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Residual Service Life of Concrete Structures

Vie résiduelle des structures en béton armé

Restnutzungsdauer von Betontragwerken

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SUMMARY

This paper outlines the nature and scope of a project entitled "The residual life of reinforced concrete structures". The deterioration mechanisms covered by the project are: reinforcement corrosion, freeze-thaw damage and alkali-silica reaction. Preliminary ideas are outlined on the options avaliable for developing a deterministic model to predict future strength and serviceability, while taking account of variable client needs in terms of minimum technical performance and of future management strategy for the structure.

RÉSUMÉ

L'article décrit la nature et les objectifs du projet "La vie résiduelle des structures en béton armé". Les mécanismes de détérioration traités dans le cadre du projet sont: la corrosion de l'armature, les dommages infligés par le cycle gel-dégel et la réaction au silicate alcalin. Les auteurs offrent des idées préliminaires sur les options disponibles pour l'élaboration d'un modèle déterministe, qui servira à prédire la résistance et le potentiel d'utilisation ultérieurs, compte tenu des exigences diverses des clients en matière de performances techniques minimum admissibles et de la stratégie de gestion future des structures concernées.

ZUSAMMENFASSUNG

Der vorliegende Aufsatz umreisst Art und Umfang des Projektes über "Die verbleibende Lebenserwartung von Stahlbetonbauwerken". Das Projekt deckt die folgenden Verfallsmechanismen ab: Korrosion der Bewehrung, Schädigung durch Frost-Tau-Wechsel und Alkali-Silika Reaktion. Es werden vorläufige Ideen bezüglich der Optionen aufgezeigt, die für ein deterministiches Modell zur Vorhersage künftiger Festigkeit und Nutzbarkeit zur Verfügung stehen. Gleichzeitig werden die unterschiedlichen Anforderungen der Klienten hinsichtlich minimaler technicher Leistung und künftiger Managementstrategien für das Bauwerk berücksichtigt.

1. INTRODUCTION

When a decision is taken to appraise a deteriorating structure - perhaps based on input from routine inspection - the client will generally want a simple answer to the simple question "Is the structure safe and serviceable now, and how long will it remain so in the future ?". In posing this question, he will most probably have established his minimum acceptable requirements for technical performance - based on his future plans for the structure, primarily for financial and functional reasons - and will want to know how long it will be before those may be reached [with or without interim repairs], i.e. the residual service life.

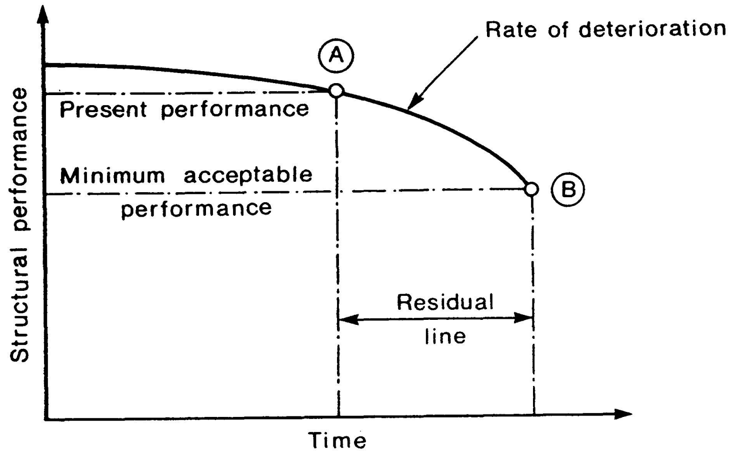

Fig. 1 Schematic illustration of assumed behaviour

The situation is shown schematically in Figure 1. The problem is to establish the performance at Point A, and how long it will take to reach point B. Point B itself requires definition; this will depend on future client needs, while also taking account of the levels of safety and serviceability provided in the original design.

The essential steps in the process, and the links between them, are shown in Figure 2. In short, where one or more specific deterioration mechanisms are involved, these have first to be identified, their effects quantified, and the results integrated into the procedures usually adopted for conventional structural appraisal.

