Important message

This document is one of a set of standards developed solely and specifically for use on Transport Assets (as defined in the Asset Standards Authority Charter). It is not suitable for any other purpose.

The copyright and any other intellectual property in this document will at all times remain the property of the State of New South Wales (Transport for NSW).

You must not use or adapt this document or rely upon it in any way unless you are providing products or services to a NSW Government agency and that agency has expressly authorised you in writing to do so. If this document forms part of a contract with, or is a condition of approval by a NSW Government agency, use of the document is subject to the terms of the contract or approval. To be clear, the content of this document is not licensed under any Creative Commons Licence.

This document may contain third party material. The inclusion of third party material is for illustrative purposes only and does not represent an endorsement by NSW Government of any third party product or service.

If you use this document or rely upon it without authorisation under these terms, the State of New South Wales (including Transport for NSW) and its personnel does not accept any liability to you or any other person for any loss, damage, costs and expenses that you or anyone else may suffer or incur from your use and reliance on the content contained in this document. Users should exercise their own skill and care in the use of the document.

This document may not be current and is uncontrolled when printed or downloaded. Standards may be accessed from the Asset Standards Authority website at www.asa.transport.nsw.gov.au

© State of NSW through Transport for NSW 2017
Standard governance

Owner: Lead Civil Engineer, Asset Standards Authority
Authoriser: Chief Engineer, Asset Standards Authority
Approver: Executive Director, Asset Standards Authority on behalf of the ASA Configuration Control Board

Document history

<table>
<thead>
<tr>
<th>Version</th>
<th>Summary of changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>First issue</td>
</tr>
</tbody>
</table>
Preface

The Asset Standards Authority (ASA) is a key strategic branch of Transport for NSW (TfNSW). As the network design and standards authority for NSW Transport Assets, as specified in the ASA Charter, the ASA identifies, selects, develops, publishes, maintains and controls a suite of requirements documents on behalf of TfNSW, the asset owner.

The ASA deploys TfNSW requirements for asset and safety assurance by creating and managing TfNSW's governance models, documents and processes. To achieve this, the ASA focuses on four primary tasks:

- publishing and managing TfNSW's process and requirements documents including TfNSW plans, standards, manuals and guides
- deploying TfNSW's Authorised Engineering Organisation (AEO) framework
- continuously improving TfNSW’s Asset Management Framework
- collaborating with the Transport cluster and industry through open engagement

The AEO framework authorises engineering organisations to supply and provide asset related products and services to TfNSW. It works to assure the safety, quality and fitness for purpose of those products and services over the asset's whole-of-life. AEOs are expected to demonstrate how they have applied the requirements of ASA documents, including TfNSW plans, standards and guides, when delivering assets and related services for TfNSW.

Compliance with ASA requirements by itself is not sufficient to ensure satisfactory outcomes for NSW Transport Assets. The ASA expects that professional judgement be used by competent personnel when using ASA requirements to produce those outcomes.

About this document

T HR CI 12002 ST Durability Requirements for Civil Infrastructure sets out the requirements for durability for new railway civil infrastructure on the TfNSW Transport Network.

This standard was prepared by the ASA in consultation with TfNSW agencies.
Table of contents

1. Introduction.............................................................................................................................................. 6
2. Purpose .................................................................................................................................................... 6
   2.1. Scope..................................................................................................................................................... 6
   2.2. Application ............................................................................................................................................. 7
3. Reference documents ............................................................................................................................. 7
4. Terms and definitions ............................................................................................................................. 8
5. General ................................................................................................................................................... 10
6. Design life............................................................................................................................................... 10
7. Site investigation ................................................................................................................................... 12
   7.1. Early design phase investigations ....................................................................................................... 12
   7.2. Operational phase investigation .......................................................................................................... 13
8. Durability strategy and criticality ......................................................................................................... 14
9. Durability plan ........................................................................................................................................ 15
10. Specific durability actions for concrete .............................................................................................. 16
   10.1. Exposure conditions ........................................................................................................................ 16
   10.2. Construction considerations ............................................................................................................ 19
11. Specific durability actions for steel ..................................................................................................... 22
   11.1. Design detailing ............................................................................................................................... 23
   11.2. Corrosion allowance ........................................................................................................................ 24
   11.3. Cathodic protection .......................................................................................................................... 25
   11.4. Substitution with corrosion resistant materials ................................................................................ 25
   11.5. Selection of durability measures for steel structures ....................................................................... 25
12. Additional requirements ....................................................................................................................... 26
   12.1. Technical Maintenance Plan............................................................................................................ 27
Appendix A   Concrete degradation........................................................................................................ 28
   A.1. Alkali silica reaction ............................................................................................................................. 28
   A.2. Delayed ettringite formation.............................................................................................................. 28
   A.3. Early age thermal cracking................................................................................................................. 29
   A.4. Acid and soft water attack .................................................................................................................. 30
   A.5. Sulfate attack ....................................................................................................................................... 30
   A.6. Reinforcement corrosion ..................................................................................................................... 31
Appendix B   Maintenance class classification .......................................................................................... 33
1. Introduction

Access to carry out renewal or maintenance activities on the metropolitan rail network is currently severely limited and it is anticipated that access will be further reduced in the future as demands on the system increase. Restrictions on access significantly increase maintenance costs and reduce the effectiveness of maintenance activities.

It has been identified that the whole-of-life cost of civil infrastructure could be reduced if maintenance requirements are reduced by improving durability. To a large extent durability is determined by decisions made at the concept and detailed design stages.

The durability requirements in this standard supersede the requirements of AS 5100 Bridge design and other documents such as RMS QA Specification B80 Concrete Work for Bridges because of the longer service life and the limitations caused by the restricted access environment.

In addition to the requirements of this standard, asset decisions shall take into account the life cycle cost considerations specified in T MU AM 01001 ST Life Cycle Costing.

Clarification should be sought from the ASA if the intent of stated requirements is not clear.

2. Purpose

The purpose of the standard is to specify requirements to increase the durability and reduce maintenance of new railway civil infrastructure.

2.1. Scope

Civil infrastructure covered in this document includes the following:

- bridges and culverts
- tunnels and associated underground station structures
- retaining walls
- overhead wiring structures
- signal gantry structures
- structures supporting services
- drainage systems
- maintenance structures such as walkways and gantries
- other structures over the tracks such as station concourse supporting structures
- new elements being added to existing civil infrastructure
The following civil infrastructure is not covered in this document:

- existing civil infrastructure
- civil infrastructure that will not be owned by TfNSW

### 2.2. Application

The requirements of this standard apply to TfNSW; TfNSW agencies; and external third party organisations (where the third party organisation is involved with civil infrastructure that will be owned by TfNSW) involved with new designs of civil infrastructure within TfNSW heavy rail corridors. External third party organisations can include commercial organisations such as private developers, local government authorities and providers of electrical, water, sewerage and gas utilities.

### 3. Reference documents

The following documents are cited in the text. For dated references, only the cited edition applies. For undated references, the latest edition of the referenced document applies.

