Steel bridge quality management and weathering steel application technologies in Japan

S. Horii & Y. Mishima
Japan Bridge Association, Minato-ku Nishishinbashi 1-16-1 ,Tokyo, Japan

M. Hashimoto
Japan Bridge Association, Minato-ku Nishishinbashi 1-16-1 ,Tokyo, Japan

ABSTRACT: Japan consists of several major islands and many small islands, and there are various geographical features such as plain, mountain, river and strait. And to develop traffic network, various types of bridges are constructed. Meanwhile, weathering steel has been available to the bridge engineering field for about 30 years. This paper reports steel bridge quality management and application technologies for weathering steel in Japan.

1 INTRODUCTION

Consisting of four main islands and a large number of smaller islands, Japan has a diverse range of geographical features, including plains, mountains, rivers and straits. Moreover, it has highly developed traffic networks in its urban areas. Due to the wide range of geographical features found in Japan, a variety of different types of bridges have been constructed there.

Over 60 short-span bridges in Japan have been in service for more than 100 years. Figure 1 shows an example of a bridge that was constructed over 120 years ago. In addition to short-span bridges, Japan also has many long-span bridges that span straits. The example shown in Figure 2 has been in service for more than 20 years without experiencing any serious problems. For infrastructure such as bridges, quality control is vitally important throughout the entire process, from the construction phase through to the maintenance phase. It is also essential that quality control results are documented to ensure traceability.

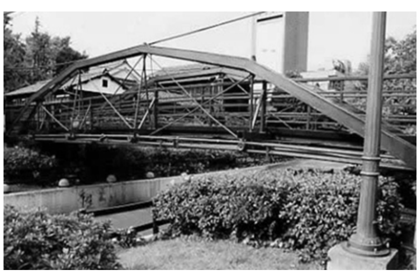


Figure 1. Hachiman Bridge (1890), Tokyo.

Figure 2. Kanmonkyo Bridge (1973), Yamaguchi Prefecture.

Meanwhile, in Japan, weathering steels have been available to the bridge engineering field for about 30 years. Weathering steels are used to minimize Life Cycle Cost for about 25% of bridges recently under construction, and unique technologies for weathering steels are applied to minimize their Life Cycle Cost.

This paper describes how quality management is conducted in Japan throughout the entire process of a steel bridge's fabrication and construction, and explains weathering steel application technologies in chapter 8.

2 MATERIAL MANAGEMENT

2.1 *Construction Workflow*

Figure 3 shows the workflow for the fabrication and construction of a steel bridge. Each process is conducted based strictly on the required specifications. Moreover, a system of double or mutual checking has been established to identify defects, with defective products being sent back to the previous stage in the fabrication process or to the supplier in order to ensure high quality management. Another important aspect of the workflow is that the results are documented so that the relevant details are available at a later stage.

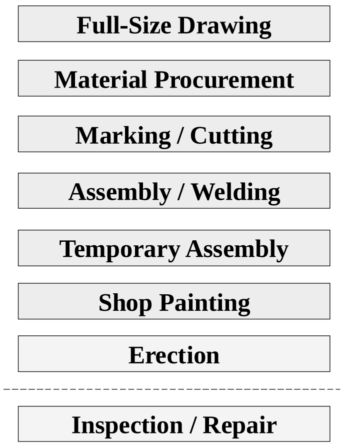


Figure 3. Construction workflow for a steel bridge

2.2 *Full-Size Drawings*

The full-size drawings used at the start of the fabrication process provide details such as the basic bridge geometry, the sub-structure locations, and the sizes of all of the materials to be used.

2.3 *3D-Model Generated by 3D-CAD System*

A 3D model is used for the fabrication process. The use of such a model is a recent development that makes it possible for the drawing work to be checked visually. The most important aspect of this stage is that data and information on the 3D model are documented. This enables the owner to inspect the data and confirm the details visually. After that, the owner and fabricator store the information.

