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Life Cycle Cost of Road Bridges Affected by Salt Attack on the Sea of Japan Coast in Niigata Prefecture

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ABSTRACT

In this study, the repair history of bridges located on the Sea of Japan coast in Niigata Prefecture was examined and analyzed to determine actual maintenance costs. The results indicated that distance from the coast is a dominant factor in salt attack, and that pre-tensioned PC bridges cost more to maintain than other types. The maintenance costs involved in applying cathodic protection were also compared with those of patching/painting repair work for pre-tensioned prestressed concrete (PC) bridges. Although the initial cost of the former was much higher, the overall costs of both were similar. These outcomes suggest that renewal is preferable to repair in reducing life cycle cost (LCC), especially for pre-tensioned PC bridges.

Keywords: salt attack, LCC, maintenance, cathodic protection, PC bridge

INTRODUCTION

Concrete bridges constructed in coastal regions of Japan in the 1960s and 1970s have deteriorated as a result of salt attack as shown in Figure 1 (Tanaka, 2012). In this process, high concentrations of chloride ions accelerate the corrosion of reinforcing materials inside concrete structures.

The resulting reduction in the cross-sectional area of reinforcing materials impairs the strength of such structures, and associated corrosion products cause cracking and spalling of concrete. Accordingly, repair, strengthening and re-construction work is required to maintain the function of deteriorated concrete structures.

The variety of repair methods developed to recover the durability of deteriorated concrete bridge structures include patching, painting, electro-chemical desalination and cathodic protection. However, there is widespread debate among engineers regarding the best way to prolong the remaining lifetime of bridges. Life cycle cost (LCC) is a useful index for determining the effectiveness of repair methods. While many researchers have adopted theoretical approaches to this problem, few have focused on the actual LCC of existing concrete bridges.

In this study, the repair history of bridges located on the Sea of Japan coast in Niigata Prefecture was investigated and analyzed to determine actual maintenance costs. Based on comparison of the actual LCC of bridges, the influences of distance from the coast, bridge types and repair work approaches were studied.

Figure 1. PC bridge beam affected by salt attack in Niigata Pref., Japan (constructed in 1975)

DATA COLLECTION AND LCC ANALYSIS

As quantitative evaluation to determine the durability of repaired bridges is impossible because the recording of related inspection data began only recently, data on construction and repair costs were collected from the local road administrator’s office and actual maintenance costs were calculated for each bridge. National Routes 8 and 18 were surveyed in this study (Figure 2). Since Route 8 is located on the Sea of Japan coast, many bridges along it are affected by chloride attack. Conversely, Route 18 is located inland.

Figure 2. National routes surveyed

To account for changes in the value of money over time, construction and repair costs were converted to present-day values using Equation 1.

$$C(2005) = I(2005) / I(t) \times C(t) \tag{1}$$

Here, C(2005) is the present value of money (base year: 2005), I(2005) is the deflator in the base year, C(t) is the cost in year t and I(t) is the deflator in year t. The construction cost deflator used in Equation 1 is shown in Figure 3. These data are published by MLIT (Japan's Ministry of Land, Infrastructure, Transport and Tourism) every month.

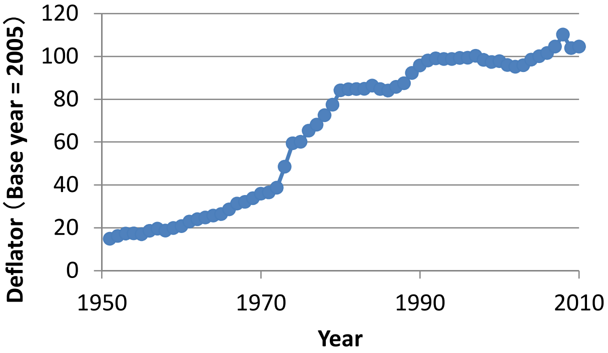
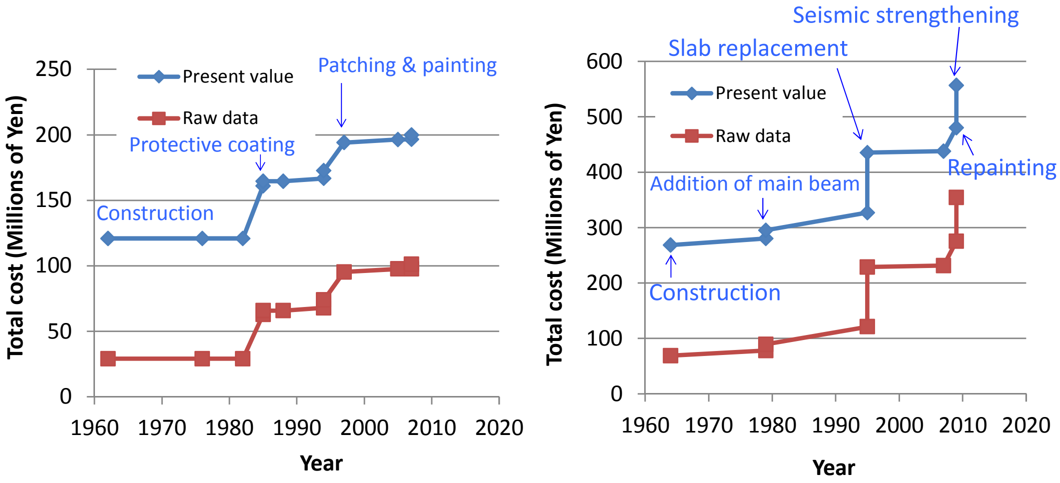


