Journal of Constructional Steel Research 148 (2018) 97–111

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Section moment capacity tests of hollow flange steel plate girders

Nilakshi Perera, Mahen Mahendran *

Queensland University of Technology (QUT), Brisbane, QLD 4000, Australia

ARTICLE INFO

Article history:
Received 13 July 2017
Received in revised form 6 April 2018
Accepted 30 April 2018
Available online xxxx

Keywords:
Hollow flange steel plate girders
Rectangular hollow sections
Flexural members
Section moment capacity tests
Design guidelines

ABSTRACT

Hollow flange steel plate girder (HFSPG) is a new hollow flange I-section made using cold-formed rectangular hollow sections (RHS) as flanges and a steel plate as web. Due to the increased torsional rigidity and unique geometry, it can provide enhanced flexural capacities and thus are effective flexural members in long span applications. The production of proposed HFSPGs contains welding currently available RHS sections to a web plate, which allows engineers to form girders by varying dimensions, thicknesses and grades to suit their design requirements. As the first step of this study, the section moment capacities of fully laterally restrained HFSPGs were investigated. Despite earlier researches on the flexural capacities of hollow flange sections, HFSPGs have not been tested previously. Therefore, twelve section moment capacity tests were conducted to study the flexural performance and capacities of HFSPGs. The ratios of ultimate moment capacity per unit area of tested beams were compared with conventionally used hot-rolled I-sections with similar cross-sectional area, which proved the structural efficiency of HFSPGs over commonly used hot-rolled I-sections. The ultimate capacities of tested HFSPGs were then compared with capacity predictions provided by the Australian, American and European design standards (both hot-rolled and cold-formed). It was found that the current design standards under-estimate the section moment capacities of HFSPGs in general and the level of under-estimation varied depending on the section slenderness. Suitable recommendations are made regarding the appropriate use of these design standards for HFSPGs. This paper presents the details of this research and its findings.

1. Introduction

The applications of cold-formed steel have increased due to the benefits it offers over conventionally used hot-rolled steel. To enhance the structural performance of widely used cold-formed open sections, hollow flange sections have been introduced in recent years. The use of hollow flanges eliminates weaker elements with free edges and increases the torsional rigidity of open I-girders. In addition, it provides a higher second moment of area as a result of locating considerable steel area away from its neutral axis, thus leading to an increased flexural capacity about its major axis. After the introduction of the first hollow flange section in 1990, various mono-symmetric and doubly-symmetric hollow flange sections have been introduced and investigated.

Palmer Tube Mills Pty Ltd. produced the first hollow flange beam (HFB) (see Fig. 1 (a)), which consisted of two closed triangular flanges. HFBs were used for spans <10 m, however, connection difficulties with triangular flanges was a weakness of HFBs. Following HFBs, mono-symmetric LiteSteel beams (LSB) (see Fig. 1 (b)) were developed for use as flexural members. Extensive research on the flexural performance of LSBs was conducted by Anapayan and Mahendran [1] and Anapayan et al. [2]. LSBs provided a solution to the connection problem in HFBs and were used in spans up to 15 m. However, although the use of LSBs was advantageous, they are no longer manufactured. Wanniarachchi and Mahendran [3] introduced screw fastened rectangular hollow flange beams (RHFB) (see Fig. 1 (c)) for use in short to intermediate span construction. However, this production method lead to higher initial geometric imperfections and cannot be recommended for larger unsupported spans. Following the applications of single LSBs, designers proposed the use of built-up LSBs by connecting two LSBs using bolts, in order to achieve improved performance. Jeyaragan and Mahendran [4] studied the flexural behaviour of back to back LSBs. Recently, Siahaan et al. [5] studied the flexural behaviour of RHFCB, which is a rivet fastened channel section with rectangular hollow flanges for use in medium span floor systems. As described above, a range of innovative hollow flange sections has been investigated by many researchers for use as flexural members in small span applications (<15 m). However, studies on hollow flange sections for use in large unsupported spans are limited to date.

Advanced architectural designs increase the demand for innovative steel members with more favourable characteristics in large span applications. Hot-rolled and welded I-sections (universal beams-UB, welded beams-WB) are the primary elements used in large span applications. These I-sections are available in 9 to 30 m lengths, therefore, the previously mentioned hollow flange sections cannot be used as alternatives. Due to the unique properties of hollow flange sections, development of a suitable girder with hollow flanges is beneficial for long span applications. Dong and Sause [6] showed that hollow tubular flange girders

* Corresponding author.
E-mail address: m.mahendran@qut.edu.au (M. Mahendran).

https://doi.org/10.1016/j.jcsr.2018.04.034
0143-974X/

Nomenclature

M_s, $M_{c,Rd}$	Section moment capacity
M_y	First yield/elastic moment
M_p	Plastic moment capacity
r_o	Outer corner radius
t	Element thickness
M_{yw}	First yield/elastic moment when yielding commenced at the extreme fibre of the web element
M_{yf}	First yield/elastic moment when yielding commenced at the extreme fibre of the flange element
A_g	Cross-section area
B_f	Width of the flange
D	Total depth of a cross-section
Z_e, $W_{eff,\min}$	Effective section modulus
λ_s	Slenderness of the section
λ_{sy}	Yield slenderness of the section
λ_{sp}	Plastic slenderness of the section
Z, $W_{el,\min}$	Elastic section modulus of the section
Z_c, W_{pl}	Plastic section modulus of the section
b	Width of the element excluding the radii
ρ	Effective width factor
b_e	Effective width of the element
E	Modulus of elasticity
k	Plate buckling coefficient
f^*	Applied stress
M_{bl}	Nominal member moment capacity for local buckling
M_{be}	Nominal member moment capacity for laterally restrained members
M_{ol}	Critical elastic local buckling moment of the section
γ_{M0}	Partial factor of resistance