**International standards**

- ACI 305 Specification for Hot Weather Concreting
- ASTM D1004 Standard Test Method for Tear Resistance (Graves Tear) or Plastic Film and Sheeting
- EN 50162 Protection against corrosion by stray current from direct current systems
- ISO 9223 Corrosion of metals and alloys – Corrosivity of atmospheres – Classification, determination and estimation
- ISO 9224 Corrosion of metals and alloys – Corrosivity of atmospheres – Guiding values for the corrosivity categories
- ISO 13823 General principles on the design of structures for durability
- NACE SP0178 Design, Fabrication, and Surface Finish Practices for Tanks and Vessels to be Lined for Immersion Service

**Australian standards**

- AS 1726:2017 Geotechnical site investigations
- AS 2159 Piling – Design and installation
- AS 2239 Galvanic (sacrificial) anodes for cathodic protection
AS 3600 Concrete Structures
AS 4058 Precast Concrete Pipes (Pressure and Non-Pressure)
AS 4312 Atmospheric Corrosivity Zones in Australia
AS 4832 Cathodic Protection – Installation of Galvanic Sacrificial Anodes in Soil
AS 5100 Bridge Design – Set
AS 5100.5:2017 Bridge Design – Part 5: Concrete
AS/NZS 2312.1:2014 Guide to the Protection of Structural Steel Against Atmospheric Corrosion by the Use of Protective Coatings – Paint Coatings
AS/NZS 2832.5 Cathodic Protection of Metal – Part 5: Steel in Concrete Structures
SA HB 79 Alkali Aggregate Reaction – Guidelines on Minimising the Risk of Damage to Concrete Structures in Australia

**Transport for NSW standards**

MN A 00100 Civil and Track Technical Maintenance (extracted from formerly ESC 100)
T MU AM 01001 ST Life Cycle Costing
T MU AM 01002 MA Maintenance Requirements Analysis Manual
T MU AM 01003 ST Development of Technical Maintenance Plans
T HR EL 12002 GU Electrolysis from Stray DC Current
SPC 301 Structures Construction

**Other reference documents**

Roads and Maritime Services Bridge Technical Direction BTD2008/13 Provisions for Future Cathodic Protection of Reinforced Concrete Bridges
Roads and Maritime Services 2013 Guide for Preparation of a Durability Plan
Roads and Maritime Services QA Specification B80 Concrete Work for Bridges
Roads and Maritime Services QA Specification B280 Unreinforced Elastomeric Bearing Pads and Strips
Roads and Maritime Services QA Specification RMS specification R57 Design of Reinforced Soil Walls

### 4. Terms and definitions

The following terms and definitions apply in this document:

**AEO** Authorised Engineering Organisation
aggressivity a measure of the ability of the environment to attack concrete or other non-metallic materials

ASR alkali silica reaction

ASTM American Society for Testing and Materials

coating system the total number and types of paint coatings, or other protective or decorative materials, applied separately in a predetermined order to produce a laminated coating membrane

corrosivity a measure of the ability of the environment to cause corrosion of metals (AS 4312)

CP cathodic protection

design life the specified period of time for which a structure or a component is to be used for its intended purpose without major repair being necessary (ISO 13823).

Where a structure or component cannot be maintained, then the durability requirements for the nominated design life may be more stringent, or a lesser design life selected (with approval) and replacement required during the nominated design life.

DEF delayed ettringite formation

durability the capability of a structure or any component to satisfy, with planned maintenance (if applicable), the design performance requirements over a specified period of time under the influence of the environmental actions, or as a result of a self-ageing process (ISO 13832).

For assets either with no availability to program maintenance or for physically inaccessible assets or parts of assets, then the durability requirement will typically need to be increased beyond that required for a maintainable structure, to satisfy the specified design life.

failure the loss of the ability of a structure or a component of a structure to perform a specified function (ISO 13823)

HDPE high density polyethylene

maintenance the combination of all technical and associated administrative actions during the components service life with the aim of retaining it in a state in which it can perform its required functions (ISO 13823)

MLWS mean low water spring (that is, average spring low tide)

MSCL mild steel cement lined

NACE National Association of Corrosion Engineers

ppm parts per million
rail corridor the land between the boundary fences over which a railway line passes or, where there are no fences, the extent of land owned, leased, or otherwise used by the rail owner or leaseholder or state

service life the actual period during which a structure or any of its components satisfy the design performance requirements without unforeseen major repair (ISO 13823).

The service life of a structure should be greater than the design life.

sheltered partially enclosed area, treated as an outdoor system

TfNSW Transport for NSW

TMP technical maintenance plan

5. General

The relevant AEO is responsible for ensuring that the selected design, materials, construction and associated maintenance will achieve the durability objectives and requirements for each civil infrastructure asset and asset component. This shall be achieved in conjunction with the specified design life for that particular asset. Requirements defined in this standard may be in addition to, or at variance with, the requirements of AS 5100 and other documents such as RMS QA Specification B80. In such cases this document shall take precedence. Some of the ‘deemed to comply with requirements’ contained in AS 5100 and RMS QA Specification B80 that applies to maintainable assets with a service life of 100 years can be insufficient for civil infrastructure within the rail corridor.

6. Design life

The specified design life applies to asset items and sub-items.

The design lives noted in Table 1 have been nominated with reference to relevant standards and guiding documents. The design life will guide the minimum durability requirements for each asset item and sub-item.

For concrete structures, the onset of active corrosion of the steel reinforcing and prestressing tendons shall not have commenced within the specified design life. Active corrosion is defined as corrosion with an ongoing current density > 0.2 µA/cm².

When designing for fatigue, the effective number of stress cycles specified in the relevant standard shall be adjusted proportionally to reflect the design life specified in this standard, where appropriate.

For requirements relating to maintenance inputs, durability and design life refer to Section 8.
### Table 1 – Nominated design life

