Stress Concentration Factors in Circular Hollow Section T-joints with Concrete-Filled Chords

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Abstract

The use of welded trusses made up of concrete filled circular hollow sections (CFCHS) is currently being increased in highway bridges in many countries. Most bridge failures are due to fatigue problems in welded joints. Therefore, many research studies are paying attention to the improvement of fatigue strength in these types of joints. Cyclic loading has direct impact on increasing the chance of fatigue to occur, especially at hot spot locations, where cracks are likely to initiate and propagate. In this paper, experiments on a welded concrete filled circular hollow sections (CFCHS) T-joint with a small non-dimensional parameter, β (ratio of diameter of brace, d, to diameter of chord, D) subjected to axial loads and in-plane bending are presented to determine the strain concentration factors (SNCF) on hot spots in a welded joint.

Keywords: Tubular section, tubular joints, concrete-filled steel tube, stress concentration factor, fatigue.

1. INTRODUCTION

Cyclic loading is a repeated loading or stress applied to a structure. Due to cyclic loading, fatigue will develop in the structure in general and in the welded parts in particular. Fatigue is the weakening of the material caused by cyclic loading (Fisher & Roy, 2010). The behavior of steel under cyclic loading has been studied for a long time; therefore, the allowable fatigue stress has been determined to be a function of type of loading, strength of steel, and the ratio of minimum stress to maximum stress.

In recent years, fatigue failure has been one of the most common concerns that requires special focus and a good understanding of its mechanisms and risk factors to minimize possibilities of failure. To study fatigue life of steel structures, design engineers should examine fatigue strength under realistic loading conditions such as, traffic, wind and wave loading, in addition to the structure dead load (Mann, 2010). The stages of the fatigue process are; crack initiation, crack propagation, and sudden fracture or brittle fracture. Fatigue cracks always initiate at the welded joints due to high stress concentration at the intersections (the hot spot region).

Therefore, a welded steel tubular T-joint has been tested to determine the location of high strain concentration. Strain concentration factors have been determined based on the hot spot stress method for T-joints subjected to axial tension, compression and in-plane bending, and the strain concentration factors (SNCF) for concrete filled circular hollow section (CFCHS) T-joints have been compared to those for empty tubular joints based on current design guidelines.

2. TEST SPECIMEN

A specimen of concrete filled circular hollow section (CFCHS) T-joints was prepared for testing. The specimen has a concrete filled circular hollow section chord member welded with an empty circular hollow section brace. The chord and the brace have different geometric parameters. The chord is of size 165.1x5.4 mm with a length of 1000 mm and the brace is 48.3x5.4 mm with a length of 572 mm, Figure 1. The specimen is made of grade C250LO steel, whose minimum yield strength is 250MPa and minimum tensile strength is 320MPa (Standards Australia 2009). Steel tensile testing showed that the mean yield stress for the steel was 300MPa, the ultimate tensile strength was 370MPa, and the elongation percentage was 32%. The chord has been filled with concrete of grade 32MPa and the compressive strength test showed that the compressive strength for the concrete was 36MPa.

A jack was used to apply tension and compression axial load as well as in-plane bending at the end of the brace. The magnitude of the applied loads was 3kN, 6kN, 9kN, and 12kN respectively in ten cycles of loading. The specimen was loaded under linear elastic condition. This test was carried out to determine the differences in joint behavior under tension, compression and in-plane bending. The specimen was simply supported at the two ends of the chord member. The dimensions of the specimen are shown in Figure 1.

