discrete pits rather than uniform section loss. This type of corrosion is of concern as the volume of corrosion product is relatively small and cracking and spalling may not develop until the reinforcement has suffered significant section loss.

The first signs of corrosion activity are usually cracks on the surface of the concrete. Rust stains may or may not be evident. The concrete may sound "drummy" when struck, indicating that it has delaminated from the reinforcement. Spalling follows delamination.

An example of spalling due to extensive reinforcement corrosion on a deck cantilever soffit is shown in Figure 3.2.

Figure 3.2: Spalling due to extensive reinforcement corrosion on a deck soffit.

3.2.4 Spalling

Apart from spalling caused by corrosion of reinforcing steel, pieces of concrete may detach from the structure as a result of local over-stressing, overloading, impact, excessive relative movement of one or more components or fire damage. Figure 3.3 shows a spall caused by seismic movement.

Figure 3.3: Spall caused by seismic movement.

3.2.5 Surface Erosion

Surface erosion will remove the dense, impermeable surface layers of cement paste and reduce the depth of effective cover to the steel. The principal mechanisms of surface erosion are:

- Soft water (i.e. water with little dissolved mineral matter) which leaches components of the hydrated cement paste, softening the surface of the exposed concrete. This is commonly observed on concrete piers, piles and abutments where immersed at river level. The softened surface is vulnerable to removal by water flow with or without suspended particles;
- Freeze-thaw cycles causing gradual and continual removal of surface mortar and aggregate exposed to frost, e.g. on wing walls and kerbs (Figure 3.4);
- Abrasion by solid particles erodes the concrete surfaces of piles, abutments or piers at bed level in rivers with a high bed load;

- Salt scaling caused by the crystallisation of salt crystals in the surface layers of concrete. It extends several millimetres in depth. Distinctive white salt deposits are visible;
- Surface wear due to traffic, and minor surface erosion due to weather and water.

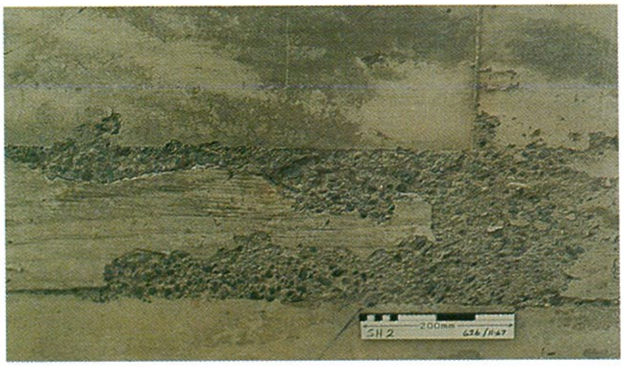

Figure 3.4: Surface mortar can be removed by frost

3.2.6 Drainage and Leakage of Water

Staining, biological growths and efflorescence may indicate where surface water has leaked through deck joints, inadequate drainage detailing has directed water over concrete surfaces, ground water has leaked through cracks and construction joints in abutments, or blocked drains, gutters and weep holes may have caused water to seep through cracks.

Reinforcement corrosion is commonly assoc-iated with such water flow.

See also Section 7.

3.2.7 Construction Defects

Several common construction defects are likely to result in the concrete failing to provide adequate protection to the reinforcement, which may then corrode. These defects include:

- Poor placing and compaction techniques and/or inappropriate mix designs, causing honeycombing (Figure 3.5), voids, plastic settlement. Shallow honeycombing is often repaired by bag-rubbing at the time of construction;
- Inappropriate mix design, resulting in segregation or highly permeable concrete;
- Incorrect placement of steel, resulting in shallow cover depths.

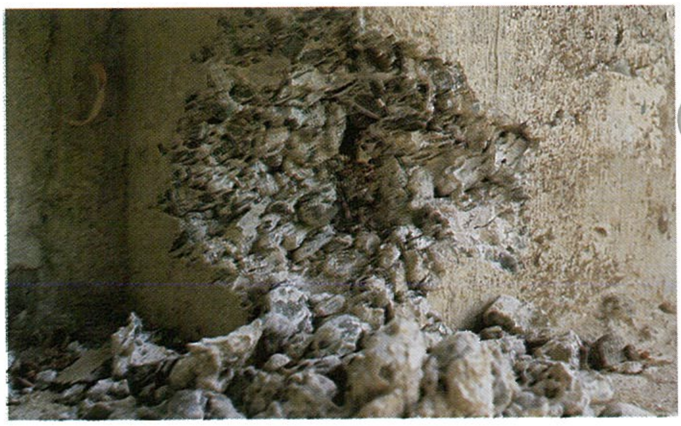

Figure 3.5: Honeycombed concrete and associated reinforcement corrosion

3.2.8 Surface Deposits

The most common type of surface deposit is efflorescence where water is passing through cracks, joints or poorly compacted concrete.