2.4 *Material Procurement*

It is essential to confirm the validity of the inspection certificate (Fig. 4) in the material procurement process. Generated by the material supplier, this document indicates physical properties such as the material's size, chemical composition and strength. It is also important to conduct material tests such as tensile strength testing (Fig. 5) and V-notch testing (Fig. 6) to confirm whether the material plates have required strength. It is important to document these certificates for use during future maintenance.


検 査 証 明 書
INSPECTION CERTIFICATE

Figure 4. Inspection certificate.

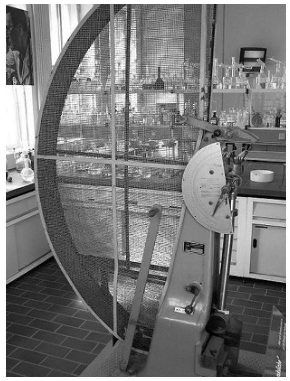


Figure 5. Tensile strength testing. Figure 6. V-Notch testing.

3 WELDING

3.1 *Types*

The assembly process is conducted following completion of the material inspection, after which the welding process is carried out. The welding procedure is dependent on factors such as the types of joints, and the quality of this procedure has a significant impact on the durability of the bridge. Japanese bridges have a service life of more than 100 years, because the appropriate welding types (e.g. groove welding and fillet welding) are applied to the appropriate places.

3.2 *Operation*

In preparation for the welding procedure, the gap between the plates is checked and preheating is applied. Interpass temperatures and the heat input are observed and controlled during the welding operation. Doing this helps not only to minimize any potential decline in quality, but also to improve the quality of the products.

3.3 *Non-Destructive Testing*

After completion of the welding procedure, non-destructive testing (NDT) is conducted to confirm the soundness and quality of the welds. There are several NDT methods available. Radiographic testing (Fig. 7) and ultrasonic testing are applicable of detecting embedded flaws, while magnetic particle testing (Fig. 8) and liquid penetrant testing can be employed to find surface welding defects. All of these testing methods highlight the extent of flaws and make them visible. The results of these tests are documented.

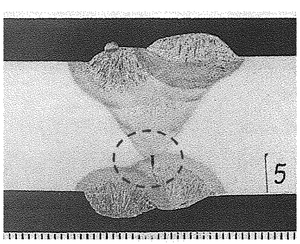
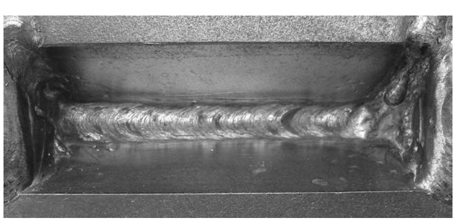
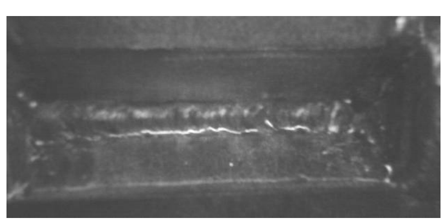


Figure 7. Radiographic testing.





a. Invisible. b. Visible.

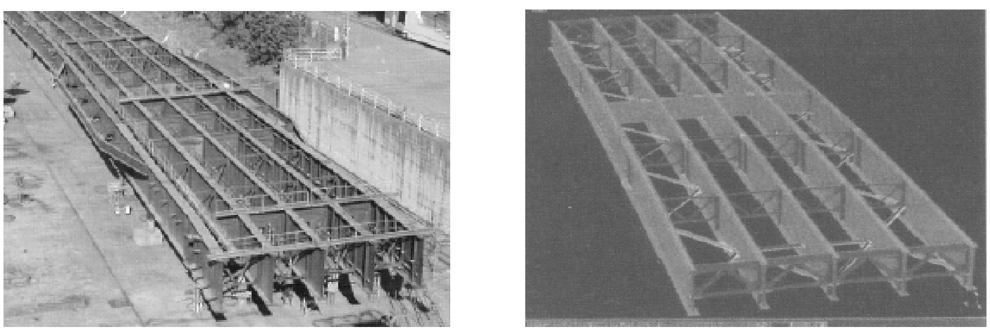
Figure 8. Magnetic particle testing.

