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Bending moment and axial compression interaction of high capacity hybrid fabricated members

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ABSTRACT

Along with proposing any innovative structural element for design purposes it is necessary to understand its behaviour under combined structural actions. This paper includes experimental, numerical and analytical investigations on an innovative type of hybrid fabricated section consisting of high strength tubes and mild steel plates under the effect of axial compression and bending moment interaction. As a special case of interactive condition, pure bending performance of the hybrid fabricated member is examined with focus on the local failure mechanisms and analytical expressions are proposed to predict the moment resisting capacities. Furthermore, compression-bending interaction curves are obtained from plastic analysis of hybrid hollow sections and compared to relevant standard formulations. The compression-bending curves obtained for various ratios of tube cross-section and strength to that of plate show that a linear interaction formula is applicable to predicting the plastic interaction behaviour of sections with high ratios while sections with lower ratios are closely predicted by a bilinear interaction formula. This paper also includes beam-column tests accommodating combined effects of compression, bending and also shear. Employing the developed and validated finite element model, a parametric study is conducted on the effect of section geometry and material on the axial-lateral interaction of beam-columns. Referring to the member interaction results, reaching an optimum interactive performance stands on the design of both geometry and material of plate and tube elements.

1. Introduction

The main concern involved in the flexural behaviour of bending members, especially thin-walled fabricated sections is the local failures occurring before the section reaches its full capacity. Local buckling, yield or rupture can take place depending on the geometry and mechanical properties of the constituting elements of fabricated sections as well as the global restraining and support conditions of beams. These local mechanisms vary depending on the type of cross-section. Built-up members, for instance, are commonly used as structural elements such as bridge beams, plate-girders, etc. due to their high moment resisting capacities. Various buckling modes namely local, lateral-torsional and interactive buckling may also occur in I-sections depending on their geometry [1–4]. Sections with closed cross-sections such as box girders require additional design provisions such as distortion, buckling of wide flanges, force transfer to support bearings etc. [5]. New unaccustomed cross-sections have been proposed in previous research in order to optimise the flexural behaviour of beams [6,7] in which I-shaped and H-shaped bridge girders with tubular flanges were examined and design criteria were proposed. These studies showed the benefits of having rigid hollow flanges and distributing the section away from neutral axis [8,9]. Innovative hollow square fabricated sections with high strength steel tubes at corners have recently been proposed for various structural purposes [10–12] and due to their significant load-bearing enhancement, these sections are the main focus of the present study. These sections consist of tube elements at corners of four mild steel plate elements shaping a closed high capacity section. The corner tubes of this hybrid section can act as torsionally rigid hollow flanges minimising the local buckling of plate elements. Furthermore, the location of tube elements at corners of section helps distribute material away from the neutral axis thus increasing the bending stiffness. An additional benefit of this hybrid fabricated section is utilizing high strength corner tubes. Increasing the strength of corner tubes from mild steel to grade 800 and grade 1200 steel, can increase the stresses at far ends of section resulting in a higher moment capacity.

To date, innovative hybrid fabricated sections consisting of mild steel plates and high strength tubes have been investigated under centrally loaded compression forces. Accordingly, due to limited

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Nomenclature

A_p	Cross-sectional area of plates
A_t	Cross-sectional area of tubes
B	Distance of external plates in hybrid section
D_t	Tube diameter of hybrid fabricated section
f_{yp}	Plate yield strength
f_{yt}	Tube yield strength
L	Beam and beam-column specimen length
M_{bs}	Total bending moment capacity of hybrid section
M_p	Available section capacity
M_{pbs}	Plastic bending capacity of hybrid section obtained from plastic analysis
M_{pr}	Reference plastic moment for R calculation
M_{ps}	Required flexural strength
N	Applied axial force
N_p	Available axial strength
N_{ps}	Required axial strength
R	Plastic rotation capacity
S	Plastic section modulus
t_p	Plate thickness of hybrid fabricated section
t_t	Tube thickness of hybrid fabricated section
V	Applied shear force
V_u	Shear capacity of a web panel under uniform shear stress distribution
V_w	Shear capacity of a web
W_p	Plate width of hybrid fabricated section
Z	Elastic section modulus
Z_c	Effective section modulus for a compact section
Z_e	Effective section modulus
α_v	Web shear buckling coefficient
$\varkappa$	Non-dimensional section parameter
λ_s	Section slenderness
λ_{sp}	Section plasticity limit
λ_{sy}	Yield slenderness
ϕ	Capacity factor

