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Long Term Effects of Section Repair Method applied to PC Girders damaged by Chloride Attack

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ABSTRACT

This paper reports the results of follow-up survey on the repair effect at about 10 years after applying three types of section repair methods to a real pre-tensioning PC girder damaged by chloride attack. In this research, three repair materials were used for each method, such as polymer-cement mortar including corrosion inhibitor with lithium nitrite, non-shrinkage cement mortar including corrosion inhibitor with amino alcohol, cement paste and mortar with chlorine ion adsorbent. Also, these methods were partially applied under PC wires passed through the repaired and the unrepaired portions. As a result, it was found that the repair effects could be expected for about 10 years in case of less than about 4.5 kg/m^3 of chlorides contained in the unrepaired portion, although corrosion cracks due to macro-cells occurred near the boundary of the repaired and the unrepaired portions in case of about 6.8 kg/m^3.

Keywords. Chloride Attack, Macro-cells, Corrosion, Section Repair Method, PC Girder

INTRODUTION

When RC and/or PC structures damaged by chloride attack are repaired, it is very important to select the optimum repair methods taking the situation of deterioration in the structures and the repair effects of the applied methods into consideration. So, we have been conducting the follow-up survey on the repair effects of various methods (section repair, cathodic protection, electrochemical desalination and re-alkalization) by using two real pre-tensioning PC girders damaged by chloride attack. In this paper, the results of follow-up survey at about 10 years after applying three types of section repair methods to one girder (named as G15) are reported.

OUTLINE OF SURVEY

Outline of PC Girders. In this research, two PC girders (named as G14 and G15), which was separated from a real road bridge, were used as shown in Figure 1. This bridge was constructed in 1972 and at about 70 m away from the Sea of Japan, Hokuriku, Japan. This bridge had been exposed to severe marine environment and it was finally removed in 1997 after repeatedly conducting several times of repair works while in service. As shown in Figure 1, this bridge was composed of 15 pre-tensioning PC girders with the length of about 14 m. The dimensions of cross-section and the arrangement of reinforcement are shown in Figure 2. 28 PC wires of 7-ϕ9.3 (JIS G 3536) and the stirrups of D10 (JIS G 3112) were arranged. According to the construction records, the concrete with the design compressive strength of 50N/mm^2 and the water-cement ratio of 0.5 were used.

In this research, in order to investigate the repair effects of existing repair countermeasures against chloride attack, various methods were applied to G14 and G15. The scope of application of each repair method to G15, which is the investigation object of this paper, is shown in Figure 3. After applying these methods, G15 have been exposed on the Pacific Ocean side, Tokyo bay, Japan (see in Figure 4), while G14 on the Sea of Japan side, Niigata, Japan.

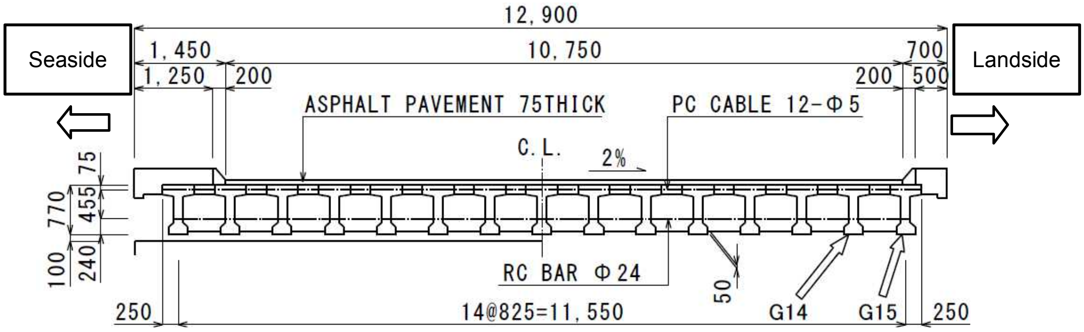


Figure 1. Outline of Removed Road Bridge (Unit : mm)

