WATER CORPORATION ABN 28 003 434 917	***Inspection Guidelines for the Condition Assessment of Concrete Structures***

Doc ID 11963553	**Custodian** Principal Engineer, In Service Assets, Asset Planning Group
Version Date 18 January 2018	**Accountabilities Framework** Level 1 - Manage Infrastructure Assets Level 2 - Plan and Investigate Asset Renewals
Next Review Date 18 January 2021	

Concrete Structures Condition Assessment Guidelines

(Business Rules)

18 January 2018

Revision - 2

WATER CORPORATION

ater Corporation

ABN 28 003 434 917

629 Newcastle Street, Leederville WA 6007

PO Box 100, Leederville WA 6902

Telephone: (08) 9420 2420

www.watercorporation.com.au

Document Status

Rev	Prepared by	Reviewed by	Approved by	Date
1.0	Venkat Coimbatore	Mafizul Islam Sam Lee Mohan Des McEwen	Janet Ham	24 November 2014
2.0	Venkat Coimbatore	Zororai Choto	Tino Galati	18 January 2018

FOREWORD

Inspection guidelines are prepared to ensure that the Corporation's staff, consultants and contractors are informed as to the Corporation's requirement on the methodical approach to asset condition assessment.

Inspection guidelines are intended to promote uniformity so as to simplify the condition assessment methodologies and reporting practice. Corporation's ultimate objective of this Guideline is to ensure the provision of safe and functional plant and equipment at minimum whole of life cost.

In 2014, Water Corporation, Western Australia developed the inspection guideline for steel structures (other than the pipelines) in water and wastewater infrastructures operating areas in Western Australia where the Water Corporation has been licensed to provide water services subject to the terms and conditions of its Operating License.

Using the concrete structures methodology and its framework various levels of inspections were carried out in a methodical manner using cutting-edge technologies [Refer: AquaDoc. No. 11573252].

During this time, comments suggestions and criticisms were given to In-Service Assets by the Metro, Regional Operations and also by the internal and external Inspection Service Provider's (ISP's). They were captured in the internal document [Refer: AquaDoc. No. 11986633] reviewed and incorporated in this revision.

The Corporation's inspection methods and assessments described in this guideline have evolved over a number of years as a result of design and field experience. Research publications by engineering associations, construction agencies, consultants, inspection equipment manufacturers and suppliers are gratefully acknowledged and referenced in this document.

Deviation, on a particular method, from this inspection guideline may be permitted in special circumstances, but only after endorsement by the Materials and Corrosion Specialist in the Corporation's Asset Planning Group. Users are invited to forward recommendations for continuous improvement to the Supervising Engineer or Manager, Asset Planning Group, Water Corporation who will consider these for incorporation into future revisions.

This document contains colour pictorials. For optimum resolution colour printing is recommended.

Tino Galati
Section Manager
In-Service Assets - Metro

DISCLAIMER

This Guideline is intended solely for inspection of water and waste water infrastructure in operating areas in Western Australia where the Water Corporation has been licensed to provide water services subject to the terms and conditions of its Operating License.

This Guideline is provided for use only by a suitably qualified professional inspector, engineer or technician who shall apply the skill, knowledge and experience necessary to understand the risks involved and undertake all infrastructure condition assessment work.

Any interpretation of anything in this Guideline that deviates from the requirements specified in the project design drawings and construction specifications shall be resolved by reference to and determination by the design engineer.

The Corporation accepts no liability for any loss or damage that arises from anything in the Guideline, including loss or damage that may arise due to the errors and omissions of any person.

This document is prepared without the assumption of a duty of care by the Water Corporation. The document is not intended to be nor should it be relied on as a substitute for professional engineering design expertise or any other professional advice.

Users should use and reference the current version of this document.

TABLE OF CONTENTS

AMENDMENT REGISTER

Section	Version/Revision	Date	Description of Amendment	Authoriser
All	1.0/0	14.08.14	New Version/Revision	SM
All	1.0/0	05.09.14	Updated Stakeholder comment	SM
All	2.0	15.01.18	Incorporated and revised the lessons learnt	TG

BASIC UNIT CONVERSIONS

Pressure		
1 Psi	=	6.9 KPa
1 Atmosphere	=	101.3 KPa
1 KPa	=	0.145 Psi
1 MPa	=	145 Psi
1 Meter Head	=	9.8 KPa

Linear		
1 mm	=	1000 microns
1 Thou (mil)	=	25.4 microns

Volume		
1 m^3	=	1000 litres
1000 m^3	=	1 Mega Litre

GLOSSARY OF TERMS

AAR	Alkali-Aggregate Reaction - Reaction between the aggregates and the alkaline cement paste, leading to the development of expansive crystalline gel which is sufficiently strong to cause cracking of the aggregate and of the concrete matrix. Also called Alkali Silica Reaction, (ASR).
Anode	The positive pole of an electric circuit. In a cathodic protection system, a sacrificial material introduced to act as the site of corrosion to inhibit corrosion of the structure itself.
Binder	The materials that comprise the cementing agents in concrete, mortars and renders. Cement is mixed with water and added to aggregates to make concrete.
Carbonation	Loss of alkalinity in the concrete as a result of calcium hydroxide depletion (brought about by the presence of atmospheric carbon dioxide, which with moisture forms carbonic acid).
Cathode	The negative pole of an electric circuit. In a cathodic protection system, the metal protected against corrosion due to the presence of a sacrificial anode.
Cathodic protection	Technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell. A simple method of protection connects protected metal to a more easily corroded “sacrificial metal” to act as the anode. The sacrificial metal then corrodes instead of the protected metal.
Concrete	Composite material composed mainly of water, aggregate, and cement. Additives and reinforcements included to achieve the desired physical properties of the finished material. When these ingredients are mixed together, they form a fluid mass that is easily molded into shape. Over time, the cement forms a hard matrix which binds the rest of the ingredients together into a durable stone-like material with many uses.
Cement	A cement is a binder, a substance that sets and hardens and can bind other materials together. Cements used in construction can be characterized as being either hydraulic or non-hydraulic, depending upon the ability of the cement to be used in the

	presence of water.
Chlorides	As these occur in calcium chloride (used as a cement-setting accelerator in the past) and sodium chloride (in sea-water, wind-blown sea spray), they combine with water to form an aggressive agent leading to accelerated corrosion of reinforcement.
Corrosion	'Rusting' or formation of iron oxides and other compounds by electrolytic action when steel is exposed to water and oxygen. Aggravated by other aggressive agents such as acids or chlorides.
Cover	The concrete between the reinforcement and the adjacent face of the element. It provides protection of the steel from corrosion. The required thickness of cover and the quality of concrete mix used are influenced by the severity of exposure, and must be correctly chosen to ensure durability.
Creep	The long-term shortening or deflection of the concrete as the strain increases under sustained stress, which usually has to be allowed for in the structural design of the reinforced concrete.
Dampness	Presence of unwanted moisture in the structure, either the result of intrusion from outside or condensation from within the structure.
Delamination	Separation of layers of concrete from the main body of the material.
Delayed Ettringite Formation	DEF is believed to be a result of improper heat curing of the concrete where the normal Ettringite formation is suppressed. The sulphate concentration in the pore liquid is high for an unusually long period of time in the hardened concrete. Eventually, the sulphate reacts with calcium and aluminium containing phases of the cement paste and the cement paste expands. Due to this expansion empty cracks (gaps) are formed around aggregates. The cracks may remain empty or later be partly or even completely filled with Ettringite.
Efflorescence	A white deposit on the surface of the concrete arises when the water that results from excessive permeation of water through the concrete evaporates and leaves calcium carbonate deposited on the surface.

Ettringite	Ettringite is an expansive compound, is bigger in volume (is of smaller density) than it's forming chemicals (calcium aluminate and sulphate taken together). Whenever it forms, it tends to cause tensile stresses within the concrete (or mortar) because it will tend to occupy a bigger volume than the volume occupied by its forming reactants.
Filler	The aggregates which mixed with the binder and water result in concrete. Typically categorized as coarse aggregate (crushed stone, gravel, etc.) and fine aggregate (commonly sand).
Galvanic action	Occurs when two dissimilar metals are placed together in solution. The most active metal will become an anode and corrode as a current passes between them.
In-situ concrete	Concrete cast in its intended location.
Latent damage	Non-visible damage that is impairing, or will impair the functionality of the structure and will eventually require some form of remedial action.
Langelier Saturation index	The Langelier Saturation Index (LSI) is an equilibrium model derived from the theoretical concept of saturation and provides an indicator of the degree of saturation of water with respect to calcium carbonate. If calcium carbonate deposits, then the Langelier Index is positive and the water will be passive or protective of any grade of concrete.
Mass concrete	A term generally synonymous with unreinforced concrete.
Passivation	The process by which steel in concrete is protected from corrosion by the formation of a passive layer due to the highly alkaline environment created by the pore water.
Patent damage	Visible damage in reinforced concrete decay. Damage can include cracking, spalling etc.
pH	Logarithmic scale for expressing the acidity or alkalinity of a solution based on the concentration of hydrogen ions. Concrete has a pH of 12 to13. Steel corrodes at pH 10 to 11.

Pore (water)	Concrete contains microscopic pores. These contain alkaline oxides and hydroxides of sodium, potassium and calcium. Water will move in and out of the concrete saturating, part filling and drying out the pores according to the external environments. The alkaline pore water sustains the passive layer if not attacked by carbonation or chlorides.
Post-tensioned concrete	Prestressed concrete made by casting-in conduits or sheaths for prestressing steel that is tensioned and secured by anchorages once the concrete has cured.
Portland cement	Basic ingredient of Portland Cement (PC) is: concrete, mortar, stucco, and most non-specialty grout. It is a fine powder produced by heating materials in a kiln to form what is called clinker. Grinding the clinker, and adding small amounts of other materials. Typical constituents of Portland cement are: Calcium oxide, CaO 61-67%; Silicon dioxide, SiO_2 19-23% ; Aluminum oxide, Al_2O_3 2.5-6% ; Ferric oxide, Fe_2O_3 0-6% and Sulphate 1.5-4.5%
Precast concrete	Reinforced concrete cast in moulds as units or elements elsewhere than their final intended location, before being placed into position.
Pre-stressed concrete	Pre-stressed concrete made by tensioning the prestressing steel before the concrete is poured. The prestressing steel may take the form of rods, wires, cables, or bars. Prestressing increases the strength of the element and can eliminate cracking in service.
Pre-tensioned concrete	Pre-tensioning generally employs straight runs of steel, although sometimes it is profiled, following the pattern of the bending moment to give a more efficient use of the material.
Reinforced concrete	Concrete reinforced with metal rods, straps, wires or mesh that provides a composite material strong in tension and compression.
Repair action	Taken to reinstate to an acceptable level the current functionality of a structure or its components that are either defective/degraded or damaged in some way.
Rust	Occupies a larger volume than the original iron, and consequently

	can cause cracking and spalling in the surrounding concrete.
Shrinkage	Contraction of the cement paste as it hardens, due to loss of moisture and changes to the paste's internal structure. Some shrinkage is non-reversible due to these changes, while reversible shrinkage occurs as the concrete becomes wet in service and then dries again.
Spalling	Detachment of surface concrete, usually due to reinforcement corrosion that put the concrete locally into tension, resulting in cracking and then spalling.
Stucco or render	Material made of an aggregate, a binder, and water. Stucco is applied wet and hardens to a very dense solid. It is used as decorative coating for walls and ceilings and as a sculptural and artistic material in architecture.

ACRONYMS

ACA	Asset Condition Assessment
ACR	Alkali Carbonate Reaction
APG	Asset Planning Group
ARA	Asset Risk Assessment
ASR	Alkali Silica Reaction
AS/NZS	Australian Standards
ASTM	American Society for Testing Materials
BS	British Standard
CA	Condition Assessment
CRA	Corrosion Risk Assessment
CRSL	Concrete Remaining Service Life
CP	Cathodic Protection
DEF	Delayed Ettringite Formation
E2ERP	End-to-End New Process Architecture Renewal Planning
IIMM	International Infrastructure Management Manual
IPWEA	Institute of Public Works Engineering Australia
ISP	Inspection Service Provider
MESB	Mechanical and Electrical Services Branch
MFL	Magnetic Flux Leakage
MSDS	Material Safety Data Sheet
NACE	National Association of Corrosion Engineers
NATA	National Association of Testing Authorities
NDI	Non-Destructive Inspection
OC	Operations Centre

OH & S	Occupational Health and Safety
RPA	Remotely Piloted Aircrafts (formerly known as Unmanned Aerial Vehicles (UAV's)
RC	Reinforced Concrete
RWT	Remaining Wall Thickness
SAP	Systems Analysis Program
SCORE	Sewer Corrosion & Odour Research
SCUBA	Self-Contained Underwater Breathing Apparatus
SEM	Scanning Electron Microscope
SHRP	Strategic Highway Research Program
SIBC	Strategic Investment Business Case
SOP	Standard Operating Procedure
SSBA	Surface Supply Breathing Apparatus
SSPC	Steel Structures Painting Council
TWI	The Welding Institute
UT	Ultrasonic Thickness (Testing)
WBS	Work Breakdown Structure

REFERENCES

[1] Code of practice Concrete and masonry cutting and drilling 2010, https://www.commerce.wa.gov.au/sites/default/files/atoms/files/code_of_practice_concrete_masonry_cutting.pdf

[2] http://en.wikipedia.org/wiki/Hydrogen_sulfide.

[3] Asset Class/Other doc Asset Management Branch, Aqua Doc No. 7691780.

[4] Concrete Structures Condition Assessment Methodology, Renewals Branch, Asset Management Branch, Aqua Doc No. 11573252.

[5] Steel Structures Condition Assessment Guideline, Asset Management Branch, Aqua Doc No. 11051170.

[6] Concrete Structures Remaining Service Life (CRSL) Tool Version 1.0, AquaDoc No. 11654487, Asset Management Branch.

[7] Concrete and Steel Structures Inspection Services Providers List (ISP's), Asset Management Branch, Aqua Doc No. 11380256.

[8] CSWIP 3.1U - NDT Inspection Diver, http://www.twitraining.com/home/course-schedule/cswip-3.1u-ndt-inspection-diver?country=UK

[9] The Australasian Corrosion Association Inc. http://www.corrosion.com.au/

[10] Concrete Structures - Level 1 Inspection Database, Aqua Doc No. 11795743.

[11] Condition Assessment & Asset Performance Guidelines, Practice No.7, Water Supply & Sewerage, IPEWA, Australia, 2007.

[12] Concrete Structures - Level 2 Inspection Database, Aqua Doc No. 11795696.

[13] Concrete Structures - Level 3 Inspection Database, Aqua Doc No. 11833402.

[14] Concrete Reinforcement Corrosion, http:// www.fibertex.com.

[15] Rebar Corrosion, Duromac Deutschland GMBH, Ziegelhütte 22, D-74196 Neuenstadt a.K. http://www.duromac-cp.de/en-korrosion.htm

[16] Rebar Corrosion, Taywood Engineering, Article by: Main Roads, Western Australia, Doc. No. 6706-02-2241.

[17] Detailed Non-Destructive Bridge Inspection Guidelines, Concrete and Steel Bridges (Level 3 Inspections), Doc. No. 6706-02-2241, Main Roads, Western Australia, 2012. Email Correspondence: Refer Aqua Doc 11790225, Dated: 27-10-2014.

[18] Kropp, J. and Hilsdorf, H.K. Performance criteria for concrete durability, Rilem report 12, E & FN Spon, London, 1995.

[19] Andrews-Phaedonos, F. Establishing the Durability Performance of Structural Concrete, VicRoads, Melbourne, Australia, January 2010.

[20] http://pavemaintenance.wikispaces.com/Carbonation+of+Concrete+-+Dahee.

[21] Grant T. Halvorsen, Troubleshooting concrete cracking during construction, Publication #C930700, The Aberdeen Group, http://www.concreteconstruction.net

[22] Report on Aging of Nuclear Power Plant Reinforced Concrete Structures, D. J. Naus et. al, The Johns Hopkins University, 1996.

[23] Concrete Cover meter, http://en.wikipedia.org/wiki/Cover_meter.

[24] Control of Pipeline Corrosion, A.W. Peabody, NACE Corrosion Association, Houston, Texas, USA.

[25] Corrosion of Steel in Concrete, Causes, Detection and Prediction, State of the Art Review, G. Song and, Report No.4, A. Shayan, http://www.arrb.com.au/admin/file/content13/c6/RevRpt%204%20Corrosion%20of %20steel.pdf

[26] F. Papworth and R. Barnes, Establishing Time to Corrosion and Corrosion Rate of Reinforcement to Give Life Assessments, ACA Annual Conference, 2007.

[27] Factors involved in the Long Term Corrosion of Concrete Sewers, Robert E Melchers et.al, The University of Newcastle, Australia, ACA Corrosion, 2009.

[28] Clifton, J.R. Predicting the Service Life of Concrete, ACI Materials Journal, V. 90, No.6, Dec, 1993, pp. 611-617.

[29] Broomfield, J.P. Corrosion of Steel in Concrete: Understanding, investigation and repair, E & FN SPON, London, 1997.

[30] Neville, A.M. (1995) Properties of Concrete, 4th Edition, S & T Press, page 506. ISBN 0582230705.

[31] Bamforth, P.B. and Pocock, D.C. Design for durability of reinforced concrete exposed to chlorides, Workshop of structures with Service Life of 100 years-or more, Bahrain, 2000.

[32] Building Research Maintenance, Digest (BRE), 434, 444 – Parts 1 and 2. http:www.bre.co.uk.

[33] Crank J: The mathematics of diffusion. 2nd edition, Clarendon, Oxford, 1975.

[34] Probabilistic failure modelling of reinforced concrete structures subjected to chloride penetration, Caio G. Nogueira, et al, International Journal of Advanced Structural Engineering 2012.

[35] Enhancing reinforced concrete durability: Guidance on selecting measures for minimising the risk of corrosion of reinforcement in concrete, Concrete Society Technical Report No. 61, 2004.

[36] Browne R.D. Design prediction of the life of reinforced concrete in marine and other chloride environments, Durability of Building Materials, Vol. 3, Elsevier Scientific, Amsterdam, 1982.

[37] Prediction of Time-variant Probability of Failure for Concrete Sewer Pipes, Kong Fah Tee et al, School of Engineering, University of Greenwich, United Kingdom, Durability of Building Materials and Components, Portugal, 2011.

[38] T. Wells, Identification of controlling factors for the corrosion rate of concrete, ARC Corrosion & Linkage Project, SP1B, www.score.ogr.au.

[39] Concrete Structures Condition Assessment Report Template, Aqua Doc. No. 11649813.

ENGINEERING STANDARDS & DESIGN DOCUMENTS

ASTM Standards

ASTM G16 Standard Guides for Applying Statistics to Analysis of Corrosion Data.

ASTM C42/C42M Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.

ASTM G46 Standard Guide for Examination and Evaluation of Pitting Corrosion.

ASTM G57 Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four Electrode Method.

ASTM C227 Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations.

ASTM E247 Standard Test Method for Determination of Silica in Manganese Ores, Iron Ores, and Related Materials by Gravimetry.

ASTM C295 Standard Guide for Petrographic Examination of Aggregates for concrete.

ASTM E488 Standard Test Methods for Strength of Anchors in Concrete Elements.

ASTM C597 Standard Test Method for Pulse velocity through concrete.

ASTM C642 Standard Test Method for density, absorption, and voids in hardened concrete.

ASTM C805 Standard Test Method for Rebound Number of Hardened Concrete.

ASTM C856 Standard Practice for Petrographic Examination of Hardened Concrete.

ASTM C876 Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete.

ASTM C900 Standard Test Method for Pull-out Strength of Hardened Concrete

ASTM C1202 Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.

ASTM C1383 Standard Test Method for Measuring the P-Wave Speed and the thickness of concrete plates using the Impact-Echo Method.

ASTM C1543 Standard Test Method for Determining the Penetration of Chloride Ion into Concrete by Ponding.

ASTM D4580 Standard Practice for Measuring Delamination's in Concrete Bridge Decks by Sounding.

ASTM D6432 Standard Guide for using the surface ground penetrating radar method for subsurface investigation.

Australian Standards

AS/NZS 1012.9 Determination of the compressive strength of concrete specimens.

AS/NZS 1012.10 Methods of testing concrete - Determination of indirect tensile strength of concrete cylinders.

AS/NZS 1012.14 Method for securing and testing cores from hardened concrete for compressive strength.

AS/NZS 1012.20-1992 Determination of chloride and sulphate content in hardened concrete and concrete aggregates.

AS/NZS 1012.21 Determination of water absorption and apparent volume of permeable voids in hardened concrete.

AS/NZS 1379 Specification and supply of concrete.

