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fib Model Code 2020 – Durability Design and Through Life Management of New and Existing Structures

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ABSTRACT

Work has recently started in fib (Fédération Internationale du Béton) on the preparation of a new fib Model Code for Concrete Structures, under the working title of Model Code 2020 (MC2020). This will be a single code dealing with both new and existing concrete structures, that is both the design of new structures and all the activities associated with the assessment, interventions and the through-life management and care of existing concrete structures. Numerous goals relating to durability and service life design have been identified, including that ideally MC2020 should incorporate:

- *Better models for deterioration processes addressing issues such as propagation stage deterioration, deterioration processes not currently addressed in fib MC2010, the influence of cracking and the existence of a wider range of aggressive service environments and situations than previously considered.*
- *Improved models for service life prediction / estimation*
- *Models for 'repaired' structures / intervention behaviour*
- *Reliability requirements for new and existing structures*
- *Consideration of the use and value of monitoring data / the level of knowledge available for decision making in the through-life management and care of concrete structures.*

The paper provides background to the work being undertaken in each of these areas.

Keywords: Durability, Design, Repair, Codes, Modelling, Testing.

1.0 INTRODUCTION

In June 2016 the *fib* Technical Council approved the start of activities on the MC2020 project to undertake the preparation of a single general code fully integrating the provisions for the design of new concrete structures with matters relating to the management and care of existing concrete structure.

A series of *fib* technical workshops and discussions, involving participants from around the world, have developed ideas on how to extend *fib* MC2010 and its treatment of durability design of new structures and of the assessment and conservation of existing concrete structures.

The discussions have recognised the rapid pace of technical development in many areas including those relating to materials, design, analysis, assessment, construction and interventions, to mention just a few. It is anticipated that the pace at which such developments occur will continue to increase.

Many of the specific points to be addressed in MC2020 relate to the following:

- Revision and / or extension of basic principles and concepts
- Revision and / or development of principles of structural design and assessment
- Extension of the provisions on materials and their modelling
- Extension of the provisions on interface characteristics between different materials
- Revision of the provisions for design and the development of provisions for assessment
- Extension of the provisions relating to construction and interventions
- Updating the provisions relating to conservation and through-life management & care, and
- Updating / extending the provisions on recycling, dismantlement and end of life aspects

It is envisaged that Model Code 2020 will provide a through-life management approach, for new and existing structures, including:

- sustainability objectives that balance environment, social and cost perspectives,
- promotion of structural safety, serviceability and durability,
- use of advanced life-cycle cost methods,
- reliability concepts, that takes account of uncertainties and risk,

- use of performance-based concepts to remove inappropriate constraints on the use of novel types materials and approaches,
- use of improved models for assessment of initiation and propagation phases,
- attention to new types of concrete and new techniques for construction and interventions,
- definition of test methods, and performance evaluation of concrete,
- worldwide knowledge of materials and structural behaviour, and recognises the differing needs of engineering communities around the world,
- guidelines to practitioners when provisions in other standards are deficient or lacking.

Preparation of MC2020 is being led by Task Group 10.1 established for the purpose. It will rely on twelve Action Groups designated to deal with various aspects. One of these is Action Group 4 (AG4) which is concerned with durability design and service life prediction (Fig. 1). This paper focuses on AG4 and its interaction with other *fib* groups.

2.0 COMMON APPROACHES (TG8.8)

Although the ultimate durability design output for new and existing structures involves deterioration modelling, there are many supporting aspects essential for a functional design model.

Durability verification approaches, risk and reliability and structural assessment are being considered by a combined group at this stage as there is a high degree of overlap between these topics. These may be teased out as the requirements for each become clearer. Being considered independently are life plans, exposure zones and early age cracking.

2.1 Life Plans (WP1)

TG8.1 (part of *fib* Commission 8 – COM8) is finalising a report on 'Birth Certificates' and 'Rebirth Certificates' that details how durability design and construction information may be compiled for reference through the service life of structures. These certificates will provide a valuable project reference, but other durability design documents are prepared that determine the course of construction. These include:

- Durability Plans - These are used as a formal process for formulating and implementing durability requirements. These include the translation of client requirements (e.g. length of service life, maintenance, end of life condition and reliability), exposure conditions, the materials available and proposed construction methods into performance and / or prescriptive requirements.
- Specifications - The interpretation of the durability plan into contractual requirements to produce, transport, place, compact, finish and cure concrete to the required quality.
- Inspection and Test Plans - The system for testing and reporting that the requirements of the specification will be and have been met.
- Method Statements - A document prepared by the

