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Patch loading resistance of slender plate girders with longitudinal stiffeners

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ABSTRACT

It is commonly known that the patch loading resistance model of the EN1993-1-5 has a relative large scatter, and it can lead to significant underestimation of the patch loading resistance in case of slender plate girders with longitudinal stiffeners. Large number of previous investigations studied the structural behavior of the stiffened girders subjected to concentrated transverse force. Although a reliable and simple design method is not available in the international literature. The main part of these investigations focus on girders with one longitudinal stiffener, however in the bridge design praxis, usually more stiffeners are applied on the web. For these structures the applicability of the improved design methods is not proved. It is also known, that the current design method of the EN1993-1-5 does not consider the location of the longitudinal stiffener properly. The focus of the current paper is on the investigation of the patch loading resistance of longitudinally stiffened slender web girders and an enhanced design method development. Based on a large number of numerical simulations the structural behavior is studied and failure modes are classified. The effect of each geometrical parameter on the patch loading resistance is investigated and an improved design method is developed, which is consistent with the design philosophy and safety requirements of the EN1993-1-5 standard.

1. Introduction

Nowadays the incremental launching technique is one of the most competitive bridge erection method. This building process, however, involves a problem with buckling of the thin steel web under patch loading. Steel girders with longitudinally stiffened webs are commonly used in the field of bridges. During incremental launching the main girders are subjected to transverse force (F) at the location of the piers, where the patch loading resistance can give the governing failure mode. All the Hungarian bridges built in the last decades using incremental launching technique had to be reinforced by transverse stiffeners to eliminate the web crippling failure. The reinforcement is usually executed by small transverse stiffeners placed in a distance of 300–450 mm along the girder length, as shown in Fig. 1. This reinforcement method is cost and time consuming and increases the welding and erection time of the bridge.

It is commonly known from previous researches that the patch loading resistance model of the EN1993-1-5 [1] can lead to significant underestimation of the patch loading resistance. Significant efforts have been made by several researchers to develop improved design methods. Numerous previous investigations have focused on the actualization of the mechanical model developed for unstiffened girders [2–8] and for girders with longitudinal stiffeners [9–16]. It has to be highlighted, however, that the main part of these investigations focused on steel I-girders with only one longitudinal stiffener placed on the web, which is not a common design practice for box section bridges.

A systematic review on the previously developed patch loading resistance models and on the recent improvements and research requests is made by Graciano in 2015 [17]. Based on this review it can be concluded, that despite the large number of previous investigations the prediction of the patch loading resistance model developed for longitudinally stiffened girders has still a large scatter and needs further improvement.

The main criticism of the current design methods is that these models are developed for one longitudinal stiffener and they cover the web crippling resistance of the lower and upper sub-panels and their coupled instabilities within one mechanical model, as shown in Fig. 2. Therefore, they are not applicable for girders with more than one longitudinal stiffeners explicitly. The second criticism is that the current design methods do not consider the location of the longitudinal stiffener in the patch loading resistance properly. An optional solution to eliminate this problem is proposed by Davaine [12]. This design method gives better resistance prediction than the proposal of the current EN1993-1-5 [1], however it is validated only for one stiffener and still underestimates the resistance. The third remark is that the effect of the longitudinal stiffener is implemented in the buckling coefficient

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Fig. 1. Steel box section bridge reinforced by transverse stiffeners on the web.

(k_F), which consequence is that increase in the stiffener stiffness results in increase in the critical load amplifier and in the patch loading resistance as well. It comes from the mechanical model where the patch loading resistance corresponds to the global web buckling and the stiffener can have a positive effect on the buckling resistance. However, if the stiffener has enough rigidity to separate the buckling shapes into the web sub-panels (Fig. 2.*a*), the further increase in the longitudinal stiffener stiffness has no effect on the patch loading resistance and the tendency represented by the mechanical model does not fit the real structural behavior. Several previous laboratory tests and numerical investigations of the author prove, that stiffeners with relative small stiffness can separate the buckling shape into the sub-panels of the web. In this case the stiffener size have no effect on the patch loading resistance. The consideration of this phenomena is missing from the current design methodology of the EN1993-1-5 [1].