<table>
<thead>
<tr>
<th>Asset</th>
<th>Asset item/ sub-item</th>
<th>Typical material</th>
<th>Design life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridges*</td>
<td>Structural elements</td>
<td>Concrete</td>
<td>120</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Structural elements</td>
<td>Steel</td>
<td>120</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Bearings – replaceable elements</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Bearings – non-replaceable elements</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Deck expansion joints – Replaceable elements</td>
<td>Aluminium, galvanised steel, and stainless steel (grade 316)</td>
<td>40</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Deck expansion joints – elements cast in concrete</td>
<td>Galvanised steel, stainless steel</td>
<td>120</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Joint rubber</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Traffic barriers</td>
<td>Concrete</td>
<td>120</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Traffic barriers</td>
<td>Steel</td>
<td>60</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Safety screens, protection screens, access walkways, refuges, pedestrian balustrading, handrails</td>
<td>Steel</td>
<td>60</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Drainage systems – replaceable elements</td>
<td>Non-metallic (plastic)</td>
<td>40</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Drainage systems – non replaceable items</td>
<td>MSCL, cast iron, HDPE, stainless steel or concrete</td>
<td>120</td>
</tr>
<tr>
<td>Bridges (overbridges and footbridges)</td>
<td>Deck wearing surface</td>
<td>Asphalitic concrete</td>
<td>20</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Walkway precast panels</td>
<td>Concrete</td>
<td>120</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Waterproof membrane</td>
<td>Non-metallic</td>
<td>40</td>
</tr>
<tr>
<td>Bridges*</td>
<td>Pier protection structures</td>
<td>Concrete</td>
<td>120</td>
</tr>
<tr>
<td>Noise walls</td>
<td>Structural panels</td>
<td>Concrete</td>
<td>50</td>
</tr>
<tr>
<td>Noise walls</td>
<td>Supporting structural elements</td>
<td>Steel</td>
<td>50</td>
</tr>
<tr>
<td>Noise walls</td>
<td>Footings for supporting structural elements</td>
<td>Concrete</td>
<td>50</td>
</tr>
<tr>
<td>Rail and pedestrian tunnels</td>
<td>Tunnel lining and structural elements</td>
<td>Concrete or steel</td>
<td>120</td>
</tr>
<tr>
<td>Rail and pedestrian tunnels</td>
<td>Access walkways, balustrading, handrails</td>
<td>Steel</td>
<td>60</td>
</tr>
<tr>
<td>Rail and pedestrian tunnels</td>
<td>Drainage systems</td>
<td>Non-metallic</td>
<td>120</td>
</tr>
<tr>
<td>Asset</td>
<td>Asset item/ sub-item</td>
<td>Typical material</td>
<td>Design life (years)</td>
</tr>
<tr>
<td>-------</td>
<td>----------------------</td>
<td>-------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Track slabs</td>
<td>Slabs</td>
<td>Concrete</td>
<td>120</td>
</tr>
<tr>
<td>OHW structures/signal gantries</td>
<td>Steel structure</td>
<td>Steel</td>
<td>100</td>
</tr>
<tr>
<td>OHW structures/signal gantries</td>
<td>Footings</td>
<td>Concrete</td>
<td>120</td>
</tr>
<tr>
<td>Lighting and communication poles/towers</td>
<td>Structural elements</td>
<td>Concrete</td>
<td>50</td>
</tr>
<tr>
<td>Lighting and communication poles/towers</td>
<td>Structural elements</td>
<td>Steel</td>
<td>50</td>
</tr>
<tr>
<td>Rail corridor retaining walls</td>
<td>Structure</td>
<td>Concrete or steel</td>
<td>120</td>
</tr>
<tr>
<td>Rail corridor retaining walls</td>
<td>Drainage system</td>
<td>Non-metallic</td>
<td>120</td>
</tr>
<tr>
<td>Station platforms walls</td>
<td>Structure</td>
<td>Concrete or steel</td>
<td>120</td>
</tr>
<tr>
<td>Air space developments</td>
<td>Supporting structure over tracks</td>
<td>Concrete or steel</td>
<td>120</td>
</tr>
<tr>
<td>Drainage systems</td>
<td>Buried elements</td>
<td>Concrete or steel or plastics</td>
<td>120</td>
</tr>
<tr>
<td>Inspection gantries</td>
<td>Structure</td>
<td>Steel</td>
<td>60</td>
</tr>
<tr>
<td>Rock fall structures</td>
<td>Structure</td>
<td>Steel or concrete</td>
<td>120</td>
</tr>
<tr>
<td>Rock and soil anchors and soil nails</td>
<td>Structure</td>
<td>Steel</td>
<td>120</td>
</tr>
<tr>
<td>Crash beam installations</td>
<td>Crash beams, replaceable fittings and bearings</td>
<td>All</td>
<td>60</td>
</tr>
<tr>
<td>Crash beam installations</td>
<td>Supporting structural elements (non-replaceable)</td>
<td>Concrete or steel</td>
<td>120</td>
</tr>
</tbody>
</table>

* Bridges includes underbridges, overbridges, footbridges and culverts

## 7. Site investigation

### 7.1. Early design phase investigations

Project durability investigations are required in the early design phase and they are also recommended in the operational phase of the asset.

Early design phase investigations shall be undertaken to classify the corrosivity and aggressivity of the exposure conditions to enable the minimum durability requirements to be determined for an asset and sub-asset items.
For buried asset and sub-asset items a geotechnical site investigation shall be undertaken in accordance with AS 1726 *Geotechnical site investigations*. The typical information that shall be collected and used for durability purposes includes:

- Soil testing – Field identification of soil components (AS 1726:2017 Clause 6.1), soil pH, soluble chloride ion content, soluble sulfate ion content and resistivity shall be undertaken.

  If acid sulfate soil (that is, naturally occurring soils containing pyrites, or chemical precursors of pyrite, which oxidise when exposed to air (oxygen) resulting in the development of acidity in the soil) is suspected, SPOCAS testing (sulfur units), including titratable actual acidity, $pH_{KCl}$, net acidity and $pH_{Ox}$ and organic matter content shall be undertaken.

  If conditions conducive for microbiologically influenced corrosion are expected, that is, sulfate reducing bacteria content (a type of bacteria that can cause microbiologically influenced corrosion where suitable conditions exist including adequate water, sulphate and nutrients).

- Groundwater testing – pH, magnesium ion content, chloride ion, sulfate ion, calcium ion content, total alkalinity (expressed as mg CaCO$_3$/L) and ground water level.

For atmospherically exposed assets the likely exposure to micro climates shall be assessed. The following information shall be included in the assessment:

- predominant wind and weather direction
- topography
- design features that can affect exposure to aggressive airborne elements, cause collection of moisture or debris and minimise beneficial effects of rain washing or restrict ventilation

### 7.2. Operational phase investigation

During the period in which the asset is operational and exposed to the environment, it is recommended to ascertain that the durability measures designed into the assets are adequately resisting the exposure conditions.

Requirements for operational phase investigation shall be included in the technical maintenance plan (TMP) for the asset. The operational phase maintenance investigation of durability shall be determined when the TMP is initially developed.

Embedded or surface mounted probes can be used to monitor an indication of rates of ingress of chloride or a carbonation front in concrete, reduction in thickness or deterioration of coatings, and so on. For permanently embedded probes, this information could be accessed remotely and used to confirm durability assumptions.
Where it is not practicable to install probes, companion specimens or coupons should be placed in a secure location adjacent to the actual structure. These specimens can be removed for testing to determine the rate of deterioration. Both probes and companion specimens can provide a more accurate assessment of likely service life and verification of any durability modelling.

Where neither probes nor companion specimens are practicable, visual inspections are required for noting the following:

- cracking or spalling of concrete or early corrosion of steel reinforcement in concrete structures
- signs of early coating breakdown and subsequent corrosion
- performance of construction phase repairs and project durability nonconformance issues

If the rate of deterioration is suspected to be faster than had been predicted in the durability plan, some physical testing may be utilised to verify the rate of deterioration.

The frequency of inspections and testing should be based on the likelihood of deterioration and the consequence of early failure and unplanned maintenance as determined from the maintenance requirements analysis in accordance with T MU AM 01002 MA Maintenance Requirements Analysis Manual. Inspection programmes should initially focus on assets with high durability risk and, where possible, coincide with planned maintenance. Information relating to the determination of durability risk for the rail assets is presented in Section 8.

### 8. Durability strategy and criticality

The durability strategy for a new design should address criticality and risk.

Accessibility for inspection and maintenance is a key concern in the rail environment. Some areas of an asset may be in locations where maintenance is restricted while other areas of the same asset may be readily accessible for inspection and maintenance. Items that cannot be readily inspected, for example, buried elements should have more stringent durability requirements. The durability approach can be considered differently for different assets or elements of an asset. The effect of increased durability requirements on the balance between capital expenditure and operational expenditure will need to be considered in parallel with the maintainability of each specific asset and sub-asset and the nominated design life as part of a life cycle cost analysis.

Structures that cannot be readily maintained or areas of the structure with maintenance access restrictions include the following:

- buried elements
- parts of the structure within the rail corridor that cannot be maintained without a track possession
areas of the structure where maintenance works could be a safety risk to public and staff

The consequences of failure should take into account whether an asset is available for maintenance and whether maintenance, either planned or unplanned, has an impact on the operability of the rail asset. A number of assets, in particular rail bridges, are frequently not available for maintenance as these assets are critical to the operation of the rail network. Such assets would have a significantly higher durability risk than an asset that can be readily maintained without affecting continued operation of the rail asset.