Efflorescence is a deposit of salts, usually white, which results from the flow of a solution from within the concrete to the surface where the water evaporates. It is commonly observed in deck slab soffits due to water leakage through the deck.

3.2.9 Failure of Applied Finishes

An applied plaster repair material may crack or detach from the substrate, effectively reducing the depth of concrete cover.

3.2.10 Distortion of Shape

Beams and decks may sag, piers and walls may bow or lean, and joints may open, close or fault due to settlement, overloading, deterioration or failure of the concrete or reinforcement or prestressing.

See also Sections 6 and 9.

3.3 INSPECTION AND DIAGNOSIS

3.3.1 General

Before any repair can be contemplated, it is essential that the causes, extent and severity of the concrete deterioration are accurately diagnosed and assessed. Defects may be aesthetic (e.g. construction stains), indicating possible problems (e.g. honeycombing, efflorescence, lack of cover), non-progressive (e.g. crazing, shrinkage cracking), or progressive (e.g. reinforcement corrosion,

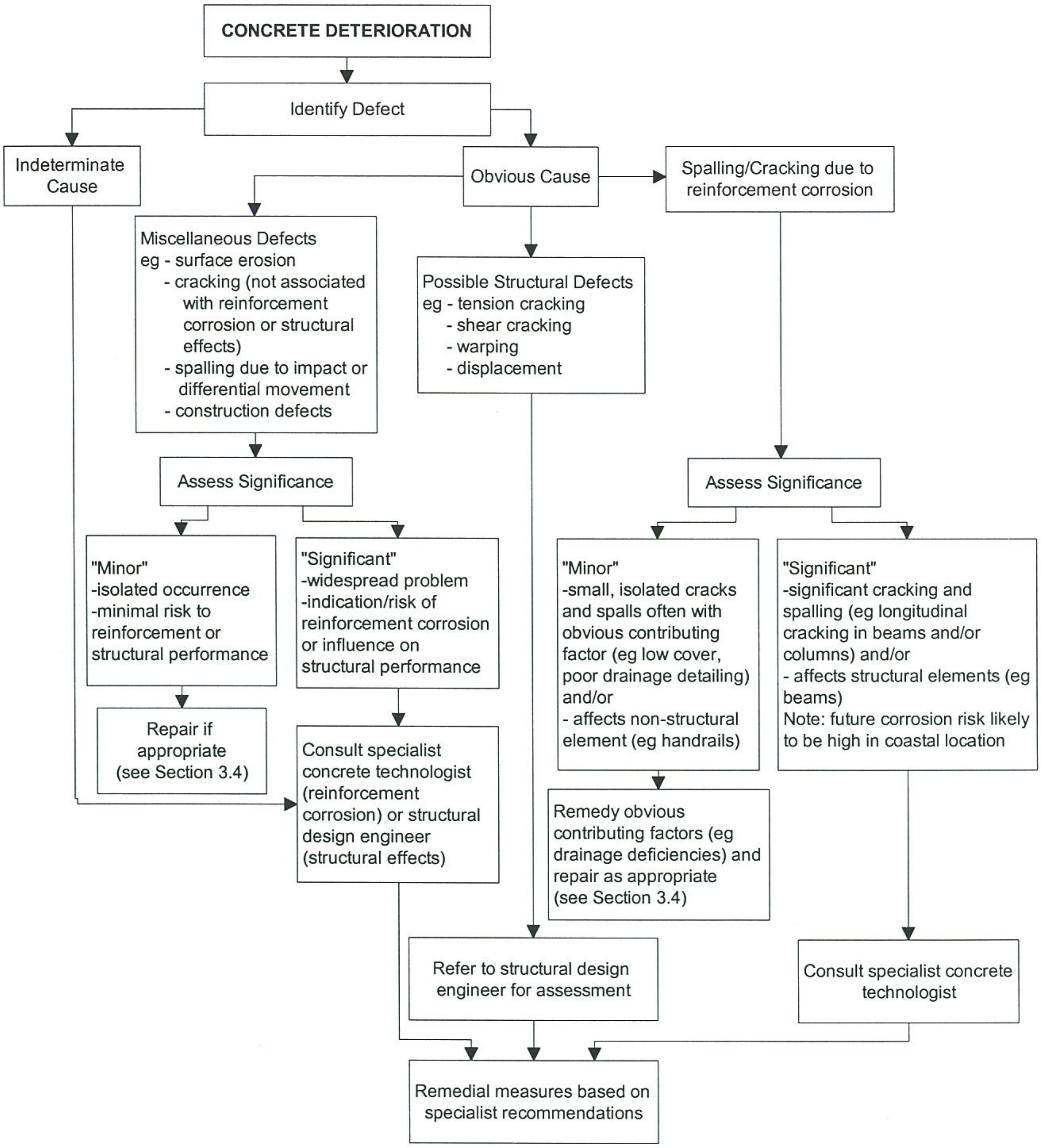

Figure 3.6: Criteria for assessment of concrete deterioration.

working cracks, frost damage, alkali-aggregate reaction).

An approach to defining the significance of concrete deterioration and selecting the most appropriate option for assessment is outlined in Figure 3.6. This emphasises the need to consult experienced concrete technologists or structural design engineers to assess significant concrete defects when their cause is not obvious. A common cause of repair failure is the use of inappropriate repair methods or materials because the cause or significance of the deterioration has not been correctly assessed.

3.3.2 Interpretation of Observations

The need for specialist input to identify the cause, extent and repair of observed defects is most commonly associated with reinforcement corrosion and defects indicative of structural distress.

Detailed visual inspection will establish the nature and extent of reinforcement corrosion, then the more specialised techniques outlined in Section 3.3.3 can be used to establish the cause. Sampling to establish the deterioration mechanism will also help to identify the future corrosion risk and the most appropriate remedial options. Where significant corrosion is evident, cover concrete should be removed at critical locations and the section loss to reinforcing steel determined.

