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Resistance of Axially Loaded T- and X-Joints of Elliptical Hollow Sections at Elevated Temperatures – A Finite Element Study

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ABSTRACT

This study presents the results of a numerical study to develop a method to calculate the static strength of welded Elliptical Hollow Section (EHS) joints at elevated temperatures. Extensive numerical simulations using the non-linear finite element package, ABAQUS v6.14–1 on EHS T- and X-joints under brace axial compression or tension and pre-stress in chord member with different type of joint orientations at elevated temperatures over a wide range of diameter ratio have been conducted. The adjustments required to be made to the equations of joint resistance under ambient temperature conditions for estimating joint resistance at elevated temperature conditions are investigated in this study. The FE simulation results have been compared with the calculation results of a number of existing methods at ambient temperature. It has been found that the method proposed by Packer et al. gives the best agreement with the authors' simulation results at ambient temperature. At elevated temperatures, for T- and X- joints with braces in compression welded to the wide sides of chords, replacing the ambient temperature yield strength of steel by the elevated temperature value in the current design method overestimates the ultimate load carrying capacity of axially loaded EHS T- and X-joints due to inability of the ambient temperature calculation equations to take into consideration EHS flattening at high temperatures. For these cases, it is recommended to calculate the joint strength reduction factor at elevated temperatures according to the Young's modulus of steel.

1. Introduction

Elliptical Hollow Sections (EHSs) have recently become more popular for architectural applications due to their favourable aesthetics and elegant appearance. EHSs have advantages compared to circular hollow sections (CHSs) and rectangular hollow sections (RHSs). From the architectural point of view, EHSs give a sense of slenderness since their minor diameter is half the major diameter and these sections do not have distinct edges like RHSs. Therefore, EHSs allow us to build aesthetically pleasing structures. In terms of engineering standpoint, EHSs have higher flexural and torsional resistance and decrease wind loading effect due to smooth curvature [1–3]. Applications of these steel profiles include bridges, airports, exhibition halls, etc. (see Fig. 1). This study focuses on elevated temperature resistance of joints which are generally the most critical part of the structure. The authors have previously investigated elevated temperature resistance of welded SHS and CHS joints [4] and this research extends the study to EHS joints.

Compared to the research existing on the welded CHS and RHS joints, there is a paucity of research on EHS joints at either ambient or elevated temperatures. Bortolotti et al. [5] and Pietrapertosa et al. [6] conducted a number of tests on EHS X- and N-joints at ambient temperature, however the tests were terminated before joint failure was reached due to a lack of capacity of the loading jack. Choo et al. [7] numerically modelled EHS X joints to examine the behaviour in various orientations as shown in Fig. 2. They concluded that the joint capacity decreased from type 4, 3, 2 to 1. Shen et al. [8–11], Wardenier et al. [12] and Packer et al. [13] investigated EHS X-joints with braces welded to either the narrow or wide side of the chord when the braces

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Notations

A_{chord}	Cross sectional area of chord member
B	Smaller diameter of chord member
C_1	Constant
D	Larger dimension of chord member
L	Length of chord
$N_{1,Rd}$	Design value of the joint capacity expressed as a brace load
T	Wall thickness of chord
P_{20}	Joint strength at ambient temperature
P_{θ}	Joint strength at elevated temperature
Q_f	Function to take account of the effect of chord stress in the connecting face
Q_u	Function in the design strength equations accounting for the effect of geometric parameters
b	Smaller diameter of brace member
d	Larger dimension of brace member
f_k	Buckling stress for chord side wall failure
f_{y0}	Yield stress of chord member
$k_{E,\theta}$	Reduction factors for modulus of elasticity at temperature θ
$k_{y,\theta}$	Reduction factor for yield strength at temperature θ
l	Length of brace
n	Chord pre-stress parameter
t	Wall thickness of brace
β	Diameter ratio (=d/D)
θ	Brace-to-chord intersection angle
θ_i	Included angle between brace member i and the chord
γ	Half width to thickness ratio of the chord (=D/2T)
η	Brace depth d (in direction chord axis) to chord width B ratio
ε_T	The true strain
ε	The engineering strain
σ_T	The true stress
σ	The engineering stress

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Fig. 1. Examples of EHS applications.

were subjected to either compressive or tensile forces. They carried out both experimental and numerical investigations on the behaviour of welded EHS T- and X-joints at ambient temperature. They concluded that the behaviour of EHS X-joint types 1 and 2 (see Fig. 1) were similar to that of RHS joints, whilst EHS X-joints types 3 and 4 could be treated as equivalent CHS joints, and proposed a new method to calculate the joint strength. However, Haque and Packer [14] performed twelve tests to investigate the effects of joint orientation, brace-chord angle and brace loading on the static strength of EHS X- and T-joints. It was found that the equivalent RHS approach was able to predict the capacity of these joints better than the equivalent CHS approach. This may be because an EHS joint has different behaviours in two different directions as an RHS joint and the wider side of an EHS is close to being flat. Moreover, in those studies mentioned above, it was noted that the load – displacement curves did not present a definite peak in some cases. Hence, the joint resistance was defined as the maximum axial force in the brace with a defined joint deformation limit. This will be explained in detail in the next section.

Till date, limited research exists investigating the effects of chord pre-stress (n) on tubular joint strength at elevated temperatures as per the authors' literature review. Shao et al. [16] tested six specimens to examine the influence of chord compressive pre-stress on maximum load carrying capacity of CHS T-joints at elevated temperatures. Feng and Young [17] conducted numerical simulations on T- and X-joints with compressive pre-stress in chord members. They reached similar research findings as Nguyen et al. [18] that chord compressive pre-stress significantly affects