Study on corrosion distribution and ultimate strength of a plate girder bridge’s support area

S. Matsumoto, M. Kurihara, K. Nogami & Y. Kishi
Tokyo Metropolitan University, 1-1 Minami-Osawa, Hachioji-shi, Tokyo, Japan

N. Hosomi, S. Komine & T. Irube
TTK Corporation, 101 Shimotakai, Toride-shi, Ibaraki, Japan

ABSTRACT: Corrosion is an important factor to consider the physical life time of steel bridges. However, relationship between corrosion and ultimate strength of structures is still not well understood. This research focuses especially on the support area of an I-beam steel plate girder bridge and conduct a detail measurement of the distribution of its corrosion along with a compression loading test. As a result, corrosion was mainly found at the end of the girder, especially around the support area causing serious reduction of thickness at the end stiffener. However, remaining load-carrying capacity was found to be higher than its designed load.

1 INTRODUCTION

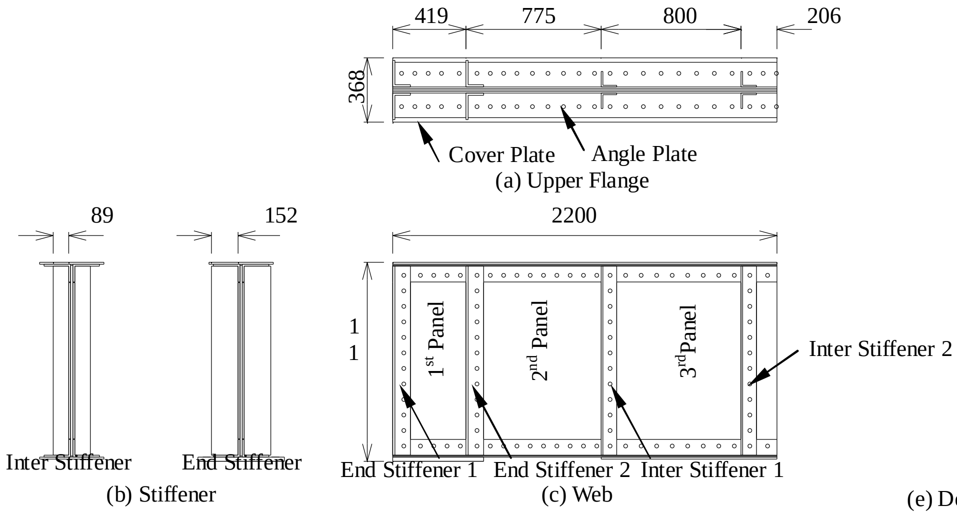
Today, maintenance of bridges is one of the most important elements concerning the formation of sustainable infrastructure system. As developed countries are facing growing number of bridges in need for major maintenance, and constructions of new bridges are active in developing countries, there is an increasing significance to establish quantitative and accurate criterions to evaluate deterioration of the structure. Focusing on steel bridges, fatigue and corrosion are known to be the two major elements influencing the physical life-time of the structures. Since forms of corrosion appear uniquely to each structure according to the complex factors of its surrounding environment, evaluation of deteriorating load-carrying capacity due to corrosion based on mechanical theoretic has not yet been concreted (Huang et al. 2002) (Yamasawa et al. 2009). Thus, this research focuses on a specimen of plate girder bridge’s support area where corrosion tends to develop typically, and experimentally seeks to elucidate the relationship between corrosion and its ultimate strength. (Matsumoto et al 2015).

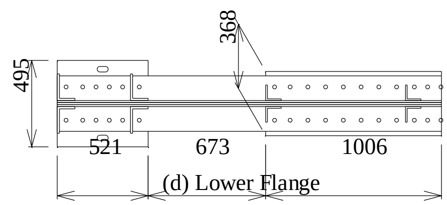
2 SPECIMEN

Specimen focused on this research is collected from an I-beam steel plate girder bridge called Kanasugi Bridge, shown in Figure 1. Kanasugi Bridge is a single span bridge with 2 main girders of a 9.4 meter length which was placed in Minato-District, Tokyo, Japan. The bridge was removed after approximately 90 years in service due to change in train route. The bridge’s designed load is Cooper’s E45 which is based on Cooper’s loading system. Main girders of the bridge are assembled by rivet joint, and are consisted of web plate, angle plate, cover plate, and sole plate. Since information about the steel used for this bridge was lost, this research has conducted tensile test and chemical analysis. As the result of the tests, steel used for Kanasugi Bridge satisfied standards for SS400 steel plate defined in Japanese Industrial Standard.

