

ISSUE 574 **BULLETIN**



PREVENTING CORROSION OF REINFORCING STEEL IN CONCRETE

August 2014

■ Corrosion of reinforcing steel in concrete is one of the most common and obvious causes of poor concrete durability and serviceability.

■ Primary factors that influence the risk of corrosion are the exposure environment, the quality of the concrete and the thickness of the protective concrete cover over the steel.

■ This bulletin, which replaces and updates Bulletin 464 of the same name, outlines the causes of corrosion of reinforcement and suggests ways to reduce the risk of such corrosion occurring

1.0 INTRODUCTION

1.0.1 Corrosion of concrete reinforcing steel is one of the most common and obvious causes of poor concrete durability in New Zealand. It has implications for both the durability and serviceability of concrete structures as a result of loss of reinforcing steel area and damage to the concrete as well as compromising the ability of the structure to resist tensile stresses, which can lead to cracking and/or structural failure. Generally, such damage is expensive and difficult to repair, but steps to prevent it can be fairly simple and inexpensive.

1.0.2 New Zealand's maritime climate means that concrete structures are very likely to be exposed to moist salt-laden winds in coastal areas (B1/B2 exposure classification in NZS 3101:2006 *Concrete structures standard*). Further from the coast, any corrosion that occurs is more likely to be as a result of carbonation.

1.0.3 The first outward signs of corrosion of reinforcing are usually small cracks in the concrete along the lines of the reinforcing and, sometimes, rust stains. The corrosion products (rust) have a volume of three times that of the steel from which they form, and their accumulation will cause the concrete cover to flake off or spall. Once this happens, the reinforcing is fully exposed to the atmosphere and the corrosion rate will increase rapidly. Once corroded, the steel's ability to resist tensile stress will also be reduced.

1.0.4 The cover photo of this bulletin shows advanced deterioration of reinforced concrete due to corrosion of reinforcing in an aggressively corrosive marine environment.

1.0.5 When corrosion has already occurred, obtain specialist advice before undertaking repairs. Repairs to concrete with corroded reinforcing steel will be easier and cheaper if carried out when the damage is first noticed – leaving the repair will make it more difficult and expensive.

1.0.6 This bulletin replaces and updates Bulletin 464 of the same name and describes:

- the main causes of corrosion of reinforcing in concrete
- the corrosion mechanisms
- factors that can affect the corrosion mechanisms
- the level of concrete quality required to reduce the risk of corrosion
- ways of providing additional corrosion protection to reinforcing steel.

2.0 BUILDING CODES/STANDARDS

2.0.1 New Zealand Building Code clause B2 *Durability* requires that (unless a specified minimum is stated), with normal maintenance, the structural elements of a building should be expected to be durable for not less than 50 years (or the life of the building).

2.0.2 The following standards are applicable to concrete construction:

- NZS 3101:2006 *Concrete structures standard, Part 1 – The design of concrete structures* applies to detailing and specifying for durability of concrete structures with an intended specified life of either 50 or 100 years.
- NZS 3109:1997 *Concrete construction* provides minimum requirements for the construction of reinforced concrete, unreinforced concrete, prestressed concrete or a combination in elements of any building or civil engineering structure.
- NZS 3604:2011 *Timber-framed buildings* (Section 4.5) specifies minimum durability requirements, including concrete strength and reinforcing cover (depth of reinforcement) for concrete and concrete masonry when used with timber-framed buildings.
- NZS 4229:2013 *Concrete masonry buildings not requiring specific engineering design* (Section 7.8) specifies minimum durability requirements, including concrete strength and reinforcing cover for concrete and concrete masonry when used with masonry buildings.

2.0.3 Concrete structures built in accordance with NZS 3101:2006 Part 1 and NZS 3604:2011 and in accordance with good trade practice should provide, with minimal maintenance, good performance with an extended service life. The concrete mix needs to be correctly specified and, on delivery to site, must be correctly placed, vibrated, finished and cured to ensure long-term performance of the concrete. Getting it right the first time and resolving maintenance issues as soon as possible are essential to preventing corrosion of reinforcing in concrete structures.

3.0 WHY CORROSION OCCURS

3.0.1 Corrosion of reinforcement occurs when the concrete environment around the reinforcing changes as a result of:

- reduction in the pH level (loss of alkalinity) of the concrete (due to carbonation – a process known as depassivation)
- introduction of chlorides beyond a critical threshold.

