

Changing perceptions: Durability of concrete structures

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Abstract. Studies by PWD show a significantly high percentage of concrete structures are in distress prematurely. Coupled with additional number of new public assets created yearly, the high increase in the amount of public funding required to ensure these assets are in good condition has generated demands from the policy makers for new, innovative and more cost effective solutions to be adopted. In Eurocode 2, performance-based concepts are implemented whereby concrete structures are designed to meet “design working life” (or “service-life” or “repair-free period”) expectancy of 50 and 100 years, rather than the usual design life. Thus, concrete structure designed to Eurocode 2 requires more stringent compliance to the specified cover thickness and quality at site. Compliance to the present MS EN 1992 in itself does not guarantee compliance to 50 or 100 years design working life. The cover requirements in MS EN 1992 are essentially a full adoption of BS EN 1992. This paper discusses the implication of structural design to MS EN 1992 to meet design working life expectancy of the Code. It highlights some priorities that the industry should undertake as a way forward.

1. Introduction

Public Works Department (PWD), Malaysia is the biggest engineering organisation in Malaysia, tasked with providing engineering consultancy, project management and asset management to the Government of Malaysia. It has been in existence for more than 140 years and arguably, the oldest technical department in the country. It has been the Government’s consultant for design and project implementation of infrastructure, buildings and many other facilities since the colonial era through to independence and up to the present day in 21st century.

Annually, PWD is spending more than RM1 billion in maintenance, rehabilitation and upgrading works of public infrastructures, buildings and the related engineering services. The expenditure is rising rapidly, as a result of continuous addition of new facilities over the successive 5-year Malaysia Development Plans. It is certainly a considerable strain to the annual Government’s budget to finance the works required to keep the assets in good operational conditions. As such, calls for new, innovative and more cost effective construction approaches to be adopted by the local industry are getting louder and louder from the owner, end-users as well as the stakeholders, that are now almost impossible to ignore.

In order to address this issue, improvements have to be done at both stages of construction works, which are, the design as well as the construction stages. At the design stage, prevailing design concepts may have to be purposely changed in order to guarantee the completed building to have sufficiently long maintenance free period. Whereas, at the construction stage, conventional construction approaches also



have to be changed to allow the burden of proving the performance of the assets to be shifted to the constructor, and thus reducing the occurrence of premature failure.

2. Concept of design working life

Traditionally, concrete structures have been designed to meet certain design-life expectancy, for example, bridges for 120 years. The 120 years design-life is the intended useful life of the bridge. During this period, the bridge is expected to be functionally adequate provided it is maintained or repaired regularly. Likewise, a bridge may not be functional up to 120 years, if there has been lack of adequate maintenance and repair. The issues here are “When do we need to repair a bridge?”, “How often do we need to repair a bridge during its design-life of 120 years?” Clearly, engineers could not provide satisfactory answers to those questions based on design practice to British Standards.

Today, the concept of design working life in Eurocode 2 (or more commonly known as service-life design in many literatures) for concrete structures is becoming an area of increasing interest and a challenge for structural engineers. The term “service-life” was used in the draft Eurocode 2, prEN 1992. However, in the final published version of EN 1992, the term has been changed to “design working life” but retaining its definition as before. Eurocode 2 is the first code in the world today to introduce “service-life design” concept for structural design.

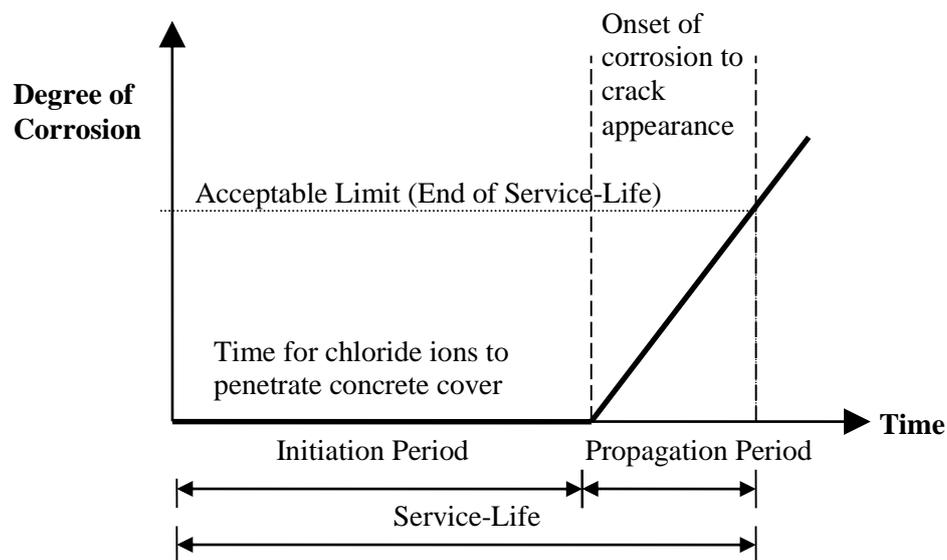


Figure 1: Service-Life Model by Tuutti [9]

