

Technical Report

New recommended practices in concrete durability

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Abstract: Prior to the 1970's concrete was generally regarded by asset owners, designers, and contractors as a reliable construction material that provided long term durability with relatively little maintenance. Subsequently, premature deterioration of concrete structures, arising from changing cement characteristics, quality management, and a number of other factors, damaged this reputation. The durability of concrete structures is a complex and difficult issue to design and manage due to many variables. Whilst research into concrete durability continues, the knowledge on exposure significance, deterioration processes, materials properties and workmanship implications has developed significantly over the last 25 years. In this time new durability design practices have been developed, including durability modelling methods, and new methods of construction have been introduced. The Concrete Institute of Australia (CIA) Durability Technical Committee perceived a need for a broader review of durability requirements, and following extensive industry consultation, determined that a comprehensive and unified durability guidance was required. The concrete durability topics considered under this review include: planning, exposure classes, deemed to comply requirements, good practice, modelling reinforcement corrosion, cracks and crack control, and testing.

Keywords: concrete, durability planning, exposure classes, modelling reinforcement corrosion, cracking, testing.

1. Introduction

Durability requirements in Australian Standards are fragmented through different standards and their commentaries dealing with concrete durability requirements for different structure types (e.g. AS 2159, AS 3600, AS 3735, AS 4997 and AS 5100.5). Perceived conflicts between these documents (e.g. higher covers in AS 3735 than AS 3600 for the same life and exposure) might sometimes be explained by the different owner requirements (e.g. reliability required) but reasons for the differences are not given and the associated assessment methods not clearly stated. To some extent the concrete industries energy for contributing to development of durability codes is diluted through maintenance of the multitude of codes that cover the same topic in variable ways.

For many, concrete elements in mild exposures incorporating the recent durability related developments into a unified durability design process for all structure types may make little difference to their durability design because existing codes

deemed to satisfy provisions often provide adequate performance. However, for elements in more severe exposures, guidelines that comprehensively detail how to assess owners' needs, environmental exposures and materials requirements; how to specify performance or prescriptive materials properties; and how to ensure construction is appropriate to the design will provide structures that meet their durability requirements more consistently. The durability series provides the required guidelines.

The Concrete Institute of Australia first introduced Z7 "Durable Concrete Structures" in 1990 as an initial response to concerns about the poor durability performance of some concrete structures. This was revised in a second edition in 2001, which gave some excellent information on how to achieve durability but did not set out to provide a set of unified design guidelines as an alternative to the approach in the Australian Standards noted above.

The Concrete Institute of Australia's Durability Committee was formed in late 2008 to review Z7. In view of the committee's perceived need for a broader review of durability requirements it managed workshops around Australia in mid-2009 to review issues with concrete durability practices and standards in Australia. The outcome from these workshops, and other feedback from Concrete Institute of Australia members at the Concrete Institute

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of Australia National Conference in 2009, was that comprehensive and unified durability guidance was required. In response, the Durability Committee established Task Groups to produce a series of recommended practices as a major revision to Z7 that would form a durability series. The series comprises:

- Z7/01 Durability – Planning (published 2014)
- Z7/02 Durability - Exposure Classes (in progress)
- Z7/03 Durability - Deemed to Comply Requirements (in progress)
- Z7/04 Durability – Good Practice through Design, Concrete Supply and Construction (published 2014)
- Z7/05 Durability – Modelling – Reinforcement Corrosion in Concrete Structures (in progress)
- Z7/06 Durability – Concrete Cracking and Crack Control (in progress)
- Z7/07 Durability – Performance Tests to Assess Concrete Durability (published 2015)

2. Durability terminology and design life

Definition of terms commonly used for durability is variable in Australian Standards with some important terms having different words or not being defined, which is a consequence of the many people involved in different standards. In the absence of an Australian Durability Standard, CIA Z7/01 provide terminology that takes account of international durability use and can be referenced for common definition understanding in Australia. Definitions of durability and durability consultant CIA Z7/01 are important for Australian future use and are given below.