3.0.2 The rate of corrosion depends on the availability of water and oxygen. Higher concrete temperatures can also increase the rate of corrosion. Moist concrete will have a higher rate of corrosion than dry concrete because of the increased conductivity. However, totally saturated concrete is often protected by reduced oxygen diffusion rates. The greatest danger of corrosion exists where the concrete is exposed to cyclic wetting and drying of marine salts splash or spray, a condition often seen in concrete structures built in the tidal zone, for example.

4.0 RATE OF CORROSION

4.0.1 Carbonation of exterior concrete or alternatively the entry of chlorides into the concrete is possible, but the rate depends on the environment the concrete

is exposed to. The effect on the concrete depends on various factors such as the environment and quality of the concrete. Corrosion of reinforcing steel in dry interior concrete is unlikely.

4.0.2 The aim of concrete design and specification is to choose a combination of concrete strength and concrete cover that ensures that the carbonation/chloride entry does not reach the reinforcing over the intended service life of the structure.

4.0.3 The porosity of the cover concrete also influences the length of time it takes for the pH to reduce or chlorides to increase and cause corrosion of the reinforcing steel.

- a surface finish that is tight and dense
- ensuring supply is from a concrete plant with a current certificate of audit complying with NZS 3104:2003 *Specification for concrete production*.

- 5.1.2** Factors that can also influence the quality are:
- using water that does not meet the requirements of NZS 3104:2003 – the use of recycled concrete truck wash water is an accepted industry-wide practice (and permitted under certain conditions by NZS 3104:2003) to minimise environmental impact
 - the use of specialist cement types and concrete additives to make the concrete more impermeable in aggressive environments
 - incorrect use of admixtures or the combining of admixtures.

5.0 CONCRETE QUALITY

5.0.1 The quality of the concrete (crack free with low permeability) covering the reinforcing steel is the main factor that determines the risk of corrosion. The ratio of water to cement in the mix is the most critical factor affecting durability of concrete.

5.1 WHAT INFLUENCES CONCRETE QUALITY?

5.1.1 Influences on the quality of the concrete include:

- the quality of the cement used – concrete’s alkaline environment provides significant protection to the steel by reducing the possible rate of corrosion
- cleanliness of the aggregates
- the correct water:cement ratio
- proper curing
- low permeability
- a minimum of voids as a result of being well compacted or vibrated
- the presence of cracks – any cracking should be less than 0.3 mm as this is considered to have minimal impact on reinforcing durability

5.2 THICKNESS OF CONCRETE COVER TO STEEL

5.2.1 Covering reinforcing steel with an adequate thickness of well compacted, low permeability concrete (Tables 1 and 2) will increase the time until the concrete around the steel carbonates. In good-quality concrete, this can take many decades.

5.2.2 NZS 3101:2006 gives minimum values for cover thicknesses, measured from the outside of the steel (stirrup, tie, bar or any corrodible embedded item) to achieve minimum durability requirements (Table 1). Tables in the standard and this bulletin also take account of the cement type used and the exposure classification. NZS 3604:2011 also has minimum cover requirements for concrete foundations of buildings within the scope of the standard (Table 2).

5.2.3 Concrete structures require good detailing and construction methods at interfaces, corners and transitions with proper placement of reinforcing steel and adequate vibration to ensure the steel is fully protected, as these junctions may be more vulnerable to corrosion of the reinforcing.

TABLE 1. RELATIONSHIP BETWEEN CONCRETE STRENGTH AND MINIMUM CONCRETE COVER (FOR SPECIFIED INTENDED LIFE OF 50 YEARS)* (FROM NZS 3101, WITH PERMISSION PROVIDED BY STANDARDS NEW ZEALAND UNDER LICENCE 001103)

Exposure classification defined by Table 2 NZS 3101:2006 (see Table 4 below)	Cement binder type	Specified compressive strength (MPa)							
		20	25	30	35	40	45	50	60–100
		Minimum required cover to reinforcing steel (mm)							
A1	GP, GB or HE	25	25	20	20	20	20	20	20
A2	GP, GB or HE	40	35	30	30	25	25	25	20
B1	GP, GB or HE	50	40	35	35	30	30	30	25
B2	GP, GB or HE	-	-	45	40	35	30	30	25
C	30% FA	-	-	-	-	60	60	60	55
C	65% GBS	-	-	-	-	-	50	50	50
C	8% MS	-	-	-	-	-	60	50	50

Notes:

- For zone C, the total binder content shall be equal to or greater than 350 kg/m³.
- The minimum cover for exposure zone C shall be 50 mm.
- For cements, GP = general purpose, GB = general purpose blended, HE = high early strength.
- FA = fly ash, GBS = ground granulated iron blast-furnace slag, MS = amorphous silica.