For assets which have restricted access to carry out maintenance works, only minor maintenance will be able to be carried out within the design life of the assets. For the purposes of determining durability requirements of these assets, it shall be assumed that maintenance will be limited to periodic examinations, cleaning and flushing as well as replacement of sub-items that have specifically been designed to be replaced.

Appendix B provides information relating to maintenance class descriptions and risk and exposure matrices that may be used to determine maintenance class classifications to assist assessment of durability requirements.

All assets and asset sub-items covered by this standard, however, shall be designed to be effectively maintenance free with the exception of maintenance as defined above (that is, Maintenance Class 5), unless approved otherwise by the Lead Civil Engineer, ASA.

If it is considered that the assumption of Maintenance Class 5 is too onerous for a particular project, the assessed maintenance class can be used to support a request for approval of a lesser maintenance classification.

Refer to Appendix B for information maintenance class descriptions and risk and exposure matrices that may be used to determine maintenance class classifications.

9. **Durability plan**

The AEO shall prepare a durability plan for all civil infrastructure projects with an estimated construction cost greater than $2 million or where the project is such that its early failure due to inadequate durability would have disproportionate operational or cost implications.

The durability plan shall address the minimum requirements of this standard including design life and specific factors related to durability stated in Section 10, Section 11 and Section 12. The durability plan shall demonstrate a durability performance equivalent to or better than that achieved by conforming to these sections of this standard.

The durability plan shall be prepared in accordance with the requirements of RMS publication *Guide for Preparation of a Durability Plan*.

The results of the durability plan shall be included as tasks within the relevant TMP service schedule and applied at the appropriate frequency and stage of the asset lifecycle.
For projects with an estimated construction cost less than $2 million and where early failure due to inadequate durability would not have disproportionate operational or cost implications, a durability plan can be prepared or the following shall be applied:

- Minimum requirements of this standard including design life requirements and Section 10, Section 11 and Section 12 shall be applied.

- Where the cover requirements are not established by a durability plan, the cover requirements for prestressed or reinforced concrete elements shall conform to the requirements of AS 5100.5:2017 Table 4.14.3.2, excluding spun or rolled members. Spun or rolled members complying with AS 4058 *Precast Concrete Pipes (Pressure and Non-Pressure)* may require a suitable coating or integral system to ensure that the required 120 year design life is achieved.

10. **Specific durability actions for concrete**

The specific durability actions for concrete asset items will depend on the environmental exposure category (macro and micro climate) and the design life. While concrete elements shall be designed to achieve the required design life with a low risk of unplanned maintenance, the ability to maintain the structure would change the approach to detailing such as joints where sealants may require replacement. The specific durability measures taken to achieve the required durability will include a combination of the following:

- penetrability performance requirement such as carbonation coefficient, chloride diffusion or migration coefficient
- composition of cementitious binder system
- cover to reinforcement
- cathodic protection (only for atmospheric or immersed sub-asset items)
- avoidance of deterioration/maintenance prone detailing
- substitution with corrosion resistant reinforcement

Concrete durability shall be addressed in the durability plan specific to the proposed works as outlined in Section 9 and shall address the specific durability concerns stated in this section.

Information on concrete deterioration mechanisms is given in Appendix A.

10.1. **Exposure conditions**

The various types of exposure that affect concrete are described in Section 10.1.1 through to Section 10.1.5.
10.1.1. Atmospheric exposure

For reinforced concrete assets situated in a B1 atmospheric environment according to AS 5100.5:2017 (near coastal – 1 km to 50 km from coastline), carbonation of the concrete leading to corrosion of the reinforcement would be the primary durability consideration. Detailed carbonation modelling can be considered for different cover and concrete requirements.

*Note: As a guide for maintenance class 5, assets with a design life of 120 years and 40 MPa concrete a minimum cover of 50 mm would be expected to prevent carbonation to the depth of the reinforcement within the design life.*

Where practicable, embedded corrosion detection probes or companion specimens should be installed within or adjacent to major assets, in a sheltered location that is representative of the highest expected rate of carbonation to confirm the service life prediction modelling.

10.1.2. Maritime exposure

Surfaces of concrete structures permanently submerged in sea water or brackish water (chloride > 6000 ppm) or, in above ground coastal environments (< 1 km from the coastline) are considered to be in B2 exposure according to AS 5100.5:2017. Surfaces of concrete structures in the spray or tidal and splash zones are considered C1 or C2 exposure classification respectively. As the spray zone can be at least as aggressive to reinforced concrete as the tidal zone, the spray, tidal and splash zones require the same performance and replacement level as shown in Table 2 (adapted from RMS QA Specification B80).

**Table 2 – Minimum durability requirements for concrete with maritime exposure**

<table>
<thead>
<tr>
<th>Exposure Classification</th>
<th>Maximum chloride test coefficients at 20°C - NT Build 443 (D_e) (x10^-12 m^2/s)</th>
<th>Maximum chloride test coefficients at 20°C - NT Build 492 (DRMC) (x10^-12 m^2/s)</th>
<th>Minimum strength for durability F_c.min(d) (MPa)</th>
<th>Actions required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submerged (B2)</td>
<td>3.5</td>
<td>8.0</td>
<td>40</td>
<td>Use blended cement with minimum 25% FA or 50% BFS</td>
</tr>
<tr>
<td>Tidal/splash/spray (C1 and C2)</td>
<td>2.0</td>
<td>4.0</td>
<td>50</td>
<td>Use blended cement with minimum 30% FA or 65% BFS</td>
</tr>
</tbody>
</table>

Legend for Table 2:

**FA** – Fly Ash

**BFS** – Ground granulated iron blast furnace slag confirming to Specification RMS 3211

**D_e** – denotes effective diffusion coefficient from Nordtest NT Build 443
The minimum cover requirements for reinforced concrete elements shall be in accordance with AS 5100.5:2017 Table 4.14.3.2 unless the durability plan determines an alternate cover. Reductions in cover thickness due to rigid formwork and intense compaction can be considered based on reinforcement fixing tolerance. No reduction in cover shall be considered for steam cured elements without testing of the cover zone of prototype elements to confirm improved performance.

Because of the risk of early chloride penetration in the tidal and splash zone, concrete for civil infrastructure assets in maritime exposure shall be placed within precast concrete forms which are part of the final structure or cured by retaining the formwork for the required curing period in AS 5100.5:2017. During the curing the top surface of cast in situ concrete shall be ponded with fresh water that shall be replaced in the event of overtopping by waves.

10.1.3. Massive sections

To mitigate the concerns relating to delayed ettringite formation (DEF) and reduce the risk of external restraint cracking, the concrete temperature for both precast and in situ elements shall not exceed 70°C.

The temperature differential across the cross section of the concrete member shall not exceed 28°C.

10.1.4. Acid or soft water

Acid or soft water exposure is classified as 'U' exposure classification in AS 5100.5 and shall be considered on a case by case basis in the durability report. Paste loss from concrete exposed to running water in culverts is generally limited to 10 mm in depth, even after prolonged exposure. B2 concrete complying with Table 2 with an additional 10 mm sacrificial cover over the AS 5100.5:2017 Table 4.14.3.2 requirements is recommended for elements exposed to potential leaching from flowing water such as culverts.

