Thin-Walled Structures 132 (2018) 79–92

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Stress concentration factors in joints of square hollow section (SHS) brace and concrete-filled SHS chord under axial tension in brace

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ARTICLE INFO

Keywords:
Stress concentration factor
Truss
Square hollow section
Chord
Brace
Concrete-filled
Fatigue

ABSTRACT

It has been shown that concrete filling of square hollow section (SHS) chords in trusses increases fatigue life at the joint between the chord and the SHS brace. Nonetheless, currently there are no expressions for the stress concentration factor (SCF) at these joints. In this study, a robust finite element investigation is carried out to examine SCF in 90° joints made up of empty SHS braces and concrete-filled SHS (CFSHS) chords under axial tension in the brace. Results were validated against experimental data. A comprehensive parametric study was then carried out on 80 FE models to generate a large database for SCFs, considering the effects of key non-dimensional parameters, namely; width ratio between brace and chord of 0.4–1.0, width to wall thickness ratio of the chord of 12.5–25, and wall thickness ratio between brace and chord of 0.25–1.0. Using multiple regression analyses, a series of formulae for SCF were developed for practical design applications. A comparison of SCFs in joints with hollow and concrete filled chords shows a 10–26% reduction in SCFs in concrete-filled chords, leading to better fatigue behavior.

1. Introduction

Composite truss structures with concrete-filled tubular chords are increasingly being used in bridge engineering designs. In a continuous truss girder bridge, the combination of the steel tube and the concrete infill in the lower chord takes full advantage of the confinement effect in compression at the negative moment region over the support [1,2]. Additionally, the presence of the concrete core improves ductility and fire resistance of the member.

The fatigue of welded tubular joints is a well-recognized concern in the design of truss bridges. A review of current literature shows that much research has been carried out on hollow section joints [3–11], among others. Also, fatigue design guidelines for hollow section joints are well established. Because of the high stress concentration factors (SCFs) at the weld toes, fatigue failure of hollow section joints occurs predominantly in the chord. Filling the hollow chords with concrete showed a significant reduction of SCFs by reducing the chord face deformation (in square sections) or ovalization (in circular sections). Udomworarat et al. [12,13] conducted experiments on the fatigue behavior of concrete-filled circular hollow section (CFCHS) K-joints and showed significant reductions in SCFs compared to the hollow tubular joints. Other studies on CFCHS T-joints by Chen et al. [14] and Wang et al. [15] indicated that the concrete infill enabled a more uniform rigidity in the vicinity of the chord-brace joint, thereby decreasing the SCFs and increasing fatigue life. Similar conclusions were drawn by Xu et al. [16] for thin-walled CFCHS T-, Y-, K- and KT-joints. Mashiri and Zhao [17] carried out experimental work on concrete-filled square hollow section (CFSHS) T-joints subjected to in-plane fatigue loading in the brace. It was concluded that an average reduction of 40% in the highest SCF was observed at the joint, compared to the hollow section joint. Tong et al. [18,19] investigated the fatigue behavior of CHS-CFSHS T-joints made up of circular hollow section (CHS) braces and CFSHS chords. The maximum SCFs in the CHS-

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https://doi.org/10.1016/j.tws.2018.08.014
Received 10 March 2018; Received in revised form 1 August 2018; Accepted 8 August 2018

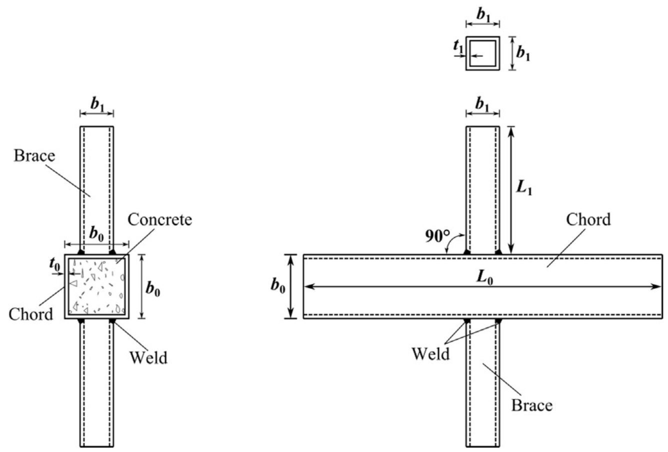

Fig. 1. Schematic of X-joint showing geometric parameters.

CFSHS joints subjected to axial compression, axial tension and in-plane bending were 42%, 67% and 78% (on average), respectively, of those in the empty joints.

