Internal Pressure Induced Load on Single-sided Fillet Welds of Small- sized Box Girders

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Abstract Small-sized box girders have been successfully used in steel and composite bridges for several decades. Internal pressure measurements on small-sized box girders have shown that there are seasonal and daily fluctuations in internal pressure. These pressure fluctuations cause bending stress on the longitudinal single-sided fillet welds. In Germany, this load case is considered by the regulation “RE-ING”. This regulation leads to an increase in the weld thickness. As part of the ongoing research project "Economic Dimensioning of Fillet Welds in Small-Sized Box Girders," this unplanned stress and the load-bearing capacity of single-sided welded fillet welds are investigated. The aim of the research project is to further develop the current design method in terms of material efficiency while maintaining the safety level of the Eurocode. This contribution presents the first results of the research project "Economic Dimensioning of Fillet Welds in Small-Sized Box Girders."

1 Introduction

Small-sized box girders have been successfully used in steel and composite bridge construction for several decades. Their advantages include high torsional stiffness, a reduced surface area exposed to corrosion, and a high degree of prefabrication. Before the introduction of the DHK design details in RE-ING [1], the longitudinal fillet welds of the box girders were designed solely for longitudinal shear. However, measurements from [2] showed that internal pressure fluctuations, caused by the heating and cooling of the internal air of the girder, induce bending stresses in the longitudinal fillet welds (Figure 1). These stresses must now be considered in the design and calculation of box girders according to the DHK specifications in RE-ING [1].

The research project "Economic Design of Fillet Welds in Small-Sized Box Girders" aims to address the unexpected stresses identified in [2]. The aim is to further develop the current design method in terms of material efficiency while maintaining the safety level of the Eurocode. The research project is divided into two parts. The first part examines the effects resulting from internal pressure. To this end, temperature simulations based on weather data are carried out. From the annual maximum internal air temperatures obtained, a design value can eventually be defined. The second

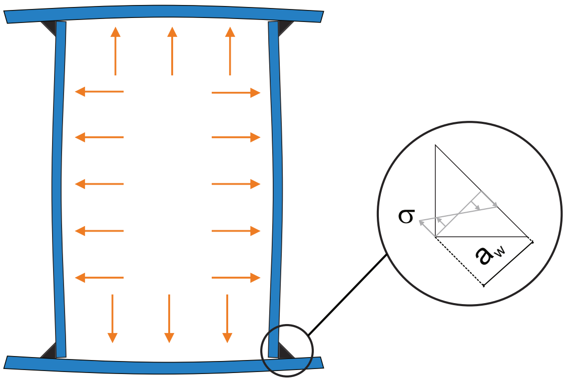

Figure 1: Internal pressure leading to bending on single-sided fillet welds

part focuses on the static load-bearing capacity and fatigue resistance of single-sided fillet welds. Extensive static and dynamic tests will be conducted for this purpose. By integrating these findings, the design model for RE-ING can subsequently be further developed. The preliminary findings from the research project are presented in this paper.

2 Internal Pressure Load of Small-Sized Box Girders

The internal pressure load results from climatic effects. These climatic effects, illustrated in Figure 2, lead to temperature fluctuations in the structure as well as in the internal air of box girders. Due to the requirement for airtightness in small-sized box girders, no air exchange with the environment can occur, causing the temperature fluctuations in the internal air to lead to pressure variations within the box girder.

The thermal behavior of the structures can be modeled based on the external influences, as presented in [3,4], using weather data from measurement stations. The thermal model introduced in [3] accounts for convective heat transfer between the environment and the structure. Additionally, radiative heat transfers are considered, which can be divided into longwave and shortwave radiation. Solar radiation is the shortwave radiation, which is predominantly responsible for the heating behavior during summer. Longwave radiation occurs between adjacent structural elements, the atmosphere, and the ground, and it is partially responsible for the cooling of the structure.
Through numerical modeling of climatic effects, the temperature fields in relation to the internal air temperature can be shown over a certain period. From the simulations, the annual maximum and minimum internal air temperatures over the simulation period can be extracted, as described in [3]. A parametric study was used to determine cross-sectional configurations that lead to maximum and minimum internal air temperatures. Thermodynamic and geometric influences on the internal air temperature were examined in this study. As a result, the two cross-sectional configurations shown in Figure 3 (steel and composite cross-sections) were identified as the most unfavorable configurations.

