A comparative study of the patch loading resistance of longitudinally stiffened girders

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Introduction

Bridges can be constructed in various ways. For bridge decks greater than 250 meters in length, the method of incremental launching can be considered. With this method of construction, the bridge deck is built in sections by pushing the structure outwards from the abutments towards the pier. Figure 1 displays a schematic representation of this method.

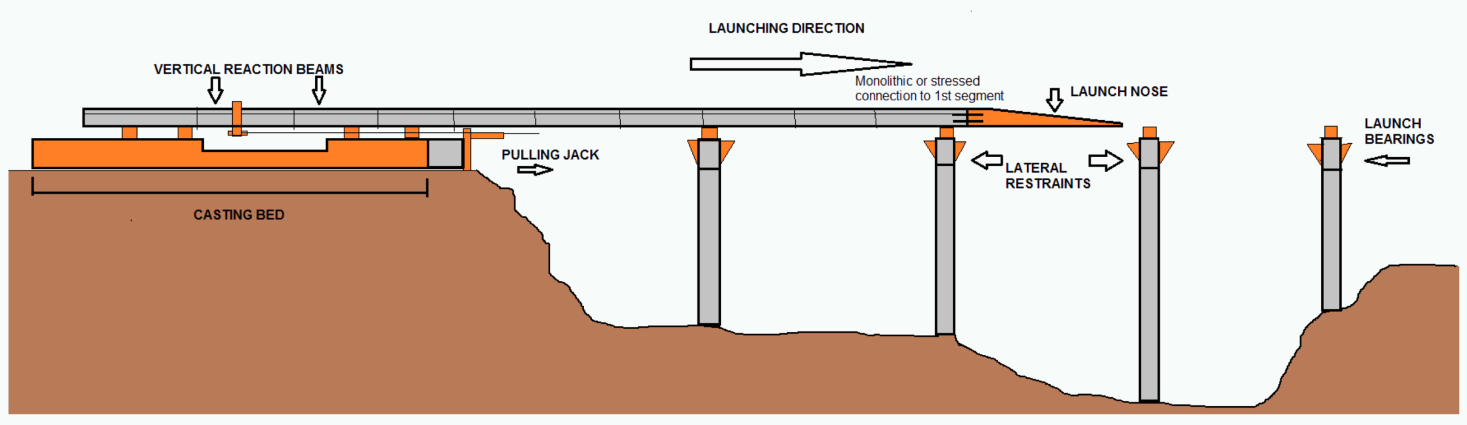

Figure 1: Schematic of the method of incremental launching [1].

During the incremental launching of bridges, patch loading is an important factor to consider. Patch loading happens when concentrated transverse loads are applied to one flange, over the loading length of a steel girder. To this date, the calculation of the patch loading resistance of longitudinally stiffened girders still lacks a reliable and simple design method [2]. The EN1993-1-5 [3] describes the current design method, but it has a relatively large scatter. This can lead to a significant underestimation of the patch loading resistance of said girders. However, various new design methods have been proposed throughout the years and are available in the international literature [4].

Open section stiffeners

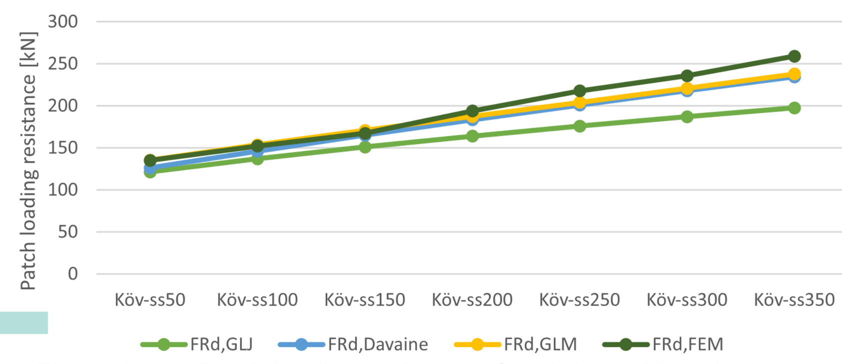

Figure 6: Patch loading resistance for girders with a single open section stiffener with varying loading length.

Figure 6 depicts the change in patch loading resistance for an increasing loading length (s_s) and displays a nearly linear behaviour for all results. The EN1993-1-5 is represented in light green, Davaine's proposal in blue, Graciano's in yellow, and the FEM results in dark green.