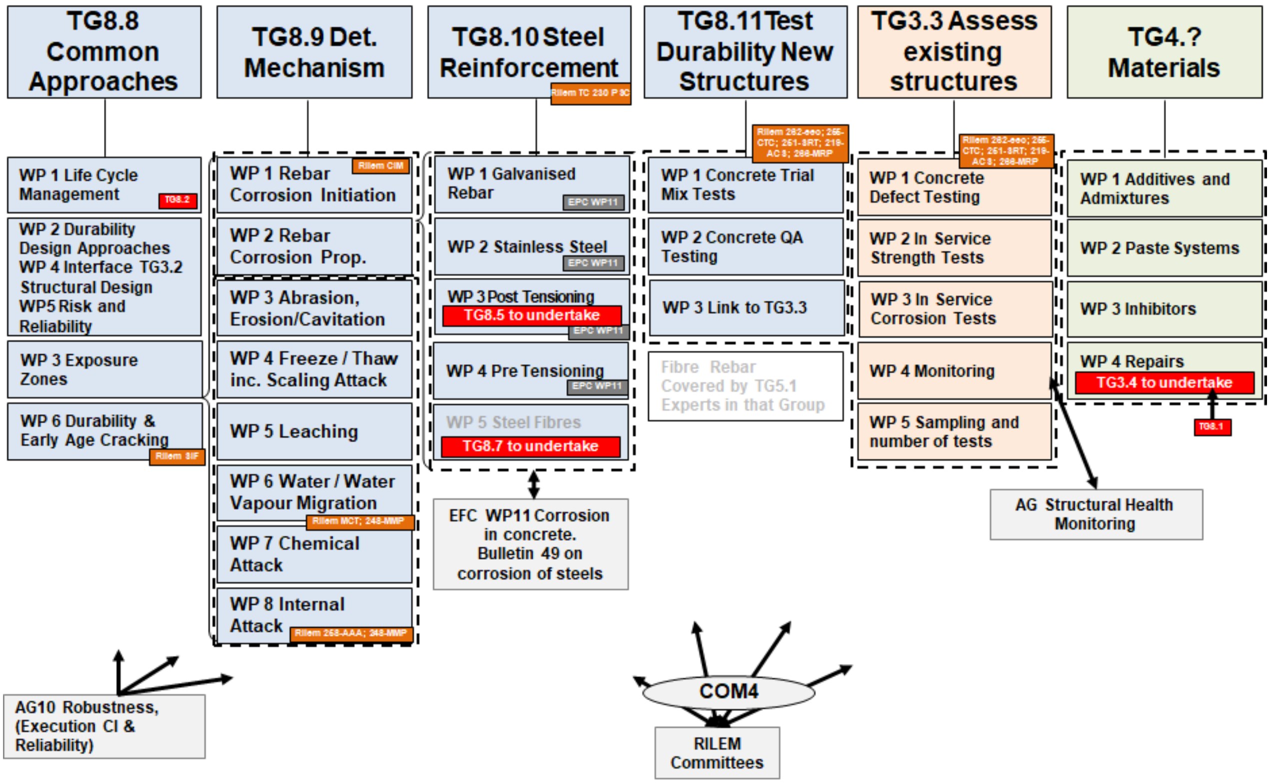

Fig. 1. Structure of TG10.1 Action Group on Durability and Service Life Design, AG4, and its Working Parties (WP)

contractor, and reviewed by the durability engineer, that details how the contractor will construct the works to meet the durability requirements.
- Maintenance Management Plans - Detailing the testing to be undertaken at intervals through the life of the structure and what actions are to be taken on the basis of the results obtained. This includes any specific actions required to maintain the structure regardless of the test outcomes.

How these documents are prepared and fit into the design documentation is being considered by WP1.

2.2 Durability Verification Approaches (WP 2)

The four pillars of verification in *fib* Model Code 2010 are full probabilistic design, partial factor design, deemed to satisfy rules and avoidance. Each approach is being reviewed to provide improved guidance and to consider the approaches applicable to existing structures. Some aspects being considered are:
- Model Code 2020 intends to use modelling to provide a guide on deemed to satisfy requirements with some guidance on the influence of reliability.
- Satisfying all limit states (e.g. cracking, spalling, excessive deflections and collapse) and not just the limit state of depassivation.
- Processes for developing partial factors in durability models for various reliabilities in a fashion consistent with *fib* Bulletin 80.
- When the original design assumptions are no longer valid.
- How to change from a general design approach in a new structure to specific cases where deterioration (e.g. spalling) is already known to exist at certain locations.
- Methods of full probability design giving guidance on appropriate methods for durability assessment.
- Criteria for acceptance of 'avoidance measures.'
- How quality management is incorporated to define performance achieved. 'Design Supervision Levels' and 'Execution Quality Management Differentiation' are two ideas from *fib* Bulletin 34 that will be considered.

2.3 Exposure Zones (WP3)

CIA Z7-02 is proposing to introduce a range of exposures classes not currently included in the Eurocodes. In some cases, these increase the number of severity levels of a current exposure class, in other situations a new exposure class is created.