knowledge, this paper follows the comprehensive research previously conducted on the axial performance of hybrid fabricated sections [18–20] and extends the work to pure bending and compression-bending interaction loads, focusing on section specifications such as geometry and steel material. The individual behaviour of single circular hollow high strength and stainless steel tubes has previously been studied under bending loads [21,22]. However, flexural performance of different grades of steel tubes namely mild steel (MS), high strength steel (HSS) and ultra-high strength steel (UHSS) incorporated in innovative hollow fabricated sections are the focus of this paper. Initially, four point bending tests are conducted as a special case of the compression-bending interaction condition where no axial compression loads are applied. Due to the unique geometry of the hybrid sections, an exclusive experimental setup was designed. Taking the event of local mechanisms into consideration, the pure bending capacity of these thin-walled elements are predicted.

Plastic axial-flexural section interaction curves have previously been obtained for several symmetric cross sections such as bisymmetrical and mono-symmetrical I shaped sections and other types of unaccustomed cross sections [13–15]. Steel design standards also provide interaction formulas for the estimation of plastic section capacity under combined uniaxial or biaxial bending and axial compression [16,17]. In this study, the beam-column interaction curves of fabricated sections are extracted for three types of hybrid beam-columns. A method for plastic analysis of structures is considered when the full section reaches a plastic stress state under the applied loads. The interaction curves extracted from this type of plastic analysis is an upper bound estimation applicable to cases where the section does not fail under local mechanisms prior to the plastic failure of section. Analytical results obtained from plastic section investigations are compared against relevant standard design recommendations. At the final stage of this paper, the influence of generated shear stresses on the beam-column performance of full-scale members under combined axial and lateral loading is experimentally and numerically investigates. Subsequently, axial-Lateral force interaction curves are parametrically studies for various geometries and steel materials. This study has been conducted as part of a group research work on fabricated hybrid steel elements and steel material under extreme loading scenarios [23–31].

2. Experimental program

2.1. Hybrid test specimens

The innovative hybrid fabricated sections considered in this study are composed of steel tube elements welded to the corners of steel plate forming a square-shaped hollow thin-walled hybrid section. Geometry

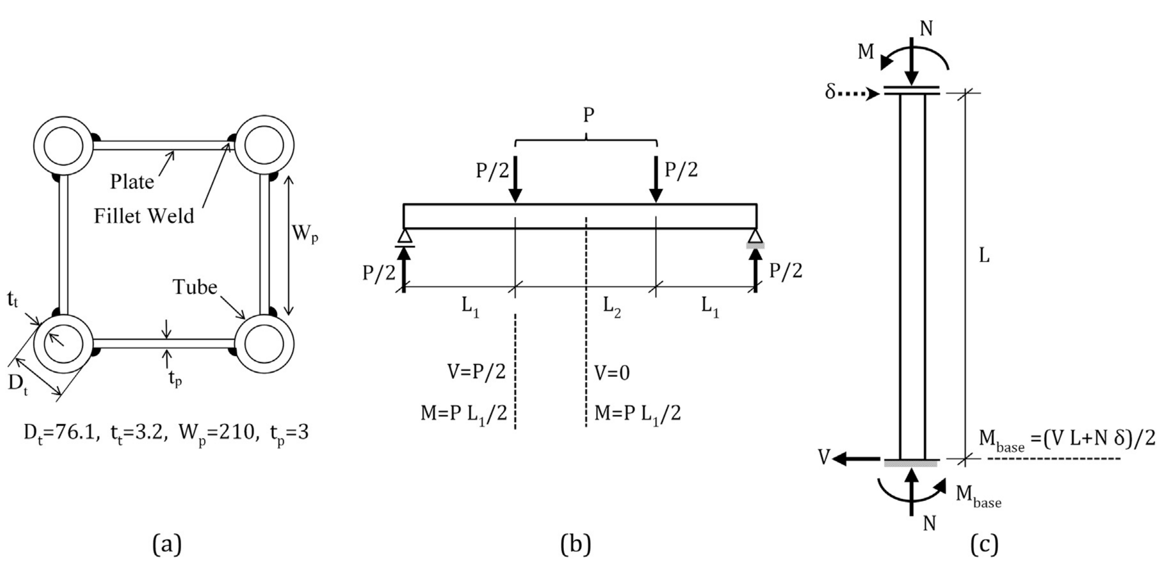

Fig. 1. (a) Specimen geometry; (b) four point bending configuration; (c) beam-column test configuration.