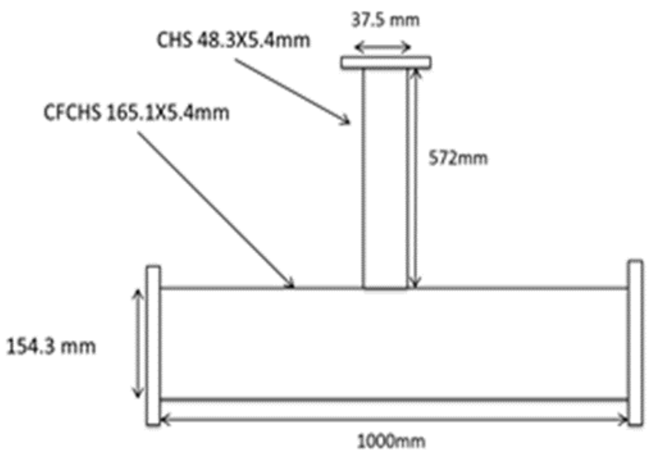

Figure 1. Specimen and dimensions

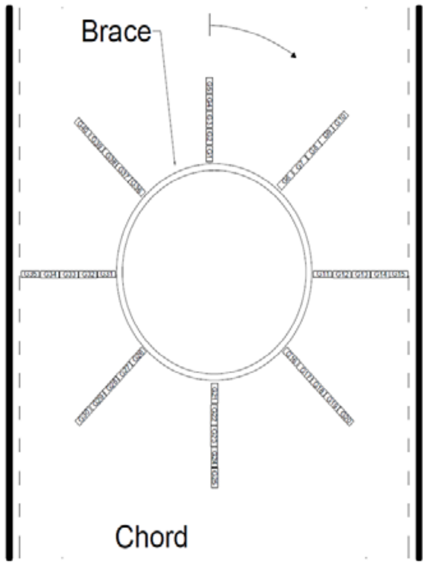

Figure 2. Strain gauge locations in the chord (Chen & Roy, 2011)

Strain gauges were placed around the entire chord-brace intersection in lines on both the brace and chord at 45˚ intervals as shown in Figure 2. A set of strip strain gauges with five strain gauges each was located in each line, as shown in Figure 2. The minimum distance between the strain gauges and the welded toe was 4 mm, and the maximum distance was 8 mm based on recommended extrapolation region from CIDECT Design Guide (Zhao et al 2001). In order to measure the nominal strain, four strain gauges were placed at the midpoint of the brace around the outer surface at 90˚ intervals.

2.1. T-joint under axial Tension

Axial tension loads were applied to the end of the brace starting with a minimum value of 0kN and ending with maximum load value of 12kN. By recording strain values around the intersection of the chord and the brace, hot spot strain can be calculated by using the linear extrapolation method after plotting the strain with respect of strain gauge distance from the welded toe on the crown, middle, and saddle position of the chord and the brace. Figures 3 and 4 show the strain distribution on the chord crown and brace crown respectively, under axial tension for consecutive load increases.

2.2. Strain Concentration Factors (SNCF)

The strain concentration factors (SNCFs), fatigue life would be easy to assess at welded joints. The SNCF can be determined experimentally by measuring strain at the hot spots using strain gauges.

SNCF is the ratio between the hot spot strain at a welded joint and the nominal strain in the member that causes this hot spot strain (Tong et al 2007).

$$SNCF = HSS / Nominal\ strain = \varepsilon_{hssn} / \varepsilon_{nom} \quad (1)$$

