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Numerical modelling of steel plate girders at normal and elevated temperatures

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ABSTRACT

The main goal of this study is to increase the knowledge on the behaviour of steel plate girders subjected to shear buckling at both normal and elevated temperatures. Hence, numerical models were duly validated with experimental tests from the literature. Experimental tests on steel plate girders with different configurations were numerically reproduced, showing a good agreement between numerical and experimental results. Afterwards, applying the validated numerical models, sensitivity analyses on the influence of initial imperfections were performed. Different values for the maximum amplitude of geometric imperfections were considered and residual stresses were also taken into account. Finally, the effect of the end supports configuration was also studied aiming to understand the strength enhancement given by the rigid end support at normal temperature and evaluating if that strength enhancement is maintained in case of fire.

1. Introduction

Plate girders are widely used as structural members in steel construction because of their ability to support heavy loads over long spans. They are in general fabricated by welding together three steel plates corresponding to a web and two flanges. The web is designed to resist shear forces and the flanges to resist the applied bending moments. For economic reasons, plate girders have slender webs in order to have a high strength to weight ratio. These slender webs are highly susceptible to instability phenomena, particularly shear buckling. Therefore, it is common to design plate girders with transverse stiffeners and in some cases with longitudinal stiffeners in order to increase the buckling strength of the web plates.

Shear buckling is a type of local buckling caused by shear forces. Presently, the Rotated Stress Field Method [1] is the basis of the expressions adopted in European Standards, Part 1–5 of Eurocode 3 (EC3) [2], to check the ultimate shear resistance of steel plate girders subjected to shear buckling. In the last years, the accuracy of design methods at normal temperature have been analysed by different researchers, as for example Lee and Yoo [3–5], highlighting the shear buckling importance on the design of steel structures. However, it is still necessary to perform similar analyses for fire design.

Fire is an accidental action that may cause several damages in steel structures, as for example steel bridge structures, where the plate girders are often used. In fact, a research conducted by the New York Department of Transportation (NYDOT) found that 53 of the total recorded bridge failures up to 2011 are caused by fires and only 18 are caused by earthquakes [6]. Moreover, Kodur and Naser [7] stated that shear capacity can decrease faster than bending capacity meaning that the shear limiting state may be a dominant failure mode in steel plate girders subjected to fire. However, despite of the growing attention of the researchers on the behaviour of steel plate girders in fire situation, the accuracy of the application of the Rotated Stress Field Method to fire design has not yet been studied. For that reason, it is necessary to develop a solid numerical model to performing parametric studies in future works, in order to evaluate the applicability of the Rotated Stress Field Method to fire design.

Due to the limited size of furnaces and the high cost of the fire resistance experimental tests, several studies about fire resistance of steel structures have been performed in recent years based on numerical simulation [8]. However, it is still necessary to validate some of these numerical models to enable future parametric studies for the development of new analytical approaches very useful for designers that do not have always access to advanced calculation methods. Hence, a total of seventeen experimental tests [9,10] at normal temperature carried out on steel plate girders were numerically reproduced, as well as nine experimental tests at elevated temperatures [11,12]. Comparisons between the experimental and the numerical results were performed. Afterwards, numerical sensitivity analyses at both normal and elevated