*Note: An additional table is provided in NZS 3101:2006 for structures with a specified intended life of 100 years.

TABLE 2. MINIMUM CONCRETE COVER TO REINFORCING IN FOUNDATIONS (FOR TIMBER-FRAMED STRUCTURES WITHIN THE SCOPE OF NZS 3604:2011, CLAUSE 4.5.1)

Concrete against or on ground	75 mm
Concrete placed in formwork	50 mm
Top cover over reinforcing mesh (wall or floor slab is in a closed area)	30 mm
Top cover to reinforcement where exposed	50 mm

5.3 CONCRETE STRENGTH

5.3.1 When used in conjunction with concrete cover (Table 1), concrete strength provides an approximate measure of concrete permeability for a given binder type. As strength is readily measurable, it has been adopted by NZS 3101:2006 and NZS 3604:2011 as a compliance criterion for determining the relative durability of concrete.

5.3.2 Generally, higher-strength concrete provides improved protection against steel corrosion because higher cement contents and lower water:cement ratios decrease the permeability of concrete to water, chlorides, carbon dioxide and oxygen.

5.3.3 The minimum concrete strengths for specific reinforcing cover thicknesses, as required by NZS 3101:2006, are given in Table 1. NZS 3604:2011 and NZS 4229:2013 also specify minimum concrete cover to reinforcing (Table 2) and concrete strength (Table 3). NZS 3604:2011 Section 7.5 *Concrete slab-on-ground floors for timber buildings* applies to timber-framed structures within the scope of the standard.

TABLE 3. MINIMUM CONCRETE STRENGTH (AT 28 DAYS) TO COMPLY WITH NZS 3604:2011 TIMBER-FRAMED BUILDINGS

Unreinforced concrete in mass foundations	10 MPa
Unreinforced concrete	17.5 MPa
Reinforced concrete either not exposed to weather or exposed to weather in zone B	17.5 MPa
Reinforced concrete exposed to weather in zone C	20 MPa
Reinforced concrete exposed to weather in zone D	25 MPa
For direct-wearing concrete floors	Refer NZS 3101:2006 Table 5.3
Concrete in geothermal hotspots	Specific engineering design (SED)

(From NZS 3604:2011, with permission provided by Standards New Zealand under licence 001103. Refer to exposure zone maps Figure 4.2.)

5.4 WATER:CEMENT RATIOS

5.4.1 The speed at which reactions such as carbonation penetrate into the concrete is reduced when the water:cement ratio of the concrete is kept as low as is practical for delivery and placement and the concrete is well compacted and cured. This results in strong, dense concrete. Concrete that was too wet when poured or was poorly compacted is much less resistant to movement of moisture and chemicals. A higher water content will increase shrinkage as the concrete dries, increasing the risk of cracking.

5.5 OTHER MIX COMPONENTS

5.5.1 Fly ash, slag-based cements or micro-silica mineral admixtures (supplementary cementitious materials, SCMs) are mandatory under NZS 3101:2006 in splash and tidal zones – exposure classification C. The use of these materials in concrete results in a much tighter pore structure within the concrete.

5.6 VIBRATION AND COMPACTION

5.6.1 Proper vibration and compaction is essential to achieve optimum strength and durability of concrete. The density of concrete is increased through the compaction process by packing together the aggregates within the mix and expelling entrapped air to minimise voids.

5.6.2 The two most commonly used types of vibrators on building sites are immersion vibrators and surface vibrators. Surface vibrators such as beam screeds or roller screeds are used mainly for concrete floor slabs. Form vibrators (where the formwork itself provides the vibration) are often used for precast concrete or in situations where reinforcing is particularly congested. Within these categories are a multitude of specific tools and techniques for use depending on factors such as the size of the job, the slump and workability of the concrete mix and the degree of vibration required.

5.6.3 To avoid serious consequences on durability and strength of the concrete mix, it is important that it should not be undervibrated. In general, well proportioned concrete cannot be overvibrated.

