Experimental analysis of electric potential distribution in steel corrosion in reinforced concrete members*1

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(Abstract)

In order to predict the deterioration and service life of RC structures, the degree of steel corrosion and its evolution with time must be measured. This is usually done by measuring the electric potential distribution. However, the relationship between changes in electric potential over time and the degree of steel corrosion is not very well known on a theoretical basis.

In this study, we examine a means of calculating the propagation coefficient of electric potential distribution (C_1) from the electric potential distribution in an exposed specimen using a differential method of analysis. We are able to clarify that the propagation coefficient of electric potential distribution tends to increase with increasing ratio of crack length.

1. Introduction

It is important to quantitatively know the degree of steel corrosion occurring in a reinforced concrete structure with the elapse of time; such knowledge enables the deterioration of RC structures and their service life to be predicted and evaluated. The authors have long been measuring electric potentials in RC structures, but the relationship between our data and the mechanism of the deterioration process is complex and remains unclear despite our many studies.

In this basic experiment, we focus on the phenomenon of steel corrosion by modeling the change in electric potential in RC over time. From the measured data, we estimate the propagation coefficient of electric potential distribution. The relationship between deterioration factors and the degree of deterioration is also studied.

2. Method of Study

2.1 Definition of analysis

The phenomenon of steel corrosion in RC members occurs because differences in electric potential arise at certain points in the steel, thus setting up an electric cell effect and leading to corrosion. The amount of corrosion is proportional to the integral of electric current. It

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can be assumed that the differences in electric potential which develop in an RC member are related to the initial electrical conditions at each point in the steel, the boundary conditions at the steel surface, and the propagation of electric potential. In the early stages of steel corrosion, it is assumed that no location nor range can be clearly defined and that the electric potential differences are non-localized and non-stationary. Furthermore, it is assumed that points of high potential and points of low potential arise clearly after the non-stationary stage. The stationary state becomes a state in which much current is integrated.

2.2 Mathematical model for analysis

The change in electric potential at each point is expressed for each time increment by applying the one-dimensional heat conduction equation. In estimating the propagation coefficient of electric potential in this study, the model is simplified such that the latent heat term, which relates the electric cell effect by corrosion of steel in RC, is not taken into account. Accordingly, the one-dimensional conduction equation is expressed as follows [2] :

$$\frac{\partial u}{\partial t}=C^2\frac{\partial u^2}{\partial x^2}(u=u(x,\ t)) \qquad \text{Equation (1)}$$

where, the coordinates of each point are X, time is t, and the electric potential is u. Equation (1) is solved by a differential method using numerical analysis techniques. C is a constant, and it is assumed that C is unity for the sake of simplification. Strictly, it varies and should be assessed at each step according to certain corrosion-related factors.

2.3 Analysis process

A flowchart of the analysis procedure is shown in Fig. 2.3.1. The critical point of the analysis is the correct assumption of a value for C. Therefore, one of the method is the problem of phase change by changing of C. As a simplification, two cases are considered :

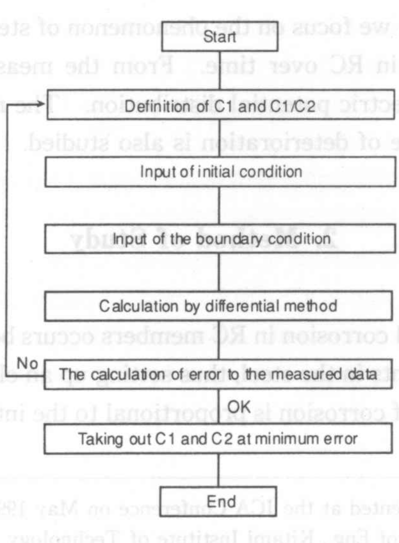

Fig. 2.3.1 Flow chart of the analysis

case C_1 with no corrosion state and case C_2 with serious corrosion state. The case of transition between states C_1 and C_2 is also considered. But in this study, C_1 is assumed only without C_2 and transition state of C_1 to C_2, in order to know the property model, as an outline.

