Fatigue Tests of Practice-Oriented Tubular Bracings in Steel and Composite Bridges – Analysis and Classification

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SUMMARY

In steel and composite bridges, tubular bracings are due to their critically assessed fatigue behaviour under discussion. In the master thesis, experimental fatigue tests were supervised and evaluated, measurement systems and crack patterns were analysed and numerical investigations were carried out. The aim of the thesis was to give proposals for the detail categories of prEN 1993-1-9 and design recommendations.

1 Project objectives and goals

Tubular bracings inside or outside box girders, see Figure 1, are realised in the construction and renovation of large steel and composite bridges more and more often. The welded joint between the slitted circular hollow section and the gusset plate is due to its critically assessed fatigue behaviour under discussion. The different design variants of circular hollow sections as they are realised in various bridge constructions, e.g. in the German Bridges Heidingsfeld, Rinsdorf, Schierstein and Lennetal, are not regulated by the current standards EN 1993-1-9 [1] and EN 1993-2 [2]. According to the current standard [1] hollow sections with a thickness $t \leq 12{,}5$ mm are classified in detail category 63 or 71 depending on the angle of chamfering. A further classification, e. g. depending on the type of welding or the sealing plate, is not given.


Figure 1: Design variants of tubular bracings inside or outside box girders: German bridges Heidingsfeld (left) [3] and Lennetal (right) [4]

By supervising the experimental test series in the Master thesis with three different design variants, which were developed within the German Aif-DASt research project “Practice-oriented design of tubular bracings in steel and composite bridges” [5], the results of the fatigue tests could be statistically evaluated and classified into detail categories for prEN 1993-1-9 [6]. For one of the three design variants numerical investigations with Ansys Workbench [7] were carried out. Additionally, the measurement systems like strain gauges, displacement sensors and compressed air as well as the crack patterns and fracture surfaces were investigated to analyse the fatigue behaviour of tubular bracings. The aim of the experimental and numerical investigations in this Master thesis was to evaluate the fatigue strength of the three design variants and to give proposals for the detail catalogue for the next generation of the Eurocode prEN 1993-1-9 [6] and for design and execution recommendations like the German RE-ING guideline drawings [8].

2 Description of method and results

Eight test specimens per design variant were experimentally tested at the Material Testing Institute of the University of Stuttgart, see Figure 2, at different stress levels Δσ from 50–225 N/mm² with a stress ratio R = 0.1. The test specimens, see Figure 3, had a diameter of 168.3 x 8 mm, whereas the thickness of the gusset plate t_p was 20 mm, the thickness of the sealing plates t_s was 10 mm and the thickness of the welds was a_w= 8 mm with weld lengths l_w= 265 mm. The test specimens had an overall length of approx. 2 m and the material of the tube, gusset plate and sealing plate was S355.

Series 1 was carried out with a cut-out at the end of the slit in the hollow section. The advantage of the cut-out is the possibility for tolerance compensation in longitudinal direction of the tube. Additionally, this design variant allows a good welding and post-weld treatment. Furthermore, the crack does not occur at the weld, but at the cut-out and can easily be detected. One disadvantage of this variant is that water can accumulate on the interior sealing plate. In this series, the type of welding is not the decisive notch, which explains the execution with double fillet welds.

Series 2 had a straight sealing plate and a HY-weld with fillet weld. A disadvantage of this variant is that no tolerance compensation in longitudinal direction of the tube is possible. Further, the fatigue crack at the gusset plate tip weld cannot be easily detected. The gusset plate tip and the end of the slitted tube in Series 2 were executed with 45° chamfers. Compared to Series 3, Series 2 is more economical and practice-oriented.

Figure 2: Overview of test setup at the Material Testing Institute of the University of Stuttgart [5]

Series 3 had an inclined sealing plate and a full penetration weld with pool backing. In addition, the gusset plate tip in Series 3 has been rounded. With this design, the inclined tube allows a better accessibility inside the tube to control the weld or pool backing. Also, there is no tolerance compensation in longitudinal direction possible. Series 3 is compared to Series 2 a notch-optimised variant but it involves higher production costs. The fatigue tests allow a direct comparison between the practice-oriented Series 2 and the notch-optimised Series 3.

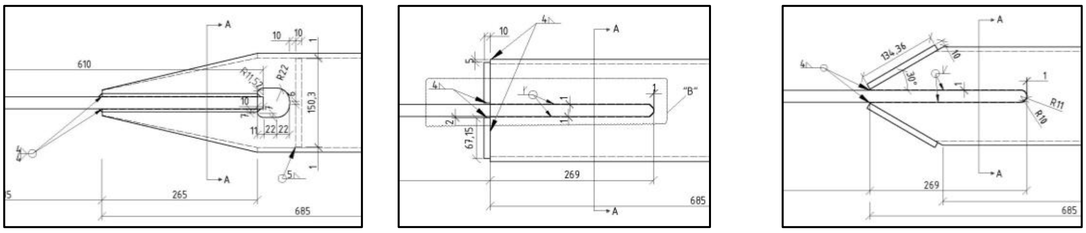

Figure 3: Extract of constructional execution plans: Series 1 (left), Series 2 (middle), Series 3 (right) [5]

