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An extended evaluation for the shear behavior of hollow tubular flange plate girders

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ABSTRACT

In this paper, an extended numerical investigation is conducted to study the shear behavior of transversely stiffened hollow tubular flange plate girders (HTFPGs) using ABAQUS software. A comparison between the HTFPGs and plate girders with flat flange plates (IPGs) is first made considering the elastic-buckling and the post-buckling strength. The results indicated that the realistic support condition at the juncture of the web and flanges of HTFPGs is nearly fixed. The study is then extended to examine hybrid HTFPGs (HHTFPGs). The main goal of this extension was to examine the validity of the current EN 1993-1-5 provisions regarding both the shear resistance and the behavior trend of such hybrid girders. The validity of the other international design codes such as the AASHTO, AISC and BS 5950 were also checked. The results of the finite element (FE) models confirmed that using HHTFPGs provides economy as their strength could be utilised efficiently. In addition, it was found that the strengths obtained with EN 1993-1-5 provisions do reproduce suitably the trends obtained numerically, but their design equations were found to be extremely conservative. Moreover, the shear strength recently proposed for homogenous HTFPGs seemed to be slightly conservative for the case of HHTFPGs. Therefore, it was modified herein by taking the relative effect of the actual flange yield strength into account. This shear strength currently modified is found to represent the actual behavior of these girders better than the original and recently proposed EN 1993-1-5 shear strengths. Several remarks regarding the selection of optimum dimensions for the HTFPGs are also presented.

1. Introduction

I-section plate girders (IPGs), as can be seen in Fig. 1(a), are generally fabricated by welding together two flanges, a web and a series of transverse stiffeners. Flanges resist the applied moment, whereas web plates resist the induced shearing force in addition to maintaining the relative distance between the top and bottom flanges. *These girders are mainly used to bear high loads that a universal rolled section could not support or when it becomes uneconomical.* In most practical ranges of span lengths of plate girder, the induced shearing force is relatively lower than the axial forces in the flanges. Accordingly, the thickness of the web plate is generally much smaller than that of the flanges.

In fact, the measured yield strengths of the web and flanges of typical IPGs are rarely identical as they are seldom formed from the same steel sheet. Hence, the plate girder might get higher yield strengths than its nominal one. As a result, nearly every plate girder could be considered as hybrid. Hybrid plate girders are nowadays trendy as they provide greater flexural capacities at lower costs compared to homogeneous girders [1,2]. It is well known that the web generally contributes with a small percentage to the bending resistance for such a typical IPG. Many practical girders have smaller web area and the contribution from web is then smaller. *Therefore, it is often good economy to use less expensive steel with lower strength in the web than that in the flanges.* In this case, the loss in moment resistance will be quite small. On the other hand, welding different grades of steel has been done for a number of years and to the authors' knowledge no particular problem has ever been documented as long as the base metals meet the requirements of adequate weldability of the steel.

In design, the European standard [3] assumes higher steel grade in flanges compared to webs. However, the treatment of hybrid plate girders in EN 1993-1-5 [3] is generally the same to that of homogeneous girders. For the particular case of shear resistance, the formulas for the resistance in EN 1993-1-5 [3] already consider different yield strength in flanges and web.

On the other hand, IPGs could develop various forms of failure mechanisms, as the flexural–torsional buckling being one of them. If the girder unbraced length between two lateral supports exceeds a given threshold, compression flange becomes unstable and tends to buckle laterally prior to reaching maximum flexural strength. Accordingly, this failure mode could prematurely lead the girder to

