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Load-Carrying Capacity of End Cross-Girder with Inspection Holes in Composite Bridge

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ABSTRACT

A severely corroded end cross-girder is found occasionally, while the girder is expected to play an important role under seismic loading. The prevention of the end cross-girder against corrosion is therefore crucial in the bridge maintenance. To this end, the present research aims at improving its inspectability by installing inspection holes in the end cross-girder. The influences of the holes on the load-carrying capacity are then studied, to be specific. It is revealed that the inspection holes would reduce the load-carrying capacity considerably; the degree of the influence varies with the shape, the position and the size of the hole. Six reinforcement methods are therefore considered. Full recovery of the capacity turns out to be possible if the inspection hole is the same size as that of the standard opening (manhole) in a steel bridge structure, while it is not an easy task when the inspection hole is larger.

1. Introduction

Cross girders or cross frames at the girder end are essential structural elements for the bridge to resist earthquakes. The current Japanese specifications for highway bridges require that the end cross-girder be large and strong with its lower flange as close to the lower flange of the main girder as possible [1]. In Chile, bridges with no end cross-girders or no end cross-frames had been constructed, many of which were damaged badly by the earthquake in 2010 [2]. The incident has demonstrated the importance of the end cross-girder/end cross-frame for the earthquake resistance.

The severe corrosion of the steel bridge has occurred mostly at the girder end [3]. This is attributed to water leakage through the expansion joint and the formation of congested space at the girder end. In short, corrosion environment is quite bad around the end cross-girder.

The corrosion reduces the cross sectional area, which deteriorates the load-carrying capacity of the member [4–6]. Many steel bridges were replaced in Japan because safety was threatened by corrosion [7]. Thus the protection of a steel bridge from corrosion is a very important issue for bridge maintenance.

The corrosion of the end cross-girder can reduce the safety margin of a bridge and can endanger a bridge during large earthquake. Nevertheless, the girder end is often exposed to corrosive environment. More careful inspection is therefore required for the girder end than for the other members. Quite frequently, however, the distance between the end cross-girder and the parapet is so small that visual inspection on the parapet side is practically impossible. This creates a situation where the corrosion is not noticed until it penetrates through the plate of the end cross-girder and holes are made. Photo 1 shows an example of such an end cross-girder. In this bridge, in addition to the partial loss of the cross section of the web, the severe reduction in the flange thickness on the parapet side had been caused, but it was recognized only after the repair work was started.

Against the background of the information above, the end cross-girder with inspection holes in the web is proposed. The holes enable one to conduct visual inspection of the parapet side of the girder. In addition, the improvement of ventilation can be expected as well.

However, the inspection holes would inevitably degrade the load-carrying capacity of the end cross-girder. In the present study, the reduction in the capacity is evaluated and the reinforcement method to make it up is then investigated.

2. End cross-girder model

Referring to the bridge in the textbook on composite-bridge design [8], the end cross-girder shown in Fig. 1 is employed for the present study. The whole end cross-girder and the parts of the main girders are taken out to construct the end cross-girder model. The end portion of each main girder, the length of which is 220 mm, is used in this end cross-girder model. It is noted that the textbook intends to provide a standard design procedure so that the present end cross-girder model is a typical one.

Young's modulus of steel E and Poisson's ration ν are 2.0×10^5 N/mm^2 and 0.3, respectively. The yield stress σ_Y of the main girder is 355 N/mm^2 and that of the end cross-girder 235 N/mm^2. The material behavior of the steel is elastic-plastic of von Mises type with the kinematic hardening rule. The uniaxial stress-strain relationship in

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Fig. 1. End cross-girder.

tension is described by the bilinear curve with the second slope of E/100, which is the material modeling commonly employed for steel members [9].

The horizontal load is applied to the upper flange as uniformly distributed load as well as the dead load of concrete slab. The horizontal load is the inertia force of the concrete slab, by which the basic characteristics of the mechanical behavior of the end-cross girder during earthquake is studied. Since only the end cross-girder is analyzed instead of the whole bridge, some constraints are imposed on the movements of the upper flange of the end cross-girder so that the end cross-girder does not topple laterally: the rotation around the flange-axis (the axis normal to the bridge-axis) and the lateral displacement in the direction of the bridge-axis are not allowed, to be specific. It is noted that in the composite bridge the concrete slab prevents the end cross-girder from toppling laterally.

