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Analysis of Chloride Ion Penetration for NPP Concrete Structures by Crack

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1. Introduction

One of the most important deterioration mechanisms of NPP concrete structure is that caused by the *chloride penetration* of the cement matrix through concrete crack. The main problems caused by chloride penetration in concrete by crack are the lowering of durability and reduction of life due to the corrosion of tensile steel reinforcement in concrete rather than the chemical deterioration of concrete itself. Such problems related to the corrosion of steel reinforcement in concrete occur when a concrete structure is directly exposed to chloride ions through a marine environment or deicers [1]. In addition, problems can arise, in the case of an underground facility (such as the radioactive waste disposal facility of a nuclear power plant), when seawater flows into the groundwater, causing chloride penetration in the concrete structure.

2. Chloride penetration model

In this study, the impact of the cracks that can occur on the concrete surface (occurring from the contraction during concrete curing) on the chloride penetration speed was revealed through modeling. The accuracy of the established model was also verified through laboratory testing.

2.1 Mathematical Methods

In Fig. 1, the ideal crack formation, under the assumption that cracking at the surface is one element of concrete, is diagrammed in the directions of the x- and y- axes. When the chloride penetration through a concrete crack is interpreted to be in the y-axis direction, the total chloride penetration capacity is defined to be the total of chloride penetration through the concrete medium with or without a crack, as shown in Eq. 1.

$$J_t w_e = J_1 w_1 + J_2 w_{cr} + J_3 w_3 \quad (1)$$

$$D_{eff} \nabla C w_e = D_0 \frac{C_1 - C_4}{h_e} w_1 + D_{cr} \frac{C_2 - C_5}{h_e} w_{cr} + D_0 \frac{C_3 - C_6}{h_e} w_2 \quad (2)$$

D_{eff} is the coefficient of total chloride diffusion, D_0 is the coefficient of chloride diffusion without a crack, D_{cr} is the coefficient of chloride diffusion with a crack, h_e is the chloride penetration depth and w is the chloride penetration width.

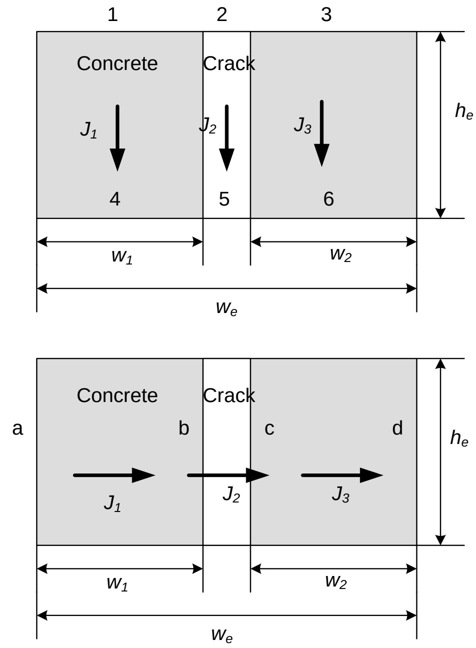

Fig. 1 Influence of crack on chloride diffusion

If the movement caused by the diffusion of chloride ions occurs in a steady state, then the chloride gradient can be defined as the relationship shown in Eq. 3.

$$\frac{C_1 - C_4}{h_e} = \frac{C_2 - C_5}{h_e} = \frac{C_3 - C_6}{h_e} = \nabla C \quad (3)$$

In conclusion, the coefficient of chloride diffusion in the y-axis direction can be defined as shown in Eq. 4.

$$D_{eff} = D_0 (1 - \frac{w_{cr}}{w_e}) + D_{cr} \frac{w_{cr}}{w_e} \quad (4)$$

When the chloride diffusion caused by a crack is interpreted to be in the x-axis direction, since the crack does not affect the chloride movement, the chloride amount at each point is always constant, as shown in Eq. 5 and 6.

$$J_t = J_1 = J_2 = J_3 \quad (5)$$

$$D_{eff}\frac{C_a - C_d}{w_e} = D_0\frac{C_a - C_b}{w_1} = D_{cr}\frac{C_b - C_c}{w_{cr}} = D_0\frac{C_c - C_d}{w_2} \quad (6)$$

The chloride diffusion in the x-axis direction can thus be defined as Eq. 7.

$$D_{eff} = \frac{D_0}{1 - \frac{w_{cr}}{w_e}} \quad (7)$$

2.2 Experimental method

In this study, empirical tests were performed to assess the impact of cracking at the concrete surface on the speed of chloride diffusion. Mortar specimens were produced to remove the effect of interfacial cracking due to course aggregates. A standard mixture of cement/water/fine aggregates at a ratio of 1.00: 0.45: 2.45 was used. As shown in Fig. 2, the crack depth was limited to 4 cm and the crack width was adjusted by using an open-cracking slip to three phases of 20, 84, and 125 µm. After cracking was induced, the mortar specimens were immersed in an aqueous solution of 4.0% chloride concentration for 28 days at 20℃. The chloride profile was measured within 1 hour of pulling out the mortar specimens from the aqueous solution of chloride ions in order to prevent the movement of chloride ions due to the drying of the salt solution. Powder was collected from a depth of 2 mm from the surface of the mortar specimens and the total chloride ion amount for each was measured by using the silver nitrate titration method.

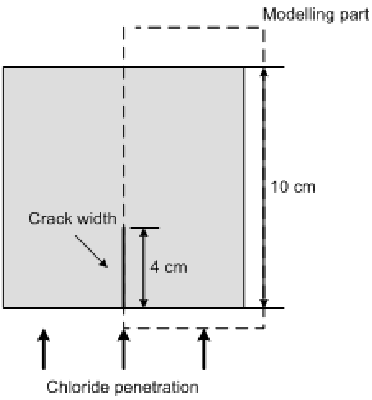

Fig. 2 Configuration of specimens for verification

3. Conclusions

Fig. 3 shows the comparison of expected values resulting from the chloride profile and model based on the chloride diffusion that depends on the crack width. As expected, a clear difference was shown in the penetration capacity of chloride ions depending on the crack width. For a crack width of 20 µm, there was virtually no chloride penetration, whereas when cracking increased to 84 and 125µm, the chloride penetration capacity sharply increased. Moreover, the predicted values from the modeling presented in this study and the test values showed very high correlation. In Fig. 4, the chloride penetration capacity is also shown two-dimensionally for the crack width of 125µm. As seen in the modeled graphic, it can be grasped that the chloride concentration is definitely high depending on the location of the crack occurrence.

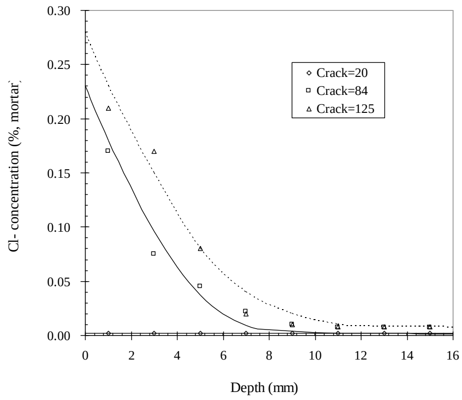

Fig. 3 Chloride profiles depending on the crack width

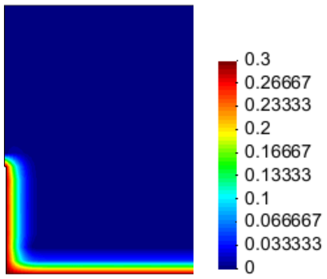

Fig. 4 Chloride distribution in cracked concrete with 125µm crack width

ACKNOWLEDGEMENT

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