2.4 Experiment results

Experiment data was measured for a period of one year by the Japan Concrete Institute's Committee for Research into Repair Techniques. The layout of specimens from which the measurements were taken is shown in Fig. 2.4.1. These specimens were set up for the measurement of experimental data with no separation, no anticorrosion treatment, no repairs, no paint repairs, and no salt in the mix. The exposure site was a splash zone at Izu Kaiyo Koen, as shown in Photo 2.4.1. The measured electric potential data are shown in Fig. 2.4.2. The boundary condition adopted in the analysis is the electric potential 0 mm from the edge of the specimen. The 12-month data are obtained by measurement and the initial data by estimating values linearly from the 0-month data at nearby points. The intermediate boundary conditions are distributed proportionally to elapsed time. The initial electric potential at each point in the specimens is estimated linearly every 50 mm. The

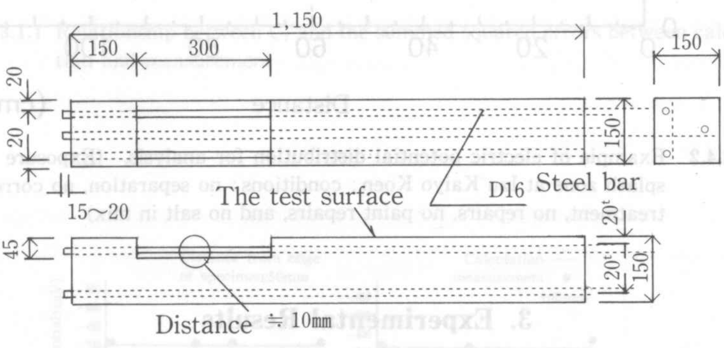

Fig. 2.4.1 The layout of measured specimens

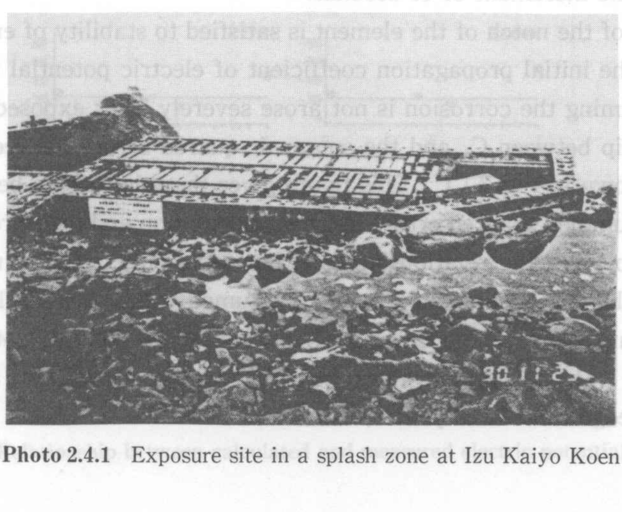

Photo 2.4.1 Exposure site in a splash zone at Izu Kaiyo Koen

calculated data is then compared to the measured data at every 50 mm increment by linear interpolation.

