Implementing Innovative Ideas in Structural Engineering and Project Management
Edited by Saha, S., Zhang, Y., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-1-7

ANALYSIS OF DETERIORATION IN REINFORCED CONCRETE BRIDGE GIRDERS DAMAGED BY CHLORIDE DETERIORATION AND FATIGUE

H. HONDA, T. SHIMOZATO, and Y. ARIZUMI

Dept of Engineering, Ryukyu University, Okinawa, Japan

The subject of this research was a concrete T-girder bridge which had been exposed for 40 years to the sub-tropical archipelago environment off the east coast of Okinawa, with large amounts of windblown salt, high temperatures and high humidity, a harsh environment for salt damage and steel corrosion. It had suffered damage in the forms of 1) concrete spalling due to reinforcing bar corrosion, 2) internal loss of cross section and severance in internal reinforcing bars, and was therefore removed. Various tests and inspections were applied to analyze the state of deterioration of a real salt-damaged bridge, with the aim of providing technical reference material of use in formulating appropriate maintenance management methods. Distant visual inspection was performed prior to removal of the girder. After the removal, close visual inspection and non-distractive inspections were performed. Compressive strength, elastic modulus and chloride ion content of the concrete were measured. Corrosion of reinforcing bar was observed after chipping the concrete. Chloride-induced deterioration inside the concrete and competence of non-destructive inspection for the deterioration were studied. Static loading test and fatigue-test were performed.

Keywords: Fatigue loading test, Steel bar corrosion, Reinforced concrete.

1 INTRODUCTION

There are approximately 670,000 bridges in Japan, and their construction was particularly concentrated between the second half of the 1950s and the 1980s, which included the high economic growth period. In recent years there have been cases of collapses among that group of bridges, due to aging com-pounded with inadequate maintenance and salt damage. There is concern that this kind of severe safety-related problem will become much more pronounced, with a concentration of bridges coming due for large-scale repairs and reinforcement, or re-placement. This situation will make the maintenance management of bridges increasingly important in future. On the other hand, the socioeconomic situation prompts increasingly harsh calls for reduction in public works investment, so there is a need for efficient maintenance management.

The subject of this research was a concrete T-girder bridge that had been exposed for 40 years to the sub-tropical archipelago environment of Okinawa, with large amounts of windblown salt, high temperatures and high humidity, a harsh environment for salt damage and steel corrosion. It had suffered damage in the forms of 1) concrete spalling due to reinforcing bar corrosion, 2) internal loss of cross section and severance in internal reinforcing bars, and was therefore removed (it is therefore referred to below as “the removed bridge”). Various tests and inspections were applied to analyze the state of deterioration of a real salt-damaged bridge, with the aim of providing technical reference material of use in formulating appropriate maintenance management methods.

In this paper, we performed external visual inspections, materials tests and fatigue loading tests to check the state of scaling and other internal concrete defects caused by reinforcing bars corroded by salt damage in the removed bridge, and analyzed the state of chloride-induced deterioration.

2 SUMMARY OF INVESTIGATION OF THE REMOVED BRIDGE

The removed bridge is a steel-reinforced concrete T-girder bridge with three continuous spans, built in 1972. It was constructed on the east coast of the main island of Okinawa, in a tidal river section approximately 150 m upstream from the mouth, facing the Pacific Ocean. As such, it was exposed to a harsh chloride attack environment, in which it was directly splashed with seawater during typhoons, strong winds from the southeast, and some other conditions, for around 40 years.

Figure 1 is a structural summary of the removed bridge. The bridge was 25.0 m long, with five main girders and sidewalks on both sides. The steel used was deformed reinforcing bar, and the design standard strength of the concrete, judging by the period of construction, is thought to have been 21 N/mm2. The bridge remained in use as a bridge for the old road, after a new bridge was built in 1987 to carry a bypass. In 2001, an investigation and tests, including external visual inspection and compression strength tests, were conducted to find the state of chloride-induced deterioration. Since that time, there have been reports of severe damage to the bridge, including reinforcing bar corrosion, and concrete scaling and spalling. The bridge was taken out of service from that time, and the decision was taken in 2011 to remove it.

