SMART FRP USAGE FOR PREVENTION IN STEEL GIRDER BRIDGES AGAINST CHLORIDE ATTACK

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Abstract

This paper mentions the corrosion progress profile of the steel plate girder bridges under chloride attack and a rational method that prevents the attack by using FRP plates smartly. At first, it is confirmed by the laboratory tests and the bridge monitoring that the steel corrosions are promoted remarkably by existing of the surface chloride contents. The wind tunnel tests are also performed in order to confirm the wind flow in the inside of the bridge structure. From the monitoring and the wind-tunnel-testing, the corrosion damage parts of the bridge girders and the transfer path of the aerosol chloride particles carried by wind between the girders become clear. Based on the clarified results, a construction measure to protect the girder system from the corrosion damage by closing the bridge cross section between the girders with FRP plates is proposed. Moreover, the FRP plates can be used as the inspection way. This smart FRP usage is applied to a steel girder bridge erected in Okinawa, Japan. The monitoring on the prevention effect obtained by the FRP cover plate is continued.

Keywords: FRP application, steel girder bridge, corrosion, monitoring, chloride attack

1. Introduction

Today, demand for decreasing life cycle costs of bridges is the most strict of all major infrastructures. Repaints of steel bridges occupy the most of their maintenance expenses, so that the interval extensions of the repaints are desired strongly. The clarification of the corrosion profile of steel bridges may bring a rational suggestion for the extension measure of the repainting interval.

The corrosion progress of steel structures is affected by the environmental parameters of humidity, temperature and chloride. Especially, the amount of chlorides contained in the air is required to determine how corrosive an environment will be [1]. The bridge structures nearby seashores are damaged severely by the chloride attacks [2], [3].

Splashing of the salt waters over breakwaters at seashores generates aerosol chlorides as shown in **Fig.1**. The aerosol chloride particles are transported around the girders in the vicinity of the seashore by the wind flow. Since the kinematic behaviour of the wind depends on the parts of the girders, the chloride contents attached to the surfaces of the girder are different from those parts. The accumulation of the surface chlorides is also different. It is practically needed to clarify the wind vortex between the bridge girders and the profile of the surface chlorides.

Figure 1. Splashing of salt waters.

Before discussing steel girder bridges versus chloride attacks, this paper at first examines the results obtained from the rapid corrosion tests performed in the laboratory using the temperature and humidity cabinet that is able to keep the inside temperature and humidity under control. The effect of chlorides on steel corrosions is investigated by the test. The test result shows that the steel corrosions are promoted remarkably by existing of the surface chloride ions. Next, this paper presents monitoring data during over one year for a steel plate girder bridge exposed nearby the seashore in Okinawa, which is the semi-tropical island in Japan. The data contain the corrosion profile of the girders and the amount of aerosol chloride ions attached to the girder surfaces carried by wind. From the monitoring, the corrosion damage profile becomes clear. The monitoring on the amounts of the aerosol chlorides enables to estimate the transfer path of the wind flow between the girders. In order to confirm the wind flow between the girders, the wind tunnel experiments are also performed using the plate girder model. This paper concludes that the prevention of the chloride accumulation is most effective approach in order to protect the steel bridge girders from the corrosion damage. Finally, based on the research result, a rational measure to prevent from the damage by closing between girders with FRP plates is proposed and applied to a steel girder bridge erected in Okinawa. The structural design and construction of the FRP plates were based on the *Guidelines for Design and Construction of FRP Footbridges* [4]. The monitoring on the confirmation of the prevention effect by the FRP plate closing between the girders is continued.