An exposure which may require greater consideration is coastal. Winds and shoreline topography have a strong influence on how far chlorides are carried inland and what the loading of chlorides will be at different distances from the ocean.

Some novel exposure classes are:
- Structures where seawater immersion is not on all faces of an element
- Capillary Rise - Where water may rise up an element due to constant wetting
- Evaporative Concentration - where water evaporates leaving salts deposits behind

2.4 Assessment (WP 4)

AG4 will not specifically consider structural assessment of existing structures as this is the domain of other MC2020 Action Groups. However the methods of structural assessment plays a significant role in determining how much of each type of damage is critical. Hence a liaison will be created to ensure structural and durability experts jointly determine how durability modelling is applied to give an appropriate input to structural design and assessment.

2.5 Reliability (WP 5)

A major new feature in Model Code 2010 was the introduction of reliability as a durability design parameter. Reliability is an integral part of full probabilistic design analysis as the calculated result gives the reliability at the design life and this must exceed the required value.

Model Code 2010 provides some guidance on using serviceability limit state values as the target reliability, but current work is considering under what circumstances higher or lower reliability values may be applicable. Particular aspects for consideration will be how the knowledge from the existing structure improves the precision of the analysis and how different structural mechanisms, before and after repair, will determine the consequence of failure.

2.6 Early Age Cracking (WP6)

Two prominent documents on design for early age crack width are available. CIRIA C660 was prepared in 2007 and a major update is proposed for early 2018. In Australia CIA Z7-06 has been prepared. This incorporates many of the aspects addressed in CIRIA C660 and some unique considerations of crack control, particularly the combination of load, shrinkage and thermal strains. *fib* will produce a further document, on which the authors of CIRIA C660 and CIA Z7-06 and other leaders in this field will contribute. The document will minimise the tendency for over-reinforcement in C660 with specific design requirements for cracks originating from thermal contraction and / or drying shrinkage.

3.0 DETERIORATION PROCESS MODELS (TG8.9)

Model Code 2010 places emphasis on models for durability design for certain deterioration mechanisms (see TG8.9 details in Fig. 1). For the last 10 years the major deterioration mechanism considered in *fib* has been corrosion initiation due to carbonation and chlorides. Some of this has been published and this needs to be incorporated in Model Code 2020. While it is recognised that the propagation period is an important part of design life, no guidance has previously been included on how to assess this. This will be addressed by TG8.9 WP2. Models for other mechanisms have been outlined in previous Model Codes (*fib* Bulletin 34) but it is now proposed to develop a greater understanding of how and when these models should be implemented through other TG8.9 working parties.

3.1 Corrosion Initiation (WP1)

Empirical models for corrosion initiation due to carbonation and chloride ingress were first published in *fib* Bulletin 34 and were subsequently developed in MC2010 and ISO16204. These models were used in *fib* Bulletin 76 to assess the reliability of the provisions given in national codes and TG8.3 draft report reviews how the models are applied. These last two documents identify a number of issues with the current deemed to satisfy provisions and the application of modelling methods.

It is proposed to review *fib's* empirical models to determine how life prediction can be improved by further testing (e.g. national aging factors, chloride activation based on the bar-paste interface).

The empirical model for chloride ingress cannot be manipulated like a diffusion solution. Significant errors may occur if the *fib* model is used and diffusion-based model manipulations are undertaken inappropriately. This gives significant limits on the application of the empirical model. The empirical model was adopted because development of a theoretical model was considered too complex to yield reliable results. WP1 will consider the knowledge available in respect of theoretical models to determine if a holistic theoretical model can be proposed that would enable greater flexibility in its application.

The *fib* model has no version suitable for use in repair situations. WP1 will consider how to apply initiation models (empirical and theoretical) to repair situations where the surface is sealed.

fib Bulletin 34 provides partial factors for carbonation assuming normal serviceability limit state reliability requirements. However none are provided for chloride ingress. Some partial factors were developed recently but only for normal serviceability limit state reliability requirements. The provision of a wider range of partial factors in MC2020 is to be considered.

A criticism of the *fib* model is that the calculated reliability has no meaning in relation to the corrosion distribution. Spatial distributions of model variables are to be reviewed to define the meaning of reliability in terms of corrosion distribution.

3.2 Corrosion Propagation (WP2)

Typically service life design modelling for reinforcement corrosion has been based on the initiation phase as no agreed propagation models exist. *fib* Bulletin 34 Appendix R4 introduces a background to propagation modelling. TG8.3 present it in an Appendix.

Propagation can represent a major component of a structure's life, and is included in some deemed to satisfy exposures (e.g. dry carbonated concrete, permanently and fully immersed concrete). When performing modelling its exclusion can lead to expensive over design.