- Durability: The capability of structures, products or materials of continuing to be useful after an extended period of time and usage. In the context of performance-based design of structures, durability refers to the fulfilment of the performance requirements within the framework of the planned use and the foreseeable actions, without unforeseen expenditure on maintenance and repair.
- Durability consultant: Person or group who completes the durability assessment and is the author of the durability assessment report and durability checklists. Intent is a person or group who can apply materials deterioration knowledge to construction materials and construction processes, additional to more common structural, civil, geotechnical and other engineering knowledge of design, construction and maintenance. Maybe an in-house employ-

ee of the design team, or an independent consultant engaged for the purpose. Intended to have a close working relationship with the asset owner, design team and construction team to ensure durability is provided to achieve the asset owner required service life. Practical experience is essential to ensure the durability assessment report and durability checklists do not become a research exercise. Contractor reviews are included to achieve a buildable final design for the asset owner service life. The durability consultant may be a person with relevant technical qualifications other than a qualified engineer (e.g. materials scientists), with the asset owner client (or authorised representative) responsible to approve the durability consultant for a project.

Design life is one of the most important durability parameters yet this is not always clearly identified in codes and specification and definition are not always clear and consistent. CIA Z7/01 provides some clear definitions which are also shown in Figure 1. The term “design life” is often used to convey the same intent as “design service life” and both terms are acceptable to convey the same intent. It is the period in which the required performance shall be achieved, used in the design of new structures construction. Service life (operational) however is the period in which the required performance of a structure or structural element is achieved, when it is used for its intended purpose and under the expected conditions of use. It comprises design service life and prolonged service lives.

3. CIA Z7/01 Durability planning

3.1 Approach and durability assessment report

Information on processes involved in concrete deterioration are available for engineering analysis but a formal process for achieving durable structures in design, construction and operational maintenance is missing. Durability planning outlined in CIA Z7/01 is a system to formalise the process of achieving durability through appropriate design, construction and maintenance.

CIA Z7/01 sets out the process of planning to achieve the required level of durability. The durability planning outcomes will be delivered in a durability assessment report or durability plan (alternative names for a durability deliverable report) specific for the project. This will describe how the desired level of durability will be achieved and ensured using appropriate tools and recommendations given in Codes and Recommended Practices (e.g. CIA Z7/02-07).

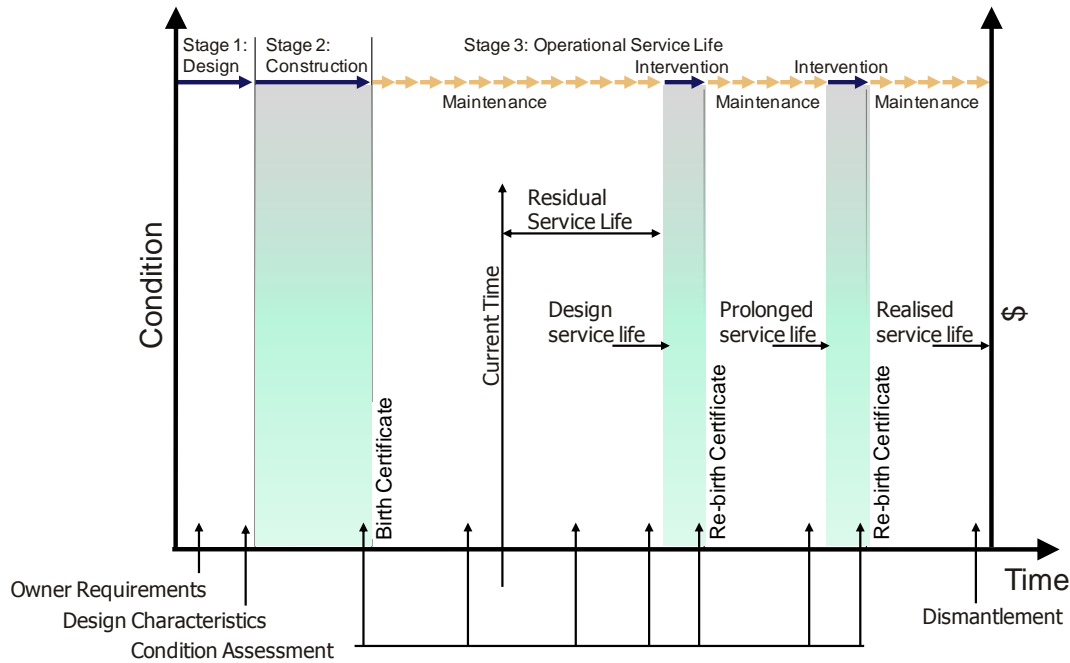


Fig. 1 – Phase in the life of a structure from Model Code 2010

A durability assessment report provides a continuous link in durability objectives between design, construction and maintenance. Durability planning evaluates, explains and provides solutions for all stakeholders. Greater confidence is provided for the design and required service lives to be achieved.