10.1.5. Sulfate attack

According to AS 2159 Piling – Design and installation, exposure of concrete structures to a groundwater sulfate concentration of up to 1000 ppm in low permeability soil is considered to be non-aggressive. According to AS 5100.5:2017 the exposure classification depends on the sulfate concentration and the presence of magnesium ions (greater or less than 1 g/L in the groundwater). In this Standard sulfate greater than 1000 ppm in high permeability soils is considered aggressive and a 'U' exposure classification and should be considered on a case by case basis in the durability plan or, where the project cost is less than $2m, after receiving specialist advice.
10.2. Construction considerations

The durability requirements that need to be considered during construction and planned for at the design stage are discussed in Section 10.2.1 through to Section 10.2.8.

10.2.1. Reinforcement fixing

Cover measurements should be made prior to concrete placement and again after placing to ensure there has been no movement during placement and compaction. Post placement reinforcement cover measurements should be made on initial pours to demonstrate that the construction method is achieving the desired cover. Spacers used to achieve cover shall have at least the same durability performance rating as the parent concrete.

Project documentation shall include for testing of concrete cover to reinforcing.

Note that no cover reduction is allowed for concrete that has been exposed to accelerated curing without testing of the concrete cover zone of prototype elements to confirm required performance has been achieved.

10.2.2. Concrete placement

Poor concrete workability can lead to honeycombing, segregation, slower construction and uncontrolled water addition. The contractor and concrete supplier shall confirm to the AEO that the rheology of the concrete is satisfactory for the proposed placement procedure and the mix developed complies with the specified performance parameters.

10.2.3. Early concrete protection

When the evaporation rate exceeds approximately 0.75 kg/m²/hr, the risk of plastic shrinkage cracking is high. The use of wind breaks, sun shades and/or an evaporation retarder to reduce the evaporation of bleed water is recommended for all flatwork (decks and slabs) and also for the top surface of large pile caps and headstocks. Aliphatic alcohol shall be sprayed to reduce the evaporation of bleed water. In the event of using very low bleed concrete mixes, a lower evaporation rate may require measures to limit plastic cracking. The evaporation rate can be calculated using the nomograph in ACI 305 Specification for Hot Weather Concreting (Figure B1).

10.2.4. Curing

The AEO shall develop a realistic curing methodology including testing of the in situ concrete cover to ensure that the required performance is achieved. The following shall be considered in the development of the curing methodology:

- 'continuous moist curing' in reality may be significantly inferior to retention of the formwork or the application of a curing membrane
• steam curing to 60% to 70% of characteristic strength may result in significantly lower durability than comparable concrete not exposed to accelerated curing and cured for 3 days to 7 days

10.2.5. Joints

Construction joints can frequently be a plane of weakness because of the following:

• Concrete at the interface being more porous than bulk concrete due to 'bleed' increasing the water/cement ratio or because of inadequate compaction (reinforcement congestion being a major contributor).

• Poor preparation of the joint in the cover zone. Preparation is typically better between the inner and outer rebar layers as operators tend to avoid getting too close to the edge of the concrete because of the possibility of spalling.

• Failure of the water stops.

Construction joints shall be prepared in such a manner that there is a strong bond between the new and old concrete surfaces. Where the joint is likely to be exposed to a hydrostatic head and potential leakage, a double hydrophilic seal or regrouting tube type or equivalent watertight detail shall be installed into the joint. Where practicable, construction joints exposed to hydrostatic pressure should be located outside the rail danger zone to enable access for repair of leakage if required.

In locations, such at the junction between piled and un piled sections or where thermal or shrinkage movement of concrete is expected a full movement joint may be required. Where practicable, the concrete elements should be designed such that movement joints are located outside the rail danger zone to enable access to replace sealants and other replaceable items.

10.2.6. Concrete crack control and crack limits

Appropriate mix design, curing and construction practices are required in the design and construction phases to limit shrinkage and other types of cracking of precast and cast in situ concrete. Reinforcement shall be provided for drying and thermal shrinkage effects to minimise cracking. The use of hot weather concreting practices during summer and control of concrete temperature is important for the durability of the final structure. Thermal cracking can be controlled by limiting the section thickness, by appropriately detailing with adequate reinforcement (in accordance with relevant design standards), by the replacement of Portland cement with supplementary cementitious materials such as fly ash or blast furnace slag, or by other means, such as chilling the mix. Insulating the section is rarely an appropriate option as external rather than internal restraint cracking is the more common.
For concrete members with thickness greater than 1000 mm, thermal shrinkage modelling is required to determine specific precautions necessary to mitigate the risk of thermal cracking. These measures include the following:

- limit the quantity of cementitious material
- replacement of Portland cement with supplementary cementitious materials such as fly ash or blast furnace slag
- use of water ponding for curing to provide nominal insulation, curing and facilitate heat loss
- controlling the temperature of the concrete prior to placement
- scheduling pour times to minimise excessive heat generation and temperature differentials during hydration

For durability purposes, a crack limit of 0.3 mm is acceptable for most structures. Lower values of 0.2 mm or 0.1 mm are specified for water retaining structures to facilitate autogenous healing (self-healing) to help seal the cracks. The durability plan should consider potential salt accumulation at the internal surface of water retaining elements around cracks and other defects.

10.2.7. Cathodic protection

To limit the consequences of failure, provision shall be made to ensure continuity of the reinforcing steel to facilitate the installation of cathodic protection (CP) systems in the future, if required. Provisions for future CP protection of concrete bridges shall be made in accordance with RMS Bridge Technical Direction BTD 2008/13 *Provisions for Future Cathodic Protection of Reinforced Concrete Bridges*, including the following:

- Positive electrical continuity of the steel reinforcement in each element by ensuring each reinforcing bar is connected to the reinforcement grid by appropriate continuity testing in accordance with AS/NZS 2832.5 *Cathodic Protection of Metals, Part 5: Steel in Concrete Structures*.
- Electrical connection points between each element of the structure that can be used for CP installation, if required in the future.
- Provision of corrosion monitoring points in high risk structures to assess the ongoing corrosion state and the efficiency of CP if installed in the future.

10.2.8. Stainless steel reinforcement

Stainless steel reinforcement shall be provided within the tidal/ splash zone for bridges and structures over creeks and rivers that have tidal flow. Where such structures have exposure to a spray zone with high chloride contamination, stainless steel reinforcement shall also be provided.
Where provided, stainless steel reinforcement shall extend above and below the tidal/splash zone for a distance that is appropriate for the lap splicing of the stainless steel reinforcement with the carbon steel, except that, for a pile cap where the soffit of the pile cap is no higher than 0.5 m below MLWS and where the edge distance to the pile is at least 200 mm and the top of the pile reinforcement extends no closer than 250 mm from the top of the pile cap, carbon steel pile reinforcement may be anchored directly into the pile cap.

For the purposes of this section, the general tidal zone is the zone between the following:

- the level which is 0.5 m below the MLWS
- the level which is 0.5 m above the mean high water spring (that is, average spring high tide)

The grade of stainless shall be Grade 316 unless demonstrated in the durability plan that a higher or lower grade would be appropriate to meet the design life.

The splash zone shall be assessed for each bridge and structure based on the site conditions.

Carbon steel reinforcement (that is, non stainless steel reinforcement) shall not be used in the tidal/splash zone of bridges and structures except for the piles as described above.