WP2 will consider:

- Allowances to be made when using probabilistic approaches for inaccuracies in the model.
- Resistance and oxygen control (including the anode-cathode ratio) for different exposures.
- Structural assessment criteria
- Post-repair application of models and particularly how repair might be designed to influence either oxygen or resistance control.
- Significance of variables to the accuracy of each model and the distribution type for each variable.
- Recommendations on performance tests relevant to the model(s)
- Partial factors for each model that achieve the reliability required for the designated damage level (related to TG8.8 WP 4).

3.3 Abrasion Erosion and Cavitation (WP3)

Abrasion is commonly a problem when concrete is exposed to traffic or flowing water with solids in suspension. While abrasion resistance is commonly related to compressive strength this can be misleading as abrasion is highly dependent on a range of factors.

For pavements and slabs the performance of the surface layer is critical and this is determined by the materials (paste and aggregate) and the construction method, particularly finishing method and curing.

Cavitation arises where bubbles form in water flowing through hydraulic structures. When the cavities (bubbles) collapse they cause a high pressure drop and a transient pressure wave /

impact that damage the concrete surface causing pitting. ACI 210R provides considerable guidance on cavitation.

Models for abrasion of concrete have been applied to hydraulic structures and pavements but no guidance is given in MC2010 for abrasion, or design methods to avoid the effects of cavitation.

WP3 will:

- Consider international codes, national amendments and research on abrasion and cavitation.
- Evaluate models considering the variables and their distributions and recommend whether a model(s) can be provided for abrasion resistance of pavements and / or of hydraulic structures.
- Recommend abrasion performance test(s) suited to the evaluation of performance levels
- Determine whether prevention of cavitation damage can be managed by relationships between exposure, design life, reliability and concrete performance or if it is an issue of designing to avoid the development of a regime potentially causing cavitation.
- Develop deemed to satisfy requirements and damage allowance approaches for abrasion and cavitation.
- Provide guidance on avoidance measures.

3.4 Freeze-Thaw including Scaling (WP4)

fib Bulletin 34 Section 3.5 provides background on probability and partial factor approaches for a model representing freeze-thaw damage. Appendix B3 provides some background to frost induced internal damage. *fib* Bulletin 34 Appendix B4 provide background to salt-scaling (salt-freeze thaw scaling). These are incorporated into Section 7.8 of MC2010.

Salt-scaling is a well-recognised form of attack. Notably a thesis by J.J Valenza from Princeton IST discusses its assessment as a fracture mechanics issue. MC2010 Clause 7.8.6 refers to this for the probabilistic and partial factor format. Deemed to satisfy and avoidance approaches are only briefly discussed, although ISO 22965-1 is referred to for the deemed to satisfy requirements.

Non-destructive test methods are now being used to identify the significance of pore structure to the likelihood of scaling damage.

Models for water transport through concrete and the understanding of the cause of damage have improved since *fib* Bulletin 34 was developed and it is quite likely that the models in MC2010 should be updated.

This Working Party will

- Determine whether models can be applied with advantage to design for freeze-thaw attack.
- Review probability and partial factor approaches in relation to available models.
- Develop the most appropriate model(s) for inclusion in MC2020 and provide background to the distributions of variables used.
- Provide guidance on damage allowances for different applications.
- Recommend exposure classes and deemed to satisfy and avoidance measures.
- Provide methods of assessing current condition and freeze-thaw resistance of existing concrete.
- Provide criteria for residual life calculation regarding.
    - o Loss of section for structural assessment (ref. TG8.8 WP 4).
    - o Time to corrosion activation (ref. TG8.9 WP 1).

3.5 Leaching (WP5)

Leaching of concrete can be an issue due to percolation of water through or over concrete, or migration of soluble compounds through the capillary water to the surface and into the environment. Issues that arise may be:

- The leaching of calcium ions increases the voids content of the concrete raising two key issues:
    - o Reduction in strength.
    - o Increasing penetrability.
- The potential for release of dangerous substances from concrete [CEN Mandate M-366].

Model Code 2010 Clause 5.1.13.7 provides an empirical model for leaching based on the diffusion coefficient for the substance in concrete and the availability of the substance in concrete. Netherlands test method NEN 7345 describes leaching potential.

This WP will review the literature in regards a model(s) suited to the prediction of leaching of all components.

The expected outcomes are the provision of:

- The most suitable model(s) currently available to give estimates for the rate of leaching of the various components for design
- Safe leaching rates of hazardous components. This will include guidance on acceptable exposure levels.
- Safe leaching rates as it effects strength (ref. TG8.8 WP 4) and durability (ref TG8.9 WP 1). This will include guidance on the relationship between leaching and strength.
- Guidance on the effect of concrete composition and performance on leaching rates.
- Guidance on test methods
- Definition of reliability requirements in relation to concrete as a hazardous material due to leaching.

3.6 Water Migration (WP6)

Water migration may be an issue in itself where it leads to leakage or raised internal relative humidity.

