Appropriate Test Data & Durability Design of Concrete Marine Structures

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Summary
Experts in Europe have reached a consensus on a new approach to durability design. ISO 16204 [1], *fib* Model Code 2010 [2] and the Eurocode are beating to the same drum. Levels of Approximation (LoA) permits increasingly complexity of design methods. A structure can be designed using durability deemed to satisfy (DtS) provisions where more costly and complex design is not warranted, but where saving might be significant more complex modelling methods can be used. This paper describes the LoA approach, the durability models allowed, and explains where errors in performance data and modelling may occur.

Keywords: Concrete durability design, performance testing, condition assessment, incorrect data and design risks.

Introduction

Modelling of concrete durability has taken 40 years to reach its current stage of incorporation in international codes. It has moved from a design idea, through extensive research to publication of a model code in 2006 [3]. It has now reached a more mature stage of publication in ISO 16204 and soon in Eurocodes. This has taken extraordinary co-operation amongst leading durability and structural engineers with the minutiae taking months of consideration and debate.

Arriving at a point where the design approach detailed in *fib* Model Code 2020 [2], and associated support documents, can be incorporated in Australian Codes requires the co-operation of those responsible for national codes and project specifications. This is appropriate because these approaches are intended to improve safety, economy and sustainability.

The objective of this paper is to bring this paradigm shift in design to the attention of the marine structures industry, one of the most affected industries due to the severe exposures. At the same time as recommending the changed approaches be adopted, the paper also warns of some of the pitfalls.

Deemed to Satisfy

DtS provisions in codes are intended to be conservative provisions that are based on demonstrated historical performance. Unfortunately, there are several issues:

- as materials and quality management change, there is no assurance that the provisions remain conservative,
- very severe local exposures are not covered by, or specifically recognised by codes,
- with no DtS for new materials the codes stifle innovation,
- it is not reasonable for a code to provide one set of DtS for a wide variety of materials, construction qualities, climates and reliabilities required in a large country like Australia,
- In Europe, acceptance of different structure conditions has led to different DtS requirements. This can be recognised in modelling by designing for different target reliabilities.

Levels of Approximation

Levels of Approximation (LoA) (see Figure 1) is now recognised as a process in durability assessment. It is based on using basic design methods, which have a high degree of conservatism and are quick and easy to use, where there is no significant benefit from using more complex methods. However, where there is benefit from using less conservative and more precise design methods then the greater cost and time involved should be expended.

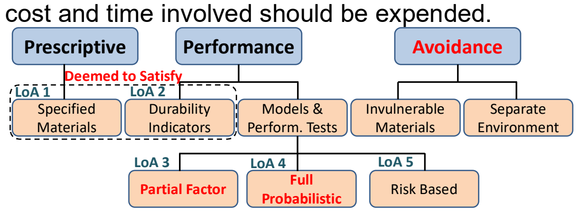

Figure 1 Different approaches to, & levels of, durability design

When using DtS code provisions risk assessment may dictate that modelling is used to verify if the likelihood of failure is acceptable. In severe exposure, e.g. for marine structures, Level 4 full probabilistic modelling, with appropriate testing, is much more likely to be used due to the higher risks.

Data As Distributions

Test results have a mean and standard deviation, i.e. they are distributions. When determining whether a test result is compliant, the probability that the measurement is within the specified limit at an acceptable confidence level must be established. Key aspects are:

- The spread of the data as determined by the standard deviation,
- By how many standard deviations the average exceeds the required average,
- The number of tests undertaken.

The T distribution can be used to verify if a hypothesis that survey data shows a specified value has been achieved. The T distribution is important as often the number of samples is small, and the T-distribution takes this into account in 'degrees of freedom'.

Modelling

The variables used for durability design are not unique/discrete values but are distributions. Incorrect use of the variables statistical definition has a significant effect on the predicted life as shown in Figures 2-4. For chloride ingress modelling based on distributions full probabilistic analysis (FPA) is used. Typically, 10,000+ solutions to the chloride penetrability equation are used to determine how frequently the concrete fails. The complex use of multiple distributions requires skills not present in most design offices.