AS/NZS 1816.1 Metallic materials - Brinell hardness test - Test method (ISO 6506-1:2005, MOD).

AS/NZS 2062 Non-destructive testing – Penetrant testing of products and components.

AS/NZS 2159 Piling – Design and installation

AS/NZS 2239 Galvanic (Sacrificial) anodes for cathodic protection.

AS/NZS 2832 CP standards AS 2832, Parts 1-3.

AS/NZS 2870 Residential slabs and footings – Construction.

AS/NZS 3600 Concrete structures (Revised Draft (DR) 05252).

AS/NZS 3978 Non-destructive testing – Visual inspection of metal products and components.

AS/NZS 3725 Design for installation of buried concrete pipes.

AS/NZS 3735 Concrete structures retaining liquids.

AS/NZS 4020 Testing of products for use in contact with drinking water.

AS/NZS 4058 Precast concrete pipes (pressure and non-pressure).

AS/NZS 4671 Steel reinforcing materials.

AS/NZS 4676 Structural design requirement for utility service poles.

AS/NZS 4678 Earth-retaining structures (DR 02355 CP).

AS/NZS 5100.3 Bridge design – Foundations and soil-supporting structures.

AS/NZS 5100.5 Bridge design – Concrete.

British Standards

BS EN 1992 Design of concrete structures.

BS EN 206-1 Concrete – Part 1: Specification performance, production and conformity.

BS 8500 Concrete – Complementary British Standard to BS EN 206-1.

BS EN 14630 Products and systems for the protection and repair of concrete structures. Test methods. Determination of carbonation depth in hardened concrete by the phenolphthalein method.

BS 1881 Part 124 Methods for Testing Concrete Part 124: methods for Analysis of Hardened Concrete.

BS 1881 Part 204 Testing concrete. Recommendations on the use of electromagnetic Covermeter.

BS EN 444 Non-destructive testing. General principles for radiographic examination of metallic materials by X- and gamma-rays.

BS EN 571 -1 Non-destructive testing. Penetrant testing. General principle.

BS EN 1435 Non-destructive examination of welds. Radiographic examination of welded joints.

BS 8110 Structural use of concrete - Code of practice for design and construction.

NACE Standards

NACE RP01-73 Collection and Identification of Corrosion Products, Materials Protection and Performance, Volume 12, June 1973, p. 65.

Design Standards

DS 61 Water Corporation Design Standard DS 61, Water Supply Distribution - Tanks.

Miscellaneous

S151 Water Corporation's Prevention of Falls Standard - Worksafe WA Code of Practice - Prevention of Fall at Workplaces.

OPERATIONAL SAFETY

[I] Concrete Sample Handling During Breakout

During concrete drilling operation, inspection personnel face a wide range of health hazards caused by silica dust and toxic exhaust fumes. For safe handling and practices of concrete sampling, references shall be made to code of practice in the handling of concrete and masonry equipment issued by Department of Commerce, Government of Western Australia [1].

[II] Ladders

Due to operational reasons, Steel, Stainless Steel and FRP ladders in the ground level and elevated tanks, reservoirs, chemical dosing, waste water treatment plants etc. are not assessed regularly and hence the condition cannot be ascertained.

The condition of the ladder may be in poor condition and the inspector shall follow Water Corporation S151 Prevention of Falls standard [Refer: Aqua Doc 580792] prior to the inspection of the tanks.

[III] Roofs

Due to corrosive environment resulting from chlorine dosing in the potable water tanks, or H_2S in sewage retention structures there may be severe corrosion on the roof structural members. Inspection Service Provider (ISP) shall not walk over the roof without consulting Operational Asset Managers (OAM).

[IV] Chemicals

For safe handling of toxic chemicals such as Hydrogen Sulphide, Chlorine, Hydro Fluorosilicic acid etc. references shall be made to documents and websites suggested by Department of Health (DOH), Western Australia [2].

Any hazards when identified, the ISP's should alert Site Supervisor and a site safe entered in the OSH branch Sentinel program, http://sentinel/Cintellate/jsf/main.jsp

1.0 PURPOSE & SCOPE

The purpose of this document is to establish the guidelines for the Condition Assessment (CA) of concrete structures in both potable water and wastewater environment in the Water Corporation **[Refer: Photos 1-12]**.

The guideline will assist the Inspection Service Providers (ISP's)/Region/Alliance/OAM to conduct objective, consistent and reproducible asset condition ratings and Remaining Service Life (RSL)] [3].

The condition assessment in this document is based on the relevant AS/NZS, ASTM, BS, NACE standards, Standard Operating Procedures (SOP's), Water Corporation design standards and in-house concrete structures inspection experience.

The guideline clarifies the qualification(s), responsibilities, accountabilities, inspection data capturing techniques, interpretation and reporting format for ISP's.

The guideline will also aid the ISP's to prepare and deliver the inspection findings to an appropriate format so that Asset Planning Group (APG) can verify the RSL of the asset and subsequently prioritise the asset renewal based on the informed Asset Risk Assessment (ARA) and Concrete Structures Remaining Service Life (CRSL) Tool.

In accordance with the Water Corporation Design Standard DS 61, the design life of concrete asset is minimum 100 years. If the design life differs, then subsequent management strategy will be developed to achieve the intended service life by APG.

For concrete structures condition assessment methodology, references shall be made to Aqua Doc. 11573252 [4].

For steel structural elements condition assessment guideline, references shall be made to Aqua Doc. 11051170 [5].

Photo 1 - Ground Level concrete potable water tank.

Photo 2 - Elevated concrete potable water tank.

Photo 3 - Pump Station.

Photo 4 - Groundwater Treatment Gallery.

Photo 5 - Water Reservoir.

Photo 6 - Dam Spillway.

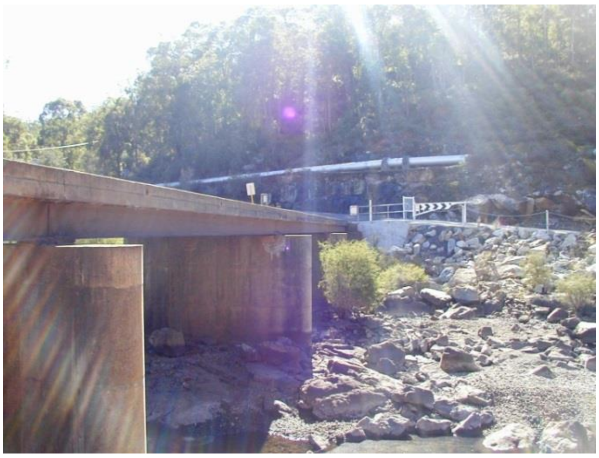


Photo 7 – Spillway Bridge.

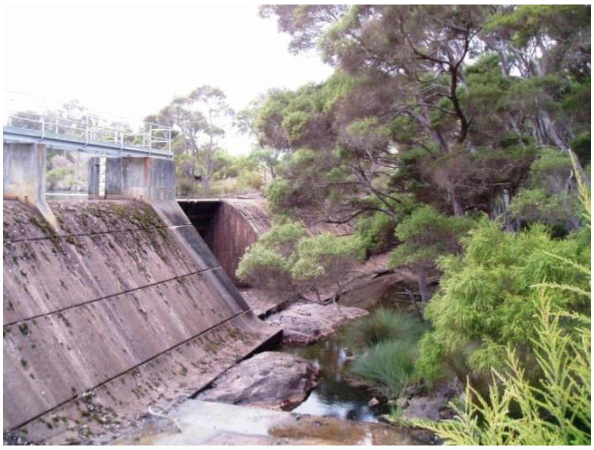


Photo 8 - Weir.

Photo 9 - Sewer wet well.

Photo 10 - Clarifier in Wastewater Treatment Plant.

Photo 11 - Primary Sedimentation Tank in Wastewater Treatment Plant.

Photo 12 - Chemical Bund.

2.0 CONCRETE PRE-INSPECTION PREPARATION

2.1 Inspection Requirements

Prior to conducting inspection, the Operator/Inspector/Diver (collectively "Inspector") must fully understand the condition assessment and data capture process. The inspectors must also be familiar with the criterion (condition rating & priority repair works) used to assess the tank condition.

Any Inspector undertaking on-site condition assessments shall be appropriately qualified and experienced for the task. This is applicable to in-house personnel or external ISP's. The data collection and reports will provide valuable information not only on the asset condition but also assists in understanding the risk and current performance of the concrete structures.

The inspector should ensure that the assessment is complete with appropriate levels of detail for each relevant component of the structures with a rated condition. The corrosion measurements and assessments must be made with high degree of accuracy. The data collected should adhere to the criteria provided so that there is consistency between surveys.

The external ISP's can obtain the inspection work pack from the Asset Manager or Responsible Person for the inspection activities.

After completion of inspections, the report should be sent to the Asset Manager or Responsible Person in Renewals Planning. The inspection data will then be updated and analysed in the Concrete Structures Remaining Service Life (CRSL) Tool database [6]. Inspection reports should be saved into the ACA program for future reference.

All inspecting personnel shall hold appropriate site safety inductions both general and site specific. If the asset is deemed to be confined space and/or working at heights, then appropriate valid certification shall be possessed by the in-house personnel and ISP's. The certificates shall be available to the Water Corporation for verification at least 10 working days prior to the inspection.

2.2 Roles and Responsibilities

Activities	Role(s)*	Responsible Branch*
Level 1	Visual Inspection	Alliance Partners/Region /Divers/Water Corporation employees
Level 2	External & Internal Inspection	Inspection Services Providers†
Level 3	Detailed & Laboratory Assessment	External Consultants◆
ARA	Alliance Partners/Region Civil Asset Planners and Maintainers	Alliance Partners/Region/In-Service Assets, APG
Inspection data review	Level 1 by APG & Region/Alliance Partners. Level 2 and 3 inspection data analysis by In-Service Assets team.	In-Service Assets, APG
Inspection data update in Database	Analyst in In-Service Assets team	In-Service Assets, APG

Table 1 – Roles and Responsibilities Matrix for Steel Tank Condition Assessment.

* Changes in Roles and Responsibilities matrix shall only be approved by Section Manager, In-Service Assets.

† Approved External Contractors – Refer ACA Panel, [AquaDoc. No. 16729525].

◆ Approved Materials Testing and Corrosion Specialists - Refer ACA Panel, [AquaDoc. No. 16729525].

2.3 Defects Notification

During tank cleaning process, Level 1 and Level 2 inspections, corrosion and structural related failures may be identified by the ISP's that requires urgent attention shall be notified to the Operations Group in the Region/Alliance.

The defects/issues recognised needs to be addressed as soon as practicable, so that the asset can be brought back to operation. Some of the common issues that may require immediate notification include:

- Safety compliance issues.
- Tank security issues.
- A structural defect that will have detrimental effect on the asset if not rectified.
- A structural defect including water quality issues that is adversely affecting the service being provided by the asset.

2.4 Inspection Data Interpretation

After completion of Level 1 Divers inspection for the potable concrete tanks, the report should be sent to the Asset Investment Planner or Responsible Person in the APG. The inspection data will then be updated and analysed in the Concrete Decision Support Tool (CDST) database. All the inspection reports should be saved into the ACA database linked to the relevant Functional Locations for easy access and future references.

Persons responsible for identifying and recording defects, service conditions and construction features for preparing reports and operating equipment shall hold a suitable qualification for various levels of inspection and is discussed in Section 3.0.

In-Service Assets is responsible for analysing the tank inspection data (Level 1, Level 2 & Level 3) provided by ISP's and shall be competent in the following:

- Interpreting information contained in the inspection reports.
- Identifying defects and other features.
- Verifying the inspection scoring/grading system.
- Recording the inspection scoring/grading system in CRSL tool.
- Recognising corrosion related defects and the likely parameter contributing to the defects.
- Recognising poor quality inspection videos and camera inspection.

3.0 LEVELS OF CONCRETE INSPECTION

APG propose on all the Water Corporation concrete structures that the condition assessment is undertaken at three levels:

3.1 Level 1 – Routine Operation and Maintenance Inspection

Level 1 inspection will assist in assessment of the overall safety and performance of the concrete structure. A Level 1 inspection can be carried out by Water Corporation employees including treatment plant operators, chemical dosing plant supervisors, asset maintainers, asset planners, service delivery representative and diving contractors. Relevant inspection data is captured as part of the on-going operation and maintenance process.

If concrete deterioration is a threat to the structural integrity of the asset, then an Asset Deficiency Report (ADR) must be created by the asset inspector. The Asset Manager or responsible person must also use the Asset Risk Assessment (ARA) system and verify the likelihood and consequence of failure i.e. risk rating for the concrete structure.

In-Service Assets, APG will endorse the risk assessment and also use the appropriate Concrete Remaining Service Life (CRSL) tool to calculate the indicative Remaining Service Life (RSL) of the structure from the Level 1 assessment. Where the indicative RSL is calculated to be within 5 years, a Level 2 inspection may be initiated and planned in the appropriate year for condition assessment.

In the Corporation, the following inspection activities are classified as Level 1 inspection.

Photo 13a – Pipework and hangers on the underside of the bridge using RPA.

Photo 13 b– Tank inspection by ROV.

3.2 Divers Inspection – Potable Water Concrete Tanks & Reservoir

3.2.1 Tank Cleaning and Detailed Inspection by Divers

The divers shall vacuum all the sediment and ensure the tank floor is thoroughly cleaned. Once cleaned, a "Standard Inspection" should be carried out by taking photos of key components.

The diver's standard inspection, (i.e. after tank cleaning), shall capture typically 60 to 100 photographs. The photos should be labelled with the name of the tank component followed by the numbering sequence i.e. a photo should be called "Wall to Floor Joint 2".

In addition, short video clips shall be captured on the hand held camera with no voice commentary. If there are problems found within the asset, a greater volume of photos should be taken to capture the problem.

3.2.2 Tank Cleaning - Divers Qualifications

For Diving Inspector, the minimum level of qualification to carry out inspection of Water Corporation tanks shall be a valid Part 2 - Surface Supply Breathing Apparatus (SSBA) accredited by ADAS.

The qualification for Diving Supervisor is a valid Part 1 - Occupational Self-Contained Underwater Breathing Apparatus (SCUBA) to 30 metres. It is intended to establish occupational SCUBA qualification for engineering inspection diving.

The qualification limits the diver to using hand tools or conducting inspections. The Part 1 certified diver cannot operate surface controlled power tools, or dive in operations where the use of overhead lifting or other similar activities is required.

3.2.3 Detailed Civil Inspection by Divers

The current format of a "Detailed Inspection" is where the diver completes the same process outlined above but with more detail. It is recommended that more photos are taken on each component and problematic areas. Photos should not be individually renamed, but are filed in named folders, so the Corporation can get a folder called "walls" with a bundle of un-named photos of the walls.

The divers shall produce interactive video typically an hour or two long and record every part of the asset in detail with commentary by the diver and supervisor. The video record shall include the entire inspection. The diver shall submit 3 copies of the tank inspection video and inspection report in electronic format able to read by the Corporation including the following defects or features:

1. Deformed or broken appurtenances.
2. Multiple failed components.
3. Continuous defects or features such as defect coating, corrosion on the floor, wall, weld joint corrosion etc.

4. Significant erosion, corrosion or surface damage.

5. Defective steps, ladders, platforms, inlet pipe, columns, scour pipe, overflow pipe etc.

6. A minimum of one image should be a direct view showing the defect feature in the context of the tank. Images from zoomed, titled or panned camera are supplementary and should not be used alone.

7. Lighting and focus should be adjusted to ensure a quality image. If the feature is not identifiable it may be useful to capture several images from different positions.

8. The minimum resolution for the photographs shall be 4500 x 3000 pixel dimensions and the file size for individual photos shall be 5 MB or higher.

9. The file size for individual videos should be no more than 2GB. The Contractor may therefore need to submit multiple video files for the same tank.

Note: During civil inspection, Diver shall use appropriate and approved Ultrasonic Thickness (UT) and localised metal loss (pit depth) gauges to record remaining steel thickness readings of the steel columns and any problem areas of the tank.

3.2.4 Divers Qualifications

For Civil Inspection, the divers shall possess valid CSWIP 3.1U - NDT Inspection certification issued by The Welding Institute (TWI) [8].

In addition, the Divers shall also attend one-day corrosion awareness course “Introduction to Corrosion” conducted by Australasian Corrosion Association (ACA) [9].

3.2.5 Divers Inspection Report

The inspection report shall consist of structural elements nominated in the scope of work. The report shall be computerised version detailing the observations including location and characteristics of reportable features including defects and features of interest.

The supervisor shall fill out a Microsoft Excel® template with information based on the diver’s comments. Refer **Appendices B and C** for the standard inspection checklist template.

3.2.6 Inspection by Others and Water Corporation Personnel

Before carrying out visual inspection, the Water Corporation employees shall complete and possess approved permits including Job-Safety Analysis (JSA), Job Safety and Environment Analysis (JSEA) and site-safe inductions. If the Corporation employees carry out roof inspection then they shall also possess valid working at heights certificates.

The inspection finding shall be reported to OAM/Regional Alliance/APG. If the defects deemed to be significant, then OAM will conduct an ARA. APG will review the ARA with the asset owner and further actions will be discussed.

3.3 Level 2 - Formalised Inspection

Level 2 is a planned inspection after an ARA on the concrete structure has been endorsed by APG. The condition rating from the Level 2 inspection will be captured into the CRSL whereby the RSL of the concrete structure will be ascertained. A Level 2 inspection may be used to identify remedial action required to extend life to prevent premature failure of a concrete structure.

On an annual basis, the Renewals Planning team will carry out an evaluation of all concrete structures using the relevant CRSL tool and where the theoretical RSL for the worst defect is shown to be between 3 to 5 years and/or high/extreme risk, a Level 2 inspection may be triggered. For all assets requiring a Level 2 inspection, an ARA must be completed by the Renewals Planning team of APG and approved by the Asset Manager or Responsible Person. Level 2 inspection is carried out as part of the planned condition assessment capital program.

Level 2 inspections are undertaken to ensure the following objectives:

- Ensure that the concrete structure continues to operate to the required level without operational problems;
- To record the current asset condition i.e. corrosion deterioration, general wear and tear;
- To assess and determine maintenance requirements such as replacing cathodic protection sacrificial anodes, nuts and bolts etc.;
- To forecast future technical problems;
- Confirm if the previous repairs works that are carried out functioning properly or new repair methodologies are required to remediate the problem.
- Determine the RSL of the concrete structures.

Level 2 inspection findings will be sent to APG for further analysis. In Level 2, APG will then carry out ARA and infer the effective remaining life using CRSL tool [Refer: Aqua Doc. 11795696] [12]. Level 2 inspection is carried out as part of the planned condition assessment capital program.

On an annual basis, the Renewals Planning team will carry out an evaluation of concrete structures using CRSL and where the theoretical RSL is shown to be between 3 to 5 years, a Level 2 inspection may be triggered. For all assets requiring a Level 2 inspection, an ARA must be completed by the Renewals Planning team and approved by the OAM. Refer **Appendix D** for the Level 2 inspection template.

3.3.1 Calibration of Inspection Gauges

Inspection gauges shall be calibrated in accordance to the manufacturers recommended practices and interval. Calibration certificates shall be available to the Water Corporation prior to the inspection.

3.3.2 Qualification of Level 2 Inspectors

The formalised concrete structure inspection shall only be carried out by qualified and experienced inspectors [7]. This is to ensure quality and reliability of inspection and data obtained for further analysis. Under no circumstances, non-qualified ISP's shall be engaged for Level 2 inspection.

The Level 2 inspectors shall prove to Water Corporation that they have enough experience in tank inspection and shall submit any one of the certification gained from Australasian Corrosion Association and/or by Australasian Concrete Repair Association (ACRA):

- Corrosion Technician certification;
- Corrosion Technologist certification;
- Corrosion and Protection of Reinforced Concrete;
- Concrete Repair & Protection Course.

For coating inspection, the inspector shall possess ACA Coating Inspector (or) National Association of Corrosion Engineers (NACE) minimum NACE CIP Level II Coating Inspector.

Where the RSL is calculated to be within 3 years, a Level 3 assessment may be initiated by the Renewals Planning team where it is deemed cost effective and/or further data is required to determine the requirement for intervention.

3.4 Level 3 – Detailed Investigation

Level 3 inspections will be carried out, where the ARA is very high and/or Level 2 inspection showed that the asset is nearing the end of its physical life. APG will recommend Level 3 inspection based on the asset Physical Life and Level of Service (LOS), Refer Aqua Doc. No. 11833402 [13]. Where the RSL is calculated to be within 3 years and/or high/extreme risk, a Level 3 assessment may be initiated by the Renewals Planning team of APG where it is deemed cost effective and/or further data is required to determine the need for intervention.