It can also lead to issues where it transports contaminants such as chlorides and sulfate salts. Complex models including flow due to pressure, sorption, diffusion and water vapour have been developed and verified for predicting various deterioration processes. Basic models, sufficiently accurate to many situations, are also available and commonly used. However, these models have not been introduced into MC2010.

A major issue found with water penetration models is the reduction in permeability with time due to hydration and pore blocking by chemical reactions. Hence, use of water penetration models requires aging factors to be developed.

The objectives of WP6 are:

- Provide a realistic water penetration and flow rate model for concrete leakage, including the situation for assessing whether evaporative concentration will develop.
- Consider other deterioration mechanisms in relation to how they are controlled by and are affected by water flow.
- Provide a model for water vapour distribution in regard to impermeable coverings. Provide a methodology for determining the current state of water ingress and the likely future ingress and flow rates.
- Provide guidance on how remedial treatments can be modelled to assess the potential reduction in water and water vapour ingress.

3.7 Chemical Attack (WP7)

The WP is to consider acid and sulfate attack including biological mechanisms (e.g. sewers). Acid and sulfate attack can occur in ground, in tanks and in ground.

MC2010 Clause 5.1.13.6 provides a model for calculating the depth of acid attack based on a dissolution constant that is derived from experiments according to Beddoe 2009. However, Clause 7.8.7 notes that the probabilistic and partial factor approaches are still under discussion. It also notes that deemed to satisfy requirements are based on experience. Avoidance approaches are frequently used as the design basis, e.g. coatings and linings.

Mechanism to be considered include:

- Sodium sulfate attack
- Magnesium sulfate attack
- Thaumasite form of attack
- Acid sulfate attack
- Salt scaling
- Biological attack in sewers

The WP will review test methods as part of the model assessment in order to provide a means of assessing mix performance. It will provide

- A state of the art review for each mechanism and where appropriate recommended modelling approaches to be used. Where models are proposed it will provide probability and partial factor approaches and include recommendations on probability distributions to use for variables.
- Performance tests and criteria for performance levels.
- Allowable damage levels to be assumed in design, and how to assess the current damage level in existing structures.

3.8 Internal Attack (WP8)

MC2010 provides no model for AAR and Clause 7.8.8 notes that currently there is no probabilistic or partial safety approach available. Only general comments on deemed to satisfy and avoidance approaches are provided. Given the extensive research undertaken on this topic, and the detailed guidance given in national codes, it seems that the design approach given in MC2010 could be developed further.

Similarly, MC2010 Clause 7.8.9 provides no model and no probabilistic or partial factor format for DEF. Little guidance is given on deemed to satisfy or avoidance approaches.

It is proposed that the following are considered:

- Existing models for AAR and DEF to determine if a suitable model for internal attack can be developed in a probabilistic format.
- Approaches for avoidance.
- Assessment methods to define the current degree of deterioration and likely progress of deterioration in existing structures.
- Deterioration rates following application of protective measures giving residual strength and considering future strength reductions.
- Impact on reinforcement performance at all stages of the deterioration process.

4.0 STEEL REINFORCEMENT (TG8.10)

TG8.10 is investigating how to describe design requirements for different steel reinforcements. *fib* Commission 8 (COM8) already has groups working on post-tensioning and steel fibres and working parties are to be formed on prestressing, galvanised bars and stainless steel.

4.1 Galvanised Reinforcement (WP1)

fib Bulletin 49 provides a guide to galvanised reinforcement production, properties, potential damage and deterioration, bond and applicable codes. This and other references provide a starting point for a durability design guide in that the influence of production, damage, initial reactions and required properties can be assessed.

Other references provide evidence as to how galvanised bars have performed in service. Of less use are accelerated tests that employ very high chloride levels at the bar and just show that at high chloride levels the galvanising breaks down quickly. Some data is available for chlorides activation levels and it may be possible to use this to develop a critical chloride (threshold) distribution.

4.2 Stainless Steel (WP2)

fib Bulletin 49 provides guidance on the various grades of stainless steel available and gives corrosion resistance guidance. Hence, it gives a general understanding about using high grades of stainless steel for structures subject to higher chloride levels or consequence of failure, but these are not related to a critical chloride (threshold) level.

BS 6744 and BS EN 10088-3 specify the requirements and test methods for solid stainless-steel bars in Europe. ASTM A955 provides details for the US market but there is no reference as to how the quality levels can be used in association with the fib Model Code service life and durability design approaches for carbonation and chlorides.

Corrosion mechanisms in stainless steel are different to those in low carbon steel and this may have unexpected deterioration influences, e.g. is corrosion of highly stressed steel at crack locations a greater risk. The various deterioration mechanisms are to be considered to give insight into appropriate durability design procedures for each verification process.

