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Method on the aging evaluation in nuclear power plant concrete structures

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ABSTRACT

In this paper, method on the durability evaluation in nuclear power plant concrete structures was investigated. In view of the importance of evaluating the degree of deterioration of reinforced concrete structures, relationships should be formulated among the number of years elapsed, *t*, the amount of action of a deteriorative factor, *F*, the degree of material deterioration, *D*, and the performance of the structure, *P*. Evaluation by *PDFt* diagrams combining these relationships may be effective. A detailed procedure of durability evaluation for a reinforced concrete structure using *PDFt* concept is presented for the deterioration factors of thermal effect, irradiation, neutralization and penetration of salinity by referring to the recent papers.

1. Introduction

Important reinforced concrete structures in nuclear power plant require aging management and evaluation, which comprise integrity evaluation assuming their use for decades ahead to confirm the effectiveness of the current maintenance program, as well as extraction of new maintenance measures as required. There has been an enormous accumulation of study results regarding the durability evaluation and deterioration prediction of reinforced concrete structures. However, durability evaluation of reinforced concrete structures generally involves the problems of a wide variety of external factors and a combination of reinforcing steel and concrete. In view of the importance of evaluating not only each material but also the composite body for evaluating the degree of deterioration of reinforced concrete structures, relationships should be formulated among the number of years elapsed, *t*, the amount of action of a deteriorative factor, *F*, the degree of material deterioration, *D*, and the performance of the structure, *P*. Evaluation by *PDFt* diagrams combining these relationships may be effective.

In this paper, a detailed procedure of durability evaluation for a reinforced concrete structure using *PDFt* concept is presented for the deterioration factors of thermal effect, irradiation, neutralization and penetration of salinity by referring to the recent papers.

2. Thermal effect

2.1. Current evaluation method

In the current evaluation method contained in the "Review Manual for Age-Related Technical Assessment" (JNES, 2009), the degradation of concrete is evaluated according to whether or not the temperature levels of concrete structures over the life span of the structure is less than reference levels (the reference levels of temperature of 90 °C for concrete structures in designated areas and 65 °C for structures elsewhere indicate the risk for thermal degradation.)

2.2. F-t diagram. Relation between the amount of action of a deteriorative factor, F, and the number of years elapsed, t

F_3 (subscript "3" represents the thermal deterioration) is the amount of action of a thermal deteriorative factor, which is related to the change of cement hydrates due to thermal effect. Relation between this factor and time *t* (year) is shown in the extrapolation formula (1).

$$F_3 = \alpha_3 \cdot t \quad (1)$$

where α_3 is the thermal deterioration coefficient for change of cement hydrates due to thermal effect. As on example, based on the chemical kinetics, this reaction can be shown as Eq. (2). Where, *a* and *b* is constant. *T* is temperature (°C).

$$\alpha_3 = a \cdot \exp\left(-\frac{b}{T}\right) \quad (2)$$

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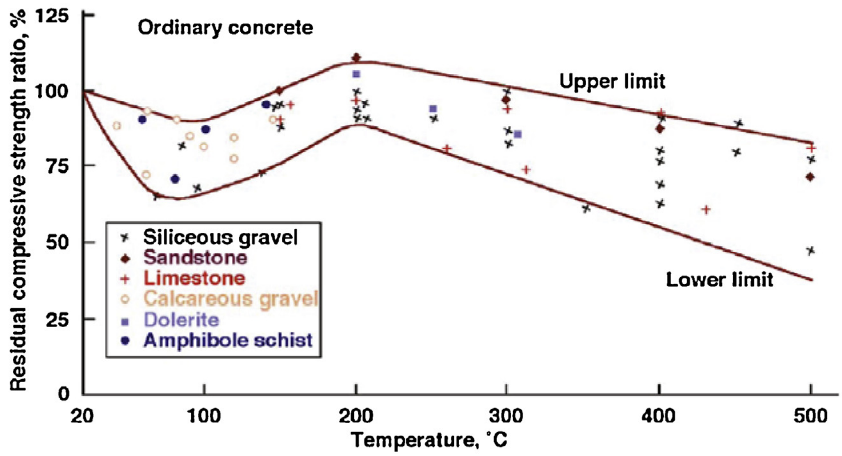

Fig. 1. Relation between the temperatures and the compressive strength reduction of concrete (US Nuclear, 2006).

2.3. D–F Diagram. Relation the degree of material deterioration, D, and the amount of action of a deteriorative factor, F

The compressive strength of concrete has a tendency toward significant decreases in the early stages of exposure to a high temperature environment. Fig. 1 shows test results of U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research Washington (US Nuclear, 2006).

