Journal of Constructional Steel Research 115 (2015) 121–130

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Local joint flexibility of completely overlapped tubular joints under out-of-plane bending

Fei Gao [a], Biao Hu [b,*]

[a] School of Civil Engineering and Mechanics, Huazhong University of Science and Technology, Wuhan, Hubei 430074, PR China
[b] Department of Architecture and Civil Engineering, City University of Hong Kong, Kowloon, Hong Kong

ARTICLE INFO

Article history:
Received 9 March 2015
Received in revised form 12 July 2015
Accepted 4 August 2015
Available online 22 August 2015

Keywords:
Completely overlapped tubular joint
Local joint flexibility
Parametric study
Parametric equation
Out-of-plane bending

ABSTRACT

Parametric equations are proposed to predict the local joint flexibility (LJF) of completely overlapped tubular joints under lap brace out-of-plane bending (OPB). MARC, a general finite element (FE) package, is adopted to simulate the joint behavior with 8-node thick shell element. The FE model is calibrated and verified with existing database of both completely overlapped tubular joints and T/Y-joints. Using the verified FE models, a comprehensive parametric study is subsequently conducted to explore how each selected non-dimensional parameter affects local joint flexibility coefficient (f_{LJF}) and mechanism is given based on a simplified mechanical model. According to the findings from parametric study, significant design recommendations are put forward to reduce the LJF of the joint. A set of parametric equations is proposed based on the regression database of 5184 FE models and have been assessed against the acceptance criteria of Fatigue Guidance Review Panel. Finally, the comparison of f_{LJF} calculated by the proposed equations and existing T/Y-joint equations indicates that it is excessively conservative to use T/Y-joint equations directly to predict LJF of completely overlapped tubular joints.

1. Introduction

In offshore structures, the use of simple gap tubular joints is more popular than circular hollow section (CHS) joints with complete overlap of braces. This might be attributed to the fact that the configuration of simple gap joints is relatively straightforward and that an extensive research with regard to the joints has been conducted and better understanding was acquired. The completely overlapped tubular joints, however, have substantiated advantages of affording easier fabrication and better strength behavior than simple gap joints [1]. In terms of the configuration, the lap brace is first fully welded onto the through brace, which is then welded onto the chord to form the so-called completely overlapped tubular joint, as shown in Fig. 1. In recent years, a few research works with regard to the joint have been reported, which, however, have yet to be fully investigated, especially in the area of local joint flexibility (LJF).

The tubular CHS joints with complete overlap of braces showed a higher capacity (about 7.3%) than that of the K-joints [2] and several failure criteria were established to define the ultimate load of the joints [3]. Research works [4,5] suggested that completely overlapped tubular joints dissipated much more energy in the compression phase than in the tension phase and showed better performance than N-joints under cyclic loading. Gho et al. [6] specified four failure modes of completely overlapped tubular joints and plastification of through brace wall was found to be the most common type of failure modes for the joints. More recently, Gho and Yang [7] indicated that the boundary conditions and the chord pre-stresses showed little influence on the ultimate strength of completely overlapped tubular joints. In addition, an equation based on 3888 FE models was proposed to predict the joint ultimate capacity and a simplified equation in characteristic format was also developed for limit states design. Through both experimental and theoretical analyses, research works [8–13] proposed a set of parametric equations to predict stress and strain concentration factors of the target joints.

Although the ultimate capacity, hysteretic behavior, failure modes as well as stress and strain concentrations have been studied and meaningful results have been obtained, it should be noted that the LJF of completely overlapped tubular joints is seldom investigated. In the open literature, in terms of completely overlapped tubular joints, the only available findings were the parametric equations to predict LJF of the joints under lap brace axial loading and in-plane bending [14,15]. The effect of LJF on tubular structures is significant and research works [16,17] have suggested that LJF would increase the deflections, redistribute the nominal stresses, reduce the buckling loads and change the natural frequencies of an offshore platform. As a result of this, more work is needed to investigate the LJF of completely overlapped tubular joints under other types of load, i.e., out-of-plane bending (OPB) or combined loadings.

Over the past decades, the LJF for simple tubular joints such as T/Y-, X- and gapped K-joints has been extensively studied and well-established

---

* Corresponding author at: Department of Architecture and Civil Engineering, City University of Hong Kong, Kowloon, Hong Kong.
E-mail address: biaohu3-c@my.cityu.edu.hk (B. Hu).

http://dx.doi.org/10.1016/j.jcsr.2015.08.016
0143-974X/© 2015 Elsevier Ltd. All rights reserved.