Durability is provided with improved confidence when the concrete structure asset owner is actively involved starting from the project brief stating specific durability requirements. Designer and/or contractor provided durability without adequate asset owner defined formal requirements has uncertainty that an optimum whole of life cost will be achieved. In a worst case scenario of reduced structural adequacy and/or functionality, asset owner maintenance cost funding and resources may be excessive to keep the asset operational or the asset owner may face rapid premature depreciation.

Concrete structures recommended to use durability planning will have durability design requirements that are complex, critical or uncertain. Durability planning is not expected for simple structures in exposure conditions excluding moderate or severe (e.g. house slab and paths).

The durability assessment report issued will explain the durability requirements and provide details to be included in the project design reports, specifications, design drawings, asset maintenance plans and/or operation and maintenance manuals. This report may be a page for simple structures or detailed for complex, critical or uncertain structures. Durability checklists in tabular form provide useful project guidelines complementary to the durability assessment report.

3.2 Why durability planning

All capital works, whether government or privately owned assets, must achieve the design life intended, operational functionality, acceptable return on capital investment, safe operational environment (e.g. durability provides acceptable serviceability and ultimate risk to the community) and environmental sustainability. An appropriate durability philosophy throughout the project delivery will provide this.

In engineering terms, durability planning is cost-effective selection and usage of materials combined with design process, construction methods and detailing to achieve the asset owner intended service life without premature unexpected operational maintenance. A technical analysis determines the nature and rate of materials deterioration for given macro and micro environmental conditions, which is used to influence the design, construction and operational maintenance during the service life.

Design and construction to National or International Standards may not achieve the asset owner's required design life in aggressive exposure conditions. Significant premature maintenance and/or repair could be necessary. A durability review is required as Codes do not cover all environmental exposure conditions and specific location micro exposure conditions can be more severe than the general exposure conditions.

Asset owners may require a design life of 20, 50, 70, 100, 150 or 300 years whilst Standards may state 40 to 60, 50, 100 or not comment on design life. Owners may have specific desires for the performance of the structure at the end of the design

life so that rehabilitation and extended life can be achieved. Future different owners may have upgrade requirements. They may also have views on reliability required through the design life. Durability planning allows owners to give specific design life requirements. Durability planning evaluates, explains and provides solutions to all parties and provides greater confidence that the design life will be achieved.

Durability design is expected by all construction parties but formal design by durability consultants is not a common specified requirement. The common informal expectation is someone completes the durability design within the design process and, in the absence of a named person, the structural engineer is deemed to have completed the task. This is not a reasonable obligation for the structural engineer who does not have durability training and /or experience. An alternative view is that Australian Standards take full account of durability such that structural design being acceptable equates to acceptable durability design.

However, Australian Standards state that compliance with the durability provisions of the standards is not sufficient given the complexity of the subject. For example, AS 3600: 2009 Section 4.1 Note 2 “Durability is a complex topic and compliance with these requirements may not be sufficient to ensure a durable structure.”

Furthermore, reliance on durability provided by a current Standard is not an acceptable legal defence for premature durability damage to a structure where a reasonable engineer is expected to have awareness of more recent related Standards or other technical society publications that require additional durability provisions.

Is premature deterioration or unacceptable maintenance a present day problem? Yes, in some aggressive environments where materials selection or construction techniques are inadequate, or design agreed maintenance is not implemented. Therefore, acceptable durability is not always being achieved to the level expected.

It is recommended that asset owner project briefs include the requirement that design and non-compliance reports that effect durability are reviewed by a durability consultant. On projects where the contractor’s construction method is different to the design or influences durability a durability consultant review is required.

The durability planning process benefits all parties:

- The asset owner is likely to have a structure that more closely matches expectations in terms of reliability through the design life. The contribution to the proactive maintenance approach will lead to a lower maintenance cost.

