Irregular Shear Flow in Simply Supported Composite Concrete Beam with Corrugated Steel Web

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Introduction

A number of recently constructed Japanese PC-Box girder bridges utilizing corrugated steel plate as their web have proven an acceptance of corrugated web as a new choice in bridge construction. One of the most favorite behaviors of corrugated steel web is its high shear buckling strength.

However, under an application of loading, an irregularity of shear stress in corrugated panels has been observed. It is thought that a difference in elastic modulus of steel web and concrete, and a stress concentration along a connection of corrugated steel web and concrete in a beam induce a local deformation, which results in this irregular stress distribution, especially in a region near the connection between steel and concrete. The purpose of this study is to investigate such a phenomenon and a finite element analysis is used.

Model and Analysis

Six beams of 2 different corrugated angles (angle of horizontally inclined corrugated plate element), 37°, 45° and 3 different wavelengths, 600, 750 and 900 mm are considered. General view of a simply supported beam model loaded centrally is shown in Figure 1. The beam is symmetric and thus it is modeled and analyzed by a finite element analysis program, ABAQUS, with respect to only a half of the beam as shown in Figure 2.

Shell element, S4, is used in modeling corrugated steel plate and solid element, C3D8, for concrete flanges and concrete stiffeners. Linear elastic analysis is carried out by assuming Modulus of Elasticity, $E=2.06\times10^{11}$ N/m^2 for steel plate and $E=3.00\times10^{10}$ N/m^2 for concrete. The ratio of Modulus of Elasticity is 6.9.

Analysis result

As an example, Figure 3 shows a waterfall plot of calculated shear flow (Depth of web = 1.2 m) in ABCD panel of a model beam with 37 degree corrugated angle and 900 mm wavelength, SL37-900. Shearing force is mainly carried by corrugated web (around 89% maximum) and the remaining is carried by upper and lower flanges.

It can be seen that shear flow is irregularly distributed on each corrugated panel both in corrugated direction (z-axis) and in spanwise direction (x-axis). Maximum and minimum shear flow are found along the connection region of steel plate and concrete flange, especially near the folded points of the plate (encircled points shown in the figure).

Irregular deformation of corrugated section at connection

Figure 4 shows scaled-up deformed shape of the ABCD panel after applying load. Considerable deformation