5.7 CURING

5.7.1 The durability of concrete is directly related to the extent and quality of curing because adequate curing is required to achieve impermeable concrete. Curing requirements under ambient conditions are:

- for exposure classifications A1, A2 and B1 – at least 3 days
- for exposure classifications B2 and C – at least 7 days.

5.7.2 Correct curing is required to moderate the risk of shrinkage cracking (but which may still occur) and ensure effective hydration of the cement, which also improves the impermeability of the concrete. Wet curing is the best method of curing, but curing compounds complying with NZS 3109:1997 may be used except in exposure classification C.

5.8 CONCRETE IMPERMEABILITY

5.8.1 While less significant than having the correct water:cement ratio and providing sufficient cover, a dense surface finish to concrete:

- slows access of gases (oxygen, carbon dioxide, chloride ions) to the reinforcing steel, and thus the onset and speed of corrosion (chipped or scabbled concrete speeds up this access)

- reduces the amount of water (rain, groundwater) that may be absorbed by concrete.

5.8.2 Impermeable, dense concrete also improves the resistance to sulphate attack, abrasion and impact.

5.8.3 Surface coatings can also be applied to the surface of weather-exposed concrete to reduce the permeability.

6.0 HOW CORROSION OCCURS

6.1 LOSS OF CONCRETE ALKALINITY

6.1.1 Acidity or alkalinity is expressed as a pH value, which ranges from 0 (very acid) to 14 (very alkaline). Water has a neutral pH of 7. Fresh concrete has a pH value of 12.5 to 13, and this very strong alkalinity forms a passive layer of black iron oxide around the reinforcing steel and protects it from corrosion.

6.1.2 If chemical reactions with the concrete reduce the pH value to approximately 9 or less at the reinforcing steel, this protection is lost, and active corrosion (rusting) will start to occur.

6.1.3 Carbonation (or neutralisation) resulting from carbon dioxide entering the concrete in the presence of moisture is the cause of alkalinity loss. The rate of carbonation depends on the rate of entry of the carbon dioxide (from the atmosphere) and the depth of the concrete, so carbonation generally occurs more quickly:

- around external corners in the concrete where a larger surface area is in contact with the atmosphere
- in poor-quality permeable concrete because it is easily penetrated by carbon dioxide.

6.1.4 The process of lowering the pH is known as the carbonation front. This front defines the extent of the affected concrete. Corrosion of reinforcement depends on the rate of penetration of the carbonation front and the cover provided to the reinforcement to prevent this occurring.

6.2 CHLORIDE ATTACK

6.2.1 The most frequent and most severe cases of reinforcement corrosion in New Zealand can be attributed to the presence of chloride ions. Greatest areas of risk are within 100 m of the high tide mark or within 500 m if downwind of a prevailing onshore wind.

6.2.2 Chloride ions can cause localised pitting corrosion, which rapidly reduces the reinforcing bar diameter at a very localised point. If chlorides are present in sufficient quantity, they can initiate corrosion (even in an alkaline environment). The presence of chloride ions in the atmosphere increases with proximity to the coastline, and the risk of corrosion from chloride attack in concrete near the coast is significantly higher than that due to carbonation.

6.2.3 Chloride ions will enter all concrete to some degree through absorption and diffusion. They may be present in the concrete from the time of construction or can enter after chloride-containing water wets the concrete through:

- areas of poor-quality concrete
- cracks
- areas of damage caused by impact or freeze-thaw cycling.

6.2.4 Sources of chloride are:

- concrete exposed to salt spray in service
- seawater, particularly from periodic wetting in the tidal zone (but less so from total immersion)
- during construction, the use of:
 - admixtures – accelerating the setting of concrete by adding calcium chloride is unacceptable when concrete contains reinforcing (chloride-free accelerators are available)
 - contaminated aggregates or sand
 - reinforcing or formwork that has a coating of salt spray deposited on it before use – reinforcing steel and formwork should be cleaned if it has been exposed to a near-coastal or coastal environment
- ground conditions where the soil contains water with high levels of chloride or organic matter.

6.2.5 The chloride content of concrete can be significantly reduced by:

- complying with the strict limits set out in NZS 3101:2006 on the maximum amounts of chloride allowed in reinforced concrete (different limits are given, depending on whether the concrete will be wet or dry in service and whether it is exposed to chloride from outside the concrete)
- never using seawater to mix concrete
- limiting the use of beach or dune sand unless it has been thoroughly washed to remove the chloride salts
- use of chloride-free admixtures (the use of calcium chloride accelerators is not recommended).