The assessment of prestressing steel corrosion is similar to the process for reinforcing steel, although specialist techniques are required to assess tendons in grouted ducts. Pre-tensioned steel is usually associated with high-quality precast concrete and so has a low risk of corrosion, although where corrosion has occurred the potential loss of prestress is a significant structural concern. Post-tensioned tendons rely on grouting for their primary protection and this can be variable both in quality and continuity. Voids in the ducts not only increase the risk of corrosion but also reduce the degree of bonding.

Structural implications of cracks and distortions are assessed by considering first the effect of the damage on the performance of the component, and second how the integrity of the whole structure is affected. Existing codes, structural analyses, drawings, specifications, soil investigations, construction records and previous inspection reports should be studied. Foundation movements and estimated actual loads should be compared with those assumed in the original structural analysis. For prestressed structures the conformity of structural analysis, drawings, actual stressing forces and the effects of concrete shrinkage and creep should be checked. Environmental factors which may accelerate deterioration should also be considered.

3.3.3 Test Methods

Testing may be required to assess the cause and extent of deterioration. Some of the tests can be carried out by inspection personnel to assist in the initial evaluation. Other techniques should be used by specialist concrete technologists to assist in identifying the most appropriate remedial options.

i) Common Methods

- Hammering to detect delaminations;
- Taking Schmidt hammer measurements to detect variability in concrete quality;
- Core sampling to determine concrete strength and crack depth;
- Crack-width monitoring.

ii) Specialist Methods

- In situ or laboratory testing for permeability;
- Microscopic analysis of cores;
- Ultrasonic techniques for detecting cracks and voids;
- Covermeter surveys to locate and verify the size of reinforcement, and to determine the depth of concrete cover (Figure 3.7);
- Testing for carbonation depth;
- Chemical analysis of chloride ion contamination;
- Half-cell potential mapping to ascertain the probability and extent of corrosion;