Figure 9 shows the Tokyo Gate Bridge, which was constructed in 2012. One of the features of this bridge is that most of its members are connected by welding. Stringent quality control ensured that the bridge has highly durable connections and a smooth exterior.

Figure 9. Tokyo Gate Bridge (2012), Tokyo.

4 TEMPORARY ASSEMBLY

A final geometry check is conducted to confirm the fabrication tolerances after completion of the welding process and the NDT. The entire structure is then erected to the correct line and elevation in the fabrication shop (Fig. 10a). This is referred to as the temporary assembly. If a bridge is regarded as a simple structure, temporary assembly can be conducted in cyberspace by using computer simulation (Fig. 10b).



a. Fabrication shop. b. Computer simulation.
Figure 10. Temporary assembly.

5 SHOP PAINTING

5.1 *Blast Treatment*

Shop painting is conducted after completion of the temporary assembly. The steel has to be blasted prior to painting. Blast treatment on the steel surface improves the quality of the paint finish. As the surface profile influences adhesion between the steel and the paint, the steel surface is checked by performing a comparison with the blast specimen.

5.2 *Painting*

Bridges are usually spray painted, but narrow areas or material edges are painted by brush to obtain an appropriate paint thickness. In Japan, fluorine resin is generally used as the paint material due to its high durability. The use of this resin is said to lengthen a bridge's life-span by more than 40 years under normal conditions.

5.3 *Points to Consider*

The principal conditions that affect the application of paint are temperature and humidity. The air temperature affects the drying and curing times, and paint should not be applied when the steel surface is wet. These factors have to be checked before the painting begins and recorded on the product sheet. The thickness of each coating layer is measured at multiple points on the surface to ensure that a uniform paint thickness is obtained.

6 SITE JOINTS

6.1 *High Strength Bolts*

After they have been fabricated at the factory, the bridge members are transported to the construction site. They are then bolted together on site. High strength bolts that are controlled by torque are often used for bolted connections in Japan. As shown in Figure 11, when the spline of the bolt snaps off, an appropriate tensile force is applied.

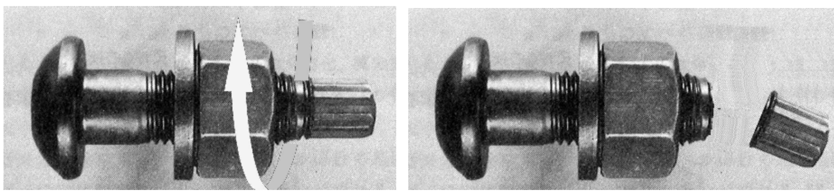


Figure 11. High strength bolt control.

6.2 *Operation*

This type of bolt has to be used on site in the condition it was received. Attention must be paid to factors such as storage and cleanliness. Joint work is never performed on rainy days, because rainwater could result in hidden corrosion inside the bolt hole.

7 MAINTENANCE

7.1 *Storage of Information*

Construction of the bridge is completed once the visual inspection has been completed by referring to the reports from the temporary assembly stage. For future maintenance, however, it is important even after completion to continue retaining relevant information, such as design report documents, drawings, fabrication information and test results. Most of these types of documents are stored in an electronic format nowadays.

7.2 *Inspections in Service Stage*

Once the bridge goes into service, several types of inspections, including ordinary inspections and periodic inspections, are conducted and repair work is undertaken as required. The inspection results are documented and used for reference in future inspections. If problems are found in service stage, the previously documented and stored information is extracted and utilized to help resolve the problem.

