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Elastic buckling of longitudinally stiffened patch loaded plate girders using factorial design

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ABSTRACT

This paper is aimed at investigating the elastic buckling of longitudinally stiffened plate girder subjected to patch loading. At first, buckling coefficients are computed by means of linear buckling analysis using the finite element method. Thereafter, a first order factorial design is performed to weigh the geometrical parameters on the buckling coefficient. Finally, a second order model is obtained to predict the buckling coefficient for longitudinally stiffened plate girders. A significant improvement, within the range of geometric parameters investigated herein, is achieved when compared to similar formulae found in the literature.

1. Introduction

A renewed interest in linear buckling analyses has called upon the attention of researcher around the world. It is mainly due to the harmonization of the stability based verifications within European design standards. EC 1993-1-5 [1] provides design rules for plated structures with the main focus on girders for which plate buckling influences the behavior [2,3]. Patch loading is a clear example where the resistance is calculated using the same approach as for other buckling phenomena. In these approaches, namely $\chi-\lambda$, the ultimate strength is calculated through a procedure that depends on a resistance function $\chi = f(\lambda)$ [4]. The slenderness parameter λ depends on both the plastic and the elastic critical buckling resistances, which are defined separately.

The current edition of the EN1993-1-5 [1] includes a check of the buckling resistance of girder webs to concentrated transverse loads or patch loading at ultimate limit state. This methodology is originally based on the research conducted by Lagerqvist and Johansson [5], which makes use of

- a yield resistance F_y
- a slenderness parameter $\lambda = \sqrt{F_y/F_{cr}}$, where F_{cr} is the elastic critical load
- a resistance function $\chi(\lambda)$ which reduces the yield resistance depending on λ.

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The critical load used to define the slenderness for patch loading can be expressed as

$$F_{cr} = k_f \frac{\pi^2 E}{12\,(1-\nu^2)} \frac{t_w^3}{h_w} \tag{1}$$

where k_f is the buckling coefficient that depends on the geometry and the type of loading. Fig. 1 shows a schematic representation of a longitudinally stiffened plate girder subjected to patch loading. Graciano and Lagerqvist [6] derived a formula for the critical buckling coefficients k_f of longitudinally stiffened girder webs subjected to patch load

$$k_{fl} = 5.82 + 2.1\left(\frac{h_w}{a}\right)^2 + 0.46\sqrt[4]{\beta} + k_{sl}. \tag{2}$$

The first three terms on the right side of Eq. (2) are valid for unstiffened webs, with $\beta\ (=b_f t_f^3/h_w t_w^3)$. Furthermore, the contribution from a flat, or open section, stiffener to the critical buckling load k_{sl} is given by

$$k_{sl} = \left(5.44\frac{b_1}{a} - 0.21\right)\sqrt{\gamma_s} \tag{3}$$

where $\gamma_s\ (=10.9 I_{st}/h_w t_w^3)$ is the relative flexural rigidity of the stiffener. For the calculation of the second moment of area I_{st}, the effective cross-section consists of the stiffener itself and an effective portion of the web plate having a width of 15 t_w on each side of the stiffener weld. Eq. (3) is valid in the range $0.05 \le b_1/a \le 0.3$

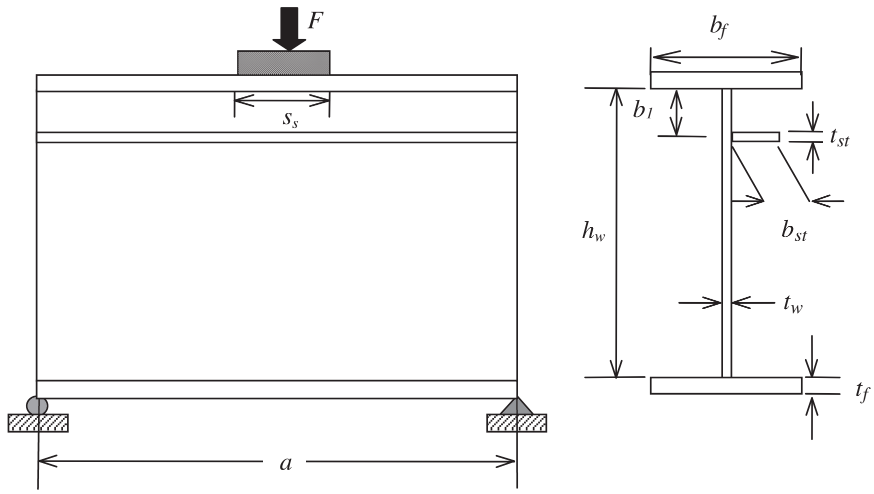

Fig. 1. A longitudinally stiffened plate girder under patch loading.

