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Solutions for cracks.

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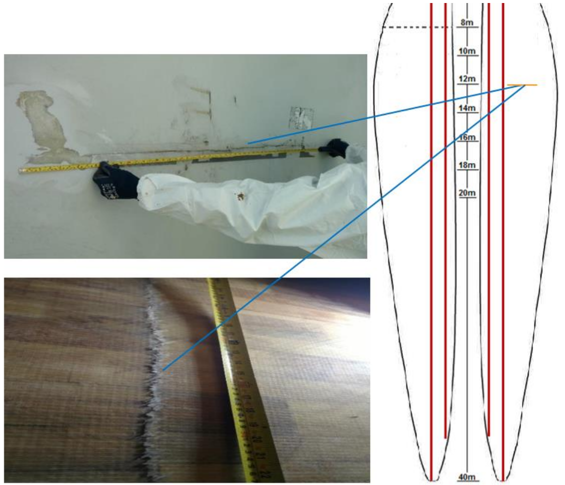
Overview

1. Damages found in the field
2. Awareness of damage
3. Root Cause Analysis
4. Solutions
5. Conclusions

Common damages found in the field

No.	*Damage type*	*Root-Cause*
1	Transverse cracks	Out-of-plane bending of panels on top of skin debonded areas.
2	Peeling in bondlines	Breathing and Cross-Sectional Shear Distortion (CSSD).
3	Corner failures	Cross-Sectional Shear Distortion.
4	Transition zone	Out-of-plane bending of panels in the transition zone.
5	Cracks in the mid-span area	Insufficient buckling capacity in the trailing edge often caused by edgewise vibration



Damages lead to catastrophic failures

- Damages observed in the field are sometimes monitored by WTOs and not repaired until they reach a certain size (high risk).
- It is a risky approach, as the surface does not always indicate the “true” risk. In many cases the damage grows fast and the risk for failure is higher than anticipated.

Transverse crack

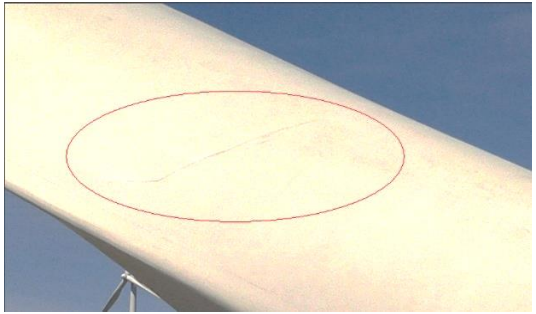
Surface observation

Under the skin observation

Rapid development

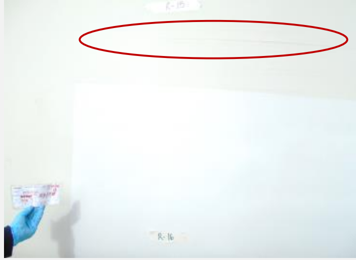
Common damage: transverse cracks

- In real life we have, regardless of today’s testing standards plenty of structural blade damages that occur again and again.
- The reoccurrence happens because root cause is not removed.

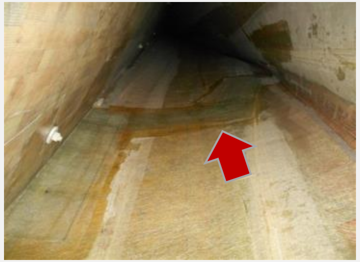


Transverse crack is found

Extensive repair is made



External crack



Internal crack

2 years after repair

- Cracks appear again in the same spot where repairs were previously made.