Simulations to determine the characteristic value of the internal air temperature were conducted on these cross-sections. Based on weather data from Stuttgart, Schleswig, and Mannheim, the

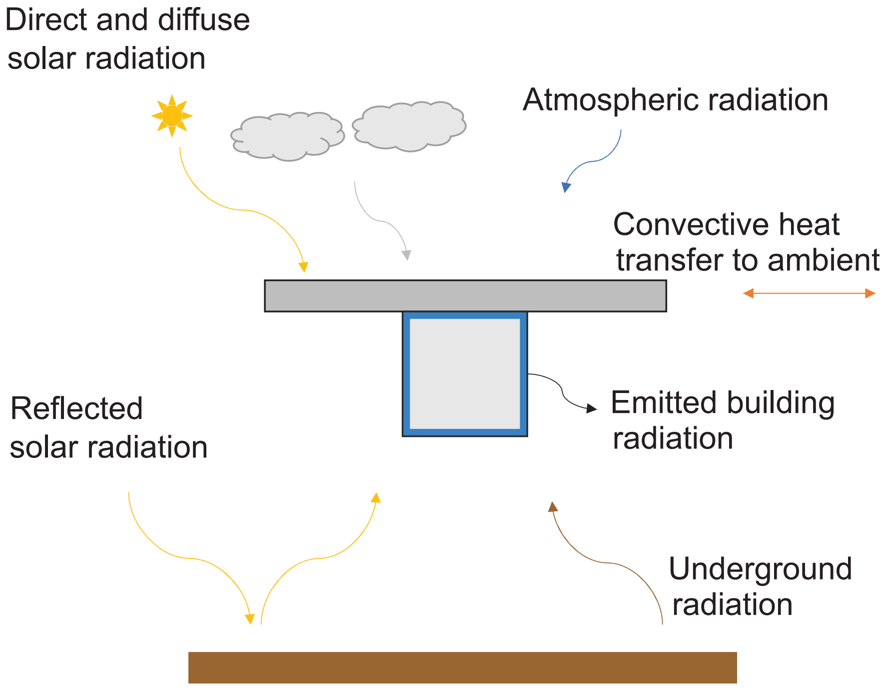

Figure 2: Climatic actions on bridges

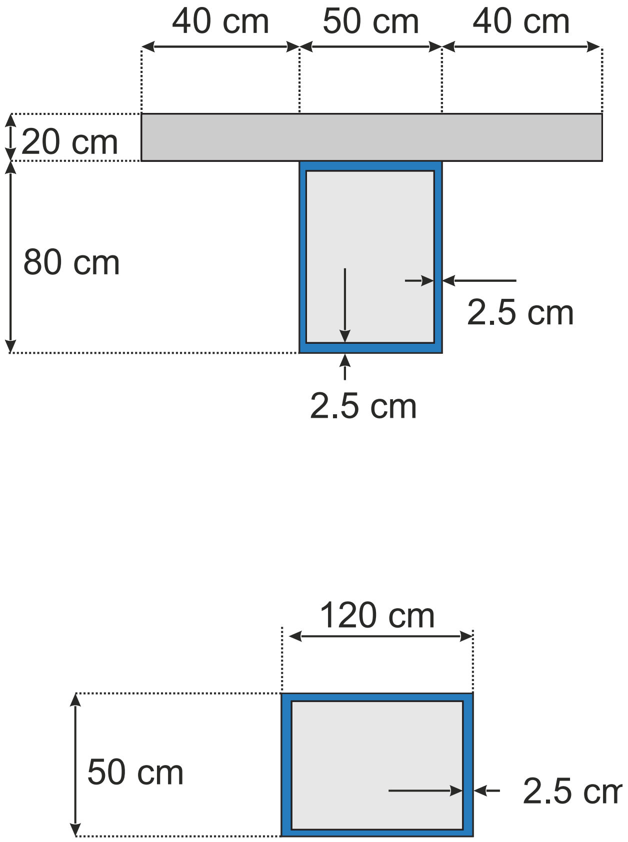

Figure 3: Investigated cross-sections

maximum and minimum values of the internal air temperature were extracted. The weather data used for the simulations were taken from [5]. Figure 4 shows the annual maximum internal air temperatures, which was obtained by the simulations, as well as the surrounding air temperatures for the examined locations.

