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Flexural behaviour of concrete filled tubular flange girders

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A B S T R A C T

In this paper, the behaviour of concrete filled tubular flange girders (CFTFGs) is investigated through both numerical and analytical modelling. These are new and complex members and their behaviour is governed by a number of inter-related parameters. This work aims to study the relative influence of a number of these variables on the flexural behaviour, particularly for CFTFGs with stiffened webs. A nonlinear three-dimensional finite element (FE) model is developed in the ABAQUS software and is validated using available experimental data. The validated model is then employed to conduct parametric studies and investigate the influence of the most salient parameters. For comparison purposes, and to observe the effect of the concrete infill, steel tubular flange girders (STFGs) with a hollow flange are also studied. The finite element models consider the effects of initial geometric imperfections, as well as other geometrical and material nonlinearities, on the response. In addition, simplified analytical expressions for the flexural capacity are proposed, and the results are compared to those from the FE analyses. It is found that CFTFGs and STFGs with the same dimensions have similar buckling shapes but different buckling loads, with the CFTFG offering greater buckling resistance. This highlights the influence of the concrete infill which increases the stiffness of the upper flange, and hence allows the member to carry additional bending moments compared to STFGs. The proposed analytical expressions, which are suitable for design, are also shown to be capable of providing an accurate depiction of the behaviour and bending moment capacity.

1. Introduction

Concrete filled tubular flange girders (CFTFGs) are I-shaped steel beams that use a hollow structural section as the compression flange which is filled with concrete and a flat plate as the tension flange. Hollow sections exhibit high torsional and compressive resistance when compared with open sections. Therefore, employing a tubular flange as the compression flange in CFTFG, the resulting sections have been shown to offer substantially higher torsional stiffness compared with conventional steel I-beams of similar depth, width and weight [1]. This results in increases in the lateral-torsional buckling resistance of these members which, in turn, leads into a reduction in lateral bracing requirements for CFTFGs. Hence, several researchers have investigated the use of concrete filled tubular flange girders in structural applications, such as bridges, car parks and multi-storey buildings.

A number of researchers have investigated the behaviour of hollow flange beams in recent years including triangular hollow flange beams (THFBs), LiteSteel beams (LSBs) and hollow tubular flange plate girders (HTFPGs), as presented in Fig. 1. Pi and Trahair conducted pioneering studies in to lateral-distortional buckling of triangular hollow flange beams and a simple expression was proposed to define the effect of web distortion on the flexural strength of these members under uniform bending [2]. Avery and Mahendran [3] concluded that including transverse stiffeners on the web of hollow flange beams significantly improves the lateral buckling flexural strength of the member. LiteSteel beams (LSBs) are a relatively new structural form, typically made from cold-formed steel in a channel shape but with rectangular hollow flanges as presented in Fig. 1(b), and these have been studied recently in Australia [4,5]. Hollow tubular flange plate girders (HTFPGs) with a slender web, as shown in Fig. 1(c), have also been proposed and investigated [6–9]. In these studies, the shear strength of homogeneous and hybrid HTFPGs was examined, where hybrid girders are sections which use different materials for the web and flanges, as well as the buckling behaviour of members with slender stiffened or un-stiffened webs. It was noted that HTFPGs are still sensitive to lateral-distortional buckling even with the hollow flanges although they can resist much higher critical loads than conventional I-beams.

For hollow flange plate girders, it has been generally noted that members with a relatively thin tube thickness are susceptible to local buckling of the compression tubular flange, which limits the flexural resistance of the cross-section. To overcome this, concrete filled tubular flange girders (CFTFGs) have been proposed and investigated by a number of researchers. Early studies at Lehigh University in the USA tested two 18 m long CFTFGs with a rectangular concrete filled tube as the compression flange and a flat plate as the tension flange, as depicted in Fig. 2(a) [10,11]. Kim and Sause [12] studied the performance of CFTFGs with a circular concrete filled tube as the compression flange

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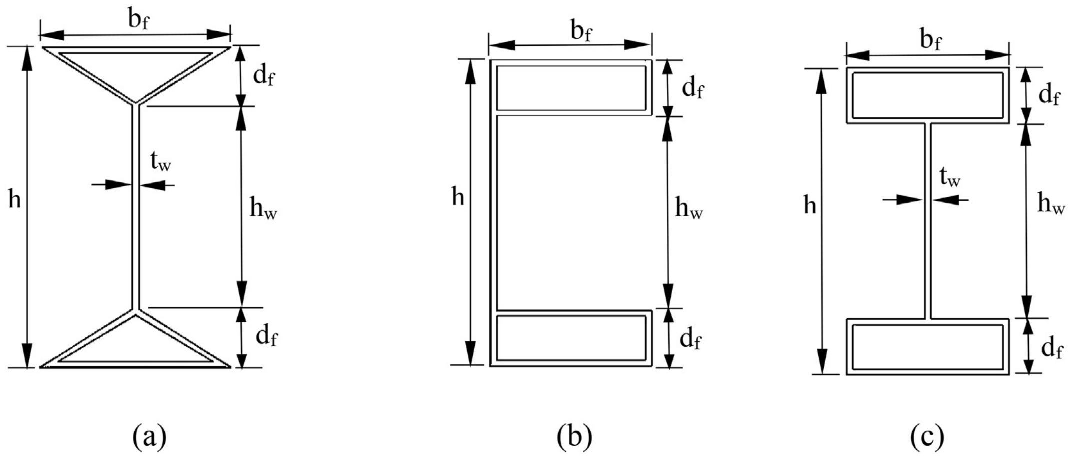