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2. Rapid corrosion test

2.1 Specimen and Method

The temperature and humidity cabinet shown in **Fig.2** is used for the rapid corrosion tests. The cabinet used for the test is able to keep the inside temperature and humidity under control. The inside temperature and humidity of the cabinet are controlled by cyclical repetition of wet and dry during the test period. One cycle is composed by 9 hours, in which first 3 hours of wet condition (*temperature 35 , humidity 90%*) and following 6 hours of dry condition (*temperature 40 , humidity 50%*). Mild

Figure 2.Test cabinet.

steel pieces (*50 mm×50 mm×2mm*) are used as the test coupons. The chloride contents are given to the coupon surfaces by coating salt waters with a certain time-interval, wherein the salt waters are coated by hand brushing. The consistency of the salt waters is changed in each test coupon such as 0%, 3% and 5%, respectively. Each coupon is kept during 24 days (the total of 64 cycles) in the cabinet and its corrosion thickness is measured every 4, 5, 6, 7, 8, 16 and 24 days by the electromagnetic thickness gage shown in **Fig.3**.

2.2 **Test Results**

The test results of the corrosion thicknesses with various values of surface chlorides are presented as a function of the test period as shown in **Fig.4**. In the figure, the results of the corrosion thicknesses of the coupon without the chloride are also shown for comparison purpose. From the figure, it is clear that the steel corrosions are promoted remarkably by existing of the chlorides. The test results also show that the corrosion of the coupon with the chlorides increases as increase of the test period. **Fig.5** is a photograph of the corrosion aspect of each coupon after testing. It can be seen clearly from the test results that the steel corrosions are promoted more remarkably as increase of the chloride consistency.

Figure 3. Thickness gage.

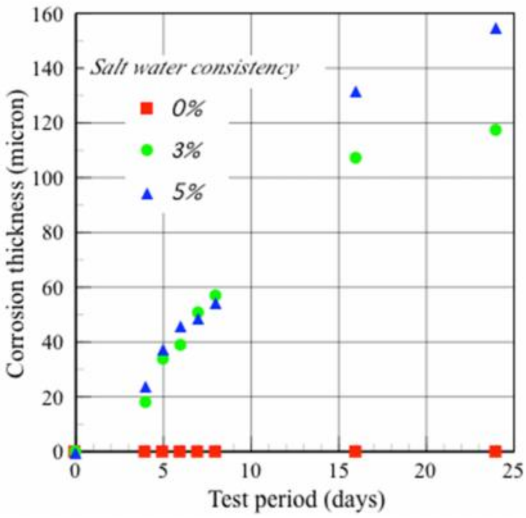


Figure 4. Corrosion thicknesses vs. test periods.

(a) 0% of salt water

(b) 3%c of salt water

(c) 5% of salt water

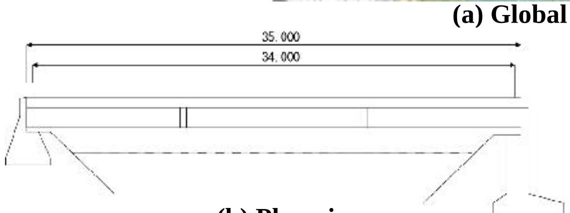
Figure 5. Corrosion aspects.

3. Corrosion profile of a steel plate girder bridge

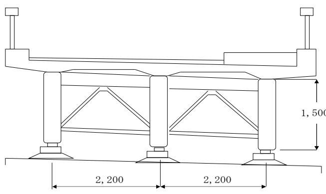
3.1 Monitor methodology

Bridge corrosion profile is investigated using a monitor plate girder bridge fabricated from weathering steel in unpainted condition and exposed at the site of 50m from the seashore in Okinawa, the semi-tropical island in Japan, during 28 years shown in **Fig.6**. The aerosol chlorides attached to the girder surfaces are investigated. Generally, out side surfaces of out side girders in bridge structure are washed by rainwater, so that the chloride contents attached to the out side surfaces are remarkably smaller than those to the inside surfaces [2], [3]. To determine and monitor the chloride levels in the inside atmosphere of the bridge structure, the atmospheric chloride gauze (surgical gauze) is placed at each part of the girders in the inside of the monitor bridge under the bridge slab that served to minimize the effect of dilution from rainfall shown in **Fig.7**. The chloride gauze measurements are conducted in accordance with the Japan Industrial Standards (JIS Z 2381) method. The principle behind the chloride gauze relies on a rain-protected textile surface, with a known area, being exposed for a specified duration. The concrete slab of the monitor bridge serves to minimize the effect of dilution from rainfall. The amount of chloride deposition is determined by chemical analysis. The JIS Z 2381 provides common caustic titration to be conducted on the sample to determine the chloride content. From the results of this analysis, the chloride deposition rate is calculated, expressed in milligrams of NaCl per square decimeter per day [mdd=mg/(dm^2/day)]. The corrosion profile of the plate girder is estimated by the corrosion thickness. The thickness is measured with ultrasonic thickness meter.