As presented in Figure 7, Davaine's and Graciano's proposals are an improvement upon the EN1993-1-5, yet the FEM results are still underestimated. Furthermore, it presents that doubling the thickness of the stiffener (t_{st}) brings no significant change to the patch loading resistance.

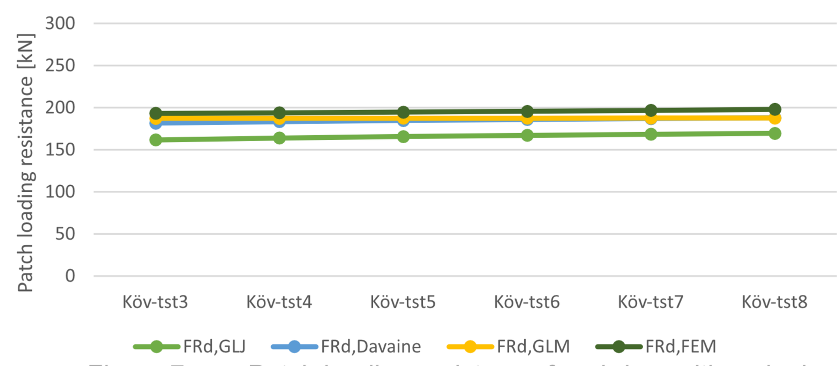

Figure 7: Patch loading resistance for girders with a single open section stiffener with varying stiffener thickness.

Conclusion

To conclude for girders with open section stiffeners, Graciano's proposal is in most cases the more accurate calculation method. However, the current analytical methods do not take multiple stiffeners correctly into account which leads to an underestimation of the patch loading resistance. Increasing various parameters can either lead to a negligible increase, or a significant amplification of the patch loading resistance. For example, doubling the stiffeners' stiffness (t_{st}) results in a marginal improvement, while doubling the web's thickness (t_w) can lead to more than doubling the patch loading resistance. Lastly, applying an extra stiffener may actually have a negative effect on the patch loading resistance, as a different and more critical buckling behaviour can be induced.