The two-phase model shown in Figure 1, proposed by Tuutti in 1982, is commonly used for service-life prediction of structures in a marine environment. The service-life consists of the initiation period and propagation period. For marine environments, the initiation period is defined as the time taken for the chloride ions to reach the steel reinforcement and to initiate corrosion. The propagation period is the time from the onset of steel corrosion to an acceptable level of reinforcement corrosion deemed to be the end of the service-life, e.g., at the first visible crack on the concrete surface.

In many cases, the service-life of a concrete structure is associated with the “corrosion-free” (initiation period) or “repair-free” (until first visible crack). Using the service-life design concept, a structure can now be designed to be “repair-free” for a specified period during its design-life. The model

in Fig. 1 forms the basis for Eurocode 2 to develop cover requirements for 50-year and 100-year design working life for concrete structure.

3. Provisions for service-life design in Eurocode 2

Eurocode 2 (or specifically EN 1992-1-1) provides cover requirements for 50-year and 100-year service-life. However, the cover requirements were derived primarily from extensive long-term research works in European countries. For tropical countries, like Malaysia, the requirements in Eurocode 2 may not necessary be adequate to achieve the desired service-life. This is largely due to the different climatic conditions (temperature, humidity, etc) and environment (salinity of seawater, etc) between Malaysia and European countries.

Local cover requirements are allowed in National Annex. However, due to lack of local data in Malaysia, MS EN 1992 has fully adopted the cover requirements of BS EN 1992. Hence, MS EN 1992 may not necessary ensure compliance of 50-year or 100-year service-life (or “repair-free period”) of concrete structure in Malaysia. Research works based on local climatic environment should be initiated to develop suitable cover requirements for use in Malaysia. The information, when become available, may be used to revise the National Annex to MS EN 1992. As a comparison, SS EN 1992 (of Singapore) adopted a more conservative approach on durability. SS EN 1992 specifies concrete strength of one grade higher than that given in BS EN 1992 for the same exposure class. However, the approach is seemed as a discretionary decision rather than justified by research evidence.

4. Service-life design

Today, owners are very concern with expensive repairs incurred to their concrete assets due to premature durability issues. Using state-of-the-art knowledge in concrete technology, it is now possible to design and construct bridges with excellent durability performance, sound integrity and minimum maintenance cost. As an alternative to the cover provisions in Eurocode 2 for 50-year and 100-year service-life, a designer may choose to perform the service-life design from the “first principle”. It is called the durability design. The philosophy of durability design is similar to that for structural design, except that in this case, it compares the durability resistance of the concrete cover and the environmental load (e.g. chloride ions concentration on concrete cover). By performing a durability design on a concrete structure, a designer has the freedom to decide on any specific service-life span and to determine the corresponding quality (or properties) of the concrete cover to achieve the desired service-life span. Although the design principle has not been formally codified, there are sufficient literatures and references to enable such design to be carried out.

Concrete is usually modelled as a saturated medium and that chloride transport is by means of pure diffusion complying with Fick’s Second Law, given as;

$$\frac{\partial C}{\partial t} = D_c \frac{\partial^2 C}{\partial x^2} \quad (4.1)$$

Applying the following boundary conditions and assuming that D_c does not vary with distance, x , from the exposed surface;

Boundary conditions:

- $C(x, t=0) = 0$; $0 < x < \infty$
- $C(x=0, t) = C_s$; $0 < t < \infty$

an analytical solution to equation (5.1) for a semi-infinite medium is given as;

$$C_x = C_s \left[1 - \operatorname{erf} \left(\frac{x}{2\sqrt{D_c t}} \right) \right] \quad (4.2)$$

Re-writing equation (5.2) as equation (5.3);

$$t = \frac{x^2}{4D_c} \left[\operatorname{erf}^{-1} \left(1 - \frac{C_x}{C_s} \right) \right]^2 \quad (4.3)$$

where,

- t : service-life (or repair-free period) (year)
- x : distance from the exposed surface (mm)
(note: in this case, equals cover thickness)
- C_x : chloride concentration at depth, x (% by wt of cement)
(note: in this case, equals chloride threshold limit)
- C_s : surface chloride concentration (% by wt of cement)
- D_c : chloride diffusion coefficient (mm²/year)
- erf : mathematical error function

Over the last 20 years, many concrete bridges all around the world have been designed using the service-life approach.