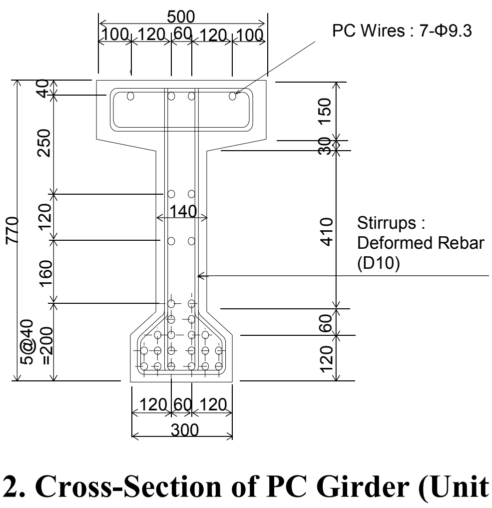


Figure 2. Cross-Section of PC Girder (Unit : mm)

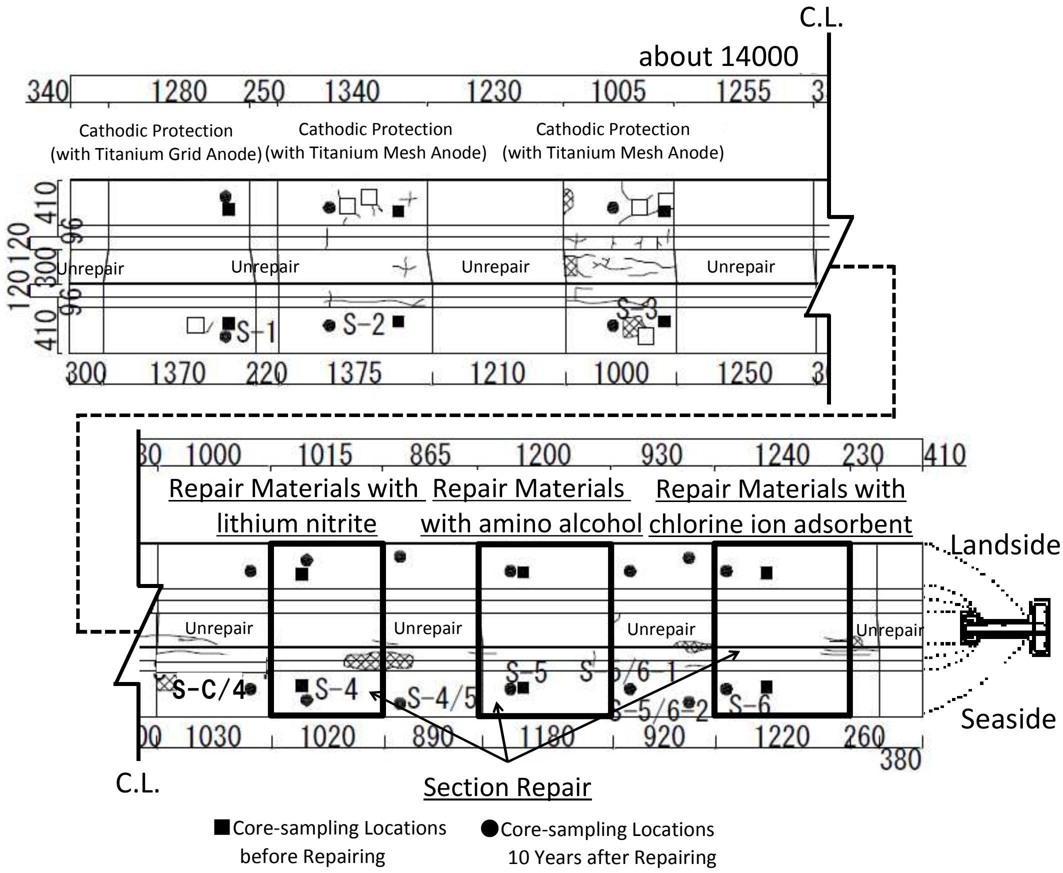


Figure 3. Scope of Application of Each Repair Method (G15 ; Unit:mm)

Figure 4. Exposure Situation of G15

Deterioration Situations before Repairing. The surface coatings were applied to G14 and G15 in 1982 and 1992 as a countermeasure against chloride attack while in service. Therefore, as the first step, the coatings were removed before applying the various repair methods. At that time, some repaired traces were observed on the surface. A lot of traces on the seaside surface were observed but few traces on the landside surface were observed. Particularly, some cracks due to chloride induced corrosion were observed on the seaside surface at the end of span in G15.

The distribution profiles of chloride content at the locations shown in Figure 3 before repairing are shown in Figure 5. The procedure of measurement of chloride content was as follows; as the first step, core-samples were taken by penetrating the web of girder. Secondary, each core-sample was sliced at every 20mm from the seaside surface to the landside surface, and the total chloride content for each slice was measured according to JIS A 1154 [Methods of test for chloride ion content in hardened concrete].