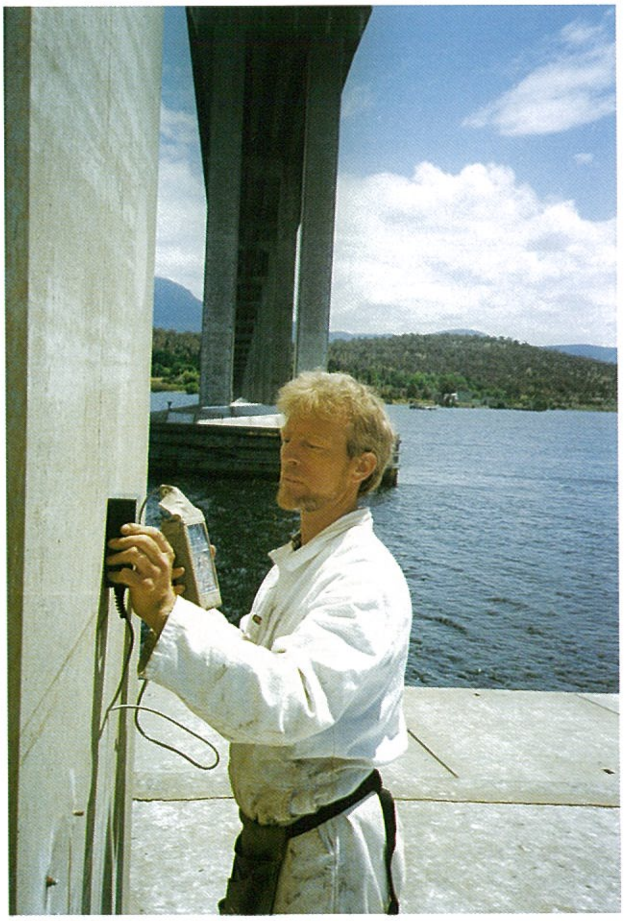

Figure 3.7: Detection of reinforcing steel using an electromagnetic covermeter

- Measurement of electrical resistivity to indicate the likely rate of corrosion;
- Strain and deflection measurements to indicate the effects of cracks;
- In situ, non-destructive measurement of reinforcing steel strength;
- Proof load testing.
- Detection of volume and continuity of voids in grouted ducts;
- Detection of prestressing strand deterioration.

3.4 REPAIR

3.4.1 General

Repairs may be carried out on concrete bridges for many reasons but repairs to mitigate reinforcement corrosion damage are by far the most common. Resin injection of structurally significant cracking is also frequently carried out.

The methodology chosen to mitigate the effects of reinforcement corrosion depends on technical, economic and strategic factors. If technically appropriate, electrochemical repair methods (e.g. cathodic protection, desalination, realkalisation) offer a longer maintenance-free period than conventional patch repair systems. Service lives in excess of 25 years are claimed for some of the electrochemical methods, and although they have a relatively high capital cost, the extended life of the repair means the whole-of-life costs are likely to be favourable.

Conventional patch repair methods based on proprietary cementitious materials are technically well-advanced and show good performance when executed correctly. However, in some circumstances, such as on coastal bridges where the concrete is extensively contaminated with chloride ions, patch repairs are unlikely to provide long term durability and further cycles of repair will probably be required. In such cases an electrochemical treatment such as cathodic protection or desalination would provide a more durable repair. However, the final choice of repair method will also depend on factors such as availability of funds for repair, logistics, the bridge replacement strategy and future alterations to the bridge structure due to road widening or re-alignment.

If frequent repeat cycles of patch repair are expected then the long term structural implications of these repairs should be considered.

3.4.2 Concrete Patch Repair

3.4.2.1 Materials

Concrete patch repair involves reinstating cracked and/or spalled concrete with compatible proprietary cementitious materials. These products contain polymer modifiers, admixtures and fillers to improve bond, increase strength, reduce shrinkage and decrease permeability. They are entirely pre-packaged apart from the mixing water or sometimes the gauging fluid. Manufacturers guarantee the performance of their proprietary cementitious repair systems when used in accordance with their instructions by approved applicators.

Some of the main factors influencing durability of repairs are the thoroughness of the preparation and cleaning of the steel (particularly the removal of salts from the surface) as described in Section 3.4.2.4, the quality of the adhesion of the repair material to the original concrete, and the permeability of repair material, which is influenced both by the material chosen and by the quality of its application. The use of proprietary repair systems and approved applicators should ensure that these factors are addressed.

The quality of repair materials batched on site will vary. They are not recommended due to the significant risk carried by the owner of the structure in the event of ongoing durability problems.

Epoxy mortar repairs are not recommended for repair of concrete damaged by reinforcement corrosion. The thermal expansion and electrical properties of epoxy resin are significantly different to concrete and such repairs are likely to fail prematurely (Figure 3.8) as well as promote and accelerate corrosion in adjacent parts of the structure. This latter type of corrosion is known as incipient anode corrosion.

