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Fundamental behaviour of concrete-filled pentagonal flange plate girders under shear

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ABSTRACT

Hollow tubular flange plate girders are found to possess higher flexural and shear strengths over those of I-section plate girders with flat flanges. Recently, concrete-filled pentagonal flange girders (CFPFGs) have been suggested in literature to increase the out-of-plane flexural strength of the girders. The geometrical configuration of the section is assumed identical to that of the girder with the rectangular concrete-filled flanges, but the flange depth-to-width ratio is designed to be larger in order to reduce the local buckling of the web. In this paper, the fundamental shear behaviour of these CFPFGs with slender stiffened webs is investigated. Nonlinear three-dimensional finite element (FE) analyses using ABAQUS are employed to conduct parametric studies, having first validated the models against available experimental data. For comparison purposes and to examine the effect of the infill concrete, steel pentagonal flange girders (SPTGs) are also generated. It is found that CFPFGs and SPFGs with the same dimensions have similar buckling shapes but with different loads with the buckling load of the CFPFG being higher than that of the corresponding SPFG. In the post-buckling stage, the width of the inclined tension field becomes greater in the CFPFGs relative to that of the SPFGs. This highlights the influence of the infill concrete which increases the stiffness of the upper flanges, and hence allows the webs to carry additional shear loads compared to SPFGs. Several affecting parameters are, additionally, examined and important conclusions are remarked. The FE strengths are compared with the design strength of the webs following the EN 1993-1-5, indicating that it can conservatively be used with the SFPGs. On the other hand, it becomes highly conservative for the CFPFGs.

1. Introduction

Girders, in practice, are subjected to significant levels of bending moment and thus failure typically occurs when the applied moment at the critical section exceeds its flexural capacity. Therefore, girders, in conventional design, are typically designed to satisfy the flexural limit state, controlled by the flexural-torsional buckling or by the propagation of plastic hinges, and then they are checked for the shear limiting criteria. To increase the flexural-torsional buckling strength of I-section plate girders with flat flanges (IPGs) several solutions may be applied, such as reducing their unbraced lengths, increasing the dimensions of their flanges or recently by replacing the flat flanges by hollow tubular flanges [1–6]. By using hollow tubular flanges, the vertical dimension of the tube reduces the depth of the web, overcoming problems with web slenderness design limits. Nevertheless, the web panel of plate girders with slender webs buckles at a relatively low value of the applied load, at which the shear may control the design. To overcome the shear strength reduction associated with utilizing plate girders with slender webs in construction, the webs are often reinforced with transversal stiffeners along their spans. Overall, it was found that using the hollow tubular flange plate girders instead of IPGs is a powerful tool not only to increase the flexural strength of the girders, but also to provide higher shear strengths [7,8].

On the other hand, using concrete-filled steel tubular (CFST) members in structures and bridges has been increased in recent decades, due to their excellent structural performance characteristics including high strength, stiffness as well as high ductility; see for example [9,10]. Hence, several researches investigated bridges with concrete-filled tubular flange girders (CFTFGs) [11–14]. Typical examples of the CFTFGs are shown in Fig. 2(a) and (b). Wimer and Sause [12] investigated the CFTFGs with rectangular CFST as the compression flange (Fig. 2(a)), while Kim and Sause [13,14] examined those with round CFSTs (Fig. 2(b)). Generally, it was found that CFTFGs provide more strength, stiffness and stability than IPGs with flat plate flanges with the same amount of

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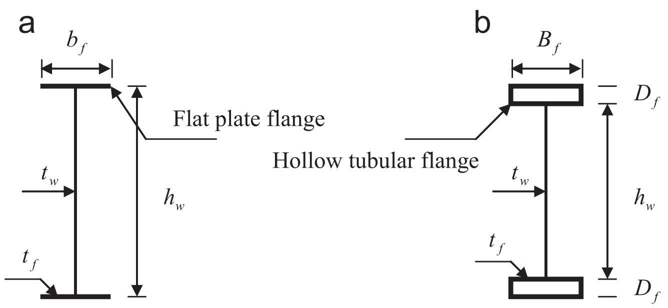

Fig 1. Typical plate girders.

steel [12–14]. It was, as well, found that the large torsional stiffness of the tubular flanges permits the use of large unbraced lengths in bridge framing systems. More recently, Gao et al. [15] investigated experimentally and numerically the flexural behaviour of the girder shown in Fig. 2(c) which is called the concrete-filled pentagonal flange beam. The cross-section of an I-section beam was modified by welding an additional steel plate (drawn by dashed lines in Fig. 2(c)) to its top flange to form an upper box flange section filled with concrete. The geometrical configuration of the section was, however, assumed by Gao et al. [15] identical to that of the CFTFGs with the rectangular CFST but the flange depth-to-width ratio was designed to be larger *in order to reduce the tendency of web local buckling*.