A number of differences between assessment work and original design should be noted. The most important of these are:

- material properties can be measured, not assumed
- dead loads can either be measured, or otherwise determined with some accuracy
- more realistic estimates of live load can be made
- more rigorous analytical methods can be used, while taking account of interactions between all elements, and possibly establishing alternative load bearing mechanisms
- the relative importance of load effects may be different. While basic effects such as bending, shear and compression will have to be checked, actions such as anchorage and bond can become more important when deterioration is involved.
- the establishment of the likely future environment [especially micro-climate] is of critical importance, since it will influence future deterioration rates.
- lower factors of safety, and smaller "margins", can be used, because of the greater knowledge of the structure - compared with the assumptions made in design.

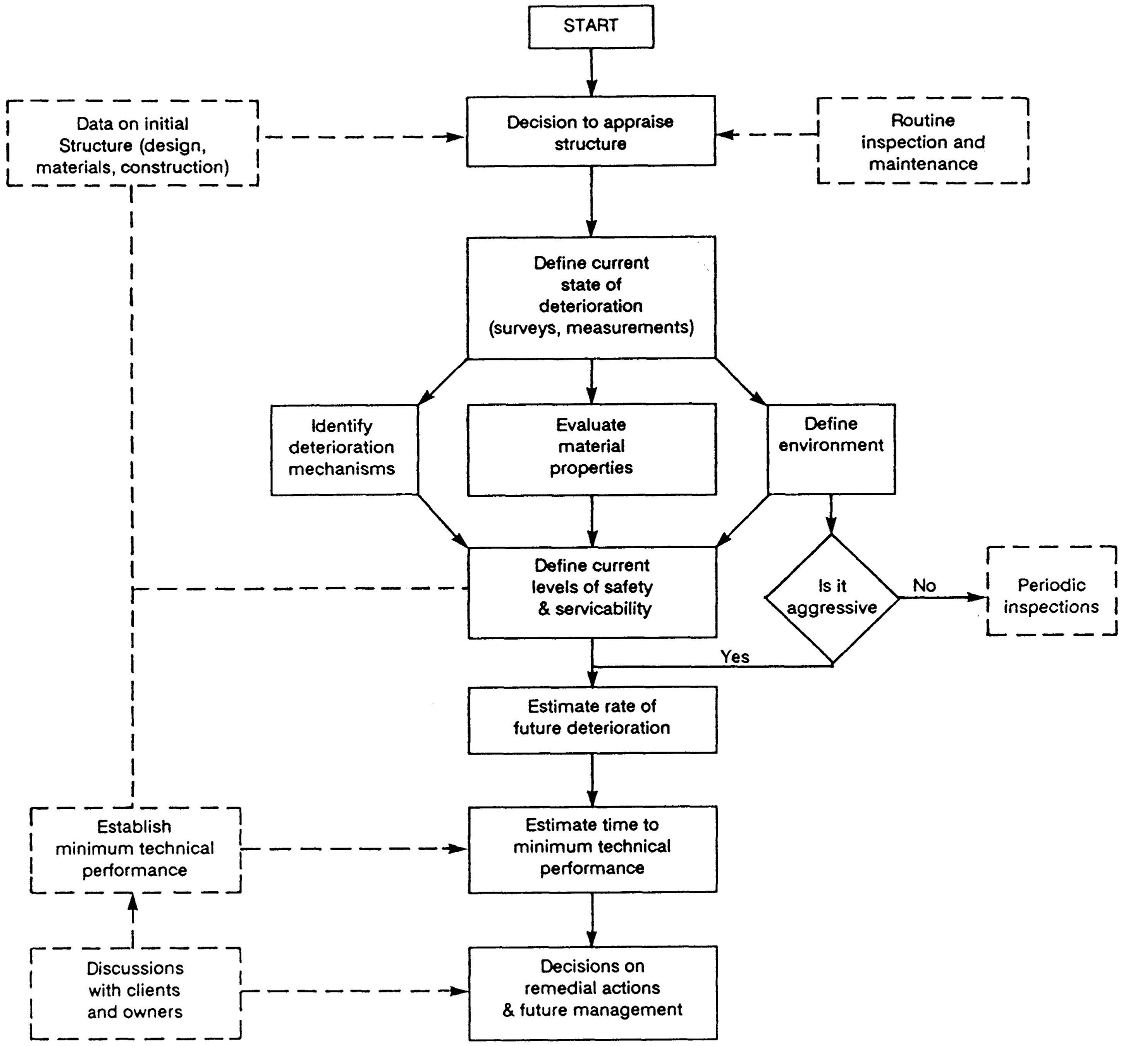

Fig. 2 Steps involved in assessing structures and residual service life

2. BRIEF DESCRIPTION OF BRITE PROJECT BREU-CT92-0591

This 3-year project, which started officially on 1/3/92, is concerned with developing a quantifiable system to enable residual service life to be evaluated in accordance with Figures 1 and 2. The specific deterioration mechanisms to be covered are: reinforcement corrosion; freeze-thaw; alkali-silica reaction; with their effects considered singly and in combination.

While the project is concerned with all the steps identified in Figure 2, particular emphasis is placed on certain factors, where new data or a new approach is required; these are:

(a) definition of the aggressivity of the environment. This has to be appropriate for each deterioration mechanism, while allowing for both macro- and micro-climate.

(b) assessment of current material properties in the structure. Basically, this is concerned with test methods for all relevant material properties - and the interpretation of data from these.

(c) definition of current levels of safety and serviceability. This is a modelling process, taking account of the output from (b) above, other known characteristics, and modern methods of analysis.

(d) assessment of future deterioration rates. Using stage (c) above as a starting point, while augmenting the data from stages (a) and (b), future deterioration rates are assessed.

(e) definition of minimum acceptable technical performance. As indicated in Figure 2, this depends not only on the output from stages (a)-(d) above, but also on input from clients regarding future performance requirements.