The failure criterion of the fatigue tests was the complete fracture of the specimens. During the fatigue tests, strain gauges were used to identify the number of cycles for the crack initiation and compressed air to identify the tube wall crack. Furthermore, displacement sensors were used. By

taking pictures of the fracture surface and the crack patterns as well as macro sections, the fatigue behaviour could be analysed more in detail.
The fatigue tests were statically evaluated with the prediction interval and a fixed slope of m= 3. For Series 1 with the cut-out, the nominal stresses were calculated using the net hollow section $A_{net} = A - 2 \cdot d_H$, with d_H as the hole diameter. The three test series were evaluated separately. For the proposal for the detail category, these were evaluated together with previous fatigue tests of the literature [9][10][11]. For Series 1 the characteristic fatigue strength for fixed slopes was $\Delta\sigma_C$ = 43.5 N/mm² and it could be classified in detail category 40. The evaluation of the fatigue strength of Series 2 resulted in $\Delta\sigma_C$ = 50.8 N/mm² and for Series 3 in $\Delta\sigma_C$ = 56.9 N/mm². The test results of Series 2 and Series 3 were compared with previous fatigue tests of Zirn [10] and Hanswille et al. [9]. The fatigue test results of Series 2, Series 3 and the present literature by [9] and [10] shows that the type of welding is the decisive parameter for the fatigue strength of tubular bracings without cut-outs at the end of the slit. See Figure 4 for an overall evaluation with previous fatigue tests of Zirn [10] and Hanswille et al. [9] for full penetration welds, which leads to a characteristic fatigue strength of $\Delta\sigma_C$ = 55.6 N/mm².

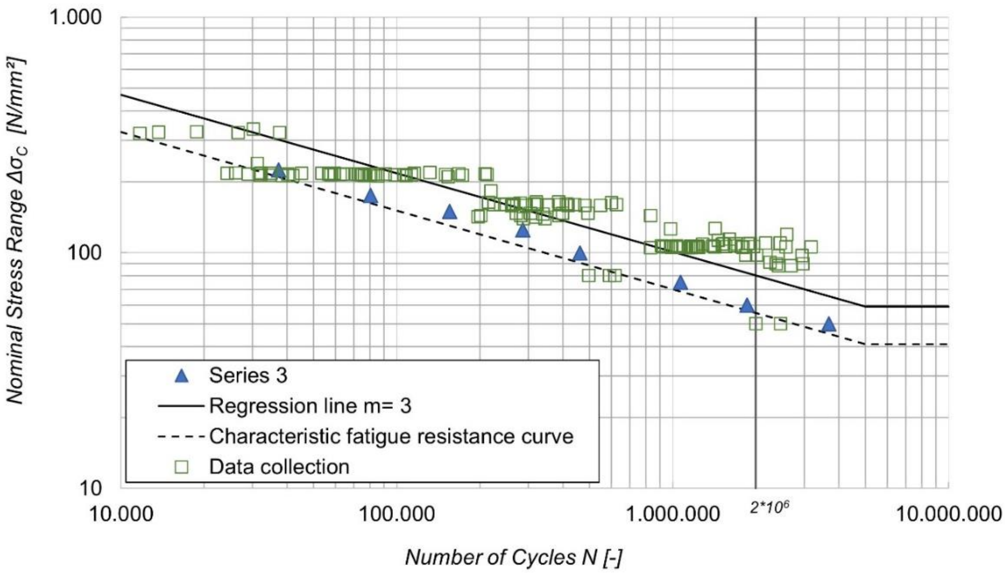

Figure 4: Overall evaluation of tubular bracings with an inclined sealing plate (without fillet weld).

By comparing all investigated series, it could be shown that the notch-optimised Series 3 leads to the highest detail category 56 and the difference between the practice-oriented Series 2 and the notch-optimised Series 3 is only one detail category. Series 1 with the cut-out was numerically investigated with Ansys Workbench [7] to determine the influence of various geometric parameters, such as the sealing plate or the geometry of the gusset plate and the cut-out on the effective notch stresses. The global displacements were computed on a global model in a first step and in a second step, the notch stresses were derived in a sub model, see Figure 5. The numerical model was validated with the experimental tests and verified. It was shown in the parameter study for example, that the sealing plate had no negative influence on the notch stresses. Furthermore, the numerical investigations showed that a straight gusset plate has a negative influence on the notch stresses and that the gusset plates should therefore has to be designed elastically.

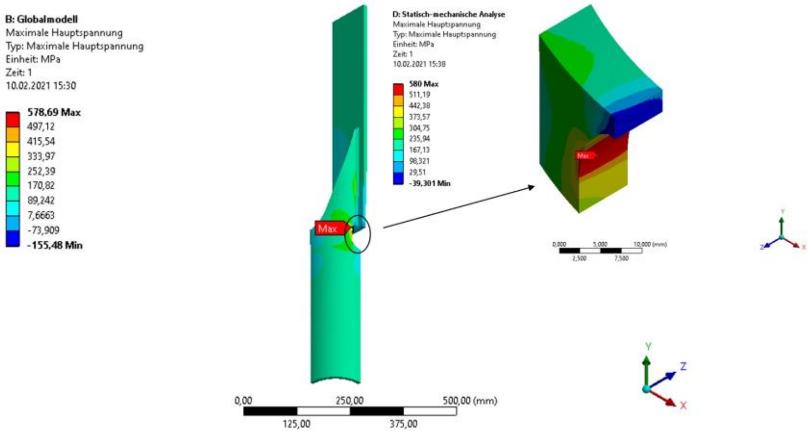

Figure 5: Global and sub model of numerical investigations for Series 1 [5]

3 Potential for the normative application of the results

The results of this Master thesis show that for tubular bracings the current detail category 63 or 71 acc. to EN 1993-1-9 [1] is not conservative and the decisive parameter for the fatigue strength is the type of welding. Based on the experimental investigations and the research about the fatigue behaviour from previous fatigue tests of the literature [9], [10], [11] and the supporting studies like analysis of measurement systems and crack patterns, proposals and recommendations for prEN 1993-1-9 [6] and the German RE-ING guideline drawings [8] could be given. Detailed explanations for the proposals can be found in the master thesis and those proposals for three different constructional details are already included in the detail catalogue of the Final Document of the future Eurocode prEN 1993-1-9.

4 References

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