6.3 FACTORS CONTRIBUTING TO CORROSION

6.3.1 Other factors, all related to concrete quality, that can influence the speed of corrosion are:

- the environmental conditions the concrete is exposed to (see Table 4)
- the presence of cracks, which can provide paths of easy access through the concrete for gases and liquids
- impact or abrasion damage, reducing or removing concrete cover
- contact between dissimilar metals (such as a copper pipe in contact with floor slab reinforcing)
- damage to the concrete as a result of acidic or sulphate attack, which destroys the protective concrete cover to the reinforcing and exposes it to corrosion
- the presence of sulphates in soil or natural groundwater can affect the setting time for concrete and also the long-term strength of concrete – sulphates in high concentrations may also cause long-term crazing and cracking.

TABLE 4. ENVIRONMENTAL CONDITION AND EXPOSURE CLASSIFICATIONS (FROM NZS 3101:2006, WITH PERMISSION PROVIDED BY STANDARDS NEW ZEALAND UNDER LICENCE 001103. NOTE THAT THE EXPOSURE ZONES USED BY NZS 3604:2011 DIFFER).

Surface and exposure environment	Exposure classification ¹
Surfaces of concrete in contact with the ground: • protected by a damp-proof membrane • in non-aggressive soils	A1 A2
Surfaces of concrete in interior environments: • fully enclosed within a building except for a brief period of weather exposure during construction ² • in buildings or parts of buildings where the concrete may be subject to repeated wetting and drying ²	A1 B1
Surfaces of concrete in above-ground exterior environments in areas that are: • inland ³ • coastal perimeter ³ • coastal frontage ³	A2 B1 B2
Surfaces of concrete in water: ⁴ • in fresh (not soft) water: – contact – pressure – running • in fresh (soft) water: – contact – pressure – running • in seawater: – permanently submerged – tidal/splash/spray zones ³	B1 B2 B2 B2 U U B2 C
For surfaces of members exposed to chemical attack, refer to NZS 3101:2006	XA 1, XA 2, XA 3 (refer to NZS 3101:2006)
Surfaces of concrete in other environments, namely any exposure environment not otherwise described above	U

Notes:

1. Exposure classification

A1 and A2 Relatively benign environments, such as building interior or inland sites remote from the coast, where the provision of adequate cover will give satisfactory performance.

B1 Moderately aggressive environments, such as locations close to the coast with prevailing onshore wind patterns, for which protection can be satisfactorily provided by a combination of appropriate concrete quality and associated cover.

B2 Aggressive environments such as locations 100 m to 500 m from an open sea situation.

C The most aggressive environments covered by NZS 3101:2006.

U Environments outside the scope of NZS 3101:2006. They may be more aggressive than C or more benign than A1. It is up to the designer to quantify the severity of exposure.

2. Where concrete is in industrial applications, consider the effects of any manufacturing process on the concrete that may require a reclassification to exposure classification U.

3. The boundary between the different exterior environments is dependent on many factors, which include distance from sea, prevailing wind and its intensity. Refer to clauses 3.4.2.4 and 3.4.2.5 of NZS 3101:2006 for the extent of the coastal frontage zone or tidal/splash/spray zone.

4. Water analysis is required to establish the characteristics of water softness. Soft water is defined as water that has a calcium carbonate or equivalent salt content of less than 50 mg/litre.

6.4 EFFECT OF CRACKS ON CORROSION OF EXTERNAL CONCRETE

6.4.1 In serious cases, cracks caused by corrosion can lead to severe spalling, which may result in ultimate structural failure.

6.4.2 From a corrosion viewpoint, less risk is posed to reinforcing steel by:

- narrow cracks – wider cracks create a higher risk because they may let in more moisture
- cracks crossing the reinforcing – cracks parallel to and immediately above the reinforcing (see section 7.5) increase the risk.

6.4.3 Cracking of concrete can occur before and after hardening. Cracks before hardening result from:

- plastic shrinkage caused by concrete drying too quickly before final set (especially in floor slabs)

- plastic settlement caused by the reinforcing steel, embedded items or formwork restricting the movement of concrete during placement and compaction.

6.4.4 Many small bars, closely spaced, usually result in many narrow cracks. A few larger bars, serving the same structural purpose, can lead to fewer but wider cracks, which generally increases the risk of corrosion. Using many smaller bars is preferable for better control of crack widths.

