DURABILITY DESIGN APPROACH FOR CONCRETE BRIDGES

Ainars Paeglitis, *Ph.D.*, Inzenierbuve Ltd. Azenes st.20, LV-1048, Riga, Latvia

Summary

Traditional design methods and approaches still used for concrete bridges are showed great durability problems in 20 to 40 years, when exposed to environmental influences and deicing salt. This determines the development of methodology of durability design for concrete. Design for durability of bridge structures requires methodology and predictive models for the degradation process of concrete structures, as well for factor of safety, to cover variability and uncertainty in materials and construction. Design for durability will provide the formal end of the service life of structure, what is considered acceptable appearance and acceptable costs for maintenance and repair.

1. Introduction

The capability of concrete to take any shape is widely used for creating beautifully and aesthetic structures. Concrete as structural material is widely applied in bridge construction. We know many fascinated examples of concrete bridges. From the last time structures can be mentioned such as Shakh Isa bin Salam Bridge in Bahrain (Fig.1) or the bridge over the Lerez River at Pontevedra in Spain (Fig.2), or the Shiosai Bridge in Japan (Fig.3).

Fig.1 The Shakh Isa bin Salam Bridge in Bahrain

Fig.2 The bridge over the Lerez River at Pontevedra in Spain

The concrete is the most used material for bridge structures in Latvia, 94% of all existing bridges are made from concrete. Concrete bridges are required to maintain their serviceability for a long period, sometimes 100 years or more. The designer and owner should be assured that the structure during all his lifetime could not lose the strength, functionality and aesthetic performance.

Fig.3 The Shiosai Bridge in Japan

2. Deterioration

The structures from reinforced concrete have generally shown satisfactory performance regarding to strength but have indicated some problems with durability. The concrete properties will change with the time. The important role in the concrete deterioration process plays the transport mechanisms of gas, liquid and ions caused by interaction between the material and the environment.

The most important deterioration mechanisms [1,2,3] are:

- Reinforcement corrosion introduced by carbonation or chloride ingress;
- Chemical attack: alkali aggregate reaction, sulphate and acid attack;
- Physical damage: freeze-thaw cycles, salt scaling, abrasion and fatigue.

The deterioration process, according to [4], can be divided into two phases (Fig.4):

1) During the *initiation phase* no weakening of the concrete or of the function of the structure occurs.

2) During the *propagations phase* active deteriorations proceeds rapidly and in many cases with acceleration.

A durable concrete structure has a long initiation phase and a slow propagation phase. The ideal situation by design of new structure is if the initiation phase exceeds the target service life.

To describe the deterioration process of the concrete structures are used the time dependent model for the actual degradation processes. The durability design methodology should be able to predict the capacity of the materials to resist the certain climatic conditions. The deteriorations models should show the degradation long-term effect, as well predict the service life as function of corresponding design parameters.

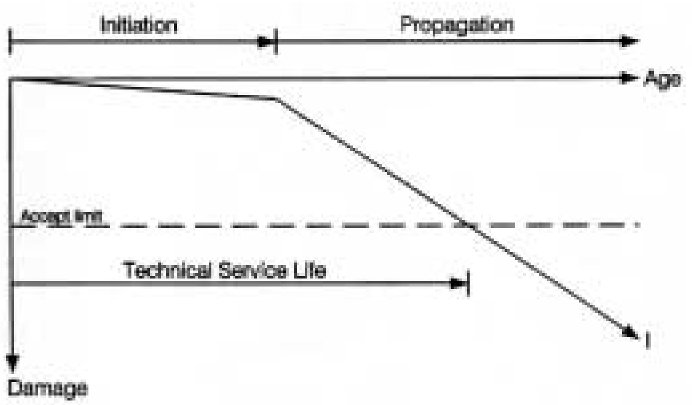

Fig.4. Technical service life [4]

For example, the carbonation rate model in [2] is formulated as follows:

$$d_c = \sqrt{2k_1k_2k_3\Delta_C} \cdot \sqrt{\frac{D_{nom}}{a} t \left(\frac{t_0}{t}\right)^n}, \qquad (1)$$

with, d_c – the carbonation depth; D_{nom} – the diffusion coefficient of dry concrete for carbon dioxide in defined environment (20^0C, 65% rel. humidity); a – the amount of CO_2 for complete carbonation; Δ_C – the concentration difference of carbon dioxide at the carbonation front and in the air, which usually means the carbon dioxide content of the surrounding air c_0; k_1 – parameter for micro climatic conditions, describing the mean moisture content of concrete; k_2 – parameter to describe curing conditions; k_3 – parameter to describe the effect of water separation (local w/c ratio); n – parameter for micro climatic conditions; t_0 – reference period; t – time.