Notation

L	chord length
l_T	through brace length
l_L	lap brace length
D	chord diameter
d_T	through brace diameter
d_L	lap brace diameter
T	chord wall thickness
t_T	through brace wall thickness
t_L	lap brace wall thickness
g_T	gap size
α_C	chord length parameter ($2L/D$)
α_T	through brace length parameter ($2l_T/d_T$)
β_{CT}	through brace-to-chord diameter ratio (d_T/D)
β_{TL}	lap brace-to-through brace diameter ratio (d_L/d_T)
γ_C	chord radius-to-wall thickness ratio ($D/2T$)
γ_T	through brace radius-to-wall thickness ratio ($d_T/2t_L$)
τ_{CT}	through brace-to-chord wall thickness ratio (t_T/T)
τ_T	lap brace-to-through brace wall thickness ratio (t_L/t_T);
ξ_T	gap size-to-through brace diameter ratio (g_T/d_T)
θ	angle between chord and through brace
E	Young's modulus
ν	Poisson's ratio
f_{LJF}	local joint flexibility coefficient

parameter equations have been proposed to predict the LJF of the respective joints [18–21]. However, unlike simple T/Y-joints and partially overlapped K-joints, the loads of completely overlapped tubular joints are mainly transferred between the braces without passing the chord and are distributed depending on members' stiffness. Recent research results [7,13] revealed that the completely overlapped tubular joints with small gap size could have lower stress concentration and higher ultimate capacity than simple T/Y-joints. Thus, the equations to predict LJF derived from simple tubular joints may not necessarily be appropriate for the case of CHS joints with complete overlap of braces.

In the current study, the main objective is to afford a better understanding by developing a set of design parametric equations for predicting the LJF of completely overlapped tubular joints under OPB. The results of previous studies are used for the verification and calibration of finite element (FE) models. Then, a detailed parametric study is carried out to explore the effect of each parameter on the LJF and feasible recommendations are presented to reduce the LJF of CHS joints with complete overlap of braces. The parametric equations that are proposed based on a large database of 5184 FE model results are assessed according to the acceptance criteria of Fatigue Guidance Review Panel [22]. Finally, the LJF equations proposed by this study are compared with the existing T/Y-joint parametric equations.

2. Determination of local joint flexibility coefficient

The LJF of tubular joints is defined as the displacement attributed to the local chord or through brace wall deformation caused by a unit external loading. Thus, to obtain the LJF at the intersection of chord and through brace (CT-joint) and the intersection of through brace and lap brace (TL-joint) under lap brace OPB, the rotation of CT- and TL-joints caused by the overall displacement must be eliminated from the total measured rotation. In FE models, the local rotation at CT- and TL-joints can be directly measured without considering the overall beam rotation movement. The LJF at CT- and TL-joints is determined by the local deformation caused by a unit lap brace OPB at the respective joint as expressed in Eq. (1),

$$LJF = \frac{\phi_{OPB}}{M_{OPB}} \tag{1}$$

where, M_{OPB} is the lap brace OPB; ϕ_{OPB} is the joint local rotation as expressed in Eq. (2),

$$\phi_{OPB} = \frac{(\delta_2 - \delta_1)}{d - t}(\sin\theta) - \frac{\delta_4 - \delta_3}{D - T} \tag{2}$$

where, d and D are the brace and chord diameters, respectively; t and T are the brace and chord wall thicknesses, respectively; and θ is the angle between chord and brace. δ_1 and δ_2 are the respective deformations at both saddles measured in the direction of brace axis as shown in Fig. 2. δ_3 and δ_4 are the deformations at the side face of chord corresponding to δ_1 and δ_2, respectively. Local joint flexibility coefficient (f_{LJF}) is introduced, which is non-dimensional and calculated by the LJF multiplied by ED^3 as expressed in Eq. (3),

$$f_{LJF} = \frac{\phi_{OPB}}{M_{OPB}}\left(ED^3\right) \tag{3}$$

where, E is the Young's modulus.

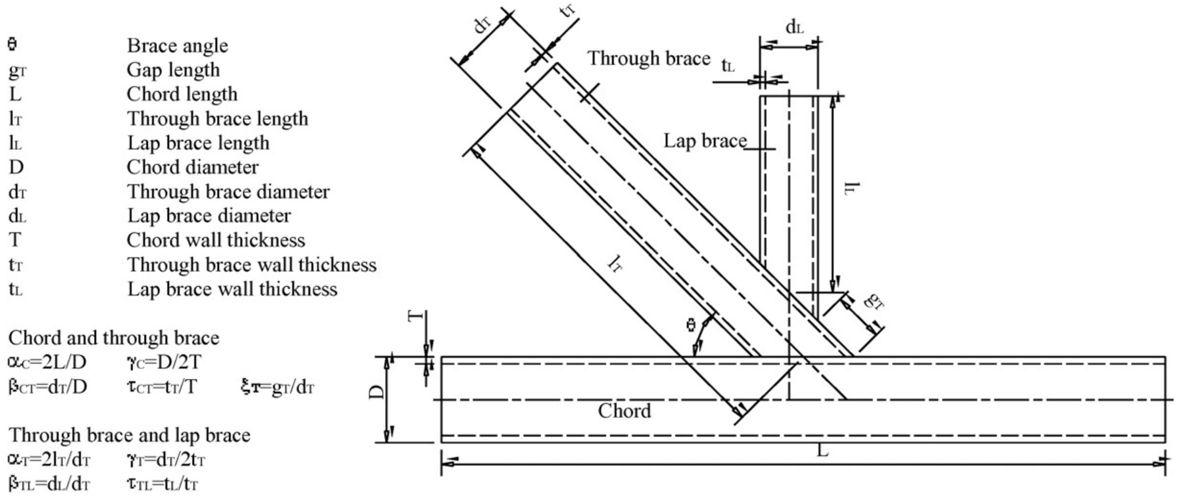

Fig. 1. Geometric parameters of completely overlapped tubular joint.