Are We Really Designing for a 100-Year Service Life?

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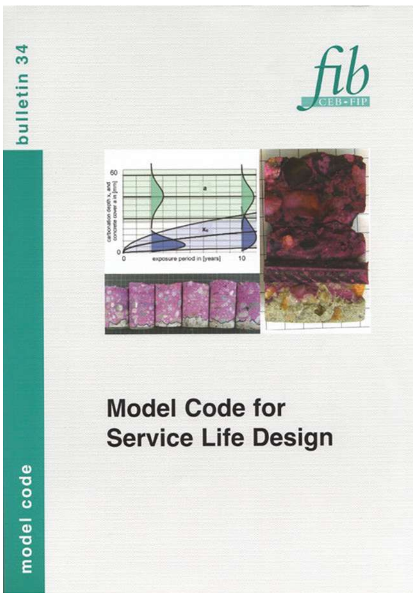
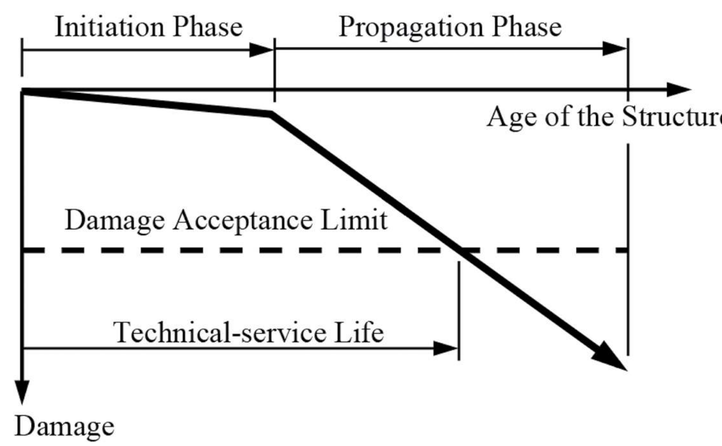


fib Model Code for Service Life Design (Bulletin 34). Figure: *fib*.



Two-phase deterioration model for reinforced concrete due to corrosion. Figure: Mike Bartholomew.

Recently, requests for proposals for several large bridge projects have had requirements for the structure to have a service life of 100 years. With no U.S. standards or guidelines in place to establish performance criteria for service life design (SLD), it is often unclear what is being requested and what is being achieved.

SLD for concrete structures has developed over the past 30 years in Europe, and has been documented in several international standards and specifications:

- *Model Code for Service Life Design* by the International Federation of Structural Concrete (*fib*) (Bulletin 34)
- *Model Code for Concrete Structures 2010* by *fib*
- *Durability—Service Life Design for Concrete Structures* (ISO 16204) by the International Standards Organziation (ISO)

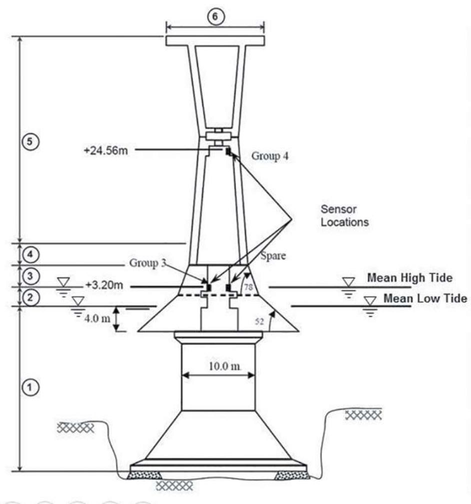
In the United States, SHRP2 research project R19A, "Service Life Design for 100 Years and Beyond," was completed in 2013. Currently, the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) are sponsoring the SHRP2 R19A Implementation Action Program to promote the use of SLD. Four state departments of transportation (Iowa, Oregon, Pennsylvania, and Virginia), along with FHWA Central Federal Lands Division, are developing bridge projects using SLD principles. As these projects are completed, training materials will be developed and published to show the need for using SLD.

SLD is based on the way materials deteriorate in their environmental exposure conditions. Concrete structure deterioration is generally due to corrosion of the reinforcing steel. Chlorides from seawater or deicing chemicals represent the most severe environmental exposure zones. Other deterioration mechanisms include reinforcement corrosion after concrete carbonation, concrete damage due to alkali-silica reaction, and abrasion on bridge decks.

