V-19 SIMULATION OF CORROSION PROBABILITY CONSIDERING DISTRIBUTION OF WATER-CEMENT RATIO, COVERING CONCRETE, CHLORIDE CONCENTRATION AT CONCRETE SURFACE, AND THRESHOLD CHLORIDE CONCENTRATION

Kochi University of Technology (JSCE student member) Songkram PIYAMAHANT
Kochi University of Technology (JSCE member) Sachie KOKUBO
Kochi University of Technology (JSCE member) Hiroshi SHIMA

1. Introduction

To countermeasure the corrosion problem at the reinforcing bars embedded in concrete, the chloride concentration at the position of reinforcing bars is limited according to JSCE design standard specification of concrete 2002 [1]. This method is to protect the reinforcing bar from corrosion problem, so called corrosion free. Besides with the corrosion free concept, the minimum requirement of water-cement ratio and covering in constructing reinforced concrete bridges is specified in JH design specification and complementary of concrete bridge 2002 [2]. By following the method of JSCE and minimum requirement of JH design specification together, the corrosion probability of designed structures affected by the distribution curves of water-cement ratio, covering concrete, chloride concentration at concrete surface and threshold chloride concentration was simulated and shown in this study.

2. Simulation method

Following JSCE design specification, the period of non corrosion at reinforcing bars can be checked using design chloride concentration equation as shown in Eq.1.

$$C_d(c,t) = C_0\left[1 - erf\left(\frac{0.1c}{2\sqrt{Dt}}\right)\right] \quad ; \quad \gamma\frac{C_d}{C_{\lim}} < 1.0 \qquad \text{Eq.1}$$

where C_d is design chloride concentration [kg/m^3], C_0 is chloride concentration at concrete surface [kg/m^3], c is covering, D is diffusion coefficient [cm^2/year], t is time, and $C_{\lim}$ is threshold limit of chloride concentration [kg/m^3].

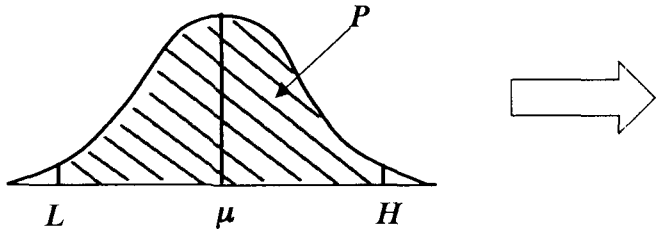

Fig.1 Characteristic of normal distribution curve

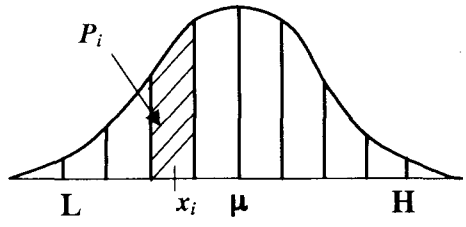

Fig.2 Partitions of normal distribution curve

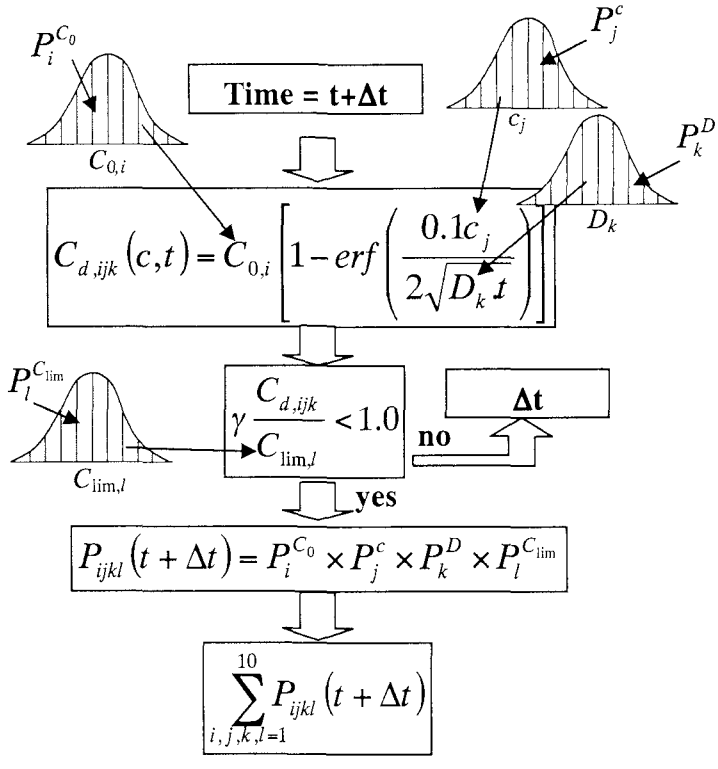

Fig. 3 Probability of Deterioration (Calculation schematic)

Simulated by using probabilistic method, the corrosion probability for real structures has to consider the distribution of input parameters due to the different designing concepts and quality control during construction. Thus, the distribution curves of water-cement ratio, covering concrete, chloride concentration at concrete surface, and threshold chloride concentration have to be constructed as input parameters. In this study, all distribution curves of input parameters are assumed to be normal distribution. These normal distribution curves are characterized by expected value [μ], confident area [P], and lower [L] and upper [H] confident value bound for confident area as shown in **Fig.1**. According to given characteristic, each normal distribution curve of input parameters is subdivided into ten partitions where each partition possesses probability values [P_i] and representative values [x_i] as shown in **Fig.2**.