Figure 3. Construction cost deflator used for conversion to present-day values

Figure 4 shows examples of the total cost/time relationship. The red line indicates the cumulative raw cost, while the blue line represents the cumulative present value. Obviously, the initial cost is underestimated if the raw cost is cumulative. Bridge E located near the coast was first repaired about 20 years after construction due to salt attack. Patching and painting repair was conducted 10 years later due to re-deterioration, and as of 2012 the structure was again in a state of deterioration. The total cumulative repair cost stands at more than half the initial cost. The total cost for the inland Bridge P is about twice the initial cost, and no degradation was observed. This is because regulations on live and seismic loads were changed in the 1990s, and slab replacement and seismic strengthening were conducted as a result.



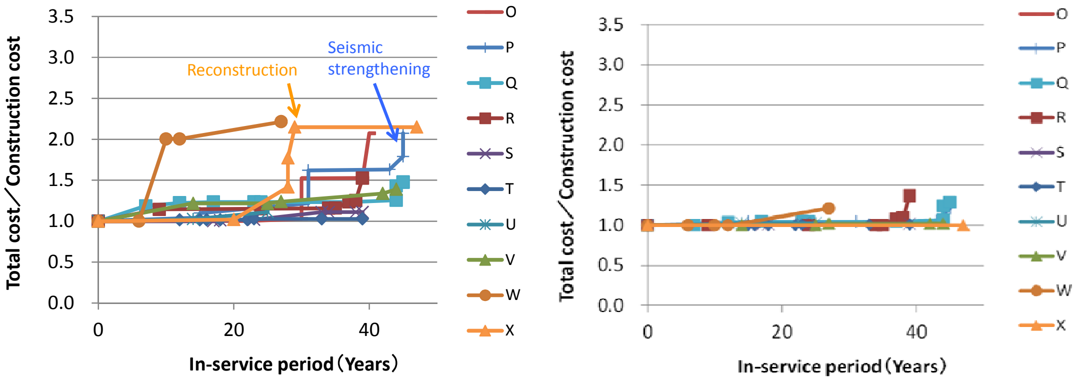
(a) Bridge E (a PCT girder bridge near the coast, Length = 76.8 m, width = 7.8 m, 3 spans)

(b) Bridge P (a steel girder bridge far from the coast, Length = 72.4 m, width = 10.2 m, 2 spans)

Figure 4. Examples of cumulative cost

INFLUENCE OF DISTANCE FROM THE COAST ON TOTAL COST

Figure 5 (a) shows changes in the total cost of steel girder bridges located more than 500 m from the coast. Here, the total cost is divided by the initial construction cost to allow intercomparison. As mentioned above, the total cost of steel girder bridges includes investment related to slab strengthening and seismic strengthening. In Figure 5 (b), the costs of these two types of strengthening to increase loading capacity are not included in the total because they are not related to chloride deterioration. As most bridges have not been repaired (except for periodical repainting), the total cost is low for all structures. It is clear that a distance of 500 m from the coast is enough to avoid salt attack in Niigata Prefecture.



(a) Raw data

(b) Without slab strengthening/seismic Strengthening costs

Figure 5. Changes in total cost of steel girder bridges (more than 500 m from the coast)

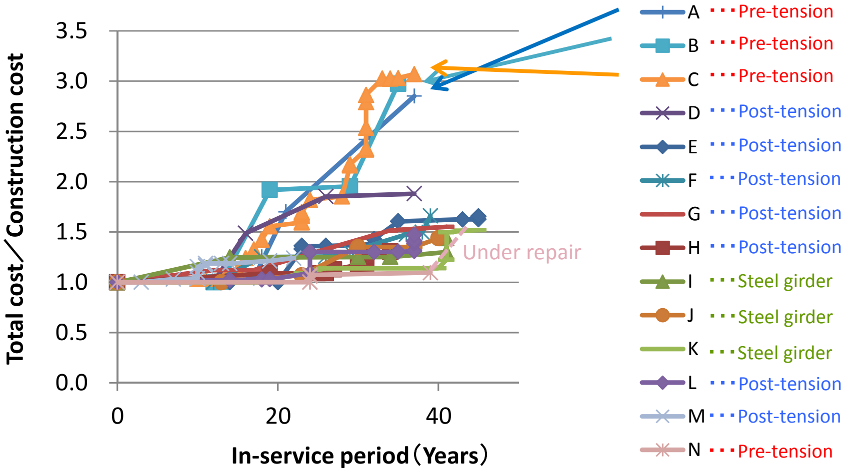


Figure 6. Changes in total cost of concrete and steel bridges (less than 150 m from the coast)

Figure 6 shows changes in the total cost for concrete and steel bridges located less than 150 m from the coast. All bridges in the figure were affected by chloride attack. As concrete bridges were repaired with patching and painting several times, the total cost is 1.5 times that of construction in most cases. For the pre-tensioned PC T girder bridges A, B and C, the total cost exceeds three times the initial cost. Both the concrete cover depth and the bar diameter of pre-tensioned PC bridges are smaller than those of post-tensioned PC bridges. Steel corrosion starts earlier with less cover depth, and corrosion reaction is faster with a large number of small-diameter bars. The reason why repair costs more for pre-tensioned PC bridges remains to be determined.

Figure 7 shows re-deteriorated concrete bridges on the coast in Niigata Prefecture. These structures were repaired with patching and painting several years before the photos were taken, but the repair was clearly ineffective. As re-deterioration occurs periodically, the total cost continues to increase after patching repair as shown in Figure 6.

(a) Bridge C (7 years after last repair)　　(b) Bridge G (2 years after last repair)

Figure 7. Re-deteriorated PC bridges in Niigata Pref.

COMPARISON OF REPAIR METHODS

Two repair methods were used on Bridge C. As shown in Figure 8 (a), patching and painting were applied to all spans except the eighth one, which was repaired using cathodic protection. The total costs of each span are compared in Figure 9. Cathodic protection was applied 23 years after construction, and although this method costs more than patching and painting,

(a) Patching and painting work (7th span)　　(b) Cathodic protection (8th span)

Figure 8. Repair methods for Bridge C

post-maintenance costs are low and no re-deterioration has occurred on the eighth span. Meanwhile, deterioration reoccurred on all spans after painting and patching repair. As a result, the total costs for both repair methods are similar at present. As cathodic protection is a relatively new approach in Japan, its durability needs to be verified in future to allow the development of rational maintenance strategies for coastal areas.

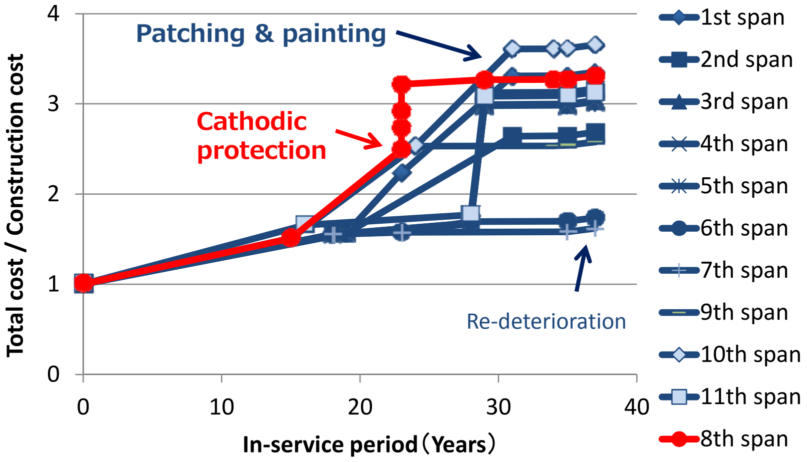


Figure 9. Changes in total cost for each span on Bridge C

DISCUSSION OF RATIONAL MAINTENANCE

To support the discussion of maintenance for bridges affected by chloride-induced deterioration, Figure 10 compares patching/painting and renewal in terms of LCC for a pre-tensioned PC bridge. Based on actual data, chloride deterioration is assumed to start 20 years after construction. Estimated upper and lower limits are shown by lines in the figure for patching and painting. Renewal costs are assumed to be similar to those of construction, and the lifespan of a renewed bridge is taken as 50 years. As the total cost of renewal is lower than that of patching and painting 20 years after renewal, renewal or a more effective repair method should be chosen for the maintenance of pre-tensioned PC bridges affected by

