



Bending and shear buckling interaction behaviour of I-girders with longitudinally stiffened webs

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ABSTRACT

Steel I-girders with longitudinally stiffened webs are commonly used in the civil engineering field, especially in bridges. Therefore, the load-carrying capacity of these types of girders under a combined loading scenario (interaction of bending and shear) is an important feature of the design. Previous research results proved that the current design method of EN1993-1-5 [1] does not always provide safe resistances for the M-V interaction in scenarios where longitudinally stiffened and unstiffened girders are utilised. Because there has only been a small number investigations on this topic, a systematic review of the M-V interaction behaviour for unstiffened girders was executed by Jäger et al. [2] in 2016. This type of review is still missing in international literature for longitudinally stiffened girders; therefore, the current study focuses on the M-V interaction behaviour of longitudinally stiffened I-girders with slender webs, and investigates the applicability of the M-V interaction resistance model developed for unstiffened girders [2].

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1. Introduction

The determination of the bending and shear buckling resistances and their interaction has a special focus in the civil engineering practice, especially in the case of longitudinally stiffened girders. There is a large number of previous investigations in international literature that address the bending and shear buckling resistances of stiffened girders, but there are only a few investigations that discuss the M-V interaction. Sinur and Beg conducted a notable research program on the M-V interaction behaviour of I-girders with longitudinally stiffened webs by investigating a large parameter range [3,4]. Based on their results, it was concluded that the current M-V interaction equation of EN1993-1-5 [1] does not always yield safe results, and therefore a modified lower limit design interaction equation was proposed. This enhanced design equation uses the elastic bending resistance instead of the plastic moment capacity, and the exponent of the shear term was changed from 2.0 to 1.0, which caused a linearization of the interaction curve. This design method was developed and verified only for a certain type of longitudinally stiffened I-girder.

The previous investigations performed by Kövesdi et al. [5,6] on the M-V-F interaction behaviour of longitudinally stiffened and unstiffened I-girders also proved that the current M-V interaction equation of EN1993-1-5 [1] can generate unsafe results for certain girder geometry. These investigations had the original aim of investigating longitudinally stiffened and unstiffened I-girders under a combined M-V-F loading

condition, and to verify the developed design method of Braun and Kuhlmann [7]. Within this research program, the M-V plane was also studied; however, it was not evaluated in detail. Hendy and Presta [8] investigated transversally stiffened I-girders with heavy flanges, which are commonly used in bridge structures in the United Kingdom. The authors concluded that the M-V interaction resistance can be significantly underestimated using the design equation of EN1993-1-5 if the resistance contribution of the flanges is not considered for the shear buckling resistance.

To evaluate and explain the reason for previous contradictions, Jäger et al. [2] executed a numerical parametric research program in cooperation with Hendy in 2016. In this program, only the longitudinally unstiffened girders are investigated, and the following conclusions are formulated based on the results:

- The $M_{f,R}/M_{el,eff,R}$ ratio has a significant impact on the M-V interaction behaviour; therefore, all of the results should be evaluated in a function of this ratio.
- The M-V interaction equation of EN1993-1-5 does not provide safe solutions for girders with $M_{f,R}/M_{el,eff,R}$ ratios smaller than 0.92. For larger $M_{f,R}/M_{el,eff,R}$ ratios, the standard M-V interaction equation yields safe solutions across the entire interaction domain.
- The proposal of Sinur and Beg [4] yields safe solutions across the entire analysed parameter range.
- An improved M-V interaction equation is developed by changing the index, κ , from 1.0 to an increased value in a function of the $M_{f,R}/M_{el,eff,R}$ ratio, which ensures a better fit to the numerical simulations.

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Because the above conclusions refer only to longitudinally unstiffened girders, the aim of the current investigation is to execute a systematic numerical parametric study for longitudinally stiffened girders. However, previous investigations showed that the consideration of the flanges in the shear buckling resistance needs improvement, thus the current resistance model does not follow the observed tendencies of the numerical simulations. The investigation of this phenomena is also a focus of the current study.

In the current research program, an advanced numerical model is developed to extend the previous investigations and to analyse the applicability of the proposed interaction equation for longitudinally stiffened girders. The basis of the numerical model development is the experimental work of Pavlovčič et al. [9] and Sinur and Beg [3]. Based on the developed numerical model, the bending and shear buckling resistances of the analysed girders are determined and the structural behaviour under the combined loading situation is investigated. The notations used in this study are shown in Fig. 1.

