Statistical assessment of the consequences caused by deviations in the cross-sectional geometry of hot-rolled I-sections

Introduction and aim

Steel profiles naturally show a certain variability in their characteristics. When monitoring these properties, the focus is usually set on the yield strength, as this is indisputably the most decisive attribute for structural safety. However, steel beams also exhibit deviations from the nominal geometry, which have been rather poorly documented by current research. Also the investigation of the influence on the resulting load-bearing resistances is typically limited to the calculation of sectional properties.

In this thesis, the measurements of 561 cross-sections are statistically analysed. On the one hand, this is done directly on the basis of the cross-sectional dimensions, whereby the stochastic parameters given in Annex E of the new Eurocode 3 [1] are to be confirmed. On the other hand, the effect on the load-bearing capacity is explored using parametrised finite element simulations.

Method and results

In the evaluation of the dimensional measurements, among other things, it was discovered that the flanges generally become thinner towards the outside, which implies negative effects for bending around the weak axis. On the other hand, it was found that larger profiles tend to have less scatter, which offers potential for optimisation.

The influence of the imperfect geometry on the cross-sectional resistance is studied focusing on three load cases: Pure compression, bending around the weak axis and bending around the strong axis. Firstly, this is done by calculating the corresponding sectional properties. As the estimation of the cross-sectional resistance purely based on these values cannot be seen as a very accurate prediction, the resistances are further examined making use of the numerical finite element software Abaqus. In order to investigate the 561 cross-sections, a parametrized Python script was programmed that automatically creates the simulation input files and later reads the results. This procedure allows for the large number of required simulations to be carried out systematically (in total over 5000 simulations). Both residual stresses and local buckling were taken into account, guaranteeing a realistic model behaviour.

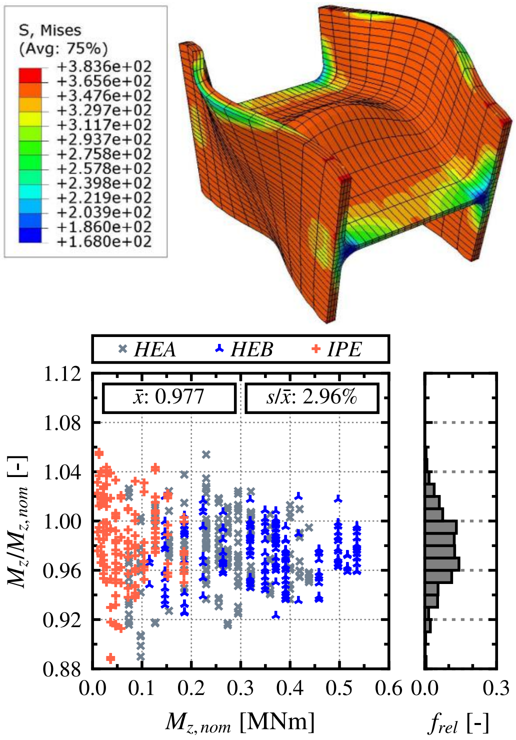

Figure 1: Excerpt of Abaqus model (top) and scatterplot of obtained cross-sectional bending resistances around weak axis (bottom)

Finally, it is observed that there are large discrepancies between the cross-sectional resistances of the nominal cross-sections compared to the ones of the real measured cross-sections. The main discrepancy can be observed for bending around the weak axis as the reduced thicknesses of the outer flange parts have a pronounced contribution to the resistance for this load case. This can be seen in the scatter plot on the right where the normalized resistances around the weak axis are depicted on the y-axis (normalized means that the obtained resistances of the measured sections are normalized with the resistances obtained with the nominal sections). Moreover, the comparison of the numerically derived cross-sectional resistances with the pure sectional properties shows impressively that there is a certain overestimation of the resistance of the real cross-sections if it is estimated solely based on the sectional properties.

Conclusions and outlook

The results of this thesis have interesting implications for the design practice. For example, the derived statistical information of the sectional dimensions and properties could be incorporated in a further step to detect the influences on the probability of failure, the reliability indices or the safety factors of the standards. This would then enable to optimize the design process and to achieve more reliable structures. It is pointed out that the present thesis concentrates on the geometrical properties and neglects the influence of the statistical variation of some mechanical properties such as the yield strength. This could be done in a further step by considering different steel grades. A subsequent sensitivity analysis would show the relative significance of the variability of the cross-sectional geometry compared to the mechanical properties. In a further step, it would be interesting to see some possible implications of the non-idealized cross-sectional geometry on member resistances by considering global instability phenomena.

References

[1] Europäisches Komitee für Normung: prEN 1993-1-1; Bemessung und Konstruktion von Stahlbauten –Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau; Deutsche und Englische Fassung; prEN 1993-1-1:2020