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Non-Proportionality in Wind Turbine Blades

FE-based comparative study of adhesive joint fatigue damage

Wind turbine blades are subjected to complex loading states consisting of stochastic wind forces and deterministic gravitational forces. These lead to non-proportional stress histories. The aim of this study is to search for a correlation between blade length and the change of fatigue damage in the trailing edge adhesive joints when non-proportional loadings are accounted for or not. Therefore, we used the in-house tool MoCA (Model Creator and Analyzer) for the generation of 3D finite element models of three different blade designs. Figure 1 shows the blade shapes in terms of planform views and presents the blade lengths of 86 m (DTU blade[1]), 80 m (IWES IWT blade[2]), and 20 m (SB2 demo blade[3]). A representative trailing edge adhesive joint is shown in Fig. 2.

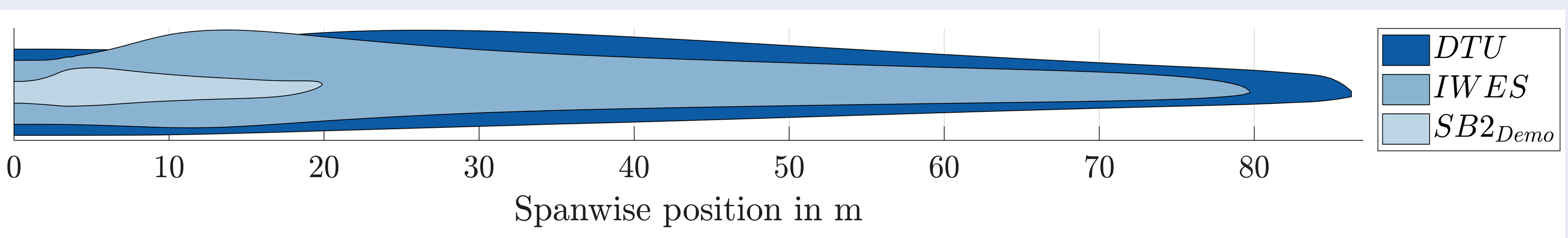

Fig. 1: Planforms and dimensions of the considered wind turbine blades

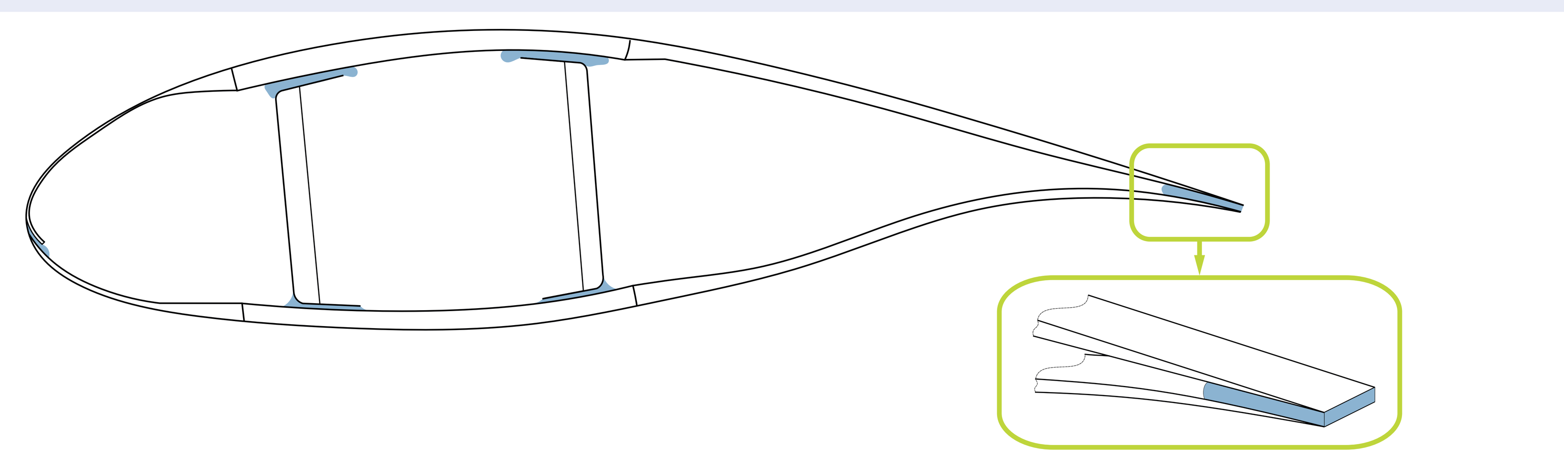

Fig. 2: Cross-section of a wind turbine blade structure with detail of the trailing edge adhesive joint