Fig. 1(a) is the view of the parapet side of the end cross-girder. The arrows in this figure indicate the loading direction. The lateral stiffener and the longitudinal stiffeners are placed on the other side of the girder. The stiffeners are therefore drawn by the dotted lines in this figure. Due to the transverse stiffener at the center of the web and the longitudinal stiffeners, the web can be considered to have two panels: the left panel is named Panel L and the right one Panel R as shown in Fig. 2. Note that all the figures in this paper are the views of the parapet side.

3. End cross-girder model with inspection holes

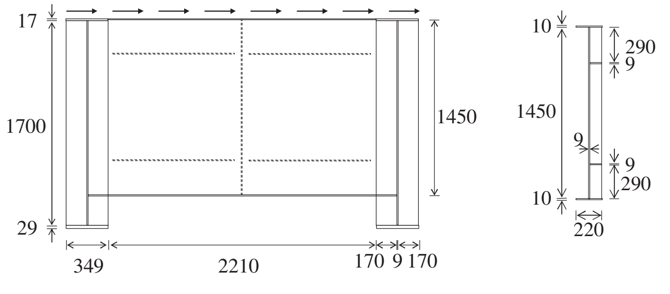
According to the survey by Nakai et al. [10], the standard size of the opening (manhole) in a steel bridge structure is 600 mm in height and 400 mm in width. 95% of the existing manholes are of this size. There are two types in terms of the shape: one has straight left and right sides with semicircular top and bottom sides; and the other is a rectangular hole with rounded corners. 62% of the existing manholes are of the former type and the remaining 38% are of the latter type. The radius of the semicircular side in the former is 200 mm and that of the rounded corner in the latter is 100 mm.

Four end cross-girder models shown in Fig. 3 are constructed for the present study. The inspection holes in Models A and B are of the size identical to that of the standard manhole described above: the hole in Model A is of the semicircular type and the hole in Model B is of the rounded-corner type. Two inspection holes are made in each model, one in Panel L and the other in Panel R. The two inspection holes are located in the symmetric positions with respect to the web center. This is because the seismic loading is cyclic.

The size of the standard manhole is the minimum for a man to pass through without much trouble. For a better inspection in practice, larger holes are preferred. From this viewpoint, another two end cross-girder models, Models C and D are constructed in addition. The holes in these two models are of the same, size 800 mm in height and 530 mm in width. The hole shape in Model C is the same as that of Model A while that of Model D the same as that of Model B.

The position of the hole may influence the load-carrying capacity, which therefore needs be investigated. “a” and “b” in Fig. 3 are utilized to specify the position of the inspection hole. Because of the stiffeners, the values of these parameters are bounded. The holes in Models C and D are so large that they cannot move vertically. That is why only “a” is given in Fig. 3(c) and (d).

In the present study, the following values are assigned to “a” and “b” for Models A and B: a = 25, 350, 675 mm, b = 25, 135, 245 mm. The combination of these values yields 9 different end cross-girders for each of Models A and B. For Models C and D, “a” takes 25, 302.5, 580 mm. Therefore there are three end cross-girder models for each of Models C and D. The name of the end cross-girder model uses the values of these parameters. For example, A-350-25 is Model A with a = 350 mm and b = 25 mm; and D-302.5 is Model D with a = 302.5 mm.



(a) Side view (b) Cross section

Fig. 2. Panels L and R in web.

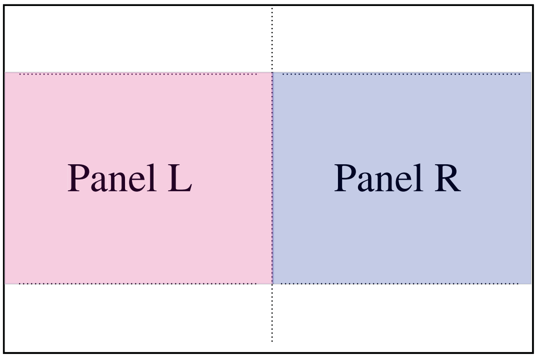


Fig. 3. End cross-girder model.

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