Extensive experimental work is planned for stages (a)-(d) above, but probably the key to the whole project is stage (e), where discussions are necessary with clients/owners to establish a range of future needs for different types of structure [e.g. nuclear reactors v bridges v domestic housing]. Finally, to verify the applicability of the whole approach in practice, a series of case studies are planned; this means that, with the co-operation of clients, our system of assessment will be used on structures which have been examined previously and decisions taken on their residual life and future management. When all of this work has been completed, the entire approach will be produced in the form of a Manual, for convenient every-day use in practice.

3. CURRENT STATUS OF THE PROJECT

Initially, most effort is being concentrated on obtaining experimental data. For each deterioration mechanism, research is well advanced in relating changes in material properties to a wide range of environmental conditions, since the realistic classification of aggressive environments is seen as a high priority. The starting point is a classification for reinforcement corrosion, concentrating on local conditions close to, and within, the structural concrete cover. Separate conditions are foreseen for corrosion due to carbonation and to chlorides, with chlorides being further sub-divided into de-icing salts and sea water. Conditions for corrosion initiation and propagation will be treated separately.

Moisture conditions in the concrete are seen as being critical. When the classification is subsequently extended to cover freeze-thaw and ASR, this will become all-important, since different moisture conditions will be critical (see, eg. Table 1, taken from the CEB Recommendations on durability[1]). Nevertheless, a quantitative approach is considered feasible, and the proposed classification for corrosion will be finalised before the end of 1992.

Effective relative humidity	Process				
	Carbon-ation	Corrosion of steel in concrete which is		Frost attack	Chemical attack
		carbonated	chloride contaminated		
Very low [< 45%]	1	0	0	0	0
Low [45-65%]	3	1	1	0	0
Medium [65-85%]	2	3	3	0	0
High [85-98%]	1	2	3	2	1
Saturated [> 98%]	0	1	1	3	3

Risk : 0 = not significant 1 = slight 2 = medium 3 = high

Table 1 Significance of moisture state in influencing different durability processes

Further experimental work is in hand on corrosion, concentrating initially on the relationships between levels of corrosion and both cracking and bond; information here is important in assessing levels of structural safety and serviceability.

Corresponding experimental programmes already exist for the other two deterioration mechanisms - freeze-thaw and ASR. These data will be obtained early in the 3-year programme, since considerable effort will then be required, in deriving assessment procedures for the combined effects of the three deterioration mechanisms - an important, and original, part of the project.

In parallel to this activity, preliminary ideas are being formulated for the overall framework necessary for the assessment of residual service life, while satisfying the basic need in Figure 1 and concentrating on the steps in the bottom half of Figure 2. The factors involved, and preliminary development work are described below.