Figure 3.8: Continuing reinforcement corrosion where repaired with epoxy mortar

Cementitious repairs may also promote incipient anode corrosion due to a change in the electrochemical condition of the reinforcing steel adjacent to the repaired area. However, the effect will be much less severe than for epoxy mortars. Recent developments in repair technology have produced a method of mitigating incipient anode corrosion using sacrificial zinc anodes in conjunction with a cementitious repair system.

3.4.2.2 Extent of Repairs

Concrete patch repairs are commonly carried out on a 'measure and value' basis. This approach involves defining the methodology and estimating the extent of repairs required before the repair contract commences. The actual extent of repair is then measured as the repair contract proceeds.

Corrosion of steel and the cracking and spalling of concrete may be relatively localised, even though the causes of the problem are quite general. Decisions must be made on the extent of repairs needed. A visual inspection will usually be adequate for deciding on the basic form of the repairs, but not necessarily on the size of the area to be treated. For all-over repairs, e.g., re-building or re-casting, obviously no further examinations are required, but if the method of repair is to be local patching, then further inspection of the surfaces will be necessary before the full extent of the repairs can be estimated.

The area for repair is normally based on the visible spalling damage plus an allowance for additional reinforcement corrosion likely to be detected during repair. Additional areas of repair may be defined where particular circumstances (e.g. low cover depths, poor quality concrete) indicate an increased corrosion risk without any visible deterioration.

Half-cell potential mapping can detect areas of concrete where the steel could be corroding but where the symptoms are not yet visible. Repairs in these areas would then need to be considered.

3.4.2.3 Structural Considerations

Where reinforcement corrosion damage is severe, its effect on strength must be considered. Where it is necessary to restore both the strength and durability of an element, the following factors will need to be considered:

- Unless load is taken off the structural element before repair, for example by jacking onto props, the repair will only contribute to the resistance of the element to additional loads;
- The ability of a repair to take load will depend not only on its compressive strength, but also on its elastic modulus and on the strength of the bond to the concrete. For example, a material with low modulus requires greater deformation to occur for a stress to develop in the repair than does a material with a higher modulus;
- Differential shrinkage and creep between the repair material and the original concrete will affect the load-bearing contribution of a repaired section. The base concrete, being old, will creep much less than the repair. This, together with any shrinkage in the repair material, will result in proportionately less load being taken by the repair, although the bond between the repair and the base will be stressed.

Thus the way in which a repair will contribute to the restoration of structural strength requires careful assessment, taking into account loading conditions and the properties of repair materials.

Repairs almost always involve cutting behind the corroding reinforcement. The likely effect of this will need to be carefully considered before a remedial scheme is drawn up. Structural considerations may require limits to be placed on the extent and timing of the breakout work. Particular care will be needed in regions of end anchorage of reinforcement and in any work associated with prestressed concrete.

3.4.2.4 Patch Repair Methodology

Proprietary patch repair materials may be applied as:

- Trowellable mortars;
- Free flowing micro-concretes;
- Spray applied mortars.

Trowellable mortars are historically the most common type of repair material (Figure 3.9) but may need to be applied in several layers in areas where a substantial depth of repair is required.

Free flowing micro-concretes are placed into preformed boxing and allow large volumes of repair to be completed in one process. These repairs are commonly used in beam soffits.

The preferred application process for spray applied mortars is by wet spraying of a pre-mixed mortar (Figure 3.10). Dry process shotcrete (gunite) is less suitable as the quality of the applied mortar is controlled by the nozzleman.

Figure 3.9: Initial application (by hand) of a trowellable mortar.

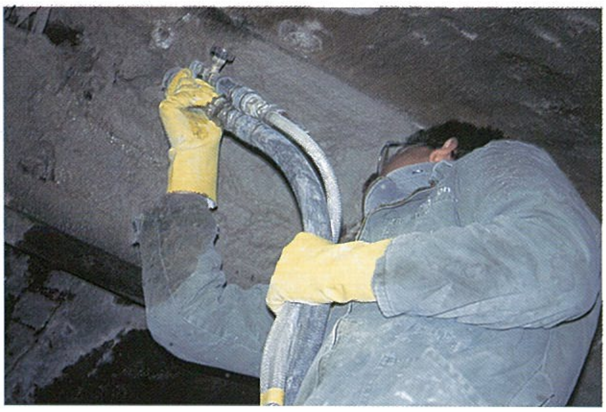

Figure 3.10: Application of sprayable mortar.