The research work is completed according to the following research strategy:

- A literature overview of the interaction behaviour of longitudinally stiffened girders is provided.
- A numerical model was developed with variable geometry and loading conditions.
- Numerical models were verified based on previous test results.
- A numerical parametric study was performed to investigate the effect of different geometric parameters on the interaction behaviour.
- The numerical results were compared to the M-V interaction equation proposed by EN1993-1-5 and with the enhanced interaction equation developed by Jáger et al. [2] for I-girders without longitudinal stiffeners.
- A statistical analysis was performed to determine the safety level of the M-V interaction equations, and the equations were proposed for an applicable interaction equation.

2. Literature overview

This section summarises the previously developed bending and shear buckling resistance models, and provides an overview of their M-V interaction behaviour. A detailed literature review on M-V interaction behaviour is provided by the authors in [2] regarding unstiffened girders. The current study focuses only on the characteristics of longitudinally stiffened girders. The first experiment on this topic was

conducted by Cooper [11] in 1965. Since then, several researchers have conducted notable experimental and/or numerical research programs, which led to the currently used design methods [3,9,12–16].

2.1. Design model for the bending resistance

In the current study, the bending resistance model of EN1993-1-5 is used to determine the bending moment resistance of girders with longitudinally stiffened webs. According to the standard, the design bending moment resistance of girders with class 4 sections can be determined by Eq. (1), based on the effective width method.

$$M_{c,Rd} = \frac{W_{el,eff} \cdot f_y}{\gamma_{M0}} \quad (1)$$

where $W_{el,eff}$ is the cross-sectional modulus considering the effective area of the section, f_y is the yield strength, and γ_{M0} is the partial safety factor. In the cross-sectional modulus, the local and global buckling behaviour of the stiffened web is also taken into account to consider plate-like and column-like behaviour. New proposals for the improvement of the Eurocode-based resistance model have been provided by several research papers. Galéa and Martin [17] developed and proposed a new method for the calculation of the global critical buckling stress for longitudinally stiffened plates in 2010, which refers to the critical elastic buckling stress of plate-like behaviour in EN1993-1-5, Annex A. In addition, a comparative study was performed by the different methods, showing that a conservative result is provided by the standard if non-rigid longitudinal stiffeners are used. In 2016, Park et al. [18] numerically studied the bending resistance of plate girders with longitudinal stiffeners from the point of view of the flange-to-web juncture. According to EN1993-1-5, the compression flange is simply supported by the web; however, the test results obtained by Johnson [19] demonstrated a moderate rotational restraint of the web for unstiffened girders. Based on the results obtained by Park et al., modified slenderness limit ratios are proposed for the cross-section classification of the flange and web. The optimum location of a single longitudinal stiffener in the web panel under pure bending was investigated by several researchers [20–23]. It is concluded from these studies that $0.2 \cdot h_w$ under the compression flange is optimal using rigid stiffeners. In the case of non-rigid stiffeners, this distance depends on the relative flexural stiffness of the stiffener and the aspect ratio of the web panel [21].

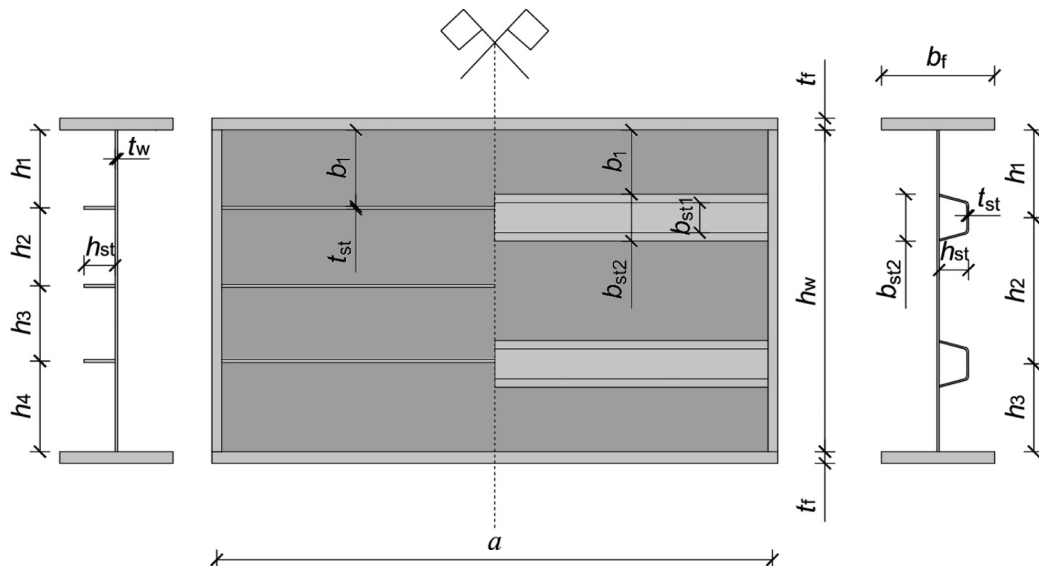


Fig. 1. Notations used in the study.

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