Level 3 inspection is carried out as part of the planned condition assessment capital program. The guideline below describes how the Corporation is undertaking condition assessments on its concrete structure assets. The methodology below describes how the Corporation is undertaking condition assessments on its concrete structural assets. An overview of the process is depicted in Figure 1. Refer **Appendix E** for Level 3 inspection template.

3.4.1 Aim of Level 3 Inspection

Level 3 inspections may be required due to concerns over concrete structural safety, complexity of remediation works recommended during Level 2 inspection. The main objectives are:

- To establish and record the current physical and functional condition of a structure;
- To identify likely future problems and the approximate timing of those problems;
- To determine and measure the type and extent of the maintenance needs;
- To establish a history of material performance; and
- To provide feedback to design, construction and maintenance engineers.

3.4.2 Scope of a Level 3 Inspection

The scope of Level 3 inspection will be defined in the investigation brief. The extent may be very broad and will depend on the purpose of the inspection. For example, the purpose may be testing of material condition to establish a reference from which to measure and monitor deterioration (establishing a benchmark), or to establish extent of maintenance works, (defect identification) or to provide information on components that are not accessible during a Level 2 Inspection.

3.4.3 Outputs of a Level 3 Inspection

The outputs of a Level 3 Inspection include:

- Summary of purpose and scope
- Description of test plan and test methods utilised
- Diagrammatic and photographic information on test locations
- Test results with analysis and interpretation where required
- Photographic records of all deteriorated materials observed on site.
- Recommended maintenance options including intervention schedule for use by the APG.
- Recommended repair materials
- Quantification of the extent of repairs suitable for comparison of alternatives and also for preliminary budgetary purposes.

3.4.4 Qualification of Level 3 Inspectors

In general, the Contractor shall be very knowledgeable in various disciplines including Concrete, Corrosion, Materials Science and Structural Engineering. The Contractor should be very thorough in non-destructive testing methods of concrete structures as well as various aspects of construction materials including design, construction, rehabilitation and maintenance.

The Level 3 inspector's shall possess an engineering associate or degree in relevant discipline.

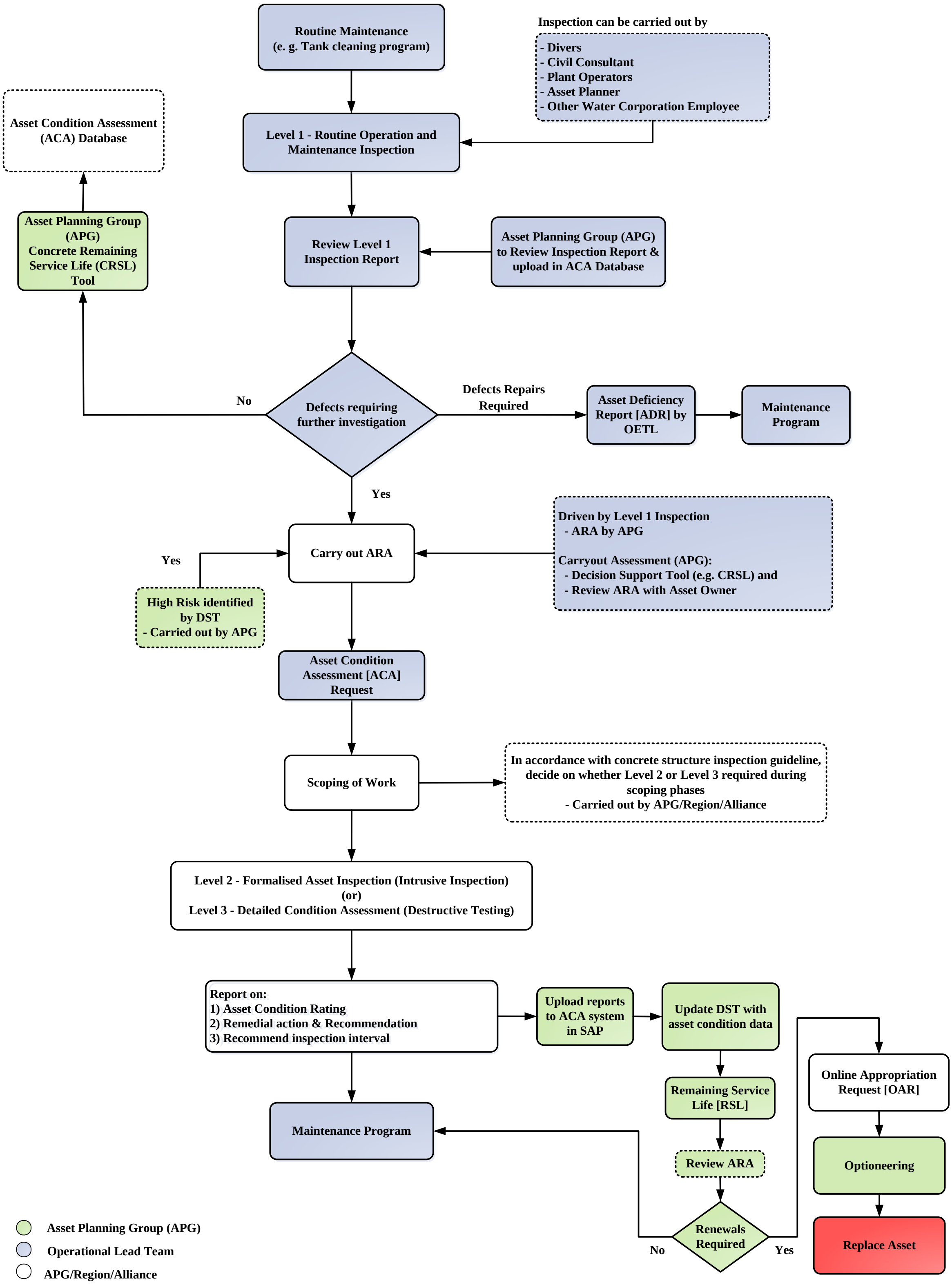


Figure 1 - An overview of Level 1, Level 2 and Level 3 process in the condition assessment of Concrete Structures.

4.0 CONDITION RATING INTERPRETATION

4.1 WERF – Why This Approach?

Prior to 2014, various condition rating systems were used in the Corporation to assess the civil structures. They were all so called industry practice and/or based on the "hearsay". Also, the assessments were qualitative, debateable and hence inconsistent rating.

The main purpose of rating the tank is to evaluate the condition in an objective approach and its effective RSL. The assessment will assist further decision-making about the Level of Service (LOS) provided by the tanks. It is well known that deterioration of material range from 0% to 100%. Currently, the best deterioration model readily fits to this approach is Water Environment & Reuse Foundation (WERF).

The WERF model approach is either "aged based" or "condition based". If no prior inspection or condition data is available, then the service life of the asset will be based on the age and will take the precedence over the condition and vice versa.

Corporation's inspection experience and condition assessment of the asset clearly proved only certain levels of inspection (Level 1 – Visual, Level 2 – Formal and Level 3 – Destructive) is warranted. It is well known that the asset failure leading to physical mortality is not uniform and at certain point the asset unserviceable and beyond economic repair. Also, Capacity, Level of Service and Finance factors play major role in the renewals planning decision [3]. So, after any inspection activity the condition rating should be within the margin of "Serviceable and Unserviceable". If this concept is not followed, the rating in 5 scale will also provide a huge margin of error when compared to the 10 rating. In simple words, for a rating 4 in 5 scale, the deterioration is 80%, because each scale will equate to 20% deterioration; whereas the same 80% deterioration equates to a condition rating of 8 in a10 scale.

For the past 3 years, Level 2 inspection of water and wastewater assets clearly showed that the steel structures are still within the serviceable range. The asset condition rating of 10 scale provides a pragmatic maintenance repair works on the assets individual components. Most importantly, Corporation follows Capital Program which is of 5 years plan for repairs and replace approach. Hence, asset with 30% deterioration which is rated as 3 in a ten point scale can be repaired in 3 to 5 years.

4.2 Condition Rating System

For the condition assessment of tanks, In-Service Assets utilises TDST model **[Refer: Figure 2]**. The condition rating is based on 1 to 10 scale and the outcome is summarised as below [3].

☑ **Excellent condition** - Observable deterioration is none. Less than 10% physical life is consumed.

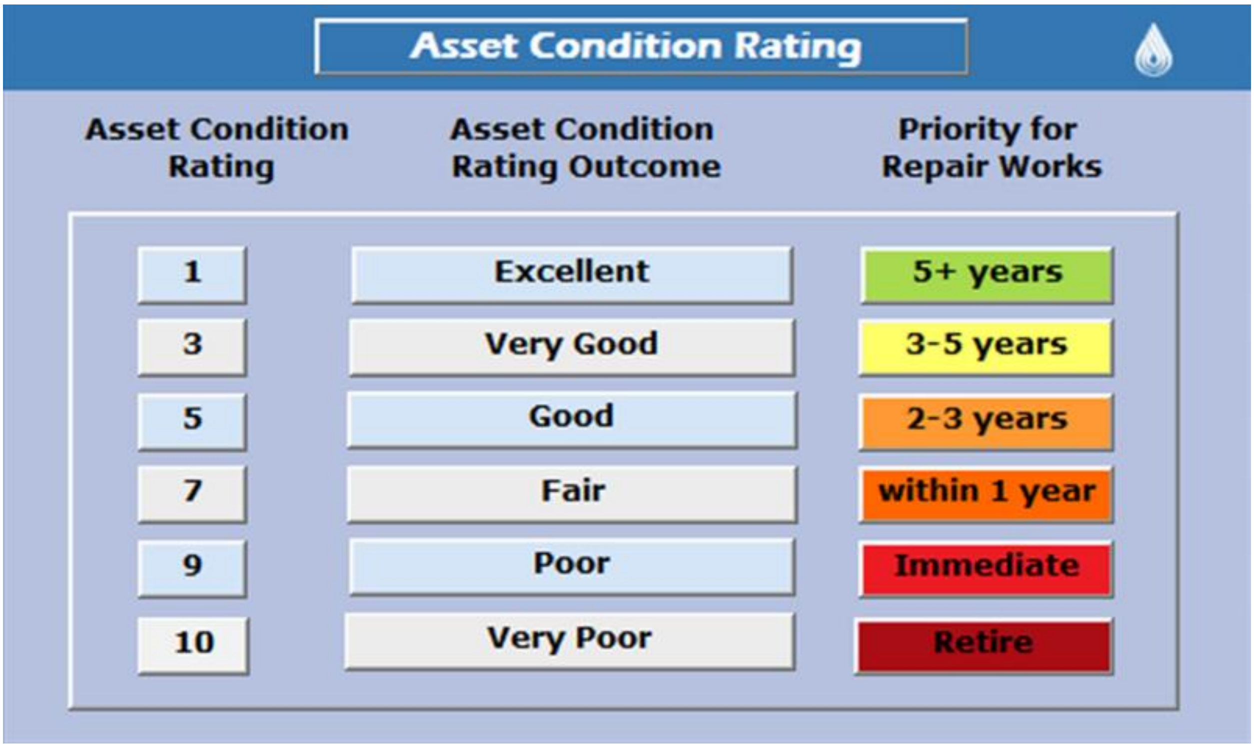
☑ **Very Good condition** - Observable deterioration is insignificant. No adverse service reports. 30% physical life is consumed.

☑ **Good condition** - Observation and/or testing indicate that the asset is meeting all service requirements. Sound Physical condition. Minor deterioration/minor defects observed. 50% physical life is consumed.

☑ **Fair condition** - Moderate deterioration evident. Minor components or isolated sections of the asset need replacement or repair now but not affecting short term structural integrity. 70% physical life is consumed.

☑ **Poor condition** - Serious/Significant deterioration evident and affecting structural integrity. Asset is now moving into zone of failure. 90% physical life is consumed.

☑ **Very Poor** - Failed or failure imminent. Immediate need to replace most or the entire asset. 100% physical life is consumed.



Asset Condition Rating

Asset Condition Rating	Asset Condition Rating Outcome	Priority for Repair Works
1	Excellent	5+ years
3	Very Good	3-5 years
5	Good	2-3 years
7	Fair	within 1 year
9	Poor	Immediate
10	Very Poor	Retire

Figure 2 – Asset Condition Rating based on CRSL model.

Note: A series of charts published by the AS/NZS engineering standards, Standard Practices (SP) published by NACE, ASTM standards and IPWEA can also be used to make an informed decision on the condition rating of the asset for Level 2 and Level 3 inspections.

5.0 EXPOSURE ENVIRONMENT FOR POTABLE WATER & WASTE WATER ASSETS

5.1 Exposure Environment for Water Corporation Assets

Water Corporation concrete structures are located in various exposure environments, characterised by various degrees of severity of exposure. The exposure environments for Water Corporation concrete structural components are classified in accordance with AS/NZS 3735 Section 4.

The exposure classification refers to the exposed surfaces of a concrete member and indicates the aggressiveness of the environment to these surfaces. Four basic exposure classifications for exposure to chemical or penetrating agents are defined in terms of their resultant effect on a concrete member as follows:

A - Where the concrete is in a non-aggressive environment or is protected from aggressive agents. This classification may be appropriate for surfaces protected or isolated from the attacking environment or where a lower level of durability is applicable.

B - Where the concrete is in an aggressive environment but only subjected to agents to which normal concrete of adequate quality is resistant. This is the lowest category applicable to concrete members in contact with water or condensation.

C - Where aggressive agents will attack the concrete but provision of a superior quality will enable the member to remain serviceable for the required design life.

D - Where the concrete is subject to an environment that will attack the concrete to such an extent that the required design life cannot be met i.e. cannot retain or exclude the liquid in an acceptable manner.

These exposure classifications are further subdivided by a number such that the sequence A1, A2, B1, B2, C, D indicates an increasing severity of attack to the exposed environment. An exposure classification U indicates no guidance is given. In general, the Water Corporation concrete structures falls into either group B1 or B2.

The exposure classification for the concrete surface that will be subjected to during its operational life shall be determined from AS/NZS 3735, Table 2. For more information, on the appropriate exposure classification from within the below range specified in AS/NZS 3735 Supp1 - Concrete structures for retaining liquids - Commentary.

Item	Characteristic of liquid in contact with concrete surface	Exposure classification		
		Predominantly submerged		Alternate wet and dry (condensation splashing or washing)
		Generally quiescent	Agitated or flowing	
1	1 Freshwater: (Notes 1, 2, 3) (a) I positive of pH >7.5 (b) I negative & pH 6.5 to 7.5 (c) I negative & pH 5.5 to 6.5	B1 B1 B2	B1 B2 C	B1 B1 B2
2	Sewage and waste water: (Note 4) (a) Fresh—low risk of H_2S corrosion (b) Stale—high risk of H_2S corrosion (Note 8) (c) Anaerobic sludge	B1 B2 B1	B1 B2 B1	B2 D B1
3	Sea water: (Notes 5, 6) (a) General immersion and pH $\geq$7.5 (b) Retaining or excluding situations or pH <7.5	B1(7) C	B2(7) C	C C
4	Corrosive liquids, vapours or gases Severity (Note 8) (a) Slight/mild (b) Moderate (Note 9) (c) Severe/extreme (Note 9)	B1 B2 D	B2 C D	B2 C D

5	Other liquids: (Note 10) (a) Water containing chloride, sulphate, magnesium or ammonium (b) Wine, non-corrosive vegetable oils, mineral oils and coal tar products	B1-D B1-D	B1-D B1-D	B1-D B1-D
6	Ground water (in-ground) (Notes 10, 11)	B1-D	—	—

Table 2 - Exposure classification recommended by AS/NZS 3735.

NOTES:

1. An approximate value of Langelier Saturation Index (LSI) may be obtained from the equation:

LSI = pH of water − pH when in equilibrium with calcium carbonate

= pH −12.0 + log10 [2.5 × Ca^{2+} (mg/L) × total alkalinity (as $CaCO_3$ mg/L)].

(A negative value for LI means the water has a demand for $CaCO_3$).

2. For lower pH values see Item 4.
3. For water containing significant quantities of aggressive dissolved materials see Item 5(b).
4. Industrial sewage and waste water may contain aggressive chemicals. The designer shall refer to other liquids as given in Table 4.1 (see also AS 3735 Supp1).
5. The use of galvanized or epoxy-coated reinforcement or a waterproofing agent should be considered. Details are given in AS 3735 Supp1.
6. The use of sulphate-resisting cement is discouraged.
7. Only applicable for submergence greater than 1 m below low water ordinary spring tide.
8. Typical examples of severities are given in AS 3735 Supp1.
9. The use of calcareous aggregate should be considered. Details are specified in AS 3735 Supp1.
10. Guidance on the selection of an appropriate exposure classification from within the range indicated is specified in AS 3735 Supp1.
11. For members in contact with extracted ground water see Item 1 or 5.

6.0 REBAR CORROSION & CONCRETE DETERIORATION MECHANISMS

6.1 Rebar Corrosion - Mechanism

Corrosion is an electrochemical process involving the flow of charges (electrons and ions). The passivating film provided to the steel by the highly alkaline cement is destabilised when contacted with aggressive agents such as chloride. This process is called a half-cell oxidation reaction, or the anodic reaction, and is represented as:

$$2Fe \rightarrow 2Fe^{2+} + 4e^{-} \qquad [1]$$

The electrons remain in the reinforcing bar and flow to sites called cathodes, where they combine with water and oxygen in the concrete. The reaction at the cathode is called a reduction reaction.

$$2H_2O + O_2 + 4e^{-} \rightarrow 4OH^{-} \qquad [2]$$

To maintain electrical neutrality, the ferrous ions migrate through the concrete pore water to these cathodic sites where they combine to form iron hydroxides, or rust:

$$2Fe^{2+} + 4OH^{-} \rightarrow 2Fe(OH)_2 \qquad [3]$$

This initial precipitated hydroxide tends to react further with oxygen to form higher oxides resulting in the increase in volume. As the reaction products react further with dissolved oxygen internal stress within the concrete are developed that may be sufficient to cause cracking and spalling of the concrete. Figure 3 shows an overview of the concrete deterioration due reinforcing steel corrosion [14].

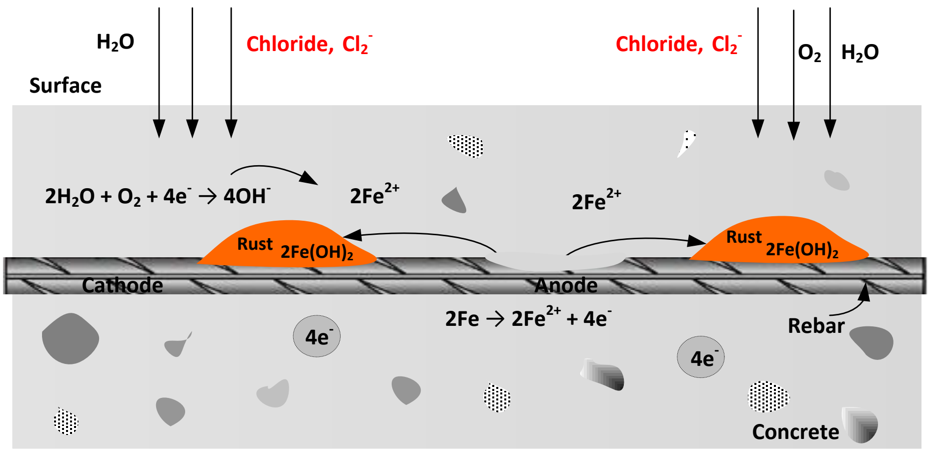


Figure 3 – Corrosion of rebar in Concrete.

Corrosion of reinforcement is mostly caused by either carbonation of the concrete or by contamination with chlorides or both [15, 16].

A small amount of loss of reinforcement section can produce copious rust product because of its expansive nature. Therefore extreme care should be taken to ensure that the loss of rebar section is not estimated from the thickness of corrosion product. Estimates of loss or rebar section should be made by cleaning of the rebar and measuring its diameter. The corrosion on the rebar is classified as follows: G = General and L = Localised **[Refer: Photos 14 & 15]**.

Photo 14 - Generalised chloride induced rebar corrosion. [Photo Courtesy: http://civil-engg-world.blogspot.com.au/2011/03/corrosion-induced-by-chloridesrcc.html].

Photo 15 - Localised chloride induced rebar corrosion. [Photo Courtesy: http://www.en.wikipedia.org/wiki/Concrete_degradation].

6.2 Rebar Corrosion Classification

6.2.1 Classification 1

Rebar appears passive. There is no observable corrosion, but the rebar may have mill scale on the surface. In some instances, surface "lime" deposits from the surrounding concrete may also be seen on the rebar. Neither section loss of the rebar, nor any signs of pitting attack on the profile of the ribs **[Refer: Photo 16]**.

Photo 16 - Classification 1, Mill Scale on the rebar.