11. Specific durability actions for steel

The specific durability actions for steel asset items will depend on the design life, the maintainability or maintenance class of the structure and the environmental exposure category. However specific durability measures shall include a combination of the following durability measures:

- avoidance of corrosion prone detailing
- substitution with corrosion resistant materials
- protective coating
- corrosion allowance
- cathodic protection (only for immersed or buried sub-asset items)

As the maintenance class Table 3, Appendix B increases, the minimum durability requirement will escalate as less maintenance or intervention to correct defective durability becomes possible. Additionally, the likelihood of corrosion, early failure due to corrosion and inadequate durability increase with the corrosivity of the exposure environment (Table 5, Appendix B).

For maintenance class 5 assets with a design life of 120 years situated in a class C3 atmospheric environment the durability measures are likely to be a combination of protective coatings, corrosion allowance and avoidance of corrosion prone detailing.
Maintainable steel structures shall be designed to enable all protective coatings to be readily maintained. However, whether a coated steel structure is or is not maintainable, the detailing shall be designed to prevent early breakdown of the protective coatings as outlined in Section 11.1.

A typical decision making flowchart for selection of durability measures is presented in Section 11.5.

Protective coatings shall comply with Transport for NSW engineering specification SPC 301 Structures Construction.

11.1. Design detailing

Since the performance of protective coating systems is usually compromised in the first instance by undesirable design features and lack of attention to detail during fabrication finishing, design detailing is critical and shall be addressed at the design and planning phase.

Even the best coating system will not achieve its full service life potential if design features present constructability (access for preparation and application) risks or if they create severe micro climates. The same features tend to also present maintainability risks further into the life of these structures.

The following details are prone to corrosion and shall be avoided:

- galvanic coupling of dissimilar metals (failure to isolate dissimilar metals)
- non-free draining sections
- intermittent welding
- inadequate fabrication finishing (for example, sharp edges and corners, weld splatter, rough welds)
- narrow crevices between adjacent sections

Regardless of exposure conditions of the selected corrosion protection system, design detailing to eliminate or reduce corrosion prone design features shall follow the recommendations of Section 3 of AS/NZS 2312.1:2014 Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings - Paint coatings and appendix A of NACE SP0178 Design, Fabrication, and Surface Finish Practices for Tanks and Vessels to be Lined for Immersion Service.

The second aim of design detailing to optimise coating performance is to facilitate sufficient access to all members for welding, weld dressing and finishing, abrasive blast cleaning and coating application by brush and spray. A minimum clearance of 300 mm around all components shall be incorporated in the design to allow for adequate access for welding, grinding, surface preparation and coating application. For example, universal beams used to
support a bridge deck shall be designed with a minimum of 300 mm gap between adjacent beam flanges.

Wherever feasible, the design shall be based on the use of sealed hollow members rather than universal beams, universal columns, parallel flange channels or angle and eliminate or minimise the number of bolted connections. As early breakdown of protective coating commonly occurs along the edges of beams or around bolted connections, the minimisation of components with edges or bolted connections will assist in the optimisation of the performance of the protective coating system.

11.1.1. Maintainability of structures

The corrosion protection system selection process should involve consideration of whether the protection system applied or installed to the structure can be maintained without unduly compromising transport operations, the safety of maintenance workers, the travelling public, TfNSW staff and the public in general. The following issues shall be contemplated to determine if a structure is to be considered maintainable or not:

- type of access (including shrouding and other environmental controls) that would be required to conduct maintenance to the structure
- environmental impact
- safety of the operators and the travelling public
- impact on the ability to provide the transport service

Access for maintainability of the asset shall be confirmed with the relevant TfNSW asset manager during the concept design stage of the asset.

11.2. Corrosion allowance

It shall be assumed that there will be no protective coating applied within the specified design life other than the initial protective coating. Additional steel thickness shall be provided to allow for any resulting section loss to ensure that the structure design capacity is maintained over the design life.

Weathering steel may be considered subject to maintenance and urban design considerations. Corrosion allowance in excess of structural allowance shall be based on the following:

- atmospheric corrosion rates presented in ISO 9223 Corrosion of metals and alloys—Corrosivity of atmospheres – Classification, determination and estimation and ISO 9224 Corrosion of metals and alloys—Corrosivity of atmospheres – Guiding values for the corrosivity categories
- buried or immersed corrosion rates presented in AS 2159
The corrosion allowance shall be recorded on the project drawings and in the TMP.

11.3. **Cathodic protection**

Cathodic protection (CP) is an appropriate durability action for steel structures that are buried in soil, or immersed in natural waters. In tidal situations CP can be used to provide durability to steel assets nominally up to the mid tide level. Where CP is undertaken it shall comply with the requirements of AS/NZS 2832.5, AS 2239 *Galvanic (sacrificial) anodes for cathodic protection* and AS 4832 *Cathodic Protection – Installation of galvanic sacrificial anodes in soil* as relevant. CP can be in form of sacrificial anodes or impressed current cathodic protection. The most suitable and cost effective type to use will depend on each situation.

11.4. **Substitution with corrosion resistant materials**

Where the durability of carbon steel may be inadequate for the design life, the use of alternative materials including stainless steel, anodised aluminium, weathering steel or fibre reinforced plastics subject to product approval, where applicable, should be considered.

Typical examples of situations where durability efficiencies may be gained are as follows:

- use of anodised aluminium or stainless steel for handrails and balustrades that are traditionally galvanised or painted
- fibre reinforced plastic, anodised aluminium or stainless steel deck grating where galvanised grating is traditionally used
- use of stainless steel fasteners (including high tensile fasteners, grade 8.8 and grade 10.9)
- use of weathering steel beams where painted steel beams have been traditionally used but are difficult to maintain

11.5. **Selection of durability measures for steel structures**

The selection of durability measures for steel structures can be undertaken using a simple decision making flowchart as presented in Figure 1 in conjunction with life cycle cost considerations.
12. Additional requirements

The following additional requirements apply:

- The potential effects of climate change shall be considered when assessing durability requirements.

- The cover sheet of the project drawings shall reference the durability plan and associated TMP (Refer to Section 9).

- The likelihood of accidental damage from the general maintenance activities that take place in the rail corridor and also damage by vandalism shall be taken into account when determining structural details.

- Fracture critical components should be avoided. Where incorporated in a structure, fracture critical components shall be clearly identified in the design documentation and associated TMP.

- Design shall consider access for maintenance activities including provision of walkways, and maintenance gantries.

- Structures shall be designed to enable items such as bearings (except elastomeric strip bearings conforming to RMS QA Specification B280 Unreinforced Elastomeric Bearing Pads and Strips), expansion joint seals, railings and drains to be easily maintained and readily replaced.
Where an item is not readily accessible for maintenance or replacement, it shall be designed so that it will function for the specified life of the structure without maintenance or replacement.

Design documentation and associated TMP shall specify which elements of the structure are intended to be replaceable and shall provide a detailed methodology for the replacement process. Replaceable elements should only be incorporated where replacement can occur with minimal or no interruption to rail operations and without significant interruption to road operations.

All dowels and embedded fitments shall be stainless steel grade 304L (UNS S30403) or 316L (UNS S31603). Higher strength stainless steels may be selected provided that corrosion resistance is adequate.

Protection shall be provided against stray electrical currents (refer to T HR EL 12002 GU Electrolysis from Stray DC Current and EN 50162 Protection against corrosion by stray current from direct current systems).

The durability of soil reinforcement associated with reinforced soil structures shall meet or exceed the requirements of RMS QA specification R57 Design of Reinforced Soil Walls.

Reinforced soil structures shall incorporate removable test straps. Design documentation shall specify the location of the test straps and shall define the test strap removal process. The TMP shall include detailed procedures for assessment of the straps and description of maintenance actions relevant to assessed condition states.