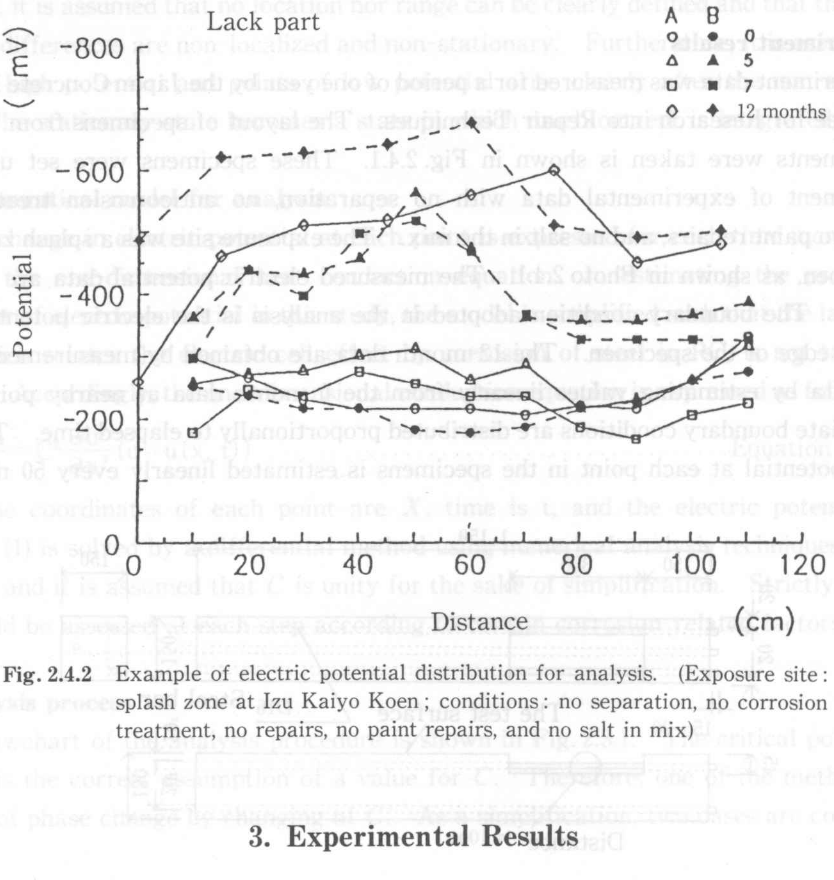

Fig. 2.4.2 Example of electric potential distribution for analysis. (Exposure site: splash zone at Izu Kaiyo Koen; conditions: no separation, no corrosion treatment, no repairs, no paint repairs, and no salt in mix)

3. Experimental Results

3.1 Numerical analysis

The analysis was carried out using a one-dimensional simulation with spatial elements of 50 mm and a time increment of 10 seconds.

The condition of the notch of the element is satisfied to stability of error of differential method. Where, the initial propagation coefficient of electric potential distribution, C_1, is assumed only, assuming the corrosion is not arose severely after exposed test for a year.

The relationship between C_1 and the summed squared errors between calculation and measurement is shown in Fig. 3.1.1. This figure gives the relationship between each coefficient, C_1, and the summed squared errors between calculation and measurement for 5, 7, and 12 months. It also gives the relationship for 12 months only. The minimum error is at $C_1 = -2.50 \times 10^{-8}$ when C_1 is calculated from an assumed value between 10^{-5} and 10^{-9}.

The relationship between the calculated and measured electric potential gradient is shown in Fig. 3.1.2. The calculated values are close to the measurements at points 50 mm to 150 mm from the edge until 0.583 years (7 months).

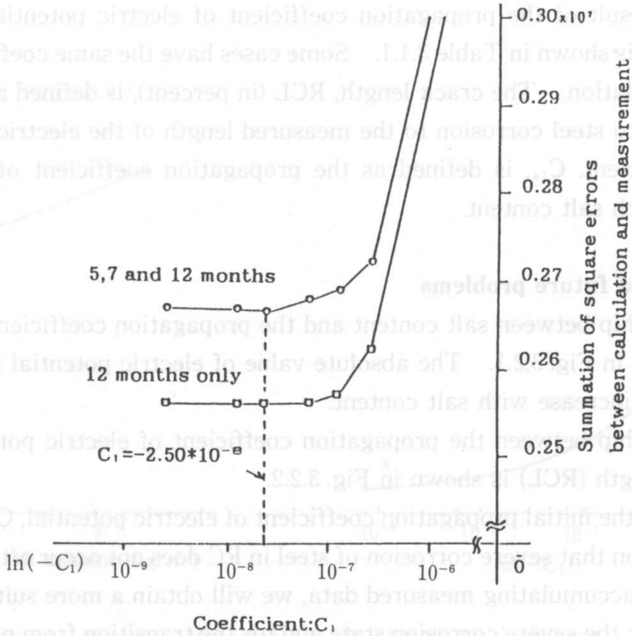

Fig. 3.1.1 Relationship between C_1 and the summed squared errors between calculation and measurement

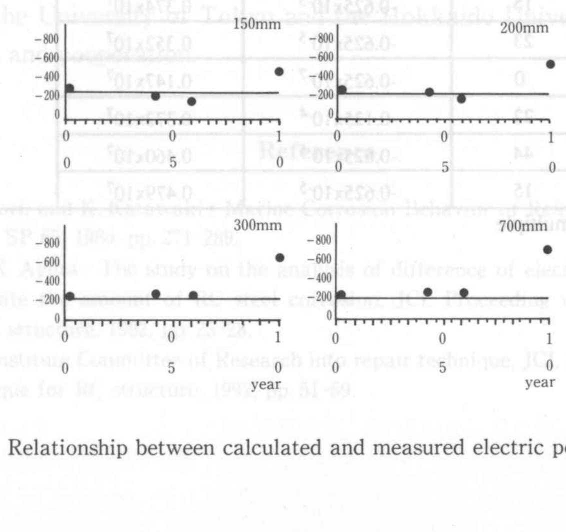

Fig. 3.1.2 Relationship between calculated and measured electric potential gradients

The calculated result of the propagation coefficient of electric potential distribution, C_1^* ($C_1^* = C_1 \times 0.0028$) is shown in Table 3.1.1. Some cases have the same coefficient because of the notch of calculation. The crack length, RCL (in percent), is defined as the ratio of total crack length due to steel corrosion to the measured length of the electric potential distribution. The coefficient, C_{1S}, is defined as the propagation coefficient of electric potential distribution of each salt content.