The aim of the current research is the comprehensive investigation of the web crippling phenomena and the improvement of the current patch loading resistance model to minimize the reinforcement request during bridge launching. In the current paper the existing experimental, analytical and numerical investigations in the topic of the patch loading resistance of the steel girders with longitudinal stiffeners are analyzed, evaluated and compared. To extend the previous investigations and to analyse the applicability of the previous design proposals a numerical model is developed based on the experimental background of Seitz [11]. On the basis of the developed numerical model the patch loading resistance is determined and the structural behavior is studied. Based on the results of more than 900 numerical simulations an improved design equation is developed. The applicability of the improved design method is studied in a large-scale parameter range for various girder geometries with diverse longitudinal stiffener configurations. The used notations in the paper are shown in Fig. 3.

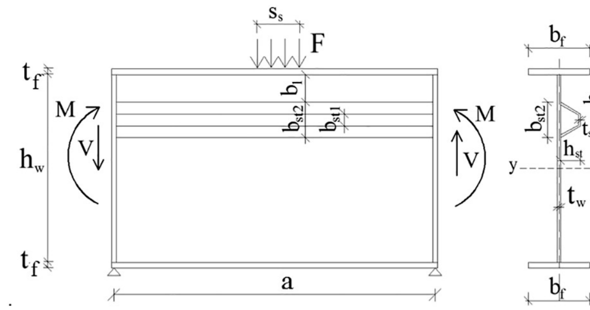

Fig. 3. Used notations in the current paper.

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

- literature review in the topic of the previous investigations on the patch loading resistance,
- development and validation of an advanced numerical model based on shell elements with variable geometry and different longitudinal stiffener configurations,
- numerical parametric study to investigate the observed failure modes and the effect of the different geometric parameters on the patch loading resistance,
- design method development for girders with longitudinal stiffeners,
- statistical analysis to determine the safety level of the improved design equation.

2. Literature review

There is a large number of previous investigations available in the international literature dealing with the determination of the patch loading resistance. Generally, there are two different design concepts to consider the resistance increasing effect of the longitudinal stiffener: (i) design models using increasing factors and (ii) design methods using reduction factors.

The strategy of the design methods using increasing factors is to determine the patch loading resistance of the same girder without considering the stiffener (F_{Ro}) and multiplying this resistance by a correction factor ($f(s)$) according to Eq. (1).

$$F_{Rl} = F_{Ro} \cdot f(s) \tag{1}$$

Different proposals are developed for the correction factor, e.g. in [7, 18–20], which are summarized in Table 1. The application range and the limitations of each correction factor proposals are also given in the table.

The other group of the design methods use buckling reduction factors (χ_F). In case of these methods the effect of the longitudinal stiffener is implemented in the critical load (F_{cr}) and in the buckling coefficient

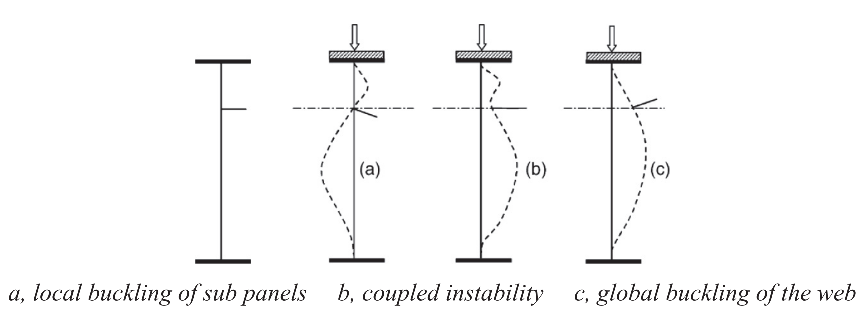

Fig. 2. Failure mode types of girders with one longitudinal stiffeners.