8 WEATHERING STEEL APPLIED TECHNOLOGIES

8.1 *Weathering Steel*

Weathering steel is a group of steel alloys which were developed to eliminate the need for painting, and form a stable rust-like appearance if exposed to the weather for several years. U.S. Steel released the products under name of COR-TEN in 1933. They were standardized in ASTM(USA),EN(Europe)and JIS(Japan). Meanwhile, the owners and designers have found their superiority from the Life Cycle Cost point of view. Substantially, there are a lot of track records of applications of the weathering in the world.

Steel type	JIS	Mechanical Properties		Chemical Composition (%)							
		Yield Point	Tensile Strength								
		N/mm²	N/mm²	C	Si	Mn	P	S	Cu	Cr	Ni
Ordinary	G3101 SM490Y	355	490～610	0.20 max.	0.55 max.	1.65 max	0.035 max.	0.035 max.	–	–	–
Weathering	G3114 SMA490W	355	490～610	0.18 max.	0.15～0.65	1.40 max.	0.035 max.	0.035 max.	0.30～0.50	0.45～0.75	0.05～0.30

Yield Point: in case of thickness is 16< t ≦ 40 mm

Figure 12. JIS-based weathering steel(490Mpa Class).

8.2 *Variations of Corrosion Protection Method*

Weathering steel has three kinds of corrosion protection methods, which are 1) Bare use ,2) Treatment film, 3) Paint use(Fig.13). At first, when bare use is applied, steel surface is covered with fine patina of rust. Steel surface is protected from the attack of corrosive air and water by this rust. When surface treatment is applied, steel surface is covered with porous film. Air and water are moderately supplied to the steel surface. When paint use is applied, steel surface is covered with paint film. Paint film block off the corrosive air and water completely.

When bare use is applied, it has an advantage to minimize Life Cycle Cost due to the elimination of painting under the proper condition .However, it has uneven color change and stain flow in the early stage, because the surface is cover by rust. When treatment film is applied, it has an advantage to improve aesthetics in middle term and save stain flow in early stage. However, it costs higher than bare use. The surface is replaced by rust during 20-30 years. When paint use is applied, because any color is available, it has an advantage to improve aesthetics and save stain flow during long term. If paint film is deteriorated, severe damage risk can be reduced by using painted weathering steel due to the corrosion protection performance of steel itself.

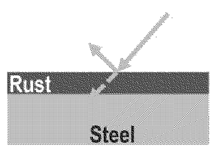
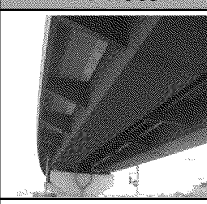
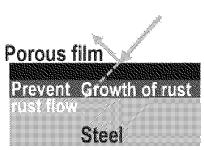
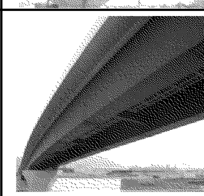
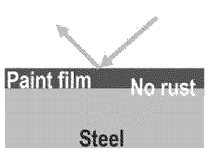
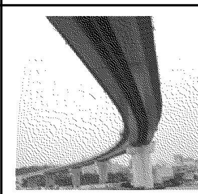
<table>
<tr><th>Method</th><th colspan="2">Protection mechanism</th><th>Photo</th><th>Exterior</th></tr>
<tr><td>Bare use</td><td>
</td><td>Covered with fine patina of rust.
Steel surface is protected from the attack of
corrosive air and water by the rust.</td><td></td><td>Dark brown only</td></tr>
<tr><td>Treatment film</td><td>
</td><td>Covered with porous film.
Air and water are moderately supplied to the steel surface.
Fine patina of rust grows under the film.
Porous film will be disappeared.</td><td></td><td>Mainly dark color</td></tr>
<tr><td>Paint use</td><td>
</td><td>Covered with paint film.
Paint film block off the corrosive air and water completely.
No air and water are supplied to the steel surface.</td><td></td><td>Any color available</td></tr>
</table>

Figure 13. Method and protection mechanism.