4.3 Post Tensioning (WP3)

COM8 has an active Task Group updating *fib* Bulletin 33 on this topic. The principal outcomes expected are:

- Updated protection levels for new structures.
- Incorporation of reliability requirements.
- Addition of a guide to the assessment of post-tensioning in existing structures.
- A summary of protection levels versus exposure environments and reliability requirements

4.4 Prestressing (WP4)

Four principal factors that will affect the durability design for prestressing cables have been outlined:

- Definition of applicable limit states. Depassivation, cracking etc used for mild steel have different implications in prestressing steel and other deterioration mechanisms may cause ULS failure long before section loss is a critical issue.
- The critical chloride (threshold) level in relation to the limit states.
- The reliability level to be applied at the various limit states. These may be ULS rather than SLS values.
- The reliability required and level of protection applied at design will be affected by how the condition of tendons can be determined in-service, particularly when an intervention is to be applied.

4.5 Steel Fibre Reinforcement (WP5)

Anecdotally steel fibres buried in concrete have shown excellent resistance to corrosion. Research has also indicated a high chloride activation level attributed to the lack of micro-voids on the surface of the fibres. However, to be consistent with conventional reinforcement design a critical chloride threshold probability distribution is required.

Even where fibres are well covered by the concrete it is not protected from carbonation induced corrosion. Fibre discontinuity may assist in providing corrosion protection but where corrosion of one end leads to loss of anchorage the fibres contribution to performance may drop dramatically even though only one end has corroded. The risk of corrosion and the distribution of fibre corrosion relative to the performance it provides needs consideration.

Corrosion at a crack is another issue. A limit of 0.1mm crack width is sometime specified because of the criticality of steel fibre corrosion. However, no assessment has been made as to whether limits applicable to normal reinforcement (e.g. 0.3mm) might also apply to steel fibres.

Once models have been developed for corrosion of fibres in different exposures designers will be able to specify the near surface thickness that should be excluded from a structural design / assessment analysis.

5.0 DURABILITY TESTS NEW STRUCTURES

Durability testing for design of new structures is a relatively new science. While performance test methods are developing for durability design a greater understanding of translating test data into performance achieved in actual structures is required. For example, chloride diffusion is affected by the stress in the concrete (Fig. 2) and values measured in a laboratory may need to be adjusted in design for the actual stress situation. This will become increasingly relevant as higher strength concretes are used.

Current durability models are based on limited data. For example, the aging factor developed from European structures in a limited number of exposures is used worldwide for exposures which are not always the same as the structures, or for the materials, from which they were determined. Measuring the aging factors for materials and exposures directly relevant to the structure to be built will increase the certainty of the analysis.

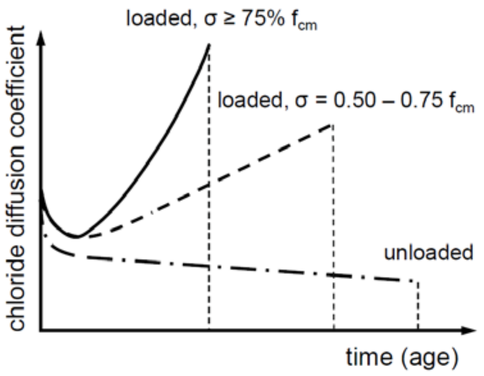

Fig. 2. Affect of load on chloride diffusion coefficient (Source H.S.Muller, TG10.1 Barcelona 2017)

Assessing concrete for new structures generally takes place in two phases, via trial mixes before construction and post construction via QA tests.

5.1 Concrete Trial Mix Tests (WP1)

The *fib* empirical chloride and carbonation models have been used for many years and yet the methods of measuring exposure have not been defined. Chloride migration is the defined measure of chloride ingress and the *fib* Bulletin 34 carbonation test the defined method of measuring carbonation resistance. Yet there is some disagreement on the suitability of these tests.

For other deterioration mechanisms the associated methods to determine performance are even less well defined.

The WP will
- Liaise with TG8.9 WP's to determine the key performance measures that will be used in modelling.
- Review test methods that have been used to measure or infer the key performance properties.
- Define the variance associated with proposed test methods.
- Detail test methods for measuring concrete and steel properties that are used in durability design.
- Where possible include relationship between prescription mix details and performance.

5.2 Concrete Quality Assurance Tests (WP2)

Quality is dealt with in MC2010 by use of Execution Classes. The MC refers to ISO 2394 for how to deal with the 3No Execution Classes. MC2010 also notes that the required Execution Classes shall be defined by appropriate inspection but does not elucidate on what inspection should be undertaken or how to relate Execution Classes to specific QA tests.

In many cases it may be that once the mix performance is established QA testing is satisfied by routine strength assessment and concrete batching records. This might apply particularly to structures that are in less severe exposures or elements of a less critical nature.

WP2 will:
- Review deterioration mechanisms and exposure severities, risks and reliabilities that might apply for each.
- Determine where conventional QA is considered adequate to identify low performance and where additional tests are considered necessary.
- Develop / confirm test methods for as-constructed elements to verify construction is in accordance with durability design include sampling, NDT and coupon testing.

