Inspection and evaluation strategy for uncoated weathering steel bridges

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Abstract. Uncoated weathering steel can significantly reduce the life cycle cost of bridges and the difficulty of maintenance during operation. However, weathering steel is not a maintenance-free material. Design and construction errors, topography, de-icing salt and other factors are likely to cause severe corrosion of weathering steel. Therefore, effective inspection and maintenance planning is essential to ensure that weathering steel bridges can reach expected service life. Weathering steel bridges must be regularly inspected to check the corrosion of weathering steel in important parts, and evaluations shall be made to develop maintenance plans. Previous investigations show that the appearance of weathering steel’s rust layer can effectively judge its stability. Therefore, the corrosion condition of weathering steel can be judged by different rating of the appearance of the rust layer. Meanwhile, corresponding maintenance measures will be formulated.

1. Introduction

Weathering steel refers to the addition of a small number of alloying elements such as copper, phosphorus, cadmium and nickel to the steel. During the atmospheric corrosion process, the steel forms a dense protective rust layer above the surface and thus has good atmospheric corrosion resistance. In country atmosphere and general industrial atmosphere, weathering steel can be used without coating on the bridge, which greatly reduces the cost of painting the bridge and its environmental pollution, and also reduces the cost of supplemental coating and maintenance during the operation period [1].

At present, the goal of using weathering steel for bridges is that there is no need to paint during the operation period and only simple maintenance is required.

However, weathering steel is not a maintenance-free steel. Previous studies[2] show that that the imperfections in design and construction make it easy for some structural parts such as supports, expansion joints, and beam ends to accumulate moisture, and it is impossible to form a dense protective rust layer in the water accumulation area, leading to severe corrosion and compromises structural safety.

In addition, even if the atmosphere is designed suitable for the formation of protective rust layer, when the bridge structure is placed close to the soil or the mountain or the bridge is arranged side by side, the weathering steel surface is easily sputtered by moisture or salt. In winter, if the road surface is frozen and deicing salt is used for deicing, the beam body will be very seriously polluted. Therefore,
weathering steel bridges must be regularly inspected and evaluated, and appropriate maintenance strategies must be adopted, just as conventional Bridge.

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2. General Inspection

According to the characteristics of weathering steel, general inspection, condition assessment and corrosion monitoring of weathering steel bridges are required.

The general inspection of weather-resistant steel is similar to that of ordinary painted bridges. It is advisable to conduct the first periodic inspection in the second year after the completion of the weathering steel bridge; thereafter, regular inspections should be carried out at regular intervals at least every two years. General inspections should focus on the parts that are difficult to produce a protective rust layer, mainly the appearance of the rust layer above surface of the weathering steel, the expansion joints, the drainage system, and the corrosion of the joints.

The appearance of the rust layer above surface of the weathering steel can effectively show whether the oxide formed on the weathering steel is protective, and the appearance of the rust layer can be rated according to the color and texture of the rust layer oxide.

For the evaluation of the appearance of rust layer, color, texture, roughness, and thickness of the rust layer can be used as indicators[3], and the most stable rust layer appearance is rated as 5, and the most unstable rust layer appearance is rated as 1.

Among them, the appearance of the rating 1 occurs layered peeling, and it is required to analyze the cause of corrosion and repair it. The appearance of rating 2 occurs flaky peeling, which needs further follow-up observation. The rating of grade 3~5 is in good condition and no measures need to be taken. Therefore, Level 2 or Level 3 is important for judging whether maintenance is repaired. Refer to Table 1 and Table 2 for the evaluation grade of rust appearance of weathering steel.

| Condition       | Rating | Appearance                                                                 | Thickness       |
|-----------------|--------|---------------------------------------------------------------------------|-----------------|
| Normal          | 5      | 1) Tone is bright and the color is orange and yellow-brown.                | Below 200μm     |
|                 |        | 2) There are almost no bumps and rust particles are very small.            |                 |
|                 |        | 3) The amount of rust is little and maximum particle size is less than 1 mm.|                 |
| Normal          | 4      | 1) The tone is dark brown and the color is uneven.                        | Below 400μm     |
|                 |        | 2) There are almost no bumps and the rust particles are fine and uniform.  |                 |
|                 |        | 3) The amount of rust is more, and the maximum particle size is less than 1 mm.|                 |
| Normal          | 3      | 1) The tone is from dark brown to brown and the color is uneven.          | Below 400μm     |
|                 |        | 2) There are slightly bumps and rust particles are uneven.                |                 |
|                 |        | 3) The amount of rust is large, and the maximum particle size is about 1~5 mm.|                 |
| Observation     | 2      | 1) The tone is from dark brown to brown and the color is uneven.          | Above 400μm,    |
| required        |        | 2) There are large bumps and rust particles are rough and scaly.        | below 800μm     |
|                 |        | 3) The amount of rust is large and the maximum particle size is about 5~25 mm.|                 |
| Abnormal        | 1      | 1) There are various local tones                                          | Above 800μm     |
|                 |        | 2) There are large bumps and rust layer occurs layered peeling           |                 |
Table 2. Rust layer rating appearance reference map

| Rating 5 | Rating 4 | Rating 3 |
|---------|---------|---------|
| ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) |
| Rating 2 | Rating 1 |
| ![Image](image4.png) | ![Image](image5.png) |

It is important to note that the visual appearance of the weathering steel surface is deceptive. Therefore, when inspecting the surface rust layer, the oxide film of the rust layer must be tapped with a hammer and vigorously brushed with a steel wire to determine whether the oxide film is still attached to the lower steel substrate, or whether it is just in the form of particles, scales or layers to make an accurate rating[4].