3.2 Discussion and future problems

The relationship between salt content and the propagation coefficient of electric potential (C_{1S}) is shown in Fig. 3.2.1. The absolute value of electric potential propagation coefficient is shown to increase with salt content.

The relationship between the propagation coefficient of electric potential (C_1) and the ratio of crack length (RCL) is shown in Fig. 3.2.2.

In this study, the initial propagation coefficient of electric potential, C_1, is an assumption only, an assumption that severe corrosion of steel in RC does not occur after an exposure test of one year. By accumulating measured data, we will obtain a more suitable coefficient by determining C_2 for the severe corrosion state and for the transition from not severe to severe.

In order to estimate the propagation coefficient of electric potential, the model has been simplified such that the latent heat term, which relates to the electric cell effect by corrosion of steel in RC, is not taken into account. In future, a more suitable model must be obtained by taking account of this term.

Table 3.1.1 Calculated result of propagation coefficient of electric potential distribution

Specimen No.	Salt content, SC (kg/m^3)	Ratio of crack length, RCL (%)	Propagation coefficient of electric potential distribution, C_1	Summation of square errors, WE	Propagation coefficient of electric potential distribution of each salt content, Cls (Note 1)
A11A	0.0	11	-0.125×10^{-7}	0.267×10^{7}	-0.280×10^{-6}
A11B	0.0	36	-0.625×10^{-5}	0.384×10^{7}	
A12A	2.4	15	-0.625×10^{-5}	0.374×10^{7}	-0.326×10^{-5}
A12B	2.4	23	-0.625×10^{-5}	0.352×10^{7}	
A14A	2.4	0	-0.625×10^{-7}	0.147×10^{7}	
A14B	2.4	22	-0.125×10^{-4}	0.372×10^{7}	
A15A	2.4	44	-0.625×10^{-5}	0.460×10^{7}	
A15B	2.4	15	-0.625×10^{-5}	0.479×10^{7}	

Note1: The mean of multiple

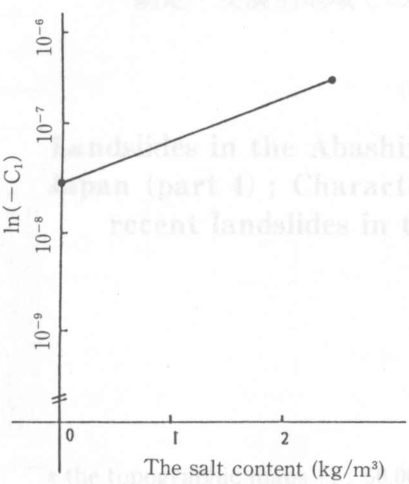

Fig. 3.2.1 The relationship between salt content and propagation coefficient of electric potential (C_1s)

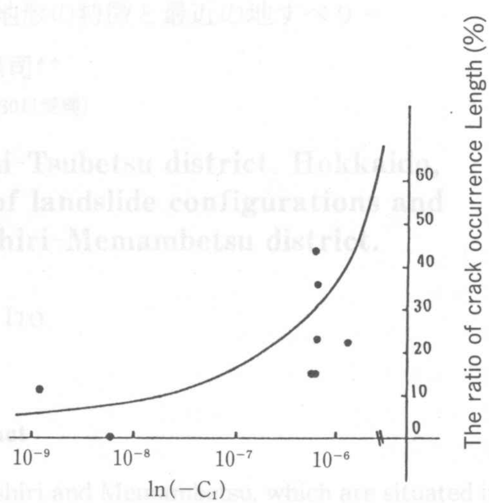

Fig. 3.2.2 The relationship between propagation coefficient of electric potential (C_1) and ratio of crack length (RCL)

4. Conclusion

The propagation coefficient of electric potential distribution, C, can be obtained by differentiating electric potential data taken from steel corrosion in reinforced concrete.

Acknowledgement

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