- For the designer, inclusion of high level materials expertise reduces the risk of premature failure and over design.
- An unexpected outcome on some projects is contractors utilise the durability consultant expertise for advice on materials and methods even where not strictly required. Consequently, they reduce the risk of not using optimal materials and this reduces the risk of failures and can lead to cost savings.
- For the operator of the structure it leads to reduced maintenance which means lower cost and less interference.

Examples of concrete structures recommended to use durability planning are listed below:

- Major civil and building structures, including:
 - Airport infrastructure.
 - Bridges and culverts, elevated viaducts, tunnels.
 - Buildings for commercial, industrial, government and residential use, including weatherproof exterior façade and below water level basements.
 - Mining and industrial structures, including material processing and handling.
 - Power stations, including seawater structures.
 - Structures of cultural, heritage, national or world significance.
 - Transmission towers.
 - Wharves, piers and jetties.
 - Water retaining or excluding structures including dams, desalination plants, pipelines, pump stations, tanks and treatment plants.
 - Wastewater treatment plants.
- Precast panels with complex metal arrangements and tight covers.
- Buildings with applications that lead to unusual exposures (e.g. where leakage with contaminants occurs like swimming pools in hotels or aquariums in restaurants).
- Industrial sites where elements or structures might be exposed to contaminated ground or air.
- Elements with critical leakage requirements.
- All concrete structures in corrosive exposure environments.

3.3 Formal durability planning

The need to incorporate durability into design, construction and maintenance to prevent premature deterioration of concrete structures has been identified in many international documents over a long

period of time. Examples of technical concerns and improvement approaches for durability in the design, construction and maintenance of concrete structures are listed below from 2001 back to 1968. Technical society publications by the American Concrete Institute (ACI) in the 1960's and RILEM in the 1980's were state-of-the-art at that time, however, formal durability planning to coordinate technical improvements was missing.

- Australia: CIA: Z7 Durable Concrete Structures (first published in 1990 and second edition in 2001) states: "The aim of this Recommended Practice is to provide designers, specifiers and users of concrete with guidance on the provision of durable concrete structures by alerting them to potential problems that may occur at any phase from concept to completion." CIA Z7/01 provides durability planning that is not given in CIA Z7.
- Europe: CEB RILEM Durability of Concrete Structures (published in 1983), with the latter stating: "The international concrete profession is, therefore, challenged by acute demands to develop and implement rational measures of solving the present twofold problems of durability, namely: 1) Find measures to ensure a satisfactory remaining lifetime of existing structures threatened by premature deterioration; 2) Incorporate in new structures the knowledge, experience and new research findings, in order to monitor the structural durability, thus ensuring the required service performance of future concrete structures." And "Furthermore, an efficient voluntary coordination of activities in order to develop the proposed rationale 'Durability Technology' on a higher professional level than the present, would be welcomed by all parts of the concrete profession." This workshop brought together about 80 international leaders in concrete technology and durability who presented on the topics of state-of-the-art, deemed to satisfy rules and future work, which provided technical papers with references that was truly "state-of-the-art" for concrete durability at that time. Transfer of knowledge from theory to practice summary comments included, "...important task now is to use our already existing knowledge regarding materials technology, and transfer this knowledge in useable form to the structural engineer, i.e. to the designer and the contractor, as in practice a design engineer will ask for a certain type of concrete, not a certain type of cement or aggregate, etc." and "...one of the objectives of explicitly stated for this workshop, i.e. bridging the communications gap between materials

science and engineering descriptions" and "...structural engineers should have a general understanding of what the materials scientists are doing – or could achieve – in order to ask the right questions to the materials science".

- United States of America: ACI Durability of Concrete Construction (published in 1968) states, "...is written for the intelligent engineer who wants to make or specify durable concrete, but who needs to be alerted to possible deterioration under various circumstances, and for students who wish to learn something about the subject" and "It will be assumed the reader is not a physicist, or chemist, or petrographer. This poses something of a problem because most of the properties and behavioural aspects of concrete of practical importance to engineers are very largely consequences of its microstructure and chemical nature, and detailed study of these matters lies mostly in the realm of the physical sciences. Furthermore, practical measures to achieve durable concrete usually comprise suitable control of microstructure or chemical properties, or both, although practitioners may not think about it in these terms. Yet they would be able to act more intelligently and with greater confidence if they had some general understanding of them."