(a) Global view



(b) Plan view



(c) Section view

Figure 6. Monitoring bridge

Figure 7. Atmospheric chloride gaze.

3.2 Test results

Typical results of the amounts of the aerosol chlorides measured from December to June when strong wind blows around the bridge site are shown in **Fig.8**. It can be seen from the figure that the amount of the aerosol chloride in the inside of the bridge decreases in increasing order from 1 to 4. This result enables to estimate the transfer path of the wind flow between the girders in the inside of the bridge. Namely, the wind might flow about anticlockwise as shown in the inset of **Fig.8.** The corrosion thicknesses of the land side surface of G1 girder and those of the sea side surface of G3 girder, which are measured typically, are shown in **Fig.9**. From the figure, it is clear that the upper part at the land side surface of G1 girder and the under part at sea side surface of G3 girder are rusted more severely. This corrosion profile shows that the corrosion of the part where the chloride is attached more is heavier.

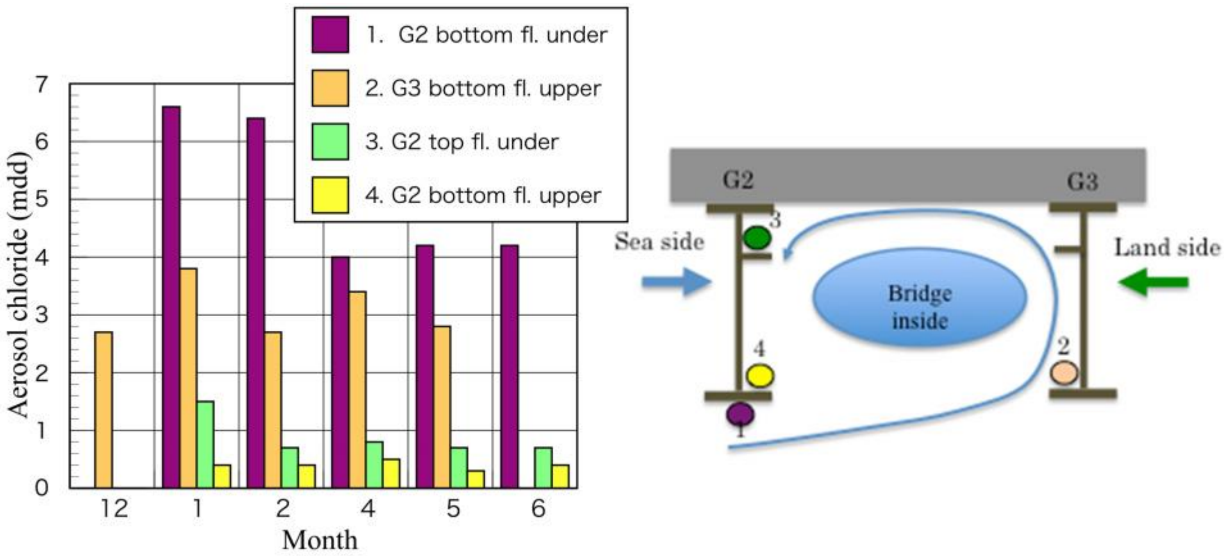
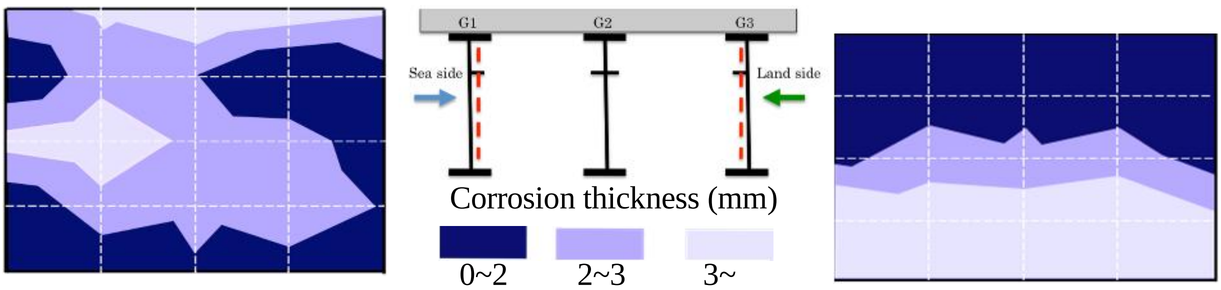