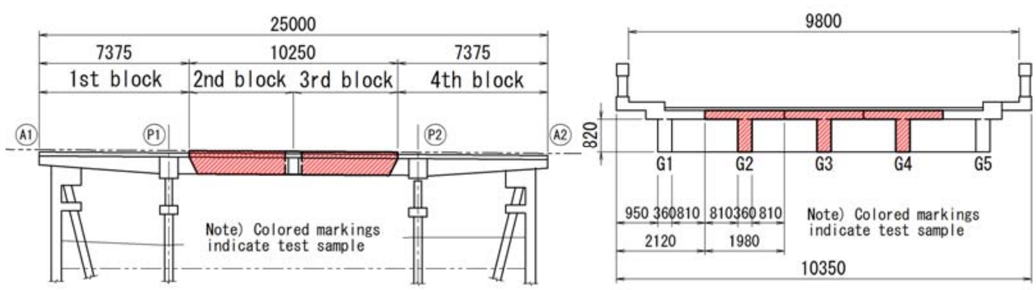

Figure 1. Structural summary of the removed bridge.

This research took parts of the main girders of the removed bridge as test samples, and performed various tests that can be performed on a real bridge. That is to say, a distant external visual inspection was performed before removal of the bridge, to grasp the state of deterioration of the bridge in situ. After the bridge was removed to a yard, it was subjected a detailed examination, including close external visual inspection, chloride ion content testing, fatigue loading testing, and non-destructive testing (before disassembly testing).

3 RESULTS OF A DETAILED SURVEY OF THE REMOVED BRIDGE

Of the five main girders, the test samples were taken from the center spans of the inner three beams, excluding the outer beams that carried sidewalks. For reasons of transportation after removal, the central spans only were divided into two, making a total of six test samples. The main girder numbering took G1 as the first girder on the sea side (Figure 1), and the test sample numbering took the main girder numbers and block names, such that the sea-side girder at the starting point was G202, and the mountain-side girder at the end point was G403.

3.1 Results of Close External Visual Inspection of the Removed Bridge

The results of the close external visual inspection of the test samples are stated below.

- The concrete was observed to exhibit cracks, scaling and spalling, and the specific extent of damage was confirmed in areas such as width of cracks and extent of scaling.
- In the reinforcing bars, corrosion, loss of cross section, stirrup fractures, and the amount of reinforcing bar corrosion were observed.
- It was not possible to observe any major difference in damage between the second and third blocks, which were cut out as test samples, and girders G2, G3, and G4.
- On the undersides of the main girders, cover concrete had spalled off, leaving the main reinforcing bars exposed and severely corroded. On the sides, spalling had not gone beyond areas around the main reinforcing bars.
- There was extensive scaling accompanied by cracking on the sea side of the main girder, exposing main reinforcing bars as far as the second layer, resulting in extreme corrosion. On the mountain side, only the lowest layer of reinforcing bar was affected.

The types and tendencies of damage observed in the close visual inspection of the test samples, and in the distant visual inspection of the bridge, in situ, were the same.

Next, Figure 2 shows the cross section of girder G2 close to the sea side, and Figure 3 is a diagram of cracking in main girders. The net cover over the main reinforcing bars was 54 mm on the underside and 69 mm on the sides, so the underside had the least cover. Cracking on the sea side of test sample G202 penetrated to the web face close to the second layer of main reinforcing bar, but had not advanced above that (Figure 3c). The cut surface at the midpoint between supports had some remaining cover concrete, with cracking observed to penetrate from the lowest main reinforcing bar layer, pass close to the second layer of main reinforcing bar, and extend to the surface. Thus, cracking had not originated from the second layer of reinforcing bars.