The chloride penetration model in [5] is formulated as follows:

$$C_x = C_S\left(1 - erf\,\frac{x}{2\sqrt{Dt}}\right), \qquad (2)$$

where, C_x – the concentration of chlorides at a distance x from the concrete surface; C_S – the surface concentration of chlorides; D – non stationary diffusion coefficient; t – the time.

3. Durability design

The traditional design approach in relation to the durability of the concrete structures of the bridges, including the former USSR Codes, is based on allowable limit principle such as minimum cover, maximum water/binder ratio, minimum cement content and limitation of cracks. For the concrete structures this principle have included the acceptably long but not specified lifetime.

The new approach developed in [3,6,7] provide two different strategies:

A. Avoid the degradation threatening the structure due to type and aggressivity of the environment.

B. Select an optimal material composition and structural detailing to resist, for a specified period of use, the degradation of threatening the structure.

The strategy A could not survey the deterioration mechanism, but are based on total protection principles. Strategy A can be subdivided into three possibilities [6]:

A1. Change the micro-environment (for example: tanking, membranes, coating etc.);

A2. Select non-reactive or inert materials (for example: stainless steel, coated steel);

A3. Inhibit the reaction (for example: cathodic protection, prevent frost attack by providing of appropriate air void system).

Strategy B minimizes deteriorations by optimal design and choice of the materials and will be based on [6]:

- realistic and sufficiently accurate definitions of environmental actions, depending on the considered type of degradation,
- material parameters for concrete and reinforcement,
- calculation models for deterioration mechanisms.

Such approach allows updating the service life from actual results of tests and measurements during the lifetime of the structure. In this case the inspections and tests of the concrete structures of bridges will play an important role in the service life design.

The evaluation, assessment and analyze of the existing concrete bridge structures should be made according to a segmental approach [8] and indication of the critical areas, considering the system approach as well.

The information of the actual properties and measurements of the new concrete bridge structures will be included in “birth certificate” [6] of the structure and will be used for service life design. The “birth certificate” will include the information about the exposure related parameters, material properties, performance related parameters, hazard scenario and economic consequences.

The service life should be provided for new, existing and repaired concrete structures. For concrete bridges after reconstruction should be created a new - “re-birth certificate”.

The new durability design methodology developed by “DuraCreate” project use the probabilistic approach for service life design of the concrete structures. The new approach is based on the reliability theory used in structural design. The reliability analysis should determine the probability of failure, denoted P_f, describe the case when a variable resistance R(t) is lower than a variable load S(t) in time t (Fig.5)

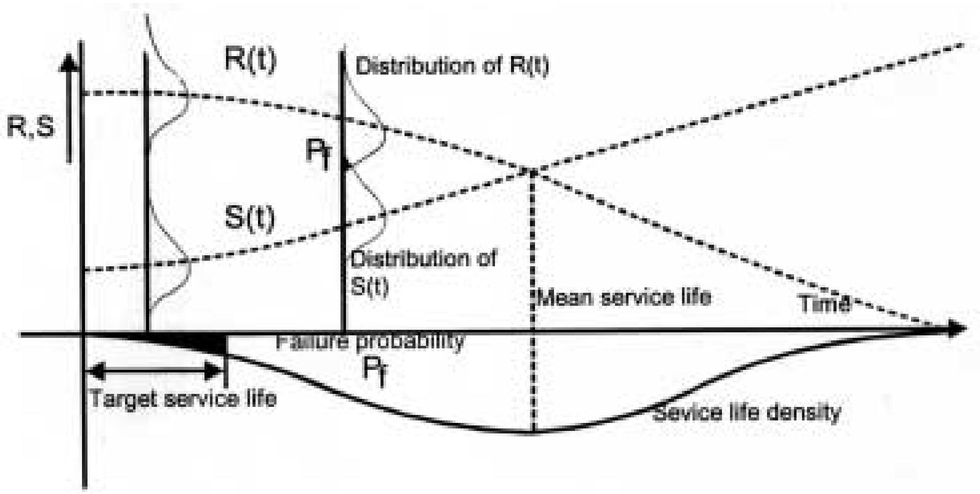

Fig. 5. Failure probability and target service life [6]

4. Conclusions

The durability design approach for the concrete bridges has been based on the reliability during the design service life. The durability design based on performance includes the probabilistic nature of the involved parameters. This methodology allows us to use the service live design similar to structural design by consideration of time-depend economical aspects, as well the updating ability.

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