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Typical ”solution to damages” approach

Damages are observed

A repair is made

The root cause is not removed

Blade is brought back to operational state

“Normal” transverse crack repair on the ground

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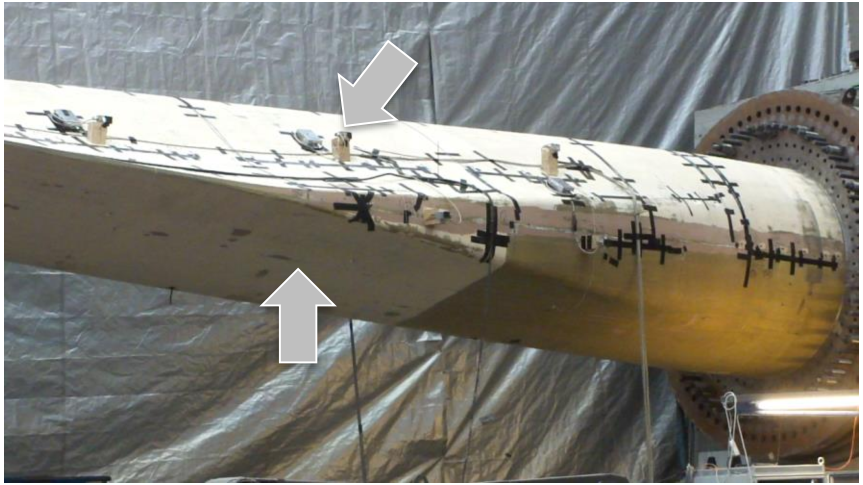
Damages are more than what is visible on the surface

A full-scale was used to point out "hidden" damages.

- Noises were heard during a full-scale fatigue test in an area where local bending of blade panels was observed.
- The blade was visually inspected, however no damages were found.
- The bending of the panels is not observed when the blade is stationary.



Out-of-plane bending of panels is observed during the blade fatigue test.

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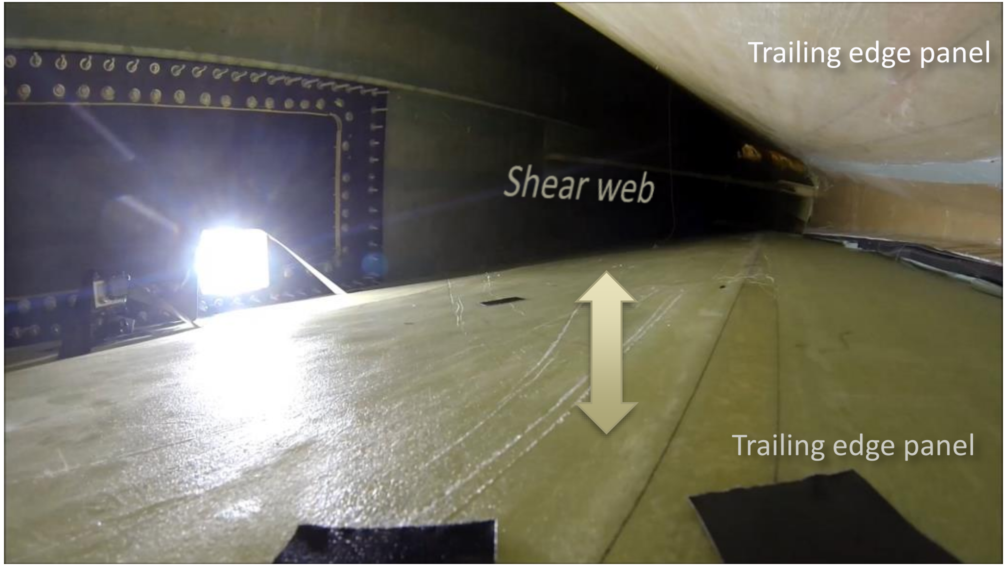
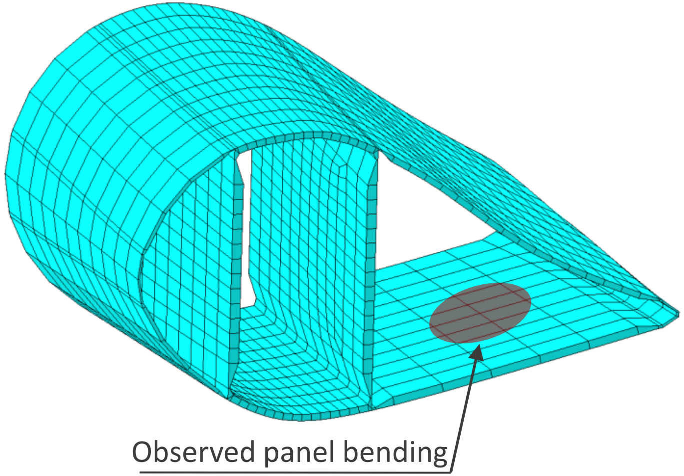
Damages are more than what is visible on the surface

- Internal camera surveillance during the test pointed out local out-of-plane panel deformation.
- Similar to the exterior visual inspection, no damage or deformation was observed when the blade was stationary.