6.2.2 Classification 2

Rebar is largely passive. There is a slight surface corrosion deposits of orange and brown corrosion products appearing in discrete "blotches", particularly at the intersection points of the ribs. These corrosion products are easily removed by scraping **[Refer: Photo 17]**.

Photo 17 - Classification 2, Discrete blotches of corrosion products.

6.2.3 Classification 3G

Rebar has a thin corrosion scale on its surface, mainly red or reddish brown in colour. There is no noticeable loss in rebar section, although slight damage to the profile of the ribs may have taken place. There will be no cracking of the concrete associated with the formation of these corrosion products **[Refer: Photo 18]**.

Photo 18 - Classification 3G. No noticeable loss in bar section.

6.2.4 Classification 3L

Rebar has a form of localised attack, which should be distinguished from the general type of attack. It leaves the bar with large areas (up to 75%) which could be in Classification 1 or 2, but the remainder of the rebar having undergone a moderately severe attack. There may also have been cracking of the surrounding concrete, due to the formation of expansive corrosion products on the surface of the rebar **[Refer: Photo 19]**.

Photo 19 - Classification 3L. Majority of the surface covered with heavy dark brown rust.

6.2.5 Classification 4G

Rebar has the majority of its surface area covered with a heavy red or dark brown corrosion scale, up to a thickness of 1mm. The scale is very difficult to remove by simply scraping. There is a loss of rebar section associated with this level of corrosion, as much as 10% in places.

The rib patterns will have been seriously damaged and, in places, totally removed. The concrete surrounding the rebar may have been cracked by the formation of expansive corrosion products **[Refer: Photo 20]**.

Photo 20 - Classification 4G. 50% of bar covered with rust & localised corrosion.

6.2.6 Classification 4L

Rebar has approximately 50% of its surface area covered with thick, dark red, brown and black corrosion products emanating from severe localised attack. The rust scale at these points may be up to 1.5mm thick. The rebar at other areas may fall into the general Corrosion Classifications 1 to 3 **[Refer: Photo 21]**.

The corroded areas may also have suffered severe loss in section, up to 25% in some cases. This will be associated with a very noticeable loss of rib patterns at the corroded points. The corrosion product formation at these points will almost certainly result in cracking on the concrete and may result in spalling in some cases.

Photo 21 - Classification 4L. Large rust layer falls off by tapping its surface.

6.2.7 Classification 5G

Rebar under this classification suffers the most severe general attack. The major characteristic of this type of attack is the scale thickness and colour. The scale will be orange and dark brown; the thickness may exceed 2.5mm **[Refer: Photo 22]**. Unlike most of the other levels of corrosion, the oxide scale flakes very easily and large pieces will come away from the rebar, simply by tapping it. There will be a severe loss of rib profile; in certain areas they will be completely removed. The concrete cover to reinforcement which has undergone this type of corrosion will be severely deteriorated, with spalling and delamination likely.

Photo 22 - Classification 5G. Severe localised attack; Rest of the bar suffered lesser uniform attack.

6.2.8 Classification 5L

The corrosion products produced may cause severe cracking, spalling or delamination of the cover concrete. This type of attack is the most severe and is likely to be the least common. Rebar has suffered a severe localised attack and will produce heavy black corrosion products, which may, in certain cases, resemble soot. Refer: **Photo 23**.

Photo 23 – Classification 5G. Complete failure of the rebar.

6.2.9 Measurement of Rebar Loss of Section

A small amount of loss of reinforcement section can produce copious rust product because of its expansive nature. Therefore extreme care should be taken to ensure that the loss of bar section is not estimated from the thickness of corrosion product. Estimates of loss or bar section should be made by cleaning of the bar and measuring its diameter.

6.3 General

The initiation and propagation of reinforcement corrosion in concrete structures can be influenced by both internal and external factors. These sources of deterioration depend on concrete properties and exposure conditions and, to a large extent, govern structural performance and remediation practices [17].

6.4 Internal Factors

The constituents of concrete may be key contributors to its internal degradation. Early age thermal restraint and shrinkage of concrete can cause cracking of the concrete, with a subsequent impact on the durability of the component and a potential for a reduction in RSL.

The presence of undesired impurities in the concrete can also be a severe cause of deterioration, primarily due to chemical reaction of the constituents. Several common undesired impurities are discussed below.

6.4.1 Sulphate Content

The presence of excess sulphate from contaminated aggregate in freshly made concrete can cause severe degradation due to sulphate attack. The percentage by mass of acid-soluble SO_4 to cement must not exceed 5.0%. Heat accelerated cured concrete, or concrete that has reached temperatures above 65-70° C during early cure, can also suffer from a form of internal sulphate attack called “Delayed Ettringite Formation” (DEF).

6.4.2 Delayed Ettringite Formation

DEF is a potential degradation mechanism that may occur in elevated temperature cured concrete structures. A reaction between sulphates and Calcium Hydroxide (Lime) to produce Calcium Sulphate (or Gypsum) may occur in concrete with a high concentration of sulphate. This consumption of lime lowers pH, allowing sulphate to react with destabilised aluminate minerals in the current paste to form an expansive mineral, Ettringite, which results in the breakdown of the cement paste.

It is generally accepted that to effectively prevent concerns relating to DEF, the temperature of the concrete during curing has to be monitored and that for concrete temperatures of 70° C or less for cement type GP and 80° C or less for cement type Low Heat (LH) cement, the formation of DEF is not likely with normally available cements.

6.4.3 Chloride Content

Aggregate contaminated with chlorides, or chlorides dissolved in chemical admixtures or mixing waters, can induce steel reinforcement corrosion. To avoid this, the mass of acid-soluble chloride ion per unit volume of concrete as placed shall not exceed 0.4 kg/m^3.

6.4.4 Alkali Aggregate Reaction

Concrete can be damaged by an expansive, chemical reaction between active constituents of the aggregates and the alkalis (sodium and potassium as soluble hydroxides) in the cement; this process in known as Alkali-Aggregate Reaction (AAR)/ Alkali-Silica Reaction (ASR). The visible signs of AAR damage are characterised by a network of cracks known as map cracking **[Refer: Photo 24]**.

The best technique for the identification of ASR is the examination of concrete in thin section, using a petrographic microscope. Alternatively, polished sections of concrete can be examined by optical microscopy and/or Scanning Electron Microscopy (SEM). A simple test using fluorescence of concrete samples treated with acidic uranyl acetate and exposed to UV-C light can often identify the presence of the gel product.

ASR can cause internal stress and, ultimately, cracking by expansion when wet. ASR does not occur without the presence of water.

Photo 24 - Alkali–silica reaction affecting a concrete step barrier.
[Photo courtesy: Federal Highway Administration, US Department of Transportation].

6.5 External Factors

Concrete deterioration from external sources can occur in a variety of ways. The most important environmental causes of deterioration are the attack of sulphate, carbonation, chlorides, and the effects of stress, temperature and moisture.

6.5.1 Carbonation

Carbon dioxide (CO_2) in the atmosphere diffuses through the empty pore of concrete and reacts with the hydration products, which is known as a carbonation process. The reduction in alkalinity will provide an environment conducive to the corrosion of the reinforcing steel should this carbonated layer reach the steel, and oxygen and moisture are present [18].

In chloride-free concrete, corrosion will not take place unless the pH drops below 11. Atmospheric carbon dioxide can penetrate concrete and react with calcium hydroxide Ca(OH) in the cement paste to form calcium carbonate ($CaCO_3$) and this reaction reduces the pH of the concrete to around 9. Carbonation of concrete in the atmosphere is represented by the following simplified equation. This process is usually most pronounced in dry concrete.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

When the carbonation front reaches the carbon steel reinforcement, the passive oxide on the steel surface becomes unstable, and corrosion of the steel commences. Corrosion rates are also aggravated by wet/dry cycling of weather.

6.5.2 Chloride Attack

The transportation of chloride ions into concrete involves diffusion, capillary suction, permeation and convective flow through the system and micro-cracking network, accompanied by physical adsorption and chemical binding.

Chlorides penetrate the hardened concrete and break down the protective iron oxide layer on the steel reinforcement to initiate corrosion and the subsequent expansive disruption of the concrete matrix. The diffusion of chloride ions into concrete from external sources is dependent on concrete quality, cement type, cover, and exposure conditions. Periodic wet and dry exposure conditions accelerate corrosion rates severely [19].

6.5.3 Sulphate Attack

The deterioration of concrete exposed to sulphate is the result of the penetration of aggressive agents into the concrete and their chemical reaction with the calcium hydroxide in the cement matrix. The main reactions involved are Ettringite formation, gypsum formation and weakening of the calcium silicate hydrates in the binder. These chemical reactions can lead to expansion and cracking of concrete, and/or the loss of strength and elastic properties of concrete.

6.5.4 Chemical Attack

Dissolution and disintegration of the concrete matrix due to the effect of harmful substances such as acids, soft water, grease and oils, which subsequently assist in the corrosion mechanism by reducing the depth and quality of the concrete cover to the reinforcing or prestressing steel.

6.5.5 Mechanical Damage

Mechanical damage may be caused by abrasion, erosion, vapours or gases, or impact damage.

6.5.6 Fire Damage

Fire damage can cause weakening of steelwork and can cause spalling of cover concrete. If the heat from a fire penetrates sufficiently deep into a reinforced concrete component, it can cause weakening of conventional reinforcement and even prestressing tendons.

6.5.7 Leaching

Loss of $Ca(OH)_2$ from hardened cement paste, increasing the porosity, reduces the alkalinity of the concrete and therefore may initiate the corrosion mechanism. Where $Ca(OH)_2$ is completely leached, the calcium silicate hydrates are destabilised by the resultant reduction in pH, and consequently the cement matrix becomes weak and friable.

6.5.8 Restrained movement

Cracking in concrete may occur due to internal stresses caused by restrained shrinkage, thermal contraction and expansion or other causes. This type of cracking may be identified by its location (e.g. along centreline of flat deck soffits, transverse cracks in kerbs) and the likelihood it is through the full thickness of the component.

6.6 Design and Construction Factors

In addition to external factors, consideration should be given to the way the structure was initially designed and constructed which may contribute to its current condition.

6.6.1 Poor Design

Inadequate structural design or lack of attention to relatively minor design details can lead to in-built deficiencies in structures. Typical errors are discussed below.

6.6.2 Inadequate structural design

This may result in cracking and/or spalling in areas which are subject to the highest stresses. To confirm inadequate design as a cause of damage, the capacity of the locations of damage should be compared to the types of stresses that should be present in the concrete. A detailed structural analysis may be required.

Inadequate structural design can include use of an incorrect mix design to suit the exposure conditions.

6.6.3 Insufficient reinforcement cover

The concrete cover provides a physical barrier against the ingress of aggressive agents such as chlorides, carbon dioxide, oxygen and moisture. Under certain conditions, lack of cover will impair the ability of the concrete to provide protection from both physical and chemical deterioration, thus leading to corrosion of the steel reinforcement with subsequent cracking and spalling of the concrete.

6.6.4 Poor detailing

Poor detailing can result in the formation of defects and/or reduced durability. Examples of defects from poor detailing include corroding reinforcement from inadequate cover, honeycombed concrete at congested reinforcement, staining and corroding reinforcement from inadequate scupper projection below soffit, cracking from widely spaced reinforcement.

6.6.5 Poor Construction Practice

Failure to follow specified procedures and good practice, or outright carelessness during construction may lead to a number of adverse conditions. Poor workmanship that creates porous or permeable concrete, placement of concrete in high temperatures, plastic and restrained shrinkage and settlement of concrete may all lead to defects in the concrete and a reduction in durability.

Typically, most of poor practices do not lead directly to failure or deterioration of concrete. Instead, they enhance the adverse impacts of other mechanisms. The following sections describe some of the most common poor practices.

6.6.6 Improper Curing

Symptoms of improperly cured concrete can include various types of cracking and surface disintegration. In extreme cases where poor curing leads to failure to achieve anticipated concrete strengths, structural cracking may occur.

6.6.7 Improper Concrete Consolidation

Unsatisfactory compaction of concrete may result in a variety of defects, the most common being “bug-holes”, honeycombing and cold joints. These defects can make it much easier for deterioration mechanisms to enter the concrete and initiate deterioration.

6.6.8 Improper Casting Techniques

Cold joints and construction joints may separate/crack due to differential thermal movement or shrinkage between the two parts.

Inaccurately placed reinforcement and/or inaccurately constructed formwork may result in cover to reinforcement being less than required, usually resulting in reduced durability of the component.

6.6.9 Improper Construction Sequence

If consideration is not given to the construction sequence, construction loads and movements associated with construction, excessive deflection and cracking may result.

6.7 Formation and Types of Cracks

All concrete has a natural tendency to crack and concrete deterioration can be classified by physical, chemical and reinforcement corrosion. Cracks can be induced by external as well as internal factors generally influenced by materials, design, construction, service loads and exposure conditions either individually or in combination [19].

The various types of cracks are essentially defined by the principal cause or mechanism associated with their function. Structural cracks are caused by applied loads, whereas non-structural cracks are mainly the result of the properties of concrete and its constituent materials, design practices and where in-service conditions cause deterioration.

Cracks of a greater width allow a more rapid penetration into the concrete of aggressive agents such as chloride, sulphates and carbon dioxide, thus creating a more rapid rate of deterioration than could have been anticipated from un-cracked concrete.

Several other minor sources of cracks exist. Cracks can be induced by such natural weathering processes as wetting and drying, alkali-aggregate reaction, freeze-thaw action, and heating and cooling cycles. Cracking of concrete due to weathering is typically confined to the surface of a structure [20, 21]. A classification of crack in concrete structures is shown in Figure 4 and the schematic drawing in Figure 5. The classification of cracks are also summarised in Table 3 [22].

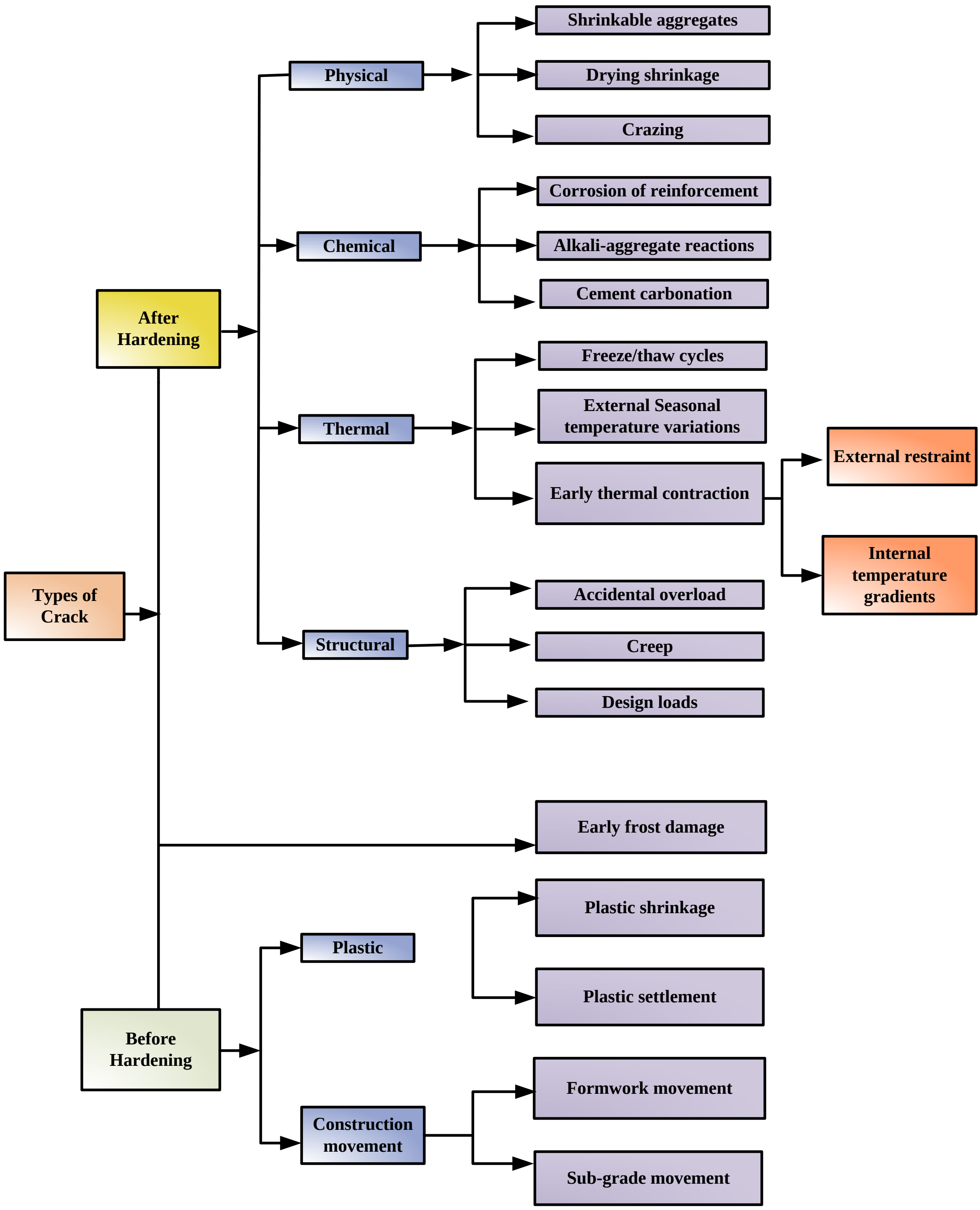


Figure 4 – Classification of concrete deterioration.

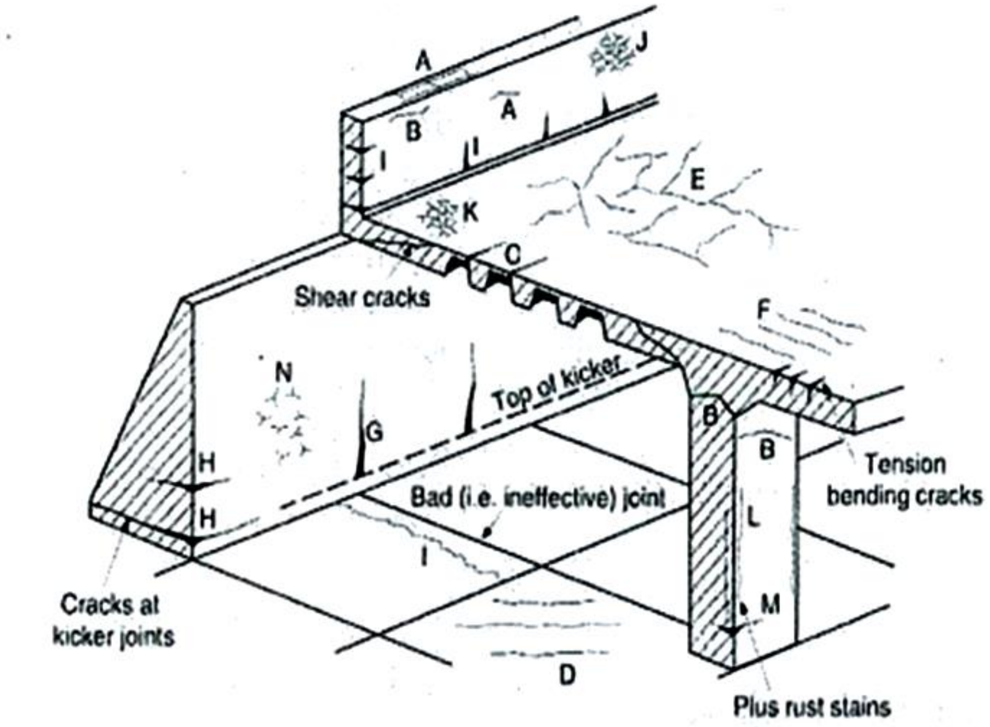


Figure 5 – Different types of cracks in the concrete.
[Courtesy: Non-structural Cracks in Concrete,"Tech. Report No. 22, The Concrete Society (London), 1982].

