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Lateral-distortional buckling of beams with hollow flanges and folded plate webs

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ABSTRACT

This paper is concerned with the effects of distortion on the lateral buckling of steel beams which have rectangular or square hollow flanges and folded plate webs. The hollow flanges potentially make very large contributions to the torsional stiffness, but flange distortion (in a shear mode) causes a significant reduction in the effective torsional stiffness and in the lateral buckling resistance.

In this paper, the shear distortion of the hollow flanges is analysed, and the strain energy stored in a distorted flange is compared with the strain energy stored during uniform torsion of the flange. This comparison allows the development of a suitable parameter for use in the evaluation of the effect of flange distortion on the torsional stiffness of a hollow flange beam. Uniform torsion test results are used to confirm the significance of this parameter.

Finite strip analyses of simply supported hollow flange beams in uniform bending show that there is a significant interaction between distortion and uniform torsion during lateral buckling, which may be approximated by combining their flexibilities. More accurate finite element analyses show that the finite strip predictions are conservative. An approximate method of predicting the effects of flange distortion on elastic lateral buckling is presented which shows good agreement with the finite element predictions.

1. Introduction

Beams with folded plate webs and flat plate flanges have been used in buildings around the world for many years. In the design of these beams, the longitudinal stiffness of the folded plate web is assumed to be negligible and so the moment capacity is derived entirely from the flanges while the shear capacity of the beam is based on the shear strength of the web alone. The advantage of beams with folded plate webs is the increased resistance to shear buckling without the need to weld stiffeners to the web [1]. Although beams with folded webs are mainly used to increase the shear capacity, lateral buckling is also an important failure mode for these beams.

Industrial Light Beams (ILBs) were first manufactured in Australia in the 1990s. These beams differ from traditional beams with folded webs by the use of square or rectangular hollow sections for the flanges, as shown in Fig. 1c. In this paper, the effects of distortion on the lateral buckling of beams with hollow flanges and folded plate webs is investigated.

Beams with hollow flanges (Fig. 1b,c) have increased torsional stiffnesses compared with I-section beams (Fig. 1a), but distortion effects reduce their effective torsional stiffnesses and their lateral buckling resistances. This paper is concerned with the effects of distortion on the lateral buckling of steel Industrial Light Beams (ILBs). These doubly symmetric beams have cold-formed rectangular (RHS) or square (SHS) hollow flanges and folded plate webs (Figs. 1c and 2b,c).

Distortion of the cross-section affects the lateral buckling of different beams in different ways. Web distortion of the flat web (Fig. 2a) [2–6] of an I-section beam allows the reduction of the twist rotations of the flanges as shown in Fig. 3a, and thereby reduces the effective resistances to uniform torsion and lateral buckling. These reductions are usually small, except in deep short span beams with thin webs. The flat webs (Fig. 2a) of such beams (plate web girders) are usually stiffened to improve their resistance to shear, and these stiffeners effectively prevent web distortion. Folded plate (Fig. 2b,c) and corrugated (Fig. 2d) webs [7–9] of I-section beams also prevent distortion.

The triangular flanges of a hollow flange beam (HFB) (Fig. 1b) potentially make very large contributions to its torsional stiffness and large contributions to its flexural stiffness. Distortion of the flat web (Fig. 2a) of such a beam [10,11] allows reduced twist rotations of the flanges, as shown in Fig. 3b [12], and thereby causes significant reductions in its effective torsional stiffness and in its lateral buckling resistance. Smaller twist reductions are likely to occur in channel

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Nomenclature

a_c	corrugation amplitude
A_f	area of flange
$b_{b,d}$	width and depth of flange
d_w	web depth
E	Young's modulus of elasticity
F	force
f_y	yield stress
G	shear modulus of elasticity
I_y	minor axis second moment of area
I_w	warping section constant
J	uniform torsion section constant
J_d	equivalent torsion section constant for flange distortion
$J_{eb,eu}$	effective torsion section constants for buckling and uniform torsion
J_t	test value of J
L	length
l_c	corrugation half-wavelength
M	End moment
M_c	elastic buckling moment when no distortion
M_p	full plastic moment
M_{fd}	elastic buckling moment with flange distortion
M_{fda}	close approximation for M_{fd}
M_{wd}	elastic buckling moment with web distortion
$t_{f,w}$	flange and web thicknesses
$U_{db,du}$	distortion strain energies in flanges for buckling and uniform torsion
$U_{tb,tu}$	uniform torsion strain energies for buckling and uniform torsion
u, v	displacements in x, y directions
x, y	principal axes
z	distance along centroidal axis
$\alpha_{b,u}$	Parameters for relative importance of flange distortion to uniform torsion
λ	beam slenderness
ϕ	angle of twist rotation
θ	maximum value of ϕ
$\theta_{h,v,ww}$	average rotations of the horizontal and vertical flange plates and web

section beams with closed drop flanges [13], because of the relatively smaller area enclosed by the drops.