Specimen used in this research is cut out at 2200mm - fully 3 panels- from the end of the girder. For this research focuses especially on the bridge’s support area, corrosion measurement is conducted for area of 1430mm - fully 2 panels - from the end of the girder. Dimension of the specimen is as shown in Figure 2.

Figure 1. Kanasugi Bridge





(e) Designed Thickness

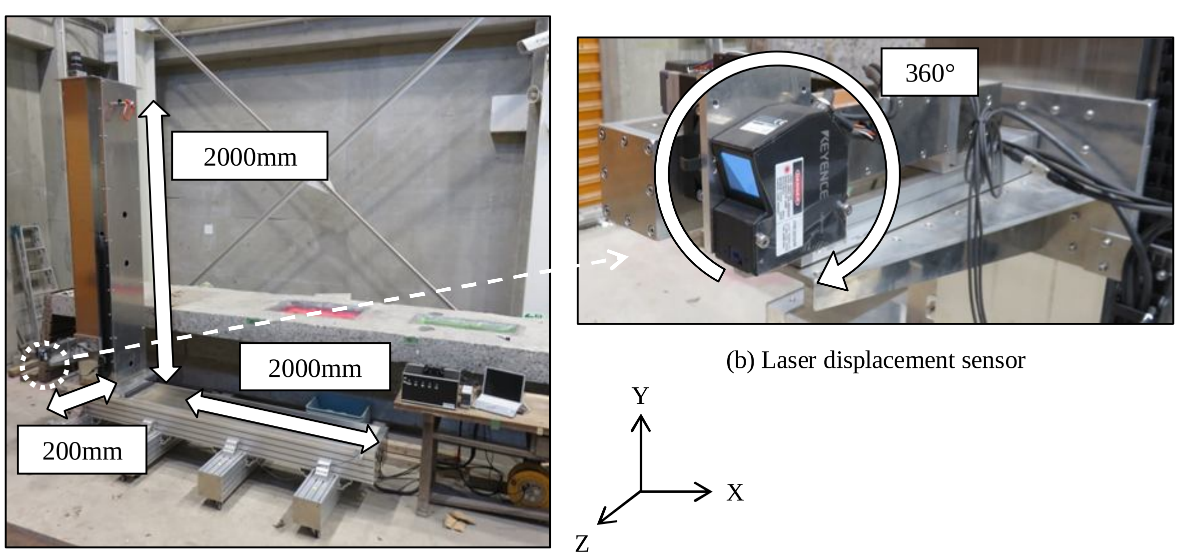
Structural member	Thickness (mm)
Web Plate	12.7
Angle Plate	11.1125
Cover Plate	11.1125
Sole Plate	23.8125
End Stiffener	12.7
Inter Stiffener	9.525

Figure 2. Dimension of the specimen

3 CORROSION

3.1 *Large-Scale Three-Dimensional Surface Roughness Measurement System*

Corroded surface measurement is conducted by using newly developed large-scale three-dimensional surface roughness measurement system as shown in Figure 3. It is consisted of a laser displacement sensor and linear locomotion units on each of the three axes. This measurement system has the ability to move freely in area of 2000mm (X) × 2000mm (Y) × 200mm (Z) × 360° (θ). The linearity of the laser displacement sensor applied to the system is ±0.05%. By selecting two axes to define the measurement surface, laser displacement sensor automatically moves from the start coordinate to the end coordinate in selected interval and records the distance from the laser displacement sensor to the measurement surface for each coordinate. The speed for measurement at 1mm interval is 0.45 sec/data.