Type of Cracking	Position on Figure 4
Plastic settlement	A B C
Plastic Shrinkage	D E F
Early thermal contraction	G H
Long – term drying shrinkage	I
Crazing	J K
Corrosion of reinforcement	L M
Alkali-aggregate reaction	N

Type of cracking	Position on Figure	Subdivision	Most common location	Primary cause (excluding restraint	Secondary causes/factors	Remedy	Time of appearance
Plastic settlement	A	Over reinforcement	Deep sections	Excess bleeding	Rapid early drying conditions	Reduce bleeding (air entrainment) or revibrate	10 minutes to 3 hours
	B	Arching	Top of columns				
	C	Change of depth	Trough and waffle slabs				
Plastic Shrinkage	D	Diagonal	Roads and slabs	Rapid early drying	Low rate of bleeding	Improve early curing	30 minutes to 6 hours
	E	Random	Reinforced concrete slabs				
	F	Over reinforcement	Plastic settlement	Rapid early drying steel near surface			
Early thermal contraction	G	External restraint	Thick walls	Excess heat generation	Rapid cooling	Reduce heat and/or insulate	1 day to 2-3 weeks
	H	Internal restraint	Thick slabs	Excess temperature gradients			
Long – term drying shrinkage	I		Thin slabs (and walls)	Inefficient joints	Excess shrinkage, inefficient curing	Reduce water content, improve curing	Several weeks or months
Crazing	J	Against formwork	Fair-faced concrete	Impermeable formwork	Rich mixes	Improve curing and finishing	1-7 days. Sometimes much later
	K	Floated concrete	Slabs	Over trowelling	Poor curing		
Corrosion of reinforcement	L	Nature	Columns and beams	Lack of cover	Poor quality concrete	Eliminate causes listed	More than 2 years
	M	Calcium chloride	Precast concrete	Excess calcium chloride			
Alkali-aggregate reaction	N		Damp locations	Reactive aggregate plus high-alkali cement		Eliminate causes listed	More than 5 years

Table 3 - Classification of Cracks

[Courtesy: Non-structural Cracks in Concrete,"Tech. Report No. 22, The Concrete Society (London), 1982].

7.0 DETAILED CONCRETE INSPECTION TECHNIQUES

7.1 Visual Inspection

Visible defects should be recorded in standard template by the ISP's and record the defects. ISP's should use the survey legend provided in **Appendix G** for defect identification. The templates should be devised from asset drawings for a particular type of asset e.g. concrete tank, Clarifier etc. Photographs of the visible defects shall be taken to document the in situ condition, with photo locations clearly noted.

Visual inspection will locate areas of advanced reinforcement corrosion, concrete defects and deterioration. It will not provide any information about reinforcement condition in apparently sound concrete. Visual inspections should focus on the following features:

- Spalling
- Weathering
- Insufficient compaction (honeycombing)
- Cracks
- Rust Stains
- Dampness
- Efflorescence

The visual survey should also be used to confirm the testing locations so the detailed investigations can confirm the cause of deterioration and represent the condition of the asset.

Equipment: Camera, measuring tape, crack width gauge, binoculars, survey proforma, pens, marker/crayon.

7.2 Delamination Survey

A delamination survey involves striking a concrete surface with a small hammer and listening to the noise produced. Sections of concrete that have delaminated from the bulk of the component will sound hollow.

Delaminated areas identified shall be marked on the structure and their location and extent recorded on survey proforma. Photographs should be taken of the majority of the delamination.

Equipment: Hammer, camera, measuring tape, pens, marker/crayon.

7.3 Concrete Breakout

A concrete breakout is a small, isolated area of concrete removed to expose reinforcement to enable inspection and measurement of the exposed reinforcement.

Concrete breakouts shall be completed on representative locations, their location dependent on the visible condition of the concrete and environments at the asset. Where visible deterioration observed, it is recommended to carry out breakout on the deteriorated surface as well as on sound concrete nearby **[Refer: Photos 25 & 26]**.

A breakout shall generally be carried out by saw-cutting an approximately 100mm x 100mm panel or by using a hand-held percussion core bit or a diamond core bit to remove an approximately 80mm diameter core). Repairing of breakouts shall be completed using Parchem Renderoc HB40® or equivalent repair mortar in accordance with the manufacturer's recommendations.

Samples from structures for laboratory investigations are in various forms such as concrete fragments, cores or powder obtained from drilling. The ideal method of sampling concrete is by diamond core drilling **[Refer: Photos 27]**. Large fragment samples may also be of use but damage during sampling can limit investigation. Sampling locations should be chosen to represent the variation in the condition of the materials on site. In many cases it is useful to examine samples of undamaged as well as damaged materials in order to establish the original quality of the material.

Powder samples can be collected rapidly and inexpensively with readily available hand held equipment. Drilled powder samples can be used for simple analyses such as chloride content, but are not recommended for more complex determinations such as cement content.

A photographic record at sample locations must be taken. The samples obtained should be labelled, their orientation clearly marked and wrapped in cling film or stored in airtight sample bags as soon as practicable after sampling.

Once samples of concrete have been obtained, whether by coring, drilling, or other means, they should be examined in a qualified laboratory. In general, the examination will include one or more of the following examinations:

a) Petrographic examination (cores or fragments only)

b) Chemical analysis (chloride content, cement content, original water cement ratio, sulphate content etc.)

c) Physical analysis (compressive strength, density etc.)

Equipment: Covermeter, tools to carry out breakout, water spray bottle to clear concrete slurry and powder, measuring tape, camera, proforma, repair mortar.

Photo 25 - Concrete coring.

Photo 26 - Condition of concrete is alkaline (Refer: Pink colouration).

Photo 27 - Example of collecting powder sample for laboratory analysis [Photo Courtesy: Main Road, WA].

7.4 Covermeter Survey

A Covermeter is an instrument to locate rebar's and measures the exact concrete cover. Rebar detectors can only locate metallic objects below the concrete surface **[Refer: Photo 28]**. The Covermeter survey shall be performed in accordance with BS1881-204 standard.

Covermeter works on the principle of electromagnetic pulse-induction method to detect rebar. Coils in the probe are periodically charged by current pulses and thus generate a magnetic field. The rebar's or any electrically conductive material which is in the magnetic field generates eddy currents which in turn induce a magnetic field in opposite directions.

The Covermeter survey shall be conducted over the concrete surface and the position of the outermost reinforcement detected should be marked in crayon on the surface [23]. The typical depth of the reinforcement in the other direction should also be noted. The position and value of the concrete cover measurements should be temporarily marked on the surface of the component and recorded. The results should be accurately drawn with locations of all other tests marked in reference to the cover survey. The distances between bars in both directions should be measured.

Equipment: Covermeter, marker/crayon, measuring tape, camera.

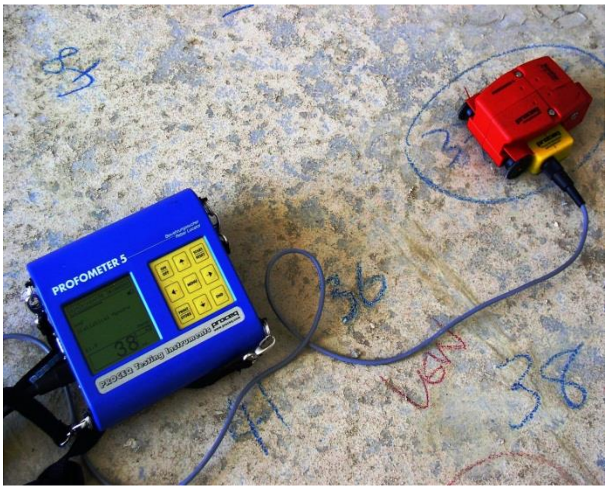


Photo 28 - Concrete cover meter inspection on the floor.

7.5 Rebound Hammer Survey

A Schmidt hammer is used to located areas of poor quality concrete and delamination. A Schmidt hammer consists of a spring loaded hammer, when released, strikes over the concrete surface. The rebound distance of the steel hammer from the plunger measured and is an indication of the quality of the concrete **[Refer: Photo 29]**. The Schmidt hammer survey shall be performed in accordance with ASTM C805-08 standard.

Prior to testing the concrete surface, a grinding stone should be used to create a smooth test surface, and then a rag used to remove all dust from the test area. Typically, 9, 16 or 25 test sites per component are used. Two or three test areas should be tested on larger components such as Sedimentation Tank, Clarifier walls, floors etc.

Manufactures documentation should include calibration charts that allow conversion of the in situ measurements to an indicative concrete compressive strength. Table 4 shows concrete quality based on rebound hammer test results.

Equipment: Rebound Hammer, grinding stone, cleaning rag, marker/crayon, proforma.

Average Rebound Numbers	Condition Rating Outcome
> 40	Excellent
30 - 40	Very Good
20 - 30	Good
10 - 20	Fair
5 to 10	Poor
< 5	Very Poor

Table 4 - Quantitative categorisation of Schmidt Hammer test results and Qualitative Condition Rating Outcome.

Photo 29 - Schmidt hammer test.

7.6 Depth of Carbonation

Depth of carbonation testing shall be performed in general accordance with RILEM CPC 18 Measurement of hardened concrete carbonation depth, 1988 [18]. It is recommended that carbonation testing is carried out in situ where the concrete has been drilled and cored for other testing (e.g. chloride testing, breakout). It is recommended that carbonation testing is carried out in situ where the concrete has been drilled and cored for other testing (e.g. chloride testing, breakout).

Carbonation testing is carried out in situ where the concrete has been drilled and cored for other testing (e.g. chloride testing, breakout). Cores taken for carbonation testing should be broken in half (on or off-site), and a carbonation test carried out on the fresh concrete.

Drill/cored holes should be thoroughly washed with potable water and allowed to become reasonably dry prior to spraying the phenolphthalein. Rebar condition in the breakout (cored) area is shown in **Photo 30**.

Equipment: Freshly exposed concrete (from coring, drilling, breakouts), phenolphthalein (acid/base indicator), ruler/measuring tape, proforma and camera.

Photo 30 - Rebar condition (Rust Classification No. 2).

7.7 Half-Cell Potential Survey

The half-cell potential survey should be undertaken in accordance with ASTM C876 standard and in conjunction with resistivity measurements.

The corrosion state of reinforcing bar can be determined from its half-cell potential with respect to the concrete [24]. Half-cell potential survey highlights possible concrete corrosion activity of the rebar before rust becomes evident. This early detection is an important step in preventing an unforeseen structural failure [Refer: Figures 6 & 7].

Equipment: Half-cell potential equipment, concrete breakout equipment, Covermeter, proformas, water spray bottle, measuring tape and marker/crayon.

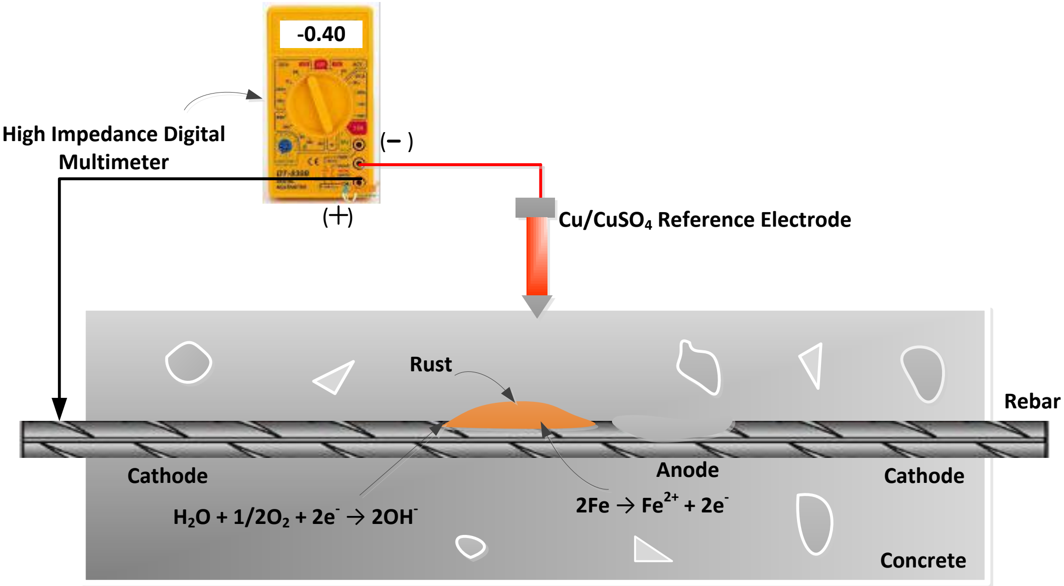


Figure 6 – Measurement of corrosion in the reinforcement bars of concrete elements using Half-cell potential method.

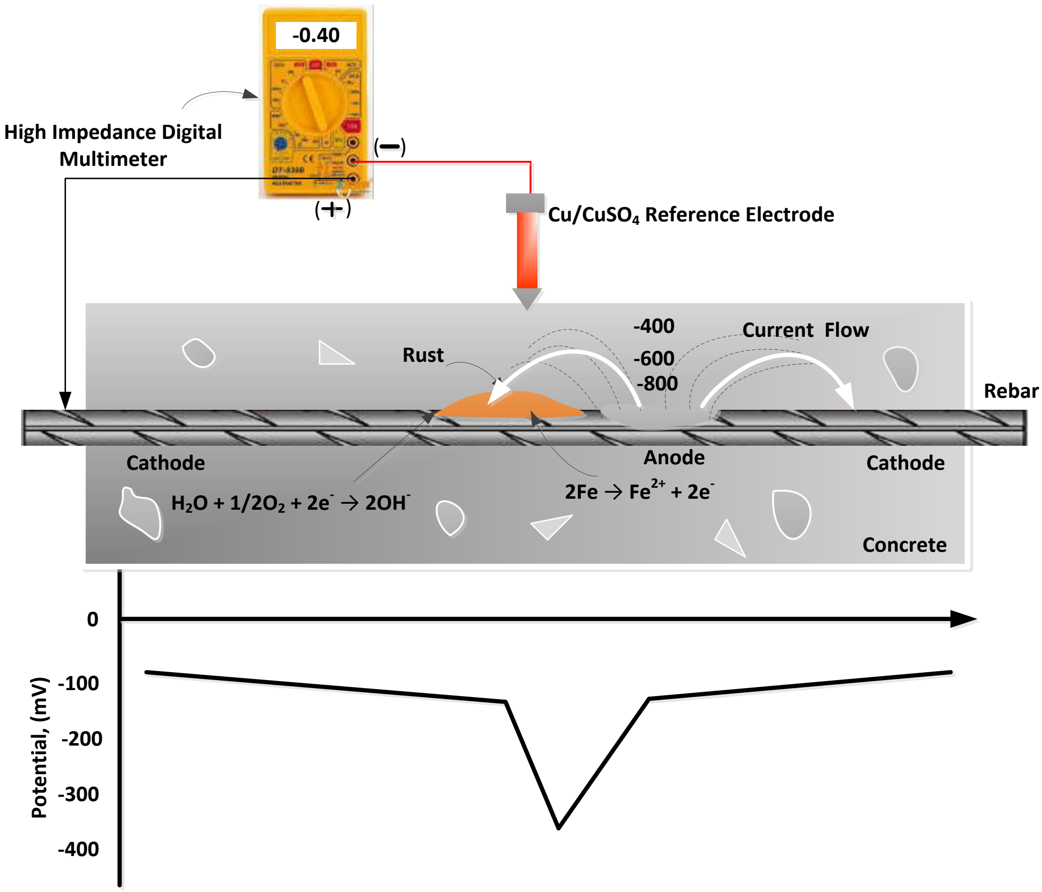


Figure 7 – Concrete rebar corrosion and Half-cell potential measurement method.

Potential vs. Cu/$CuSO_4$ [mV]	Risk of Active Reinforcement Corrosion at the Time of Measurement
More positive than -250 mV	Less than 10% probability of corrosion
Between -200 mV and -300 mV	Between 10% and 30% probability of corrosion
More negative than -350 mV	50% probability of corrosion
More negative than -375 mV	70% probability of corrosion
More negative than -400 mV	Greater than 90% probability of corrosion
More negative than -600 mV	Freely corroding

Table 5 – Half-Cell potential vs. Condition Rating.

7.8 Concrete Resistivity

Concrete resistivity should be undertaken in accordance with ASTM C1202 standard and can be obtained by applying a current into the concrete and measuring the response voltage. Four Pin Wenner probe is used to measure the electrical resistivity of concrete **[Refer: Photo 31]**. Resistivity is highly influenced by the moisture content of the concrete.

On the dry surfaces, pre-soaking the test location for at least for 20 minutes may be necessary prior taking measurement [25, 26]. The interpretation for concrete resistivity and condition rating outcome measurements is presented in Table 6.

Concrete Resistivity (Ωcm)	Probability of corrosion
>20,000	Negligible
10,000 – 20,000 >12	Low
5,000 – 10,000	High
< 5,000	Very high

Table 6 – Interpretation of Resistivity Measurements vs Condition Rating Outcome.

Photo 31 - Concrete Resistivity Meter.

[Photo Courtesy: Main Road, WA]

Equipment: Resistivity meter, Covermeter, proforma, measuring tape and marker/crayon

7.9 Cement Content and Type (Aggregate/Cement Ratio)

The cement content can be used to determine concrete characteristic strength and, therefore, concrete quality. Concrete core samples for cement content testing can be extracted at representative locations. Prior to sampling, Covermeter survey should be carried out to avoid damage to the reinforcement.

Equipment: Diamond core bit and drill, fresh water supply, Covermeter, proforma.

7.10 Concrete Compressive Strength

The compressive strength can be used to determine the strength of concrete and also measure concrete durability i.e. resistance to the penetration of chlorides, sulphate and carbon dioxide. Concrete core samples for compressive strength shall be extracted at representative locations. A Covermeter survey should be carried out to avoid damage to the reinforcement.

Compressive strength of the core samples shall be completed in accordance with AS/NZS 1012.9 and AS/NZS 1012.14 in a NATA registered laboratory.

Equipment: Diamond core bit and drill, fresh water supply, Covermeter, proforma.

7.11 Apparent Volume of Permeable Voids (AVPV)

Concrete core samples for Apparent Volume of Permeable Voids (AVPV) testing shall be extracted at representative locations. Testing shall be carried out in accordance with ASTM C642-06 or AS/NZS1012.21 in NATA accredited laboratory.

Durability classifications based on AVPV values are given in Table 7.

Vibrated cylinders (AVPV%)	Rodded cylinders (AVPV%)	Cores (AVPV%)
<11	<12	<14
11 -13	12-14	14-16
13-14	14-15	16-17
14-16	15-17	17-19
>16	>17	>19

Table 7 - Classification for concrete durability based on the AVPV limits [19].

Equipment: Diamond core bit and drill, fixed stand for drill (fixed to concrete surface or stable ground), fresh water supply, Covermeter.

7.12 Chloride Ion Penetration

Concrete core (sample to have minimum diameter of 50 mm) or powder samples for chloride content testing shall be extracted at representative locations. Laboratory testing to determine the chloride content of the samples is to be completed in a NATA accredited laboratory in accordance with AS1012.20.

To take drilled powder samples, the drill bit used should be larger than the likely aggregate size (i.e. should be >20 mm diameter) and the minimum total area of the surface drilled should be equal to the end area of a 50 mm core.

All drillings shall be in the desired increments to suit asset age, exposure conditions and reinforcement cover. Commonly, these increments are in 10mm increments up to 50-70mm. A minimum of 20g of powder sample should be collected for each increment. The chloride content test results shall be analysed to predict the approximate time when the chloride “threshold” is attained at the depth of reinforcement.

For core or powder samples the reinforcement should be located using Covermeter to avoid damages to the rebar when sampling. Concrete core sample results are more accurate in obtaining the chloride profile, however powder samples can be collected inexpensively (especially in overhead applications e.g. soffits), with less damage to the structure, and the results obtained from properly collected samples are acceptably reliable.

Equipment for Core Sampling: Diamond core bit and drill, fixed stand for drill (fixed to concrete surface or stable ground), fresh water supply, Covermeter.

Equipment for Powder Samples: Hammer drill with a 15-25mm drill bit, collection tube (usually a PVC pipe with an angled top and a hole for the drill), collection bags (any bag with an air tight seal), marker to mark depth increments and test location on the bags, ruler to measure depth increments in drill holes, Covermeter. A small bottle brush or toothbrush may be used to clear concrete powder from the hole before collecting the next depth increment.

7.13 Sulphate Content

For sulphate content testing, concrete core samples shall be extracted at representative locations. In order to determine the sulphate content of the core samples, testing shall be carried out in accordance with AS/NZS 1012.20 in NATA accredited Laboratory.

Maximum sulphate content in concrete should not exceed 50 g/kg by weight of cement in accordance with AS/NZS 1379.

Equipment for Core Samples: Diamond core bit and drill, fresh water supply, Covermeter.

7.14 Sulphide Induced Corrosion

Domestic sewage, both fresh and stale, is basically non-aggressive to concrete. The main risk is the anaerobic generation of sulphides within the sewage, which occurs particularly in slowly moving or stagnant systems. This results in the formation and release of gaseous Hydrogen Sulphide (H_2S) into the space above the liquid [27]. H_2S combine with oxygen to form sulphuric acid and attacks the cementitious material of the concrete which leads to eventual structural failure.

7.15 Corrosion Rate Measurement

Linear Polarisation Resistance (LPR) measurement is used to determine the instantaneous corrosion rate of the reinforcement bar. If the measured current density is low, then the rebar is not actively corroding i.e. passive. Table 8 shows the corrosion current density vs condition of rating of the rebar.

