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Review

Behavior of beam web panel under opposite patch loading

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A B S T R A C T

Elastic buckling is studied for a panel with various boundary conditions including simple supports, fixed supports and elastic restraints. The panel is subjected to opposite patch loading. Following a review of existing work on the effects of localized compression, also known as patch loading, a study is conducted to take into account the restraints provided by the flanges of the I beam in a realistic manner. This study is based on a finite element model implemented in the CAST3M software. A new equation is proposed to calculate the buckling critical coefficient for a beam web panel considering the rotational stiffness provided by the flanges. The model is then applied to longitudinally stiffened web panels which are subjected to opposite patch loading.
A parametric analysis is performed to determine the transition from a global buckling mode to a local buckling mode where the sub-panels on each side of the stiffener behave separately. The numerical results show that the flexural rigidity of the stiffener is the appropriate parameter that governs the buckling mode. From these results, a formula is proposed to calculate the buckling critical coefficient of stiffened web panels.

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1. Introduction

In steel structures, the connections represent critical points in the structure because of their mechanical and geometrical discontinuities. Fig. 1 shows the distribution of internal forces in a beam-to-column connection which is subject to bending with a double sided configuration. The internal tensile forces transmitted by the bolt rows (N1 to N4), are balanced by a compression force F_c. The web panel loaded in

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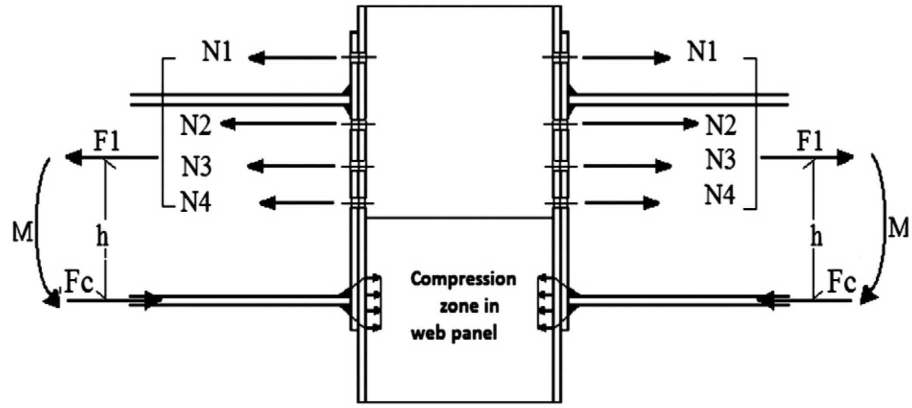

Fig 1. Distribution of internal forces in beam-to-column joint.

compression is more or less restrained by the beam flanges surrounding it. In large size joints, connecting elements of welded plate girders, this zone of web, generally with a high aspect ratio, may develop elastic or elastic–plastic instabilities under compression. This zone can be modeled as a perfect plate that is subject to boundary conditions and loading that represent the joint in a realistic way.

To assess the analytical formulae available in the literature and determine their domain of validity a numerical model is developed by using the finite element software CAST3M [1]. These numerical models are built first for "idealized" plates with an available analytical solution. Then, the models are extended to the case of a steel I beam with the web loaded in its plane. It should be noted that the boundary conditions created by the flanges in the real joint are described by elastic restraints on the web plate edges. Thus, the study is concerned with the elastic instabilities of plates and web panels of steel I beams. It can be considered as a first step covering the case of joint panels with high slenderness that have a dominant behavior in elastic buckling. Actually, in the approaches of EN1993-1-5 [16], whether dominated by a plastic yield mechanism or local elastic buckling the strength of the web panel with or without stiffeners is governed by the dimensionless slenderness ratio $\overline{\lambda}$ that takes as an input parameter the elastic critical load. The present work provides the elastic critical load for panels under elastic restraints, with or without stiffeners. Thus, the determination of the critical elastic load can be considered as a preliminary to the plastic analysis.

2. Web panel under opposite patch loading

Several studies proposed analytical models to calculate the elastic critical load of compressed panels with various boundary conditions and loadings. This concerns the web panels of beams or columns loaded in transverse compression where the panel can generally be assimilated to a perfect plate (Fig. 2). Among the available models, those based on the theoretical studies of Sommerfield [2] and Timoshenko [3] are common. They employ an energy approach to determine the elastic critical load of a plate loaded in double compression by two concentrated forces applied in the middle of two opposite edges. Timoshenko and Gere considered two boundary conditions: simple supports on the four edges or two clamped at the loaded edges and the other two simply supported.

The elastic buckling force F_{cr} of a rectangular plate was proposed by Timoshenko and Gere [4] under the general form of Eq. (1).

$$F_{cr} = k_{cr}\frac{\pi^2 E\, t_W^3}{12(1-v^2)h_w}. \tag{1}$$

In this general equation, k_{cr} represents the elastic buckling coefficient of the plate. It includes the geometrical parameters, the restraint boundary conditions and the load conditions. The parameters h_w, t_w, E and ν are the height and the thickness of the plate, the modulus of elasticity and the Poisson's ratio of the material, respectively. Given the influence of the geometrical characteristics and the boundary conditions on the elastic buckling coefficient k_{cr} and as a consequence on the critical load F_{cr}, this study is concerned with the coefficient k_{cr} to determine the critical load of a perfect plate. According to Timoshenko, for a rectangular plate ($a >> h_w$) loaded in double compression by two equal concentrated forces applied at the middle of two opposite sides, the buckling coefficient k_{cr} is equal to $4/\pi$ for the case of a plate that is simply supported on its four edges and $8/\pi$ for the plate with the two loaded opposite sides clamped and the two others simply supported.

Other investigations, performed mainly by Legget [5], showed that the solution given by Timoshenko [3] may lead to considerable errors in certain cases. Thus, he proposed another approach based on the representation of the concentrated load by a Fourier series. This led to values of buckling coefficients with reasonable accuracy. Yamaki [6] developed this energetic method to obtain solutions of buckling coefficients with improved accuracy.

Leissa and Ayoub [7] and Deolasi and Datta [8] used the finite element method to model a simply supported plate and calculate its buckling critical load for various aspect ratios. Deolasi and Datta established a comparison between buckling critical loads which were obtained by using the finite element model and those given by Yamaki.

Khan and Walker [9] studied the configuration of a simply supported plate studied by Timoshenko but considering a distributed load applied over a finite length (Fig. 2). They proposed a diagram to calculate the

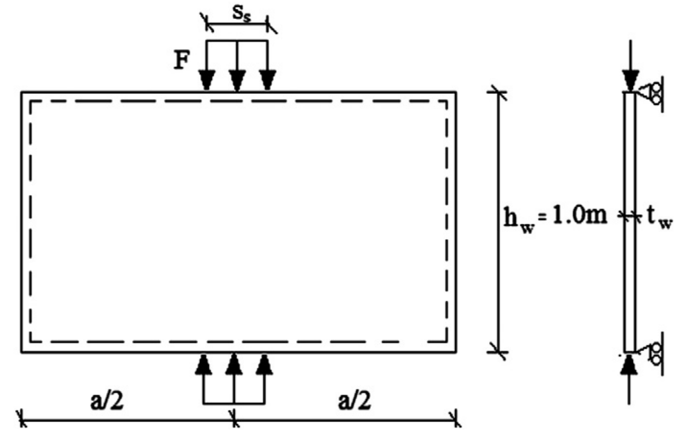

Fig. 2. A simply supported plate subjected to opposite patch loading.