8.3 *Durability of Corrosion Protection System*

Situation in Japan, it is said that normal painting (A5 paint system) ordinarily has the durability of 10-15 years, and heavy duty painting (C5 paint system) has the durability of 30-40 years. Weathering steel can be expected 100 years service life in general environment.

Figure 14 shows exposure test results of normal and weathering steel which have deteriorated paint film by scratch. Left side shows 4 years exposed, right side shows 8 years exposed. They show that the rust of normal steel progresses further than weathering steel. Thus, weathering steel improve own durability by painting. If paint film is deteriorated, severe damage risk can be reduced by using painted weathering steel due to the corrosion protection performance of steel itself. Figure 15 shows cost image for corrosion protection based on Japanese price. It is necessary to repaint normal steel frequently. However, Life Cycle Cost of weathering steel bridge becomes substantially lower than that of painted bridge (normal steel) due to the elimination of repainting.

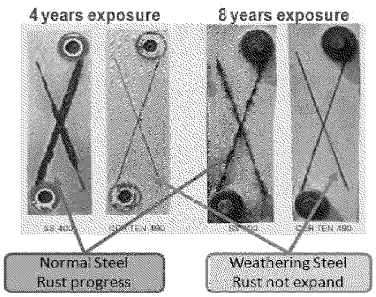


Figure 14. Exposure test result.

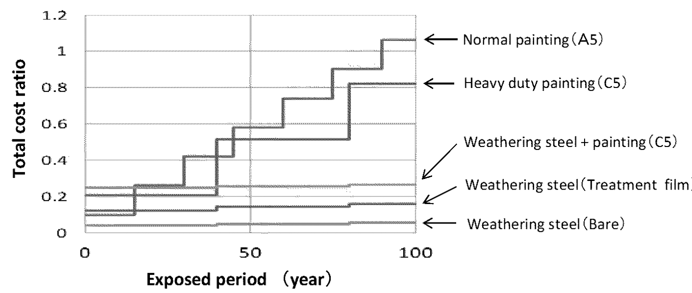


Figure 15. Cost ratio for corrosion protection.

8.4 *Proposal for using Weathering Steel*

Figure 16 shows proposal for using weathering steel. Because the aesthetics is respected in urban region, paint use will be chosen. In this case, extension of corrosion protection durability is expected by using painted weathering steel. If paint film is deteriorated, re-painting is not required. Because weathering steel itself has anti-corrosion performance. Therefore, when the aesthetics is respected in urban region, it is recommended to use painted weathering steel. But the aesthetics do not have priority in local region, and it is thought that bare use has no problem because that rust color is acceptable. It is recommended to adopt bare use to minimize Life Cycle Cost. However, it is necessary to consider following conditions when using weathering steel.

Area	Color	Specification	External appearance	Re-painting period	Initial cost	Maintenance cost
Urban region	Consideration	Normal steel + painting	◎	×	△	×
		Weathering steel + painting	◎	△	△	△
	Not Consideration	Weathering steel + treatment film	△ (Uneven color in long term)	◎	○	◎
Local region		Weathering steel (Bare)	○	◎	◎	◎

Figure 16. Proposal for using weathering steel.

8.5 *Notes for Application of Weathering Steel*

The advantage of weathering steel is to be used without painting. But weathering steel cannot be used anywhere without painting. As shown Figure 17, their conditions have a influence on its corrosion performance. In severe condition, high density salt particle area, and moist condition, weathering steel will further corrode, because steel surface is not covered with fine patina of rust. Required considerations for application are to:

1) Avoid application in high density salt particle area
2) Make considerations for design details

Figure 18 shows relations of density salt particle and corrosion loss between 9 years exposed test result. In this figure, it seems that density salt particle and corrosion loss are correlative. Black nodes show that abnormal rust is produced. If density salt particle is less than 0.05mdd, abnormal rust is not produced. The criteria on the production of abnormal rust is considered that density salt particle more than 0.05mdd.