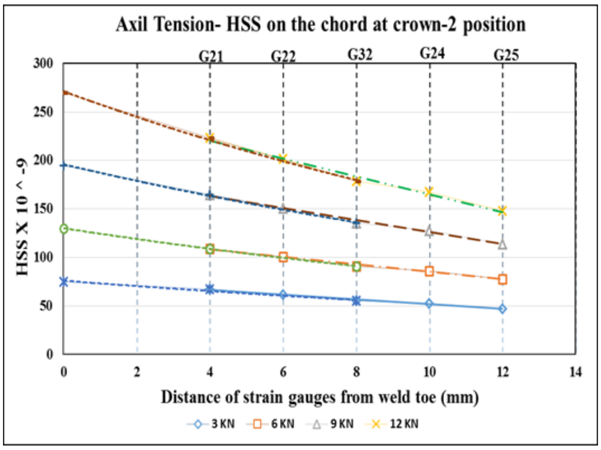

Figure 3. Hot spot strain (HSS) values on the chord crown position - tension

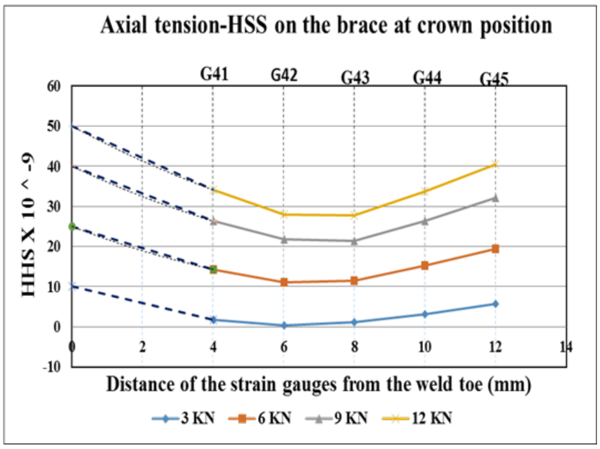

Figure 4. Hot spot strain (HSS) values on the brace crown position - tension

2.3. Experimental results and discussion

The experimental strain concentration factors at the crown, middle, and saddle locations of the chord and brace members of concrete filled circular hollow section T-joint (CFCHS) under axial tensile forces on the brace were determined based on the hot spot strain and the nominal strain. By calculating the strain concentration factor for empty T-joints using the equations given in the Design Guide for Circular and Rectangular Hollow Section Welded Joints under Fatigue Loading-8, (Zhao et al 2001) and comparing them with the experimental strain concentration factors, a significant difference can be noted. Maximum values for SNCF in the empty circular hollow section T-joint are on the saddle. The average of the experimental strain concentration factors (SNCFs) distributions on the chord and brace of the specimen and the calculated (SNCFs) for empty CHS joints are plotted in Figure 5 and Figure 6, respectively.

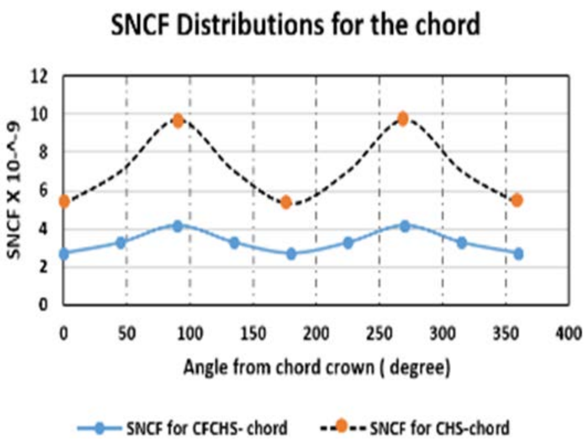

Figure 5. Axial tension-SNCFs distributions for the chord

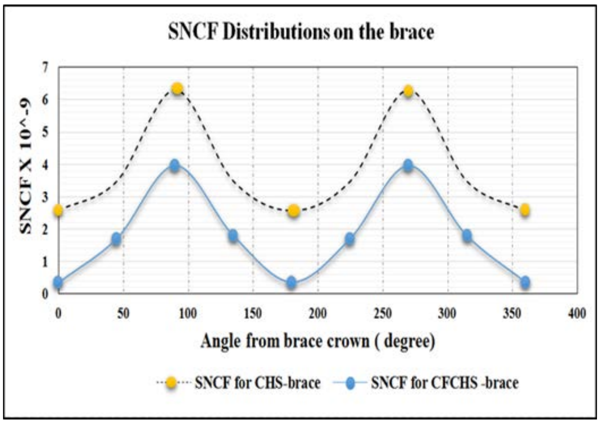

Figure 6. Axial tension-SNCFs distribution for the brace

2.4. T-joint under axial compression

Four different axial compression loads, 3kN, 6kN, 9kN, and 12kN, were applied to the end of the brace in ten cycles, starting with a minimum value of 0kN, and ending with maximum load value of

12kN. By recording strain values around the intersection of the chord and the brace, hot spot strain (HSS) can be calculated by using the linear extrapolation methods after plotting the strain with respect of strain gauge distance from the welded toe on the crown, middle, and saddle position of the chord and the brace. Figures 7 and 8 show the strain distribution on the chord crown and brace crown respectively, under axial compression.