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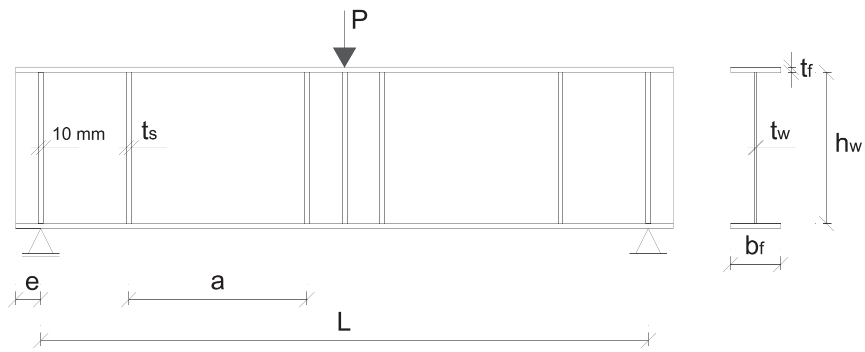
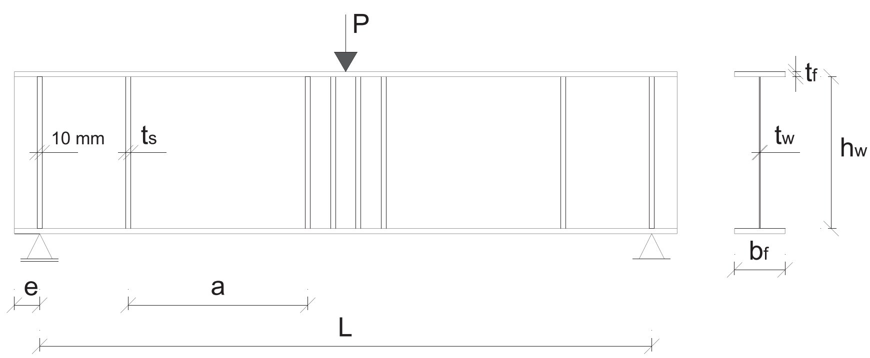
Nomenclature

a	transverse stiffeners spacing
b_f	flange width
b_{ls}	longitudinal stiffener width
e	transverse stiffeners spacing of the rigid end post
E	Young's modulus
f_{yf}	flange yield strength
f_{yw}	web yield strength
h_w	web depth
L	girder length
P	ultimate load
PG	plate girder
t_w	web thickness
t_f	flange thickness
t_s	transverse stiffeners thickness
t_{ls}	longitudinal stiffeners thickness



a) girders with 400 mm web depth (PG1 and PG4)



b) girders with 600 mm web depth (PG2, PG3 and PG5-8)

Fig. 1. Geometry of the plate girders tested by Lee and Yoo [9].

Table 1
Dimensions of the plate girders tested at normal temperature.

Label	Reference	T [°C]	L [mm]	a [mm]	e [mm]	h_w [mm]	t_w [mm]	b_f [mm]	t_f [mm]	t_s [mm]	t_{ls} [mm]	b_{ls} [mm]	a/h_w [dimensionless]
PG1	Lee and Yoo [9]	20	1700	400	80	400	4.0	130	15.0	6.0	–	–	1.00
PG2		20	2100	600	100	600	4.0	200	10.0	6.0	–	–	1.00
PG3		20	2100	600	100	600	4.0	200	15.0	6.0	–	–	1.00
PG4		20	2100	600	80	400	4.0	130	15.0	6.0	–	–	1.50
PG5		20	2700	900	100	600	4.0	200	10.0	6.0	–	–	1.50
PG6		20	2700	900	100	600	4.0	200	20.0	6.0	–	–	1.50
PG7		20	3300	1200	100	600	4.0	200	10.0	6.0	–	–	2.00
PG8		20	3300	1200	100	600	4.0	200	15.0	6.0	–	–	2.00
PG9	Gomes et al. [10]	20	1800	900	100	300	2.0	100	5.0	5.0	–	–	3.00
PG10		20	1800	600	100	300	2.0	100	5.0	5.0	–	–	2.00
PG11		20	1800	300	100	300	2.0	100	5.0	5.0	–	–	1.00
PG12		20	1800	900	100	300	2.0	100	5.0	5.0	5.0	50	3.00
PG13		20	1800	600	100	300	2.0	100	5.0	5.0	5.0	50	2.00
PG14		20	1800	300	100	300	2.0	100	5.0	5.0	5.0	50	1.00

temperatures were made in order to evaluate the influence of the geometric imperfections, the influence of the residual stresses and finally the influence of the end supports on the ultimate shear strength of steel plate girders, considering rigid and non-rigid end posts. These sensitivity analyses were performed based on the dimensions and material properties of the plate girders tested by Lee and Yoo [9]. Numerical modelling was conducted using the programme SAFIR [13,14], a computer software developed at