Comparative Fatigue analysis

First, the stress non-proportionality is evaluated with a factor proposed by Meggiolaro and de Castro[4]. The basic idea behind that is to represent the stress states of all time steps as concentrated unit masses in a multidimensional stress space. The non-proportionality factor f_{NP} is then the ratio between the minimum and maximum principle mass moments of inertia of the resulting body.

In order to evaluate the impact of non-proportionality, the trailing edge adhesive joint is analysed with the Rankine equivalent stress criterion (i.e. maximum principle stress criterion) and a critical plane approach where we tracked the normal stresses in order to obtain comparable results.

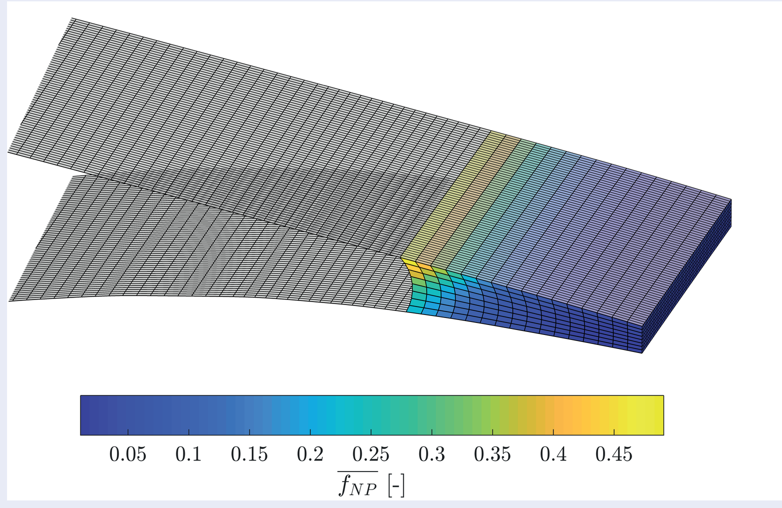

Fig. 3: Non-proportionality in the trailing edge adhesive joint of the IWES IWT-7.5-164 blade at a rotor radius of R=60m.

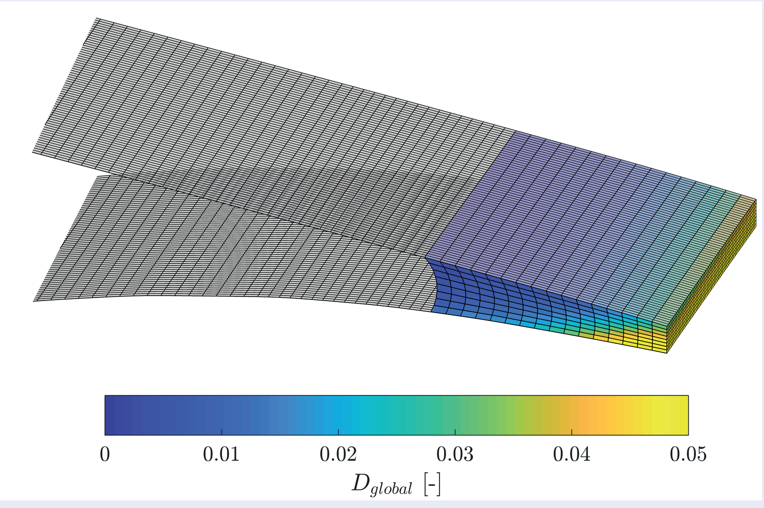

Fig. 4: Annual fatigue damage according to the Rankine approach in the trailing edge adhesive joint of the IWES IWT-7.5-164 blade at a rotor radius of R=60m.