6.4.5 Cracks that occur after hardening generally result from:

- drying shrinkage that is restrained
- differential moisture movement
- thermal expansion and contraction
- build-up of corrosion products on steel
- freeze-thaw cycles in cold conditions

- alkali-aggregate reactions (AAR) or sulphate attack (chemical cracking) – although this may indicate significant pre-existing durability issues
- overloading, creep and design loads (structural cracking from loads in excess of the design loads).

6.4.6 The possibility of cracking and the development of potential corrosion sites can be reduced by:

- specifying adequate construction and shrinkage control joints
- using appropriately designed concrete mixes
- appropriate reinforcing layout
- careful concrete placement
- adequate vibration and curing.

6.4.7 Preventing corrosion occurring as a result of cracking can be done by:

- establishing the behaviour of the crack – once it is established whether they are static or moving, an appropriate filler can be used
- for shrinkage cracks in surfaces that will be exposed to marine salt – sealing the cracks with an appropriate filler as soon as they appear
- for dormant or stationary cracks – injecting resin into the crack to seal it
- for non-structural, live or moving cracks – widening it at the surface and construct a sealed joint with a flexible sealant.

7.0 PROTECTION FOR REINFORCING STEEL

7.0.1 Corrosion of reinforcing can be significantly reduced by the use of ‘crack-free’ concrete with low permeability and sufficient concrete cover. Where additional protection to steel is required, specialist advice should be sought.

7.0.2 Options available to protect steel from corrosion are:

- use of supplementary cementitious materials (GBS, FA or MS) – use of the fillers is mandatory in exposure zone C of NZS 3101:2006
- employing chloride-based life prediction tools where the concrete cover is not less than 10 mm lower than the values given in Table 1
- using stainless steel, galvanised steel or coating the steel
- providing a protective coating to the concrete
- using controlled permeability formwork
- using corrosion inhibitors in the concrete
- cathodic protection.

7.0.3 Engineered concrete solutions (ECS) are specifically designed systems to meet or surpass the requirements of NZS 3101:2006 for the various exposure classifications cited. These solutions (which are applied particularly in marine or other highly corrosive environments) use specialised cement additives such as high-reactivity pozzolans and blast-furnace-slag-based cement to produce very dense high-quality concrete with small pores to slow the rate of chloride diffusion.

7.0.4 The risk of corrosion can also be reduced by using a more corrosion-resistant material, such as austenitic stainless steel, containing either:

- 18% chromium and 9% nickel (grade 304 alloy), or
- 18% chromium, 9% nickel and 3% molybdenum (grade 316 alloy).

7.1 PROTECTIVE COATINGS FOR REINFORCING STEEL

7.1.1 In some applications, such as cladding panels, the need to keep the weight of the concrete as low as possible can result in minimal concrete cover over the reinforcing steel. Inadequate cover can lead to spalling and further deterioration of the concrete.

One precaution that can be taken is to specify a corrosion-inhibiting coating for the reinforcing. Epoxies and hot-dipped zinc coatings (galvanising) are the two most widely tested and reported. While neither can be regarded as the perfect all-round answer to problems of reinforcing corrosion, they lessen the risk of concrete damage due to corrosion.

7.1.2 Epoxy coatings to reinforcing steel (applied either as a liquid or powder and then heat cured) have been widely used in the USA in high-risk areas such as bridge decks (where reinforcing is susceptible to attack by de-icing salts). Some problems that can reduce the attained level of corrosion resistance are:

- mechanical damage to the coating during placement of the reinforcement or from rough handling and storage
- a lower bond strength could result between coating and concrete than that occurring between steel and concrete.

7.1.3 Hot-dip zinc coating (galvanising) of reinforcing steel has also been used extensively for bridge deck reinforcing and for reinforced concrete structures close to the sea. For such uses, the galvanised bars receive a chromate coating before leaving the factory to limit the initial attack by the concrete alkalinity. Zinc corrosion products are not as bulky as iron corrosion products, so pressures that might cause spalling should be lower. Zinc, however, is attacked by chloride ions. The concrete cover should therefore not be reduced below that specified for uncoated reinforcing steel if a long life in a marine environment is intended.

7.1.4 Powder coating can also be applied to hot-dipped zinc-coated reinforcing to further improve the level of protection given.

7.1.5 Where protective coatings are used, the risk of corrosion at points where the coating may get damaged is significantly greater because localised damage leads to very high anodic current densities with resulting severe pitting corrosion.