From this figure, it was found that the amount of chloride ion penetration from the seaside is larger than that from the landside. Also, the chloride content at the depth of 20 - 40 mm from the seaside surface was 2.8 - 4.6 kg/m^3 (the cover thickness of reinforcement such as stirrups and PC wires were around 20 - 40 mm). On the other hand, the chloride content at the depth of 20 - 40 mm from the landside surface was 1.1 - 1.8 kg/m^3. The carbonation depth of the seaside was 3.5 mm and that of landside was 4.0 mm.

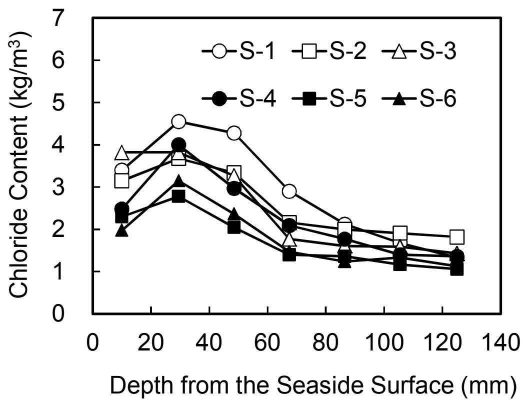


Figure 5. Distribution Profiles of Chloride Content in the Web Concrete (before Repairing)

The cover thickness of reinforcement (stirrups and PC wires) and the corrosion situation of reinforcement were inspected by partially chipping the concrete of lower flange. The measured cover thickness of stirrups of the seaside was 19 - 24 mm and that of the landside was 12 - 14 mm. The measured cover thickness of PC wires of the seaside was 33 - 37 mm, while that of the landside widely varied between 32 and 58mm. Furthermore, the superficial corrosion at some locations was observed on the surface of stirrups of the both sides and PC wires of the seaside, while the corrosion was not observed on the surface of PC wires of the landside.

Outline of Applied Section Repair Methods. Three types of section repair methods were applied to the portions shown in Figure 3. The following repair materials were used for each method respectively; one was the styrene-butadiene rubber type polymer-cement mortar including corrosion inhibitor with lithium nitrite (Sugiura, A. et al., 2001). The second was the low heat and non-shrinkage mortar including corrosion inhibitor with amino alcohol

(Moriwake, A. et al., 1998). The third was the cement paste and the cement mortar with chlorine ion adsorbent (Tatematsu, H. et al., 2000). The third material has the characteristics that can adsorb chlorine ions around reinforcement and concrete and release nitrite ions into concrete.

In this study, in order to figure out the influence of steel corrosion due to macro-cells, each section repair method was applied in the range of about 1.0 m to the longitudinal direction of the girders by remaining the unrepaired portions of about 1.0 m between the repaired portions. The cover concrete was removed to the extent that the whole surface of stirrups and the outer half surface of PC wires were exposed. Also, the rust on the reinforcement was removed by wire brushing. The repaired sections for all methods were recovered so that 30 mm of the design cover thickness of stirrups was ensured.

Each section repair work was conducted as follows;

In the section repair method using the polymer-cement mortar including corrosion inhibitor with lithium nitrite, the section was repaired by plastering. In addition, the surface on the repaired portion was coated with epoxy resin by using scraper or roller after hardening the mortar.

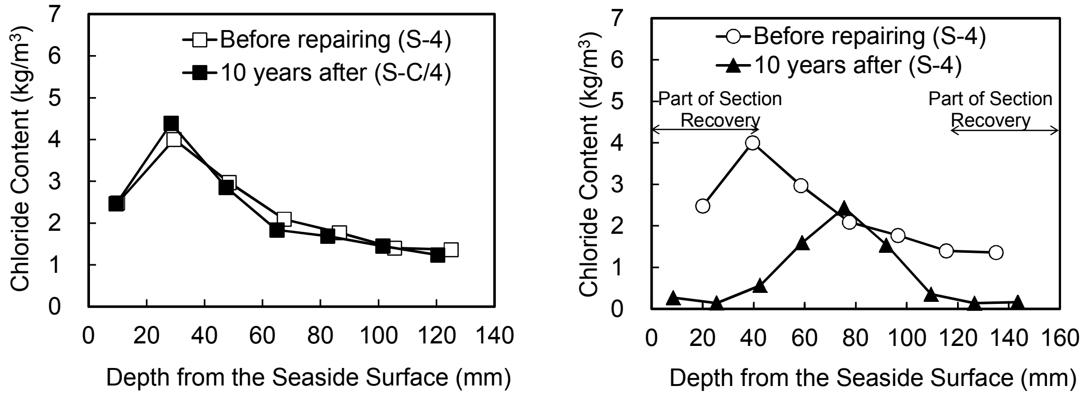
In the section repair method using the cement mortar including corrosion inhibitor with amino alcohol, the sections were repaired by firstly fabricating the formwork and then grouting. The mortar was grouted upward from the bottom of formwork. Grouting was stopped at the time of confirmation of the overflow of mortar from the upper side of formwork. Finally, as well as the method using the material with lithium nitrite, the surface on the repaired portion was coated with epoxy resin after removing the formwork.

