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Steel plate girder webs under combined patch loading, bending and shear

C. Graciano *, A. Ayestarán

Universidad Simón Bolívar, Departamento de Mecánica, Apdo. 89000, Caracas 1080-A, Venezuela

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ABSTRACT

During bridge erection employing the incremental launching method, plate girders are subjected to a combined loading situation. Due to the support reaction, the thin webs are withstanding concentrated loads, and due to the self weight of the launching nose and the span between the piers the web is also under the action of bending and shear force. This paper is aimed at investigating the nonlinear behavior of unstiffened girder webs subjected to combined loading (concentrated loading, bending and shear) by using the finite element method. Firstly, the numerical models are validated against experimental results taken from the literature. Secondly, each individual resistance is calculated in order to normalize the applied loads. Thereafter, a parametric analysis is conducted looking at the interaction between the three types of loading, and a combined failure mode is identified. Finally, the results shows limits in the resistance when all three loads are applied.

1. Introduction

Slender girders are often subjected to various loading conditions namely bending, patch loading or shear. Each one of its components are designed to withstand a particular load, the flanges are capable to withstand compressive/tensile forces resulting from bending stress distribution, thin slender webs may be capable to resist heavy shear loads as well as localized compressive loads due to patch loads. Vertical stiffeners and thin webs should be able to undertake tension field actions that derivates from shear loading.

At designing these slender girders, there is a compromise between weight-cost and strength, the webs becomes high and thin in order to reduce weight, increasing compressive/tensile loads in flanges. Consequently, the slender girder webs are prompter to failure due to instability or buckling phenomena.

Regarding patch loading, a large amount of research can be found in the literature. Roberts and Rockey [1] presented a failure mechanism model based on the formation of plastic hinges in the flanges and yield lines in the webs. Thereafter, a series of experimental investigations has been developed [2–6] in order to investigate the resistance of the slender girder webs subjected to patch loading. From the results obtained by Lagerqvist [5] a model based on strength curves was presented and used currently in design codes [7]. Numerical models have also been developed to propose improvement in current formulations [8–10]. Shear loading is perhaps the less studied case, D'Apice et al. [11] performed a series of experiments to investigate the collapse of girder webs with/without longitudinal stiffening under shear loading, and Deslesques [12] proposed a model to calculate critical shear stresses. Numerical models for transversely stiffened girder webs under shear were investigated by Lee and Yoo [13,14] and Lee et al. [15] and for longitudinally stiffened webs by Pavlovic et al. [16]. More experimental investigations focusing on the structural behavior of longitudinally stiffened girders under shear have been conducted in the last three decades [17–19]. Concerning bending, D'Apice et al. [11] also conducted an experimental investigation on the resistance of slender girder under bending moments. Dubas and Tschamper [20] studied experimentally the stability of slender girders with/without longitudinal stiffeners subjected to bending, and combined patch loading and bending.

Most experimental/numerical investigations have looked up the interaction between two types of loading: patch loading and bending or patch loading and shear [21,22] but few have been able to investigate the interaction between the three types of loading [23,24]. Braun and Kuhlmann [24] investigated first the interaction between patch loading and shear, and secondly between patch loading and bending, thus by merging both interactions an equation for the three types of loading was proposed. However, the analysis was mainly based on a two dimensional interaction between each pair of loads and then merging the equations into a three dimensional one. Therefore, it is necessary to perform computer simulations on the basis of parametric analysis where the three loads are varying simultaneously, for a deeper investigation of this problem. This paper is aimed at investigating the interaction between patch loading, bending and shear force in unstiffened girder webs by using nonlinear finite element analysis.

* Corresponding author.
E-mail address: cgracian@usb.ve (C. Graciano).

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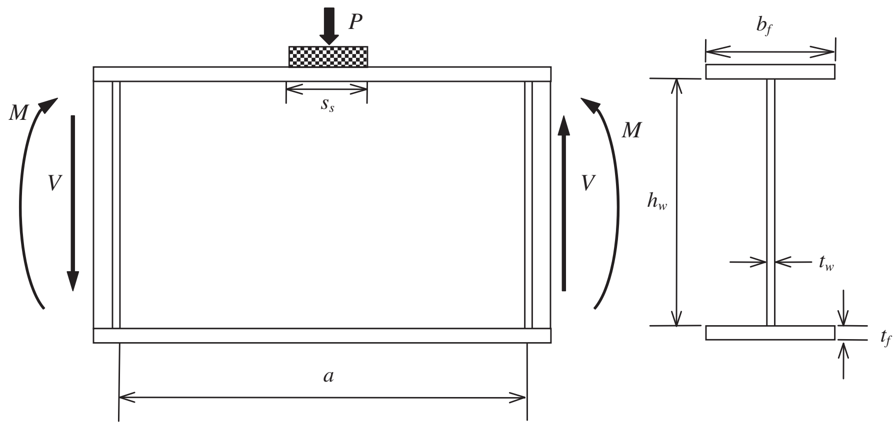

Fig. 1. A plate girder subjected to combined patch loading, bending and shear.

