# Ultimate strength of wind turbine blade structures under multi axial loading

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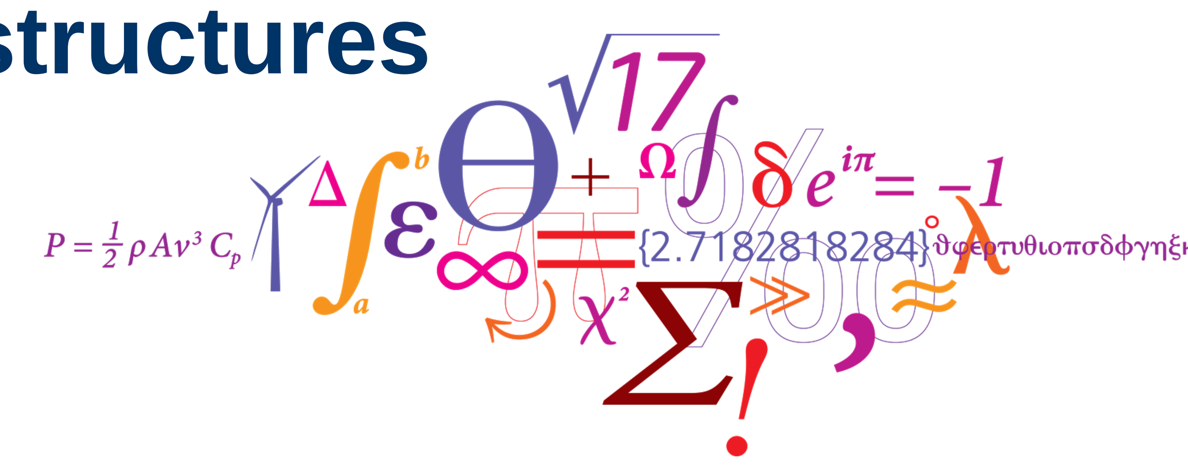

## Project description

The purpose of this PhD project is to investigate how multi axial loading effects influence the ultimate strength of typical composite structures in wind turbine blades and to develop methods to perform reliable prediction of failure on structural scale (WP4). Different failure types, load cases and prediction methods as well as different criteria ability to predict failure under multi axial load conditions have been investigated and methods to account for imperfections were studied.

## Motivation

Rotor blade issues constitute with approximately 2% to 5% to the annual failure rate of wind turbines but cause 8% to 20% of the total downwind time of wind turbines according to a NREL report [1]. In average 2% of wind turbines per year during the first 10 years operational period require blade replacements. Rotor blades see increased failure rates or reduced reliability as the concept goes from simple design concepts (simple Danish concept) with small rotor diameters towards more advanced technologies with bigger rotor span [1].

Inspection reports and technical papers indicate that delaminations, bondline failures, shear web/spar cap failures and trailing edge failures are frequently observed for rotor blades. The causes of these failure types are complex and often results as a combination of complex loading conditions, anisotropic material behaviour, complex geometries, manufacturing process and blade design.

The project has been split into four investigated topics with the following titles:

- The effect of delaminations on local buckling in wind turbine blades
- A Holistic Investigation of Trailing Edge Damage in a Wind Turbine Rotor Blade
- The effect of trailing edge damage on full-scale wind turbine blade failure
- The impact of multi axial loads on spar webs of wind turbine rotor blades (in progress)

Source: http://betterplan.squarespace.com/todays-special/tag/wind-farm-blade-failure

Figure 1: Blade failure

## The effect of delaminations on local buckling in WT blades

Complex stress states, impact and manufacturing issues can cause delaminations in wind turbine structures. In this study, the effect of delaminations on the load carrying capacity of a large wind trubine blades is studied numerically subjected to a flapwise dominated bending moment. For initial delaminations with a width of 30% to 50% of the cap width the study showed that delaminations close to the surface started to grow in load ranges of normal operation conditions and led to local buckling modes. The local buckling caused high strains and stresses in the surrounding of the delamination. Delaminations places near the mid-surface of the cap did not have a significant effect on the blade response under normal operation conditions. In the simulations the static load exceeded the design load by more than 40% before delamination growth or cap buckling occurred. It could be concluded that delamination induced near-surface buckling modes have to be condsidered critical due to an onset of local sublaminate buckling below the design load level.

