論 文

[2118] Influence of Construction Defects on Corrosion of Reinforcement

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1. INTRODUCTION

The corrosion of reinforcing steel in concrete had received increasing attention in recent years because of its wide spread occurrence in many types of structures and the high cost of repairs. Corrosion of steel, however, can occur if concrete is not adequate in quality, structure is not properly designed for the service environment, or the environment is not as anticipated or changed during the service life of the concrete.

In reinforced concrete structures exposed to chlorides and subjected to intermittent wetting, the degree of protection against corrosion is determined primarily by design and construction practices. Permeability of concrete and depth of cover over the steel are some of the factors which control the onset and rate of corrosion [1]. Other factors which play an important role in the corrosion of embedded steel are crack width, and implementation of measures designed specifically for corrosion protection.

In this study, influences of construction practices such as consolidation, finishing practices, and arrangement of the reinforcing bars on corrosion of reinforcement were investigated. In addition, other defects such as cracking of concrete and missing of surface coating were discussed.

2. TEST PROGRAM

Table 1 A summary of test program

Slab No.	Parameter	Construction Defects
1	Control	without construction defects
2	Consolidation	bad consolidation (unvibrated)
3	Finishing Practice	annealed wires are sticking out concrete surface
4	Arrangement of Steel	without construction defects, but with bent bars
5	cracking	presence of cracks in concrete
6	Coating	missing of surface coating

The test program of this study is summarized in Table 1. Concrete slabs 10 x 40 x 120 cm in size, reinforced in two directions with 13 mm reinforcing steel bars and with thickness of cover 2 cm as shown in Fig.1, were used in this experiment. Slab No.1 was prepared with good construction practice as control (Ref.), while in slab No.2, the form was vibrated at positions A & B only for 10 seconds (Fig.1). In slab No.3, few annealed wire which fix reinforcing steel bars were sticking out concrete

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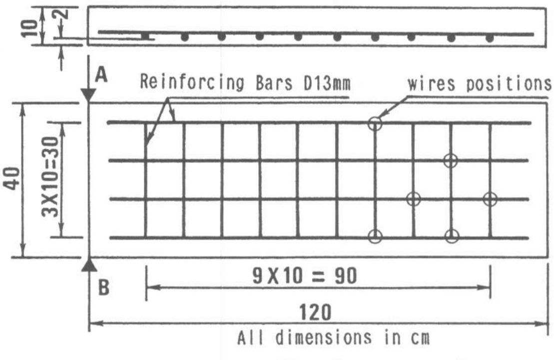

Fig. 1 Details of test specimen

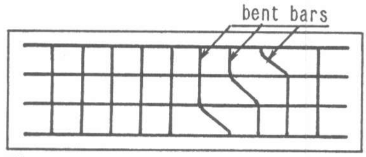

Fig. 2 Arrangement of reinforcement of slab No.4

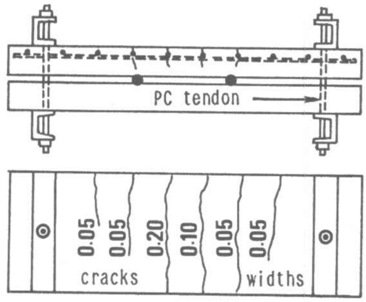

Fig. 3 Slab No.5 subjected to flexural cracking

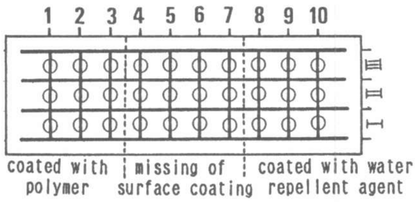

Fig. 4 Type of surface coating, and positions of half cellpotential measurements

surface, or located at just 2 mm below the surface. The position of these wires are indicated by circular mark in Fig.1. In slab No.4, three bent bars were used in the short direction as shown in Fig.2. Slab No.5 was subjected to flexural cracks as shown in Fig.3. Two types of surface coating were used to paint 2/3 of concrete surface of slab No.6 as shown in Fig.4.

The mix proportion of concrete which was used for preparing the test specimens is given in Table 2. All specimens were cured in water at 20° C for two weeks and then they were kept in a chamber with 50% R.H. at 20°C for one week. After that, specimens which would subject to cracking were loaded and all specimens were stored in the laboratory. Chloride solution (3% NaCl solution) was sprayed once a day on all specimens. The half cell potential along reinforcing steel were measured once a week as shown in Fig.4. After 6 months of spraying NaCl solution, chloride penetration depth was measured by the method referred by Sakuta et al. [2], as well as, reinforcing bars taken from the specimens were observed and corroded areas were measured.

Table 2 Mix proportion of concrete (specified)

Slump (cm)	Air (%)	W/C (%)	s/a (%)	Materials in kg/m³ of concrete				
				Water	Cement	Sand	Gravel	Admixture
10±2	4±1	60	40	180	300	702	1054	0.9

3. TEST RESULTS AND DISCUSSIONS

An equipotential contour map for slab No.1 (Ref.) at different periods of spraying NaCl solution and the corroded areas of reinforcing bars are shown in Fig.5. It was noted that half cell potential values of the reinforcing steel were numerically increased with increasing spraying time and these values became numerically greater than - 0.35 V CSE after 15 weeks as shown in Fig.6. The reinforcing bars were corroded in different

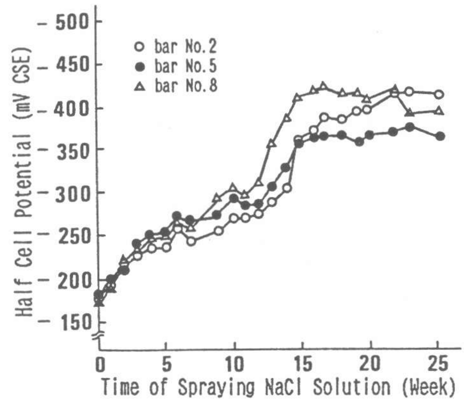

Fig. 6 The relation between half cell potential and time of spraying NaCl solution for slab No.1

parts in which high potentials were measured. This means that chloride ions penetrated through all the cover (2 cm), breaking off the passive film surrounding the steel bars at individual points where the bars became active and were corroded.

Clear [3] studied the effects of water-cement ratio and degree of consolidation on the rate of ingress of chloride ions. He concluded that a low water-cement ratio, however, is not sufficient to insure low permeability. A concrete with a water-cement ratio of 0.32 but with poor consolidation is less resistant to chloride ion penetration than a concrete with a water-cement ratio of 0.60. In slab No.2, the half cell potential values became numerically greater than - 0.35 V CSE just after 4 weeks of spraying, because it was not vibrated enough (poor consolidation). Also, it was found that the highest equipotential contour was located in unvibrated side and their values were gradually decreased towards the vibrated side as shown in Fig.7. After 20 weeks of spraying, a longitudinal crack was observed on unvibrated side and a large amount of corrosion was found for the

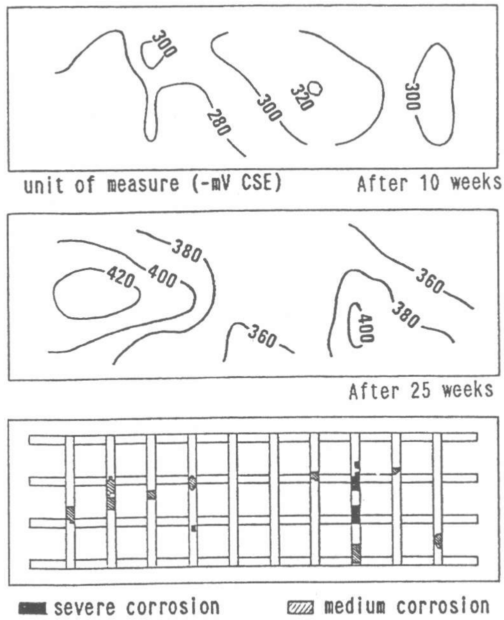

Fig. 5 Equipotential contour map and corroded areas of reinforcing bars in slab No.1

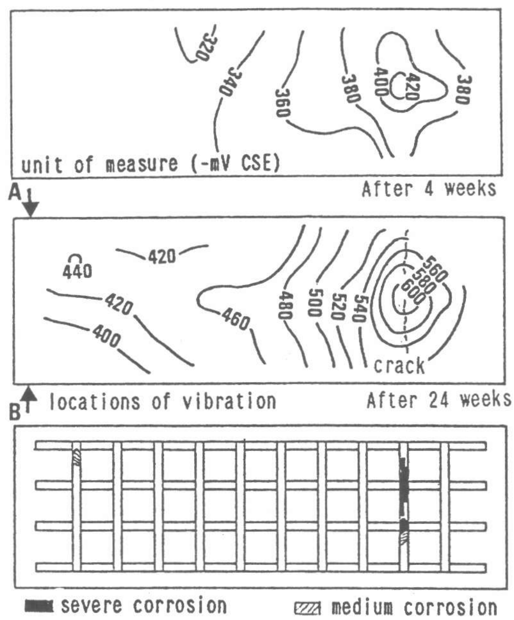

Fig. 7 Equipotential contour map and corroded areas of reinforcing bars in slab No.2

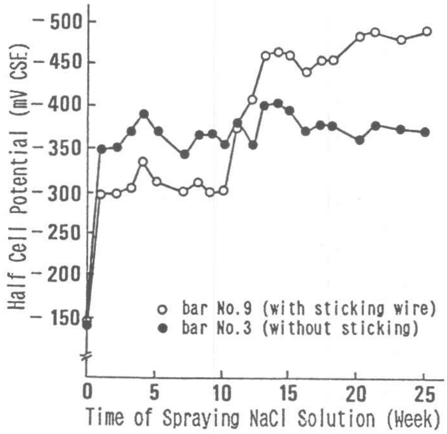

Fig. 9 The relation between half cell potential and time of spraying NaCl solution for slab No.3

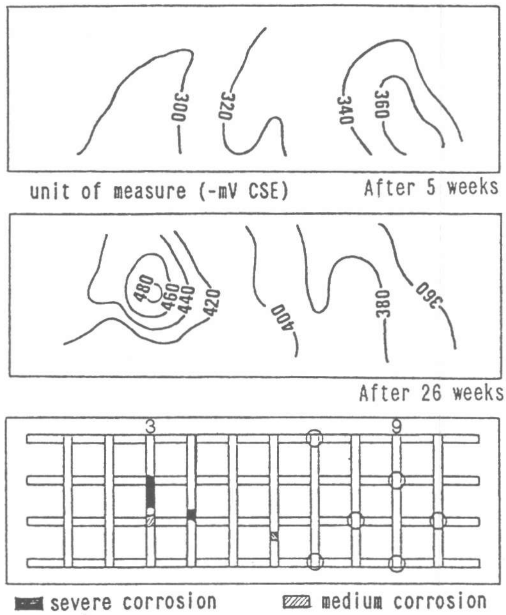

Fig. 8 Equipotential contour map and corroded areas of reinforcing bars in slab No.3

reinforcing bar parallel to that crack (Fig.7).

When the annealed wires which fix the reinforcing bars were sticking out or present near the concrete surface, brown stains were appeared on the concrete surface because of corrosion of these wires. Also, their half cell potential values were very close to - 0.35 V CSE after few weeks of spraying NaCl solution, and these values were still constant with the time as shown in Figs.8 & 9. But, the half cell potential values of reinforcing bars in other positions were numerically increased with the time. By observing the reinforcing bars on the positions which the wires were sticking out the surface, no trace of corrosion was found in these bars, while some of other bars were corroded as shown in Fig.8. This means that the wires became anode of corrosion cell and the reinforcing bars in that areas became cathode.