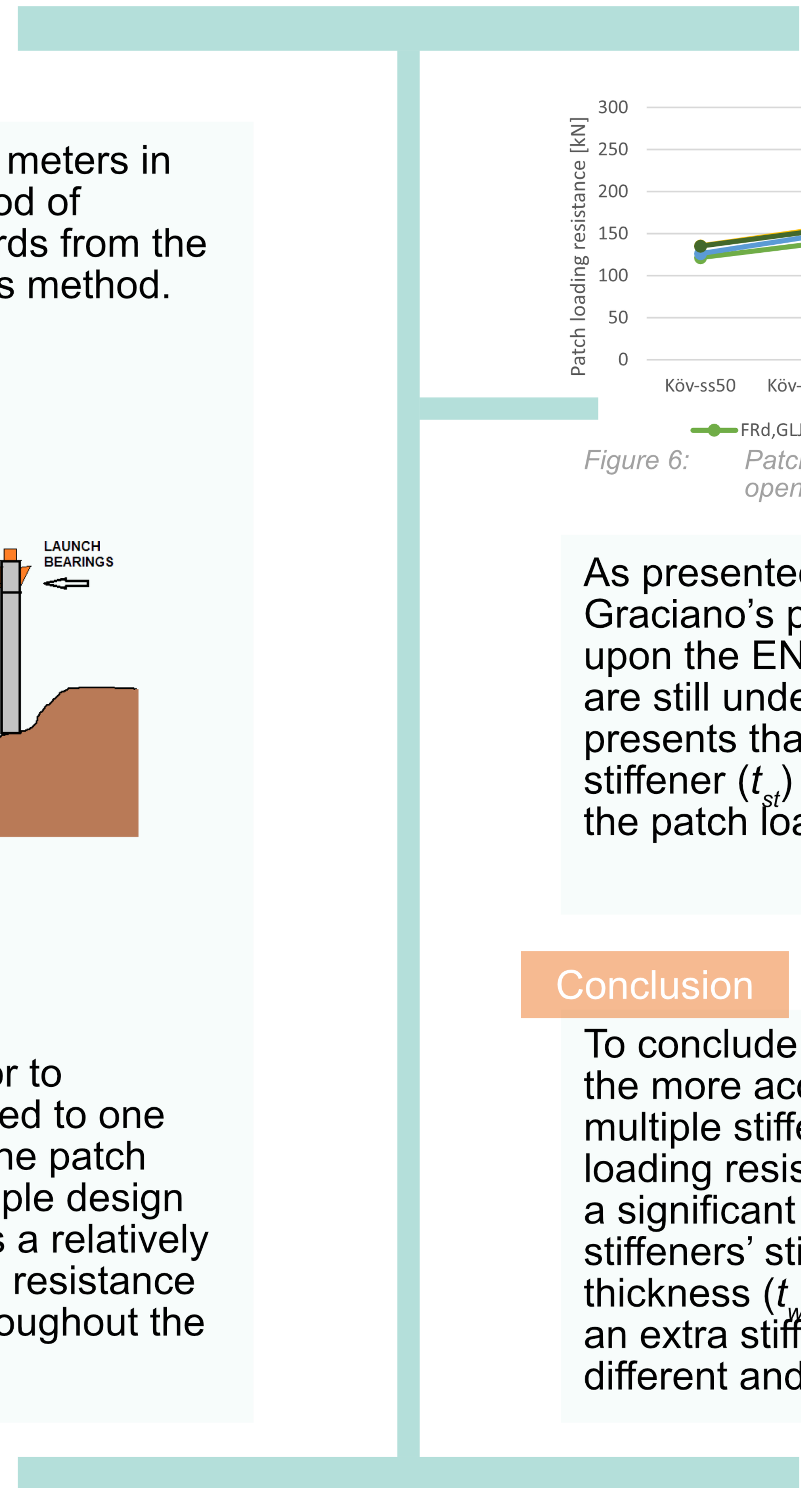

Figure 5: Schematic representation of a girder with an open section longitudinal stiffener.

Method

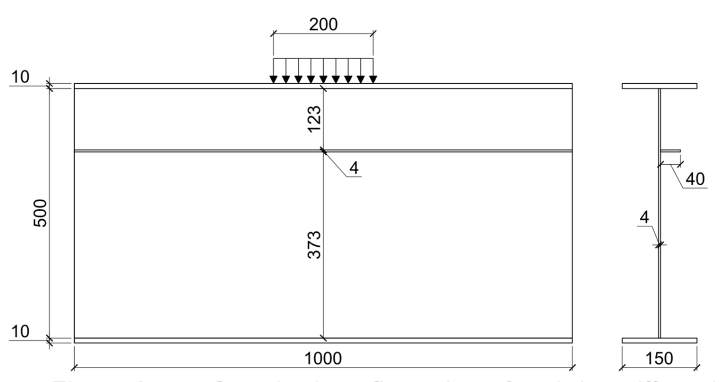

Figure 2: Standard configuration of a girder stiffened with open section stiffeners.

The first step is to determine the geometry of the base girders, and the parametric range of the various measurements that have to be tested. Base models with one, two and three stiffeners are made. The stiffeners can either have an open or a closed section. Figure 2 is an example of a base girder. The steel grade of S355 is applied.

The determination of an optimal finite element size is the next step. Choosing an average mesh size that is too small yields in an accurate result but also extends the computing time. The optimum is found when the accuracy loss is negligible, and the computing time is acceptable. Figure 3 shows an optimum at 15 mm.

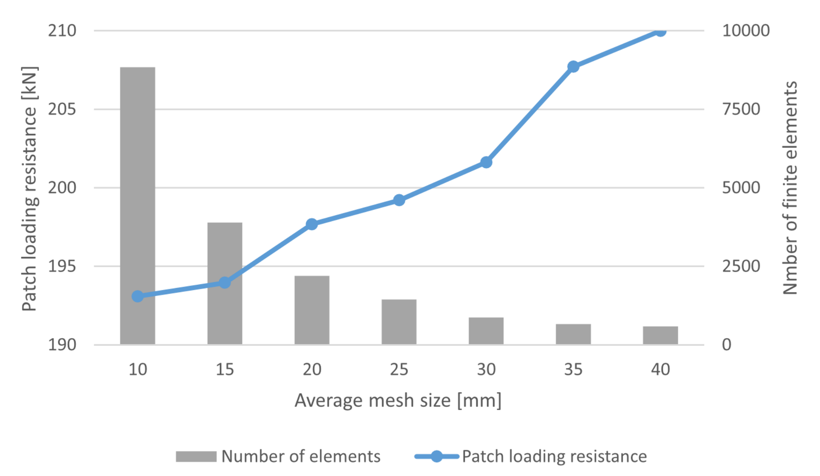

Figure 3: Results of the mesh convergence study for models with open section stiffeners.