Corrosion Current Density (i_{corr}), ($\mu A/cm^2$)	Corrosion Rate
<0.2	Passive – No corrosion
0.2 to 0.5	Low corrosion rate
0.5 to 1.0	Moderate corrosion rate
>1	High corrosion rate

Table 8 – Corrosion Current Density vs Condition Rating Outcome.

Equipment: LPR equipment, concrete breakout equipment and Covermeter and water spray bottle (to saturate surface before testing).

7.16 Petrographic Analysis

A petrographic test can be used to determine chemical and physical irregularities in concrete. This test should be performed by an appropriately experienced laboratory on cores taken from the asset. The reinforcement should be located to avoid it when breakout and the core should be taken from sound concrete.

Equipment for Core Samples: Diamond core bit and drill, fixed stand for drill (fixed to concrete surface or stable ground), fresh water supply, Covermeter, proforma.

7.17 Ultrasonic Pulse Velocity

This technique measures the transit time (in microseconds) of ultra-sound waves passing from an emitter transducer through a concrete sample to a receiver transducer. Faster the transmission time, more dense the concrete and hence better quality of the concrete and is shown in Table 9.

Longitudinal Pulse Velocity, km/s	Condition Rating Outcome
>4.5	Excellent
3.5 – 4.5	Very Good
3.0 – 3.5	Good
2.0 – 3.0	Fair
<2.0	Very poor

Table 9 - Classification of the quality of concrete on the basis of pulse velocity [25].

7.18 Summary of Commonly Used Concrete Inspection Techniques

Name of Tests	Techniques	Application*
Visual Inspection	----	Level of Inspection: Level 1/ Level 2 Surface defects such as cracking, spalling, leaching, erosion or construction defects.
Schmidt (Rebound) Hammer	ASTM C805-08	Level of Inspection: Level 2 Provides a measure of the local surface "hardness" of the concrete and under laboratory conditions the resulting rebound number has been empirically related to compressive strength of concrete.
Delamination Survey	ASTM D4580	Level of Inspection: Level 1/Level 2 Assessment and location and extent of discontinuity in the cover concrete which is substantially separated, but not completely detached, from the concrete.
Impact Echo	ASTM C1383	Level of Inspection: Level 2/Level 3 Locate a variety of defects within concrete components such as delamination's, voids, honeycombing, or measure component thickness.
Ground Penetrating Radar (GPR)	ASTM D6432	Level of Inspection: Level 2/Level 3 It is capable of detecting location of reinforcement, the depth of cover, the location of voids, and location of cracks, in situ density and moisture content variations. Can also detect the location of reinforcement and the depth of cover.
Cement content and type	BS 1881: Part124	Level of Inspection: Level 3 Assess concrete quality

Name of Tests	Techniques	Application*
Ultrasonic Transmission (Ultrasonic Pulse Velocity)	ASTM C597-02	Level of Inspection: Level 2/Level 3 Determination of the variability and quality of concrete by measuring pulse velocity. Using transmission method, the extent of such defects such as voids, honeycombing, cracks and segregation may be determined. This technique is also useful when examining fire damaged concrete.
Covermeter	BS1881-204	Level of Inspection: Level 2/Level 3 Locate embedded reinforcement, measure depth of cover, and estimate approximate diameter of reinforcement.
Corrosion Potential (electrochemical, half-cell)	ASTM C876	Level of Inspection: Level 3 Identify region or regions in reinforced concrete structures where there is a high probability that corrosion is occurring at the time of the measurement.
Concrete Resistivity	ASTM C1202	Level of Inspection: Level 2/Level 3 It is used for measuring the ability of the concrete to conduct the corrosion current. It gives an indication of the rate of corrosion which may occur if corrosion of the reinforcement commences.
Corrosion Rate Measurement/ Linear Polarisation	Linear Polarisation (SHRP-S324 and SHRP-330)	Level of Inspection: Level 3 Determine the instantaneous corrosion rate of the reinforcement located below that test point.
Concrete Breakout	Follow procedure in AS 1012.14	Level of Inspection: Level 3 Determine reinforcement details (e.g. bar size, type, orientation and taped cover) and its condition (e.g. corrosion state and loss of cross sectional area).

Name of Tests	Techniques	Application*
Pullout	ASTM C900/ ASTM E488	Level of Inspection: Level 3 It provides an estimation of the compressive and tensile strengths of hardened concrete; comparison of strength in different locations.
Compressive Strength	AS 1012.9/ AS 1012.14	Level of Inspection: Level 3 Strength of in-place concrete; comparison of strength in different locations.
Tensile Strength (Indirect)	AS1012.14. AS 1012.10	Level of Inspection: Level 3 Estimation of tensile strength of in-place concrete; comparison of strength in different locations.
Identification of presence of ASR	ASTM C227	Level of Inspection: Level 3 Identification of likely presence of ASR.
Apparent Volume of Permeable Voids (AVPV)	AS 1012.21/ ASTM C642-06	Level of Inspection: Level 3 Determine the water porosity or permeability of the concrete microstructure.
Petrographic Examination	ASTM C856 (hardened concrete) or C295 (aggregate)	Level of Inspection: Level 3 Identification of the presence of ASR susceptible aggregates and diagnosis of the presence of ASR.
Carbonation Depth	BS EN 14630-06	Level of Inspection: Level 3 Assess corrosion protection value of concrete with depth and susceptibility of steel reinforcement to corrosion due to carbonation. The results can be used to model concrete carbonation rates to estimate remaining service life.

Name of Tests	Techniques	Application*
Chloride and Sulphate Content	AS 1012.20 BS 1881: Part 124	Level of Inspection: Level 3 Assess risk of steel reinforcement to corrosion due to chloride ingress. Chloride profile will show if chloride has reached the corrosion activation threshold concentration at the steel reinforcement. The chloride profile also can be used to model future deterioration and remaining service life.

Table 10 – Various concrete inspection techniques and levels of inspection.

*ASCE 11-90, ASCE Guideline for Structural Condition Assessment of Existing Buildings, American Society of Civil Engineers, New York, New York, August 1, 1991; adapted with permission of ASCE, 1996.

*Detailed Non-Destructive Bridge Inspection Guidelines, Main Roads of WA, 2010.

Notes – Concrete coring and breakouts

- Number of breakout, samples and position may vary onsite depending on the condition of the tank.
- A Covermeter shall be used to locate the reinforcement and ensure that no reinforcement is cut or damaged during extraction of the core samples.
- All core holes shall be repaired with Parchem Renderoc HB40® or equivalent approved, in accordance with the manufacturer’s recommendations.

8.0 SERVICE LIFE PREDICTION

8.1 Corrosion Process in Reinforced Concrete

An exact or definitive RSL is not possible to devise, however a reasonable prediction can be made based on the visible evidence, relevant laboratory results, modelling results and existing literature regarding deterioration of reinforced concrete.

Two main failure mechanisms affecting the RSL of the Corporation's concrete structure are corrosion of reinforcement and Hydrogen Sulphide (H_2S) induced concrete corrosion. The rate of degradation through failure mechanisms enables a prediction of RSL from the point in time that the condition assessment was conducted.

Determination of RSL enables a well informed decision to be made on how to manage the asset going forward and when funding for an intervention may be required. Clifton [28] stated several methods to predict the service life's and are:

a) Estimations based on experience;

b) Deductions from performance of similar materials;

c) Accelerated testing;

d) Mathematical modelling based on the chemistry and physics of degradation processes; and

e) Application of reliability and stochastic concepts.

The commonly adopted mechanism for corrosion damage [29] is the time to loss of structural integrity is comprised of time to corrosion activation followed by time if corrosion propagation which is discussed in the following section.

8.2 Condition Limit States

According to Building Research Establishment (BRE) Digest 434, RSL can be defined as the time at which any of the following limit states are reached:

The mechanisms of concrete deterioration are primarily chemical-physical in nature and occur in three discrete stages **[Refer: Figure 9]**.

Stage 1: Initiation – Concentration of aggressive species such as chloride, CO_2 etc. is insufficient to initiate any chemical reactions or the chemical reaction is occurring very slowly. No physical damage has occurred. The duration of time may vary from a few minutes to the design life of the structure and may be estimated by chloride modelling and carbonation modelling which is discussed in the following sections.

Stage 2: Propagation – Chemical reactions continue to progress and some physical damage may occur e.g. cracking, delamination, spalling etc. Acceleration of the deterioration process usually occurs during this stage due to increased accessibility of aggressive ions or modification of the concrete environment.

Stage 3: Deterioration – The combined effects of the physical and chemical processes are of sufficient severity that the structure is no longer serviceable (failure occurs) and major remedial work or, in extreme cases, demolition is required.

The main failure mechanism affecting the remaining service life of the reinforced concrete components of water and waste water structure is corrosion of the reinforcement. The commonly adopted mechanism for corrosion damage states that the time to loss of structural integrity is made up of time to corrosion activation followed by time of corrosion propagation.

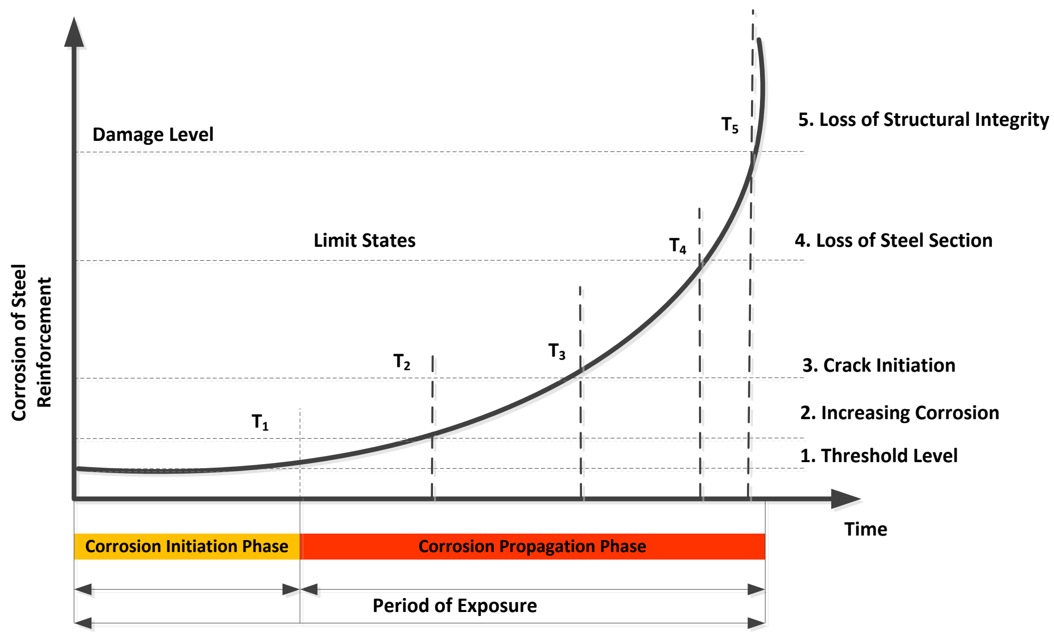


Figure 8 – Condition Limit States for rebar deterioration caused by Chloride induced corrosion.

The determination of service life must take into account three contributing factors, which may be related to the Condition Limit States in Figure 8. These are:

1. Limit of acceptability – key indicators would be loss of aesthetics and safety for all users and the environment. This could be loosely related to T3.

2. Limit of serviceability – meaning a reduction in load carrying capacity, related to T4 as a loss of steel section may result in a loss of strength.

3. Structural Adequacy Compromised – the structure is unsafe to operate, related to T5, and may require major rehabilitation

In terms of the management of a group of common structures, an Asset Management decision to define the acceptable damage level can be made in one of two ways. These are:

Generic definition – This identifies generic condition state limits for all structures, and if the damage level is at or beyond certain condition state limits, then either intervention is required, or the service life has been compromised.

Structure-by-Structure definition – This defines the condition state limit for both end of service life and intervention based on structure specific requirements.

The Consultant carrying out the Level 3 Inspection should consult with the APG to determine an appropriate damage level for the structures before it either requires intervention, or is deemed to have reached its service life.

8.3 Initiation Phase

The initiation of corrosion of the first layer of reinforcing steel (time to T1) due to chloride ingress or carbonation may be estimated by chloride modelling and carbonation modelling, as discussed in Section 14.5 and 14.6 respectively.

8.4 Corrosion Propagation Phase

Sometime after T1, stresses induced by the expansion of corrosion products will lead to fracture of concrete (cracking, delamination, spalling), loss of ultimate strength, loss of bond between steel and concrete and ultimately loss of structural capacity. This deterioration is primarily dependant on the rate of corrosion, fracture properties of concrete, reinforcement area, size and spacing and cover depth.

The time after T1 depends on the corrosion propagation rate, which is often difficult to estimate. In situ corrosion rate tests such as Linear Polarisation Resistance (LPR) or Galvanostatic pulse corrosion rate may be used to determine the rate of corrosion; however these tests have limitations and only provide an approximate estimate of corrosion rate at the time of the test. Measurement of actual corrosion loss can also provide an estimate of corrosion rate, although this may tend to over-estimate the general rate.

Other site measurements that assist in estimating probable propagation time include concrete resistivity, half-cell potential maps and visual inspections of the reinforcement at breakouts.

From literature and based on industry experience, the period between activation and first significant crack (between T1 and T3 in Figure 8) is typically of the order 10 to 20 years at high corrosion rates up to 10 microns/year as stated in BRE 43 for crack widths up to 0.3 mm. The time to cracking is longer for small diameter bars due to a smaller volume of rust product being formed, and where cover is greater. The significance of cracking depends on the structural component.

8.4.1 Prediction of RSL for Chloride Induced Corrosion

The predicted service life, however, would be the addition of time to T1 and time from T1 to the designated condition limit state for end of service life (whether this is T3, T4 or T5). With current materials condition, Renewals Planning, APG, will estimate the service life as follows:

Age at end of Service life = (Time to T1) or

(Time to T1) + (Time from T1 to T3) or

(Time to T1) + (Time from T1 to T3) + (Time from T3 to T4)

The assessment of time from T1 to T3 or T4 requires a considerable amount of engineering judgment when the reinforcement arrangement and number of bars departs from that studied in the literature above. Any engineering judgement on this time from T1 to T3 and T4 should be backed up as far as practicable with results from testing and observations of the exposed reinforcing bar and all assumptions/considerations clearly identified in the report for consideration by Renewals Planning, APG.

8.4.2 Prediction of RSL for Hydrogen Sulphide Induced Corrosion

Hydrogen Sulphide corrosion in concrete follows bilinear behaviour whereby only two parameters need to be determined– the time to initiation of corrosion loss, $t_{initiaion}$, [Refer: Figure 9] and the rate of corrosion.

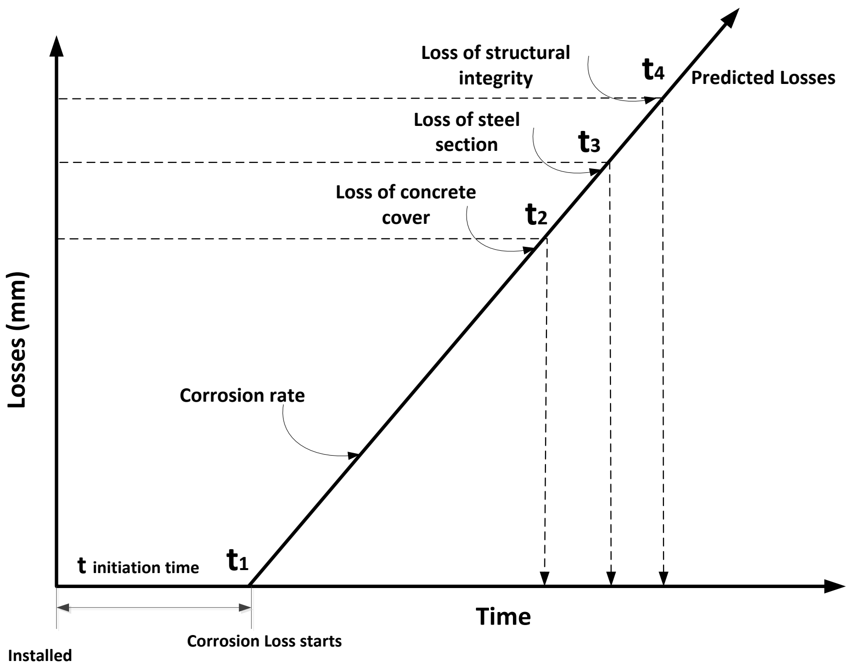


Figure 9 – Condition Limit States for rebar deterioration caused by Hydrogen Sulphide corrosion.

The predicted service life, however, would be the addition of time to T1 and time from T1 to the designated condition limit state for end of service life (whether this is T2, T3 or T4). With current materials condition, Renewals Planning, APG, will estimate the service life as follows:

Age at end of Service life = (Time to T1) or

(Time to T1) + (Time from T1 to T2) or

(Time to T1) + (Time from T1 to T2) + (Time from T2 to T3)

As explained before, the assessment of time in sulphide corrosion from T1 to T3 or T4 requires a considerable amount of engineering judgment when the reinforcement arrangement and number of bars departs from that studied in the literature above.

Any engineering judgement on this time from T1 to T3 and T4 should be backed up as far as practicable with results from testing and observations of the exposed reinforcing bar and all assumptions/considerations clearly identified in the report for consideration by Renewals Planning, APG.

8.5 Chloride Induced Corrosion

Chloride ions can penetrate concrete by means of capillary absorption, hydrostatic pressure, and diffusion. They may be added during mixing either deliberately as an admixture or as a contaminant in the original constituents. Chloride ions migrate through the concrete by diffusion under a concentration gradient **[Refer: Photo 32]**.

When concrete surface is exposed wetting and drying cycles, with water (possibly containing chlorides), it will be drawn into the pore structure though capillary suction. Absorption is driven by moisture gradients. This transport mechanism will not, by itself, bring chlorides to the level of the reinforcing steel unless the concrete is of extremely poor quality and the reinforcing steel is shallow. It does serve to quickly bring chlorides to some depth in the concrete and reduce the distance that they must diffuse to reach the rebar [30].

Photo 32 - Corrosion of the reinforcement due to chloride contamination.

[Photo Courtesy: Repair and Maintenance of Marine Structures by Cathodic Protection, Alan R. Bird, Monash University, Melbourne, Vic, 3000]

Once chloride ions have reached the reinforcement in sufficient quantities they will depassivate the embedded steel rebar by breaking down the protective oxide layer normally maintained by the alkaline environment.

The concentration of chloride ions required to initiate and maintain corrosion is dependent upon the alkalinity and it has been shown that there is an almost linear relationship between hydroxyl ion concentration and the respective threshold level of chloride [31].

Figure 10 shows the passive film breakdown and concrete failure due to the ingress of chloride ions.

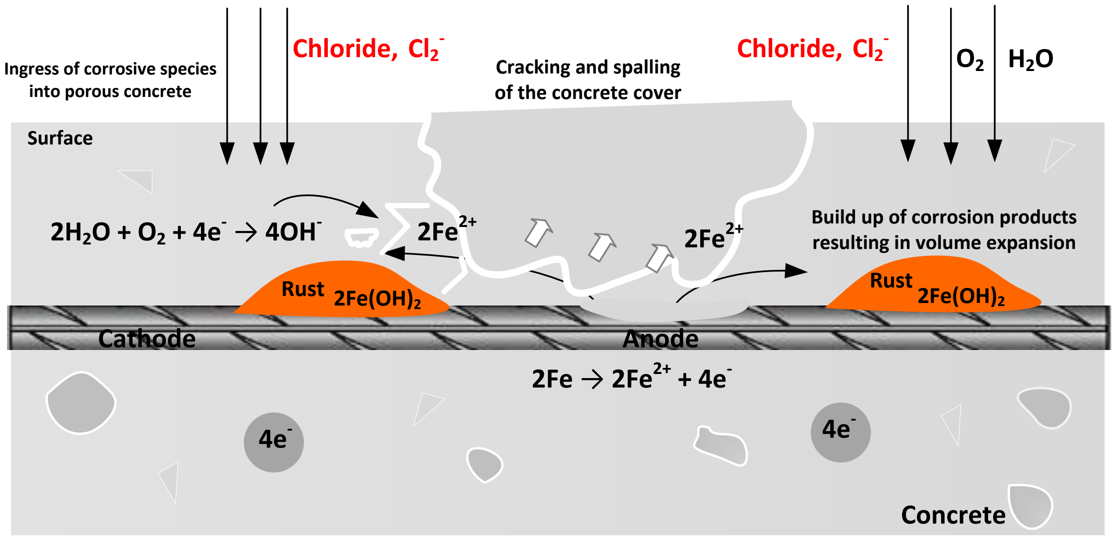


Figure 10 – Passive film breakdown and concrete failure.

