LOAD-CARRYING CAPACITY OF CORRODED END CROSS-GIRDER

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Abstract

An end cross-girder plays an important role when the steel girder bridge is subjected to seismic loading. But, located near the girder end, it is often found corroded, which could degrade the load-carrying capacity. Therefore, it is of a practical significance to investigate the seismic performance of a corroded end cross-girder. To this end, the present study conducts nonlinear finite element analysis of end cross-girders with various corrosion patterns under horizontal load. It is observed that not only the degree of corrosion but also the corrosion pattern influences the degradation of the load-carrying capacity. It is also found whether or not the lower flange is connected to the main girder makes a large difference in the load-carrying capacity

Introduction

Bridges without cross girders at the ends of main girders have been constructed in Chile. Many of them were badly damaged in the 2010 Chile Earthquake (Chen et al. 2010). The end cross-girder in the steel bridge is thus an important member under seismic loading. The seismic design code in Japan indeed requires that end cross-girders shall possess rather large cross sections (Japan Road 2012b).

Needless to say, corrosion decreases cross sectional area, leading to the degradation of the load-carrying capacity. Main cause for the replacement of steel bridges is said to be corrosion (Japan Road 2012a). Corrosion is thus one of the crucial phenomena to be dealt with in the maintenance of steel bridges, and the issue of corroded steel girders has attracted many researchers (for example, Liu et al. 2011). Nevertheless, much remains to be done since corrosion patterns are numerous.

Corrosion is most serious at the end of a main girder, as water comes in through an expansion joint and there are many members in the neighborhood of the girder end that may deteriorate corrosion environment. Hence, the corrosion problem is often investigated in association with the girder end (for example, Khurrama et al. 2012).

The end cross-girder is susceptible to corrosion and found corroded frequently. The corroded girder may not perform as expected during earthquake. However, so far, study has not been taken from this viewpoint so that the influence of the corrosion on the

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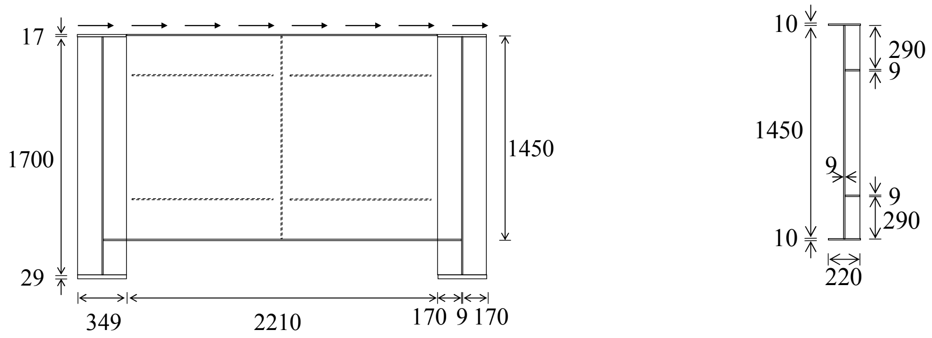


(a) Side view

(b) Cross section

Figure 1 End cross-girder model

load-carrying capacity of the end cross-girder under seismic loading is yet to be well understood.

The objective of the present study is to reveal the influence of corrosion on the seismic resistance of the end cross-girder. The study is carried out by nonlinear finite element analysis.

End Cross-Girder Model

Referring to a bridge in the design example of Japan Bridge (2005), the steel end cross-girder shown in Figure 1 is employed in the present research. The model consists of a cross girder and parts of main girders, 220 mm long. Young's modulus E of the steel is 2.0×10^5 N/mm^2, Poisson's ratio 0.3 and the yield stress 235 N/mm^2. The elastic-plastic behavior of the steel is assumed to be of Mises type and the uniaxial behavior in tension is described by two lines. The intersection of the two lines is the yield point and the slope of the second line is E/100.

To simulate the seismic behavior, horizontally distributed load is applied to the upper flange of the cross girder model. The load is monotonic so as to capture the basic performance under seismic loading. The upper flange is supposed to be connected to a concrete slab, which prevents the deformation of the upper flange and due to which the displacement of the upper flange in the bridge-axis direction (out-of-plane displacement) is assumed neglected in the analysis.