Incorporating JSCE design specification and probabilistic method, the probability of corrosion is eventually calculated as shown in **Fig.3**. The partition and probability values of covering, diffusion coefficient, and chloride concentration at the concrete surface are input in Eq.1 for determining the design chloride

concentration. The calculation times are totally ten thousand according to the multiplication of ten partitions of each parameter whereas the summation of deterioration probability is less than 1.0.

3. Simulated cases

The expected value, confidence area, and lower and upper bound for confidence area, are assumed into two cases, which is before and after year 1983, according to the first presentation of countermeasure design for chloride attack in JH design specification. Following JH design specification before 1983 [3], the covering of concrete was constant regardless of the distance from the seashore. On the other hands, the covering of concrete specified after 1983 is varied depending on the distance from the seashore. Nevertheless, the water to cement ratio of reinforced concrete members is not changed according to the publishing time of JH design specification.

Table 1: Characteristics of probabilistic distribution curves

a) Before 1983

	L	μ	H	P
w/c ratio	0.45	0.50	0.55	0.9
c(I)	70	75	80	0.9
c(II)	50	55	60	0.9
c(III)	35	40	45	0.9

b) After 1983

	L	μ	H	P
w/c ratio	0.45	0.50	0.55	0.9
c(I)	70	75	80	0.9
c(II)	50	55	60	0.9
c(III)	35	40	45	0.9

c) Chloride

	L	μ	H	P
C_0(I)	1	5	9	0.9
C_0(II)	1	2.75	4.5	0.9
C_0(III)	1	2	3	0.9
C_{lim}	1.2	1.8	2.4	0.99

All characteristics of distribution curves are shown in **Table.1**. In the table, the covering concrete and chloride concentration at concrete surface are classified into three types according to the distance from the seashore; I is near seashore; II is less than 100m from seashore; and III is less than 250m from seashore. The lower and upper bounds of confident areas are related to either minimum requirement or design values proposed in design specification. First, the minimum requirement of covering concrete is lower bound for confident area. Second, the minimum requirement of water to cement ratio is upper bound for confident area. Third, the design values of chloride concentration at concrete surface are upper bound for confident area whereas one is lower bound for confident area since non chloride attacked structures exist. Finally, the exist range of the threshold limit of chloride concentration noted in JSCE design specification is bounded as lower and upper values.

4. Simulated results

Based on the simulation method and simulated cases, the simulation results of the probability of corrosion classified by the published time of JH design specification are shown in **Fig.4** and **Fig.5** regarding on the distance from seashore. It can be clearly seen that the durability of structures near seashore and located 100m from seashore are improved a lot according to the changes of design code in year 1983.

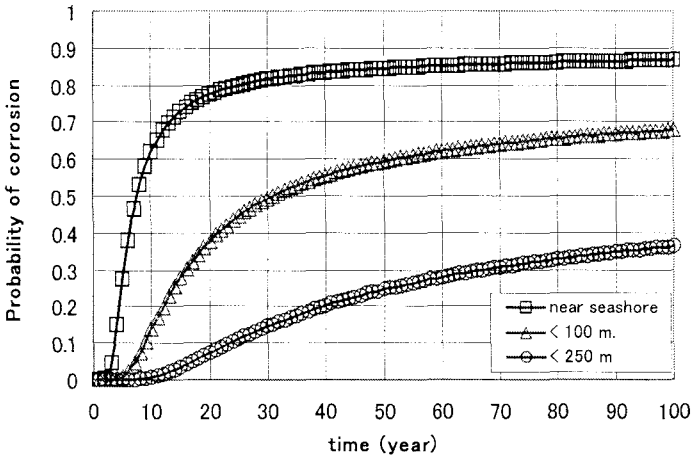

Fig.4 Probability of corrosion (Code before 1983)

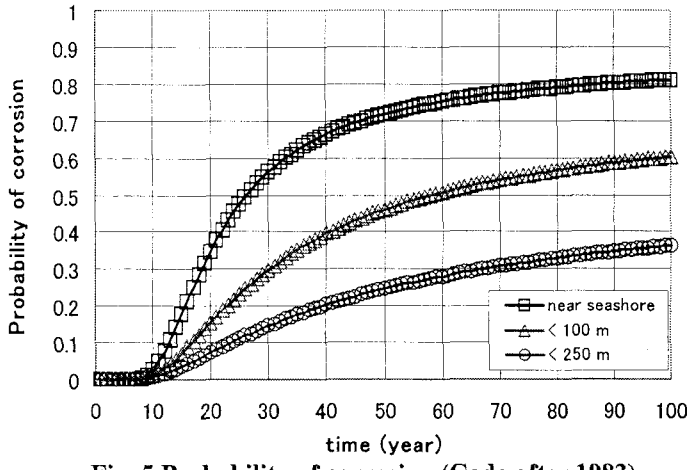

Fig. 5 Probability of corrosion (Code after 1983)

5. Conclusion

The probability of corrosion can be simulated by incorporating JSCE verification equation and probabilistic method together. Based on the published year of JH design code, the distribution curves were assumed and the simulations results showed that the durability of structures concerning with corrosion is improved.

References

1) JSCE, "Design Standard Specification of Concrete for Durability Verification", JSCE, 2002.
2) JH, "Design Specification and Commentary of Highway Bridge for Concrete Bridge", JH, 2002.
3) JH, "Design Specification and Commentary of Highway Bridge for Concrete Bridge", JH, 1980.