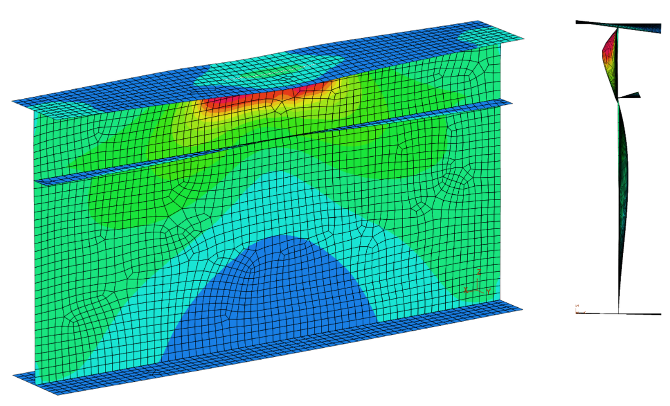

Figure 4: Deformed model with indication of strain (red is high, green is medium, blue is low).

After applying the imperfections according to EN1993-1-5 [3] and validating the results, the actual calculations are started. The most important output of the calculation for this study consists of the deformation, the ultimate load amplification factor, the failure mode and the load-displacement diagrams. Figure 4 is an example.

Closed section stiffeners

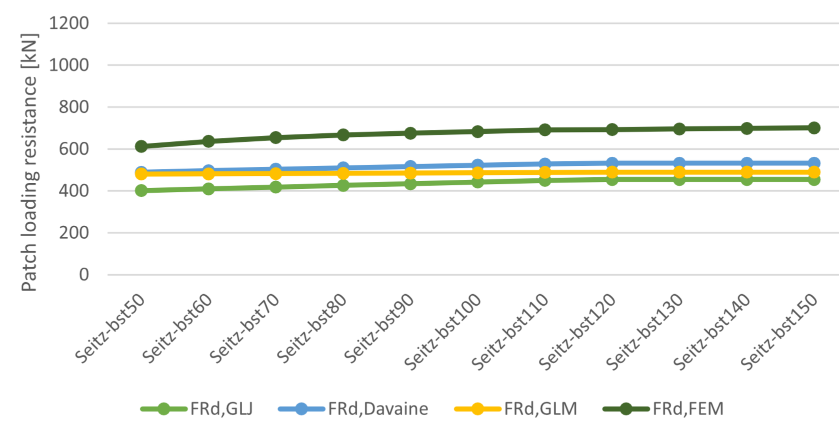

Figure 9: Patch loading resistance for girders with a single closed section stiffener with varying stiffener thickness.

Increasing the width of the closed section longitudinal stiffener (b_{st}) further beyond a certain point will not yield a higher patch loading resistance, as demonstrated by Figure 9. The FEM results show a negligible increase after bst120, just like the analytical methods do this after. Underestimation of the patch loading resistance still occurs.

Figure 10 shows that doubling the web thickness (t_w) more than doubles the patch loading resistance. However, the greater the web thickness, the higher the results scatter. Just like in Figure 9, Davaine's proposal is the most accurate one.

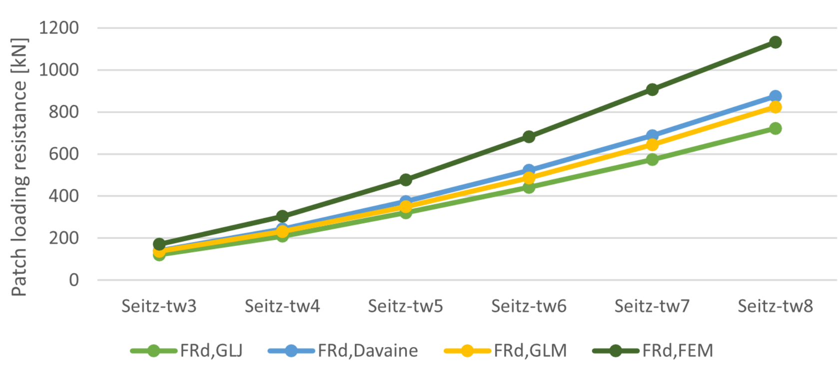

Figure 10: Patch loading resistance for girders with a single closed section stiffener with varying girder web thickness.

Conclusion

Longitudinally stiffened steel girders with closed section stiffeners are always underestimated by the current design methods and proposals. This underestimation is even more significant when multiple stiffeners are applied. Like the open section stiffeners, increasing some geometric parameters can lead to a significant increase of patch loading resistance, while others yield to little to no improvement. Changing the outer height of a closed stiffener ($h_{st,o}$) has an insignificant effect, however, adapting the inner height ($h_{st,w}$) can yield to a sizeable increase in patch loading resistance.