Figure 1(a) is the side view of the model. This figure is the view from the parapet and the horizontal load is applied toward right as indicated by the arrows. The web of the end cross-girder model has two longitudinal stiffeners and one transverse stiffener. The stiffeners are indicated by the dotted lines as they are installed on the opposite side of the web. The stiffeners and the main girders form two panels, Panel L and Panel R. The two

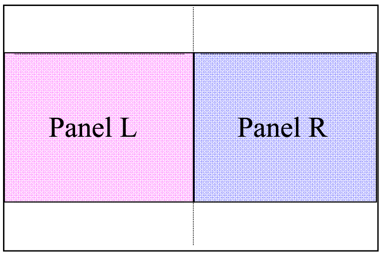
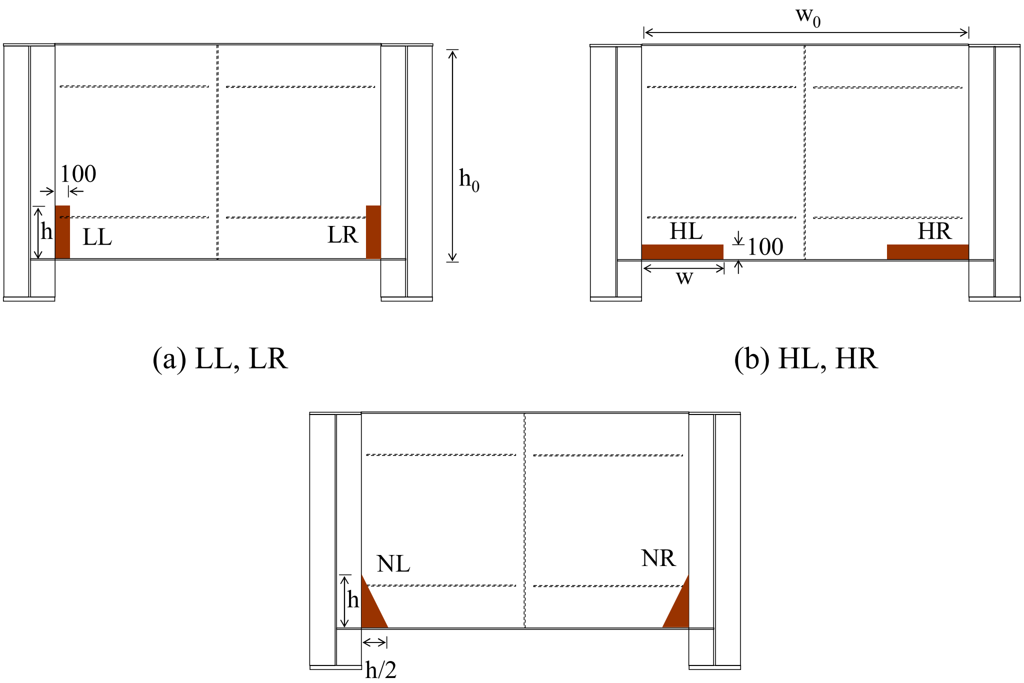


Figure 2 Panels L and R in web



(a) LL, LR

(b) HL, HR

(c) NL, NR

Figure 3 Corrosion model

panels are indicated by pink and blue, respectively, in Figure 2.

<u>**Corrosion Model**</u>

Based on the study of corrosion development in steel girders in the literature (for example, Liu et al. 2011), six corrosion models are constructed in the present study. They are illustrated in Figure 3: all the corrosion models in Figure 3(a) have the size of h-by-100 mm; all the corrosion models in Figure 3(b) the size of 100 mm-by-w; and all the corrosion models in Figure 3(c) the size of h-by-h/2.

To study the influence of the corrosion size on the load-carrying capacity of the end cross-girder, various values of h, w and Δt are considered in each model: h/h_0, w/w_0 = 25%, 50%, 75%; Δt =2 mm, 4 mm, 6 mm. Herein Δt is the reduction of the plate thickness due to corrosion. The combination of these parameters requires 54 analyses. In addition, the analysis of the original girder (no corrosion) is conducted.

Outline of Analysis

Initial imperfections of the steel girder can influence its strength significantly. Therefore, initial deformation and residual stress need be taken into account in the analysis. To find the relevant initial deformation, the eigenvalue analysis is conducted first to obtain buckling modes. The initial deformation mode is made identical to the mode of the smallest buckling strength. The initial deformation is then constructed so as to have the maximum displacement within the range of the fabrication tolerance specified in Japan Road (2012a).

Several models of residual stress distribution are available in the literature by Usami (2005). In the present study, the residual stress distribution used in our previous study (Yamaguchi and Akagi 2012) is employed. Since the residual stress distribution is in a state of self equilibrium, the residual stress is given to the analysis model by conducting thermal stress analysis. The analysis is done by assuming temperature distribution so as to insert the stress distribution desired. The relevant temperature distribution is found by a trial-and-error method.

All the analyses are conducted by ABAQUS (2008). The finite element model of the cross girder utilizes 4-node shell elements for the entire body.

Numerical Results and Discussion

The same type of the corrosion model is considered at the left and right bottom corners of the web. Since actual seismic loading is cyclic, only one of them is considered to be significant herein, the one that leads to a larger reduction in the load-carrying capacity. Therefore, although all the 54 corroded girders were analyzed, only the significant cases are reported in what follows. The significant corrosion models turn out to be LL, HL and NL.

Numerical results are presented in Table 1 and Figures 4 to 6, in which P_{max} is the maximum load of a corroded cross girder and P_0 is the maximum load of the original cross girder. The color in Figure 4 indicates the out-of-plane displacement.

In the original cross girder, shear buckling occurs in both panels, Panels L and R, and the diagonal-tension field, a region that undergoes out-of-plane displacement and is located diagonally, is developed before the maximum load is reached.

In LL, the diagonal-tension field forms in each panel, but the directions of the

Table 1 Load-carrying capacity

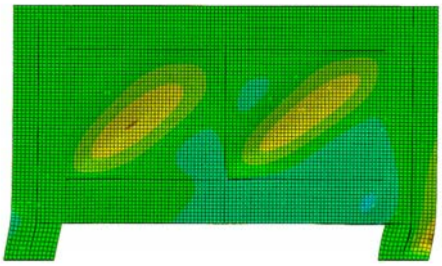
Corrosion model	Δt (mm)	h/h_0	P_{max}/P_0	Corrosion model	Δt (mm)	h/h_0 (w/w_0)	P_{max}/P_0
LL	2	0.25	0.997	NL	2	0.25	0.983
		0.50	0.984			0.50	0.963
		0.75	0.993			0.75	0.949
	4	0.25	0.984		4	0.25	0.971
		0.50	0.968			0.50	0.923
		0.75	0.972			0.75	0.887
	6	0.25	0.954		6	0.25	0.958
		0.50	0.923			0.50	0.850
		0.75	0.911			0.75	0.788
HL	2	0.25	0.997				
		0.50	0.995				
		0.75	0.996				
	4	0.25	0.986				
		0.50	0.987				
		0.75	0.989				
	6	0.25	0.980				
		0.50	0.979				
		0.75	0.849				

out-of-plane displacements in the two panels are opposite unlike in the original model. Out-of-displacement takes place also near the left upper part of Panel L. LL reduces the load-carrying capacity by up to 9%.

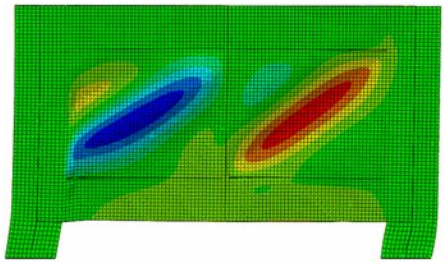
Deformation characteristics of HL model are virtually the same as those of the original cross girder and strength reduction is very little, as long as corrosion development is not so severe. In HL with w/w_0=75% and Δt=6 mm, however, the deformation mode is very different: out-of-plane displacement occurs at the right bottom part of the web while no clear diagonal-tension field in Panel L is observed; and the load-carrying capacity reduces by 15%.

In NL, each panel forms a diagonal-tension field, but the one in Panel L is larger in area and displacement. 21% reduction of the load-carrying capacity is found with h/h_0=75% and Δt=6 mm.

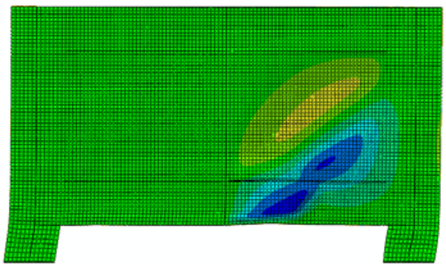
The average load-carrying capacity is shown in Figure 5. Simple average values of all P_{max} / P_0 are 0.965, 0.973 and 0.919 for LL, HL and NL, respectively. The relationship between the



