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# REMAINING STRENGTH EVALUATION OF PLATE GIRDERS WITH CORROSION NEAR SUPPORTS

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In Japan, a lot of steel railway bridges were constructed during the period of rapid economic growth in the 1960s. Now, since over 50 years have passed, the aging of these structures has become conspicuous and a major social problem. In particular, for steel plate girders with open deck system, deterioration and damage due to corrosion is becoming obvious. Moreover, the remaining strength evaluation method of corroded structures is not always sufficient. Therefore the purpose of this study is to propose an analytically-based evaluation method for the maintenance of steel railway bridges. The following are noted: 1) Regarding the shear strength of plate girders with corrosion near supports, the remaining strength depends on the corroded surface condition of each component such as a web or a vertical stiffener. And, according to the form and degree of corrosion, the fracture mode also changes from the buckling of web to the buckling of cross-shape column consisting of the web and vertical stiffener. The result shows that the corroded web has more effect on the shear strength than the vertical stiffener. 2) Regarding the peeling between the web and bottom flange due to corrosion near supports, the remaining strength is deteriorated more rapidly than above case 1, when the peeling range lengthens more than the sole plate area.

*Keywords*: Shear strength, Local buckling, Web, Vertical stiffener, Peeling.

## 1 INTRODUCTION

As of 2012, there were approximately 102,300 railway bridges of at least 1 m in length in Japan. Figure 1 shows the stock pyramid which consists of the number of these railway bridges separated by age groups. Of them, steel plate girders are one of the oldest bridges, their corrosion damage due to age deterioration is becoming more obvious. Partial repairs and reinforcement as well as total replacement of girders have taken place in recent years, but it cannot be said with certainty that these measures were selected after a proper, quantitative evaluation of the remaining strength of the girders. In light of recent socioeconomic conditions caused by budgetary and labor shortages, there is an even more pressing need to establish streamlined, economically viable methods for maintaining these bridges into the future.

One characteristic of plate girder corrosion is the occurrence of corrosion near supports. The complicated structure of members near supports at girder edges prevents the passage of wind and often limits exposure to sunlight, leading to the pooling of water atop abutments, thus facilitating the progress of corrosion than in other parts. In general, there are many observed cases of corrosion of webs and vertical stiffeners near supports. There are also some cases of peeling at joints between webs and lower flanges due to local corrosion (Figure 2).

This study focuses on steel plate girders, presents a full understanding of the conditions of corrosion and damage observed relatively near the supports, and analytically examines remaining shear capacity and declining strength near steel bridge supports based on specific corrosion models. The study also explains and evaluates how the remaining shear capacity of steel plate girders and forms of collapse change in response to the location and progression of corrosion.

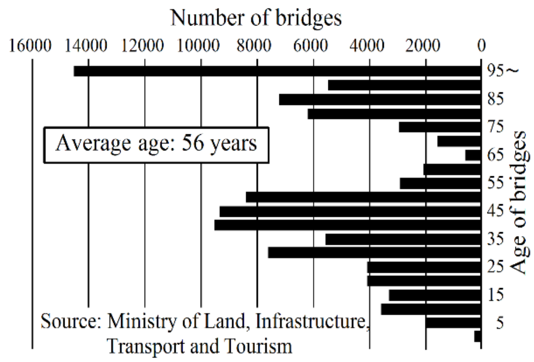



Figure 1. Stock pyramid of existing railway bridges in Japan (As of 2012).

Figure 2. Peeling conditions between webs and lower flanges near supports.

## 2 CONDITIONS OF ANALYSIS

### 2.1 Analytical Models

This analysis is conducted using elastic-plastic finite deformation analysis from the commonly used analysis program NASTRAN. SS400 steel per Japanese Industrial Standards (JIS) is used as the material for the analytical models, and material properties have a yield stress $\sigma_y$ of 235 MPa (tensile strength of 400-510 MPa), an elastic modulus $E$ of 200 GPa, and a Poisson ratio $v$ of 0.3. The constitutive law of materials is applied based on the von Mises yield criterion.

Figure 3 shows the dimension of main plate girders, the target of the analysis. The purpose of this study is to provide evaluations focused on shear capacity, therefore the analytical models are configured such that they account for the symmetry of main girders by applying loads near supports in order to lessen the effects of bending to the extent possible while working with the analytical models. In addition, rigid elements are applied to the supporting sole plate. Shell elements with 4 nodal points are applied to these analytical models, with each element divided into a size of approximately 10 mm (Figure 4). In addition, Figure 5 shows boundary conditions. These analytical models take into account initial imperfections in the out-of-plane direction on the web between the vertical stiffeners. Modeling procedures like these are listed in a reference[1].