To prevent stormwater infiltration of the reinforced soil block, reinforced soil structures shall incorporate an impermeable HDPE membrane layer. The membrane shall be placed at the top of the reinforced soil block and shall be arranged to drain water away from the reinforced soil block. The membrane shall be 2 mm thick textured HDPE with minimum tear resistance ≥ 330 N/m (ASTM D1004) and minimum puncture resistance ≥ 660 N/m (ASTM D4833). The membrane shall have protective layers of geotextile (RN380 Geo composite or equivalent) above and below.

12.1. Technical Maintenance Plan

Maintenance requirements shall be specified in the form of a technical maintenance plan in the design documentation of the structure. The requirements shall include examination tasks and frequencies, damage limits and repair standards. In many cases, MN A 00100 Civil and Track Technical Maintenance will apply. However, it may be necessary to document site specific maintenance and durability requirements.

The requirements and high level processes for the development of technical maintenance plans are detailed in T MU AM 01003 ST Development of Technical Maintenance Plans.
Appendix A  Concrete degradation

A.1. Alkali silica reaction

Alkali silica reaction (ASR) is a chemical process in which alkalis, present in cement, and combine with certain compounds in the aggregate in the presence of water. This reaction produces an alkali-silica gel that can absorb water and expand to cause cracking and disruption of the concrete. For ASR related deterioration to occur in hardened concrete, it is necessary to have the occurrence of the following three situations:

- a proportion of reactive silica or silicate in the aggregate
- a sufficiently high alkali concentration in the pore solution
- sufficient moisture in the concrete

Where allowed to occur, ASR attack will result in the progressive development of cracking. Cracks may accelerate other forms of deterioration such as chloride or carbonation induced corrosion of reinforcement.

In order for ASR to occur, there shall be sufficient alkali in the concrete and reactive silica in the aggregate together with moisture to cause the expansion. The approach to mitigate ASR risk is to eliminate one or more of the factors. This is achieved by limiting the alkali content in the concrete mix to 2.5 kg/m³ (as recommended in SA HB 79 Alkali Aggregate Reaction – Guidelines on Minimising the Risk of Damage to Concrete Structures in Australia) and the use of non-reactive aggregate as demonstrated by laboratory tests. The inclusion of fly ash, slag, or silica fume in the mix has been found to control the occurrence of ASR.

A.2. Delayed ettringite formation

Ettringite is a complex calcium sulfoaluminate hydrate that normally forms as an early hydration product in Portland cement based concrete pastes. Delayed ettringite formation (DEF) refers to late-stage formation of ettringite and related phases formed after setting and hardening of the cement paste. Formation of ettringite is accompanied by the development of high pressures, which exceed the tensile strength of the concrete and may cause cracking. DEF is mainly associated with precast concrete manufacture by accelerated steam curing but also occurs in concrete with cures above 70°C with heat of hydration.

To mitigate the concerns relating to DEF, an effective way is to limit the peak concrete temperature and limit access to liquid water. It is generally well established that DEF is unlikely to occur if the concrete temperature is kept below 70°C. Particular risk exists for precast concrete elements due to the more rapid heating and cooling, resulting in more micro cracking. Therefore, it is required to limit concrete temperature of 70°C for both precast and in situ elements.
The prudent management of the risk of DEF to heat accelerated (steam) cured precast elements can be achieved by one of the following options:

i. restriction of the peak concrete temperature during cure to less than 70°C

ii. specification of performance criteria for the cement and concrete if the peak concrete temperature during cure is > 70°C but < 85°C

Heat accelerated curing of precast concrete elements above 70°C has been found by international researchers to significantly increase the risk of the subsequent development of DEF-related deterioration. There is anecdotal evidence of DEF-related deterioration in Australia but the level of deterioration has been minor or interrelated with deterioration associated with ASR.

The risk of DEF related deterioration for concrete cured above 70°C could be controlled by the following procedures:

- The use of fly ash or slag blended cements. This has the counter effect of delaying strength gain which is counterproductive to the purpose of steam curing.
- Application of stringent controls on the steaming cycle.
- The use of cement with specific chemical compositions.

A.3. Early age thermal cracking

The hydration of cementitious materials is an exothermic reaction and in larger sections can result in a significant temperature rise. Early age thermal cracking is the result of either differential expansion within the concrete element during heating caused by internal restraint or by external restraint to contraction of an element on cooling from a temperature peak. Early age thermal cracking occurs within a few days in thinner sections, or a week or so in thicker sections which cool more slowly.

Once cracks have developed due to thermal stresses they are likely to continue to widen as the concrete element experiences drying shrinkage.

For infrastructure projects where reinforcement corrosion is not likely to cause concrete deterioration a crack width of 0.3 mm is acceptable. Moreover, crack widths of 0.3 mm are recognised as being the limit for aesthetic reasons.

The design method to achieve concrete cracking within acceptable limits involves:

- calculating crack widths
- adjusting the reinforcement or the concrete mix temperature to bring the calculated crack widths to within the defined limits

The current approach in assessing concrete cracking is to calculate and report crack widths as characteristic values at a 95% confidence level. This means that conformance will be based on
a limit that not more than 5% of the measured cracks exceed the defined value. For any concrete element where concrete cracking is likely to be a concern it will be necessary to identify each crack over the length of the poured structure and measure the widths of each crack at around 500 mm intervals, along the cracks. Individual cracks exceeding the defined limits should be repaired when considered detrimental to the life of the structure.

A.4. Acid and soft water attack

Acids in general are considered to be problematical for concrete when the pH falls below 6.5 for prolonged periods. The reduction of pH due to consumption of calcium hydroxide destabilises the calcium aluminate hydrates and the calcium silicate hydrates in the cement paste, resulting in breakdown of these cementing minerals.

Ultimately the integrity of the concrete is reduced as the surface concrete gradually erodes with time. Factors that influence the rate of acid attack of concrete include:

- concentration and type of acid
- mobility of the acid contaminated water
- penetrability, cement type and content, water/cement ratio of the concrete
- aggregate type

The flow rate of ground water affects durability since mobile groundwater will remove the products of reaction and replenish the acid attack site with additional aggressive media. Specific flow rates are not quoted in the literature and standards, although standards such as AS 2159 differentiate the aggressiveness of groundwater according to 'high' permeability and 'low permeability' soils.

Contact with soft water causes leaching of calcium hydroxide and decalcification of hydration products similar to acid attack.

A.5. Sulfate attack

Sulfates that may be present in groundwater and soil can react with constituents of cement paste to cause expansion and deterioration. The reaction depends on the form of sulfate. Sodium sulfate reacts with calcium hydroxide to form gypsum and with calcium aluminate hydrate to form ettringite. The formation of ettringite involves an expansive reaction which can eventually causes micro cracking and disintegration of the concrete. Calcium sulfate also reacts with calcium aluminate hydrate. Magnesium sulfate reacts with calcium silicate hydrates in addition to calcium aluminate hydrate and calcium hydroxide. Thus, magnesium sulfate is considered highly aggressive towards concrete since it potentially causes destruction of calcium silicate hydrate phases in cement which are responsible for strength, in addition to other deleterious reactions. According to Cohen and Mather (1991), the deterioration mechanism for
magnesium depends on the concentration. Below 4,800 ppm MgSO₄ the attack is dominated by formation of ettringite.