In the section repair method using the repair material with chlorine ion adsorbent, the surface of reinforcement was coated with cement paste including chlorine ion adsorbent by brush. Next, the surface was over-coated with cement mortar including chlorine ion adsorbent. And then the sections were repaired by grouting commonly used cement mortar without chlorine ion adsorbent. Finally, the surface on the repaired portion was coated with the inorganic protective layer by using scraper or roller after removing the formwork.

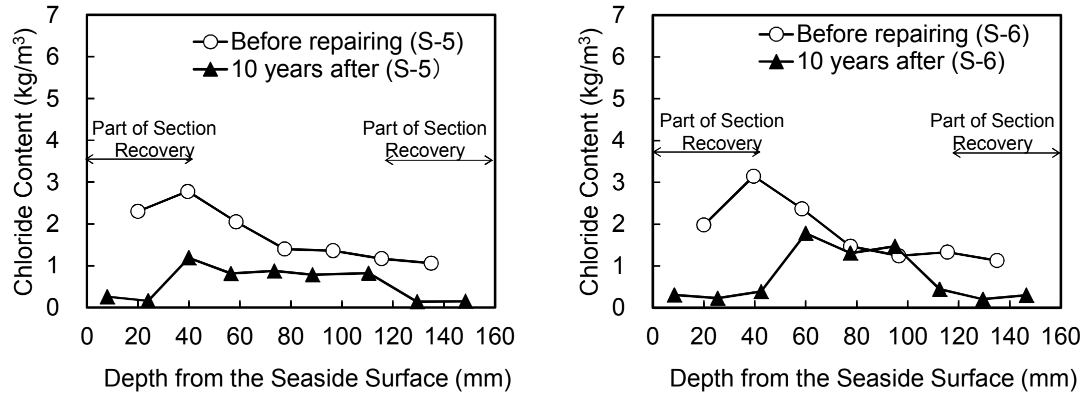
RESULTS OF THE SURVEY AT ABOUT 10 YEARS AFTER REPAIRING

Distribution Profiles of Chloride Content at About 10 Years After Repairing. The distribution profiles of chloride content in cores from the web concrete at about 10 years after applying the section repair methods are shown in Figure 6. Core-samples were taken by penetrating through the web of girder shown in Figure 3. Each core-sample was sliced at every 20mm from the seaside surface to the landside surface and then the total chloride content for each slice was measured according to JIS A 1154. Also, in these figures, the distribution profiles before repairing shown in Figure 5 were appended for reference.

As seen in Figure 6(a), it was recognized that chloride ions had not been supplied from the outside for about 10 years because the distribution profile after about 10 years was almost consistent with that before repairing. On the other hand, the tendencies could be confirmed that chloride contents of concrete between two section repair parts of the seaside and the landside became smaller at about 10 years after repairing than those before repairing, as shown in Figure 6(b), (c) and (d). This was assumed to occur by diffusing chloride ions from the inner existing concrete into the section repair parts and/or adsorbing the repair materials.