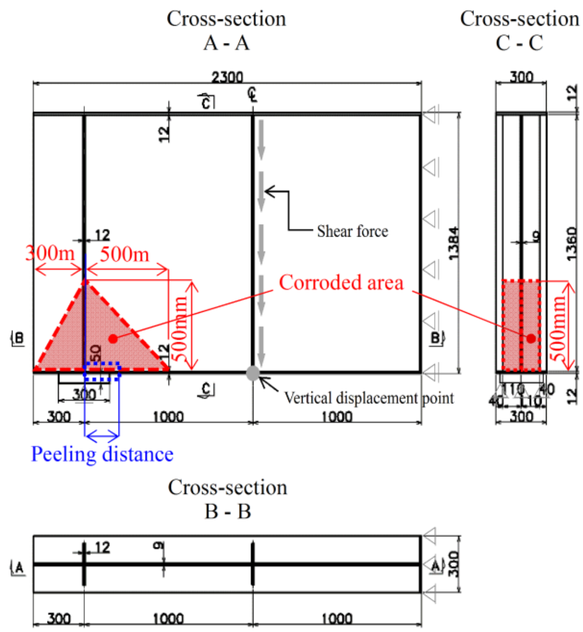



Figure 3. Dimensions of main plate girders targeted for the analysis.

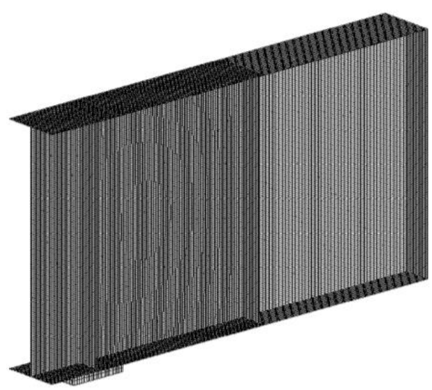
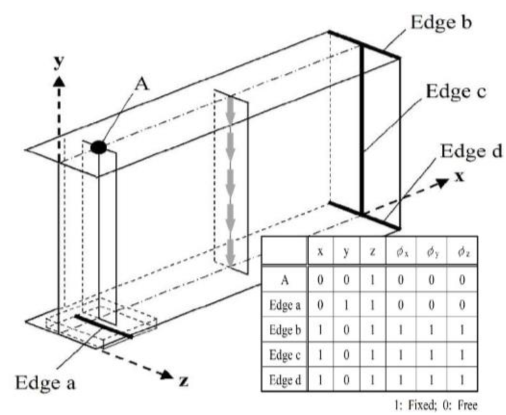


Figure 4. Analytical model.




| | x | y | z | $\phi_x$ | $\phi_y$ | $\phi_z$ |
|---|---|---|---|---|---|---|
| A | 0 | 0 | 1 | 0 | 0 | 0 |
| Edge a | 0 | 1 | 1 | 0 | 0 | 0 |
| Edge b | 1 | 0 | 1 | 1 | 1 | 1 |
| Edge c | 1 | 0 | 1 | 1 | 1 | 1 |
| Edge d | 1 | 0 | 1 | 1 | 1 | 1 |

Figure 5. Boundary conditions.

## 2.2 Corrosion Patterns

The results of investigation shown in Table 1 have been reported as the main forms of corrosion of plate girders near supports[1]. With reference to the results, the analyses are conducted on the assumption that uniform mean thickness reductions occur within the typical areas of local corrosion of webs and vertical stiffeners as shown in Figure 3. Case studies where remaining shear load bearing capacity is calculated with respect to corrosion location and remaining thickness as shown in Table 2 are analyzed. Furthermore, the same analyses are conducted on cases of peeling of the joints between webs and lower flanges directly above supports (Figure 3).

1 Tamakoshi, T., Keita Nakasu, K., Ishio, M., Tatsuya Takeda, T., and Suizu, N., Research on local corrosion of Highway steel bridges, TECHNICAL NOTE of National Institute for Land and Infrastructure Management, No.294, January 2006.

Table 1. Characteristics of corrosion at girder ends.[1]

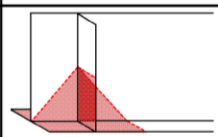
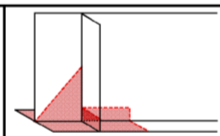
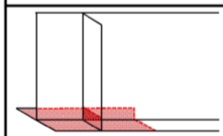
| | Main corrosion patterns and number of cases | | | |
|---|---|---|---|---|
| Corrosion configurations |  | Number of cases **3** / 20 examples ( 15 % ) |  | Number of cases **4** / 20 examples ( 20 % ) |
| |  | Number of cases **6** / 20 examples ( 30 % ) | Others | Number of cases **7** / 20 examples ( 35 % ) |

Table 2. Analytical cases (Non-corroded or corroded, peeling).

**I**. Non-corroded (Original thickness)

| Analytical case | **(1)** |
|---|---|
| Web (mm) | **9** |
| Vertical stiffener (mm) | **12** |

**II**. Web (Corroded)

| Analytical case | **(2)** | **(3)** | **(4)** |
|---|---|---|---|
| Web (mm) | 7 (-2) | **5** (-4) | **3** (-6) |

**III**. Vertical stiffener (Corroded)

| Analytical case | **(5)** | **(6)** | **(7)** |
|---|---|---|---|
| Vertical stiffener (mm) | **10** (-2) | **8** (-4) | **6** (-6) |

**IV**. Web and vertical stiffener (Simultaneously corroded)

| Analytical case | **(8)** | **(9)** | **(10)** |
|---|---|---|---|
| Web (mm) | **7** (-2) | **5** (-4) | **3** (-6) |
| Vertical stiffener (mm) | **10** (-2) | **8** (-4) | **6** (-6) |

**V**. Non-corroded (Original thickness) / Peeling between web and lower flange

| Analytical case | **(11)** | **(12)** | **(13)** |
|---|---|---|---|
| Web (mm) | **9** | | |
| Vertical stiffener (mm) | **12** | | |
| Peeling distance (mm) | **75** | **150** | **200** |

**VI**. Web and vertical stiffener (Simultaneously corroded) / Peeling between web and lower flange

| Analytical case | **(14)** | **(15)** | **(16)** | **(17)** | **(18)** | **(19)** | **(20)** | **(21)** | **(22)** |
|---|---|---|---|---|---|---|---|---|---|
| Web (mm) | **7** (-2) | | | **5** (-4) | | | **3** (-6) | | |
| Vertical stiffener (mm) | **10** (-2) | | | **8** (-4) | | | **6** (-6) | | |
| Peeling distance (mm) | **75** | **150** | **200** | **75** | **150** | **200** | **75** | **150** | **200** |

* Above ( ) values show thickness reduction

## 3 RESULTS OF ANALYSIS

### 3.1 Corrosion Models

Figure 6 shows the relationship between thickness reduction and remaining strength for models in which only one of webs or vertical stiffeners near supports corrodes, and for models in which they both corrode simultaneously. The figure shows that web corrosion has the largest effect on shear capacity at girder edges. This rapid reduction of strength is caused by the occurrence of local buckling of webs before the shear force is transferred to the diagonal tension field of the webs (Figure 7(a)). The figure also shows that, for the models in which only vertical stiffeners corroded, shear strength reduced only around 10% even when thickness was reduced 50%; the effect is not very significant. On the other hand, shear strength reduced much more dramatically for the models in which webs and vertical stiffeners corroded simultaneously than for the models in which only webs corroded. This likely has a greater effect on shear capacity than cases where only vertical stiffeners corroded because shear force is intensively redistributed to vertical stiffeners when the corroded parts of webs suffer local buckling.

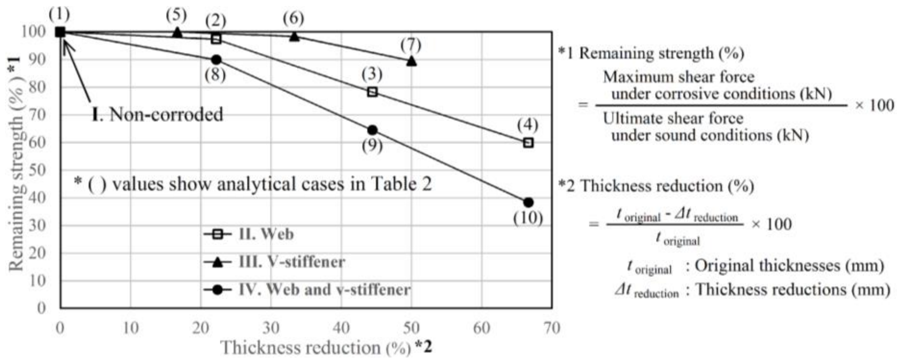



Figure 6. Shear strength reduction due to corrosion.

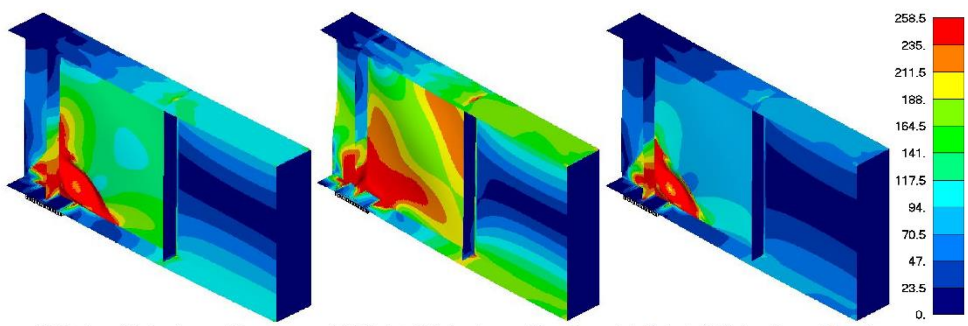



Figure 7. Stress distribution and deformation diagram at maximum shear force (Corrosion).

