LONGEVITY LIFE-CYCLE OF PRESTRESSED CONCRETE BRIDGE DAMAGED TO SALT ATTACK

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Abstract
Repairing damaged concrete by mortar overlay method have been generally applying as repair method for deteriorated Prestressed Concrete (Here in after called PC) railway bridge by salt contamination. However deterioration of concrete occur again in short time. Then, we have tried to extend service life of salt contaminated bridge by application of cathodic protection system, because we found that cathodic protection system have a possibility to reduce life cycle cost compared with mortar overlay method. Therefore, We have decided to verify the effectiveness and cost of cathodic protection system among selected five cathodic protection system.

1. INTRODUCTION
Where concrete structures located near shore line, they are corroded by splashed salt from sea. Structures for transportaion service can't be also avoided such corrosion, especially structures near to Sea of Japan suffered serious damage by much splashed salt which are blown by seasonal strong wind in winter. We have generally adopted the mortar overlay method, because of relatively low cost compared with other repairing or protection method, however that was not effective for long time and concrete was periodically repaired\(^1\).\(^2\). This has been caused by insufficient elimination or removing the permeated residual chloride ion in the concrete. On the other hand, cathodic protection system is well known as effective protection method for the salt contaminated concrete structure. Because, it prevent corrosion from rebar by electrochemical reaction and is not affected effectiveness by presence of residual chloride ion. Recently cost of cathodic protection system is down and then we have decided to adopt cathodic protection system as permanent protection system. There are some materials and installation methods in cathodic protection system. However, it is difficult to evaluate accurately and to find out different among them from the various references when we consider to apply cathodic protection system to our bridge. Then, we have decided to test by using five different methods and verified their effect from view point of effectiveness and their work efficiency. This report covers investigation of structures, selection of repairing method, abstract of cathodic protection system installation method and evaluation of economical effect.

2. SUMMARY OF TESTED STRUCTURES
Objects to be investigated are located approximately 150 m apart from shore line of Sea of Japan, 151.9m total length, 7 spans of post tensioned PC beam which 25 years passed after constructed. Layout of structures are shown in Figure-1. There are only bridge for single track service line and road between structures to be tested and shore line. There is no obstructions and they directly expose to wind from Sea of Japan. Specification of bridge are as follows;

<table>
<thead>
<tr>
<th>Type of structure</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post tensioned PC beam for single track railway service</td>
<td>1974 (Both of Upper and Lower structures)</td>
</tr>
<tr>
<td>PCI type three main beams (19.76m long beam, 19.00m span)</td>
<td></td>
</tr>
<tr>
<td>PCI type four main beams (32.06m long beam, 31.30m span)</td>
<td></td>
</tr>
<tr>
<td>PC hollow beam (19.76m long beam, 19.00m span)</td>
<td></td>
</tr>
<tr>
<td>Ballast track</td>
<td></td>
</tr>
</tbody>
</table>

3. INVESTIGATION
3.1 Visual investigation
Visual investigation results of structures are as follows;
Cracks have been observed on the side beam and it extended from bottom of main beam flange to axis direction of bridge. Peeled off and dropped concrete piece have been observed at the lower corner of bottom of main beam flange. Corroded rebar and no continuity rear by corrosion have been observed at the just bottom of main beam. No serious and completely corroded rebar have been observed. No corrosion in the PC structures have been observed (Corrosion have been observed of the part of sheath). No serious corrosion or deterioration which affect to constructional overload have been observed. Local corrosion, observed under main beams, may be caused by corrosion of spacers which were used at construction. Deterioration and damage of concrete have been mainly observed on the 3rd span main beam among 1st to 5th span. Therefore, we have decided to repair 1st to 5th beams from seven span beams.

3.2 Salt contamination measurement
(1) Core Sampling and Analysis Method
Chloride ion contents investigation have been carried for the 1st to 5th span which are object to repair and samples have been taken from sea side and mountain side. For detail investigation for the 1st span, core sample have been taken from 13 points as shown in the following Figure-2. Dimension of sampling core is 50mm in diameter and 60mm long. Core was cut every 20 mm to verify contamination in depth and crushed to the smaller size of less than 0.15mm. Total salt content in crushed samples were analyzed in accordance with JCI (Japan Concrete Institute)-SC4 “Salt content analysis method in hardened concrete”.

![Figure-2](image)

(2) Results of Analysis
Results of chloride ion analysis for the beams which have been detailed investigation are shown in the Figure-3. Total permeated chloride into concrete are maximum 6.4 kg/m² in the depth of 20 to 40mm where is the depth of embedded rebar, this value is sufficient to cause corrosion on the rebar. Much chloride have been found on the web of sea side beam and on the flange of the mountain side beam. This may cause that wind from sea blow hard to the web of sea side beam, on the other hand, no direct wind from sea blow to the mountain side beam, because other structure prevent wind from sea for mountain side beam. But wind from sea blow under beam and may blow flange of mountain side beam. There are a little different among 1st to 5th span and all beams seems in almost same climatic condition, but this is not shown in the following figure.
4. SELECTION OF REPAIR METHODS
From this investigation, we found the phenomena those are; deterioration of structure is a little, no cost for overlay may need, chloride ion content around rebar have already exceeded 1.2 kg/m³ that is threshold level of starting corrosion, to avoid cyclic repair works. Then we consequently reached conclusion to adopt cathodic protection.

5. CATHODIC PROTECTION
Cathodic protection system are mainly used as protection method for the salt contaminated reinforced concrete structures. It can sufficiently protect rebar and has following particulars; applicable to the structure even though in the severe environment, no need removal of salt contaminated concrete, no need rust prevention of the rebar. easy confirmation the effect by monitor protective potential measurement.

5.1 Cathodic Protection Methods
Cathodic protection system have following two major method; Impressed current system which apply DC current from power supply unit Galvanic system which use more active metal as anode and make electrical circuit between anode and structures to be protected. Then, suitable protection current flow into metallic structure to be protected. These methods will be categorized in accordance with anode system. We have adopted following five methods and have installed;

(1) Zinc Sheet method
This is a galvanic anode method which we adopted only one method from galvanic anode. Anode is sheet type zinc and anode is attached on the concrete surface. Electrical connection will be made between zinc sheet and rebar, then protection current flow from zinc sheet to rebar. Consequently, corrosion was controlled. In this case, no electrical source requires and no over protection appears due to low driving potential. However, zinc sheet, backfill binding material and protection material will be installed together, then dead load against concrete structure increase. In addition to above matters, zinc sheet will be fabricated at manufacturer's factory, it needs to confirm the dimension of material site inspection.

(2) Titanium Grid Method
Titanium anode will be installed in the groove which cut by concrete saw and titanium anode does not increase dead load against concrete structure. Installation works is not difficult.

(3) Titanium Thermal Spray Method
In this case, titanium anode is thermally sprayed on the concrete surface. This can apply to any shape of structure and no dead load increases and is recently introduced to Japan. Then, this is a first field application to the structures in Japan.

(4) Titanium Mesh Anode Method
In this case, mesh type titanium anode will be laid on the concrete structure. It can be expected uniform current distribution to the rebar. However, this type anode need mortar overlay and consequently increase dead load to the structures.

(5) Titanium Rod Inserted Method
In this case, drilling concrete with the approximately 10 mm in diameter and insert titanium rod shape anode. This system differs from other system, because no anode on the surface of concrete. This method has following particulars; no special treatment need for installation anodes are installed in the
concrete structure do not increase dead load against structures special care need to avoid contact with rebar other metallic structures in the concrete to avoid short circuit.

5.2 Installation
(1) Installed Location and Procedure
We installed anode at below main beam flange. Installation procedure are shown in the Figure-4.

![Figure-4 Cathodic Protection Installation Flow Chart](image)

(2) Confirmation of Rebar Continuity
Rebar or other metallic structure to be protected should be electrically connected each other, then we exposed rebar and confirmed continuity of them. When no continuity was found, rebar was welded to make continuity and confirmed continuity.

(3) Chipping of Concrete at Deteriorated Part Deteriorated concrete in the area where apply cathodic protection were chipped.

(4) Overlay
Chipped part, damaged part and rebar exposed parts were overlaid with low electrical resistance special mortar.

(5) Reference Electrode Installation
Reference electrode detects potential of protected rebar were tied to exposed rebar by using cable tie.

(6) Drainage and Test terminal installation
Drainage terminal is terminal to foam electrical circuit between the structures to be protected and anode and test terminal is terminal to foam the monitoring circuit to confirm protective effect. Both terminals were directly welded to exposed rebar.

6. ECONOMICAL EVALUATION
We have studied economical effect of installation cost which base on concrete. Concrete repaired structures are PC beam as well as repaired structure by cathodic protection, reported in this paper, span and quantity of main beams are almost similar shape. Mortar overlay method have been carried out for twice. Second concrete repairing was carried out after ten years from first time repairing and repairing cost of mortar overlay method is estimated as same as cost of first time repairing. We selected titanium thermal spray system for cost comparative study. Figure-5 shows comparison of repair cost between mortar overlay method and titanium thermal spray method. Repairing method describes as follows; Mortar overlay method : chipping at concrete deteriorated portion, backfill the mortar, final covering works, removing scaffolding. Cathodic protection : repairing of deteriorated portion, installation of spacer to avoid short circuit, installation of reference electrode, thermal spray of anode material, piping and wiring, installation of power supply unit, marshaling box, removing scaffolding. Figure assumes the repair cost of the first time of the section repairing method to be one and is a relativity comparison. Figure also shows that the cost of mortar overlay method at second times becomes almost same cost as cathodic protection installation cost and cost of cathodic protection system installation is slightly lower than the cost of mortar overlay method. This is, so to speak, a comparison of initiated costs of the repair cost, and maintenance control expense etc. from now on are not considered. It is thought that the damage degree of the structure has domination enough when thinking it is hardly, and the mortar overlay method changes as deterioration progressing though updates equipment to the cathodic protection method for 20 years by the assumption cathodic protection method at the design years at the design life if the repair will be repeated in ten years. Moreover, the design life of the cathodic protection has been decided by the consumption of the anode material. It is thought that the life becomes more dominant from be calculated this by the maximum current value, and anode life will be extended because steady protective current is consequently almost half of design value. In case of civil structures is considered that saving of total maintenance cost is most important due to long service time of structures.
7. SUMMARY
The amount of the content chloride in the PC bridge under the same salt damage environment concrete shows almost the same tendency at the part and the arrangement position. The cathodic protection method was adopted as a permanent life prolongation plan of the PC bridge. In the cathodic protection industrial method, one repair cost is about twice compared with the concrete damage repairing method. It is thought that there is enough domination in the life cycle when the durability of the structure was considered cost in the repair with the cathodic protection method. Durability and domination of five kinds of cathodic protection methods are examined.

REFERENCES
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