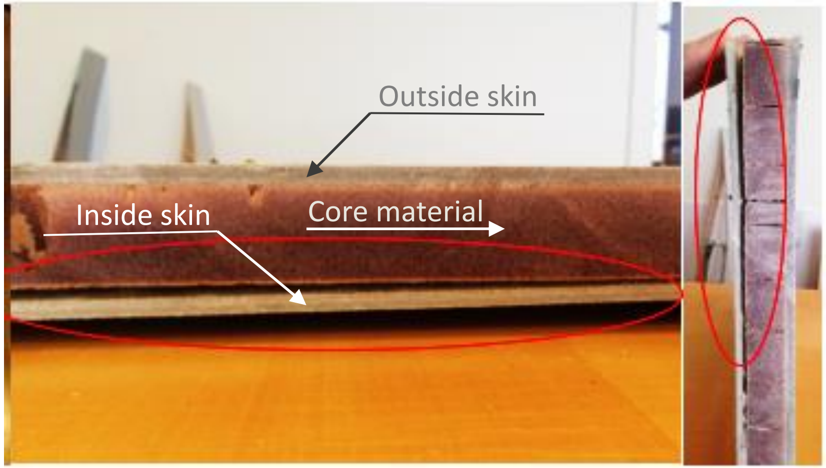




Inside view of the blade towards the trailing edge

Damages are more than what is visible on the surface

- The damage was confirmed when the blade was cut.
- A clear skin debonding from core in the inner skin was found.

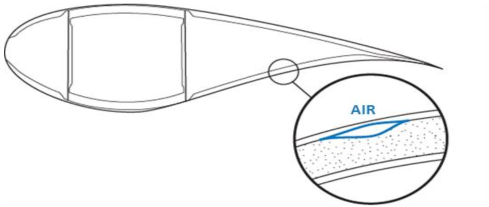


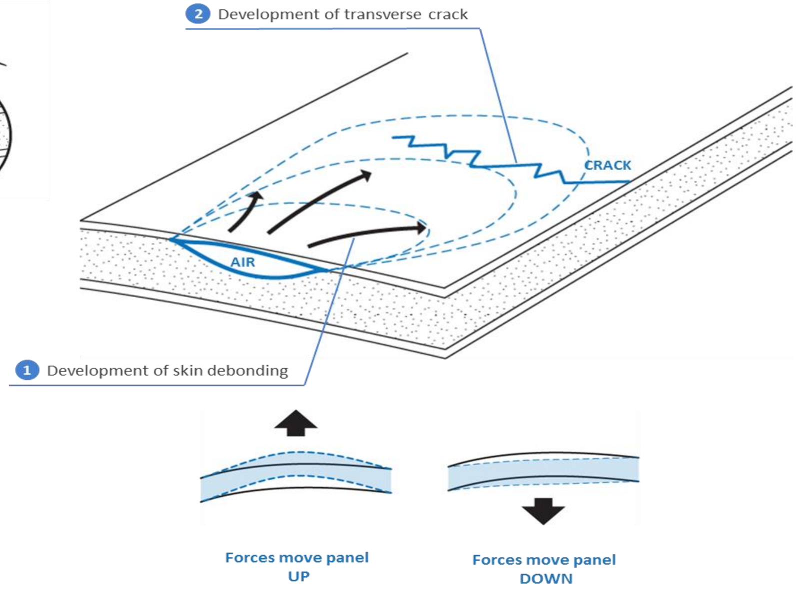
Inside view of the blade towards the trailing edge