During the preparation of reinforcement, it was found that the bent bar had a trace of corrosion after 24 hours when it was left in high humidity weather compared with straight one. This phenomenon suggests that steel bars would be corroded if they are

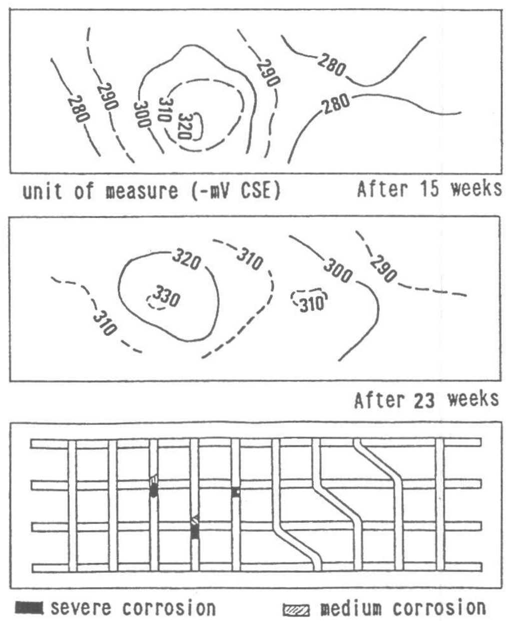

Fig. 10 Equipotential contour map and corroded areas of reinforcing bars in slab No.4

subjected to high stress or high deformation. Therefore, three bars were bent and were embedded in slab No.4. After 6 months, no trace of corrosion was observed for bent bars, while some of the straight bars were corroded. Fig.10 shows the equipotential contour map and the corroded areas of reinforcing bars for slab No.4.

The influence of crack widths on half cell potential and corroded areas of lateral bars are shown in Fig.11. This figure shows that the half cell potential values reached - 0.35 V CSE after 3 weeks for wide crack (0.2 mm wide). Also, these values were numerically decreased with decreasing crack width and the smallest value was obtained at uncracked position. The lateral bars which were parallel to cracks, were severely corroded, while those embedded in uncracked concrete were lightly corroded. The crack width had a significant effect on degree of corrosion. There were only two lightly corroded areas on longitudinal reinforcing bars (bar II) as shown in Fig.12. The position of crack to reinforcing bars and the thickness of cover could be considered together in this case. These results coincided with those obtained by other investigators [4-7], where it was observed that cracks which were parallel to the reinforcement can cause severe corrosion compared with transverse cracks, because the passivity is lost at many locations, and oxygen and moisture are readily available along the full length of the bar.

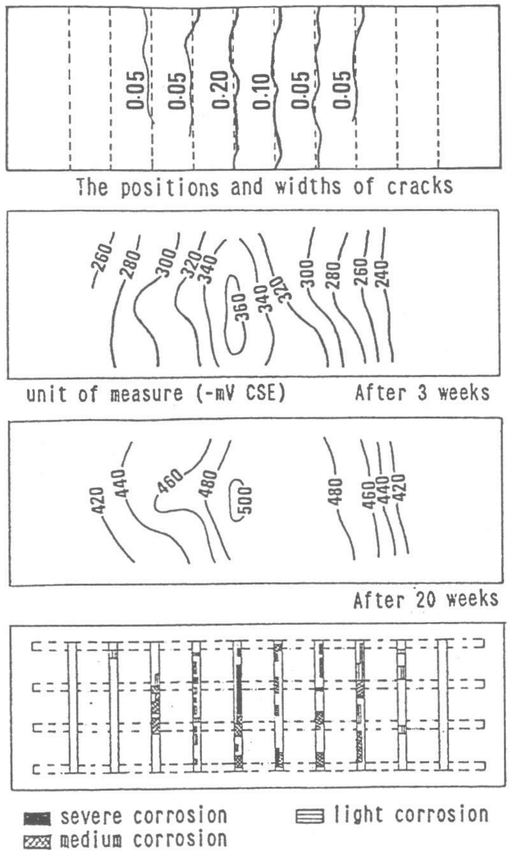

Fig. 11 Equipotential contour map and corroded areas of lateral steel bars in slab No.5

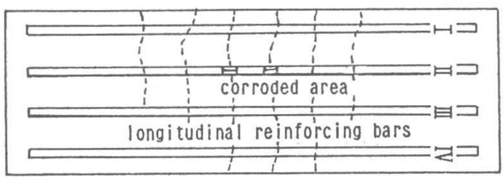

Fig. 12 Influence of transverse cracks on corrosion of longitudinal reinforcing bars

