Numerical Investigations of Tubular Bracings in Steel and Composite Bridges

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SUMMARY

Due to their critically assessed fatigue behaviour, tubular bracings of steel and composite bridges are under discussion. In the Master thesis, various geometric parameters were analysed through numerical investigations and notch factors were derived in order to optimise the design variants. The aim of the thesis was to give design and execution recommendations especially for the critical notch.

1 Project objectives and goals

In Germany most of the highway bridges were built during the economic development in the sixties and seventies of the twentieth century. With a service life of hundred years, most German bridges have already reached half of this. Mainly because of a constantly increasing heavy load traffic. Recalculation, screenings and maintenance achieve a more important role in the future. Especially fatigue failure is highly relevant. Tubular bracings that are mainly used in large steel and composite bridges inside or outside box girders, see Figure 1, are one of those fatigue loaded components. The end of the circular hollow section tube is slotted and connected by welding with a gusset plate. For example, various design variants are currently used in German bridge construction with fundamentally different notches. Within the AiF-DASt research project [1], three design details were developed and optimised with regard to manufacturing and execution and fatigue tests have been carried out.


Figure 1: Tubular bracings of the German Bridges Schierstein (left) [2] and Lennetal (right) [3]

Cyclic loading leads to fatigue cracks and damage of the material and construction. Because of notches in components, local stress concentrations occur. The fatigue resistance is standardised by the nominal stress concept acc. to EN 1993-1-9 [4] and is given in the detail catalogue for each constructional detail. For tubular bracings, currently the two detail categories 63 and 71 are specified, depending on the angle of tube chamfering and only for design variants with holes or cut-outs at the end of the slit. Previous investigations within [1] however showed, that the given detail category 63 or 71 is not conservative. Furthermore, the detail categories in EN 1993-1-9 [4] are inadequate for particular designs parameters like plate thickness, tube diameter or type of welding are not included. To investigate further geometric parameters for variants without holes at the end of the slit, numerical investigations with the effective notch stress concept were carried out in the Master thesis. Those investigated parameters were e. g. the tube diameter, the wall thickness, the geometry of the gusset plate, the tube chamfering angle and the geometry of the gusset plate tip, which is the critical fatigue spot. The aim of the Master thesis was the derivation of notch factors k_f and the identification of the influence of certain geometric parameters. The constructional details of the experimental fatigue tests, the test specimens, were optimised with regard to fatigue strength and the results were prepared for the design and execution recommendations, the German RE-ING guideline drawings [5].

2 Description of method and results

Within the AiF-DASt research project „Praxisgerechte Gestaltung von Diagonalrohr-Anschlüssen im Stahl- und Verbundbrückenbau" [1] experimental and numerical investigations of tubular bracings were carried out and detail categories for the three design variants were evaluated. Also, macro sections were made and analysed.

Within the Master thesis, numerical investigations were carried out for two different design variants (Series 2 and Series 3 of [1]) of tubular bracings with the effective notch stress concept. Series 2 was designed with a straight sealing plate and a HY-weld with fillet weld. Series 3 had an inclined sealing plate and it was executed with a HV-weld with pool backing. The numerical investigations were carried out with the finite element program ANSYS Workbench [6] and the geometry model was generated in Autodesk Inventor [7]. The symmetry of the joint is used to minimise the elements and calculation time, so there was only 1/8 modelled. Further the sub model technic is used to derive the stresses at the notch, see Figure 2.

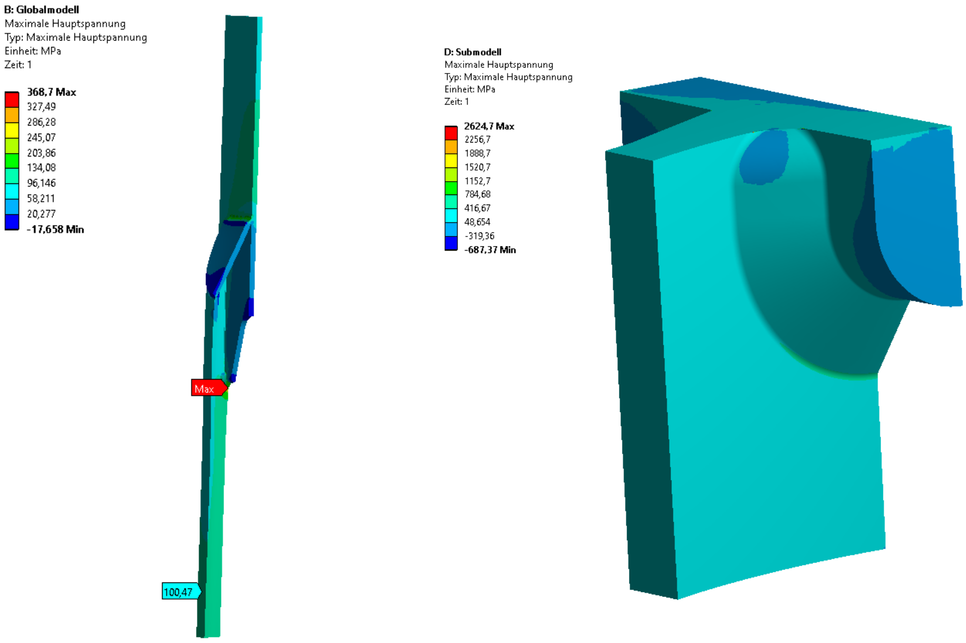


Figure 2: Numerical model of Series 3: global model (left) and sub model (right)

The sensitivity of the model was investigated for the global and the sub model of the Series 2 and 3. A comparison with the strain gauges of the experimental tests showed a good correlation for the validation of the model. A suitable mesh and dimensions of the elements were chosen in the verification process. To control the used methods and the mesh sizing of the model, it was compared with the model acc. to Radaj [8]. For modelling the geometry of the welds, the weld dimensions of the macro sections of the experimental test specimens were measured, see Figure 3.