Correct preparation of the area to be repaired is critical to the performance of all repairs. Recommended procedures are as follows:

All spalling and poor quality concrete must be removed. Either of two methods can be used. Ultra-high-pressure waterblasting at pressures greater than 80 MPa (11,600 psi) has the advantage that it removes concrete and cleans reinforcing steel in one action. More traditionally, pneumatic hammers have been used to excavate concrete (Figure 3.11) but they tend to fracture the surrounding concrete and a further operation is required to clean the reinforcing steel.

Concrete should be removed from around the full circumference of the reinforcing steel and 20 mm beyond it. Removal should continue along the length of the reinforcing steel 50mm beyond the corroded area. Reinforcing bars should be replaced where a significant percentage of the bar diameter has been removed by corrosion.

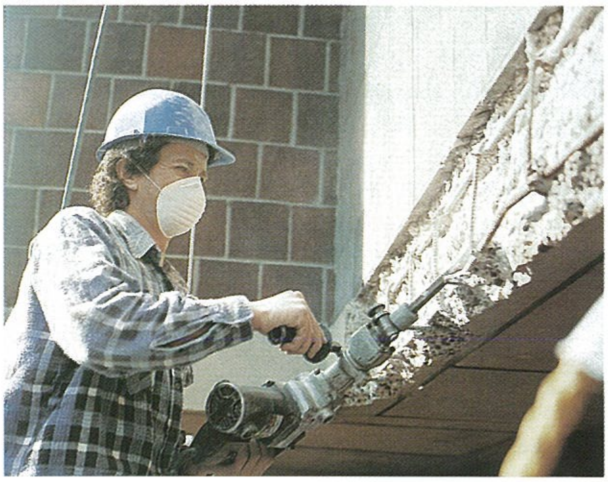

Figure 3.11: Concrete excavation using a pneumatic hammer.

Where the reinforcing steel is within 10mm of the surface, the bars may be removed, (if confirmed as appropriate by an engineer), bent back into the concrete, or left in position and an additional protective layer of cementitious mortar added to the entire concrete surface.

If concrete is removed with pneumatic hammers, abrasive blast (wet or dry) the reinforcing bars to a bright condition then thoroughly wash them with clean water.

The edge of excavations should be sawcut to a minimum depth of 10mm (Figure 3.12). Sawcuts should be perpendicular to the surface, or angled to 'retain' the repair material.

All preparation should leave a sound substrate free from dust, loose particles and any deleterious materials.

Figure 3.12: Prepared excavation showing sawcut edges and application of reinforcement primer.

As soon as practical after cleaning, the reinforcement should be primed or coated to the requirements of the chosen repair system (Figure 3.12). Coating types available include cementitious slurry and zinc-rich primers.

Reinstate the excavated area using a proprietary cementitious repair system in accordance with the manufacturer's instructions.

3.4.3 Concrete Coatings

Coatings on concrete can fulfil three functions:

- Change the appearance of the concrete;
- Improve surface properties of the concrete;
- Provide a barrier against the transmission of gases and liquids.

The principal generic types of concrete coating and their various attributes are presented in Figure 3.13.

Coating Type	Features
Silane-Siloxane	Waterproofing, chloride barriers.
Silicones	Waterproofing.
Stearates	Waterproofing.
Epoxy Resin	Versatile sealers and coatings, Hard wearing, good chemical resistance but brittle.
Polyurethanes	Versatile sealers and coatings Hard wearing, good chemical and weathering resistance, flexibility and toughness.
Polyester, Vinyl Ester, Acrylate	Excellent chemical and temperature resistance. Cure at low temperatures.
Acrylics	Decorative, good weathering, CO_2 and chloride barriers, crack bridging, allow vapour transfer.
Vinyls and Synthetic Elastomers	Similar to chlorinated rubber.
Chlorinated Rubber	General barrier uses, weather protection, solvent sensitive.
Bitumen	Low cost waterproofing.
Cementitious	Barriers against CO_2, chlorides, water, poor acid resistance.

Figure 3.13: Concrete Coatings

There are a myriad of different proprietary coatings available, with various claims for their performance. Caution should be exercised in the selection of coatings and expert advice should be sought to validate claims of performance.

AS/NZS 4548 gives guidance on the selection of architectural coatings, but does not cover materials for protecting concrete in severe environments.

