ELSEVIER

Construction and Building Materials 18 (2004) 163–172

Construction and Building MATERIALS

www.elsevier.com/locate/conbuildmat

Role of NDE in quality control during construction of concrete infrastructures on the basis of service life design

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Received 15 September 2003; received in revised form 12 October 2003; accepted 12 October 2003

Abstract

The performance and reliability based service life design follows the same principle and framework as the performance based structural design. It is based on terms such as performances, limit states, reliability and reference period or design service life. As in the structural design, during the service life design, the uncertainty is taken into account in the probability density functions of the basic variables, including their parameters like the mean value and the standard deviation. This means that during construction and use of the structure, measures must be taken to guarantee that the uncertainties do not exceed acceptable limits. Testing and quality control is therefore important at several stages during the life of a structure. To check the real performance of the structure, the material properties, the geometrical and execution variables that influence the selected degradation models have to be checked by quality control in order to define and to update the statistical quantities (type of distribution, mean value, standard deviation) of the stochastic variables that affect structural reliability. It is demonstrated in this paper that the selected non-destructive evaluation (NDE) method (so called 'Two point Electrode Method') has been successfully applied in relation to the service life design during the construction of the 'Green Hart Tunnel'. For this purpose a statistical model has been developed in order to derive practical criteria, which can be easily used in practice. Further studies have been concentrated on seeking other potential NDE methods, which can be applied in a real structure to measure and to quantify other parameters in the limit state function of the service life design (e.g. the so-called execution factor k_c). The capabilities of two promising methods, spectral analysis of surface waves and spectral analysis of lamb waves, are discussed in combination with bottlenecks that need to be passed.

Keywords: Concrete; NDE; Quality control

1. Introduction

In modern codes, like the Eurocode, the structural design is regulated on the basis of performance and reliability. This means that the design procedure for the safety and the serviceability of structures (or performance) is expressed as a limit state function. This limit state defines the border between an adverse state (such as collapse, buckling, deflection and vibration) and the desired state. In principle, performance based design should include the following items:

- Limit states, where the border between good performance and bad performance is given.
- Models, being included in the limit state and being able to describe the behaviour of the structure in a correct way.
- Input parameters in the model, having stochastic characteristics, are being statistically determined.
- A target value for the reliability, being able to prove that the relevant performance is reliable throughout the whole designed service life (reference period).

However, it is well known that despite the help of the performance and reliability based design the knowledge about the service life of a real structure is still uncertain due to the random variation of the geometry, material characteristics, execution and environment. At the design stage, this kind of random variation is dealt with through the adoption of a stochastic model (such as the geometry) or a characteristic value obtained by a compliance test in the laboratory. The real situation in practice has to be controlled during the construction and the service life of a structure. During the stage of design and construction, quality control plays a key role. When

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0950-0618/04/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2003.10.005

confronted with uncertain factors that play a key role for the reliability of a structure, during the service stage of a structure, monitoring is indispensable in order to test and to update the distribution parameters of the relevant random variables. The application of non-destructive test and non-destructive evaluation (NDE) seems to be the only way to fulfil the quality control and monitoring in practice. For example, the 'Dutch Weighted Maturity' method [1,2] and Consensor© system [3,4] have been developed in the last several years in the Netherlands for the quality control during the construction of a concrete structure. The tested and controlled parameter is the compressive strength of the actual concrete structure, which can be easily traced back in a limit state function in the performance- and reliability-based structural design.

In comparison with the structural design the present design approach with respect to durability of concrete structures is based on a reasonable understanding of the main degradation processes for concrete, reinforcement and prestressing steel. The performance of the design is however not explicitly formulated as a service life. It is based on deem-to-satisfy rules (e.g. minimum cover, maximum water/binder ratio and crack width limitation) and the assumption that if these rules are met, the structure will achieve an acceptably long but unspecified life. The information about the service life to be achieved is to a large extent empirical. To improve this situation a new design framework for durability 'DuraCrete' has been developed since last several years in Europe [5–7]. Similar to the current procedures for structural design, the 'DuraCrete' method is performance based by taking into account the probabilistic nature of the environmental aggressiveness, the degradation processes and the material properties involved.

Recently in the design and construct contracts for several large infrastructures in the Netherlands a requirement of a service life of at least 100 years has repeatedly been stated. In order to prove the validity of this required service life, performance and reliability-based calculations have been carried out according to the design method 'DuraCrete' for a certain selected project. On the basis of the service life design, one of the selected NDE method, 'Two point Electrode Method' (TEM), has been applied for the quality control during the construction stage [8].

In this paper, after brief introduction of the principle and procedure of the service life design, the experiences on the application of TEM in practice will be described. Furthermore, the potential applications of other NDE methods to test and evaluate the parameters in the limit state function, which is used in the performance and reliability based service life design, will be illustrated.

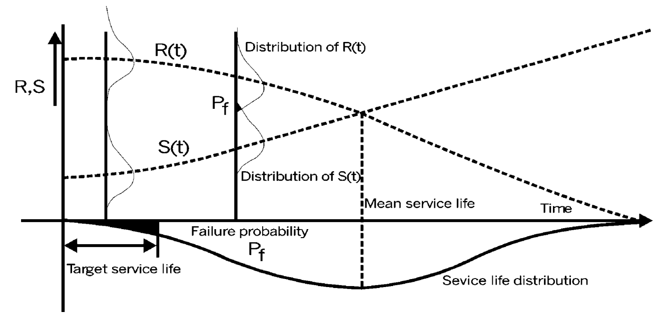

Fig. 1. Failure probability and target service life (illustrative presentation).

2. Performance and reliability based service life design

2.1. Principle

A performance and reliability based service life design should be on the basis of:

- adequate definitions of environmental actions (different micro-environmental aggressiveness classes) depending on the resulting type of degradation;
- the actual material parameters for concrete and reinforcement;
- validated mathematical models for degradation processes;
- multi-level performances (components and whole structures) expressed as limit states and reliability.

The service life design follows the same principles (reliability and performances) as a structural design code. In the service life design both the resistance R and the load S are considered to be time dependent. Relationship equation (Eq. (1)) shows a time dependent limit state function:

$$R(t)-S(t)>0 \tag{1}$$

Relationship equation (Eq. (1)) applies for all values of t in the time interval (0, T). T is the intended service period (i.e. reference period). From a mathematical point of view it can be stated that the relationship equation (Eq. (1)) can be used for service life design. The service life concept can be expressed in a design formula, similar to the structural design:

$$P_{f,T}=P\{\mathrm{R}-\mathrm{S}<0\}_T<P_{\mathrm{target}}=\Phi(-\beta) \tag{2}$$

where $P_{f,T}$, the probability of failure of the structure within T; T, intended service period.

The mathematical model for describing the event 'failure', i.e. passing a limit state, comprises a load variable S and a resistance variable R, see Fig. 1. Failure