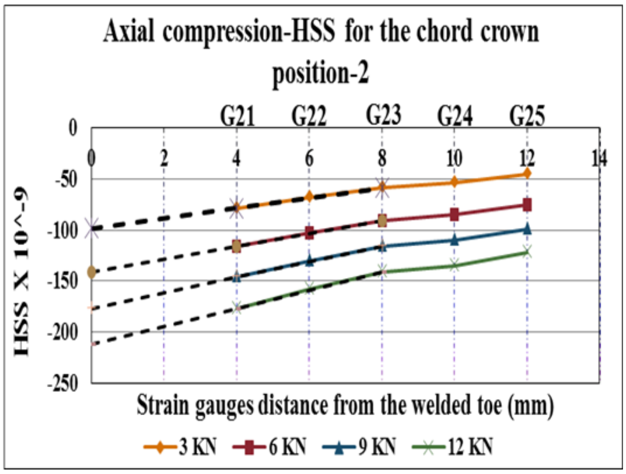

Figure 7. Hot spot strain (HSS) values on the chord crown position - compression

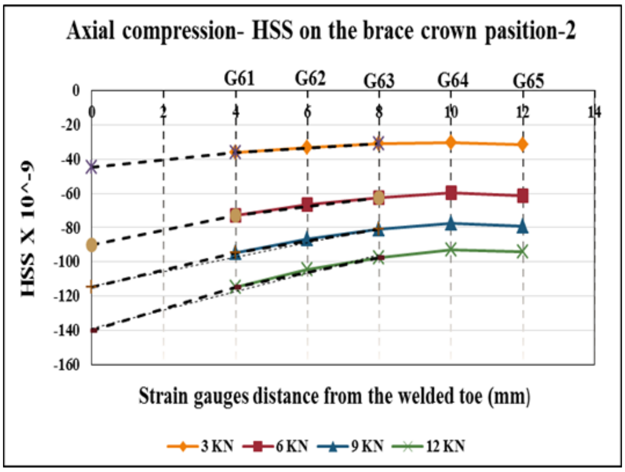

Figure 8. Hot spot strain (HSS) values on the brace crown position - compression

2.5. Experimental results and discussion

The experimental strain concentration factors (SNCF) at the crown, middle, and saddle locations of the chord and brace members of concrete filled circular hollow section T-joint(CFCHS) under axial compression forces on the brace were determined. By comparing the SNCFs for the axial tension and the SNCFs for axial compression, the magnitude of the maximum SNCF for tension in the chord is comparable to that for compression. The average of the experimental strain concentration factors (SNCFs) distributions on the chord and brace of the specimen are plotted in Figure 9 and Figure 10, respectively. Figures 9 and 10 show that the maximum SNCFs, which occur in the chord, moves from the saddle under tension to the crown location under compression.

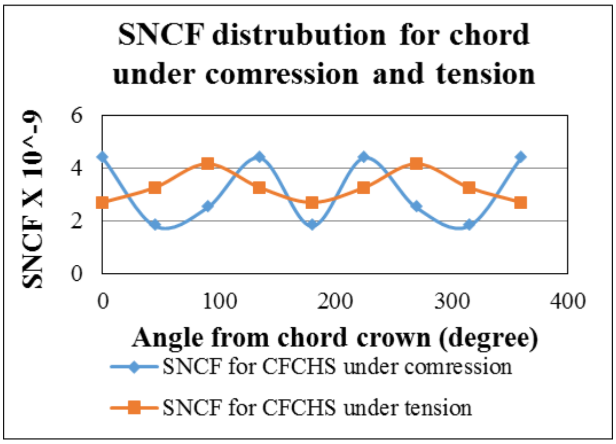

Figure 9. SNCFs distributions for the chord under compression and tension

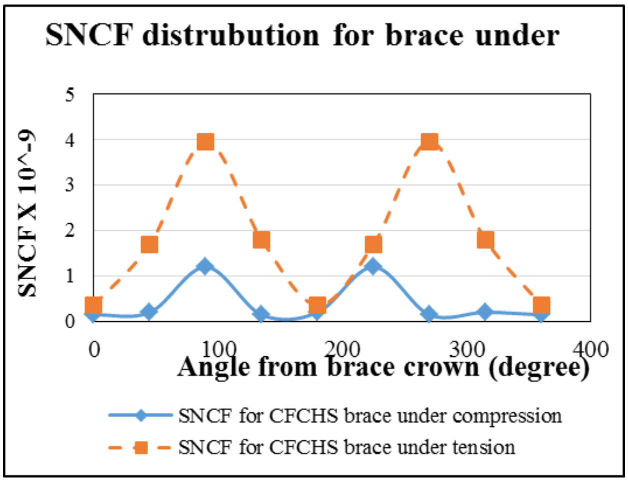

Figure 10. SNCFs distribution for the brace under compression and tension

2.6. T-joint under in-plane bending

Two different in-plane bending moments, 0.245kNm and 0.36kNm were applied to the end of the brace in ten cycles, starting with a minimum value of 0kNm, and ending with maximum load value of 0.36kNm. By recording strain values around the intersection of the chord and the brace, hot spot strain (HSS) can be calculated by using the linear extrapolation methods after plotting the strain with respect of strain gauge distance from the welded toe on the crown, middle, and saddle position of the chord and the brace. Figures 11 and 12 show the strain distribution on the chord crown and brace crown respectively, under in-plane bending in the brace.

2.7. Experimental results and discussion

The experimental strain concentration factors (SNCFs) at the crown, middle, and saddle locations of the chord and brace members of concrete filled circular hollow section T-joint(CFCHS) under in-plane bending moment on the brace were determined. The strain concentration factors for empty CHS which have been calculated using equations given in Design Guide for Circular and Rectangular Hollow Section Welded Joints under Fatigue Loading No. 8, (Zhao et al 2001). By comparing the experimental in-plane SNCFs for CFCHS and the calculated in-plane bending SNCFs for CHS, a significant difference can be noticed. The average of the experimental strain concentration factors (SNCFs) distributions on the chord and brace for the specimen and the strain concentration factors (SNCFs) distributions on the chord and brace for CHS are plotted in Figure 13 and Figure 14, respectively. SNCFs under in-plane bending show a slight decrease due to concrete filling at the crown position. However, the brace location does not seem to benefit due to concrete-filling under in-plane bending as shown in Figure 14, with SNCFs slightly higher than those in empty joints. However, the maximum SNCF for the CFCHS T-joint, which occurs in the chord, is still lower than that for the empty CHS T-joint.

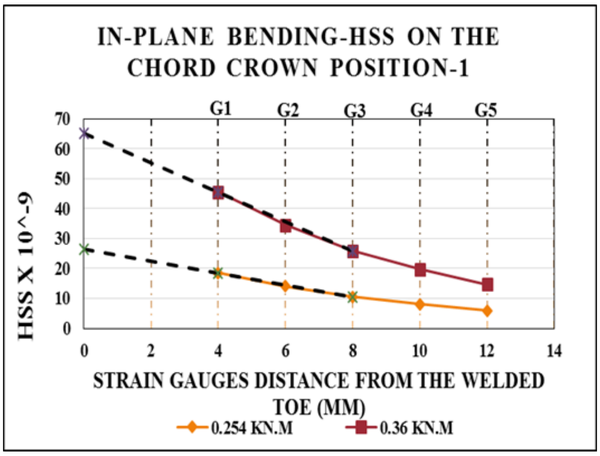

Figure 11. Hot spot strain (HSS) values on the chord crown position – In-plane Bending