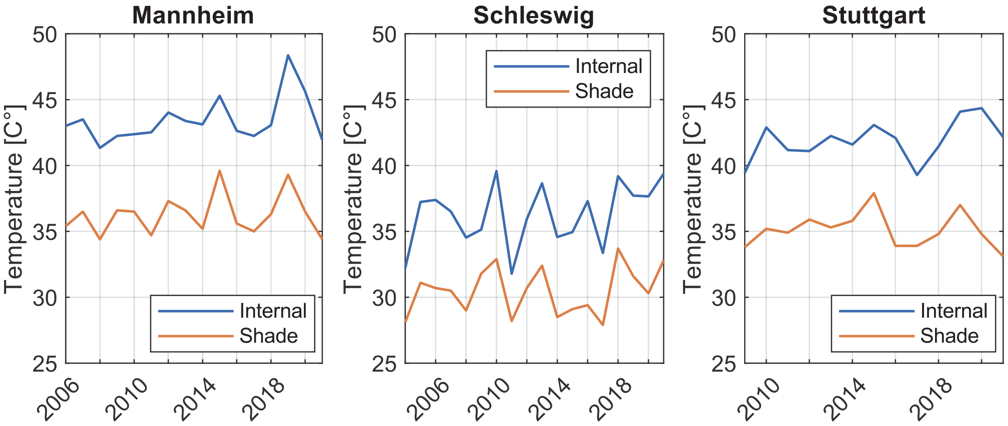

Figure 4: Annual maximum temperature of the internal air and the shade air temperature over the simulation period

From these annual maximum temperatures, a relationship between the ambient shade temperature and the internal air temperature can be derived. This relationship is illustrated in Figure 4. The correlation for the composite cross-section is shown on the left subfigure and for the steel cross-section on the right subfigure. Additionally, the temperature curves according to DIN EN 1991-1-5 [6] are shown. According to the German National Annex of Eurocode 1 (NA), the design value for the constant temperature component for bridges can be determined based on the lines shown in Figure 4. The necessary ambient temperature is also specified in [6] and is 37°C. This results in a characteristic internal air temperature of 44.0°C for the non-accessible composite cross-section and 55.5°C for the small-sized box girder. The characteristic value of the internal air temperature can be converted into a characteristic internal pressure load using the ideal gas law. These values are shown in Table 1 for both the steel and composite steel cross-sections.

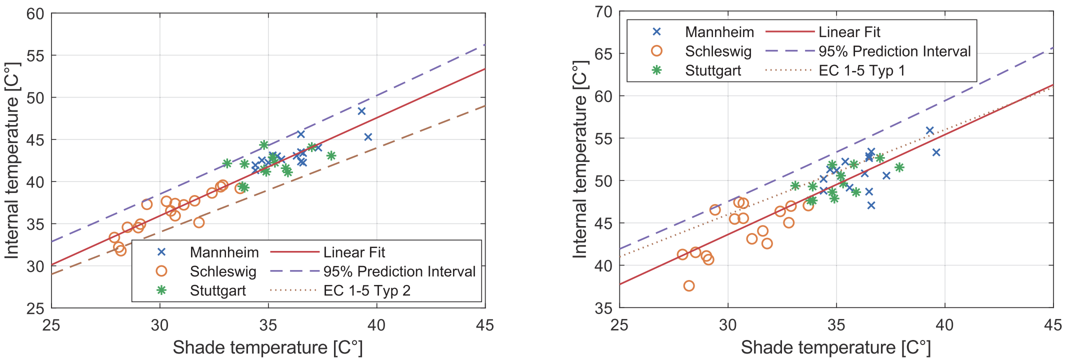

Figure 5: Correlation between the annual maximum internal air temperature and the shade temperature (left composite bridge, right steel bridge)

	$T_{int,max}$	$P_{int,max}$
Steel Bridge	55.5 °C	0.1628 bar
Composite Birdge	44.0 °C	0.1217 bar

Table 1: Characteristic value for the internal air temperature and internal pressure

3 Experimental Investigations on the Load-Bearing Capacity of Single-Sided Fillet Welds

Due to the geometrical constraints, two of the four longitudinal fillet welds in non-accessible box girders are inevitably executed as single-sided fillet welds. To determine the bending load-bearing capacity of these single-sided fillet welds, 42 tests were conducted. Variations were made in terms of steel grade, weld thickness, and welding filler materials. The investigated parameters are summarized in Table 2.

Steel grade	S355 / S460
Nominal weld thinkness	5 mm / 7 mm / 10 mm
Filler Material	G42 / G46 / T46

Table 2: Material properties of specimen

The test specimens were manufactured with a weld length of 15 cm. Two plates, each 20 mm thick, were welded together on one side using a fillet weld. An eccentrically applied load was used to generate a moment for investigating the rotational capacity and load-bearing capacity. The test setup and specimens are shown in Figure 6.