Chloride ingress deterioration has been well defined. Chlorides applied at the surface of the concrete diffuse with time through the outer concrete cover layer. When chloride ions reach a critical concentration threshold at the level of the reinforcement, corrosion initiates. Corrosion by-products are expansive, and coupled with concrete's low tensile capacity, this expansion creates surface cracking. As the corrosion continues, it leads to spalling and loss of steel cross section. The deterioration mechanism consists of two phases:

- An **initiation** phase, where there is no visible physical change to the structure
- A **propagation** phase, where the structure experiences damage from corrosion

A mathematical model based on Fick's 2nd Law for diffusion, outlined in *fib* Bulletin 34, defines the initiation phase. Currently, there are no generally accepted models for the corrosion propagation phase. Fick's 2nd Law can be evaluated as a load and resistance factor equation similar to traditional structural design.



Component	Figure ID	Exposure Class (EN206)*
Substructure		
Submerged Zone	1	XS2
Tidal Zone	2	XS3
Splash Zone	3	XS3
Spray Zone	4	XS3
Atmospheric Zone	5	XS1
Superstructure		
Atmospheric Zone	5	XS1
Roadway & Traffic Barrier	6	XD3

*Source: BS EN 206: 2013 *Concrete. Specification, performance, production and conformity.*

The environmental exposure of the structure and its components can be accomplished with the use of a structure exposure category diagram. Figure: Mike Bartholomew.

The environmental loads are the chloride concentration applied at the surface of the concrete, the initial chloride content of the concrete, and the average temperature at the bridge site. The parameters that define the durability resistance of the concrete are the chloride diffusion coefficient and the depth of cover to the reinforcement. The diffusion coefficient is affected by the mixture proportions, particularly water-cement ratio, and the presence of supplementary cementitious materials. The limit state is defined by the chloride threshold of the steel reinforcement.

SLD strategies are divided into two classes:

- **Avoidance of Deterioration:** A strategy where materials are provided that have resistance well beyond the requirements needed. For example, use of stainless steel reinforcement, which has a chloride threshold many times that of conventional reinforcement.
- **Design Based on Deterioration from the Environment**, which is subdivided into three levels:
  - *Full Probabilistic*—Uses mathematical models such as Fick's 2nd Law, where the environmental demand and resistance parameters are represented by mean values and distribution functions (standard deviations and the like), and a probabilistic, Monte-Carlo type analysis to compute the level of reliability.
  - *Deterministic*—Uses the same mathematical models as for the full probabilistic approach, but with load-and-resistance factors applied to the environmental demands and durability resistance parameters. This results in a direct solution to the model. The current state of the practice has insufficient data to develop load and resistance factors to a level of reliability satisfactory for general use.
  - *Deemed to Satisfy*—A prescriptive approach where concrete materials and cover dimensions are specified in code provisions. The *AASHTO LRFD Bridge Design Specifications* includes cover dimensions, but does not correlate them to concrete durability parameters or environmental exposures, resulting in a very low level of reliability.

Different SLD strategies may be applied to different components of the structure. For certain types of deterioration like alkali-silica reaction, no mathematical models currently exist. For these, avoidance may be the only choice.

Performing SLD on new bridges will require a systematic change in the way we perform our work, not only in design, but during construction and through operation during the life span of the structure. This process consists of the following steps:

1. Identify the environmental exposure of the structure and its components. This can be done graphically.
2. Select a limit state and an expected service life. Current practice is to define the end of the initiation phase as the limit state. This does not mean that the structure is no longer usable; rather that it has reached a condition where major repairs are required to allow safe operation. The 100-year service life typically applies only to main structural components of the bridge. Components like bearings, expansion joints, and overlays may need to be replaced periodically over the structure's life.
3. Define a SLD process and performance criteria, such as *fib* Bulletin 34 for the full probabilistic method with a probability of achieving the limit state of 90%.
4. Select concrete materials and cover dimensions to satisfy the design requirements. Concrete mixture proportions are identified at this time to establish target chloride diffusion coefficients for design.
5. Produce contract documents. Testing for the chloride diffusion or migration coefficient has not been part of standard tests used in the United States. Tests, like Nordtest NT Build 492, performed at 28 days like concrete strength tests, need to be introduced into the standard specifications.
6. Perform the same tests in the field during construction to verify that the design intent has been met. This also includes concrete cover dimension mapping after the concrete has been cast.
7. Inspect and maintain during operation. This is imperative to ensuring that the service life can be realized.

Following the above process provides a rational, scientific approach to achieving a specified service life. This entire process is not complex, but is new to owners, designers, and contractors. It will require training, but it can be and needs to be achieved.