Figure 8. Amounts of aerosol chlorides measured.



(a) Land side of G1 girder

(b) Sea side of G3 girder

Figure 9. Corrosion thicknesses measured

4. Wind tunnel experiments

4.1 Facility and girder model

The wind tunnel tests are performed in order to confirm the wind flow in the inside of the bridge structure characterized by the kinematic behaviour of the wind vortexes surrounding the girders as shown in **Fig.10**. In the tests, oil mists function as the aerosol chloride particles. The wind tunnel used is an open circuit, blows down *3.5m* long and has a test section *1.0 m* wide and *1.0 m* high. Considering the wind tunnel size, the geometric scale of *1:15* model of the monitor bridge structure is selected for the wind tunnel tests. The model is manufactured of acrylic resin plates. The model has three girders with *100 mm* of the girder depth, *133mm* of distance between the adjacent girders, and *500 mm* of the girder length. The wind speed of the wind tunnel ranges between *5* and *15 m/sec* that correspond to *0.3* and *5 m/sec* of the real wind speeds blowing to the monitor bridge girders, normally. The wind attack of the perpendicular angle to the web plate is considered.

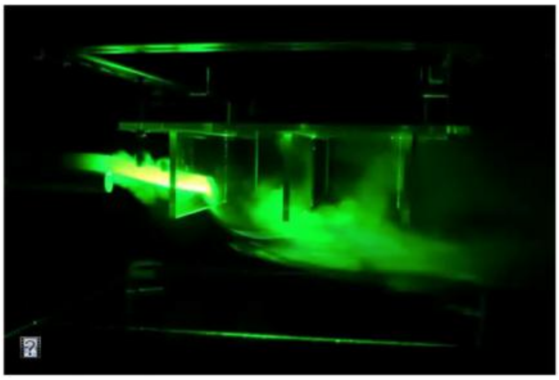


Figure 10. State of wind tunnel testing

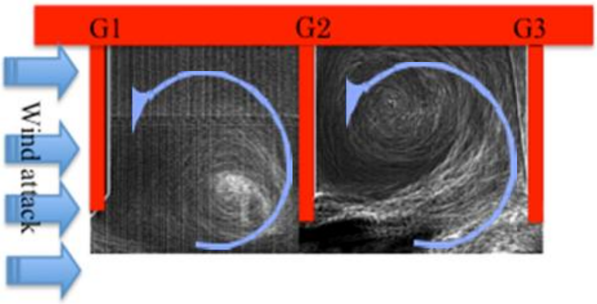


Figure 11. Wind vortexes formed

4.2 Test results

Fig.11 is a photograph of typical wind vortexes in the box cells between the main girders, which is took by a high speed camera (*2000 flames/sec*). The wind profile can be seen from the test, i.e., the wind vortexes generate first at the bottom of the windward girder of the box cell that receives directly the wind attack and continuously engulf upward in the inside of the cell. Therefore, the aerosol chlorides in the wind flow are transported in the inside of the cross section of the bridge structure by the turbulence of the wind that is represented by the vertical eddy diffusivity according to the wind profile. This profile is the same as the transfer path of the wind flow in the inside of the bridge estimated by the monitor results of the aerosol chlorides as shown in the inset of **Fig. 8.** It can be estimated physically that the amount of the aerosol chlorides attached to the girder surfaces is different from the parts of the girders. Namely, according to the transportation of the vortexes, the chloride amount decreases in order of the out side surface of the windward girder web plate, the bottom flange of the windward girder, the inside of the leeward girder and the inside of the windward girder.