Damages are more than what is visible on the surface

Conclusion:

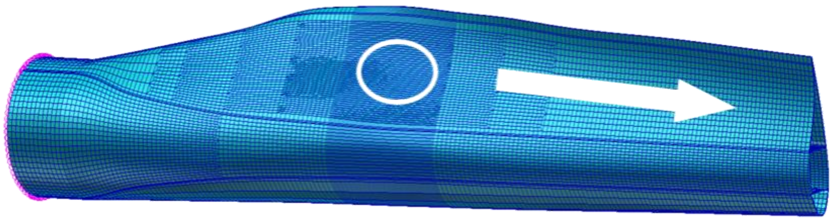
- In most cases, damages start under the visible part of blades and develop towards the surface.
- When damages are visible, an extensive zone underneath is already altered.

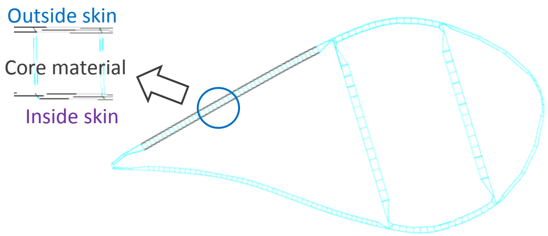


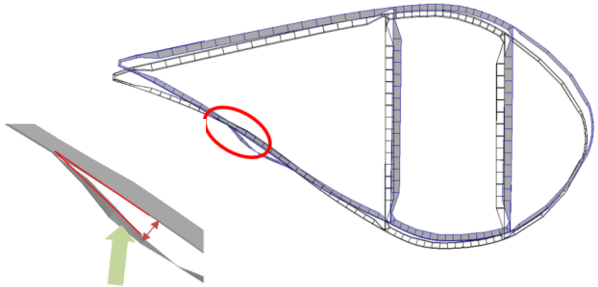


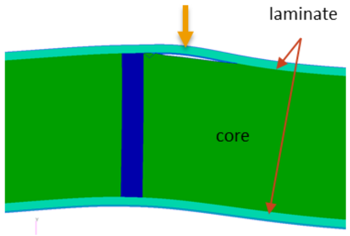
FEM moddeling of skin debonding

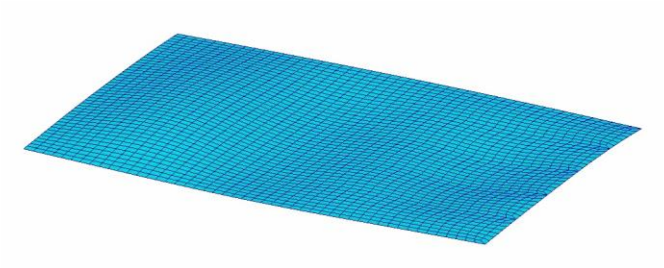
- FEM-analysis was carried out in order to understand trailing edge out-of-plane bending behaviour.











FEM analysis of an individual panel

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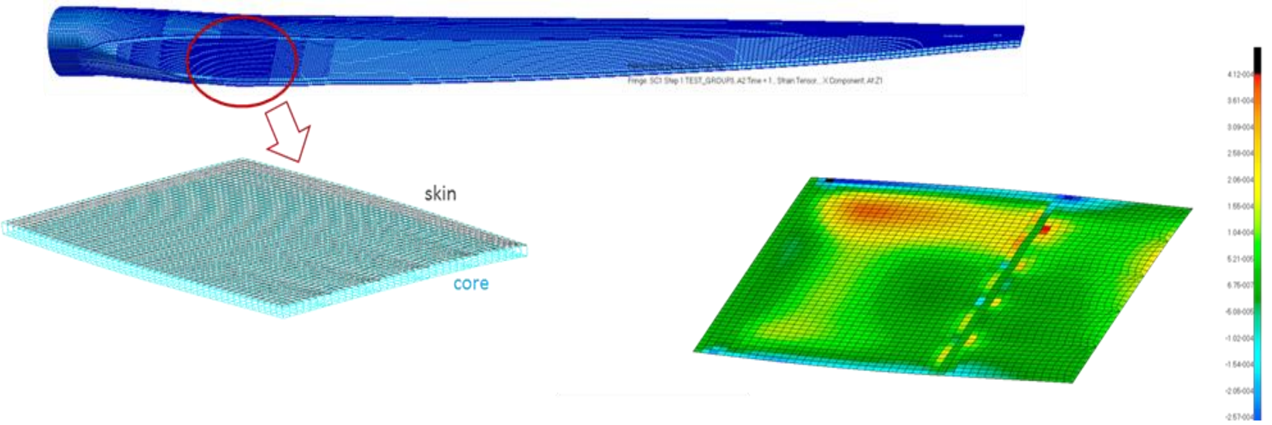
Crack propagation in sandwich panels

