Safety against fatigue of imperfect prestressed bolted ring flange connections in wind-loaded tower-like steel structures.

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Abstract

In prestressed bolted ring flange connections under repeated loading, the bolts usually control the dimensioning. Their fatigue-relevant stresses depend in a nonlinear manner on the acting tubular bending moment, even when the joint would be perfectly executed. However, deviations from the nominal geometry causing small gaps between the two flanges before being prestressed (flange imperfections) are unavoidable. The internal force system of the flange connection reacts to these imperfections rather sensitively by significantly higher fatigue stresses in the bolts. In order to be able to develop proposals for the practical design handling of these flange imperfections, experimental and numerical investigations have been carried out.

The experimental investigations included four large-scale tubular bending tests with an externally located L-flange connection of 1m diameter with 32 bolts M20-10.9. Of the four specimens, one had a perfect flange joint whereas the others had deliberately imperfect flange joints with a flange-sided angular gap or a wall-sided angular gap or a parallel gap over a quarter of the circumference, respectively. A number of bolts had strain gauges thus serving as measuring bolts. Each test included a repetitive loading period in which load/unload cycles of increasing level with intermediate pulsating sequences of 100 cycles between various load levels were applied, and a final ultimate load test. As primary test results, functions of the bolt strains and the gap deformations versus the applied tubular bending moment are presented, and prestressing losses because of microplasticizing at the threads after very high loading are evaluated.

For the numerical investigations, a FE-model of the tubular test specimen with its test flange joint was built up. The bolts and the contact phenomena between the inner flange surfaces and between the bolt head or the nut and the outer flange surfaces were carefully fine-modelled. The measured flange imperfections were approximately reproduced. The complete FE-model was validated by means of the experimental results for the prestressing process and the loading procedure. Then, in a numerical parametric study, for two selected ring flange connections which are typical for wind turbine towers, the bolt stresses and the cumulative fatigue damage values are calculated for various imperfection parameters. Based on comparative analysis of these numerical results, recommendations for execution tolerances and for approaches to a bolt fatigue design covering the tolerated gap imperfections are put forward.