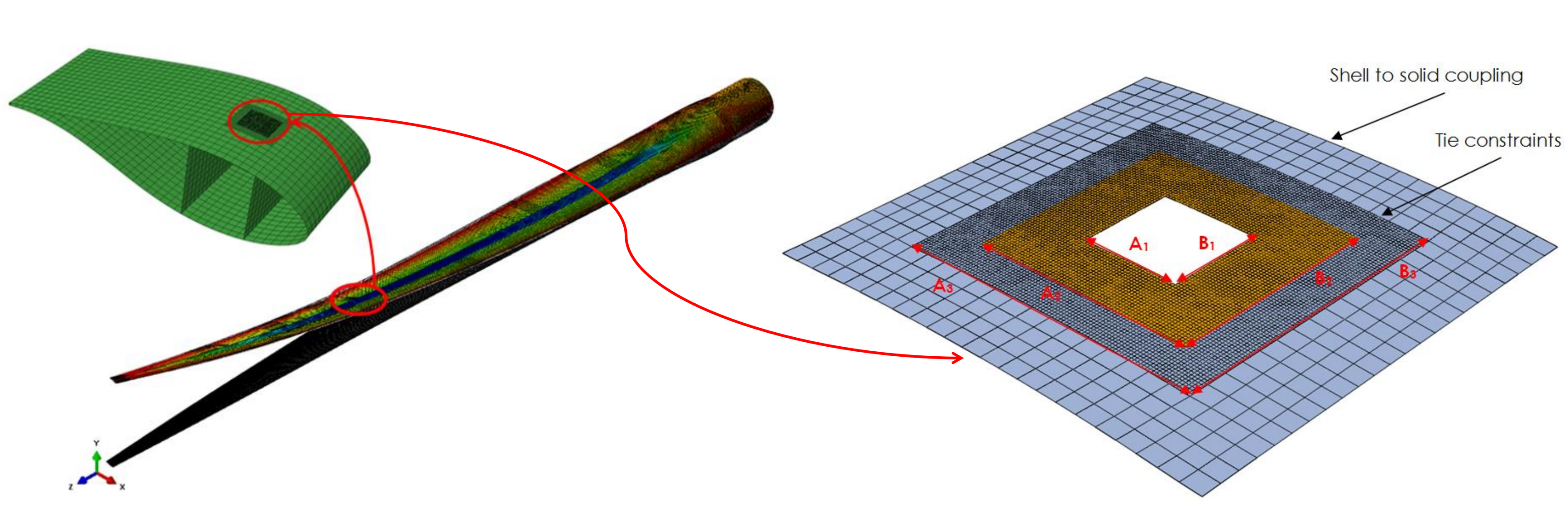


Figure 2: Large scale delamination simulation with cohesive elements

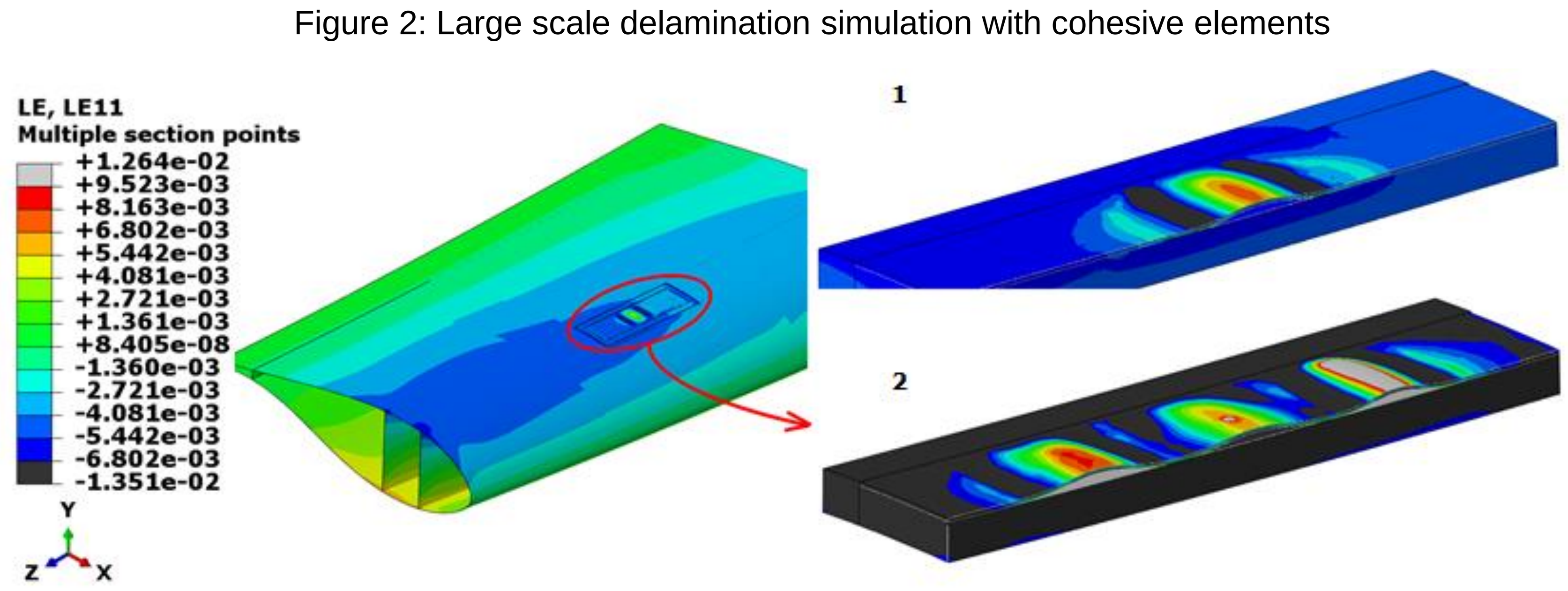


Figure 3: Local cap opening buckling mode with stable crack growth (t/T= 7.5%, b/B=0.40).

## Investigation of Trailing Edge Damage in a WT Blade

Adhesive joints are known to represent a weak link in the structural integrity of blades where particularly the trailing edge joint is notorious for its susceptibility to damage. Empiricism tells that adhesive joints in blades often do not fulfil their expected lifetime, leading to considerable expenses due to repair or blade replacement. The study presents a holistic numerical investigation of energy release rates at the tip of a transversely oriented crack in the trailing edge of a 34m long blade for a 1.5 MW wind turbine. First, results of a non-linear finite element analysis of a 3D blade model, compared with experimental data of a blade test conducted at DTU Wind Energy, showed to be in good agreement. Subsequently, the effects of geometrical non-linear cross-section deformation and trailing-edge wave formation on the energy release rates were investigated based on realistic aeroelastic load simulations. The paper concludes with a discussion about critical loading directions that trigger two different non-linear deformation mechanisms and their potential impact on adhesive trailing-edge joint failure.