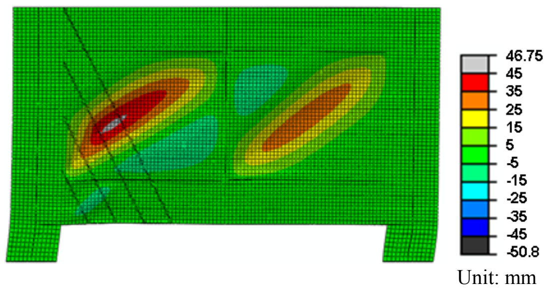
(a) Original



(b) LL

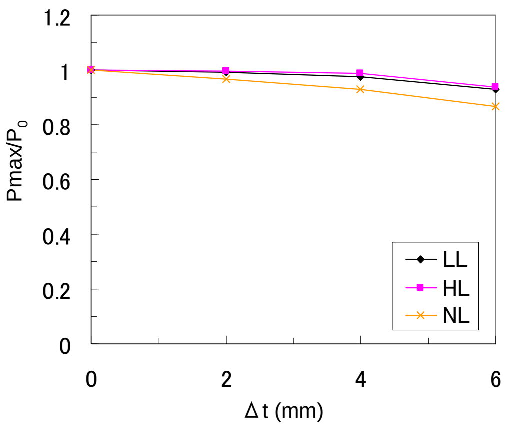


(c) HL

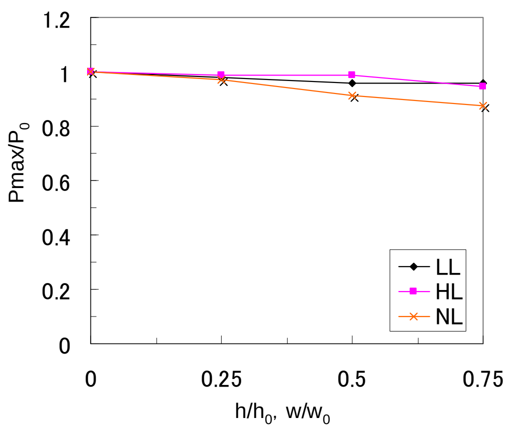


(d) NL

Figure 4 Deformation at maximum load (w/w_0=75%, Δt=6 mm for (b)-(d))



(a) Variation with Δt



(b) Variation with h or w

Figure 5 Average load-carrying capacity

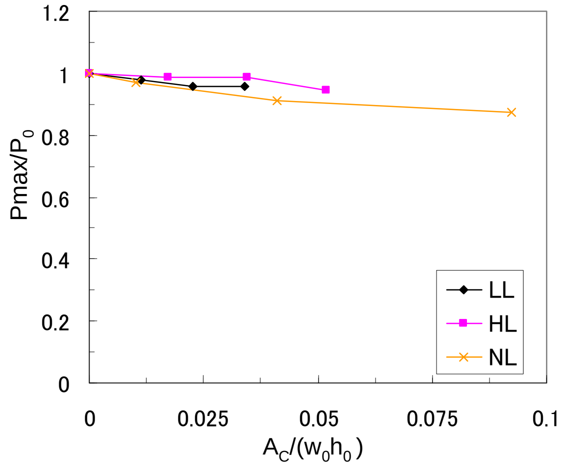


Figure 6 Variation of load-carrying capacity with corroded area

corroded area A_C and P_{max} / P_0 is investigated and plotted in Figure 6. In all theses figures, NL yields the lower bound, indicating NL has the largest influence on the load-carrying capacity.

The lower flange of the cross girder is connected to the main girder by bolts. The design requirement for the strength of the connection is not clear and may not survive under a large seismic load. Separating the connection. The original girder and LL with w/w_0=75% and Δt=6 mm are analyzed. The separation reduces the load-carrying capacity of the original girder by 11% and that of LL by 20%: P_{max} / P_0 of LL reduces to 0.73, while it is 0.91 if the lower flange of the cross girder is connected to the main girder. The result here reveals the importance of the connection, the design of which should be examined carefully.

Concluding Remarks

An end cross-girder of a steel bridge plays an important role during earthquake. However, it is often found corroded as it is located in the neighborhood of a girder end. The corrosion can reduce the load-carrying capacity. Against this background, the present study investigated the influence of the corrosion on the performance of the end cross-girder under horizontal load.

The end cross-girder undergoes shear buckling and forms diagonal-tension field before it reaches the maximum horizontal load. This basic deformation characteristic changes when it is corroded. As the degree of the corrosion becomes bigger, the load-carrying capacity decreases more. The way the corrosion influences is dependent on the corrosion type: NL is found to have the largest influence.

The connection between the lower flange of the end cross-girder and the main girder has been found significant. Once disconnected, the end cross-girder performs very differently and the load-carrying capacity decreases greatly. The present design of the connection needs more attention so as to ensure the adequate performance of the end cross-girder during earthquake.

Acknowledgments

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