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Life-Cycle Behaviour of Reinforced Concrete Structures
– What do we need to know ? –

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Abstract

This paper deals with what we know the deterioration process of concrete structures, and what we need to know for having concrete structures in sound condition during the design life time.

It has passed more than one hundred years since reinforced concrete structures were firstly constructed. At the first stage modern concrete was considered as stone and until the last three decades of this century concrete engineers must believe that concrete could be an eternal material without change. However, we have faced the deterioration problems of concrete in these days, such as alkali silica reaction of aggregates, carbonation of concrete, corrosion of steel reinforcing bars by salt attack, deterioration by cold weather and fatigue distress. The nature and the counter measures against these deterioration causes are briefly discussed in this paper, and some comments are extended to the reliability of counter measures.

What makes the deterioration problems difficult to solve is to take a long time for the examination of deterioration mechanism and for the verification of effectiveness of counter measures. In order to reduce the waiting time, various types of acceleration testing method have been developed, but it is not yet proved enough how the results by the acceleration test method coincides with the actual deterioration process.

In the first stage of taking counter measures against the deterioration, what we have done is to protect concrete from the bad influences of the deterioration causes, or to remove them. Usually with trial and error procedure we manage to find out some solutions. This approach may be all right at the time being, but can not give a long time assurance. In particular, the corrosion by salt attack and the deterioration due to cold weather can not be solved by this manner because these problems take some time to appear. There have reported many examples in which the effectiveness of repair ceased in 5 – 10 years. Then, the followings should be considered for what we need to know to obtain the proper solutions.

(1) Microscopic investigation of deterioration should be essential. In particular, the mechanism of deterioration and the deterioration rate are of most importance in study. In most cases the materials movement in pore of concrete, such as water intrusion, dispersion of chloride ion, oxygen and carbon dioxide, should be studied with respect to the time lapse. As for fatigue, the micro fracture mechanics must be a powerful technology.
(2) In order to determine the initial properties of concrete in structures, the influence of construction practice on them should be clarified although it is not easy to assess. Even if good materials are used for concrete, poor construction practice easily impairs the quality of concrete. In this point of view, self-compacting concrete can be one solution for this problem resulting in very little influence of construction practice.
(3) Except fatigue, it is not well understood how the deterioration of materials influence the structural behaviour. Taking the corrosion by salt attack as an example, the initiation of corrosion of steel bars does not affect the structural behaviour at all. When the amount of

corrosion exceeds a certain limit, cracking occur in cover concrete. The initiation of cracking is, of course, not necessarily the failure.

(4) Microscopic investigation again should be conducted to clear how the deterioration process goes after repair. The deterioration mechanism must be influenced by the repair method, and is not the same as that of original. The electro-chemical approach is necessary.

(5) Combined effects of different deterioration causes should be studied in the further step. For example, what is the fatigue strength of a corroded steel bar?

(6) In order to shorten the waiting time for deterioration study, it is necessary to develop proper acceleration testing methods.

(7) Finally, it is strongly expected to develop a model which can simulate the life cycle behaviour of concrete structures with consideration of material deterioration and effects of repair.

Everybody understands that the initial high quality of concrete with high cost can prove a longer life span of concrete structure. Nobody, however, knows how much of extra cost compensates the extra length of life span. This is because we do not know well how concrete structures deteriorate with the lapse of time. Then, it is difficult to pay an extra cost for high quality of concrete. Now is a time to consider the sustainable development with conservation of environmental resources. What we should do is to elongate the life time of concrete structures meeting with the mechanical and economical requirements. For this reason we need a new design code which enable the life cycle assessment of concrete structures. The code can be called "Performance based design code" in the world wide. The concept of the code is now being discussed in Europe, USA as well as Japan. The Japan Society of Civil Engineers has set up the time schedule to convert the current limit states design code to the performance based design code in 2006.

The performance based design code should involve the followings.

(1) The overall design flow consisting of the planning of structure, dimensioning, materials selection, consideration of construction practice, **verification of performance**, maintenance and repair, demolition.

(2) Trade off system among dimensioning, materials selection and method of construction practice.

(3) Easy acceptance of new technology for verification of performance.

(4) Life cycle assessment with consideration of maintenance and repair.

It is not to say that the verification technology for the life cycle behaviour of concrete structures is of most importance in this design code.

In order to show how the discussion in this paper is accomplished in the actual structures, the simulation is conducted on the life cycle behaviour of off-shore concrete structure under the salt attack condition. The simulation consists of three parts, such as intrusion of chloride ion in concrete, cracking and crack width of cover concrete with regard to the amount of corrosion of steel bars in concrete, and impairment of structural behaviour (reduction of flexural capacity). Although the analysis and the experimental results used in the simulation process are not necessarily sufficient enough, the example simulation indicates what is the direction we should go from now.

We are now in the century of conservation of environment and of sustainable development. What is required for structural engineers should make concrete structures durable and elongate the life time of structures. The knowledge on the structural behaviour of concrete structures becomes fairly high level although there are still some problems to solve. On the contrary, much more efforts should be done to extend our knowledge on the deterioration processes of concrete structures since the wide range of knowledge from a micro level to a macro level, and from chemical behaviours to mechanical behaviours, is necessary to reveal how concrete deteriorates under certain conditions. The development of effective acceleration testing methods is essential to proceed the study on deterioration mechanism and to establish the counter measures against deterioration. Finally, a performance based design should be introduced with the consideration of life cycle assessment for constructing durable concrete structures.