6.0 ASSESSMENT OF EXISTING STRUCTURES

6.1 Concrete Defect Testing (WP1)

With the exception of piles (pile integrity testing) and diaphragm walls (cross-hole sonic logging), unless there is some apparent reason to suspect the integrity of new concrete it is assumed that no defects exist and that no testing for defects is necessary. Hence for existing structures there is little information available on the achieved quality of construction.

There are many tests to assess concrete integrity (e.g. slab impulse response, multiple impact of surface waves, spectral analysis of surface waves, impact echo, ultrasonic pulse velocity, sonic echo / impulse response; ground penetrating radar, interferometric radar, ultrasonic pulse echo) but these are recently developed and only employed where an issue is considered likely (e.g. where honeycombing is observed on the surface).

Over recent years the post-pour measurement of cover has become a common quality check as the techniques are familiar, instruments are accurate and checking process relatively quick. This working party will consider if tests are available that could be simply undertaken, are reliable and quick to assess other critical aspects of new construction (e.g. slab thickness and absence of honeycombing).

The situation for existing structures is similar. To what extent does design allow for imperfections in the concrete placement and how might the assessment of existing structures change given different levels of checking of in-situ performance?

6.2 In-Service Strength Assessment (WP2)

prEN 13791 is in the last stages of development. It will provide an up to date and generally agreed approach to in-situ strength assessment using cores and non-destructive tests. It is envisaged that this will be used as the foundation for requirements for assessment of strength in existing structures in Model Code 2020.

6.3 In-Service Durability Tests (WP3)

A clear process for establishing the length of the residual life, with and without intervention, is not well documented. Testing process charts, backed by test methods, analytical solutions and criteria are needed. For reinforcement corrosion testing and modelling of residual time to activation, the issues of concern include:

- That the available methods of analysing potential measurements produce unclear outcomes.
- That no reliable approach is yet available for resistivity testing and assessment over time which accounts for moisture content.
- The critical chloride (threshold) level distribution may change over time, due to changes in pH and passive layer stability, and in addition is poorly defined due to inconsistencies in the test results.
- Standard procedure for chloride profiling and establishing values of parameters Sc and Dc over time need improved and clearer documentation.
- For other deterioration mechanisms the attack processes, and how they can be measured in-situ, lack adequate definition.

It is proposed that for all mechanisms the following will be considered:

- How bi-linear initiation and propagation deterioration models (ie. Tutti style $T_0 + T_1$ models) can be applied for residual life assessment,
- The process and techniques which are most effective at identifying areas at risk from deterioration,
- Suitability of test methods to define deterioration, along with their accuracy / precision and evaluation criteria.

6.4 Monitoring (WP4)

Current systems for structure assessment rely heavily on visual inspection yet these provide no information about the state of the structure before major intervention is likely to be required. Visual inspection provides little assistance in relation to preventative maintenance. NDT and sampling inspections can provide data for preventative maintenance, but they are often expensive to deploy and data is often less conclusive than that obtained by monitoring methods, e.g. benefit of a chloride profile versus activation front monitoring; benefit of vibration monitoring to check against FE model outputs compared with (say) rebound hammer tests.

It is intended to consider:

- State-of-the-art monitoring procedures for corrosion, displacement and dynamic response, including sensor types, wireless communication approaches and remote monitoring methods.
- How deterioration affects those aspects which can be monitored in different structure types.

The outcomes should enable development of recommendations for how monitoring can be employed on different structure types to detect changes in physical performance and deterioration.

6.5 Samples and Number of Tests (WP5)

Little guidance is provided on the number of durability and investigation tests required for the assessment of materials or existing structures. Such details are available for strength assessment of cylinders used at the construction stage to assess strength. The same techniques need to be applied to durability assessment of:

- Exposure environments
- Materials
- Structural performance

7.0 MATERIALS

As the number of concrete types increases and their hardened properties develop beyond those which are currently available, this adds to the complexity and diversity of the materials in use - which will, in turn, require a greater understanding of materials employed.

Shrinkage (Fig. 3) is a good example of where improved knowledge of high and ultra-high performance concretes may enhance our ability to design durable concrete structures.