4. PRELIMINARY DEVELOPMENT OF OVERALL PROCEDURES FOR ASSESSING RESIDUAL LIFE

4.1 Some basic principles

(a) A viable assessment method is made up of a number of essential and interacting elements; these are:

- a behavioural model
- criteria defining satisfactory performance
- loads under which these criteria should be satisfied
- relevant representative material properties
- factors or margins to take account of vagaries and variability in the system, and to simplify its application in practice.

There has to be a proper balance between all the elements, in deriving the reliability of the method. That overall reliability will generally [but not always] be the same as that for the original design - but calculated in a different way, using more accurately defined input.

(b) In principle, material deterioration should not be regarded as a state [to which limits might be set] from a structural point of view, but rather as something which can lead to an unsafe or unserviceable state. Its influence on individual elements and structures is what has to be assessed, in relation to defined action effects [e.g. bending, shear, compression, bond for the different regions shown in Figure 3, for a simple beam.]

(c) Element characteristics change at different rates with time, as shown schematically in Figure 4. In determining current levels of safety - e.g. at point A in Figure 4 - and in predicting future deterioration, there is a need for awareness that other mechanisms may subsequently interfere and become more critical, e.g. anchorage and bond in relation to Figures 3 and 4.

(d) Different load carrying mechanisms [see Figure 3] may have different deterioration rates, and different levels of minimum technical performance, depending on the acceptable risks for each [see Figure 5].

(e) A viable assessment method for residual service life should satisfy three essential criteria:

- the prediction of residual strength, with known acceptable safety factors, while properly representing the effects of the deterioration mechanisms involved,
- the meeting of future client needs, in terms of function and serviceability;

- incorporation of sufficient flexibility, to address the characteristics of individual structures, while being underpinned by a robust theoretical approach.

The attraction of a simple and pragmatic approach is perhaps a fourth criterion.