5. Provisions for service-life design in Eurocode 2

5.1 Prescriptive Specification Versus Performance-based Specification

Present specifications for concrete works are largely “prescriptive” in that it describes how works should be carried out at site. JKR concrete specification is no exception! The acceptance criteria for concrete at site are solely based on tests carried out on “specially” prepared cube samples or tests done on cube samples. It is well known that the quality of the cube sample does not reflect that of the in-situ concrete in the structure for obvious reasons. The way the cube sample is prepared is very much different from the way concrete is placed, compacted and cured in the formwork. For example, cube samples are water-cured for 28 days under a controlled laboratory condition. Whereas, concrete cast at site is moist-cured for 7 days and under actual environmental exposure. Thus, it is obvious that the quality of hardened concrete in the structure would be different from those of the cubes. Questions that need answers are; “Is the quality of the hardened concrete acceptable?” “Is the in-situ cover in the structure acceptable?”

What is a performance-based specification? It is a specification that specifies functional requirements of the hardened concrete in the structure. The focus is on the hardened concrete or the finished product. This is necessary to ensure that the structure “performs” in an environment for which it is expected to meet the service life design. Some of the “durability parameters”, such as, shrinkage limit, water sorptivity limit, chloride diffusion coefficient, are now being incorporated as performance-based criteria for durability assessment of the in-situ concrete. These tests shall be carried out on samples taken from in-situ structure and not on cube samples made from fresh concrete.

5.2 Why Performance-based Specification?

The prescriptive specification has proven to be inadequate in addressing durability issues affecting structural integrity. The specification cannot guarantee a satisfactory “performance” of hardened concrete in the structure. The move towards developing and adopting performance-based specifications is gaining support by all sectors of the construction industry worldwide. Greater emphasis on service-life design has also led to a strong demand for performance-based durability design principles and specifications.

Eurocode 2 is a performance-based design code. It is imperative for designer to understand that concrete structure designed to Eurocode 2 requires stringent compliance to the specified cover, at site, to ensure achievement of the desired service-life of 50 or 100 years. This can only be done through the implementation of a performance-based concrete specification. The specification should address issues pertaining to, e.g., method of assessment of in-situ cover thickness, quality assessment of covercrete, sampling (size and frequency), testing, criteria for acceptance, measures to be taken in the event of non-compliance.

6. Moving forward

Malaysian construction industry has to move along in tandem with the fast-transforming world trend in engineering practice. Propelling the industry to the next higher level is a challenge but is inevitable to remain relevant with regard to the present engineering landscape. In view of the impending mandatory implementation of Eurocodes locally, the industry should set-forth the following priorities.

- (a) Undertake collaborative long-term research projects with local Institution of Higher Learnings (IPT) in developing suitable cover requirements for use with MS EN 1992 through the revision of National Annex. The requirements should be derived from data collected from existing structures over long-term exposure to local climatic conditions and environment.
- (b) Develop a performance-based specification for works for use with MS EN 1992.
- (c) Mobilise respective local players and industry stakeholders to embrace the new concepts, such as durability design (the philosophy of such design has been described in section 4.0 above), and diligently carrying out construction works in accordingly.

7. Conclusion

In Eurocode 2, concrete structures are designed to meet “design working life” (or “service-life” or “repair-free period”) expectancy of 50 and 100 years. Thus, it is imperative for designer to understand that concrete structure designed to Eurocode 2 requires stringent compliance to the specified cover, at site, to ensure achievement of the desired service-life of 50 or 100 years.

Compliance to the present MS EN 1992 in itself does not guarantee compliance to 50 or 100 years design working life. The cover requirements in MS EN 1992 are essentially a full adoption of BS EN 1992 which may not be adequate in Malaysia due to different climatic conditions and environment. Hence, it merits further research works locally. Performance-based specification for concrete works should be developed to complement structural design to MS EN 1992.

Local construction industry is at the fore-front of national development, and as such should lead rather than be led. The industry should move away from conventional design practice that requires significant amount of resources to sustain to state-of-the-art design principle that generates more value for the same amount of resources. As it is now, the world trend is moving towards a performance-based design standards and specifications; and the local industry should seriously consider to follow suit. Large engineering structures around the world today, e.g. long span bridges, are already designed for service-life (repair-free period) of at least 100 years, why can't we?

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