5. Smart usage of FRP plate for bridge maintenance

5.1 Concept of smart usage

From the research results obtained, it can be seen clearly that the steel corrosions are promoted remarkably by existing of the surface chlorides. Furthermore it becomes clear that the aerosol chlorides are transported in the inside of the cross section of the bridge structure by the wind turbulence represented by the vertical eddy diffusivity as shown in **Fig.11**. The chloride contents attached to the out side surfaces of out side girders in the structure are remarkably smaller than those to the inside surfaces because of washing by rainwater. Therefore, it is essential to shut off the incursion of the wind vortexes into the inside of the structure. Considering this essential demand, as a rational measure to prevent the corrosion damage, it is proposed to prevent the incursion of the wind vortexes into the inside by closing between the girders with FRP cover plate shown in **Fig.12**. The FRP cover plate is also able to use as the inspection passage, so that it is convenient provision for inspecting the structure. These are very smart usages of FRP plate for the bridge maintenance.

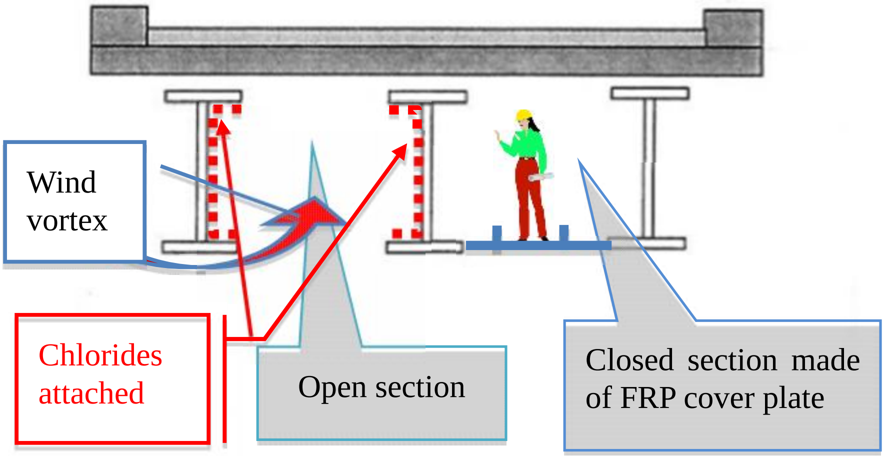
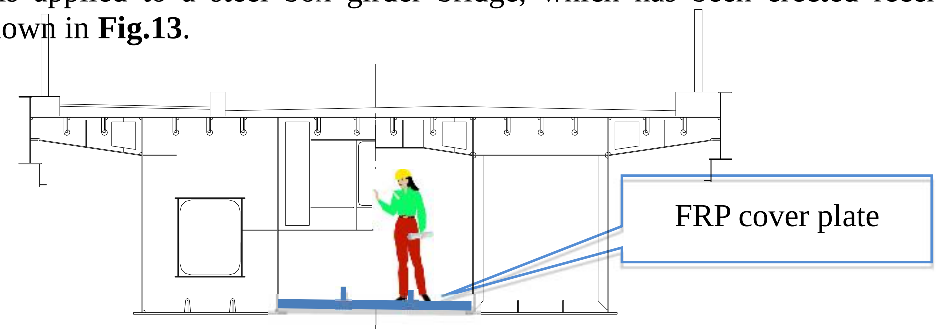


