

Estimation of Steel Corrosion by Salt Attack in Concrete

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Abstract

In order to estimate the steel corrosion in concrete, non-destructive methods such as measurements of half-cell potential, polarization resistance (AC impedance), and electric current were used in a model experiment using different sized steel plates, leading to an understanding of changes in electrochemical response of the reinforcing steel. This paper is discussed on the steel corrosion from experimental results used by the non-destructive methods.

Key words: concrete, steel corrosion, salt attack, electrochemical method

1. Introduction

Non-destructive methods currently available for evaluating reinforcing steel corrosion in concrete include half-cell potential and polarization resistance.

The half-cell potential method is most widely used in assessing corrosion because measurements are easy and measured values correlate well with corrosion conditions. On the other hand, the polarization resistance method yields an estimate of the rate of reinforcing steel corrosion, leading to predictions of future corrosion related deterioration. However, such methods are still in the examination stage, both with respect to methodology and evaluation of measured values.

It is expected that evaluation methods based on these methodologies will soon be established. [1] [2]

Steel corrosion in concrete is understood to occur through both macro-cell corrosion and micro-cell corrosion, and the interaction of the two is seen as advancing corrosion. At present, it remains difficult to distinguish between the two forms of corrosion and to estimate their progress using these non-destructive methods. An important task, therefore, is to establish evaluating of steel corrosion by a non-destructive methodology after understanding this mechanism of steel corrosion.

Table 1 Materials

Cement		B-type blast-furnace slag cement, Specific gravity: 3.05g/cm ³
	Compound (%)	C ₃ S: 31, C ₂ S: 13, C ₃ A: 5, C ₄ AF: 5
Aggregate	Fine Agg.	River sand, Specific gravity: 2.55g/cm ³ , F.M.: 2.74, Water absorption: 2.19 (%)
	Coarse Agg.	Crushed stone, Specific gravity: 2.67g/cm ³ , F.M.: 6.29, Water absorption: 0.95, Max. size: 15mm
Reinforcing steel		Steel plate, Kind: SS41(SS400), Quality: Acid processing, Thickness: 1.6mm

Table 2 Mix proportion and measurement value of concrete

W/C	Sand volume ratio s/a (%)	Unit weight (kg/m ³)					Measurement air volume (%)	Measurement slump (cm)	Meas. strength 28-d (N/mm ²)	
		W	C	S	G	AE agent			Compressive	Bending
0.5	46.8	185	370	755	899	—	2.0	8.5	33.9	5.6

2. Experimental Outline

The materials used are shown in **Table 1**. Concrete mix proportion, air volume, slump, and 28-d compressive strength obtained in measurements are shown in **Table 2**.

2.1 Test specimen

Details of the concrete and steel plate are given in **Fig. 1(a)**. Two types of test specimen were produced, for the following purposes:

(1) Specimens with a single long steel plate for the purpose of examining macro-cell corrosion (L specimens) (2) Specimens with a short steel plate for the purpose of examining macro-cell (connected together in series leads wire) and micro-cell (disconnected together) corrosion (S specimens)