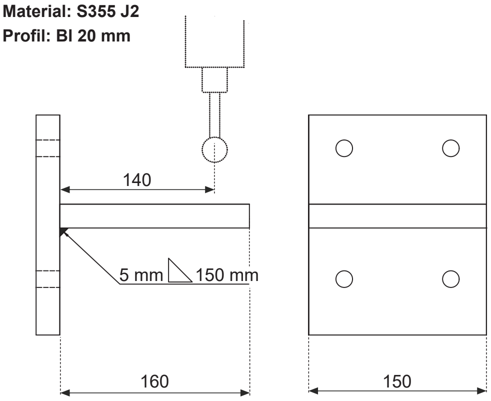

Figure 6: Test set-up

By measuring the rotation and the force, which can be converted into a moment using the distance between force and weld, the moment-rotation behavior of the single-sided fillet welds can be determined. Additionally, macro-sections allow the weld thicknesses to be measured, providing insights into the actual weld thickness while considering deep root penetration. Figure 7 shows the rotation behavior of the welds under bending stress. The following figures display the moment-rotation curves from the tests using the filler materials G42 and G46 for nominal weld thicknesses of 5 mm, 7 mm, and 10 mm. From these, the filler material does not have a significant influence on the rotation behavior of the welds. The difference in the moment curves between G42 and G46 for the nominal thicknesses can be attributed to the average weld thickness.

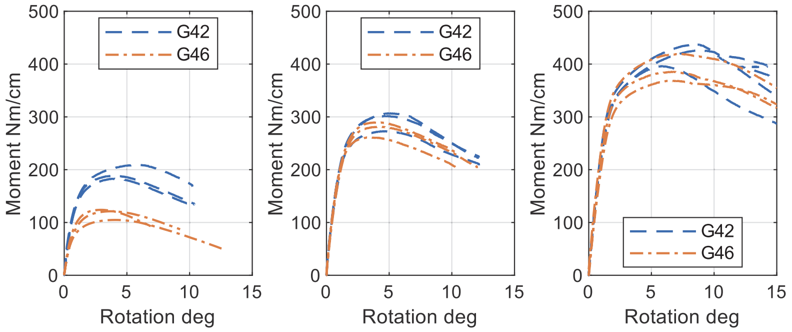

Figure 7: Rotation behavior of the welds under bending stress

4 Comparison of the Action and the Load-Bearing Capacity of Single-Sided Fillet Welds

From the test results, the bending stiffness of the single-sided fillet welds can be derived as a function of the weld thickness. Using this, as illustrated in Figure 7, the static model for estimating the bending utilization of single-sided welds can be assessed. In the following, the stress on the welds due to internal pressure will be illustrated for a box girder with a width of 100 cm as an example. A plate with a thickness of 30 mm is assumed, subjected to an internal pressure load of $p_{ED} = 1.350, 12bar = 0, 16bar$. The rotational stiffness derived from the tests for a 7 mm thick weld is 105 Nm/deg per cm of weld. This results in a weld stress of 5.18 Nm/cm with a rotation of 0.0494 degrees. When comparing the load-bearing capacity shown in Figure 6 with the action resulting from the internal pressure, it becomes evident that the weld is only slightly utilized.

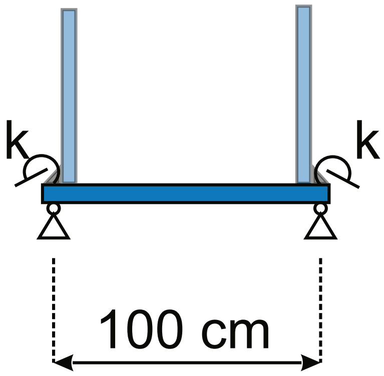

Figure 8: Static model to determine the utilization of single-sided fillet welds in small-sized box girders

5 Outlook and Further Investigations

The initial investigation results show a tendency for the static load-bearing capacity to be significantly underestimated. When the bending resistance of the single-sided fillet welds is compared to the action, it reveals significant load reserves. It can be assumed that the RE-ING leads to a conservative design of single-sided fillet welds in airtight box girders.

As part of the research project, further investigations on the bending capacity under combined longitudinal shear stresses will be conducted. Based on the findings presented here, as well as the additional results from these investigations, an approach for designing single-sided fillet welds will be developed.

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