(b) Laser displacement sensor

(a) General view of the measurement system

Figure 3. Large-scale three-dimensional surface roughness measurement system

3.2 *Corrosion Measurement Results*

The characteristics of corrosion and initial imperfection of the specimen revealed by the corrosion measurement is summarized below. An example of the corrosion depth contour figure is shown in Figure 4.

(a) Web plate

Measurement results showed tendency of the measured value to be inverted on the two sides of the specimen which indicates the effect of initial imperfection of the web plate. The maximum amount of out-of-plane initial imperfection is approximately 3.5mm. Corrosion is not apparent on the web plate on the whole and minor corrosion is found at limited to area near the support area around lower flange and end stiffener.

(b) Upper Flange

Outer side of the upper flange has much corrosion in multiple areas. In particular, areas where wood crossties were placed had sever corrosion. Wood crossties had caused those areas to be placed under high humidity for long period of time, causing intensive advance of corrosion. As a result, wood crossties had caused multiple areas of outer side of the upper flange to reduce its thickness to half of the original. In addition, much area at the end of the upper flange is either lost or deformed.

Inner side of the upper flange had much corrosion around the end of cover plate. Corrosion at the cover plate has caused some corrosion around the end of angle plate; however, there is not much corrosion at the surface of the angle plate.

(c) Lower Flange

On the outer side of the lower flange, there is an intensive advance of corrosion around the border between sole plate and lower flange which reduced the original thickness to about its half. This indicates that such section where thickness changes cause degradation factors such as rain and dust to accumulate, generating high humidity environment for long term. There is also major corrosion at broad area around the end of the sole plate. The edge of angle plate and cover plate had less corrosion. However, the surface of the angle plate and cover plate remained in good condition.

Inner side of the lower flange had moderate corrosion throughout the angle plate, cover plate, and sole plate. This is mainly because the area is likely to accumulate degradation factors and stay in high humidity environment for long term.

(d) End Stiffener

For end stiffener 1, there is severe corrosion around the lower flange which caused some area to be lost completely. Severe corrosion of more than 6mm is seen to approximately 100mm height from the lower flange at the stiffener’s width.

For end stiffener 2, there is corrosion of about 6mm locally at limited area. Other than the local corrosion, there is relatively less corrosion on end stiffener 2.

(e) Inter Stiffener

The measured value on the two sides of inter stiffener showed tendency to be inverted which indicates the effect of initial imperfection. The initial imperfection showed sinusoidal full-waveform with maximum displacement of approximately 2mm. Corrosion of about 2mm is seen locally at some areas.