3. Condition Assessment
The evaluation method of weathering steel should be based on the change of the appearance of the rust layer to grasp the corrosion condition of the rust layer and predict structural performance. The appearance evaluation of the weathering steel rust layer should be based on visual inspection of the appearance, taking the thickness measurement as a reference and supplementing the image data. The evaluation process for unpainted weathering steel bridges is shown in Figure 1.

![Diagram](image6.png)

Figure 1. Evaluation process for unpainted weathering steel bridges
4. Corrosion Monitoring

When the rust appearance level of the weathering steel is evaluated as Grade 1 or 2, corrosion monitoring is required to measure the thickness of the weathering steel at the corrosion location. It is recommended that corrosion monitoring be performed at least every 6 years. During the first 10 years of exposure, the corrosion rate is usually higher and then reaches a lower steady state of corrosion. Therefore, at least 20 years of corrosion data needs to be measured, unless significant accidental section losses are found during this period. If the corrosion rate is found to be higher than the rate at which the initial corrosion allowance is based, the cause of the corrosion must be analyzed and repair measures shall be taken for corrosion locations.

Weathering steel corrosion monitoring should include the following steps[5]:

1) The structure monitoring should be based on the appearance, and whether the structural details are appropriate on the basis of considering the environmental conditions of the structure, the upper and lower parts shall be judged.

2) Use a micrometer and an ultrasonic instrument to measure the thickness of the bridge deck on the pier and the abutment, calculate the thickness reduction of the bridge, and evaluate the safety of the bridge from the perspective of the thickness of the bridge.

3) Use ultrasonic measurement to calculate the rust thickness and determine the condition of rust development. In general, when the rust thickness is small (less than 400 μm), it is considered good, while when the rust thickness is large (greater than 400 μm), it is judged poor.

4) It can be used to measure the amount, size, color, uniformity, and unevenness of rust particles by tape test, close-up photographing, and imaging.

5) Measure the salt attached to the surface of the steel as an indicator of corrosion.

6) Make a rust map and record the distribution of rust.

When measuring the thickness at corrosion location, the surface rust layer of the oxide film to the steel substrate shall be removed by blast cleaning at the selected location, the degree of corrosion and pitting shall be qualitatively determined, and section loss shall be measured with a caliper. Alternatively, the oxide of the etched surface can be ground and the cross-sectional loss measured with an ultrasonic thickness gauge.

Portable ultrasonic thickness gauges can be used to measure the actual thickness of steel. However, if the rust layer is still formed, the surface is rough and easy to remove by hand, thus obtaining an accurate reading can be a challenge. Therefore, it is also recommended to install a detachable weathering steel specimen to more accurately monitor the formation of the rust layer and measure the corrosion rate[2]. Install at least two sets of specimens at the main structural members on the weathering steel bridge. The test piece shall be cut from the weathering steel of the same composition used on the weathering steel bridge and subjected to the same surface treatment.

5. Conclusion

1) It has been investigated that in environment that the amount of flying salt is below 0.05mdd, when the appearance rating is between 3 and 5, that is, when there is no scale-like peeling corrosion and layered peeling corrosion, the change of corrosion reduction of weathering steel is considered that it won’t exceed 0.3 mm in 50 years and 0.5 mm in 100 years, which means the rust layer of the weathering steel is in good condition. This condition corresponds to the amount of corrosion reduction being 0.03 mm or less in the first year.

When the reference value is actually used, the amount of corrosion for 50 years and 100 years can be predicted based on the amount of corrosion in the first year and the following years. When the predicted value is lower than the allowable value, the rust layer is considered to be in good condition.

The prediction formula uses the linear regression extrapolation method of ASTM G101 [6]:

\[
\log C = \log A + B \log t
\]

Where: C is the amount of corrosion reduction in year t, t is the corrosion time (year),
A is the corrosion reduction of first year,
B is the slope of the double logarithmic curve

2) After 3 years without coating, when the appearance rating is 1 or 2, after 100 years, the average corrosion reduction of single-sided weathering steel is likely more than 1mm. When the rating of exposure is 3~5, whether the future rust layer can stabilize is still difficult to judge.

3) After 9 years without coating, when the appearance rating is 3~5, after 100 years, the average corrosion loss per side is supposed not more than 0.5mm. As long as the external environment does not change greatly, it can be considered the layer reaches a steady state.

4) When the change of the external environment is not conducive to the formation of stable rust layer, the change of the appearance of the rust layer will also accelerate. At this time, if the predicted thinning amount exceeds the estimated surplus in a certain period of time in the future, it must be repaired in time.

5) When the appearance rating is 1~2, that is, scaly peeling or even layer peeling occurs, it should be maintained and repaired immediately. Firstly, the cause of the abnormality should be excluded, and the external environment that continues to cause corrosion in the future should be removed or isolated. Secondly, the adhered salt should be removed by low-pressure water to reduce the content of surface soluble salt, and it should be washed regularly to improve the condition of the rust layer; The peripheral part shall be coated at the center of the abnormal part, and some preventive coating parts such as the end of the beam should be cleaned up in time regularly [6].

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