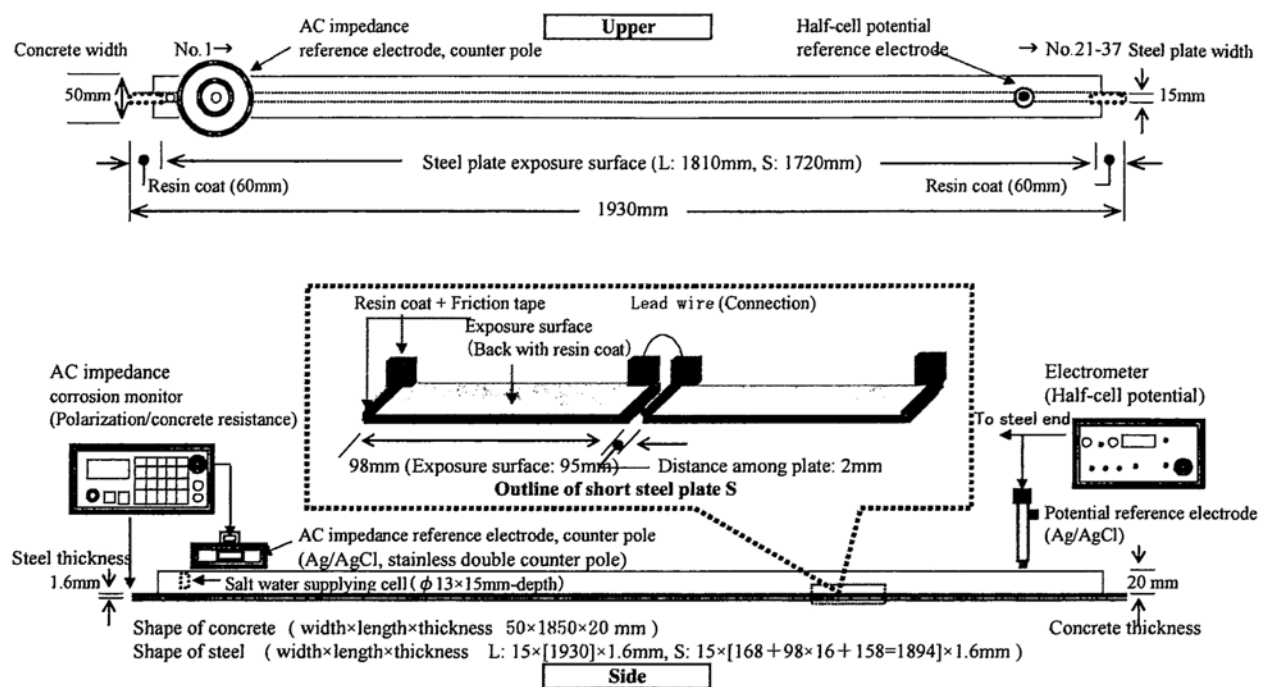
All steel plates were of the same material, thickness and width, and all surfaces except face for the purpose of corroding were coated with epoxy.

In the Series 1 (L) experiments, the steel plate was 1.6-mm thick, 15-mm wide, 1930-mm long. All faces except 15x1810-mm area of top surface for the purpose of corroding were coated with epoxy. When casting the concrete, a polypropylene cylinder of 10-mm diameter was inserted to a depth of 5 mm to the exposure surface at one ends of steel plate. It was removed after the concrete had set. The cavity left by this cylinder formed the cell for supplying salt water.

In the Series 2 (S) experiments, all steel plates except both ends plates were 1.6-mm thick, 15-mm wide, and 98-mm long, and each specimen had fixtures for lead wire at both edges. The steel plates of both ends were respectively 168-mm long (salt water supplying cell side) and 158-mm long (other side). All surfaces except exposure surface for the purpose of corroding were coated with epoxy (like as the L specimens), and the total length of the exposure surface was 1720 mm. A polypropylene cylinder was used to form the salt water cell, like the L specimens. Concrete was cast to the steel plate, which was put onto insulated adhesive sealing tape overlying the form. No concrete cracking occurred in removing the forms nor during the examination period, though the possibility of cracking was considered.

2.2 Curing and environmental conditions

After 48 hours from casting, specimens were cured in water for 14 days and then in air indoors for fixedness period. The steel plate was started to be corroded after the dry-curing in the period. To limit the corrosion position and to ensure penetration into the concrete specimen as in actual salt diffusion, salt water was supplied regularly to the cell. The salt water consisted of 3 mass percent NaCl and was supplied at a rate of about 5-6-cc per day to ensure that the cell was always filled. It was supplied through a silicon tube of diameter 1-mm from a saltwater bottle.