### 3.2 Peeling Models

Figure 8 shows the relationship between the distance of peeling from support centers and remaining strength for models in which peeling occurs at joints between webs and lower flanges directly above supports, and for models in which they both corrode simultaneously. In the non-corroded models, shear capacity decreases suddenly when the peeling distance exceeds 150 mm. In addition, deformation stress diagrams of those cases show high concentrations of stress toward the peeling areas (Figure 9(b), (c)). Sole plates exist up to 150 mm from support centers, and if peeling occurs within that area, the webs effectively work as stress transferring mechanism between vertical stiffeners and lower flanges. However, if that function fails once and peeling exceeds that area, stress becomes concentrated on the lower flange and sole plate boundaries, which likely renders lower flanges incapable of withstanding shear deformation. Furthermore, the models show that peelings with local corrosion of webs and vertical stiffeners simultaneously have smaller effects on the strength reduction according to peeling extension as the thickness reduction due to corrosion increases. This is likely because extreme local corrosion near supports causes local buckling at areas with reduced thickness earlier than in peeling areas.

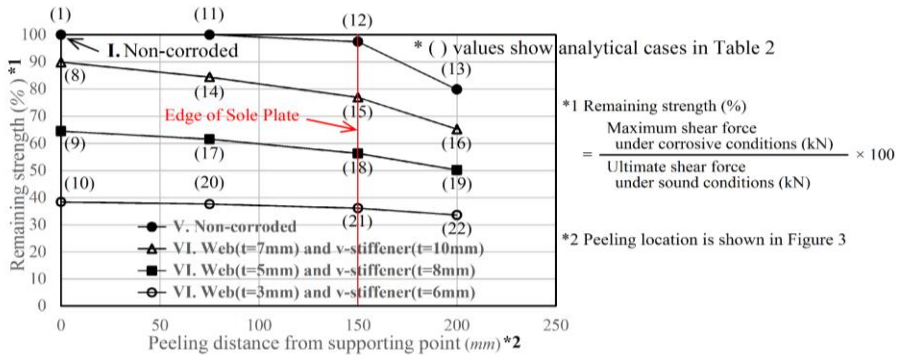



Figure 8. Shear strength reduction due to peeling (Incl. corrosion).

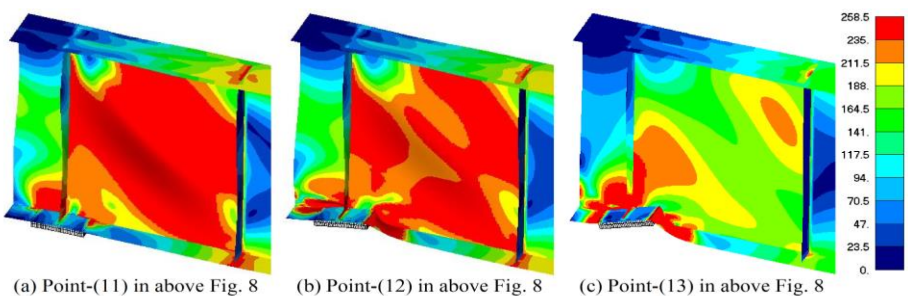



Figure 9. Stress distribution and deformation diagram at maximum shear force (Peeling).

## 4 CONCLUSIONS

1) Thickness reduction of only webs due to local corrosion near supports has more effect on shear capacity than that of only vertical stiffeners.

2) Collapse due to corrosion takes the form of local buckling of webs or vertical stiffeners, and occurs when the cross-shaped columns comprised of webs and vertical stiffeners become unable to withstand the support reaction. Thus, the strength reduction becomes even more pronounced when both webs and vertical stiffeners corrode simultaneously as compared to when only vertical stiffeners corrode.

3) When peeling occurs and extends past the range of sole plates, stress concentrates on the lower flanges above the sole plate edges, causing sudden shear deformation and strength reduction. And peelings with extreme local corrosion have smaller effects on the strength reduction according to peeling extension because local buckling at areas with reduced thickness occurs earlier than in peeling areas.

## References

Tamakoshi, T., Keita Nakasu, K., Ishio, M., Tatsuya Takeda, T., and Suizu, N., *Research on local corrosion of Highway steel bridges*, TECHNICAL NOTE of National Institute for Land and Infrastructure Management, No.294, January 2006.