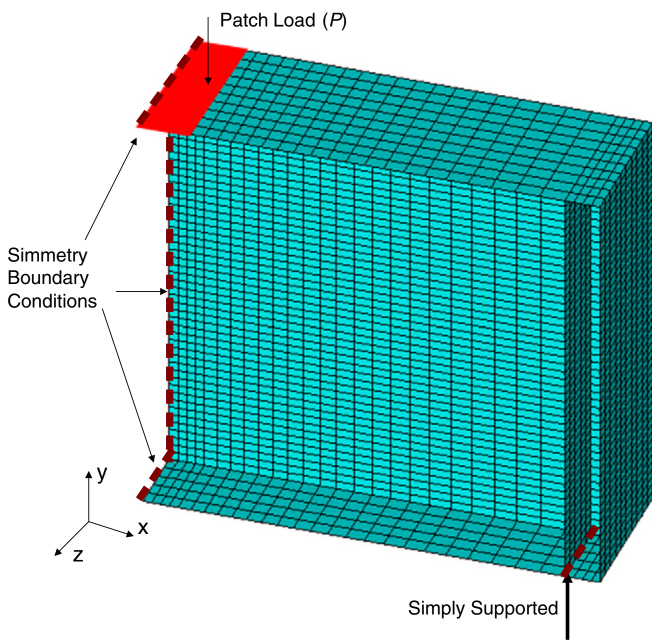

Fig. 2. Numerical model for patch loading resistance.

2. Literature review

At present, individual resistances have been investigated, regardless that in most practical cases these loading conditions act in combined forms. Three decades ago, Zoetemeijer [25] investigated the influence of shear load on the strength of rolled section under concentrated loading, as a result the following equation was proposed

$$\left(\frac{P}{P_R}\right)^2 + \left(\frac{V}{V_R}\right)^2 \leq 1 \tag{1}$$

where P and V are the applied patch load and shear, respectively; P_R and V_R are the corresponding resistances. Shahabian and Roberts [21] also investigated the influence of combined shear and patch loading on the strength of slender girder webs, and proposed a model

$$\left(\frac{P}{P_R}\right) + \left(\frac{V}{V_R}\right)^2 \leq 1. \tag{2}$$

Kühlmann and Braun [22], based on experimental and numerical studies, proposed for the interaction between patch loading and shear the equation

$$\left(\frac{P}{P_R}\right) + \left(\frac{V}{V_R}\right)^{1.6} \leq 1. \tag{3}$$

Regarding the interaction between patch loading and bending, Bergfelt [3] investigated this interaction and found that the bending moment affects considerably the patch loading resistance if the applied moments M is 60% larger than the bending resistance M_R. As a result the following equation was proposed.

$$\left(\frac{P}{P_R}\right)^8 + \left(\frac{M}{M_R}\right)^2 = 1. \tag{4}$$

In 1983, Elgaaly [26] proposed the following equation for the interaction between patch load and bending.

$$\left(\frac{P}{P_R}\right)^3 + \left(\frac{M}{M_R}\right)^3 = 1. \tag{5}$$

Later on, Ungermann [27] suggested a linear relationship between the two types of loading.

$$\left(\frac{P}{P_R}\right) + \left(\frac{M}{M_R}\right) = 1.4. \tag{6}$$

Table 1
Dimensions and material properties tested by Roberts [23].

Girder	a (mm)	h_w (mm)	t_w (mm)	b_f (mm)	t_f (mm)	s_s (mm)	f_{yw} (MPa)	f_{yf} (MPa)	P_R^{EXP} (kN)	P_R^{FEA} (kN)	Δ %
B3-3	600	500	3.05	149	3.05	50	221	221	70.56	77.1	9.3
B3-7	600	500	3.05	149	6.75	50	221	279	90.72	88.78	2.1
B3-12	600	500	3.05	149	11.75	50	221	305	111.36	115.9	4.1
B3-20	600	500	3.05	149	20.06	50	221	305	130.6	135.2	3.5