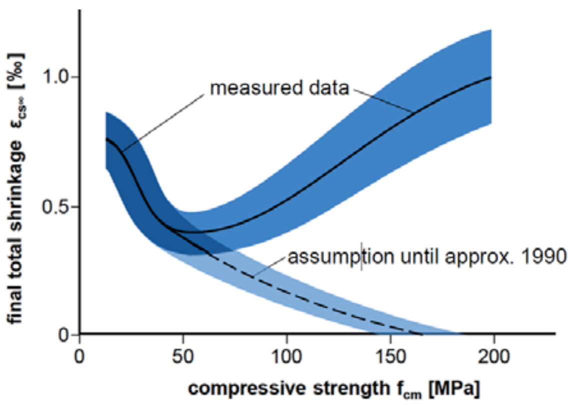

Fig. 3. Final Shrinkage of Concrete (Source Moser-Pfeifer, Weirmar University as presented by H.S. Muller, TG10.1 Barcelona 2017)

Durability design will also be a major part of optimising sustainability in structures which is already a key requirement for many structures procured by governments. Systems that minimise cement requirements by optimising packing are already being used for concrete mix design and have the added benefit of reducing temperature rise during the setting / hardening of concrete.

As concrete technology develops and the rules linking compressive strength to durability are more widely recognised as being inappropriate, use of microstructure models for concrete linking durability to porosity and transport coefficients will become an increasingly useful and commonly used design tools. As non-traditional concrete develops and is adopted to deliver structures with better durability, lower environmental impacts and improved sustainability, as well as potentially at lower cost, the durability design methods developed over the last 30 years must be implemented for the new materials as they become available, but in a much shorter time frame.

These new materials may also be tailored for different exposure types. Much like SCM's in concrete are recognised for their performance in chloride exposures, use of certain geopolymers may be comes standard for acid and sulfate attack exposures.

Admixtures for concrete are also developing to give special features for different applications. Corrosion inhibitors are proving useful to extend design lives in chloride exposures, while water repellents and pore blockers are useful for diminishing / preventing capillary rise.

This increasing complexity of materials and durability design is likely to lead to the development of specialist degrees in concrete technology and durability design.

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References

ACI 201.2R "Guide to durable concrete." American Concrete Institute, Farmington Hills, 2008.

ASTM 955 "Standard Specification for Deformed and Plain Stainless Steel Bars for Concrete Reinforcement." West Conshohocken, 2005.

Beddoe, R.E., Schmidt, K., "Acid attack on concrete - effect of concrete composition." Cement International, Part 1, Vol. 7, Nr. 3, pp. 88-94, 2009; Part 2, Vol. 7, Nr. 4, pp. 86-93, 2009.

BS 6744 "Stainless steel bars. Reinforcement of concrete. Requirements and test methods." British Standards Institute, London, 2016.

BS EN 10088-3 "Stainless steels. Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes." British Standards Institute, London, 2014.

BS EN13892-4 "Methods of test for screed materials. Determination of wear resistance." British Standards Institute, London, 2014.

CEN Mandate M-366 Essential Requirement No. 3 "Hygiene, Health and Environment" of the Construction Products Directive (89-106-EC)]. Comite Europeen de Normalisation.

CIA Z7/02 Draft for public Comment "Durability Exposure Classes" Concrete Institute of Australia, Sydney, 2017.

CIA Z7/06 "Concrete Cracking and Crack Control" Concrete Institute of Australia, Sydney, 2017.

DuraCrete - "Final technical report - General guidleines for durability design and redesign." The European Union - Brite EuRam III, Gouda, 2000.

fib Bulletin 26 "Influence of material and processing on stress corrosion cracking of prestressing steel case studies." Lausanne, 2003.

fib Bulletin 33 "Durability of post-tensioning tendons." Lausanne, 2005.

fib Bulletin 34 "Model Code for Service Life Design." Lausanne, 2006.

fib Bulletin 49 "Corrosion protection of reinforcing steels." Lausanne, 2009.

fib Bulletin 80 "Partial factor methods for existing concrete structures." Lausanne, 2016.

*fib Bulletin 65 and 66 "*Model Code 2010Vol 1 & 2" Lausanne, 2012.

ISO 2394 "General [rinciples on relaibility fro structures." International Standards Organisation, Geneve, Switzerland, 2015.

ISO 16204 "Durability - Service Life design of Concrete Structures." International Standards Organisation, Geneve, Switzerland, 2012.

ISO 22965-1 "Concrete -- Part 1: Methods of specifying and guidance for the specifier." International Standards Organisation, Geneve, Switzerland, 2007.

Matthews S, "Design of durable concrete structures", FB70, IHS-BRE Press, Bracknell, 2014.

NEN 7345 "Leaching Characteristics Of Solid Earthy And Stony Building And Waste Materials - Leaching Tests - Determination Of The Leaching Of Inorganic Components From Buildings And Monolitic Waste Materials With The Diffusion Test." Nederlands Normalisatie Instituut, 1995.

PREN 13791 Draft "Assessment of instu compressive strength in structures and precast components." Comite Europeen de Normalisation, Bruxelles, 2017.

Tutti K. "Corrosion of Steel in Concrete." Swedish Cement and Concrete Research Institute, Stockholm, 1982.

Valenza J.J. "Mechanisms of Salt Scaling", and G.W. Scherer, Materials and Structures 38 (May 2005) 479-488.