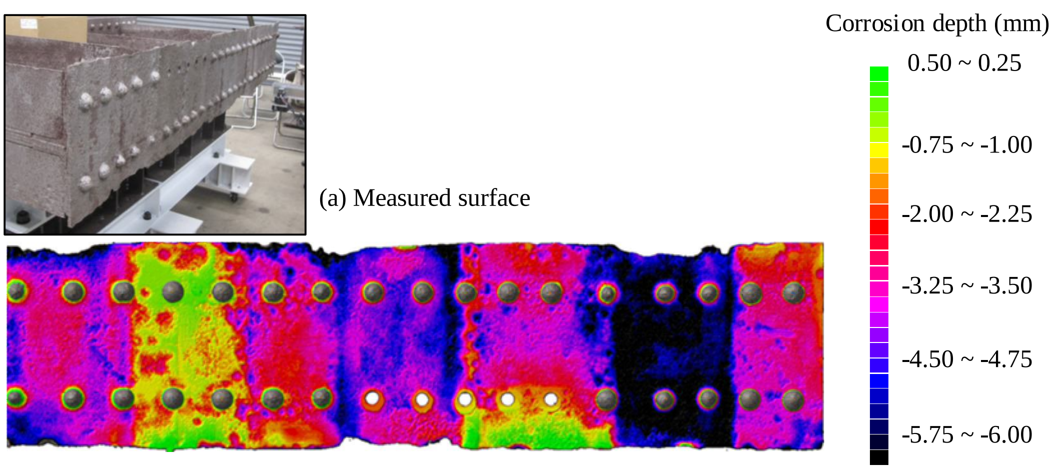


Figure 4. Corrosion depth contour figure on outer surface of upper flange

4 COMPRESSION LOAD CARRYING CAPACITY TEST

4.1 *Test Setup*

To test the specimen's compression load carrying capacity at its support area, this research had used a hydraulic system universal testing machine with maximum ability of 5000kN compression load and conducted a static loading test. Test set up is as shown in Figure 5. Since Japanese specifications for highway bridges require girder bridges' support area to be designed as a column, loading point and reaction point are set up to be pin support. This is done by placing 27mm thick plate on upper and lower flange between the end stiffeners and setting spherical support at the center of the plate. In addition, roller support is set below inter stiffener 2. Boundary condition is summarized in Figure 6.Loading is controlled by measuring the vertical displacement of the jack of the testing machine.