The extent of damage due to sulfates will depend on the type and concentration of sulfate, amount of calcium aluminate hydrate in the cement, presence of supplementary cementing materials, and concrete quality. In addition, the presence of chlorides can be influential since chloride ions also react with calcium aluminate hydrate to form chloroaluminate compounds. This reaction reduces the amount of calcium aluminate hydrate available for reaction with sulfate ions.

The following measures are generally used to reduce the risk of sulfate attack in the concrete structures:

- use of concrete with reduced water/cementitious material ratio
- use of blended cement containing supplementary cementitious materials such as fly ash, slag or silica fume

**A.6. Reinforcement corrosion**

Corrosion of reinforcement in concrete structures is discussed in Section A.6.1 and Section A.6.2.

**A.6.1 Carbonation induced corrosion**

Carbonation of the concrete will occur gradually over the service life of structures exposed to the atmosphere. Pore water in uncarbonated concrete has a pH value around 12.6 to 13.5 and this provides a passive environment for embedded reinforcement. Carbon dioxide in the atmosphere or dissolved in water can react with the calcium hydroxide in the concrete’s cement matrix. When concrete becomes carbonated the pH is reduced to approximately 8.3. A carbonation front of reduced pH progresses from the surface throughout the depth of the cover concrete.

The passive alkaline film, which protects reinforcement from corrosion in concrete structures, is only maintained at high pH levels. If the concrete becomes carbonated to the depth of reinforcement, this passive iron film is no longer stable and corrosion can occur, provided there is sufficient water and oxygen present.

The rate of carbonation of concrete is related to a combination of factors. These include CO₂ concentration, moisture content of the concrete and diffusivity of the hardened cement paste. The diffusivity in turn depends on mix design (cementitious content, presence and proportion of supplementary cementing materials, water/cementitious material ratio), extent of curing, pore size and pore distribution within the concrete, and connectivity of pores. The presence of cracks permits local ingress of CO₂ and can result in carbonation and subsequent corrosion ahead of the main carbonation front in sound concrete.
Depassivation and subsequent corrosion of steel reinforcement due to carbonation tends to have a very long propagation period and is therefore not generally a problem unless there is shallow cover and a source of moisture. Carbonation is a potential durability issue for reinforced concrete elements, particularly the precast facing panels. Appropriate quality of the specified concrete and design cover should help prevent carbonation to the depth of reinforcement within the design life.

A.6.2 Chloride induced corrosion

Chloride ingress into concrete is the main corrosion risk for the reinforcing steel in structures exposed to chloride environments. Generally, reinforcement embedded in concrete is protected by a passive film. If a sufficient concentration of chlorides at the depth of the reinforcement occurs, this passive film will be disrupted and corrosion will be initiated. This is termed the initiation phase. Corrosion can then proceed in the subsequent propagation phase provided sufficient water and oxygen are available to sustain the corrosion reactions. As the corrosion products occupy significantly greater volume than the original steel, this causes development of tensile stresses within the concrete that will ultimately result in cracking and spalling.

The time to corrosion initiation will depend on surface concentration of chlorides in the service environment, pore water pH, depth of cover, chloride diffusion properties of the concrete, and chloride binding characteristics of the cement or any supplementary cementing materials. Once initiated, the rate of corrosion will be controlled primarily by the moisture and oxygen permeability and concrete resistivity characteristics. The moisture and oxygen availability to support corrosion processes will then depend on the environment (particularly wetting and drying cycles), concrete transport properties, and presence and characteristics of any cracks. The time to failure, as manifested by spalling and cracking of the cover concrete, will depend on the mechanical and fracture properties of the concrete.

The incorporation of supplementary cementitious materials such as fly ash or slag would help by increasing the chloride resistance of the concrete.
Appendix B  Maintenance class classification

As the maintainability of rail civil assets has a direct bearing on the minimum durability requirement for each asset item to achieve the design life, the concept of maintenance class has been introduced to assist with this durability assessment process. The maintenance classes are nominated in Table 3.

Classification of the maintenance class of the asset in accordance with this document can be undertaken to determine the asset item and asset sub-item specific requirements.

Table 3 – Maintenance classification of rail assets

<table>
<thead>
<tr>
<th>Maintenance class</th>
<th>Description</th>
<th>Possible example of asset/sub-asset</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Replaceable items</td>
<td>Wearing surface, accessible drainage systems</td>
</tr>
<tr>
<td>2</td>
<td>Maintainable asset (i.e. asset located in area that does not require an extensive track possession for maintenance)</td>
<td>Traffic barriers, pedestrian balustrading, safety screens</td>
</tr>
<tr>
<td>3</td>
<td>Important to operations but asset can be maintained with appropriate planning</td>
<td>Lighting and communication towers, bridge bearings, deck joints, pier protection structures, culverts</td>
</tr>
<tr>
<td>4</td>
<td>Very important to operations – maintenance planned at 50% of design life</td>
<td>Station platform structure, signal gantries, OHW structures</td>
</tr>
<tr>
<td>5</td>
<td>Critical to operations and not maintainable</td>
<td>Overbridges, underbridges, retaining walls, track slabs, tunnels</td>
</tr>
</tbody>
</table>

The maintenance class feeds into the durability risk matrix presented in Table 4.

Table 4 – Durability risk associated with maintenance class and unplanned maintenance

<table>
<thead>
<tr>
<th>Maintenance class</th>
<th>Consequence of inadequate durability and unplanned maintenance</th>
<th>Likelihood of deterioration resulting in inadequate durability and unplanned maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rare</td>
<td>Unlikely</td>
</tr>
<tr>
<td>1</td>
<td>Negligible</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>Minor (e.g. minor maintenance)</td>
<td>Low</td>
</tr>
<tr>
<td>3</td>
<td>Moderate (e.g. partial shutdown for maintenance)</td>
<td>Low</td>
</tr>
</tbody>
</table>
Likelihood of deterioration resulting in inadequate durability and unplanned maintenance

<table>
<thead>
<tr>
<th>Maintenance class</th>
<th>Consequence of inadequate durability and unplanned maintenance</th>
<th>Rare</th>
<th>Unlikely</th>
<th>Possible</th>
<th>Likely</th>
<th>Very likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Severe (e.g. short term total shut down for maintenance)</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>5</td>
<td>Very severe (e.g. long term total shutdown)</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

The likelihood of corrosion, early failure due to corrosion and inadequate durability increases with the corrosivity and aggressivity of the exposure environment. The likelihood of deterioration is based on environmental exposure and is presented in Table 5.

Table 5 – Likelihood of deterioration due to interaction with the exposure conditions without effective precautions

<table>
<thead>
<tr>
<th>Exposure Condition</th>
<th>Probability of deterioration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete (AS 5100.5)</td>
<td>Rare</td>
</tr>
<tr>
<td>A</td>
<td>B1</td>
</tr>
<tr>
<td>Concrete – buried in soil or immersed in natural water (AS 2159)</td>
<td>Non-aggressive</td>
</tr>
<tr>
<td>Concrete (AS 3600)</td>
<td>A1/A2</td>
</tr>
<tr>
<td>Steel – atmospherically exposed (AS 4312, ISO 9223 and ISO 9224)</td>
<td>C1</td>
</tr>
<tr>
<td>Steel – buried in soil or immersed in natural water (AS 2159)</td>
<td>Non-aggressive</td>
</tr>
</tbody>
</table>

Note: Corrosiveness and aggressiveness of exposure increases the likelihood of deterioration from rare through to very likely.