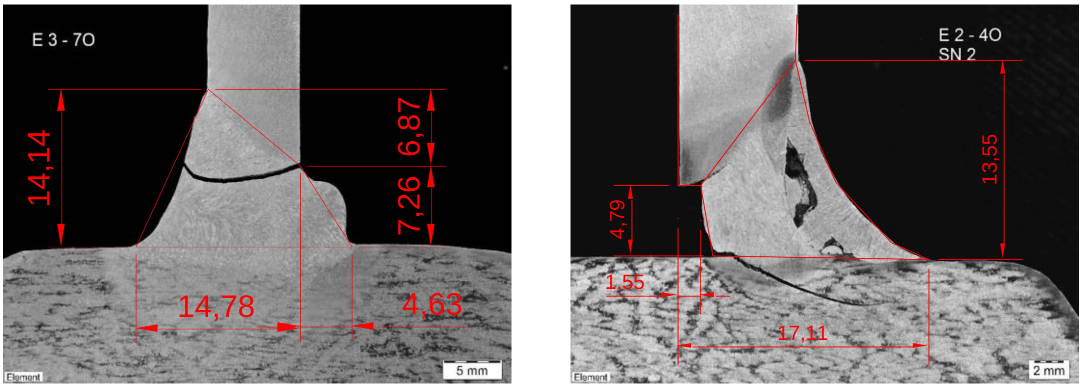
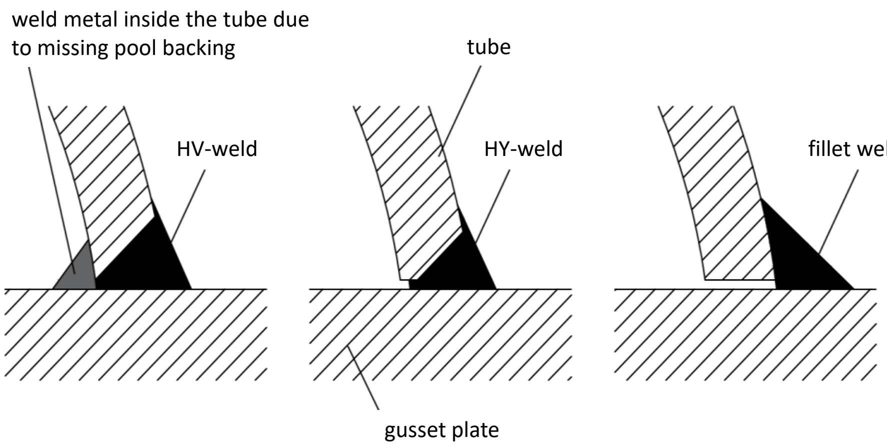


Figure 3: Macro sections of Series 3 (left) and Series 2 (right)

The parameter study was carried out with the numerical models of Series 2 and 3. The following parameters were investigated: Influence of sealing plate, type of welding, geometry of the gusset plate, chamfering of the tube, thickness of the tube and diameter of the tube. A wider gusset plate has shown an increase of the notch factor. An elastic geometry of the gusset plate inside the tube, like an ellipse, has shown a small improvement of the notch factor. A round gusset plate tip is beneficial. The thickness of the guest plate has only a small influence on the notch factor. The presence of a sealing plate has also a positive influence on the notch factor. The investigations on the chamfering angle (with 15° - 90°) of the hollow section showed that it has no significant influence on the notch factor.

The most significant influence on the notch factor has the type of welding. A HY-weld, a HV-weld and a fillet weld were investigated, see Figure 4. The comparison shows that the HV-weld of Series 3 has the lowest notch factor k_f=5.9. The HY-weld and the fillet weld had notch factors of 8.9 and 9.1. Those are significantly higher, but there is no significant difference between the HY-weld of Series 2 and a fillet weld.



k_f = 5.9 k_f = 8.9 k_f = 9.1

Figure 4: Overview of HV-weld (left), HY-weld with fillet weld (middle) and fillet weld (right) with notch factors k_f for Series 3 at the gusset plate tip

For HV-welds, a pool backing is normally used. Due to the round gusset plate tip, the ceramic pool backing could only be attached for the longitudinal weld, but not in the critical fatigue spot of the gusset plate tip welding at the rounding. The numerical investigations showed, that it has a positive influence when there is no pool backing at the critical fatigue spot at the gusset plate tip. Due to the missing pool backing at the gusset plate tip, the weld metal flowed into the inside of the tube and accumulated, see also Figure 3, and therefore a higher fatigue strength could be reached for Series 3 compared to Series 2. If the pool backing would be continuously attached, this would not be possible.

3 Potential for application of the results

In the Master thesis, it is shown that most of the geometric parameters of tubular bracings without holes at the end of the slit has no significant influence on the notch factor. Only the type of welding has a significant influence. Due to the missing pool backing at the rounding of the gusset plate tip, the fatigue strength could be increased because more weld metal is inserted inside the tube and the material and the root are completely welded. A recommendation for the design and execution is given in constructional execution plans based on the results of this Master thesis. This execution plans are the basis for the proposals for the German RE-ING guideline drawings [5].

4 References

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