(a) Shape of steel and specimen, and measurement outline

	Distance from cell (mm)	0	10	60	250	500	750	1000	1250	1500	1810	Meas. points	
L Potential	●◎	○	○	○	○	○	○	○	○	○	○	□	37
L Polarization/concrete resistance		○	○	○	○	○	○	○	○	○	○	○	18
S-MA Potential	●◎	○	○	○	○	○	○	○	○	○	○	□	21
S-MA Polarization/concrete resistance		○	○	○	○	○	○	○	○	○	○	○	18
S-MA Electric current among steel plate		○	○	○	○	○	○	○	○	○	○	○	17
S-mi Potential	●◎	○	○	○	○	○	○	○	○	○	○	□	21
S-mi Polarization/concrete resistance		○	○	○	○	○	○	○	○	○	○	○	18

Note 1) L: Long steel plate, S-MA: Short steel plate (lead connected), S-mi: Short steel plate (lead disconnected)

Note 2) ● Potential in salt water cell, ◎ Potential in vicinity salt water cell, □ Potential of steel exposure surface end

(b) Position of measurement points

Fig.1 Dimensions of specimen, measurement outline, and position of measurement points

2.3 Measurement

(1) Measurement conditions

Measurements consisted of half cell potential and polarization/concrete resistance, as well as electric current flow between steel plates in the S specimens (**Fig.1 (a)**).

These measurements were done after wetting concrete surface. AC impedance measurements were made at a voltage of +10 mV/-10 mV and at a frequency of 10-Hz/0.01-Hz. The reference electrode for the half-cell potential, polarization resistance, and concrete resistance measurements was used with a saturated silver chloride electrode. For the counter-pole in AC impedance measurements, a double type was used (these were 40-mm and 106-mm diameter). [3]

(2) Measurement points

The number of electrochemical measurement points and their position is shown for each specimen in **Fig.1 (b)**. In the case of L specimens, the half-cell potential was measured at 37 points at 50-mm intervals, while polarization resistance and concrete resistance were measured at 18 points at 100-mm intervals. In the case of S specimens, the half-cell potential was measured at 21 points, including the center point of each steel plate, the vicinity of the salt water cell, and the leftmost end of the steel plate. Polarization resistance and concrete resistance were measured at 18 points, consisting of the same points as half-cell potential except for salt water cell inner and rightmost/leftmost ends. In the case of S, each measurement was taken under two conditions: with the lead wires of short plates connecting and with the leads temporarily disconnected. An influence on the measurement was just before disconnecting or connecting the leads. Therefore, the half-cell potential was measured first and each measurement was taken after confirming that the potential had stabilized. As for the current flow in the S specimens, the current between steel plates was measured while the leads between them were connected.

3. Results

3.1 Average and distribution of half-cell potential

The average potential in L specimens and S specimens before and after supplying salt water is shown in **Fig. 2**.

The average values while curing and before supplying salt water are similar. One specimen each from among the L specimens and the S specimens was chosen for the addition of salt water, and these were kept regularly supplied with salt water in the cell. These specimens are denoted, respectively, by "L1" and "S1".

The average half-cell potential fell (shown rise in Figure) to negative (base) value rapidly during dry curing and supplying salt water in both cases, as shown in **Fig. 2 (b)**: at about 800 hours for L1 and about 1300 hours for S1. As shown by the black arrow in **Fig. 2 (b)**, the base period changed remarkably about 300 hours from the starting base both in L1 and S1, and thereafter the gradients became more gentle. The time at which the base beginning occurs is different because the depth of mortar below the salt water to reach the steel plate was different, so the time taken for the salt water to reach the steel plate would differ. As a result, the beginning of corrosion was about 800 hours after supplying salt water in L1 and about 1300 hours after supplying salt water in S1.

The potential distribution of each point on the specimen before and after the sudden change in average potential after supplying salt water to the cell is shown in Fig. 3. As for the potential of L1 (at 335 hours) and S1 (at 336 hours with the leads connected), there is no significant difference among measurement points. However, after the potential near the salt water cell changed into the base, the values of both L1 and S1 became the base in the vicinity of the salt water cell, while it became noble (rising to positive value) with distance from this point.