(HTFG) can be used in bridge construction. Wimer [7] and Kim and Sause [8] studied I-shaped girders with a concrete filled hollow flange in compression and a flat plate in tension, known as concrete filled tubular flange girders (CFTFG) (see Fig. 1 (d)). In their study Kim and Sause [8] concluded that lateral torsional buckling capacity of CFTFGs is immensely greater than that of I-girders if the cross-section distortion is controlled. Hassanein and Silvester [9] used numerical analyses to examine the shear and flexural performance of hollow tubular flange plate girders (HTFPG). In their study, they compared the performance of HTFPGs with I-section plate girders (IPGs) and confirmed the higher capacities of HTFPGs over IPGs. However, it was limited to numerical modelling. Among the novel ideas presented over the years, the literature shows that the use of hollow flange sections provides efficient options over commonly used open I-girders.

The proposed hollow flange steel plate girder (HFSPG) (see Fig. 2) in this research is a built-up hollow flange steel plate I-girder made using commonly used cold-formed rectangular hollow sections (RHS) and a steel web plate. It is expected to achieve a steel girder with improved performance. Based on the RHSs and steel plates available in the market, these sections allow designers to manufacture girders with different thicknesses, dimensions and grades to suit their capacity requirements. The widths of the currently available RHSs vary from 50 to 400 mm and the width/depth ratios commonly used for hollow flanges sections vary from 0.25 to 0.48. The use of these RHS gives HFSPGs a maximum section depth of 1600 mm, which have the potential to span up to 30 m. Also, the ability to use different thicknesses and yield strengths for web and flanges allows the designers to develop optimum sections.

However, the flexural behaviour and capacities of the proposed HFSPGs have not been investigated. Welding of RHSs to a web plate can induce unique geometric imperfections and residual stresses in the members, which will cause significant differences between HFSPGs and the hollow flange sections investigated in the past. Hence a research study was undertaken to investigate the structural performance and capacity of HFSPGs subjected to bending. The focus of this paper is the section moment capacity of fully laterally restrained HFSPGs subject to local buckling and yielding effects.

Twelve tests were conducted on HFSPGs formed using RHS flanges and steel web plates. The section moment capacities of HFSPGs were assessed by conducting four-point loading tests about the major axis on simply supported HFSPGs. This paper presents this experimental study and its results. A brief comparison was conducted with the test results and the flexural capacities of the hot-rolled I-sections used in the industry, which proved the efficiency of the proposed sections over conventionally used I-sections. Finally, test moment capacity results were compared with the predictions of AS 4100 [10], AS/NZS 4600 [11] or AISI S100 [12], EN 1993-1-1 [13] and EN 1993-1-3 [14]. Details of these comparisons and the findings are presented in this paper.

2. Experimental study

2.1. General

The section moment capacity, M_s, is influenced by local buckling and/or yielding of the cross-section elements. According to the cross-section classification given in the Australian hot-rolled steel design standard AS 4100 [10], the section moment capacities of the slender sections are limited to their first yield moment (M_y), and are subjected

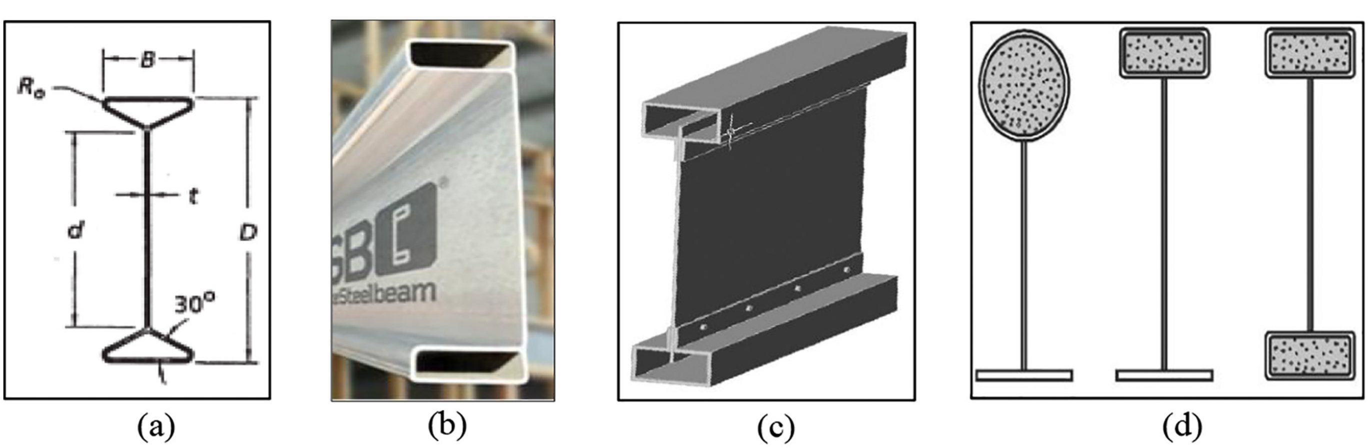

Fig. 1. Hollow flange sections (a) hollow flange beam, (b) LiteSteel beam, (c) Rectangular hollow flange beam, (d) Concrete filled hollow flange beams.