(a) Unrepaired **(b) Repaired with Lithium Nitrite**

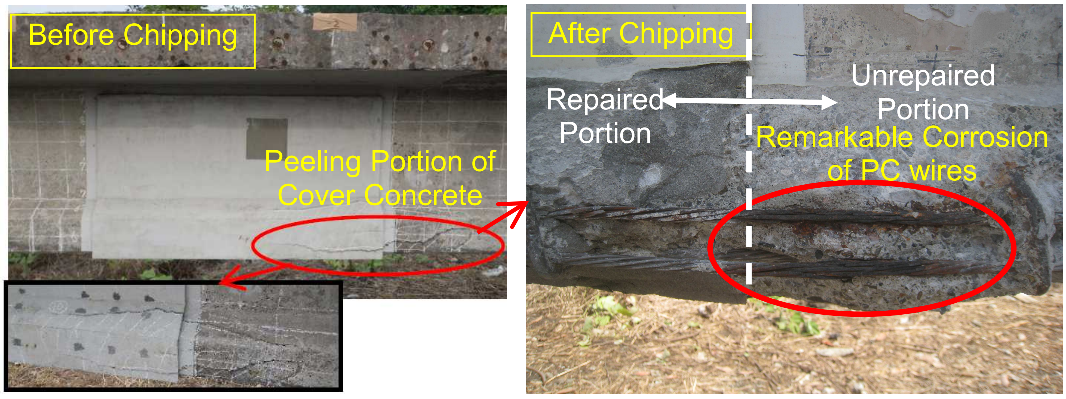


(c) Repaired with Amino Alcohol **(d) Repaired with Chlorine ion Absorbent**

Figure 6. Distribution Profiles of Chloride Content in the Web Concrete (About 10 Years after Repairing)

External Observation of Surveyed Girder. The results of external observation on the surface of the seaside at about 10 years after repairing are shown in the left side of Figure 7. The changes of appearance on both the repaired and the unrepaired potions of the landside were not confirmed for all types of methods at that time. However, cracks were confirmed near the boundary of repaired and unrepaired potions of only the lower flange of the seaside. Particularly, the wide range of peeling of cover concrete had occurred in case of using the repair materials with lithium nitrite.

Corrosion Situations of PC Wires due to Macro-cells. The observation results of PC wires near the boundary of repaired and unrepaired portions after chipping cover concrete of the lower flange of the seaside are shown in the right side of Figure 7. As seen in these figures, remarkable corrosion of PC wires in the unrepaired portions and near the boundary was observed. The result of electrical potentials of PC wires at the lower flange between the ranges of the section repair method with lithium nitrite and that with amino alcohol is shown in Figure 8. This measurement was conducted before chipping cover concrete. The potentials of PC wires in the repaired portions were nobler than those in the unrepaired potions. In addition, the differences of the potentials of PC wires near the boundary between the repaired and the unrepaired portions were drastically made large, such as the difference of 70mV in case of using the repair material with lithium nitrite and that of 100mV in case of the material with amino alcohol. Therefore, it could be recognized that corrosion due to macro-cells was obviously formed between the repaired and the unrepaired portions when the section repair method was partially applied under reinforcement passed through the repaired and the unrepaired portions.



(a) Repair Material with Lithium Nitrite

(b) Repair Material with Amino Alcohol

(c) Repair Material with Chlorine Ion Absorbent

Figure 7. External Observation on the Surface of the Seaside and Corrosion Situations of PC Wires due to Macro-Cells (About 10 Years after Repairing)