Curing period	Water curing 14 days	Indoor dry curing (Before supplying salt water) L1: 35 days, S1: 28 days	Indoor dry curing (After supplying salt water) L1: 219 days, S1: 224 days	Measurement of mass loss by corrosion
Accumulated period	16 days	L1: 51 days, S1: 44 days		L1, S1: 268 days
Change in potential	Becomes base Becomes noble		Becomes base after supplying salt water L1 ≈ 33 days -, S1 ≈ 54 days -	

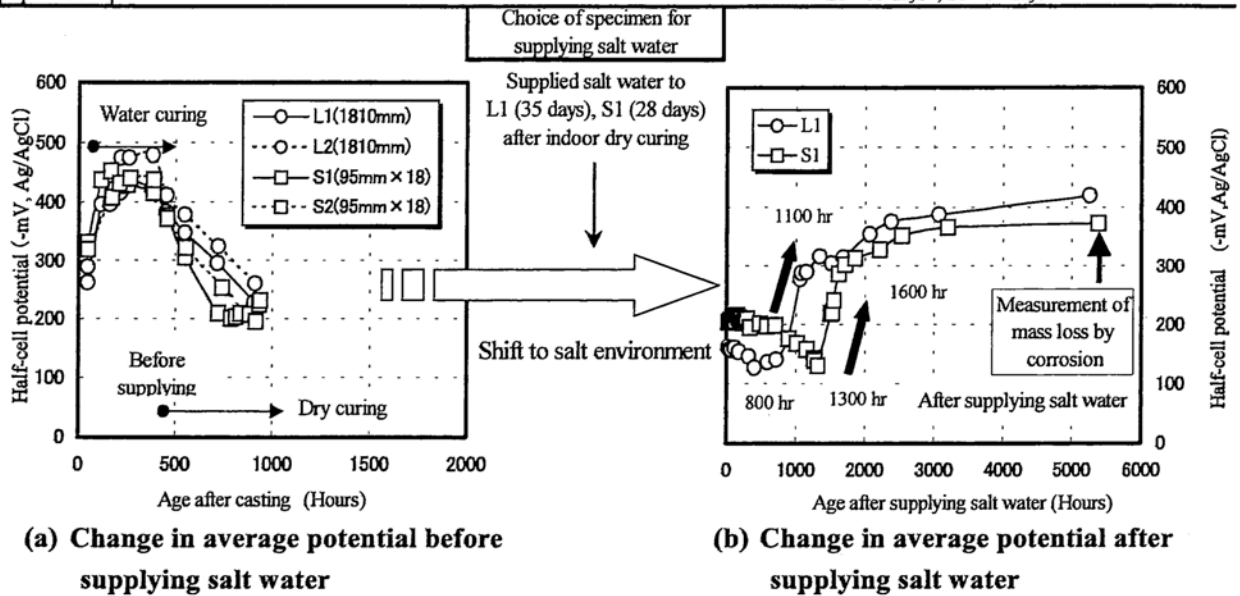


Fig. 2 Change in average of half-cell potential

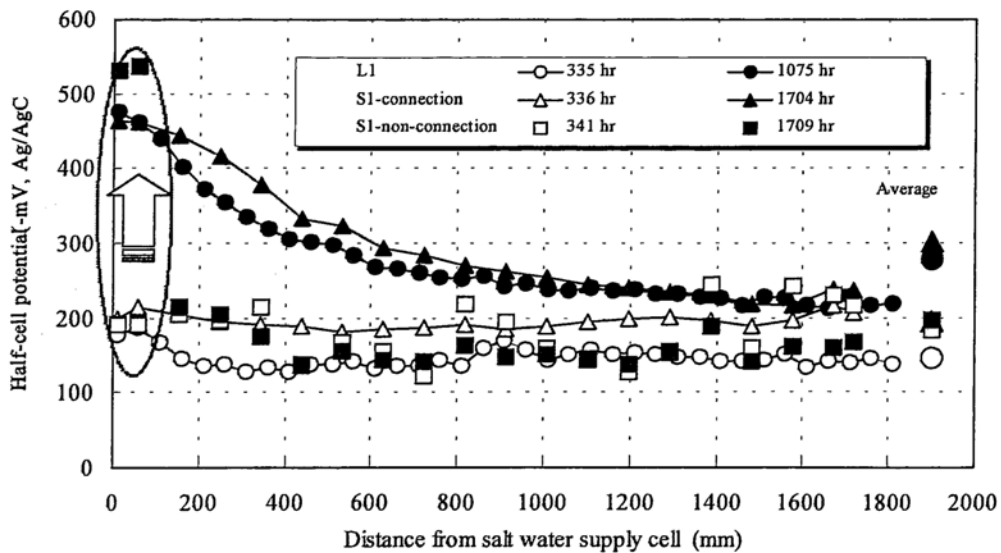


Fig. 3 Half-cell potential distribution after supplying salt water

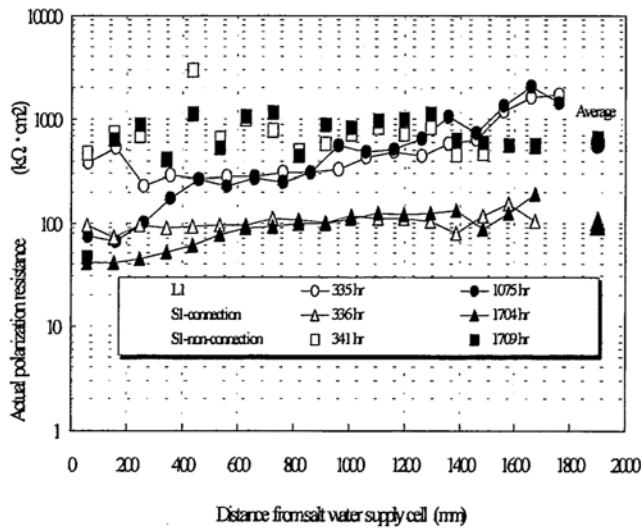
3.2 Distribution of polarization and concrete resistance

The distributions of true polarization resistance and apparent concrete resistance for specimens L1 and S1 are shown respectively in Fig. 4 (a) and (b). Concrete resistance is the apparent value, but this will form the basis of the analysis in the following paragraph.

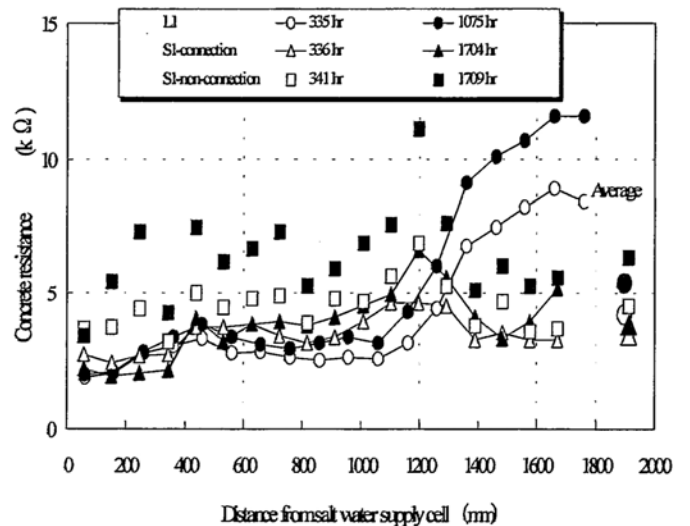
The polarization resistance and concrete resistance near the salt water cell decreased once the average potential became notably base, and these phenomena show a corrosion tendency like the results of half-cell potential.[4] After 1,075 hours in the case of L1, the polarization/concrete resistance at points far from 1200-mm from the salt water cell are larger than at points nearer than 1200-mm. Under leads disconnected after supplying salt water, the polarization/concrete

resistance in the case of specimen S1 at 1709-hours are larger than at 341-hours except the neighborhood of the cell. In mass loss of steel plate by corrosion, with mentioning later, the adhesion between the steel plate and the concrete was not broken in specimen L1 and S1. Looking at the mass loss of the steel plate due to corrosion, adhesion between the steel plate and the concrete was not lost in specimens L1 and S1.

Consequently, such a phenomenon (for polarization and concrete resistance) occurred because of formation of a passive layer, and because of drying between concrete and steel plate. The variations in concrete resistance between L1 and S1 result from environmental differences at measurement period and from varying moisture condition of the concrete.



(a) Distribution of polarization resistance



(b) Distribution of concrete resistance

Fig.4 Measurement results of polarization resistance and concrete resistance

4. Conclusion

Specimens were exposed under water and dry environments for a constant period, and continuous supply of salt water was provided to a salt water cell. During this period, the rate of corrosion of steel plates could be specified by non-destructive methods such as the half-cell potential, polarization resistance, and concrete resistance.

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