7.2 CORROSION INHIBITORS

7.2.1 Corrosion inhibitors are additives mixed into the concrete to delay the onset and reduce the rate of corrosion by forming a protective film on the surface of the steel within the concrete. Typically, these are

based on nitrites. Corrosion inhibitors are added to the concrete mix with the gauging water.

7.3 CATHODIC PROTECTION

7.3.1 Cathodic protection of reinforcing steel protects one metal in an electrolytic cell either by the:

- sacrificial method, where zinc, magnesium or aluminium are used in electrical contact with the metal to be protected (the current required is generated by the preferential corrosion of the sacrificial material)
- impressed electromotive force (EMF) method, where the direct current is provided by an external source and is passed through the system using non-sacrificial materials such as carbon, non-corrodible alloys or platinum (the impressed EMF method is preferred).

7.3.2 Reinforcing may not be able to be sufficiently electrically connected for cathodic protection to be practical unless specifically designed for at the outset.

7.4 ELECTROCHEMICAL RE-ALKALISATION AND CHLORIDE REMOVAL

7.4.1 Electrochemical re-alkalisation and chloride removal are processes that allow the reinstatement of higher pH values in carbonated concrete and the removal of chloride in contaminated concrete by electrochemical means in order to reinstate the passive environment around the reinforcing steel. The concrete must then be protected from further carbon dioxide or chloride ingress.

7.5 EFFECT OF CRACK WIDTH AND ORIENTATION ON CORROSION

7.5.1 Cracks can be anywhere between parallel and perpendicular to the reinforcing.

7.5.2 Cracks that follow the line of a reinforcing bar (coincidence cracks) (Figure 1) can cause severe corrosion problems even if the crack is quite narrow.

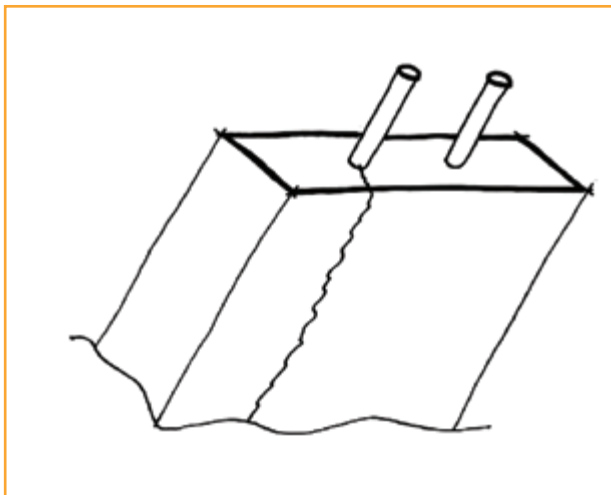


Figure 1. Crack following reinforcing – serious corrosion risk.

This is because they allow chlorides, carbon dioxide, oxygen and moisture to penetrate to the steel. The rate of corrosion is influenced by the crack length and width at the surface and its cross-section.

7.5.3 Cracks that run at right angles to the reinforcing (intersecting cracks) (Figure 2) are usually less serious from a corrosion viewpoint because the area of the steel affected is small. Corrosion can, however, be serious where there are multiple intersecting cracks.

7.5.4 Cracks can be live or moving (shrinkage, thermal expansion, frost, AAR, sulphate attack and live loads), where the crack width will vary with time or remain static (dormant).

7.5.5 Static cracks create a lower corrosion risk. They are more likely to be self-healing because:

- carbon dioxide getting into the crack will cause the calcium hydroxide to carbonate and the calcium carbonate to precipitate and fill the space
- hydroxide diffusing from the surrounding concrete will increase the pH level of the crack.

7.5.6 Live cracks are more likely to collect debris and moisture, which keep the crack wet and more likely to corrode as a result of chloride attack on the steel. Debris in a crack can also restrict movement and, if bad enough, can lead to further small cracks forming.

8.0 MAINTENANCE OF CONCRETE

8.0.1 As part of an asset management and preservation programme, the initial cost and also the immediate cost of maintenance and repair must be assessed against the economic life-cycle cost of a concrete structure.