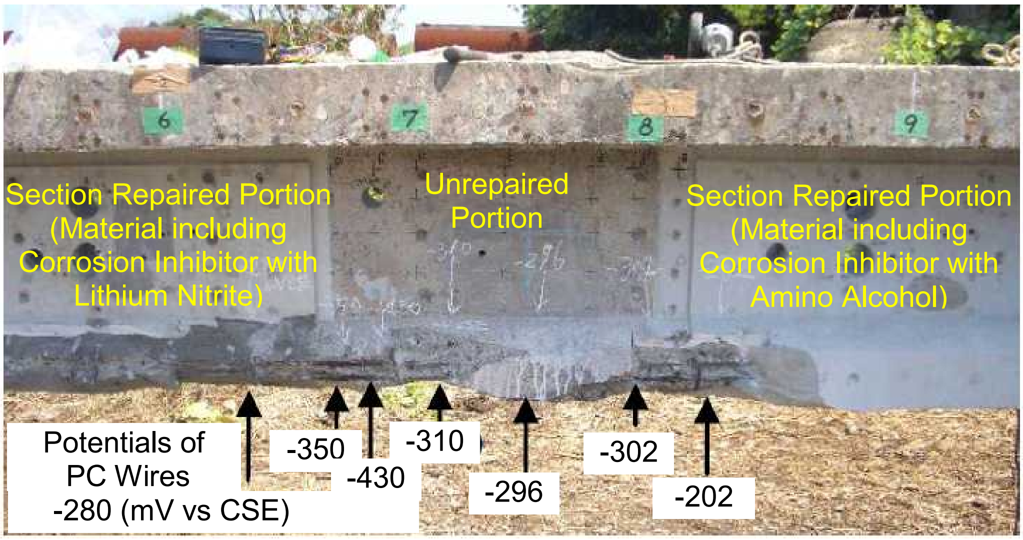


Figure 8. Electrical Potentials of PC Wires

CONSIDERATION ON REPAIR EFFECT OF SECTION REPAIR METHOD

The measurement of chloride content at the depth of 30 mm and 50 mm (around the reinforcement) from the concrete surface at the lower flange were added to that at the web of girder shown in Figure 6, because corrosion cracks due to macro-cells occurred near the boundary of repaired and unrepaired portions. The analysis samples of drilled powder were collected from the lower flange at the unrepaired portion between the portions of the section repaired method with lithium nitrite and with amino alcohol. The result is shown in Figure 9.

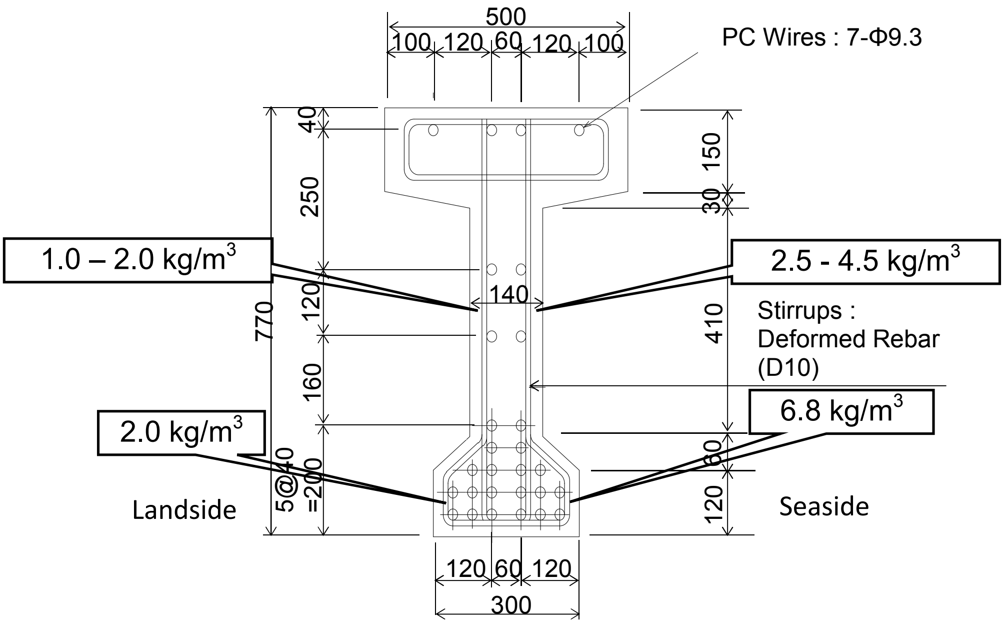


Figure 9. Chloride Content at the Depth of Reinforcement

6.8 kg/m^3 of chloride content at the depth of reinforcement was measured in the lower flange of the seaside. It was assumed to be 6.8 kg/m^3 of chlorides contained in the unrepaired portion before repairing because chloride ions had not been supplied from the outside for about 10 years as shown in Figure 6(a). Therefore, it could be recognized that the amount of chlorides contained in the unrepaired portions was greatly influenced on the occurrence of corrosion due to macro-cells when the section repair method was partially applied to the RC and/or PC structures damaged by chloride attack in the state of remaining the unrepaired portions. In this research, it was found that the repair effects could be expected for about 10 years in case of less than 4.5 kg/m^3 of chlorides contained in the unrepaired portion, although corrosion cracks due to macro-cells in case of 6.8 kg/m^3.

CONCLUSIONS

This paper introduced the repair effects at about 10 years after applying the section repair methods with three types of repair materials with corrosion inhibitor to one pre-tensioning PC girder damaged by chloride attack. These methods were partially applied under PC wires passed through repaired and unrepaired portions. As a result, it was found that the repair effects could be expected for about 10 years in case of less than about 4.5 kg/m^3 of chlorides contained in the unrepaired portion, while corrosion cracks due to macro-cells occurred near the boundary of the repaired and the unrepaired portions in case of about 6.8 kg/m^3.

ACKNOWLEDGMENT

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