The rectangular hollow flanges of an ILB (Fig. 1c) potentially make very large contributions to its torsional stiffness and large contributions to its flexural stiffness. Web distortion of such a beam is prevented by its folded plate web (Fig. 2b, c). However, distortion of the rectangular hollow flanges (Figs. 3c and 4) may cause a significant reduction in its effective torsional stiffness and in its lateral buckling resistance. The flange distortion shown (bending deflections omitted) in Fig. 4 is of a shear nature. Such flange distortion in an HFB (Fig. 1b) is prevented by the triangular shape of the flanges.

In this paper, the shear distortion of the rectangular hollow flanges of ILBs is analysed, and the strain energy stored in a distorted flange is compared with the strain energy stored during uniform torsion of the flange. This comparison allows the development of a suitable parameter for use in the evaluation of the effect of flange distortion on the torsional stiffness of an ILB. Uniform torsion test results [14] are used to confirm the significance of this parameter.

The effect of flange distortion on the elastic lateral buckling of ILBs is then investigated.

2. Distortion of rectangular hollow flanges

The relative deflections and rotations during lateral buckling of a simulated ILB have been determined using the finite strip computer program THIN-WALL [15]. This simulated 1800LB198 beam has 291 mm × 291 mm × 9 mm SHS flanges and a sinusoidally corrugated web 1509 mm × 3 mm with corrugation half wavelength and amplitude of 590 mm and 95 mm (Fig. 2d), which approximates the folded web (Fig. 2b) of the actual ILB. The span length is 16.52 m and the elastic buckling moment of the simply supported beam in uniform bending is 6.238 kNm. The square hollow flanges distort during buckling as idealised in Fig. 4 in what is essentially a sway mode, with the average rotations of the vertical and horizontal compression flange elements of θ_v = 0.110E–03 and θ_h = 0.213E–03 and of the web of θ_w = 0.385 E−03 (normalised for a centroidal lateral deflection of u = 1.0). The relative flange distortion is $(\theta_h–\theta_v)/\theta_w$ = 0.267, compared with 1.0 for an undistorted flange. Also shown in Fig. 4 is the undistorted deflected flange, whose web rotation (for u = 1.0) is 0.240E–03 [16,17]. It can be seen that the web rotation θ_w = 0.385 E–03 of the distorted beam is significantly higher.

This flange sway distortion mode may be approximated by analysing the substitute rectangular frame $b_b \times b_d$ shown in Fig. 5 whose members are of width δz and depth t_f under the loads F. Using a linear elastic analysis leads to expressions for the sway deflection v and the midpoint rotation ϕ (which corresponds to the web rotation shown in

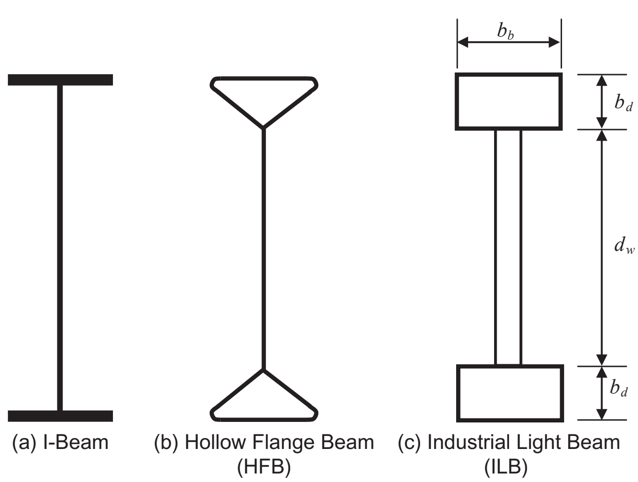

Fig. 1. Beam types.

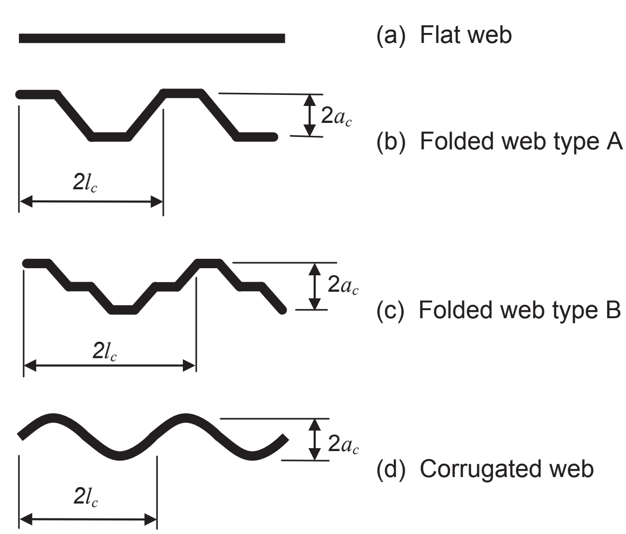

Fig. 2. Web types.