The non-proportionality factor (Fig. 3) is maximum at the internal edge of the adhesive, since the bending stress in spanwise direction is less dominant. Contrarily, the annual fatigue damage (Fig. 4) is maximum at the external edge due to higher bending stresses, no matter if the Rankine or critical plane approach is used.

The impact of the fatigue model that is utilized, which is expressed by the damage difference ΔD between the Rankine and the critical plane approach, depends on the non-proportionality factor as well as on the blade design (see the green lines in Fig. 5). However, also the extent of non-proportionality, which is quantified by the number of elements with a particular f_{NP} related to the overall number of elements, strongly depends on the blade design, as can be seen from the blue lines in Fig. 5.

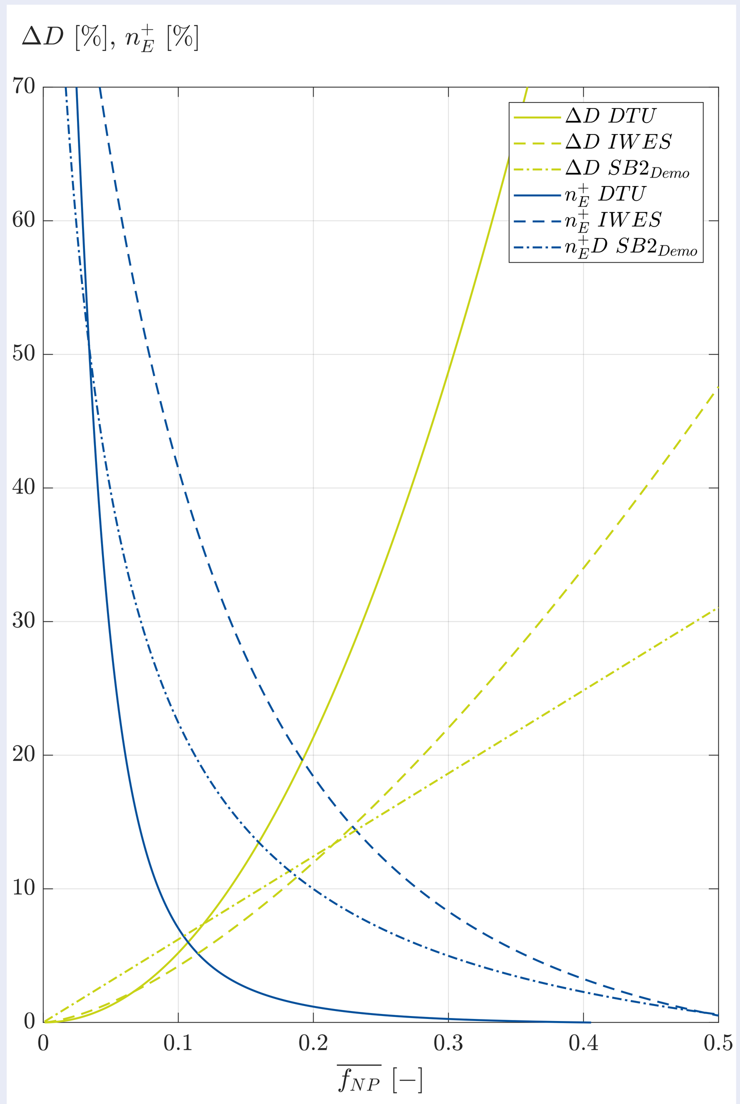

Fig 5.: Damage difference ΔD between Rankine and critical plane analysis and percentage of elements n_E^+ with at least the related non-proportionality factor f_{NP}, both plotted against f_{NP}.

Conclusion

The individual performance of wind turbine blades makes their comparison very difficult. Conclusions on the extent of non-proportionality or the impact of particular damage models on annual fatigue damages are highly blade-dependant and cannot be expressed in terms of a general rule-of-thumbs.

References

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[4] M. A. Meggiolaro, J. T. P. de Castro, Prediction of non-proportionality factors of multiaxial histories using the Moment of Inertia method, International Journal of Fatigue, Vol. 61, 151-159, 2014

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