Imperfection analysis on the patch loading resistance of girders with open section longitudinal stiffeners

B. Kövesdi*, B.J. Mecséri, L. Dunai

Budapest University of Technology and Economics, Department of Structural Engineering, Műegyetem rkp. 3., H-1111 Budapest, Hungary

ABSTRACT

Previous studies proved that the patch loading resistance model of the EN1993-1-5 can lead to significant underestimation of the patch loading resistance in case of longitudinally stiffened girders. Recently there are several research activities to improve the design method. In the current study experimental research program is executed on 8 large scale test specimens having different longitudinal stiffener configurations and loading lengths to extend the available background and to verify advanced numerical model. In parallel to the experiments a finite element model is developed considering the geometrical and material nonlinearities and geometric imperfections. The current paper presents the experimental tests and focuses on the modelling technique of the geometric imperfections, which can have large importance in case of coupled instabilities. Based on the experiments and numerical investigations design recommendations are given for equivalent geometric imperfection shapes and magnitudes for girders with longitudinally stiffened web. The measured resistances are compared to different resistance models found in the international literature and their accuracies are evaluated.

1. Introduction

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 ultimate failure mode. Recently in Hungary the bridges are typically built by incremental launching technique and had to be reinforced by transverse stiffeners to eliminate the web crippling failure. In the same time I-girders with longitudinally stiffened webs can also give efficient solution for seismic design for buildings where the concentrated load introduction into the longitudinally stiffened beam has to be also checked. Previous studies and test results showed that the current design method of the EN1993-1-5 [1] can lead to significant underestimation of the patch loading resistance in case of girders with longitudinally stiffened webs. Despite significant efforts are made by numerous researchers in the past to develop enhanced design methods [2–16], these still have a relatively large scatter. Using advanced numerical model the patch loading behavior and resistance of longitudinally stiffened girders can be determined with higher accuracy. The key parameters of the numerical simulations are the imperfection shape and magnitude. It is typical to use in these models equivalent geometric imperfections which combines the effect of the residual stresses and the geometric imperfections. The shape and the magnitude of the equivalent geometric imperfection is not obvious, if the longitudinal stiffeners are relatively weak. The stiffener is defined as weak if its relative stiffness is smaller than the limit value defined by Eq. (1) according to the EN1993-1-5 [1]. It is noteworthy that Eq. (1) was originally developed [7,18] to establish a transition rigidity for linear buckling analysis of plate girders subjected to patch loading. It means that if the bending stiffness of the stiffener is larger than the transition rigidity its contribution is limited to this value. However the current and previous results showed, that in the practical application domain of longitudinal stiffeners this equation could serve as good bases to the evaluation of the buckling behavior. The meaning of the notations used in the present paper are shown in Fig. 1.

\[
\chi \leq 13 \left( \frac{a}{h_w} \right) + 210 \left( 0, 3 - \frac{b_l}{a} \right)
\]  

(1)

If the stiffener stiffness is significantly larger than this limit value, the failure mode will be localized on the directly loaded web sub-panel (local buckling). If the stiffener stiffness is smaller than this value, the failure mode can be global buckling of the whole web, or the interaction of global and local buckling. The typical failure modes are demonstrated in Fig. 2. The combined stability phenomena call the attention on the careful selection of the equivalent geometric imperfection shape and magnitude. For local buckling the magnitude of the equivalent geometric imperfection can be \( b_l/200 \) according to EN1993-1-5 Annex

* Corresponding author.
E-mail address: kovesdi.balazs@epito.bme.hu (B. Kövesdi).

https://doi.org/10.1016/j.tws.2017.11.030
Received 9 August 2017; Received in revised form 13 November 2017; Accepted 14 November 2017
Available online 22 November 2017
0263-8231/ © 2017 Elsevier Ltd. All rights reserved.
D (sub-panel imperfection). In case of global buckling the imperfection magnitude should be set equal to \( h_w/200 \). The resistance differences coming from the applied imperfection shape and magnitude can be significant, therefore it is requested to investigate this effect deeply. The aim of the current research is to give design recommendations which imperfection shape and magnitude to be applied, if the patch loading resistance is determined using FE analysis based GMNI simulations.