Cracking on the sea side of test sample G203 penetrated to the web face close to the main reinforcing bars, and to the surface close to the center of the web (Figure 3d). Thus, close to the main reinforcing bar, damage had penetrated from the lowest layer of main reinforcing bars to the second layer, and advanced gradually from the depth of cover over the stirrups at the center of the web to the surface. The net cover from the sides to reinforcing bars was around 85 mm in test sample G202, but only around 65 mm in G203, in a position 20 mm thinner.

a) Test sample G202 (sea side). b) Test sample G203 (sea side).

Figure 2. State of damage in girder G2 (sea side).

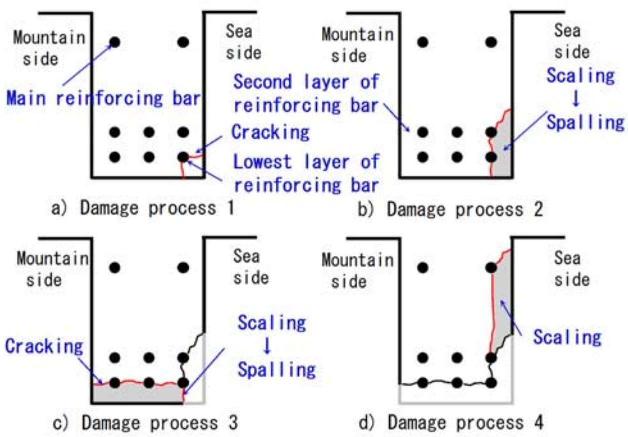

Figure 3. Cracking damage process in main girders.

Figure 4. Loading test device.

From the above, the state of deterioration can be illustrated as in Figure 3 for the undersides and sides of main girders, and for the sea sides and mountain sides, in which different damage patterns were observed. The following characteristics of chloride-induced deterioration can be inferred.

- Corrosion and expansion from the lowest layer of main reinforcing bars on the sea side caused cracking, and vertical cracks had extended on surfaces with thinner cover. (Figure 3a)
- Reinforcing bar corrosion advanced further due to windblown salt, and cracking extended from the second layer of main reinforcing bars to the web.
- Cover concrete on the sides spalled off (Figure 3b) and main reinforcing bar on the mountain side corroded due to contact with windblown salt. Cover concrete spalled off the underside. (Figure 3c)

- On the sea side, corrosion of the stirrups caused cracking to advance onto the upper web; there was scaling of the cover concrete. (Figure 3d)

3.2 Results of Loading Test of the Removed Bridge

Loading test (Figure 4) is a one-point concentrated load of simple beam of span length 4,100 mm. The basic load was set to 140 kN than impact and wheel load. In order to understand the current situation and the deterioration progress of test sample G202, static loading test by basic load was carried out after the fatigue loading test.

3.2.1 *Displacement - number of cycles*

Figure 5 shows the relationship between displacement and loading number of times. As Figure 5 clearly shows, displacement is increased due to an increase in fatigue loading times and when fatigue loading limit load is increased from 140 kN to 200 kN, displacement of the static loading test was greatly increased. However, when fatigue loading limit load is increased from 200kN to 250 kN, only displacement of 250 kN has increased significantly.

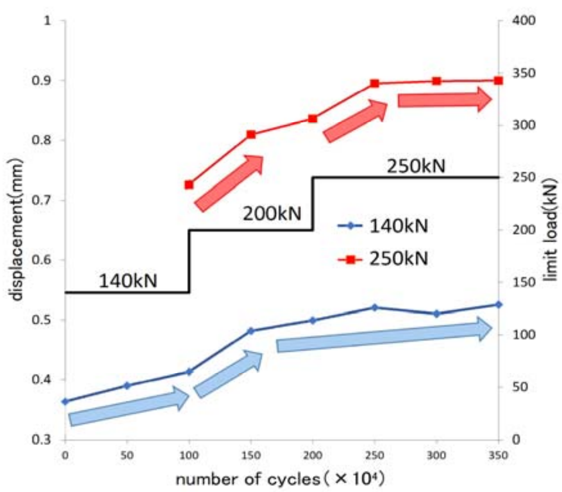

Figure 5. Displacement - number of cycles relationships.

3.2.2 *Reinforcing bars strain*

Figure 6 shows reinforcing bars strain after 3.5 million times loading. In addition, for comparison of the state of deterioration and reinforcing bars strain, photos of test sample G202 is to be displayed. As Figure 6 shows, reinforcing bar 12 of the mountain side was one point concentrated load loading state of simple beam. Other reinforcing bars did not show a tendency of the “reinforcing bar 12”. Reason as, reinforcing bar 12 that remain of side of the cover concrete are integrated concrete and reinforcing bars. The state of deterioration, such as cracks and reinforcing bars strain is not related.

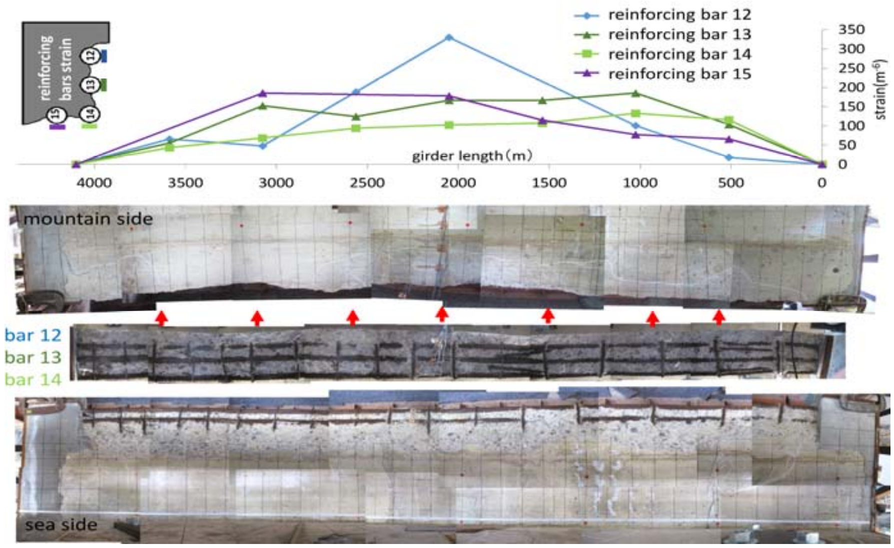

Figure 6. Reinforcing bars strain and the state of deterioration.

4 SUMMARY AND CONCLUSIONS

The main conclusions reached by this research were as follows.

- Between the undersides and sides of main girders, and between the sea sides and mountain sides, in which there were different damage patterns, it could be observed from the cut and disassembled surfaces of the test girders that the state of chloride-induced deterioration close to the main girder undersides exhibited corrosion and cracking at the lowest level of main reinforcing bars on the sea side. This damage extended to the second layer of main reinforcing bars, and caused spalling of cover concrete.
- The displacement confirmed a tendency to increase when increasing the loading by a number of times. However, displacement was greatly affected by the upper limit load than the loading number of times.
- Reinforcing bars strain tended different from the difference of anchorage. The state of deterioration was difficult to determine by observation only.

Thus the various inspections and tests on a real steel-reinforced concrete T-girder bridge that had been exposed to a harsh salt damage environment indicated the characteristics of chloride-induced deterioration, and succeeded in obtaining basic reference material for diagnosing deterioration in salt-damaged bridges.

References

Honda, H., Simozato, T., and Arizumi, Y., Analysis of the degree of deterioration in reinforced concrete bridge girders damaged by chloride induced, deterioration, and application of various non-destructive inspections, *Journal of Structural Engineering*, JSCE, 2013.