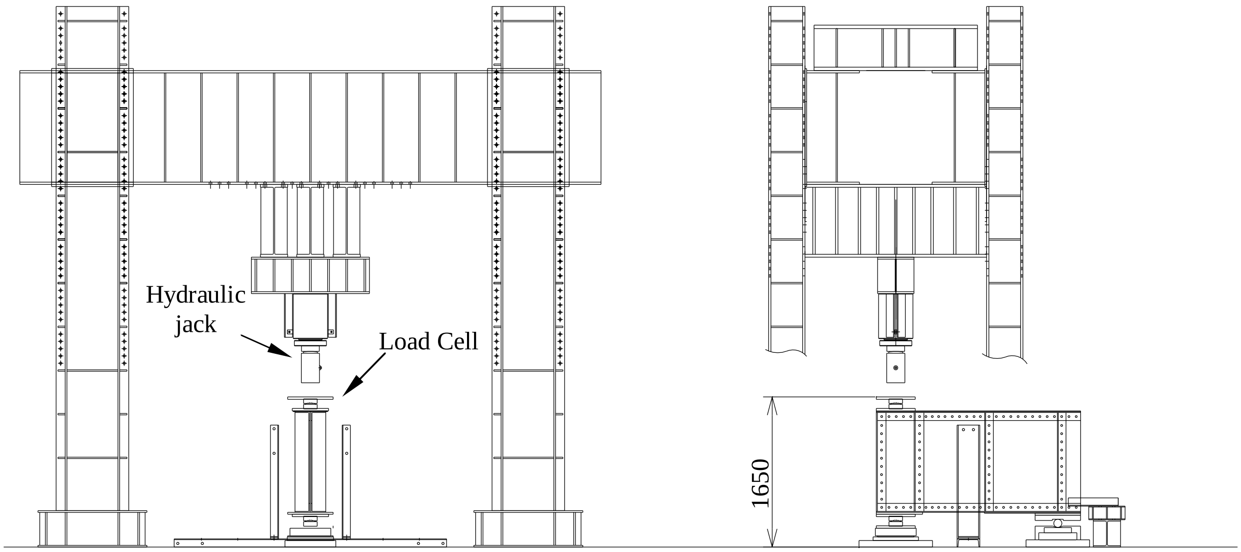


Figure 5. General view of the test set up

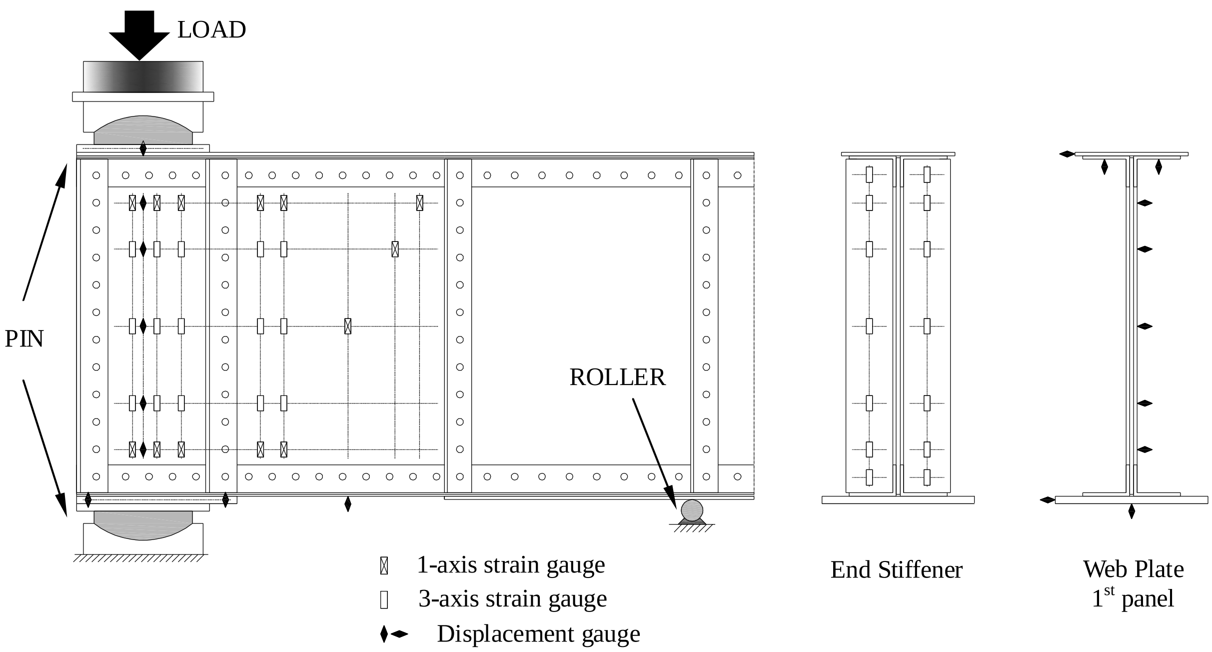


Figure 6. Boundary Condition and set up of the specimen

4.2 *Test Results*

As shown in Figure 7, load vs. displacement curve between the initial condition to 400 kN load is concave down which indicates the contact surface of the testing machine and the specimen are fitting together. For the loading plate was not rigid enough, it continued deforming to around 2000 kN which caused change in the boundary condition between end stiffeners from uniform distribution throughout the loading plate to concentrated load around the loading point. The change in the boundary condition caused the stress to concentrate on the web plate instead of flowing to end stiffeners. Local buckling was found at approximately 3290 kN on web plate around upper flange and lower flange. The form of the local buckling was sinusoidal half-waveform at both areas. Load vs. displacement curve reaches its peak at 3341 kN. After the load started to decease, the loading plate slid out because of the tilt of upper flange and the test was terminated. In Japanese standards for railway structures, compression load carrying capacity of end stiffeners at support area is calculated by adding cross-section area of end stiffeners and effective area of web plate (area of 12 × thickness of web plate) and multiplying it with allowable stress of the steel used in the structure (Railway Technical Research Institute. 2009), specified in JIS G 3101 (Japanese Industrial Standard. 2010). Designed compression load carrying capacity of the specimen calculated by the Japanese standards is 1894 kN. Compression load carrying capacity test revealed that the specimen possessed 1.76 times of its designed compression load carrying capacity.