Coatings alter the permeability characteristics of concrete and should not be applied to structures where there is a possibility of future treatment by desalination or re-alkalisation.

Coatings are often used to complete patch repairs. Almost all repairs will produce obvious visual mis-match that can be remedied using a coating to provide textural and visual continuity. Apart from improving appearance, such coatings are normally required to provide a barrier against chlorides, carbon dioxide and water to inhibit further deterioration. Polymer modified cementitious coatings have been used to provide this type of protection and are effective at masking physical imperfections of the concrete surface.

Current technology favours a coating system consisting of a silane-siloxane penetrating primer overcoated with a clear or pigmented acrylic membrane. The silane-siloxane blocks liquid water and chloride ions but allows water vapour to pass so the concrete can dry. The acrylic membrane physically protects the silane-siloxane, and provides a barrier to carbon dioxide and some protection against moisture while being permeable to water vapour. Repair material suppliers offer such coatings as a part of their patch repair systems.

Coatings may be used to seal and hide surface defects and inactive cracks on otherwise sound concrete. Coatings may also be used on new concrete to provide additional protection in an aggressive environment. Specialist anti-graffiti coatings are also available.

A coating is only as good as the substrate preparation and the application process. Care should be taken to choose a coating that is compatible with the concrete or repair material beneath it. It is important also to ensure that all properties of the proposed coating are understood. As an example, if a coating is required to enhance the appearance of a structure in a marine environment, it should also be resistant to the passage of salt-laden air.

The protective value of a coating is greatly reduced by the presence of any defects such as cracks or pinholes. Long-term durability depends on a number of factors including the chemical composition of the binder, the formulation, the total film thickness and the application techniques.

3.4.4 Electrochemical Repair

3.4.4.1 Cathodic protection (CP)

Corrosion or dissolution of a metal can be prevented when its electrical potential is reduced below a certain level, such that ions are prevented from leaving the metal surface. The principle of making a metal 'cathodic' relative to its surrounding material has been used for over 60 years to protect ships' hulls, marine structures and buried pipelines. Steel is cathodically protected when it is kept 700 to 800 millivolts more negative than its surroundings by either:-

a) Connecting it to a more electrically active or anodic material such as zinc, aluminium or magnesium in 'sacrificial anode' systems, which allow the anode to preferentially corrode, or;

b) Connecting it to the negative terminal of a suitable source of DC power in an 'impressed current' system, with the positive terminal connected to a suitable anode which might be scrap iron or a corrosion resistant material such as activated titanium.

Use of CP on above-ground reinforced concrete structures began in North America in the mid 1970's to protect bridge decks saturated by de-icing salts. Rapid development of the technique followed with a variety of anode systems being developed. After an extensive series of trials, the US Federal Highways Administration concluded in 1982 that "... the only rehabilitation technique that has proved to stop corrosion in salt-contaminated bridge decks regardless of the chloride content of the concrete is cathodic protection".

Cathodic protection of concrete is a relatively expensive remedial option. The cost is normally justified only when chloride levels in the concrete are or will be so high that conventional patch repairs will become uneconomic over the life of the structure.

Patch repair of spalled concrete is still required but only to replace the delaminated material and any non-conductive material, e.g. epoxy resin from previous repair. The system should be designed by a consultant with experience in this type of work in accordance with a recognised standard such as the European Draft Standard prEN 12696 or the Australian Standard AS 2832.5.

Specialist contractors are required to install a CP system. Work will include ensuring that all reinforcement is electrically continuous, and installing reference electrodes which are used to monitor the performance of the system. Activated titanium anodes may consist of rods fitted into drilled holes with a graphite based backfill (internal type), mesh strips installed into grooves cut into the cover concrete, or mesh embedded in mortar on the concrete surface. Other types of surface anodes include thermal sprayed zinc and conductive paints.

For impressed current systems, a source of DC power will be required at a rate of about 10 mA/sqm of steel surface to be protected. This is usually supplied at less than 24V via a transformer and rectifier connected to mains supply. In remote areas, current may be provided from storage batteries that are recharged by solar panels or a small wind turbine.

Once installed it is important that the system is regularly monitored, because if the potentials are set too high the steel-concrete bond will be reduced, and there will be an increased risk of hydrogen embrittlement to high-strength steels.