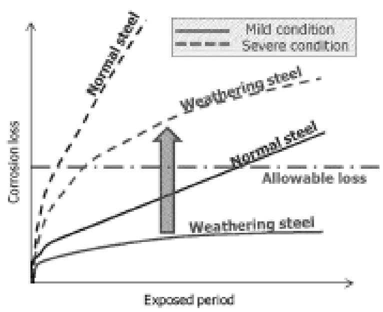


Figure 17. Exposed period and corrosion loss.

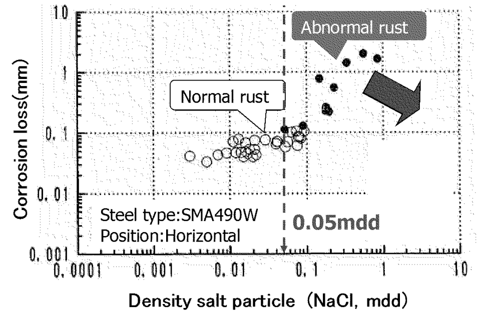


Figure 18. 9 years exposed test result.

8.6 *Design details of Weathering Steel for Bridge Use*

It is important for weathering steel to consider the structural details provide against runoff of water. Water bearing due to runoff of water produces abnormal rust (Fig.19). It is advisable to cut off the girder end for easy inspection and ventilation (Fig.20).

One of measures is to avoid runoff of water from drainpipe and slab-drain. If drain pipe and slab-drain are short, the drips on the lower flange produce abnormal rust spot. Figure 21 shows an installation of extended drainpipe provide against runoff of water from drain. Another of measures is to provide against runoff of water from expansion joint. Adoption of water through system which has large cope hole on vertical stiffener and drip bars on the top and bottom of lower flanges can be effective in providing against runoff of water. Figure 22 shows a partial painting for girder end provide against runoff of water from expansion joint.

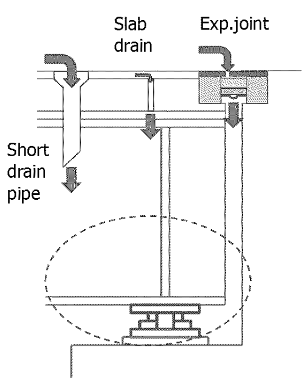


Figure 19. Water bearing.

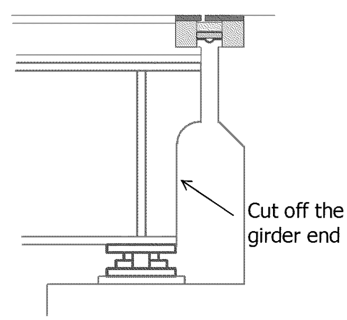


Figure 20. Cut off the girder end.

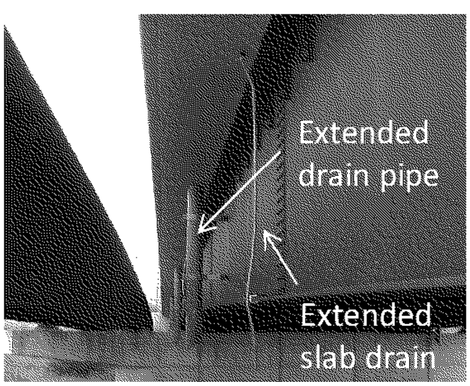


Figure 21. Extended drains.