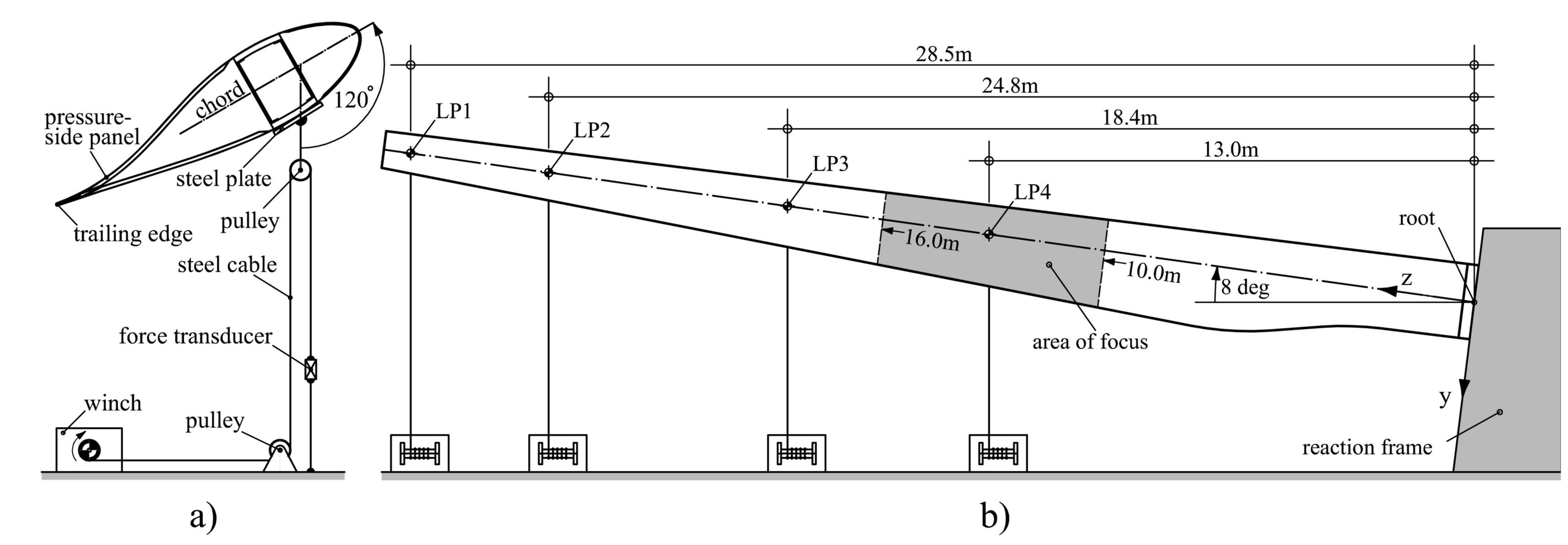


Figure 4: a) Cross section with pulley system and force transducer, b) Elevation of test setup with LP positions and area of measurement focus.

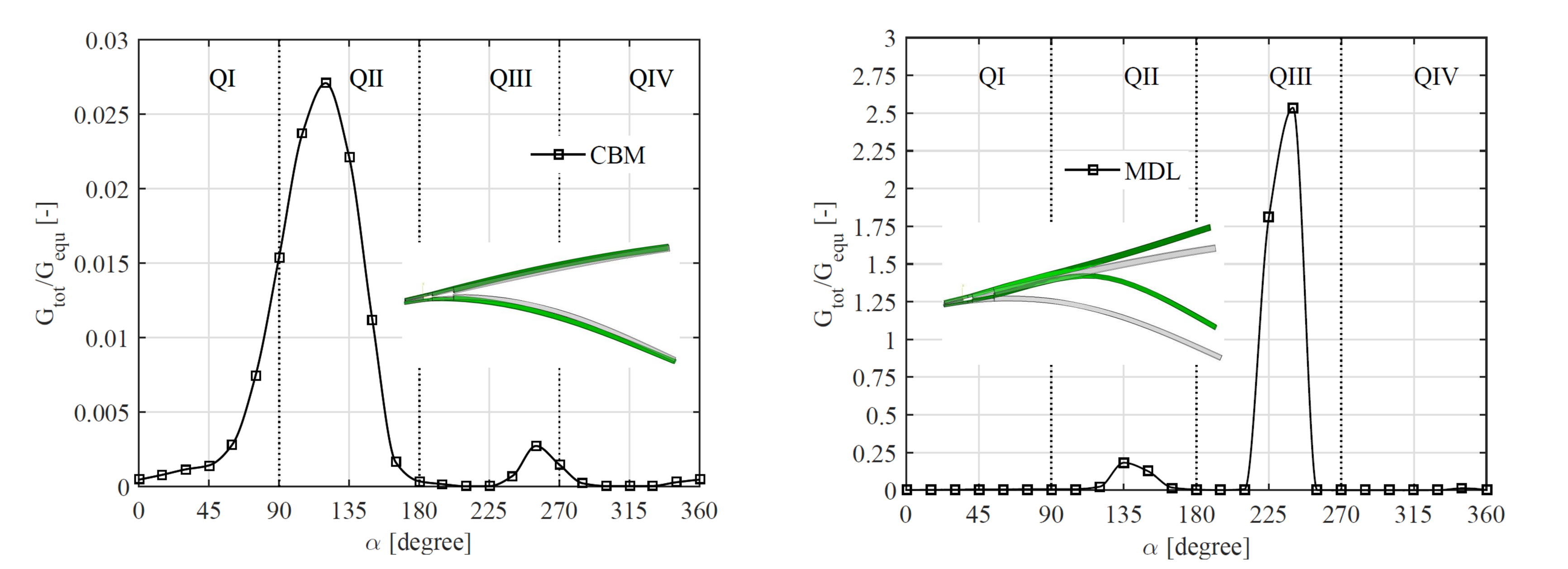


Figure 5: $G_{tot}/G_{equ}$ as a function of the bending moment vector angle α and its magnitude subdivided into four quadrants indicated by dotted lines for a constant bending moment (CBM) and the maximum design load (MDL).