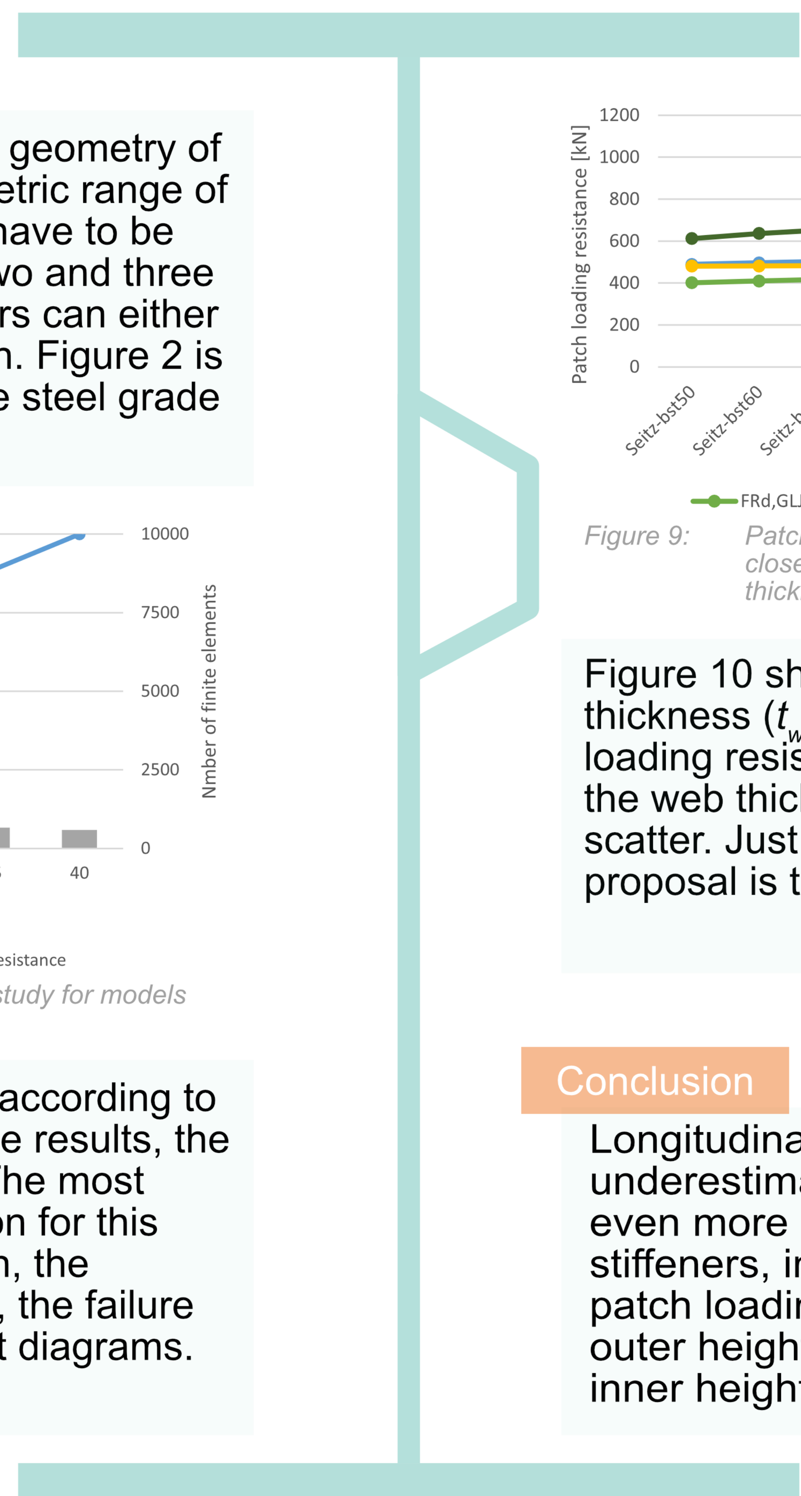

Figure 8: Schematic representation of a girder with a closed section longitudinal stiffener.

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[2] B. Kövesdi, "Patch loading resistance of slender plate girders with longitudinal stiffeners," Journal of Constructional Steel Research, vol. 140, pp. 237-246, 2018.
[3] EN1993-1-5:2006, "Eurocode 3 - Design of steel structures - Part 1.5: Plated structural elements," CEN, European Committee for Standardisation, Brussels, Belgium, 2013.
[4] M. Clarin, Plate Buckling Resistance - Patch Loading of Longitudinally Stiffened Webs and Local Buckling [PhD Thesis], Luleå: Luleå University of Technology, 2007.

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