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Nomenclature

Roman letters

a	Web panel-length used in this paper and also used in BS 5950
B_f	Hollow tubular flange-width
b_f	Flange-width of I-section plate girders
C	Shear-buckling resistance to the shear yield strength according to AASHTO
C_v	Shear coefficient according to AISC
c	Distance assumed between the plastic hinge and the end stiffener
D	Web-depth according to AASHTO
D_f	Hollow tubular flange-depth
d_0	Spacing between transverse stiffeners according to AASHTO
d	Depth of the web according to BS 5950
E	Young's modulus
f_{yf}	Yield stress of the flange
f_{yw}	Yield stress of the web
h	Web-depth according to AISC
h_w	Web-depth
k	Shear-buckling coefficient according to AASHTO
k_{sf}	Shear-buckling coefficient assuming the juncture of the web and flanges to behave as fixed support
k_v	Shear-buckling coefficient according to AISC
k_τ	Shear-buckling coefficient assuming the juncture of the web and flanges to behave as simple support
L	Span of the girder
M_{Ed}	Design bending moment
$M_{f,Rd}$	Moment of resistance of the cross section consisting of the area of the effective flanges only
M_{FE}	Maximum bending moment
M_{pl}	Plastic moment resistance
P_f	Perimeter of the tubular flange
p_{yw}	Design strength of the web according to BS 5950
q_w	Shear-buckling strength of the web according to BS 5950
t	Web thickness according to BS 5950
t_f	Flange-thickness
t_w	Web-thickness
V_{AASHTO}	Predicted shear strength according to AASHTO
V_{AISC}	Predicted shear strength according to AISC
V_{BS}	Shear-buckling resistance according to BS 5950
$V_{b,R}$	Shear resistance
$V_{bf,R}$	Shear contribution from the flanges
$V_{bw,R}$	Shear contribution from the web
V_{EC}	Design shear strength according to EC
V_{cr}	Critical shear-buckling resistance according to AASHTO
$V_{EC,Mod}$	Modified Eurocode 3 design shear strengths proposed by the current authors
V_{FE}	Shear load
$V_{pl,Rd}$	Plastic shear resistance which is assumed herein as the Plastic shear resistance of the web $V_{pl,W}$, also called V_p according to AASHTO

Greek letters

λ_w	Web slenderness according to BS 5950

Abbreviations

FE	Finite element
FPH	Flexural plastic hinge
HTFG	Hollow tubular flange girder
HTFPG	Hollow tubular flange plate girder
HHTFPG	Hybrid hollow tubular flange plate girder
LTB	Flexural–torsional buckling mode
S	Shear failure mechanism
SPH	Shear plastic hinge

fail, and hence it should as possible be prevented. The flexural–torsional buckling of IPGs may be disallowed by reducing their unbraced lengths, increasing the dimensions of their flanges or substituting them by the hollow tubular flange plate girders which can be found in Fig. 1(b). A tubular flange plate girder is an I-shaped steel girder with either hollow or concrete-filled tubes as flanges. Hollow tubular flange girders (HTFGs) are stiff torsionally, compared with a conventional IPG of similar weight [4].

Experimental tests are usually used to investigate the behavior of different steel girders. However, they are often expensive and time consuming. Finite element (FE) modeling of HTFGs can provide an efficient alternative to full-scale girders. Many researches successfully investigated the behavior of HTFGs using the *FE* modeling as can be found for instance in references [4–9].

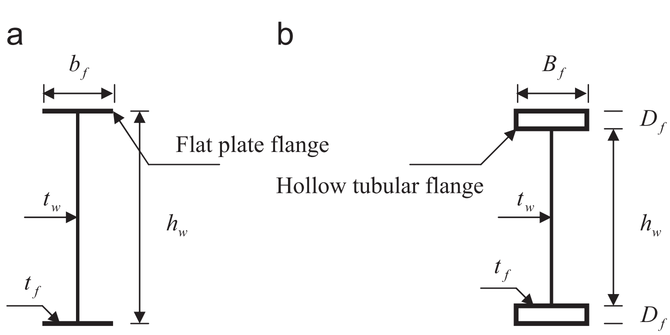

Fig. 1. Definition of symbols of typical plate girders. (a): I-section plate girder (IPGs); (b): hollow tubular flange girder (HTFGs).

On the other hand, a numerical study for hybrid IPGs subjected to patch loading is lately published by Chacón, et al. [10]. They pointed out valuable conclusions during the assessment of the current formulation of EN 1993-1-5 [3] dealing with patch loading. The response of hybrid girders under patch loading was studied by using numerical simulations for several cases. Through the assessment process made by Chacón et al. [10], it was observed that EN 1993-1-5 [3] formulation predicts a considerable increment of ultimate load capacity of the girders as the yield strength of the flange is increased. On the opposite, the numerical model did not predict the same results nor the same trend; the ultimate load capacity was maintained constant as the hybrid grade (f_{yf}/f_{yw}) ratio was increased. Thus, it was found that the EN 1993-1-5 [3] formulation leads to a structural anomaly and must be evaluated. A design proposal aimed at enhancing this peculiarity was then presented in a companion paper by the same authors [11]. Accordingly, these studies [10,11] may encourage for the revision of EN 1993-1-5 [3] formulations dealing with hybrid girders under different straining actions.

However, the previous survey of research information on HTFPGs indicates that there is no research work conducted to investigate the shear behavior of hybrid girders. Hence, this paper focuses on the shear strength of hybrid hollow tubular flange plate girders