CIA Z7/01 has major sections on the formal durability planning process through the various stages of the structures life that include:

- Asset Owner brief.
- Project tender.
- Durability planning.
- Concept design.
- Detailed design.
- Construction.
- Maintenance during operation.

4. CIA Z7/02 Exposure classes (in progress)

Inadequate identification of exposure conditions is a potential shortcoming in durability design. Reasons for this include:

- Confusion: different Standards may classify the same exposure in different ways, classify different exposures in the same way, or not explain the application of exposure classifications adequately.
- Limited range of exposure classes: for simplicity, the range of exposure classifications in Australian Standards is limited, and may not adequately cover complex and severe exposure conditions other than as 'U', for example elements such as tunnel or tank

walls that are ‘immersed’ in potentially aggressive liquids on one side and able to dry from the other.

- Unpredicted or variable exposure: exposure conditions can vary over a single member, replicate members, or an overall structure. Detailed analysis of the structure will reveal local micro and macroclimates that may differ from the overall site assessment. Exposure to seawater may increase with more frequent storms and rising sea levels.
- Lack of information: For example, soil and groundwater conditions may not be adequately assessed or significant uncertainty exists.

Potential consequences of exposure classifications in current Australian Standards include:

- Different classification systems for different structure types, meaning that different solutions could be developed for different types of structure in the same environment.
- The same classification being used to describe different types of exposure, making it difficult to tailor appropriate solutions for all conditions covered by the classification.
- Exposure classifications differing from those used internationally, making it difficult to compare durability requirements and solutions from different jurisdictions, or to use deterioration models designed for particular exposure classifications.

To overcome these problems, CIA Z7/02 will define different exposure classes for different types of deterioration mechanism / exposure condition, irrespective of structure type.

Exposure classes based on fib Model Code (2010) and ISO 16204 classifications will be considered to be introduced to cover exposure to airborne salt, atmospheric carbon dioxide, direct seawater contact, chlorides other than in seawater or groundwater, aggressive chemicals in ground exposure, freeze-thaw, fresh water, sewage gases, corrosive liquids and gases, water migration, and abrasion. Additional exposure classes will be considered for metal items embedded in the cover concrete.

The extended range of exposure classifications will be useful for situations not covered specifically or adequately in Australian Standards, for example the range of seawater splash/spray conditions experienced at different heights on piers or piles along the length of a bridge or wharf, and aggressive chemical exposures.

5. CIA Z7/03 Deemed to comply requirements

The development of new exposure classifications will necessitate review and updating of deemed-to-comply requirements. Therefore, this part of the durability series will be prepared once the other recommended practices are completed and will take them into account. It is anticipated that CIA Z7/03 recommendations will be based on minimum cover requirements and will consider:

- Requirements for each exposure class
- Requirements linked to different types of cementitious binder including type GP cement, and supplementary cementitious materials
- Guidance for galvanised and stainless steel reinforcement and prestressing, and for steel fibres
- The effect of coatings on other durability requirements
- The significance of curing methods on other durability requirements
- Options for design life of 25, 50, 100, and 200 years.

Minimum cover depths will be determined by a reliability approach that takes into account the decreasing rate of ingress of many aggressive agents with time.

The deemed-to-comply requirements will provide solutions for exposure conditions not adequately covered by current Standards. They may also provide alternatives to the default solutions provided by existing Standards, provided the requirements for material quality are consistent with or better than those in the governing concrete materials standards.

6. CIA Z7/04 Good practice through design, concrete supply and construction

Australian concrete construction standards more generally focus on minimum design and material requirements and with the exception of a few more detailed “Hand Book” standards are unlikely to provide more informative recommendations about how to design or construct a structure to get the target life expectancy.

The CIA Z7 Durability Series provides the tools for managing durability through design, construction and maintenance. As the title suggests, CIA Z7/04 has applicability to more general concrete design and construction as well as concrete requiring specifically higher levels of durability.

CIA Z7/04 provides more specific detail covering areas such as the impact of specifications and the contract process, impacts of design on construction, more detailed view of the materials used in construction, material quality control processes, construction process and supervision as well as some detailing issues in common structural elements that may present potential durability issues to the designer and constructor. These matters are considered for the categories of:

- Contractual aspects.
- Design.
- Pre-pour planning.
- Quality of concrete.
- Concrete materials.
- Concrete supply.
- Reinforcement and prestressing steel.
- Construction.
- Cast in-situ concrete.
- Precast concrete.
- Sprayed concrete.
- Spacers and chairs for support of steel reinforcement, which is included as this is an area that has demonstrated to cause weakness in durable construction and is rarely adequately specified.

The designer and durability consultant must understand not only the intended design but must understand the material properties and consider how these properties can be delivered during the construction process. There are many elements to this delivery process that impact on the final structures durability and CIA Z7/04 provides information that helps to highlight the more critical areas of concern from design detailing through material supply to construction of the structure for all concrete construction stakeholders.

7. CIA Z7/05 Modelling – Reinforcement corrosion in concrete structures (in progress)

Durability design of a reinforced concrete structure mostly involves selecting suitable concrete compositions and related durability measures for a specific exposure condition to achieve the specified design life. There are four typical approaches to conducting durability design as defined in fib Bulletin 34 - 2006 [3]. These include 1) deemed to satisfy design, i.e. complying to the durability requirements in various codes, 2) avoidance of deterioration (e.g. use of stainless steel to avoid potential issues with black steel corrosion), 3) partial safety factor design with deterministic modelling, and 4)

full probabilistic design based on stochastic modelling.

A very large proportion of deteriorated concrete structures are related to reinforcement corrosion. Therefore, CIA Z7/05 will only deal with modelling of corrosion of reinforcement. In addition, no time-dependent model of deterioration processes under other physical and chemical attacks is presently available with general international consensus for quantitative prediction of service life. A full probabilistic approach or partial factor approach for design or service life is therefore not feasible and deemed to satisfy approaches are the general approach taken. Some preliminary models have been proposed and sometimes used for very specific mechanisms (e.g. acid attack in sewers) but their use is not common as avoidance of deterioration measures (e.g. acid resistant liners for sewers) or deemed to satisfy requirements are the more general practice.

In the past, reinforcement corrosion protection to most concrete structures was designed using a deemed-to-satisfy approach by following code requirements, which were predominantly established based on long-term field observations. The durability outcomes using this approach were a mixture of some successes and some failures. It was found that the durability failures occurred more frequently on the structures in aggressive conditions built since 1970 while structures built before that performed generally better.

Although the causes of such a change have not been fully understood, this change has coincided with many changes including the cement characteristics (containing more C_3S and being finer), climate change (higher temperature and more CO_2 in the atmosphere) and construction practices (poor curing and compaction). Furthermore, these changes have not been reflected in the durability requirements of various Australia Standards.

Due to the lack of long term durability data on new materials characteristics and change of exposure conditions, a deemed-to-satisfy approach may not be sufficiently reliable in some cases and overly conservative in others where higher performing materials are used. The avoidance-of-deterioration approach can reliably provide a superior durability performance in most conditions. However, the associated high cost discourages wide application except on some critical elements in critical projects.

As an alternative durability design method, durability modelling (of either full probability design or partial factor) based on current material characteristics and mathematics has a potential ability to provide a much more reliable durability outcome if appropriate models and parameters are adopted. It is especially effective to predict long term perfor-

mance of reinforcement corrosion in concrete structures for chloride laden conditions and carbonation conditions.

The advantage of a modelling approach is that it is significantly less reliant on long term performance data of field concrete structures although initial model calibration may require some such data at the beginning and it can also be adopted for more aggressive exposure conditions compared to those in codes. Such a modelling approach (for chloride, carbonation and reinforcement corrosion) has been increasingly applied in durability design for major infrastructure projects in Australia and around the world. In addition, modelling approaches can be utilised in determining the remaining service life of existing concrete structures as part of a condition assessment process.

Various models (for chloride, carbonation and reinforcement corrosion) and preferred input parameters have been established and used in the past. However, they have produced significantly different prediction results and consequently different durability requirements even for the similar conditions and materials. Some models used and associated input values have been incorrect, incomplete, and/or inappropriate for the prevailing conditions. Therefore, to achieve accurate and reliable modelling outcomes without a risk of premature durability failure or being too conservative at a higher cost, it is critical to select suitable reinforcement corrosion durability models and input parameters across the industry. Only by this approach, can reinforcement corrosion durability designs consistently achieve reliable durability outcomes.

CIA Z7/05 key objectives are to review commonly used models for prediction of reinforcement corrosion in concrete structures and input parameters for chloride diffusion, carbonation and corrosion of reinforcement (including stressed tendons) and to determine the most suitable models and input parameters with relevant statistical distributions. Considering the complex nature of reinforcement corrosion and other concrete deterioration processes and future data from ongoing research, CIA Z7/05 will be updated in the future when new understandings and developments justify.

8. CIA Z7/06 Concrete cracking and crack control (in progress)

Cracks in most concrete structures are to be expected and to ensure that they do not impact adversely on the serviceability and durability of the structure can be a challenging task. Plastic cracks in the wet concrete during construction are sometimes inevitable despite all reasonable construction actions to minimise them. Cracks in the hardened

concrete caused by a combination of thermal contraction, shrinkage and load are to be expected, and design is generally based on limiting their width rather than preventing them all together. A key issue when a crack forms during construction is the consequence of the crack, in particular the effect of its width and depth on durability, structural and operational integrity and aesthetics throughout the design life of the structure.

CIA Z7/06 in progress will provide up-to-date guidance on concrete cracking and the design for crack control for Australian structures, as well as the assessment, monitoring and repair of cracks. The causes and factors affecting cracking in concrete structures are discussed and procedures for minimising the adverse effects of cracking are presented. In addition to providing reliable design guidance on the control of cracking in new structures to ensure serviceability and durability, the advice provided will also assist designers to diagnose the cause of cracks in existing structures and, where appropriate, to specify effective remedial measures. CIA Z7/06 is intended to complement the relevant provisions of Australian Standards and gives relevant reference to international standards, codes and technical society publications. The document can be used in other countries with due consideration of local standards and codes.

Australian Standards dealing with concrete structures, such as AS 3600, AS 5100.5 and AS 3735, do not specify maximum crack widths, but rely for crack control on limiting the maximum tensile stress in the steel reinforcement at the crack, together with certain detailing requirements. This is convenient for designers, but is not always reliable. It does not give guidance for technical specifications and does not assist project parties to deal with concrete cracks that form during construction (or at other times). By comparison, British and European Standards do provide guidance on predicting concrete crack widths and on maximum permissible design crack widths.

Crack formation during construction often initiates an investigation and an evaluation that may lead to a repair assessment. In addition to the construction contract requirements, the asset owner will seek assurance that the crack does not affect the performance of the structure during the design life, and does not result in premature damage or an increase in inspection and maintenance costs. The provisions of the current Australian Standards provide little assistance in any of these activities. The approaches and guidance provided in Technical Society publication CIRIA C660 are frequently applied for the assessment of early age thermal and shrinkage cracks in concrete structures in Australia, in particular for civil structures. CIRIA C660 is

based on experience obtained from design, assessment and monitoring of cracks in structures in the United Kingdom since the 1980s.

CIA Z7/06 will provide a comprehensive treatment of cracking in concrete structures, drawing on the information in CIRIA C660 where appropriate. It is hoped that it will form the basis of improved design procedures for crack control, improved construction practices to minimise plastic cracking, and improved guidance for the assessment and repair of cracks in concrete structures both in Australia and elsewhere.

9. CIA Z7/07 Performance tests to assess concrete durability

The Concrete Institute of Australia Durability Series provides the tools for managing durability through design, construction and maintenance. CIA Z7/07 provides guidance on performance tests for durability design and implementation.

Test methods are available to assess various aspects of durability performance through a concrete structure's life cycle including:

- Mix acceptance tests (including tests to validate values used in modelling).
- Tests for quality assurance.
- Tests where placed concrete is suspect.
- Tests for condition monitoring.