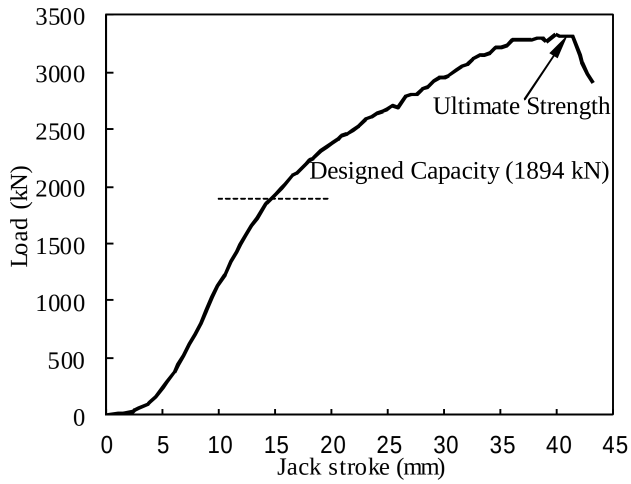


Figure 7. Load – displacement curve at loading point

Strain gauges on the end stiffener recorded no yield strain at all observation points. Figure 8a shows Load vs. Strain curve at end stiffener 1 near the upper flange. Instead, strain gauges placed at area near to upper and lower flange on the 1st panel recorded strain exceeding yield strain, as shown in Figure 8b. Strain gauges on the 2nd panel did not record yield strain. 3 axis strain gauges on 2nd panel which is placed diagonally from lower flange side of inter stiffener 1 to upper flange side of inter stiffener 2 also did not record yield strain indicating that no oblique tensile force emerged.

Displacement gauges placed horizontally on web plate at 1st panel showed that there was approximately 5mm displacement at maximum load which indicates that the specimen was tilting as the load increase. In addition, displacement gauge placed horizontally on upper flange recorded approximately 4mm displacement at 14500 kN which indicates that the tilting of upper flange started at early stage of the compression test.

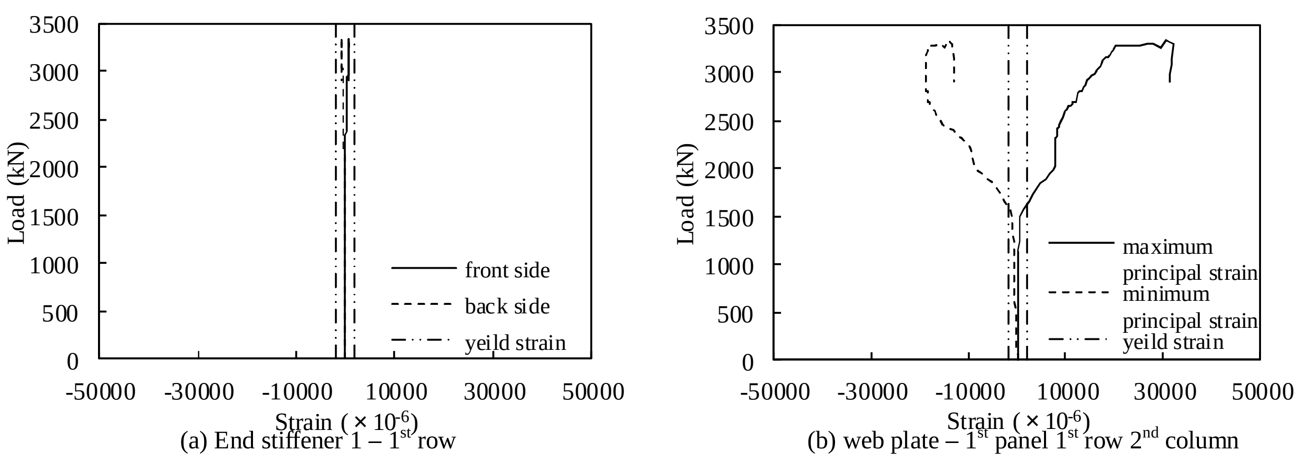


Figure 8. Load – strain curve at web plate

5 CONCLUSIONS

Summary of the conclusion derived from this research is as below.

(1) I-beam steel plate girder's corrosion

Corrosion is mainly concentrated at corners. Corrosion on web plate and end stiffeners tends to develop more at area close to the end of the girder and support area. In addition, the tendency of railroad bridges having severe corrosion at places where crosstie was placed was confirmed at this specimen.

(2) Compression load bearing ability of support area

As load increased, loading plate started to deform causing uniform distribution of load at upper flange between end stiffeners to change into point load condition. As result, much load concentrated on the web plate inducing local buckling on web plate around upper flange and lower flange. Ultimate strength of the specimen was 3341 kN, which is approximately 1.8 times of its designed compression load carrying capacity.

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