8.0.2 Regular visual inspections and even simple techniques such as tapping can identify potential problems such as:

- crack movement
- spalling
- efflorescence

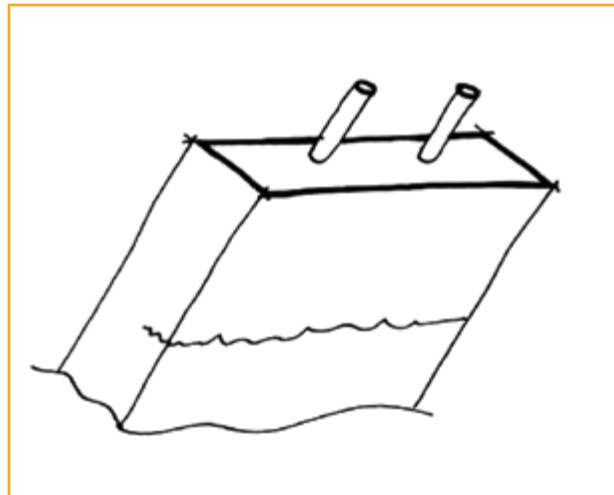


Figure 2. Crack across reinforcing – less serious corrosion risk.

- rust and other staining
- etching by acid attack.

8.0.3 Early identification of problems and the degree and rate of change of any deterioration will help to avoid more serious consequences of continuing degradation of concrete. The extent of work and repair techniques can then be evaluated and a cost-benefit analysis carried out to determine the best course of action.

9.0 REPAIR OPTIONS FOR CONCRETE

9.0.1 Unless concrete repairs are on a minor scale, it is a highly specialised task that should only be undertaken by specialists.

9.0.2 Successful repair techniques depend on thorough investigation and diagnostic surveys and careful analysis of causes. Mathematical modelling and electro-potential mapping techniques can also be used to reveal the extent of corrosion. A variety of methods can also be used to test for carbonation, most of which involve drilling holes into the concrete and carrying out chemical tests. Discussion of such investigative methods is beyond the scope of this bulletin.

9.0.3 Major repairs or even reconstruction may be required to restore the integrity of a building or structural elements. The extent, timing and staging of repairs may be dictated by structural requirements. A repair methodology will probably need to be considered within the parameters of a long-term asset maintenance programme and also other factors such as noise and dust.

9.0.4 Generally, patch repairs to severe damage caused by corrosion involve:

- breaking out concrete to expose reinforcing steel
- removing severely corroded lengths and replacing with new steel
- treatment and coating of exposed steel
- constructing boxing and placing new concrete or a specialist repair mortar.

9.0.5 Patch repairs to concrete can be problematic if the reinforcing steel passes from old, low-quality concrete through new, high-quality concrete, with the risk of corrosion by setting up an incipient anode. Electrochemical products can be used to control this incipient corrosion.

9.0.6 A huge range of specialised products are available in the area of concrete repair, including:

- (for small-volume repairs): rapid set high-strength mortars, lightweight high-build mortars and epoxy resin putties
- (for large-volume repairs): dry applied spray mortars, high-build structural cement mortars
- specific products for fixing honeycombing and blowholes and also for cracks in concrete – different mortars, sealants and epoxies are available for

repairs to either dry or wet cracks, and cracks with flowing water can be injected with various resins and gels.

9.0.7 Guarantees for partial repairs are likely to be difficult to obtain because of the possibility of ongoing risk of failure of unrepaired sections of the structure.

9.0.8 Surface-applied penetrating water-repellent agents or protective coatings (applied to new or existing concrete) can also be useful in preventative maintenance or repair. Repairs to concrete are almost always visually apparent, so in cases where visual impact is important, consideration might be given to some sort of decorative finish to match new and old sections of concrete.

10.0 REFERENCES

MINISTRY OF BUSINESS, INNOVATION AND EMPLOYMENT

Building Code clause B2 *Durability* and Acceptable Solution B2/AS1

STANDARDS NEW ZEALAND

NZS 3101:2006 Parts 1 & 2: *Concrete structures standard*

NZS 3104:2003 *Specification for concrete production*

NZS 3109:1997 *Concrete construction*

NZS 3121:1986 *Specification for water and aggregate for concrete*

NZS 3122:2009 *Specification for Portland and blended cements (General and special purpose)*

NZS 3604:2011 *Timber-framed buildings*

NZS 4229:2013 *Concrete masonry buildings not requiring specific engineering design*

STANDARDS AUSTRALIA

SAA/SNZ HB84:1996 *Guide to concrete repair and protection*

USEFUL WEBSITES

New Zealand Ready Mixed Concrete Association:
www.nzrmca.org.nz

Cement and Concrete Association of New Zealand:
www.ccanz.org.nz

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