Chloride diffusion is the transfer of mass by random motion of the free chloride ions in the pore solution resulting from regions of higher concentration to regions of lower concentration [32, 33].

Since the ingress of chloride ions into concrete involves inward movement of water containing chloride ions through its pore structure, the prediction of chloride ion penetration into concrete is usually obtained using Fick's second law of diffusion.

Theoretically, the initiation time (t) can be estimated by Fick's second law of diffusion:

$$C_{x,t} = C_i + (C_s - C_i) * \left(1 - erf\left[\frac{x}{2\sqrt{Dt}}\right]\right)$$

Where,

D = chloride diffusion coefficient;

C_i = initial background chloride concentration of concrete and is usually negligible;

C_S = surface chloride content;

x = depth in concrete;

C(x,t) = chloride concentration at depth x after time t; and erf = complement of the error function.

In general, the values of the surface chloride concentration and diffusion coefficient can be estimated from the above equation by determining the best fit curve through data obtained by laboratory analysis of chloride ion content of concrete samples [Refer: Figure 11].

For an existing structure, once the surface chloride concentration and diffusion coefficient are known, taking account of the current age, the initiation time can be estimated. If the chloride thresholds have been exceeded at the reinforcement depth at the time of testing, and no calculation of initiation time is required [34].

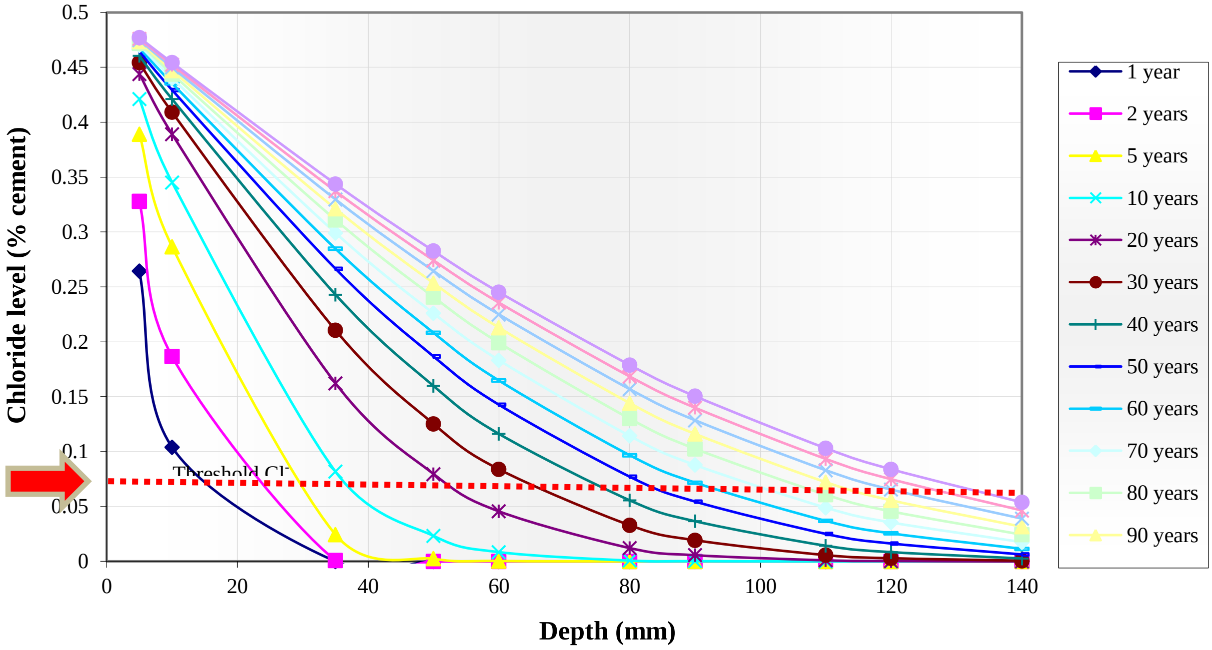


Figure 11 - Chloride level at various depths in the concrete.

Although considerable research has been carried out in an attempt to define chloride threshold levels, it has become increasingly clear that there is no single value that represents the wide range of concreting materials and exposure conditions [35, 36].

8.6 Carbonation Induced Corrosion

Carbonation is the result of the interaction of carbon dioxide gas in the atmosphere with the alkaline hydroxides in the concrete. Like many other gases carbon dioxide dissolved in water to form Carbonic acid.

Unlike most other acids, the Carbonic Acid (H_2CO_3) does not attack the cement paste, but just neutralizes the alkalis in the pore water, mainly forming calcium carbonate ($CaCO_3$) that lines the pores:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O$$

Calcium Hydroxide ($Ca(OH)_2$) in the concrete pores maintains the alkalinity and hence the corrosion resistance of the rebar. However, after all the locally available Calcium Hydroxide reacts with Carbonic Acid, precipitating the Calcium Carbonate and allowing the pH to fall to a level where steel will corrode **[Refer: Photo 33].**

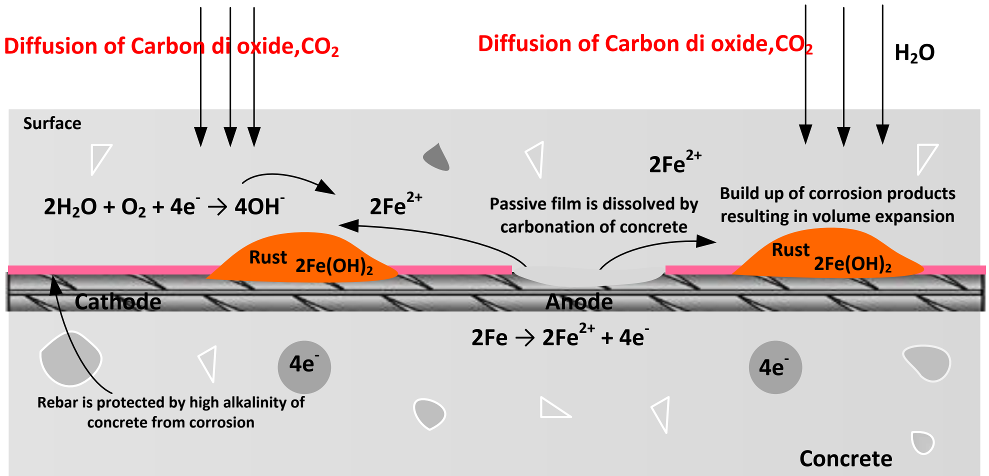


Figure 12 – Carbonation principle.

The depth of carbonation in a structure can be quite easily established by the use of phenolphthalein indicator on freshly exposed material. The distinctive colour change, from deep pink in unaffected concrete to clear in the carbonated region, is sufficiently accurate for most practical purposes provided a number of measurements are obtained to allow for local variations **[Refer: Photo 34]**.

Photo 33 – Concrete failure due to Carbonation.

[Photo Courtesy: http://www.st-astier.co.uk/blog/2013/3/4/understanding_concrete_carbonation]

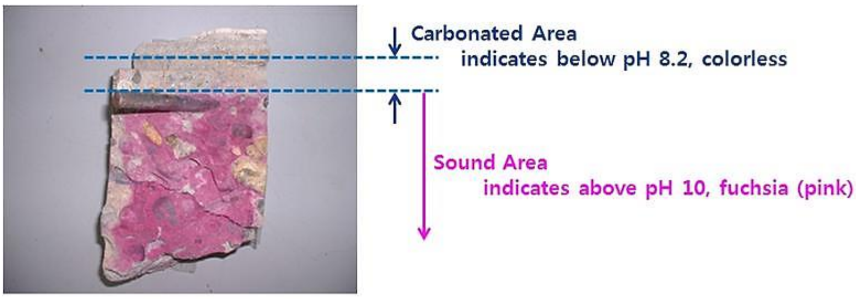


Photo 34 – Carbonation test of concrete surface.

[Photo Courtesy: http://pavemaintenance.wikispaces.com/Carbonation+of+Concrete+-+Dahee.]

Carbonation occurs progressively from the surfaces of the concrete exposed to atmospheric Carbon dioxide (CO_2,) but does so at a decreasing rate, because the CO_2 has to diffuse through the pore system, including the already carbonated surface zone of concrete.

The rate of carbonation is dependent on the permeability of the concrete to CO_2, which is dependent on the total alkali content, water/cement ratio, and available moisture in the hardened concrete (which is a function of the atmospheric relative humidity).

The rate of reaction of CO_2 with concrete is closely related to the relative humidity of the environment in which the structure resides. Permanently saturated environments and buried structures that are not in direct contact with atmospheric carbon dioxide are not at significant risk of carbonation, and thus are not covered by the model.

The optimum effective relative humidity (RH) in the concrete for carbonation is 50-60%. At a relative humidity above 95% the diffusion of carbon dioxide is very slow because of the reduced space for gaseous diffusion in water-filled pores. At a relative humidity below 50% the supply of water to dissolve the carbon dioxide is limited and the rate of attack slows.

A generalised carbonation model involving a relationship between depth of carbonation x_1, time of exposure t_1, and carbonation coefficient D_{Carb} is used for carbonation penetration predictions. This relationship is as follows:

$$x_1 = D_{Carb} \sqrt{t_1}$$

The actual depth of the concrete cover that has carbonated is determined by phenolphthalein indicator. The distinctive colour change, from deep pink in unaffected concrete to clear in the carbonated region, is sufficiently accurate for most practical purposes provided a number of measurements are obtained to allow for local variations.

Using this depth and with the age of the concrete, the above equation can be used to determine the D_{Carb}. The above equation is then used again to determine an estimate of the length of time needed for the whole cover concrete to become carbonated and leave the reinforcement in an environment where corrosion can commence.

Currently, Water Corporation adopts Concrete Structures Remaining Service Life (CSRL) tool to determine the depth of carbonation on the concrete structure. The carbonation model is based on Building Research Establishment (BRE).

The time at which the carbonation will reach to the reinforcement cover can be obtained from the above Figure 13. For example, carbonation reaches a depth of 15 mm when the concrete is at an age of approximately 70 years.

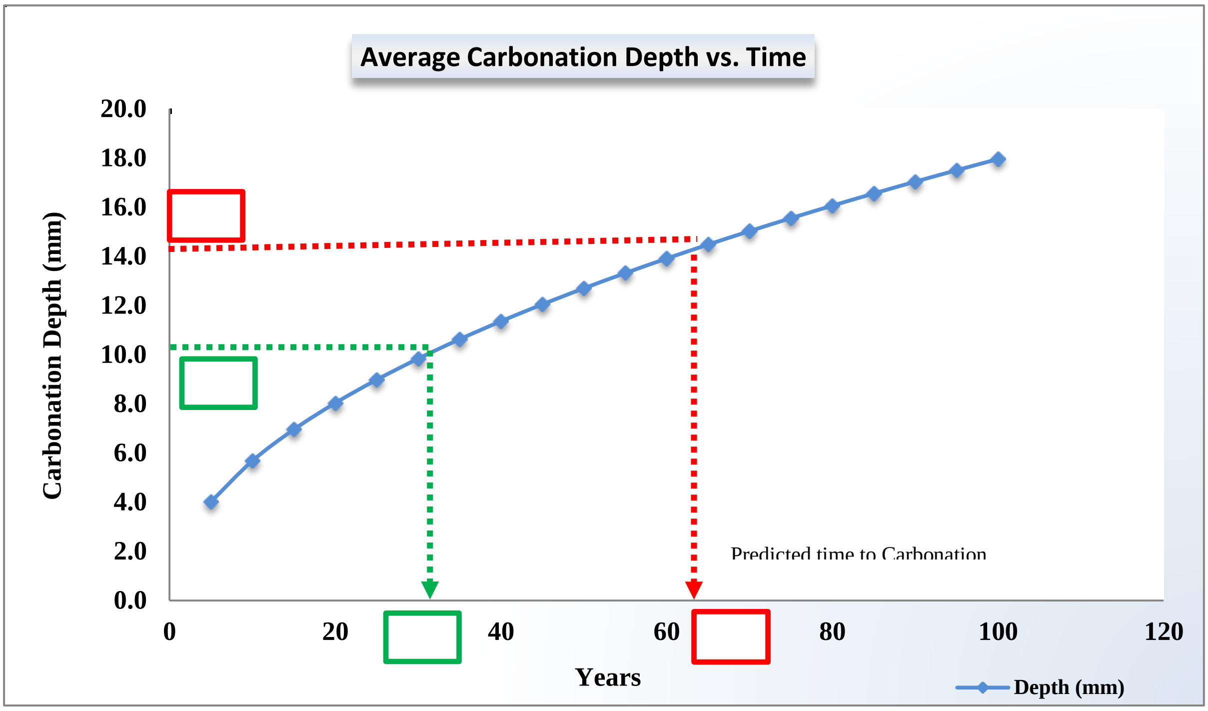


Figure 13 – Measurement of average carbonation depth vs time.

8.7 Hydrogen Sulphide Corrosion

Concrete structures in waste water treatment plant corrode as the result of chemical and biological processes. Biological processes, (Microbial Induced Corrosion or MIC); are responsible for the majority of the degradation of the concrete matrix as a result of metabolic activity.

Approximately 40% of the damage in concrete sewers can be attributed to biogenic sulphuric acid attack **[Refer: Photo 35]**. Sulphide corrosion, which is often called microbiologically induced corrosion, has two distinct phases as follows [37]:

1) The conversion of sulphate in wastewater to sulphide, some of which is released as gaseous hydrogen sulphide.

2) The conversion of hydrogen sulphide to sulphuric acid, which subsequently attacks susceptible pipeline materials.

The reduction of sulphate in the presence of waste organic matter in a wastewater collection system can be described as follows:

$$SO_4^{2-} + \text{Organic Matter} + H_2O \rightarrow 2HCO_3^{-} + H_2S$$

If concentrations of sulphate and dissolved organic material in the wastewater are high and if these materials are able to penetrate the solids deposits, then large amounts of sulphides can be produced.

Once sulphides are produced in the wastewater as the result of sulphate reduction, H2S gas will be released into the atmosphere [38].

Photo 35 – Typical concrete surface attacked by Hydrogen Sulphide.

To determine the service life of a waste water treatment concrete structure, it is necessary to predict the instantaneous rate of corrosion over time and from this calculate the cumulative loss of concrete. When the cumulative loss of concrete exceeds the depth of concrete covering the structure reinforcement, (the "concrete cover"), the service life of the structure may or may not come to an end. It is assumed that once the metal reinforcement of the structure is exposed structural failure of the waste water structure is imminent [39].

$$Service\ Life = \frac{CD_{t=0}}{CR} + t_{in}$$

Where CR is the calculated corrosion rate ($t > t_{in}$) (mm/yr), $CD_{t=0}$ is the depth of concrete overlaying the metal reinforcement at the time of the structure installation (mm) and t_{in} is the length of the incubation time in (years).

The field data suggests that corrosion losses commence once the surface pH falls below pH=6. The time taken for the surface to reach pH=6, (the incubation time or 't_{in}') fell into the range of 10 to 23 months [38]. Compared to the likely lifespan of the structure this does not constitute a significant length of time and consequently can usually be ignored when calculating the service lifespan of a structure.

The impact of the initiation or incubation period, t_{in}, would however be more significant if corrosion predictions for a limited period of a structure's service life are required (for the next decade for example). In these circumstances it would be of benefit to be able to estimate the value of t_{in} for a given site from the available environmental data.

Above pH=6 it is assumed that there is little biological activity on the concrete surface, hence corrosion results from the action of H_2S dissolves into the pore water. Once dissolved in the pore water the HS ion formed can undergo a series of chemical (i.e. abiotic) reaction to form a variety of oxidated sulphur species.

If temperature, humidity and H_2S concentration are known (or can be estimated) t_{in} can be estimated via:

$$t_{in}(years) = 1.24\ x\ 10^{-10} x\ [H_2S]^{-0.8}\ x\ \frac{(0.0955\ x\ RH\% - 9.8044)}{(1 - 0.01245\ x\ RH\%)}\ x\ e^{((56{,}000/(8.314\ x\ (T+273))} + 0.91$$

If only H_2S concentration in the gas phase is known t_{in} can be estimated via:

$$t_{in}(years) = 1.62 - 0.083\ x\ ln[H_2S]$$

9.0 APPENDIX A - ASSET CONDITION RATING

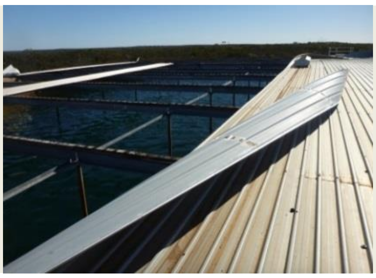
The following should be taken into consideration when condition rating various components of the steel tank:

- Condition Rating is adopted from WERF model [15].
- Level 1 inspection is visual and condition rating is subjective. Therefore, ACA Outcome can include multiple Condition Ratings for the Excellent to Fair categories.
- Level 2 is a formalised inspection will be carried out by the Corporation ACA panel Inspection Service Providers. Hence, more accurate condition rating can be achieved.

9.1 Tek Screws

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects	
3 or 4	**Very Good**	• Minor corrosion/deterioration to Tek Screws • Light surface rust to Tek Screws • Light surface rust to thread portion of the Tek Screws	
5 or 6	**Good**	• Moderate corrosion/deterioration to Tek Screws • Moderate surface rust to Tek Screws • Early signs of Necking surface rust to thread portion of the Tek Screws	
7 or 8	**Fair**	• Severe corrosion/necking to Tek Screws • Severe surface rust to Tek Screws • Severe signs of localised thinning or Necking rust to thread portion of the Tek Screws	
9	**Poor**	• Severe corrosion/necking to Tek Screws • Imminent failure to Tek Screws • Severe signs of Necking surface rust to thread portion of the Tek Screws	
10	**Very Poor**	• Tek Screw broken or disconnected from the roof sheeting	

9.2 Roof - External

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects	
3 or 4	**Very Good**	• Minor corrosion/deterioration observed on the roof sheet	
5 or 6	**Good**	• Moderate corrosion/deterioration observed on the roof sheet • Moderate surface rust to Tek Screws • At times, random holes are observed on the roof sheet	
7 or 8	**Fair**	• Severe corrosion/necking to the internal roof sheet support structures • Sagging of roof sheet observed	
9	**Poor**	• Imminent failure to roof sheet collapsing inside the tank • High velocity wind may lift the roof sheeting off from the structure	
10	**Very Poor**	• Tek Screw broken or disconnected from the roof sheeting	

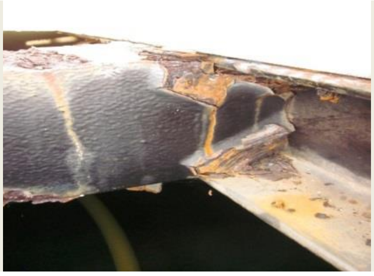
9.3 Wall - External

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects	
3 or 4	**Very Good**	• Minor deterioration to wall • There are no cracks, spalling	
5 or 6	**Good**	• Hairline cracks	
7 or 8	**Fair**	• Significant deterioration on the tank wall due to ageing • Minor seepage of water through vertical cracks and cold joints on the wall	
9	**Poor**	• Water leak is predominant in some areas	
10	**Very Poor**	• Severe leak and water is gushing out of the tank. • This may compromise tank floor integrity	

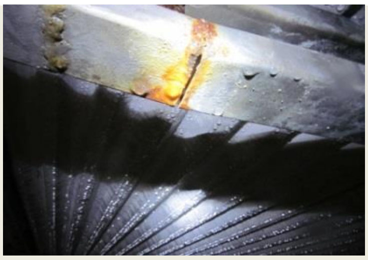
9.4 Footing Ring

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects	
3 or 4	**Very Good**	• Minor deterioration to wall • There are no cracks, spalling	
5 or 6	**Good**	• Hairline cracks	
7 or 8	**Fair**	• Significant deterioration on the tank wall due to ageing • Minor seepage of water through vertical cracks and cold joints on the wall	
9	**Poor**	• Water leak is predominant in some areas	
10	**Very Poor**	• Severe leak and water is gushing out of the tank. • This may compromise tank floor integrity	

9.5 Access Hatch

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects	
3 or 4	**Very Good**	• Minor corrosion/deterioration to zinc coating • Light surface rust to steel substrate	
5 or 6	**Good**	• Moderate corrosion/deterioration to access coating • Light surface rust to steel substrate	
7 or 8	**Fair**	• Severe corrosion due to hot dip galvanising coating deterioration • Severe surface rust noted on large areas	
9	**Poor**	• Zinc coating delamination and failure of protective coating resulting in corrosion	
10	**Very Poor**	• Severe corrosion/ on the access hatch • Imminent failure due to steel corrosion	