3.4.4.2 Desalination

When a piece of concrete containing chloride ions is placed in an electrolyte between two electrodes, the negatively charged chloride ions will move towards the positive electrode (anode). If the anode is external to the concrete, and if the driving voltage is high enough, the chloride ions will leave the concrete and accumulate in the electrolyte around the anode.

In practice, desalination is performed by first removing spalling or badly cracked concrete and repairing these areas with a cementitious mortar. An anode mesh is then fixed on spacers at the concrete surface, and embedded in a layer of sprayed-on cellulose fibre, or in liquid electrolyte contained in coffer tanks or percolated through layers of geotextile. The anode material itself can be an ordinary steel reinforcement mesh, or, more commonly, an electro-catalysed titanium mesh of the type normally used for cathodic protection. Desalination can take between 14 days and 3 months to be effective depending on the nature of the concrete and extent of chloride contamination. The anode mesh is then removed and the concrete coated. Specialist contractors are required to carry out a desalination project.

Desalination is likely to be appropriate where chloride contamination is widespread and is the principal cause of reinforcement corrosion. It may be applied to the whole structure or to the concrete elements at highest risk. The process is not appropriate where the source of chloride contamination cannot be isolated (e.g. a concrete pier in a saline estuary).

Desalination influences all concrete in the treated area. As a result the maintenance-free life of a desalinated structure should be greater than if repaired with a concrete patch repair system, albeit at a higher capital cost.

3.4.4.3 Realkalisation

Realkalisation involves drawing an alkaline sodium carbonate solution into the concrete from a disposable electrolytic mass on the surface. The process is driven by a voltage applied between a temporary anode embedded in the electrolytic mass (e.g. wet cellulose fibre) and the reinforcing steel.

Realkalisation involves the initial repair of spalled or cracked concrete, attachment of an anode mesh and sodium carbonate supply to the surface, application of an appropriate voltage between the mesh and the reinforcing steel, and removal of the electrolyte once the process has been completed. Specialist contractors are required for a realkalisation project. Realkalisation is very similar to desalination, except that a different electrolyte is used and it takes only 3 to 7 days.

Realkalisation is likely to be appropriate where carbonation is the principal cause of widespread reinforcement corrosion.

The principal advantage of realkalisation is that it treats all cover concrete, leaving no areas of carbonated concrete. The initial capital cost of this process is likely to be higher than for a conventional patch repair, but current expectations are that no further maintenance will be required once a structure is realkalised so the long term costs are minimised.

3.4.5 Crack Repair

3.4.5.1 General

Cracks can either be 'active' or 'inactive' (often referred to as 'live' or 'dead'), i.e. those where width varies with time or those where no further movement is likely. It is important to identify the cause and current movement of cracking because active and inactive cracks can be treated differently. See Section 3.2.2.

3.4.5.2 Active Cracks

Once the cause of cracking has been established beyond doubt, and any possible steps have been taken to avoid further movement, it is possible to restore the structure to its original strength and durability by injecting the cracks full depth with epoxy resin specifically developed for such application. Provided that the surfaces of the concrete in the crack are clean and sound, cracks can be successfully filled and repaired by specialised controlled pressure-injection techniques if their width is more than 0.1 mm.

The filling of cracks involves introducing the epoxy resin into the cracks to fill them completely, and holding it there while it sets to a non-flowing state. Usually the cracks have to be completely sealed on all external faces to prevent the repair resin draining out.

Resin injection should be carried out by specialised contractors with experience in injection techniques. The formulator or specialist contractor must be able to demonstrate that, when the resin system proposed is injected into the cracks, dry or wet (or both), it will achieve a structural bond to the sides of the concrete at the temperature of the structure.

If it is not possible to establish and rectify the cause of the original cracking, there are two possible solutions.

The first is to cut out along the surface of the crack adjacent to it and treat it as a normal movement joint (or alternatively, cut out a normal straight movement adjacent to the crack after having repaired it by resin injection). This will involve filling with a low-modulus sealant.

The second is to inject the crack with a flexible urethane resin. The methodology and equipment used for this injection is similar to that used for epoxy resins.

3.4.5.3 Inactive Cracks

The most significant inactive cracking on bridge structures is plastic cracking (both settlement and shrinkage). The cracks are generally fine and relatively straight, with individual lengths typically of up to 1 m. They should be filled with an injection resin as above or a polymer-modified cementitious slurry well worked into the crack. Early treatment is essential if contaminants are to be kept out of the crack.

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