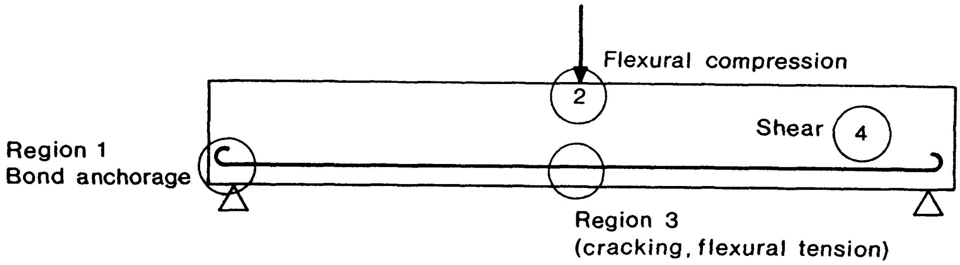

Fig. 3 Possible critical regions in a simple beam, due to deterioration

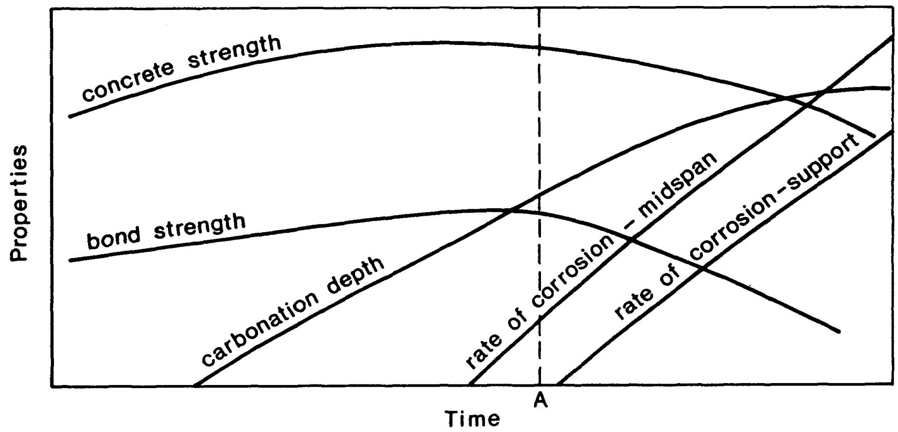

Fig. 4 Schematic change in element characteristics with time

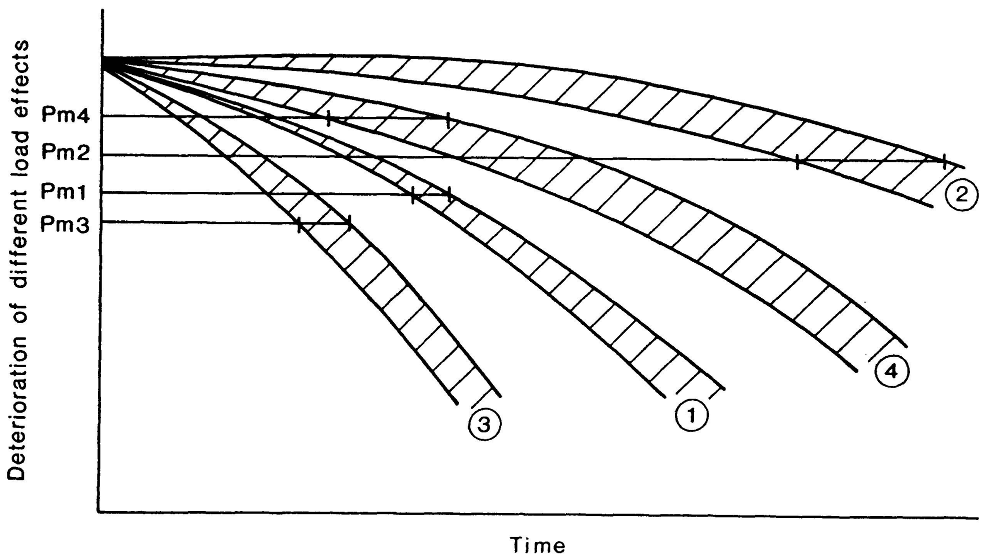

Fig. 5 Possible different deterioration rates for the mechanisms shown in Figure 3. Each may have different minimum technical performance requirements, depending on risks [P_{m1} - P_{m4}]

4.2 Available general methods of assessment

Most theoretical approaches can be put in one of two categories:

- damage classification methods, e.g. [2]
- reliability analysis, e.g. [3] [4], [5]

4.2.1 Damage classification methods

Based on condition surveys, the usual approach is to classify individual structures into one of a number of defined categories, having looked at the materials and elements, as well as the structure as a whole. The cause of the deterioration is determined, and the effects [in mechanical, physical, chemical and biological terms]. Normally, the end result is a rating system, with recommended actions associated with each rating. The discipline associated with this system has considerable merit, in terms of testing and evaluation of data.

4.2.2 Reliability methods

This favoured approach involves extending existing techniques, used in developing design methods for Codes: here, safety in assessment terms can be more easily related to that in the original design. Engineering perspectives are provided by Schneider[6] and Fagerlund[7].

4.2.3 General

Few papers and reports address the difficult question of minimum acceptable technical performance in a quantitative way: there are exceptions, e.g. [8] [9].

4.3 Practical considerations

The service lives of essentially similar structures, under apparently similar conditions, may vary considerably. There may be many reasons for this, but two key points emerge from the literature:

- some structures are inherently more vulnerable to deterioration due to their design concept and the quality of the detailing. For example, in making recommendations on the structural effects of ASR, the Institution of Structural Engineers[10] found it necessary to define the sensitivity of the structure and individual elements in three classes which reflected the potential resistance to any defined level of "load", and its associated expansion.
- if structural collapse is considered to be an extreme case of a deteriorating structure, then a study of these cases where lack of durability has contributed, e.g.[11] reveals that failure is due to a combination of factors some of which are not amenable to mathematical modelling. Again, this suggests the inclusion of a factor which reflects the quality of the original design and construction.

5. CONCLUDING REMARKS

It will be obvious that BRITE PROJECT BREU-CT92-0591 is still at an early stage. Experimental work is not finished; the development of an approach to assessment is only at a preliminary stage. What is important are the principles involved in that approach. Priority is given to meeting the needs of individual clients for individual structures, in a practical way. Nevertheless, the approach has to be soundly based technically, in accounting for the effects of the deterioration mechanisms, singly and in combination. The BRITE partners would particularly welcome comments, especially from clients and fellow professionals, both now and as the work progresses.

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