Based on the experimental formula of Abe et al. (2007) the proposed equation of the convergence value of compressive strength reduction of concrete D_u (–) is shown in Eq. (3) (Abe et al., 2007) (Fig. 2).

$$D_u = (1 - 0.2\theta + 0.45\theta^2 - 0.0436\theta^3)\exp(-0.413\theta) \quad \theta = 1.5\frac{T-20}{100} \tag{3}$$

where T is the temperature (°C), T: 20–400 °C.

Relation between the rate of compressive strength reduction of concrete D_1 (subscript "1" represents the compressive strength reduction of concrete) and the amount of action of a thermal deteriorative factor F_3 is shown in Eq. (4). Fig. 3 shows relation between the rate of compressive strength reduction of concrete and the amount of action of a thermal deteriorative factor.

$$D_1 = e{-}^{F3}(1 - D_u) + D_u \tag{4}$$

where D_u is convergence value of compressive strength reduction of concrete depending on temperature (–).

3. Irradiation (neutron radiations and gamma ray)

3.1. Current evaluation method

In the current evaluation method of "Review Manual for Age-Related Technical Assessment", the strength of concrete is evaluated according to whether or not the radiation levels over the life span of the structure are less than reference levels. The reference levels of 1.0×10^{20} (n/cm^2) for fluence of neutron radiation (Fig. 4) and 2.0×10^{10} (rad) for gamma-rays (Fig. 5) are obtained from the Hilsdorf's paper and are employed in assessing soundness of irradiated concrete (Hilsdorf et al., 1978).

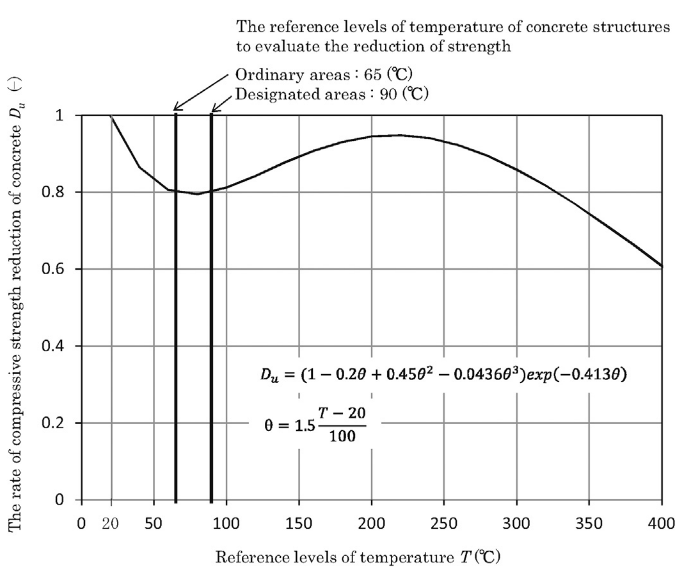

Fig. 2. The convergence value of compressive strength reduction of concrete (Abe et al., 2007).

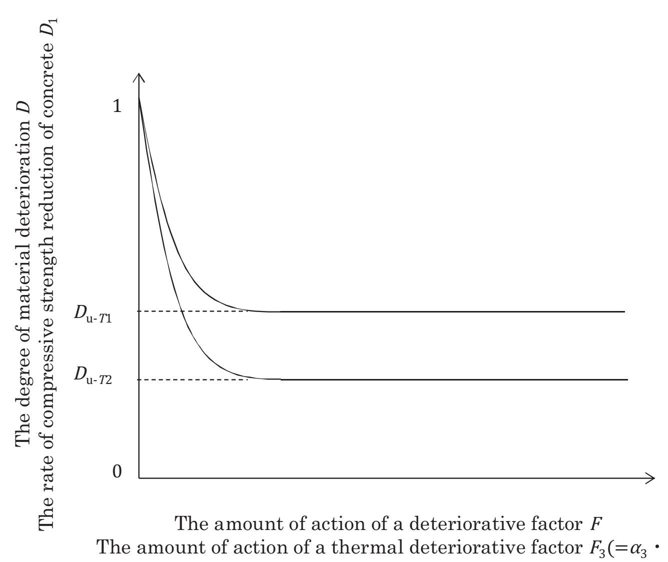

Fig. 3. Relation between the rate of compressive strength reduction of concrete and the amount of action of a thermal deteriorative factor.