Fatigue behavior of welded pipe intersections in bridges

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Summary

In the design of tubular truss-girder bridges, the critical aspect is represented by the welded pipe intersections in the structural analysis due to their limited fatigue behavior. In the case under consideration, economical reasons led to the decision to weld the joints instead of using cast steel nodes. Considering the span length of nearly 100 meters, the static design required diameters up to 800 mm and wall thicknesses up to 50 mm. As fatigue problems are covered by the current codes only for smaller dimensions, it was decided to conduct large-scale tests to investigate the fatigue behavior of the welded pipe intersections. Comparative tests comprising specimens with partially UIT-treated welding seams were performed in order to verify the efficacy for this post-weld treatment method. Furthermore a repair technique for existing fatigue cracks was investigated. For this purpose the entire fatigue crack of an already damaged specimen was grinded and rewelded.

Keywords: welded pipe intersections, high-cycle-fatigue, size effect, ultrasonic impact treatment, repair techniques.

1. Introduction

In the application of modern steel-concrete composite bridges, the steel part increasingly is built by circular hollow sections instead of steel plates. In this type of construction, the materials are preferably combined accordingly to their inherent characteristics, namely the concrete for the horizontal two-dimensional bridge deck and the circular hollow sections for the main load-carrying truss girders on the bottom side. In composite bridges, different arrangements are possible to substitute the familiar steel plate girders or steel box-girders by a steel tube truss system. Besides, a planar truss girder consisting of upper and lower chord and connecting braces, multi-planar systems with either three or four chords are feasible. Within the scope of the work presented herein, only the K-joint is considered.

As fatigue cracks occur at first from notches inherent to the structure, the welded joints of the circular hollow sections represent the critical detail for fatigue design. There are many different influences affecting the fatigue behavior of welded details, e.g. the welding operation, the joint geometry, residual tension stresses or the heat-affected-zone. To evaluate the location along the welding seam at which the fatigue crack will at first occur, i.e. the position with the maximum stress concentration factor (SCF), is obviously not apparent at first sight. Because of the complex three-dimensional load bearing characteristic depending on various parameters the most reasonable method to calculate the stress concentration factors is the finite element method.

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2. Experimental investigation

To the date a total of five specimens, each with different characteristics concerning geometrical dimensions, post-weld treatment as well as repair techniques were tested. The material used for al specimens was of the steel grade S 355. The comparison of the first two specimens, which were identical except for the brace wall thickness indicate the clear existence of the so called size effect. Considering the results of a specimen treated partially by the UIT procedure, a significant enhancement of the fatigue life can be stated for this post-weld treatment. For this test, 1.4×10^6 more load cycles, compared to the untreated specimens, could be achieved till first fatigue failures occurred in form of initial cracks at the non-treated welding toe of the intersection between brace and welding seam. After the fatigue test of a previously tested specimen it was repaired by completely grinding off the entire fatigue crack rewelding. To achieve a maximum enhancement of the fatigue life of the repaired specimen, all welding toes including the boundaries of the additional repair welding seams were treated by the UIT procedure. First cracks occurred at the welding toe in the region of the brace saddle after 1.4×10^6 load cycles. Although this welding region was treated via UIT, it was pre-damaged by the previous test, in contrary to the welding toe of the chord saddle that was ground and rewelded. The test showed that the repair technique used, combined with the post-weld treatment UIT, extends the fatigue life at least by about the same value of load cycles that was achieved for the original unrepaired specimen. As shown by the experimental investigations, the point of highest strain in circular hollow section joints corresponds to the location of fatigue cracking. To be able to compare and assess the information obtained from the tests, a numerical model was generated with the objective to transfer the results to the numerical simulation of the additionally modeled K-joint. Because of the complex geometry and rigidity, causing the non-uniform distribution of local strains, continuum (solid) elements were used for a realistic finite element model. Thus the additional stiffness provided by the increase in thickness at the welding seam can also be taken in consideration by proper modeling. The locations pigmented in red of the finite element simulation of specimen one, shown in Fig. 1, corresponds very well to the crack initiation from the test as well as to the measured strains of the strain gauges. It should be indicated that for the exact value of the hot spot stress induced by the nominal stress of σ_{max} = 50 N/mm², an extrapolation of the stresses at least in two points in front of the singularity of the welding toe is necessary.

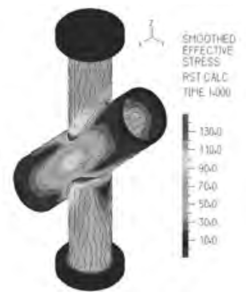

Fig. 1: Joint Model

3. Conclusions and Outlook

Within the scope of the work described in this paper, the following results should be highlighted. The significant size effect has to be considered in the fatigue life design of circular hollow section joints. The post-weld treatment method via UIT can contribute to a clear enhancement in the fatigue life. If the life time can be duplicated or even more increased by the application of UIT, will be shown by the test planned for the future. The favorable effect achieved by this post-weld treatment could also be recognized for structures that were already loaded by high-cycle fatigue before the application of UIT, as could be shown in specimen four. For this specimen, a further interesting investigation was conducted in reference to repair techniques after fatigue cracking. Therefore the fatigue crack was totally ground off and rewelded, supplemented by the UIT procedure. Thus a further lifespan even exceeding the first one could be achieved. Provided that inspections at regular intervals are carried out, this approach permits to extend the fatigue life of a tubular truss girder bridge for a further life span. In order to gain more information about the above mentioned attributes concerning the fatigue behavior of pipe intersections, the benefits of the application of UIT, particularly for bigger dimensions as well as the above mentioned repair technique, a wider range of experimental data would be preferable.