The most commonly used method to assess the fatigue behavior of welded tubular joints is the hot spot stress method, which takes into account the uneven stress distribution, through the SCFs. Finite element (FE) analyses have been used for the prediction of SCFs (e.g. Kim et al. [20] derived equations to estimate SCFs for CFCHS N-joints while Tong et al. [18] derived equations to estimate SCFs for CHS-CFSHS T-joints under various brace loading conditions). Square hollow sections (SHS) provide a simpler profile for the joints, which reduces the cost of fabrication compared to circular sections. However, there are no specialized SCF formulae for CFSHS joints in the literature.

In practical bridge joints, different load cases, such as axial force, in-plane bending moment and out-of-plane bending moment could be applied to the brace and chord members. In the hot spot stress method, the hot spot stress at one location under one loading case is the product of the nominal stress and the corresponding SCF. Superposition of hot spot stresses at the same location can be used for the combined loading cases in practical bridge joints.

This study focuses on establishing SCF for 90° joints of square sections, namely CFSHS chords and SHS braces subjected to axial tension. Axial compression in the brace was deemed less critical because SCFs in this case are much lower than in tension, due to the core concrete in the chord. Three-dimensional FE models were developed and verified using test results. A parametric analysis was then developed to evaluate the influence of the key non-dimensional geometric parameters on SCF. Finally, SCF formulae were proposed through regression analysis based on the FE results. Comparisons of SCFs in joints with and without concrete fill in the chord were also made.

2. Finite element model and verification

The numerical simulations of SHS-CFSHS joints subjected to axial tension in the brace were carried out using the FE package ABAQUS to establish the SCFs. The following sections provide details of the model. Because the study is concerned specifically with SCFs due to axial tension in the brace, the commonly known X-joint arrangement was modeled, which includes an additional fictitious brace member on the other side of the chord, in alignment with the main brace (Fig. 1). This practice which was used by other researchers in the past [e.g. 6,21,22] enables the determination of SCFs due to brace tension only and excludes the contribution of bending in the chord.

2.1. Element type and mesh size

Due to the high accuracy requirements and that focus is being on the stress concentration at the joint, three-dimensional 20-node solid elements with an integration scheme of 2 × 2 × 2 (C3D20R) were used to model the steel tube, the weld shape and the concrete fill, as recommended by the CIDECT Design Guide No.8 [23]. The feature ‘Structured’ was used to complete meshing in ABAQUS. Also, mesh sensitivity analysis was carried out to get the optimal mesh refinement. Fine mesh was adopted for the weld and its vicinities along the brace and chord (Fig. 2) to improve the accuracy of the determined SCFs. As suggested in [21,22] for FE simulation of welded tubular X-joints, four layers of solid elements were provided through the thickness of the steel tube for thick-walled tubes with width-to-thickness ratios $b_0/t_0 \le 20$ for chord and $b_1/t_1 \le 20$ for brace. On the other hand, two layers of solid elements were provided through the thickness of thin-walled tubes with $b_0/t_0 > 20$ for chord and $b_1/t_1 > 20$ for brace. Additionally, mesh sensitivity analysis showed that the difference in the mesh density

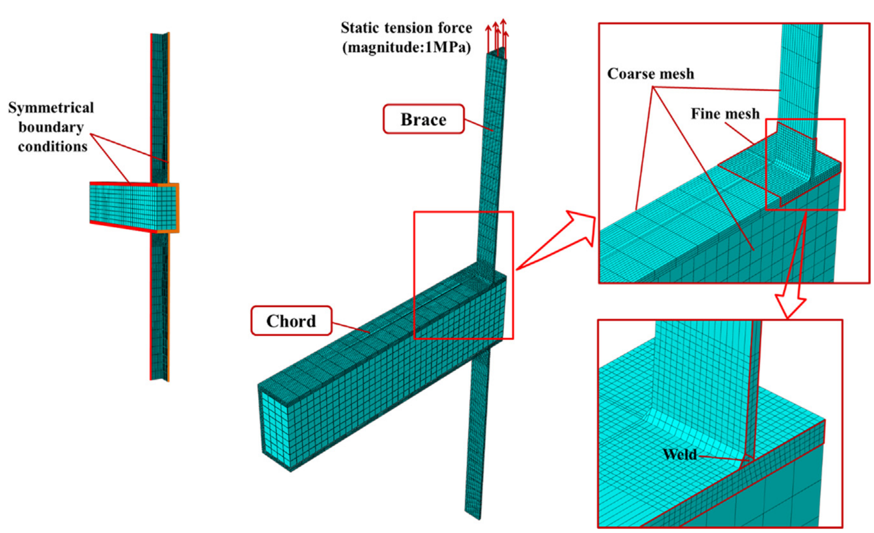

Fig. 2. FE model of SHS-CFSHS X-joint.