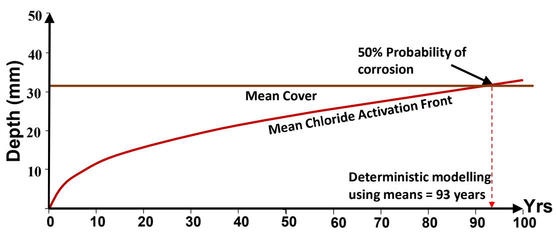

Figure 2 Mean values for variables in a deterministic analysis indicates a long design life because it gives a 50% probability of failure.

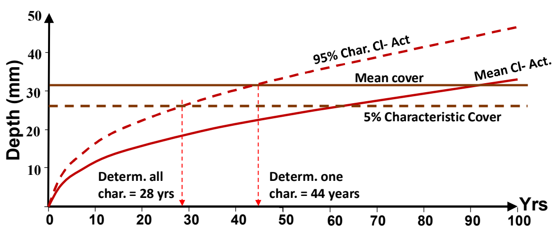

Figure 3 A characteristic value for one variable reduces the predicted design life but it is still unconservative and is of unknow reliability. Using characteristic values for all variables gives a conservative life of unknown reliability.

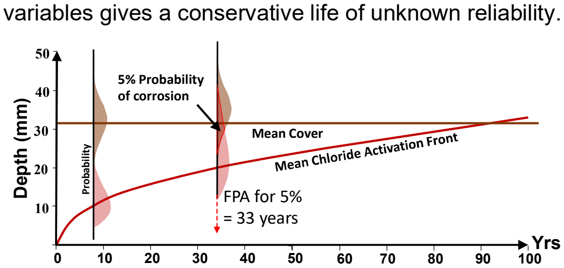

Figure 4 Using variables as distributions the life at a given target reliability can be calculated.

Reliability Based Design

Design for reinforcement corrosion uses target reliabilities of 1.3-1.5. That is consistent with a failure probability of 5-10% at the end of the design life. Figure 5 is a typical graph of reducing reliability with time. These graphs enable designers to select materials and designs suitable to the client needs. The approach also enables a wide variety of options to be considered rather that the limited DtS pallet.

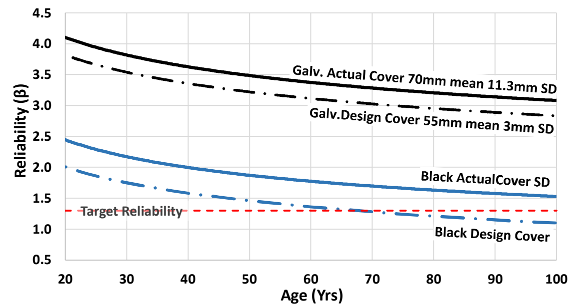

Figure 5 Typical Reliability Assessment

Critical Chloride Level

In FPA the variables distribution is used for the calculation of reliability. In some cases these distribution are given in the literature in others they should be established by testing. Critical chloride level is an example of a value difficult to determine for a project and hence values are being developed for different materials (Figure 6) and exposures.

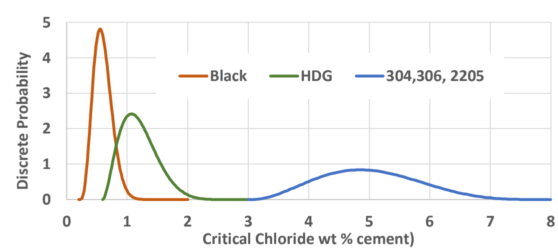

Figure 6 Beta distribution for the critical chloride content of different steels.

Discussion and Conclusion

LoA permits use of design methods of complexity suited to the cost savings that can be made. For durability design this includes FPA which enables more innovative and cost-effective designs. Specifiers should be working to include LoA and FPA in Australian codes.

References

[1] ISO 16204 "Durability – Service life design of concrete structures" International Standards, Switzerland, 2012

[2] *fib* Bulletin 65 and 66 "Model Code 2010 Vol 1 & 2" Lausanne, 2012. *fib* is the international Structural Concrete Association. Model Code 2020 is in final draft form and more fully details the durability design process.

[3] *fib* Bulletin 34 "Model Code for Service Life Design of Concrete Structures." fib Switzerland, 2006.