The influence of defects in surface coating is present in Fig.13. This figure shows the effect of coating type and coated area on chloride penetration, equipotential contour map, and corrosion of reinforcement. It was noticed that chloride penetration depth of coated concrete was about 50% of that of uncoated concrete. Also, the results show that there was a little difference between chloride penetration into concrete coated with polymer and that coated with water repellent agent. But, from point of cost, the water repellent agent was cheaper and more to apply easy than polymer. However, it should be noted that the half cell potential of bars embedded in coated concrete could not be compared with that of those embedded in uncoated concrete because the presence of coating would increase the electrical resistance of concrete. Reinforcing bars embedded in uncoated concrete were corroded, while there was no trace of corrosion for those embedded in coated concrete.

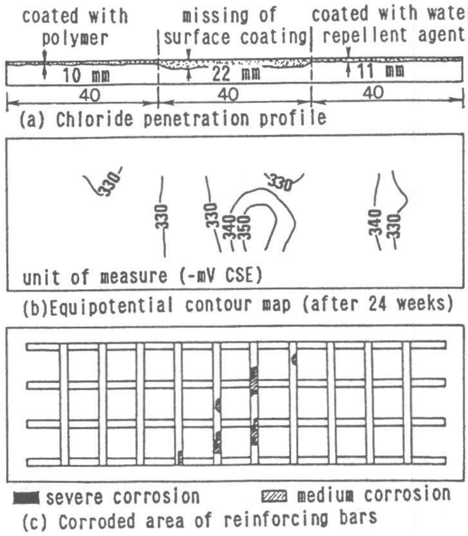

Fig. 13 Influence of surface coating on chloride penetration, equipotential contour map, and corroded aarea of reinforcing bars

5. CONCLUSION

Based on the experiments carried out in this study , the following conclusions can be drawn:

1) Equipotential measurement of half cell can predict the location of corrosion of reinforcing bars.
2) The consolidation of concrete is one of the important factors by which the protection of reinforcing steel afforded by portland cement can be maximized.
3) The presence of the annealed wire sticking out or located near concrete surface did not cause corrosion of reinforcement, hence it is suggested that these wires behaved as anode of corrosion cell while the reinforcing bars behaved as cathode. But, it would influence the appearance of concrete due to the occurrence of stains on concrete surface.
4) There is no difference between corrosion of straight and bent bars if good protection is afforded by concrete.
5) The presence of crack has a significant effect to accelerate the chloride corrosion of reinforcement especially those cracks parallel to the bars. Also, crack width has remarkable effect on corrosion areas.
6) Concrete surface coating is one of protective method by which external chloride attack on reinforcement could be eliminated. Water repellent agent, as well as polymer coating can be regarded as one of the promising methods.

REFERENCE

1) ACI Committee 222, "Corrosion of Metals in Concrete," ACI Journal, Proceedings No.1, Vol.82, 1985.
2) Sakuta, M., et al., "Development of Highly Durable Concrete," Transaction of JCI, Vol.9, 1987, pp. 241-248.
3) Clear, K., C., "Time-to-corrosion of reinforcing steel in concrete slabs. V.3 :Performance After 830 Daily Salt Applications," Report No. FHWA-RD-76-70,Fedral Highway Administration, Washington, D.C.,1976,64 pp.
4) Martin, H., and Schiessl, p., "The influence of Cracks on the Corrosion of Steel in Concrete," Preliminary Report, RILEM, International Symposium on the Durability of Concrete, Prague, 1969, Vol. 2.
5) Atimay, E., and Ferguson, P.M., "Early Cloride Corrosion of Reinforced Concrete-A Test Report," Materials Performance, Vol.13, No.12 ,1974, pp.18-21.
6) Nishida, K., et al., "Cracking of Reinforced Concrete and Corrosion of Reinforcement," Japan Concrete Institute /JCI, Vol.14, No.5, may 1976, pp. 36-40, (in Japanese).
7) Kamiyama, H., "Corrosion of Reinforcing Steel in Concrete," Cement-Concrete , No.308, Oct. 1972, pp.50-57, (in Japanese).