Fig. 1. Hollow flange girders including (a) triangular hollow flange beam, (b) LiteSteel beam and (c) rectangular hollow tubular flange plate girder.

rather than a rectangle, as illustrated in Fig. 2(b). Some of the potential benefits of CFTFGs were summarized, including the provision of more strength, stiffness, and stability compared with a flat plate flange which uses a similar amount of steel or a hollow flange, and design formulas for predicting the lateral-torsional buckling (LTB) strength of CFTFGs were proposed. Other shapes have also been studied including beams with a pentagonal top flange filled with concrete [13], as shown in Fig. 2(c), and CFTFGs which are curved along the length [14]. Generally, for the many different configurations which have been studied, it has been shown that CFTFGs bring numerous advantages compared with conventional steel girders, particularly for large spanning or heavily loaded applications, including the ability to minimize the required under-clearance, simplify erection, and eliminate the need for stiffeners, cross frames or diaphragms.

In this paper, the flexural behaviour of circular concrete filled tubular flange girders (CFTFGs) and circular steel tubular flange girders (STFGs) is investigated through numerical modelling. The paper begins with a description of the finite element (FE) model which was validated against the test data available in the literature [15], following which, parametric studies were conducted to investigate the effect of key parameters such as the size of the tube diameter (D_{tube}), the ratio of D_{tube} to the tube thickness, the thickness of the bottom flange, the web plate slenderness, the aspect ratio of the web panel and also the material strengths. Based on the analysis, as well as a fundamental assessment of the behaviour, a series of analytical expressions which are suitable for design are presented and assessed for predicting the bending capacity of circular CFTFGs.

2. Numerical modelling

2.1. General

The finite element analysis package ABAQUS [16] was employed to examine the ultimate moment capacity of simply supported CFTFGs, taking into account the geometrical and material nonlinearities. The numerical models contained an initial geometric imperfection which was generated by means of the first buckling mode shape of a perfect beam (i.e. perfectly straight and constant geometry) multiplied by an amplitude factor. For this purpose, an elastic eigenvalue buckling analysis was first conducted, and then the first buckling mode shape of the beam with an imperfection amplitude of L/1000, where L is the beam length, was imported to the nonlinear model as the starting geometry. The global imperfection amplitude was taken as L/1000 in accordance with the permitted out-of-straightness tolerance in EN 1090-2 [17]

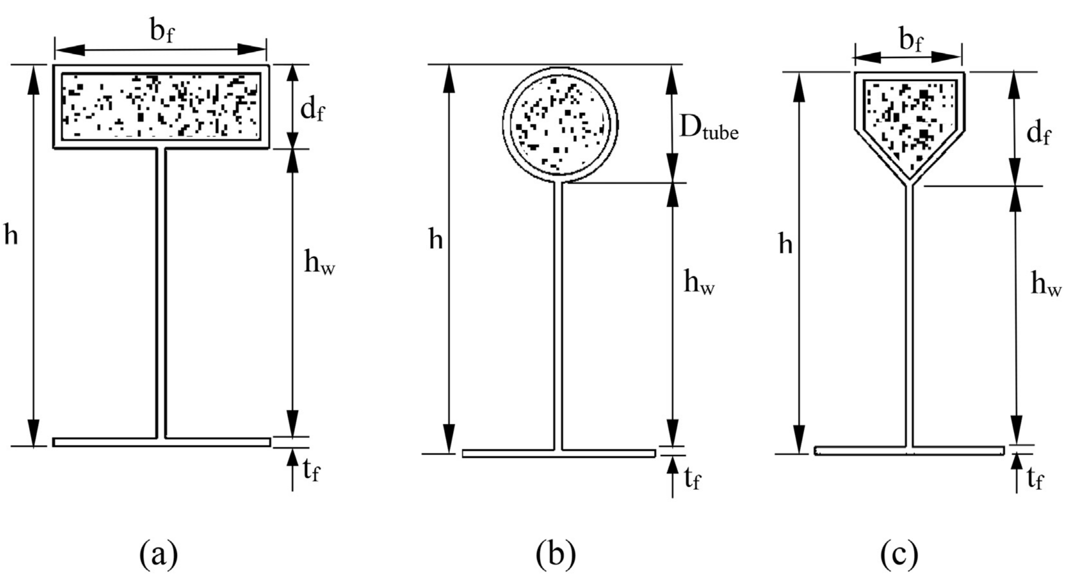

Fig. 2. Girders with concrete filled tubular flanges inlcuding (a) rectangular flange, (b) circular flange and (c) pentagonal flange.