A wide range of tests designed to demonstrate the potential durability performance of concrete have been introduced over the years. This has caused some uncertainty for:

- Asset owners: To understand what methods are available, the appropriateness of those methods to the structures' exposure, environment and life cycle, and the most cost effective testing regimes to achieve the required outcomes and level of certainty that they are looking to achieve.
- Designers: To know which tests are the most appropriate to specify and how much test data is required to ensure that the level of statistical confidence from the test results underpinning the design is appropriate.
- Contractors and material suppliers: To understand and have confidence in the consistency, repeatability and validity of trial data and quality control performance testing they are required to undertake for compliance with the project specification.
- Suppliers of laboratory testing services: To maintain and calibrate equipment, train staff, maintain third party accreditation for the tests (e.g. perform the tests to sufficient

frequency, provide regular proficiency training of staff and keep detailed records) and competitively price test methods despite some being not often specified.

Often several test methods supply similar information. Combinations of tests may be necessary. The limitations and advantages of the methods are reviewed, and recommendations provided on which test(s) is the most suitable for project specifications.

Design phase durability testing requirements are recommended to be clearly specified for four stages.

- Mix trials to confirm the mix is suitable.
- Quality assurance tests as construction proceeds.
- Tests at the end of the defects liability period to create a list of items for repair.
- Tests during the design and service life including monitoring.

Construction phase materials testing and selection requirements recommended are:

- Materials testing and selection must be completed in accordance with the project specifications prior to use in the works. Additional testing is required prior to a change in supply of materials or a new source of materials.
- Verification of concrete mix designs to meet project specification durability requirements can take considerable time, and unscheduled changes in concrete supply during construction may result in program delays. Durability testing of concrete such as chloride diffusion, water permeability, drying shrinkage, etc. may have a long test period (e.g. up to 3 months).
- Variability of durability tests must be taken into account by the durability consultant, with specification test criteria allowing for alternative solutions to achieve the required durability if the test results do not achieve the specified values. This can be achieved by conservative durability design and/or provision for use of additional measures such as protective coatings or special additives or other measures.

Operation and maintenance phase monitoring and testing recommended are:

- Practical completion inspection: Prior to a structure going into service it's important to determine if any defects need to be contractor repaired and to document the initial

structure characteristics and condition for future reference and comparison.

- Periodic in-service visual inspection: A reactive approach to on-going maintenance be limited to visual inspections only and these may be performed on a regular basis or ad-hoc. This may be adequate provided no major defects are found and may be sufficient to prevent minor defects from becoming major ones. If appropriate, follow up repairs are performed as required. This approach may be suitable for minor structures and/or structures with a short design life.
- In-service condition monitoring and testing: Proactive maintenance will involve early intervention to prevent or delay the onset of corrosion initiation. This will require regular inspections in conjunction with additional activities such as structural monitoring and non-destructive testing, as required.
- If significant repairs/strengthening have been carried out, then a post-intervention inspection should be carried out along similar lines to a new structure first inspection mentioned above.

10. Conclusions

The durability that the asset owner and community require from structures will only be obtained if specific consideration is given to how durability requirements impact on construction cost, inspections needs, maintenance requirements, aesthetics, and operational and community costs that unplanned maintenance brings. While strong emphasis is placed on achieving the design life, durability must be met long into the future, possibly well past the initial design life.

The CIA Z7 Durability Series Recommended Practices will go a long way to providing the necessary tools for design and construction of durable structures based on the latest understanding of exposure, materials and deterioration process.

CIA Z7/01 provides information on durability planning during design, construction and operational service life phases for all concrete construction stakeholders. The durability assessment report issued will explain the durability requirements and provide details to be included in the project design reports, specifications, design drawings, asset maintenance plans and/or operation and maintenance manuals. This report may be a page for simple structures or detailed for complex, critical or uncertain structures. CIA Z7/01 is intended to inform and inspire designers about the benefits of

durability design so they can inspire asset owners to elevate durability planning to a position alongside structural and architectural design.

CIA Z7/04 is intended to inform all parties involved in design and construction about the benefits of durability planning and subsequent control of implementation so they can deliver the expected level of maintenance and life of the structure to the asset owners requirements.

CIA Z7/07 is intended to inform all parties involved in design, construction and maintenance about the benefits of durability performance testing and how as part of a durability planning and implementation process will lead to an increased likelihood of achievement of design life of structures and buildings

The CIA Durability Technical Committee will complete and publish Z7/02, Z7/03, Z7/05 and Z7/06 in 2017.

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