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Shear buckling experiments of web panel with pitting and through-thickness corrosion damage

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ABSTRACT

This study considered the shear buckling behavior of a web panel with pitting and through-thickness corrosion damage in the diagonal tension field. Shear loading tests were conducted on three large-scale specimens under different corrosion damage conditions to compare their shear buckling behaviors. To consider corrosion damage, artificial pitting holes and artificial rectangular sectional damage were induced in the lower web panel of each specimen. Finite element (FE) analysis was also performed to evaluate the shear buckling strength and post-shear buckling behavior. From shear buckling test results, the specimen with artificial pitting corrosion damage exhibited similar shear buckling behavior to the specimen without corrosion damage. However, for the shear buckling specimen with artificial rectangular sectional damage, its shear buckling behavior and shear failure mode changed with a slightly distorted diagonal tension band, and its shear buckling strength and critical buckling load significantly decreased relative to the shear buckling specimen with pitting corrosion. Therefore, the region of corrosion damage should be examined with the corrosion level of the web panel because corrosion pitting or section loss of the web panel can affect the shear buckling behavior when it extends to the critical corrosion damage level in the diagonal tension field.

1. Introductions

A steel plate girder bridge in service for more than 50–70 years will exhibit various types of corrosion damage at the supports of the structure because poor air circulation causes higher relative humidity, dust deposition, and rainwater or antifreeze penetration from drainage-type expansion joints [1–6]. Coats of paint are generally used to prevent corrosion damage to the structural members of a bridge. However, degradation of the paint coating surface can cause pitting corrosion, which can be extended or enlarged according to the atmospheric environment of the bridge installation, as shown in Fig. 1. The structural members can then develop large sectional losses. Because of these corrosion problems, the plate girder bridge collapsed after about 28 years of usage in Japan [6].

Corrosion damage to the web panel of a plate girder bridge can affect the shear buckling behavior and strength. Thus, the shear buckling behavior and failure of web panels with local corrosion damage in a plate girder have been examined experimentally and numerically [1–9]. Experiments have been performed to examine the shear buckling behavior of a web panel with local corrosion through shear buckling loading tests, where the thickness of the web panel specimens is reduced to simulate corrosion damage [5]. Numerically, the shear buckling behavior and failure mode of a web panel that is fully corroded longitudinally have been examined under various corrosion and geometric conditions. Numerical analysis has been used to determine the residual shear strength reduction factor of a web panel with local corrosion based on the corroded web volume [6]. To explain the shear buckling resistant area and shear buckling behavior of a web panel with local corrosion, shear buckling has also been analyzed according to the corroded web patterns and web boundary conditions [9]. As similar condition of severe corroded case, shear buckling capacity of plate girders with large web openings was examined [10]. However, these studies considered the local corrosion in the web panel as equivalently corroded thicknesses; they did not consider the changes in the shear buckling strength, behavior, and failure mode due to pitting corrosion. Therefore, this study considered the effects of pitting corrosion and enlarged pitting corrosion on the web panel of shear buckling specimens, as shown in Fig. 1. Their shear buckling behaviors and failure modes were compared with those of a non-corroded web

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(a) Pitting corrosion

(b) Through-thickness pitting corrosion [6]

Fig. 1. Pitting corrosion in plate girder bridge.

panel. Nonlinear finite element (FE) analysis was also conducted to compare the shear buckling loading test results and evaluate the shear buckling failure and post-shear buckling behavior.

2. Test set-up and program

2.1. Test specimens

In order to examine the shear buckling behavior of web panels with artificial pitting corrosion damage and artificially enlarged corrosion damage through a mechanical process, two corrosion shear buckling specimens were manufactured as pitting corrosion specimen and through-thickness corrosion specimen (enlarged corrosion damage). A basic shear buckling specimen was also manufactured to compare corrosion effects on the shear buckling behavior and failure mode of the web panel. The web panel height of the specimens was 1000 mm, the width of the upper and lower flanges was 200 mm, and the thickness of the flange was 22 mm. The thickness of the web panel was 6 mm; thus, the aspect ratio of the web panel was fixed at 1.0, as shown in Fig. 2. SS400 grade steel was used to manufacture the test specimens. The tensile strength tests showed that the nominal yield stress and tensile strength were 260 and 452 MPa, respectively.

In the pitting corrosion specimen (PT-H200), one side of the web panel was mechanically processed to examine the effect of the distributed corrosion pitting web panel on the shear buckling behavior, as shown in Fig. 1(a). In the through-thickness corrosion specimen (ER-H100), a rectangular piece of the web was removed from the tension field of the web panel, which resists the shear buckling load, to simulate the severe corrosion damage induced by pitting corrosion, as shown in Fig. 1(b). The shear buckling loading test specimens with pitting corrosion and through-thickness corrosion damage were as follows:

1. Basic shear buckling specimen (BS-NC): without corrosion
2. Pitting corrosion specimen (PT-H200): pits with 60 mm diameter and 3 mm depth at a 200 mm height from the lower flange.
3. Through-thickness corrosion specimen (ER-H100): rectangular section with 100 mm height and 180 mm width removed.

2.2. Shear buckling loading test program and instrumentation

To examine the shear buckling behavior of the web panels with pitting and through-thickness corrosion damage, a static load was applied to the center flanges of the plate girder specimens using a 5000 kN capacity universal test machine (UTM). Before the shear loading, grid lines were drawn at intervals of 100 mm on both sides of the web panel to more clearly identify the shear buckling and failure modes. The initial deformations of the web panels were also measured to confirm the imperfection (eccentricity) of the web panel due to the welding process during fabrication of the specimens. An eccentricity of each web panel was measured based on the web plane of the girder section. For BS-NC, an eccentricity of 0.3 mm was measured at the center of the web plane. For PT-H200 and ER-H100, eccentricities of 0.65 and 1.4 mm, respectively, were measured. A relatively slight eccentricity was introduced in the corroded specimens from the welding or cutting processes.

To measure the lateral out-of plane displacement, linear variable differential transducers (LVDTs) were installed at 300 mm intervals longitudinally and vertically in the diagonal tension field area of the web panels of the specimens, and strain gauge rosettes were also attached to the web surfaces at the same intervals to measure the elastic buckling load, shear buckling strength, and shear buckling failure mode and behavior, as illustrated in Fig. 3. Displacement control was used at a load rate of 1 mm/min to load the shear buckling specimens. Shear loading was stopped after shear buckling failure of the specimen. Fig. 4 shows the setup of the shear buckling loading test for PT-H200.

3. Test results

3.1. Shear buckling failure modes

The test results of the two artificially corroded specimens and one non-corroded specimen were compared to evaluate the shear buckling failure modes. The specimens exhibited typical shear failure modes, where a diagonal tension field was developed by the shear resistant behavior of the web panel regardless of the corrosion damage, as shown in Fig. 5. For ER-H100, the diagonal tension field was slightly through-thickness and widened by the loss of the shear resistant section in the diagonal tension field area. However, distinguishing differences in the diagonal tension field areas between PT-H200 and BS-NC was difficult.

To clearly compare the differences in shear failure modes of the specimens, the deformed shape and final out-of-plane displacement of each web panel were also measured with 50 mm distance to compare shear failure conditions based on the change in the shear resistant area, as shown in Figs. 6 and 7. Their diagonal tension field angles were also calculated using final out-of-plane displacement contour results from measured out-of plane displacement results of web panel after loading test. BS-NC showed the typical shear failure mode of the