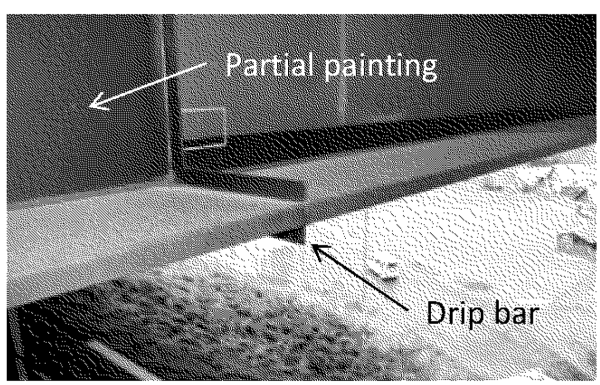
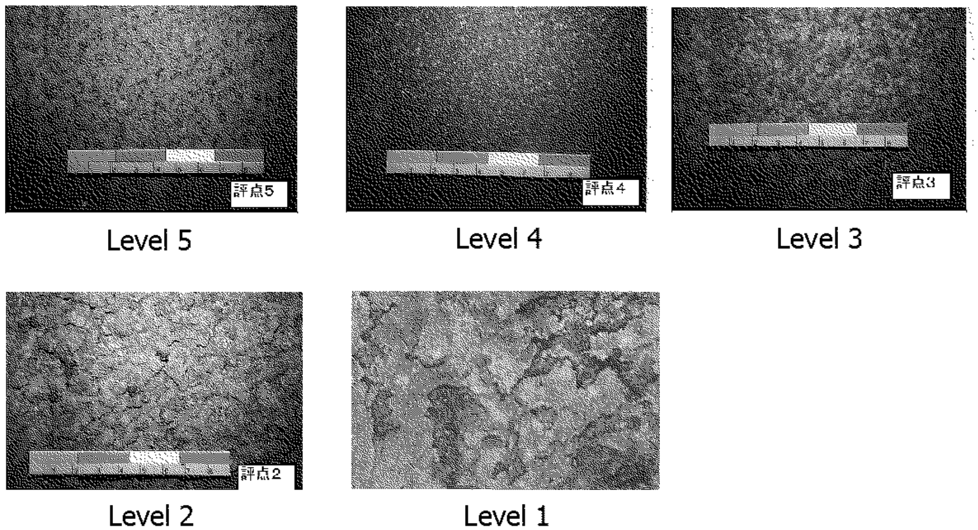


Figure 22. Partial painting and drip bar.

8.7 *Maintenance Procedure for Weathering Steel*

As for the weathering steel, maintenance is not unnecessary at all. It is necessary to confirm abnormality by periodical inspection. It is recommended to operate within 2 years, and at least every 10 years after erection, Because its surface is covered with fine patina of rust for about ten years. When there is an abnormality, measures are necessary. Basically, the state of weathering steel can be inspected by visual. When paint use is applied, it is necessary to check the state of corroded part by rust rating based on visual inspection. Figure 23 shows the rating of rust by visual inspection for weathering steel. In this example, it is judged by five rust ratings based on visual inspection .When there is no decreasing of thickness caused by the corrosion, the repair painting is unnecessary, because, it can be expected to produce the protective rust by eliminating the cause of excessive corrosion due to runoff of water. However, when it is difficult that the cause is eliminated, generally, the repair painting is adopted. The procedure of the repair painting is the same as a normal painting procedure. In weathering steel bridge, the repair painting area becomes less than the normal steel bridge, because it is necessary to paint an only excessive corrosion part due to runoff of water.



	Level	State	Judgment
Fine	5	Growing less rust and light color rust.	Safe
⇕	4	Size of rust is less than 1mm, fine and uniform.	Safe
	3	Size of rust is 1-5mm, and coarse.	Safe
	2	Size of rust is 5-25mm, and scaled.	Observation required
Course	1	Rust is layered and pilled off.	Repairment required

Figure 23. Rating of rust by visual inspection.

9 CONCLUSIONS

i. Every process involved in the fabrication and construction of the bridge is conducted under tightly controlled conditions.
ii. The results of each process are verified, and all defective products are sent back to the previous stage in the fabrication process or to the supplier.
iii. The results of each process are documented to ensure traceability, and are then utilized after the bridge goes into service.
iv. Weathering steel can minimize the Life Cycle Cost of steel bridge because they can be maintained without painting.
v. For paint use, the risk on severe damage due to less maintenance work can be reduced because steel itself has corrosion protection performance.
vi. Weathering steel should be used under proper conditions.