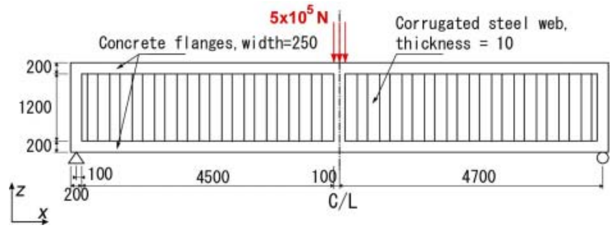

Figure 1. Model beam

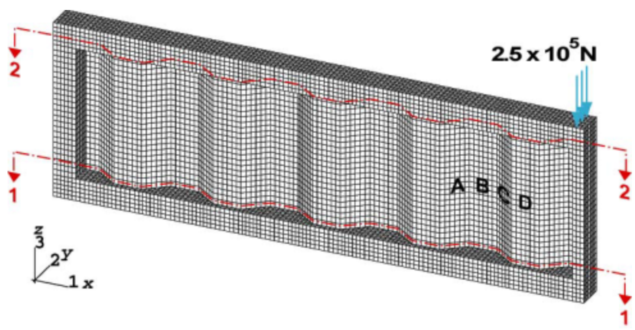

Figure 2. Finite element model

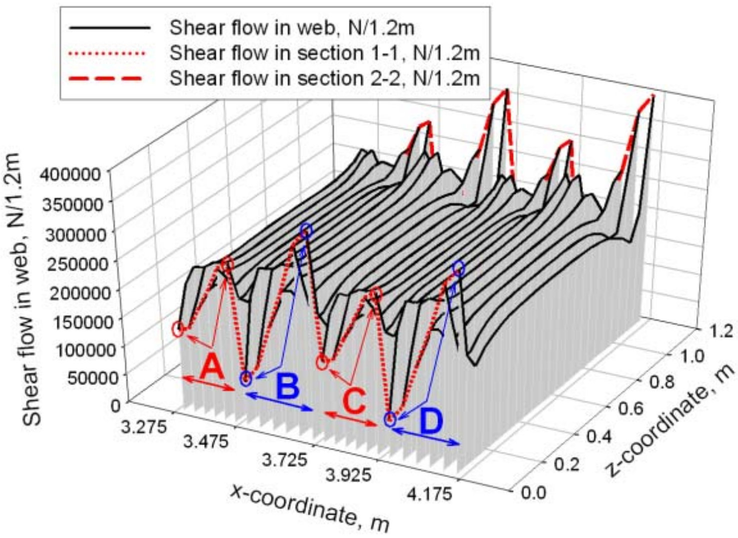

Figure 3. Shear flow in ABCD panels of SL37-900

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is observed at the upper and lower part of the each panel. Upper part of panel B and D, which represent for non-inclined panel, are subjected to inward out-of-plane bending and in-plane contraction of section. On the other hand, lower part of panel B and D are subjected to outward out-of-plane bending and in-plane stretching of section. Elements near the connection of panel A and C which incline to panel B, D and to beam-axis, are subjected to out-of-plane twisting but in-plane contraction in the upper part and in-plane stretching in the lower part.

In-plane deformation of section

In this study, a beam is loaded centrally thus upper flange is in compression while lower flange is in tension. Compression in upper flange is sustained by flange itself and partially by shear transfer at the connection of web and flange. However, because of a planar discontinuity of the corrugated plate at folded lines, shearing stress induced by compression in the flange is mostly concentrated at corner points. The phenomenon is graphically shown in Figure 5. Folding of a corrugated steel web in lower flange also results in concentrated stretching at the corner points.

From this consideration, total shearing stress acts on a connection boundary near a corner point therefore increases when shearing stresses contributed from shear loading and that of compression or tension in flanges are in the same direction (i.e. A2, A4, B2, B4) and decreases when the directions are opposite (i.e. A1, A3, B1, B3).

Out-of-plane deformation

Besides with in-plane deformation of section, out-of-plane deformation of the web is also observed. Figure 6 shows a deformed upper concrete flange where regions I, II and III are deformed locally downward in z-direction.

The difference in elastic modulus of concrete and steel and an eccentricity of the connection of steel web and flange cause non-uniform axial deformations near the lower face of the upper flange. Combined with a small secondary positive bending moment in the upper flange, a small twisting and rotational stiffnesses of the flange, it produces local twisting and rotation of the flange and make the lower face deform download. This creates bending moment along the boundary of web and then results in out-of-plane deformation in the corrugated steel web. Section 2-2 (Figure 1) undergoes contraction while section 1-1 undergoes elongation.

Comparative discussion on six beams

Irregular shear flow is observed in all beams. It is found that 37° and 45° of corrugated angle give almost no different peak shearing stress in the web. However, long wavelength of corrugation yields higher peak shearing

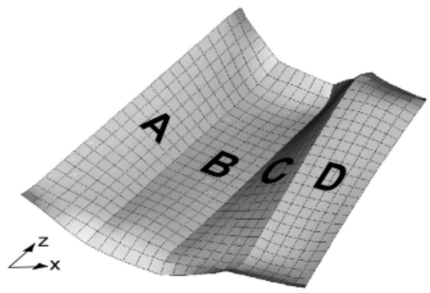

Figure 4. Deformed shape of ABCD panel

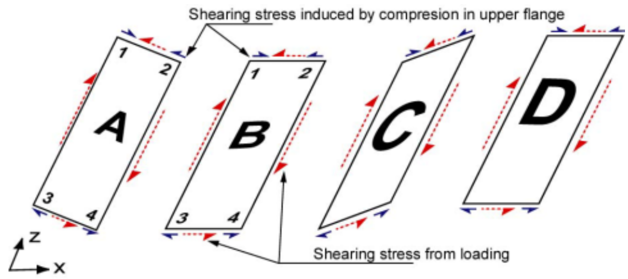

Figure 5. Shearing stresses on ABCD panel

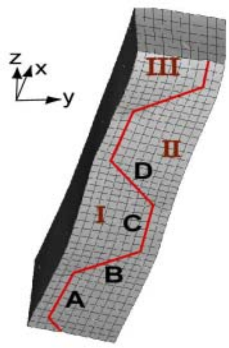

Figure 6. Scaled-up deformed upper flange

stress and more irregular shear flow. In-plane deformation of section and out-of-plane deformation are also evident in beams with long corrugated wavelength.

Conclusion

An irregular shear flow and local deformation of a corrugated steel web near boundary connection is investigated in this study. They are identified as a result caused by a difference in elastic modulus of concrete and steel web and a stress concentration at corner points of the corrugated web due to compression in upper flange and tension in lower flange.

The irregularity of shear flow studied here must not be overlooked in design because the structure is expected to show a better shear resistant, particularly in buckling analysis which initiation of buckling may start from a folded point of high locally shearing stress.

This study is a part of a preliminary investigation in behavior of corrugated steel web utilized in PC-Box girder under shear load. The phenomenon will be further studied in detail and utilized in related study.