($b_1/h_w \leq 0.3$). In Eq. (3) the contribution of the stiffener k_{sl} should not be larger than

$$k_{sl} \leq C_o \sqrt{\gamma^t} \tag{4}$$

where γ^t is the transition rigidity for open section stiffeners defined by

$$\gamma_s \leq 14 \left(\frac{a}{h_w}\right)^{2.9} + 211 \left(0.3 - \frac{b_1}{a}\right). \tag{5}$$

Graciano and Johansson [7] demonstrated that the influence of longitudinal stiffening can be considered in the EC3 through the buckling coefficient in Eq. (2). The buckling analysis of longitudinally stiffened girder webs is a theoretically difficult matter due to the number and possible range of the geometrical parameters involved. Graciano and Lagerqvist [6] used a limited number of parameters for the regression analysis used to obtain k_{sl}. Among others, the contribution of the longitudinal stiffener to the buckling coefficient was derived using a ratio s_s/h_w equal to 0.2. This assumption may lead to conservative results in most practical cases relating the application of concentrated loads ($s_s/h_w \geq 0.2$).

This paper is aimed at developing an expression for the buckling coefficient for longitudinally stiffened patch loaded plates. At first a linear buckling analysis is conducted using the finite element method. Thereafter, a first order factorial design is performed to weigh the geometrical parameters on the buckling coefficient. Finally, a second order model is obtained to predict the buckling coefficient for longitudinally stiffened plate girders.

2. Finite element modeling

The buckling coefficients are computed by means of finite element analysis using the FE-program ANSYS [8]. Shell elements *S181* from the ANSYS element library were used to model the web, flanges (top and bottom) and the longitudinal stiffener. Due to the symmetry in geometry, loading and boundary conditions only one half of the girders were modeled (Fig. 2). Transverse stiffeners at the end of the plate girder were considered by means of a rigid body kinematic constraint of the degrees of freedom located in the corresponding side. The patch load was transferred into the girder by loading all the nodes located in the loaded flange along the loading length $s_s/2$. All the nodes in the area where the load is transmitted were controlled to displace only in the vertical direction.

To prevent the longitudinal stiffener from losing carrying capacity through local buckling, the width-to-thickness ratio b_{st}/t_{st} should not exceed a limiting value for full efficiency. This limit depends on the stress level in the stiffener. The exact value is not important for this study and $b_{st}/t_{st} \leq 15$ was adopted. It has been chosen in order to minimize the possible influence of the torsional rigidity of the stiffener. The influence of the relative flexural rigidity of the stiffener, γ_s, will now be studied. For simplicity a rectangular cross section of the stiffener (flat stiffener) is used in the parametric analysis.

The following geometry is used in the analysis: $h_w = 1000$ mm, $a = 1000$ mm, $t_w = 4$ mm, $t_f = 8$ mm, $b_f = 250$ mm ($\beta = 2$), and $s_s/h_w = 0.2$. These geometrical data is similar to that used in Ref. [6], in addition, when calculating the buckling coefficients the Young's modulus is $E = 210$ GPa and Poisson's ratio is $\nu = 0.3$.

After performing a convergence analysis, a mesh with 1350 elements was used for this calculation as seen in Fig. 2. Table 1 shows a comparison of the buckling coefficients obtained numerically and those obtained by Graciano and Lagerqvist [6]. A good correlation between the results is observed.

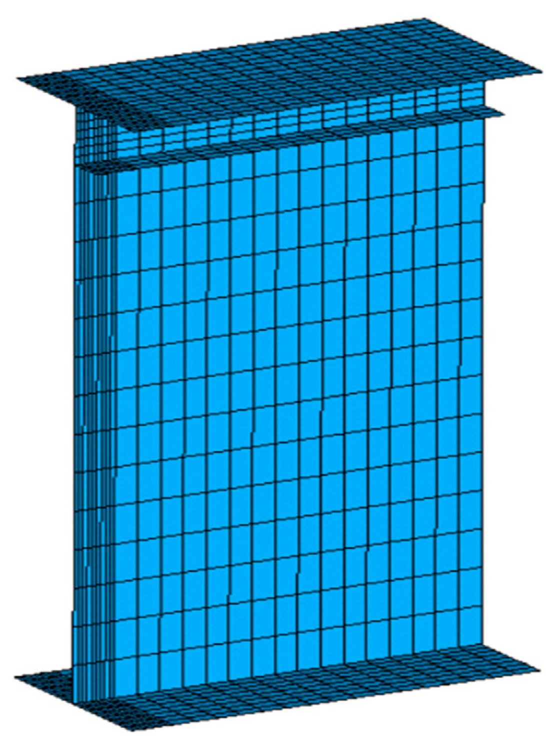

Fig. 2. Finite element model.