In the first part of the research an experimental study with 8 tests are completed. The test specimens are designed using weak, open section stiffeners. On the basis of the test results an advanced numerical model is validated and used to develop FE design recommendations for the imperfection shapes and magnitudes. Furthermore, the test results are compared to previously developed resistance models and their accuracies are discussed. It has to be noted, that stiffeners characterized by weak stiffeners in the current paper could also serve as optimal solution for another purposes (for example bending resistance increase), but from patch loading point of view these are characterized as weak stiffeners.

2. Literature review

The resistance of longitudinally stiffened plate girders subjected to concentrated load was studied intensively in the past. The current design method of the EN1993-1-5 is based on the design method developed by Graciano, Lagerqvist and Johanson [5–9]. This method, however, has a relatively large scatter and gives conservative resistances especially for bridge type girders. Therefore, an intensive research activity was started in the frame of the COMBRI-Project to improve the accuracy of the patch loading resistance model [10–12]. Large scale laboratory tests and comprehensive numerical studies are executed to enlarge the investigated parameter range, with special focus on bridge type girders with closed section stiffeners. Seitz [13] carried out a series of laboratory tests to validate his numerical model. An extensive numerical parametric study is executed to determine the patch loading resistance for different girder geometries and stiffener cross-sections. Seitz proposed an improved design method based on the combination of the column-like and plate-like buckling behavior of the stiffened web. The developed design method, however, is quite complex for practical applications.

Significant research program has been performed by Kárníková and Skaloud in 1989 on the behavior of longitudinally stiffened webs under the action of partial edge loading [27]. The results of 152 tests are analyzed, and the effect of (i) the position and (ii) the size of the longitudinal rib on the ultimate load behavior of the webs is studied. Significant conclusions are drawn from the test results and from the observed failure modes which had effect on the analytical design method development.

Significant research program was also conducted by F. Dall’Aglio in his PhD thesis in 2011. The patch loading resistance of longitudinally stiffened and unstiffened girders are studied experimentally and numerically. The effect of the stiffener geometry and the web panel thickness on the patch loading resistance is studied in a detailed manner [28,32].

Interesting research of Navarro-Manso et al. studied the optimum way to design both type and position of the stiffeners when a steel bridge is launched [29]. The main objective of their research was to numerically analyze the best stiffener combination and distribution along the length of the bridge, both longitudinally and transversally, in order to avoid the patch-loading failure mode in the slender webs. Three dimensional finite element model (FEM) is built and the design of experiments technique (DOE) is applied to obtain the best stiffener configuration. The application of the numerical modelling technique is introduced in this research work.

Significant research has been made to investigate the optimal location of the longitudinal stiffeners by Walbridge and Lebet [30], Graciano and Edlund [31], and by Loaiza et al. [33,34]. These studies investigate the effect of the different stiffener geometries and their locations on the patch loading resistance.

Davaine [14] performed an extensive numerical parametric study investigating the critical load and the ultimate resistance of longitudinally stiffened girders subjected to concentrated transverse force. Based on the numerical simulations it is observed, that the design method of the current EN1993-1-5 does not consider the location of the longitudinal stiffener in the patch loading resistance correctly. Davaine developed an enhanced design method with the aim to consider the failure mode of the different web sub-panels and the tendencies depending on the stiffener position correctly. The proposed design method was developed mainly for girders having one longitudinal stiffener. Therefore, it is not obviously applicable in the same form for girders with more longitudinal stiffeners. Detailed description of the resistance

![Fig. 1. Notations for girders with longitudinal stiffeners.](image1)

![Fig. 2. Typical web crippling failure modes.](image2)
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات