Formulation of Stress Concentration Factors for Concrete-filled Steel Tubular (CFST) T- and K-joints under Various Loading Conditions

長崎大学大学院工学研究科
鄭　建

After the construction of the first concrete-filled steel tubular (CFST) arch bridge, Wangcang East River Bridge in 1990, CFST trussed arch bridges have become very popular, and more than 400 CFST arch bridges have been constructed in the last 25 years in China. Their arch ribs can be categorized into solid type and trussed type, and the latter accounts for about 38%. The trussed arch ribs consist of concrete-filled circular chords and circular hollow braces generally connected with full penetration butt welds to form CFST joint, including T-joints, Y-joints, K-joints, N-joints and so on. The filled-in concrete delays bucking of steel tube, and improves its compressive strength and ductility. However, the intersection with full penetration butt welds in CFST joint can be the weak part in the whole structure since the axial stiffness of brace is much larger than the radial stiffness of chord tube, which leads to high stress concentration around the chord-brace intersection. In fact, the fatigue cracks seriously damaging the structural safety were found in the chord-brace intersection of a half-through CFST trussed arch bridge in China. Furthermore, very limited researches have been conducted on the fatigue problem of CFST joints. Some issues of the existing researches for CFST T- and K-joints were given as follows.

(1) The existing researches considered that filled-concrete can improves the local stiffness at the chord-brace intersection of CFST T-joints and its effect can be equivalent to the increase of chord wall thickness. They proposed a determination method of the equivalent chord wall thickness to use the existing SCF formulae for circular hollow section (CHS) T-joints. However, the SCFs calculated by the method were generally larger than the experimental investigation, especially under axial compressive force in the brace. In addition, the validity range of diameter to thickness ratio of chord (2γ) in the method does not match its practical range of bridge structures. Furthermore, the influence of relative chord length (α) on SCFs is not investigated.

(2) The SCF formulae for CFST K-joints have been not proposed because of few studies devoted to the SCFs determination. Moreover, the validity ranges of diameter to thickness ratio of chord (2γ) and thickness ratio (τ) do not match the practical ranges of bridge structures.

In this dissertation, in order to simplify SCF calculations and provide a reference for fatigue evaluation of CFST T- and K-joints, the author tries to solve the problems aiming at proposing the SCFs formulae of CFST T- and K-joints under various loading condition. It is composed of six chapters as described as follows.

In Chapter 1, it gives the background and objectives of the research together with an overview of the major previous research works conducted in the related research filed. Then the layout of the dissertation is given.

In Chapter 2, a large amount of data about 119 CFST trussed arch bridges in China were collected by literature review and website investigation, first. The geometric parameters statistics on CFST K-joints were analyzed in terms of diameter ratio (β), diameter to thickness of chord (2γ), thickness ratio (τ), the eccentric ratio (ρ) and the angle (θ) between the axis of the chord and brace. The practical ranges of each key geometric parameter were provided for the numerical parameter analysis.

In Chapter 3, the published experiments relating to the studies on SCFs of CFST T-joints under axial force in the brace and in-plane bending in the brace, and the strain distribution along chord-brace intersection of CFST K-joints were outlined first. Then FE models to replicate the SCFs of CFST T-joints and the strain distribution along the intersection of CFST K-joints were developed. By comparing the experimental results with that calculated by FE analysis, the accuracy of the FE modeling to determine SCFs for CFST T- and K-joints was confirmed. The FE modeling can be provided for parametric analysis.

In Chapter 4, it focuses on the SCFs of CFST T-joints under various loading conditions. The loading conditions include that axial force in the brace, in-plane bending in the brace, out-of-plane bending in the brace and the force in the chord. Extensive parametric analyses considering the influences of diameter ratio (β), diameter to thickness of chord (2γ), thickness ratio (τ) and relative chord length (α). Then, based on the parametric analysis results, a series of SCF formulae of CFST T-joints subjected to various loading conditions were proposed as functions of key non-dimensional geometric parameters. Finally, the accuracy of the formulae was verified by comparing the SCFs obtained by the formulae and FE analysis.

In Chapter 5, the local FE models were employed to preliminary reveal the influences of key geometric parameters on SCFs of CFST K-joints under the axial forces caused by the loading of a fatigue vehicle. The loading conditions include that basic balanced axial forces, axial compression in the chord and in-plane bending in the chord for the parametric analysis. Extensive parametric analyses considering the influences of diameter ratio (β), diameter to thickness of chord (2γ), thickness ratio (τ) and the angle (θ) between the axis of the chord and brace. Then, based on the parametric analysis results, a series of SCF formulae of CFST K-joints subjected to various loading conditions were proposed as functions of four key geometric parameters. Finally, the accuracy of the formulae was verified by comparing with the FE results.

In Chapter 6, the main conclusions of each chapter are summarized. The points that need to be conducted in the further work are also pointed out.