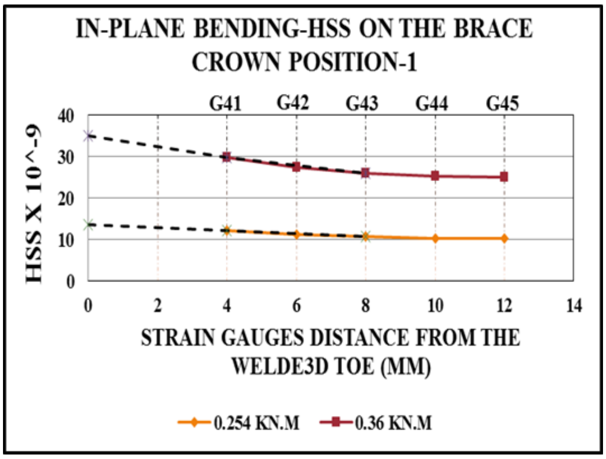

Figure 12. Hot spot strain (HSS) values on the brace crown position – In-plane Bending

3. CONCLUSIONS

An experimental investigation has been carried out at Western Sydney University laboratory on a specimen made of concrete filled circular hollow section chord welded to an empty circular hollow section brace subjected to axial tension and compression forces and in-plane bending. Material properties of the steel and concrete used in the test specimen were measured, and the following conclusions have been emerged from the study. After measuring the strain on the chord and the brace, by recording the strain data, hot spots strain (HSS) has been determined to calculate strain concentration factors (SNCF) in both the chord and the brace. The results were compared with the existing research results of welded empty T-joints made of circular hollow section (CHS) from the Design guide 8 (Zhao et al 2000).

1. The CFCHS joint has lower SNCF in its chord and brace when its brace is loaded in tension compared to empty CHS T-joints.
2. The CFCHS joint has lower SNCF in its brace when its brace is subjected to axial compression forces compared to empty T-joints. Maximum SNCFs for axial compression forces are of the same magnitude as maximum SNCFs for axial tension forces but occur in different locations.
3. The SNCFs for the CFCHS T-joints in the chord are lower when it's subjected to in-plane bending in the brace compared to the SNCFs for an equivalent empty CHS T-joint. The maximum SNCF for the empty CHS T-joint is at the chord crown position, while the SNCF for the CFCHS T-joint is minimum at the chord crown position of 180^o degrees due to compression at this location.

The concrete filling effectively reduces the peak SNCF under both axial loading and in-plane bending. The concrete in-fill in the CHS T-joint also improves the stiffness and the strength of the joint significantly.

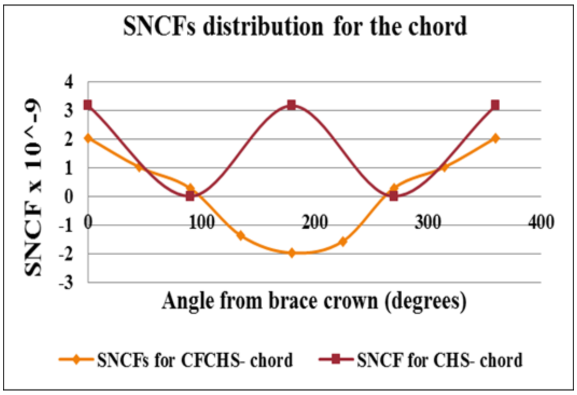

Figure 12. SNCFs distributions for the chord under In-plane Bending

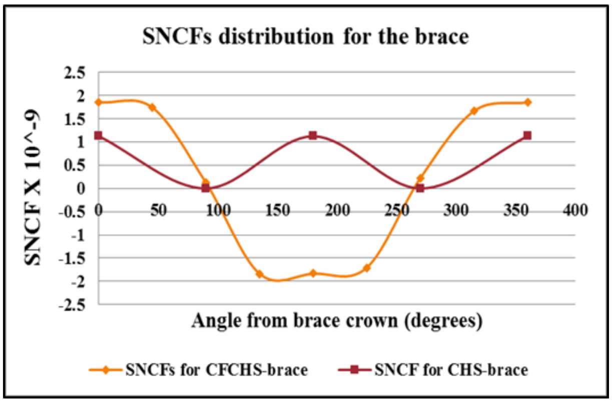

Figure 13. SNCFs distribution for the brace under In-plane Bending

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