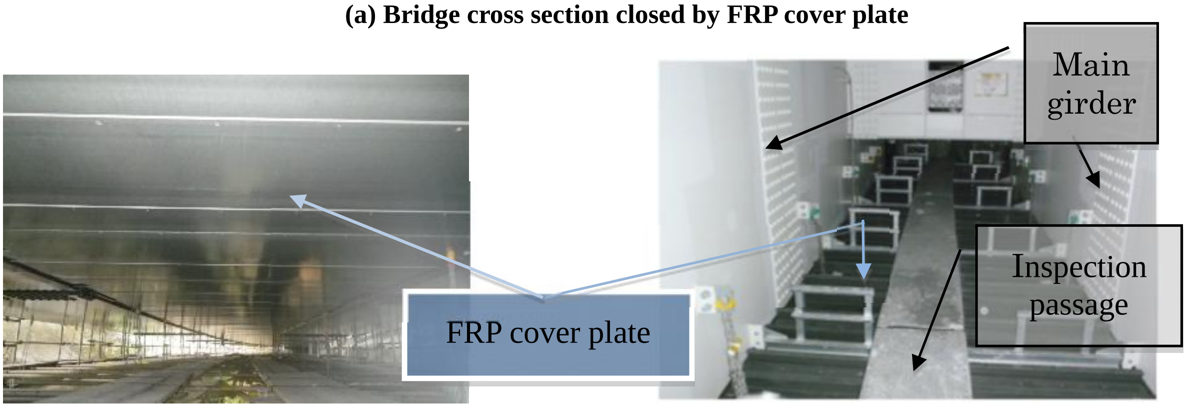
Figure 12. Smart usage of FRP cover plate for bridge maintenance

5.2 Application of FRP cover plate

The provision of the FRP cover plate (plate thickness = 6mm, flange thickness of stiffener rib= 10mm) is applied to a steel box girder bridge, which has been erected recently in Okinawa, as shown in **Fig.13**.



(a) Bridge cross section closed by FRP cover plate



(a) Outside bottom view **(b) Inside view**

Figure 13. FRP cover plate applied to a steel box girder bridge

To determine and monitor the chloride levels in the bridge cross section covered by the FRP plate, the atmospheric chloride gazes are placed in the various portions (*0m, 10m and 30m* from the girder edge) of the inside of the bridge section shown by blue marks in **Fig.14** and **Fig.15**. For comparison purpose, the atmospheric chloride gaze is also placed at the location of *0m* of the out side shown by the red mark in **Fig.14**. Coupons of bare metal specimens are also placed at the each location of the inside as shown in **Fig.15**. The coupons help standardize the baseline corrosion of the each area within the bridge cross section. Results of the amounts of the aerosol chlorides measured during one month from middle of June 2011 are shown in **Fig.14**. It can be seen clearly that the protection effect against the chloride attack is remarkable. The monitoring on the confirmation of the prevention effect by the FRP cover plate is continued.

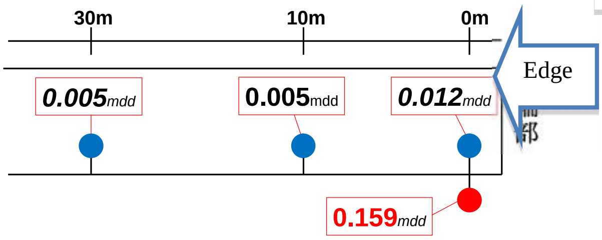


Figure 14. Chloride amounts measured

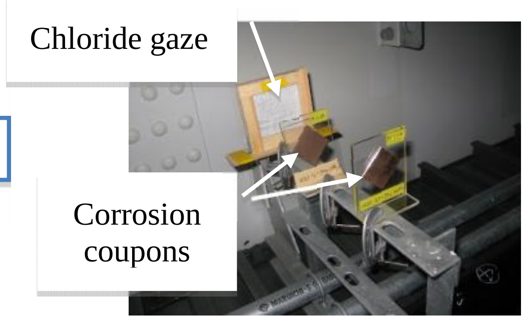


Figure 15. Measuring sensors

6. Summary and Conclusions

It is clarified in this study that the corrosions of surfaces of steel bridge girders in the inside of the bridge cross section are more sever than those in the out side, because of the aerosol chlorides attached to the girder surfaces of the inside of the bridge section, which are brought by the wind vortexes, and not washed by the rainwater. Considering with this result, a smart usage of FRP plate for maintenance of steel girder bridge is proposed and its effect is confirmed partially.

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