To widen the use of the concrete-filled pentagonal flange girder (CFPFG) with its numerous structural benefits (Fig. 2(c)), it is investigated in this paper for its shear behaviour. To the author's best knowledge, this has never been carried out in literature. Nonlinear three-dimensional finite element (FE) analyses using ABAQUS [16] are employed to conduct parametric studies, having first validated the models against available experimental data [15]. Girders with slender stiffened webs are currently considered. Several affecting parameters are examined and important conclusions are remarked.

2. FE model and validation

The nonlinear FE analysis program ABAQUS/Standard [16] was used to investigate the shear behaviour of simply supported CFPFGs, taking into account the geometrical and material nonlinearities. For nonlinear analyses, geometric imperfection should be considered in the FE model, by performing elastic buckling analysis first on a perfect beam to obtain its buckling mode. The material plasticity strains and geometric imperfections, based on the first positive eigenmode, should then be included in the second step of the nonlinear analysis (Riks method) to obtain the ultimate loads as well as the failure modes of the CFPFGs. The

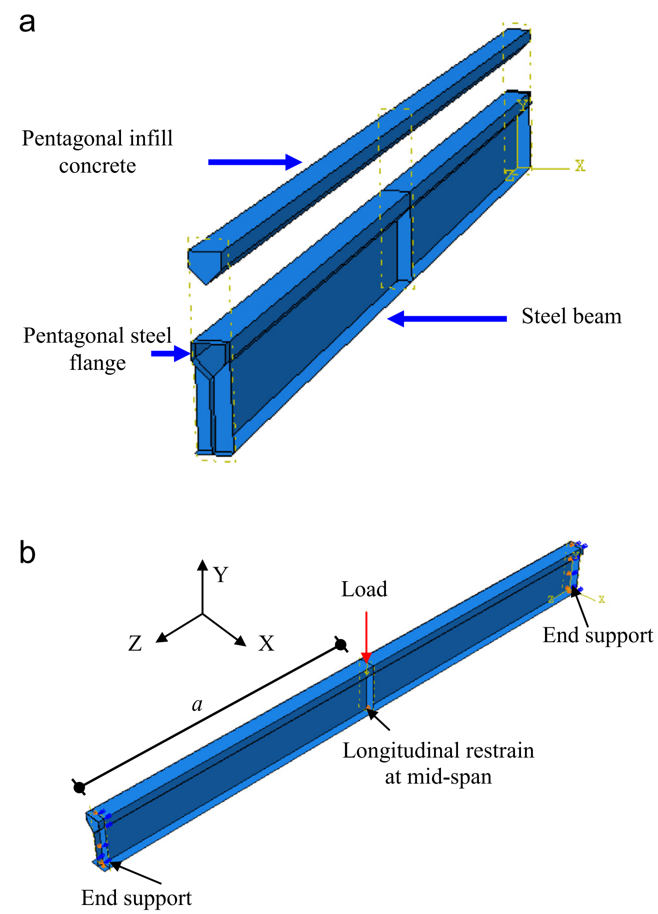

Fig. 3. Typical FE model for tested CFPFBs. (a) Components and (b) load and boundary conditions.

measured initial imperfection value of $L/1000$ is used in the FE models simulating the experimental tests [15].

2.1. General

A typical FE model for the CFPFB is shown in Fig. 3. As can be seen from Fig. 3(a), the CFPFG is composed of two main parts; the infill pentagonal concrete and the steel girder with suitable interactions between them. The pentagonal steel tubes shown in Fig. 2(c) are formed from a flat flange plate and a cold-formed section which is in turn divided into flat and corner zones. To simulate the bond between the pentagonal steel tube and the infill concrete, surface-based interactions with a contact pressure-

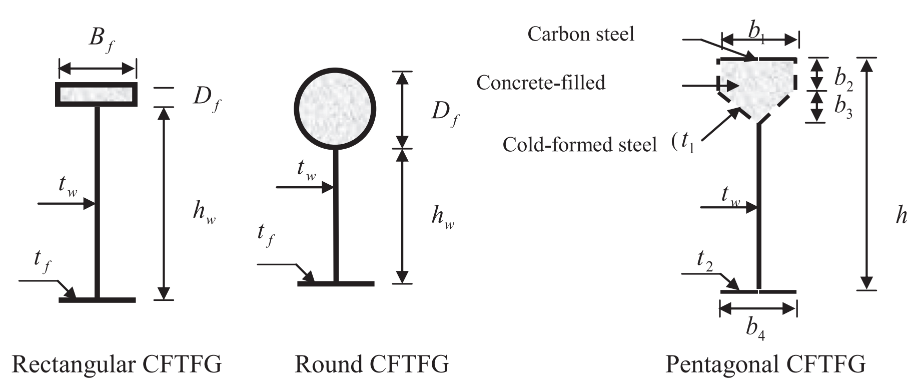

Fig 2. Typical concrete-filled tubular flanges girders (CFTFGs).