## The effect of trailing edge damage on full-scale blade failure

The focus in this study was put on the evaluation of the reliability and accuracy of a numerical shell model and the prediction capabilities of existing failure criteria and approaches. Beside the global blade response of the numerical model in comparison to the experimental findings, also the geometrical non-linear buckling effect of the trailing edge under combined loading and how it affects the ultimate strength of a holistic blade was investigated. For this reason a 34m long blade was studied experimentally and numerically under ultimate load until blade failure. The interaction between trailing edge buckling on damage onset and sandwich panel failure was studied in detail. Numerically applied fracture mechanics approaches showed good agreement with the experimental results and helped to understand the relations between trailing edge buckling and blade failure.

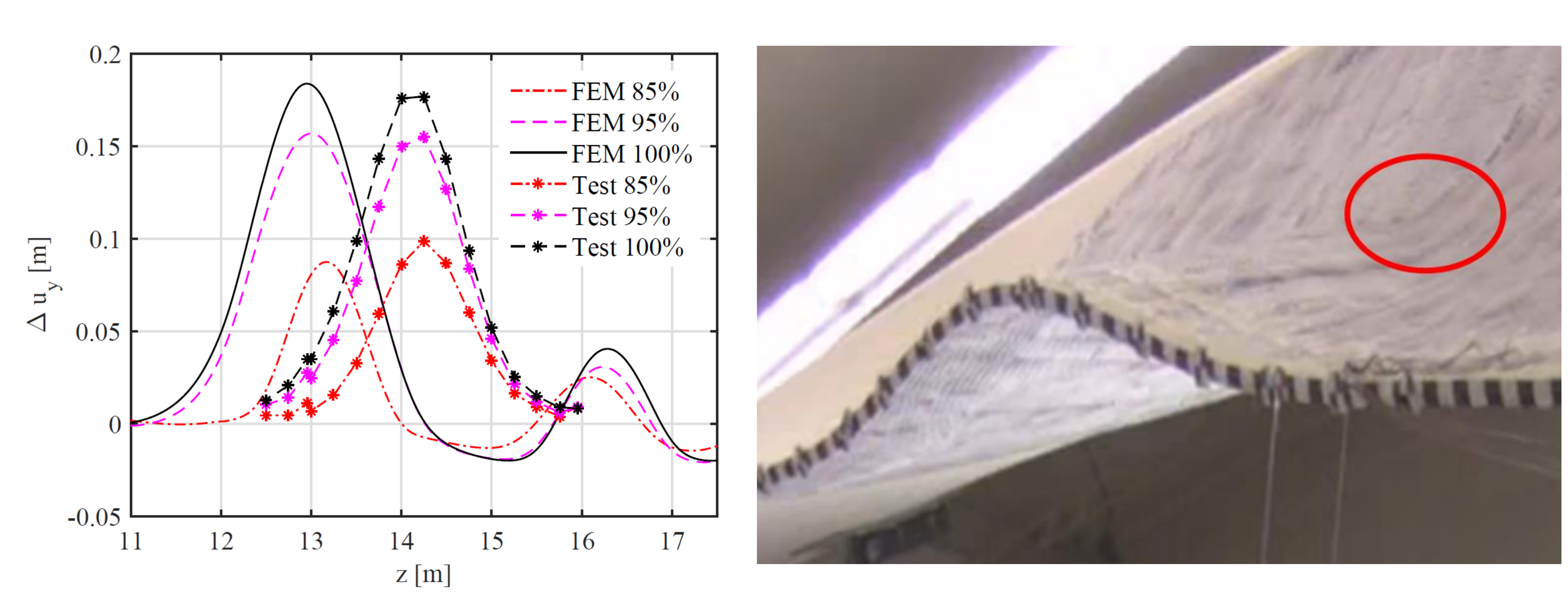


Figure 6: Comparison of local deformation as offset from a curve fit through the global displacement. Trailing edge deformation just before reaching the ultimate load. Note the distinct kink at the upper surface.

## Acknowledgement

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