9.6 Beams

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	Excellent	• No or very minor defects	
3 or 4	Very Good	• Minor corrosion/deterioration to roof beams • Light surface rust resulting from hot dip galvanised zinc depletion	
5 or 6	Good	• Moderate corrosion/deterioration to roof beams • Most of the hot dip galvanised zinc depleted on the roof beam	
7 or 8	Fair	• Severe corrosion to steel • Early signs of lamellar corrosion	
9	Poor	• Severe corrosion to steel • Severe signs of lamellar corrosion on larger areas of the component	
10	Very Poor	• Imminent failure of the beams • Failure on the weld joints	

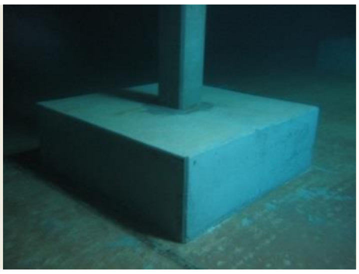
9.7 Purlins

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects	
3 or 4	**Very Good**	• Minor corrosion/deterioration to purlins • Light surface rust resulting from hot dip galvanised zinc depletion	
5 or 6	**Good**	• Moderate corrosion/deterioration to purlins • Most of the hot dip galvanised zinc depleted on the roof beam	
7 or 8	**Fair**	• Severe corrosion to steel • Early signs of corrosion and localised deterioration	
9	**Poor**	• Severe corrosion to steel • Severe signs of corrosion on larger areas of the component	
10	**Very Poor**	• Imminent failure of the purlins	

9.8 Roof - Internal

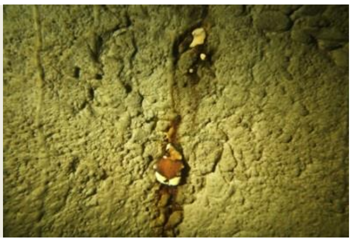
ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects	
3 or 4	**Very Good**	• Minor corrosion/deterioration observed on the roof sheet	
5 or 6	**Good**	• Moderate corrosion/deterioration observed on the roof sheet • Moderate surface rust to Tek Screws • At times, random holes are observed on the roof sheet	
7 or 8	**Fair**	• Severe corrosion/necking to the internal roof sheet support structures	
9	**Poor**	• Imminent failure to roof sheet collapsing inside the tank • High velocity wind may lift the roof sheeting off from the structure	
10	**Very Poor**	• Tek Screw broken or disconnected from the roof sheeting Roof	

9.9 Columns

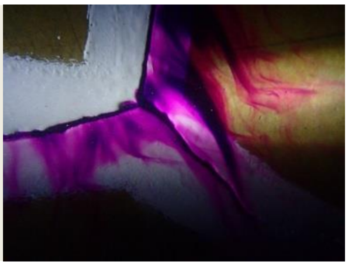
ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects	
3 or 4	**Very Good**	• Insignificant/Moderate deterioration to the column	
5 or 6	**Good**	• Moderate deterioration with signs of bug holes in some areas	
7 or 8	**Fair**	• Severe corrosion on the tank steel columns • Severe signs of localised thinning of columns	
9	**Poor**	• Cracking of columns	

10	**Very Poor**	• Cracking of columns resulting in structural failure	

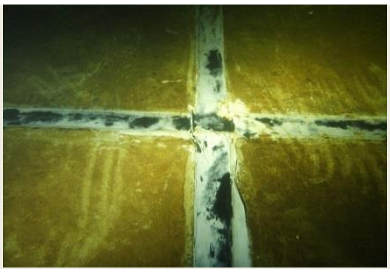
9.10 Wall - Internal

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects	
3 or 4	**Very Good**	• Minor concrete deterioration to the concrete • Random appearance of aggregate in some areas	
5 or 6	**Good**	• Moderate deterioration to wall concrete • Bug holes are observed	
7 or 8	**Fair**	• Severe deterioration of concrete • At times the concrete is soft and cheesy	
9	**Poor**	• Concrete spalling observed due to the volume expansion of rebar corrosion	
10	**Very Poor**	• Deterioration of concrete with delamination • Cracks and disjoint of concrete observed. This leads to severe water leak and eventually undermine foundation and compromising integrity of the tank	

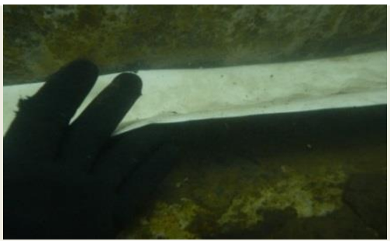
9.11 Floor

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects on the floor	
3 or 4	**Very Good**	• Moderate deterioration to the floor	
5 or 6	**Good**	• Appearance of bug holes observed on the concrete	
7 or 8	**Fair**	• Severe deterioration of concrete • At times the concrete is soft and cheesy	
9	**Poor**	• Concrete spalling observed due to the volume expansion of rebar corrosion	
10	**Very Poor**	• Cracks are observed on the concrete floor • Imminent leak through the tank floor	

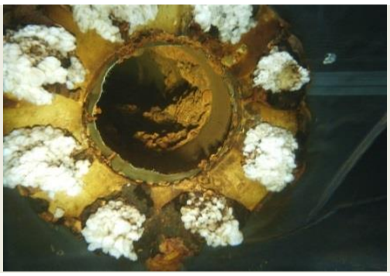
9.12 Floor – Joint Sealants

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects on the floor polyurethane joints	
3 or 4	**Very Good**	• Moderate deterioration to the floor polyurethane joints	
5 or 6	**Good**	• Moderate deterioration with signs of swelling, cracking on the floor bitumen/polyurethane joints	
7 or 8	**Fair**	• Moderate deterioration with signs of swelling, cracking, ballooning of the floor bitumen/polyurethane joints	
9	**Poor**	• Moderate deterioration of the floor bitumen/polyurethane joints noted with signs of swelling, cracking, ballooning	
10	**Very Poor**	• Significant deterioration of the floor bitumen/polyurethane joints noted with signs of swelling, cracking, ballooning • At times, joints are noted with depression (sunken) • Signs of severe leak through the tank floor	

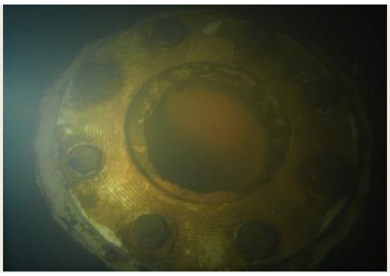
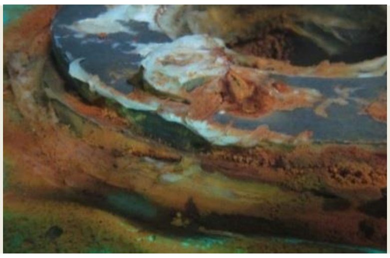
9.13 Floor to Wall Joints

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects on the floor polyurethane joints	
3 or 4	**Very Good**	• Moderate deterioration to the floor polyurethane joints	
5 or 6	**Good**	• Moderate deterioration with signs of swelling, cracking on the floor bitumen/polyurethane joints	
7 or 8	**Fair**	• Moderate deterioration with signs of swelling, cracking, ballooning of the floor bitumen/polyurethane joints	
9	**Poor**	• Moderate deterioration of the floor polyurethane joints noted with signs of swelling, cracking, ballooning	
10	**Very Poor**	• Significant deterioration on the floor polyurethane joints noted with signs of swelling, cracking, ballooning • Signs of severe leak through the tank floor	

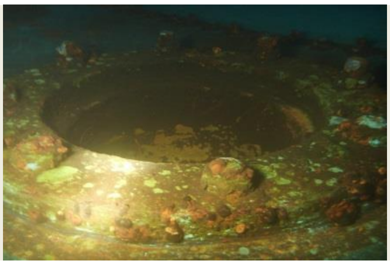
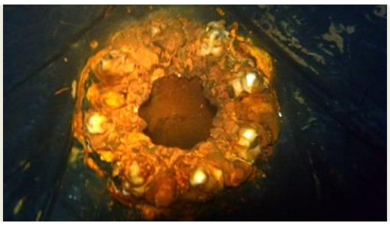
9.14 Inlet Pipe

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects on the inlet pipe	
3 or 4	**Very Good**	• Moderate deterioration/signs of corrosion to the inlet pipe	
5 or 6	**Good**	• Deposition of chloride on the zinc coated bolts • Moderate to severe corrosion	
7 or 8	**Fair**	• Signs of corrosion on the inlet pipe	
9	**Poor**	• Severe corrosion on the inlet pipe	
10	**Very Poor**	• Severe corrosion on the inlet pipe	

9.15 Scour Pipe

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects on the scour pipe	
3 or 4	**Very Good**	• Moderate deterioration/signs of corrosion to the scour pipe	
5 or 6	**Good**	• Deposition of chloride on the zinc coated bolts • Moderate to severe corrosion	
7 or 8	**Fair**	• Signs of corrosion on the scour pipe	
9	**Poor**	• Severe corrosion on the scour pipe	
10	**Very Poor**	• Severe corrosion on the scour pipe	

9.16 Outlet Pipe

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects on the outlet pipe	
3 or 4	**Very Good**	• Moderate deterioration/signs of corrosion to the outlet pipe	
5 or 6	**Good**	• Deposition of chloride on the zinc coated bolts • Moderate to severe corrosion	
7 or 8	**Fair**	• Signs of corrosion on the outlet pipe	
9	**Poor**	• Severe corrosion on the outlet pipe	
10	**Very Poor**	• Severe corrosion on the outlet pipe	

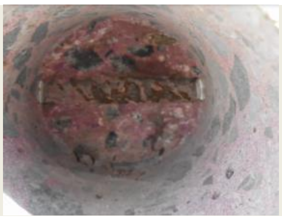
9.17 Overflow Pipe

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	**Excellent**	• No or very minor defects on the overflow pipe	
3 or 4	**Very Good**	• Moderate deterioration/signs of corrosion to the overflow pipe	
5 or 6	**Good**	• Moderate to severe corrosion on the overflow	
7 or 8	**Fair**	• Signs of severe corrosion on the overflow pipe	
9	**Poor**	• Severe corrosion on the bell-mouth of the overflow pipe	
10	**Very Poor**	• Failure of the overflow pipe due to sever corrosion/deterioration	

9.18 Ladder

ACA Rating	ACA Outcome	Description	Descriptive Photograph
1 or 2	Excellent	• No or very minor defects	
3 or 4	Very Good	• Minor corrosion/deterioration to the rails and rungs	
5 or 6	Good	• Moderate corrosion/deterioration to the ladder rails and rungs • Early signs of moderate rust	
7 or 8	Fair	• Severe localised corrosion/necking on the ladder rails	
9	Poor	• Severe localised corrosion/necking on the ladder rails • Imminent failure to the ladder	
10	Very Poor	• Ladder broken or disconnected from the wall	

9.19 Rebar Corrosion

Storage Tank Element	ACA Rating	ACA Outcome	Description	Descriptive Photograph
Rebar	1 or 2	Excellent	• No or very minor rebar corrosion	
	3 or 4	Very Good	• Minor corrosion/deterioration to rebar • Light surface rust to the rebar resulting from chloride environment	
	5 or 6	Good	• Moderate corrosion/deterioration • Light surface rust to the rebar resulting from Sulphate in the wastewater environment	
	7 or 8	Fair	• Severe corrosion to the rebar • Surface rust to the rebar resulting from chloride environment	
	9	Poor	• Severe corrosion resulting in localised 90% of rebar loss • Surface rust to the rebar resulting from chloride environment	
	10	Very Poor	• Rebar is 100% deteriorated.	

14.0 APPENDIX B – LEVEL 1 INSPECTION TEMPLATE (TANK CLEANING)

Date of Inspection	
Report Completed By	
Inspection Completed By	
Client	
Tank / Reservoir Name	
Asset ID (Functional Location)	
Tank / Reservoir Location	
Tank / Reservoir Height	
Tank / Reservoir Diameter	
Tank Stand Height (if applicable)	
Volume	
Construction Year	
Construction Materials	

INSPECTION SUMMARY AND KEY OBSERVATIONS

Urgent safety issues exist	

Tank Leakage Visible		**Estimated Leakage volume**	
Tank Seal Inadequate			
Pre-clean sediment visible			
Peak Pre-Clean Sediment Depth (mm)		**Average Pre-Clean Sediment Depth (mm)**	

EXTERNAL COMPONENTS INSPECTION

ITEM #	COMPONENT DESCRIPTION	CONDITION RATING	COMMENTS	WATER CORPORATION REVIEW REQUIRED?*
1	Access Track			
2	Site Security			
3	Compound Fencing			
4	Site Drainage			
5	Concrete Walls Structural Condition			
6	Steel Walls Structural Condition			
7	Side Access Hatch			

8	**Paint or Coating Condition (walls)**			
9	**Tank / Reservoir Roof**			
10	**Tek Screws and Fasteners (roof)**			
11	**Tank Footing Ring**			
12	**Tank Stand**			
13	**Tank Stand Concrete Footings**			
14	**Visible Leaks Around Tank**			
15	**Inlet**			
16	**Outlet**			
17	**Overflow**			
18	**Antenna / Tower**			
19	**Level Indicator**			
20	**Valve Pit**			
21	**External Access Ladder**			
22	**Ladder Ascenders & Compliance Plates**			
23	**Working Platform on Roof**			
24	**Hatch**			

25	**Handrails / Edge Protection**			
26	**Rescue Davit & Compliance Plate**			
27	**Davit Mount & Compliance Plate**			
28	**Fall Arrest Points & Compliance Plates**			
29	**Ventilation**			
30	**Bird / Insect Proofing**			

INTERNAL COMPONENTS INSPECTION

ITEM #	COMPONENT DESCRIPTION	CONDITION RATING	COMMENTS	WATER CORPORATION REVIEW REQUIRED?*
31	**Concrete Walls Structural Condition**			
32	**Steel Walls Structural Condition**			
33	**Paint or Coating Condition (walls)**			
34	**Liner Condition (walls)**			
35	**Concrete Floor Structural Condition**			
36	**Concrete Floor Expansion Joints**			
37	**Steel Floor Structural Condition**			

38	**Paint or Coating Condition (floor)**			
39	**Liner Condition (floor)**			
40	**Wall to Floor Joint**			
41	**Wall to Roof Joint**			
42	**Roof Support Columns**			
43	**Roof Main Beams**			
44	**Roof Secondary Support (purlins)**			
45	**Roof Sheeting and Fasteners**			
46	**Ventilation**			
47	**Inlet**			
48	**Outlet**			
49	**Scour**			
50	**Overflow**			
51	**Anodes / Cathodic Protection**			

52	**Internal Ladder**			
53	**Level Indicator**			
54	**Pre-Clean Sediment Depth**			
55	**Pre-Clean Sediment Description**			
56	**Foreign Objects, Insects, Animals**			

INSPECTION VIDEOS AND IMAGES

Refer to electronic data for comprehensive inspection video of internal asset components
(Attach the links)

15.0 APPENDIX C – LEVEL 1 INSPECTION TEMPLATE (DETAILED TANK INSPECTION)

1.0 Cover Page

2.0 Report Detail

3.0 Items for Review

4.0 Water Quality

5.0 Safety

6.0 External Components

7.0 Internal Components

8.0 Tank Arrangement

9.0 Asset condition rating for various tank components (Refer Appendix B Section 10).

16.0 APPENDIX D - LEVEL 2 FORMALISED INSPECTION TEMPLATE

➢ **Note**:

During Level 2 inspection, if warranted, then Level 3 inspection should be carried out at the same time. The same ISP may be used for both Level 2 and Level 3 inspections and should assist in preparing the scope of Level 3 Inspection.

The Level 2 Inspection brief should include the items discussed in the following sections. For more details on the report format, references shall be made Aqua Doc No. 11649813 [39].

1.0 Executive Summary

Provide an executive summary that captures only the essential findings and recommendations. Include the inspection's most pertinent facts in a clear and concise manner.

2.0 Objective

The objective should clearly state what outcome is expected of the Level 2 Inspection report, for example a baseline report that documents current condition parameters or a scoping report that requires appropriate recommendations for remediation.

3.0 Background

The background should summarise any past inspection findings, the history of any issues with the structure and identify the prime reason, or reasons, for undertaking the Level 2 Inspection.

4.0 Introduction

The introduction should provide background information about the asset, highlight any issues with the asset and present a detailed scope of works. The introduction may include some or all of the following:

- Purpose of the inspection
- Background
- Asset Details
- Asset Location and Exposure Environment
- Summary of Design for Durability
- Summary of Review of Previous Inspection Findings
- Project Inputs (including required service life)
- Scope of Works
- Visual and Delamination Survey
- Testing Schedule
- Other (such as specific design check associated with testing)

5.0 Formalised Inspection Results

This section is to present investigation results for each test undertaken. Full inspection data should be included in Appendices. This report section should complement, and refer to, these guidelines and only describe test procedures to the extent necessary for the understanding of the report, or where not covered by these guidelines. This section may include some or all of the following:

- Visual and Delamination Survey Results
- Rebound Hammer
- Concrete Breakout
- Covermeter Survey
- Half-cell Potential Survey
- Resistivity Measurements

6.0 Summary of Current Condition

This section shall be clearly set out by asset component in accordance with the design drawing e.g. raker arm, influent well, scum shovel etc.

7.0 Discussion

This section should discuss and recommend the various options for maintenance or remediation. Discussion of investigation results shall be clearly set out by asset component.

8.0 Conclusions and Recommendations

This section should provide condition rating of individual components inspected should be included. The rating shall be in accordance with Figure 1 of this document.

- Durability Design Requirements.
- Conclusion.
- Summary of Recommended Maintenance and Remedial Options.

9.0 Appendices

Appendices are to include any relevant workings, predictions, certificates etc. Typical appendices may include:

Appendix A - Asset Details

Appendix B - Photographs

Appendix C - Inspection and Testing Schedule

Appendix D - On-site Investigation Results

17.0 APPENDIX E - LEVEL 3 – DETAILED INVESTIGATION TEMPLATE

Note:

The Level 3 Inspection brief should include the following items.

Note 1 – number of breakout, samples and position may vary onsite depending on the condition of the tank.

Note 2 – A Covermeter shall be used to locate the reinforcement and ensure that no reinforcement is cut or damaged during extraction of the core samples.

Note 3 – All core holes shall be repaired with Parcehm Rendaroc® HB40 or equivalent approved, in accordance with the manufacturer's recommendations.

Note 4 – Any products in contact with potable water shall have AS/NZS 4020 certification.

For more details on the report format, references shall be made Aqua Doc No. 11649813 [39].

1.0 Executive Summary

Provide an executive summary that captures only the essential findings and recommendations. Include the inspection's most pertinent facts in a clear and concise manner.

2.0 Objective

The objective should clearly state what outcome is expected of the Level 3 Inspection report. For example, a baseline report that documents current condition parameters or a scoping report that requires appropriate recommendations for remediation.

3.0 Background

The background should summarise any past inspection findings, the history of any issues with the structure and identify the prime reason, or reasons, for undertaking the Level 2 Inspection.

4.0 Introduction

The introduction should provide background information about the asset, highlight any issues with the asset and present a detailed scope of works. The introduction may include some or all of the following:

- Purpose of the inspection
- Background
- Asset Details
- Asset Location and Exposure Environment
- Summary of Design for Durability
- Summary of Review of Previous Inspection Findings
- Project Inputs (including required service life)
- Scope of Works
- Visual and Delamination Survey
- Testing Schedule

- Other (such as specific design check associated with testing)

5.0 Detailed Investigation Results

This section is to present investigation results for each test undertaken. Full inspection data should be included in Appendices. This report section should complement, and refer to, these guidelines and only describe test procedures to the extent necessary for the understanding of the report, or where not covered by these guidelines. All the calculation for the Remaining Service Life (RSL) should be included in the Appendices i.e. how you deduce the RSL. This section may include some or all of the following:

- Carbonation Depth and Modelling Results
- Chloride Content and Modelling Results
- Sulphate Content
- Water/Wastewater Analysis

6.0 Summary of Current Condition

This section shall be clearly set out by asset component in accordance with the design drawing e.g. raker arm, influent well, scum shovel etc.

7.0 Discussion

This section should discuss and recommend the various options for maintenance or remediation. Discussion of investigation results shall be clearly set out by asset component

8.0 Conclusions and Recommendations

This section should provide condition rating of individual components inspected should be included. The rating shall be in accordance with Figure 1 of this document.

- Durability Design Requirements.
- Conclusion
- RSL of the components/structures
- Summary of Recommended Maintenance and Remedial Options

9.0 Appendices

Appendices are to include any relevant workings, predictions, certificates etc. Typical appendices may include:

Appendix A - Asset Details

Appendix B - Photographs

Appendix C - Inspection and Testing Schedule

Appendix D - On-site Investigation Results

Appendix E - Depth of carbonation Predictions/other predictions

Appendix F - Laboratory Test Certificates