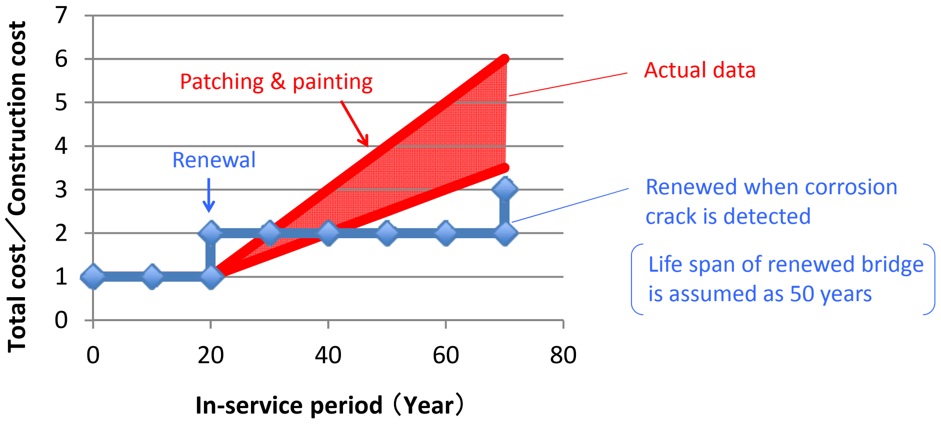


Figure 10. Simplified LCC model for a pre-tensioned PC bridge

chloride-induced deterioration.

Figure 11 compares patching/painting and renewal in terms of LCC for a post-tensioned PC bridge. Based on actual data, chloride deterioration is assumed to start 20 years after construction. If the bridge is renewed when corrosion cracking is detected, the total cost becomes similar to that of patching repair. As residual strength is reduced if patching repair is repeated several times, the bridge should be renewed within several decades when such repair is applied. As a result, the total cost of patching and painting is higher than that of renewal. Replacement to create a highly durable bridge reduces LCC in the long run because this durability will account for only a small percentage of the construction cost. Ideally, post-tensioned PC bridges should be replaced as soon as possible. Although renewal places a heavy cost burden on the administrator, it should be implemented before residual strength is significantly reduced, i.e., within several decades.

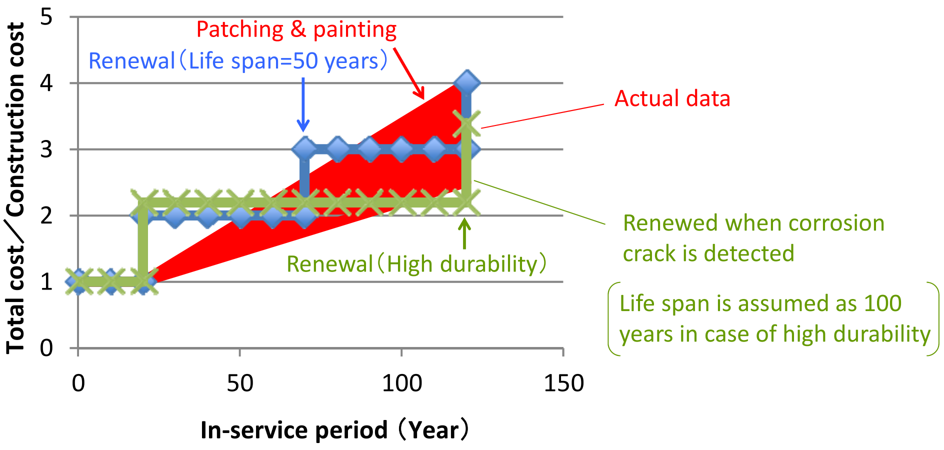


Figure 11. Simplified LCC model for a post-tensioned PC bridge

CONCLUSIONS

Analysis of data on the construction and repair of bridges on national routes in Japan clarified that distance from the coast strongly influences the intensity of salt attack. Surveying of actual LCC for bridges affected by chloride-induced deterioration showed that patching and painting repair work is not effective at all because it does not prevent further deterioration of concrete structures. Only the cathodic protection method was found to be effective in preventing further deterioration, and should be adopted in the maintenance of concrete bridges affected by chloride-induced deterioration. In certain cases, renewal may be the most economical option.

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