Conclusions:

- The strain level shifts, depending if only delamination occurred or a transverse crack was developed on top of the delamination.
- The delamination zone will have a non-ideal strain distribution and strain hot spots will appear. In these areas the material strength can be exceeded and cracks will develop.
- The developed cracks will cause a change of the deformation pattern and a new strain distribution will occur.



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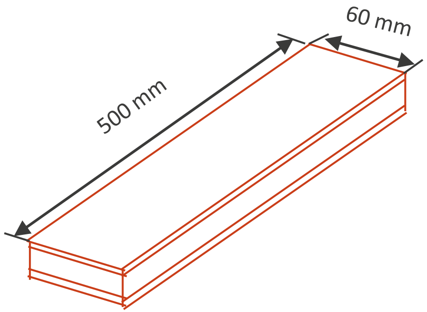
Transverse crack - 4-Point Bending Test

- A 4-point bending test campaign is undergoing.
- The specimens for the test are obtained from a used blade with PVC core and glassfiber reinforced Epoxy skins, constructed using a symetric lay-up $[\pm 45/0]_s$.
- Samples are cut both in the blade direction and perpendicular to the blade direction.



Sample size

Blade on the ground

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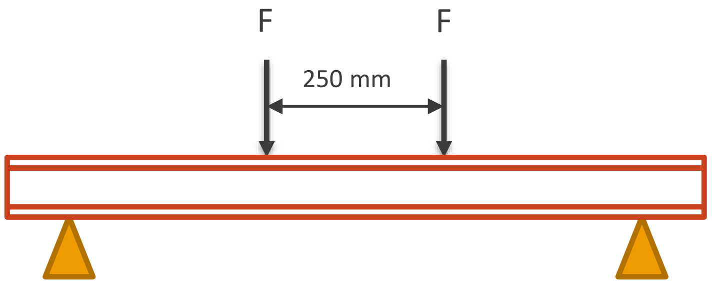
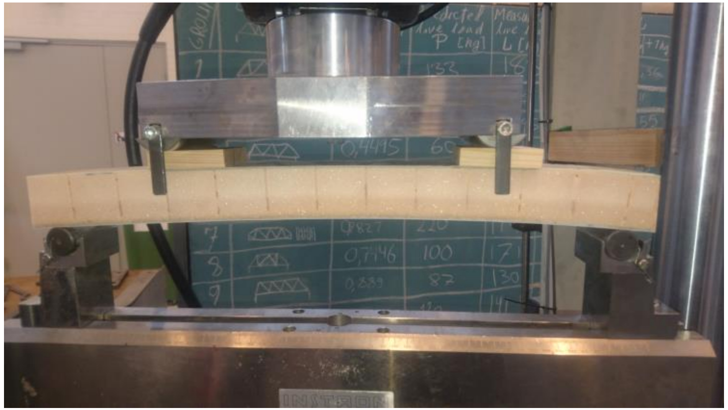
Transverse crack - 4-Point Bending Test

- The 4-point bending test has been performed at the lab test of the Technical University of Denmark (DTU)
- An initial debond of 100 mm is introduced in the samples to evaluate the crack growth
- Both static and fatigue tests have been performed





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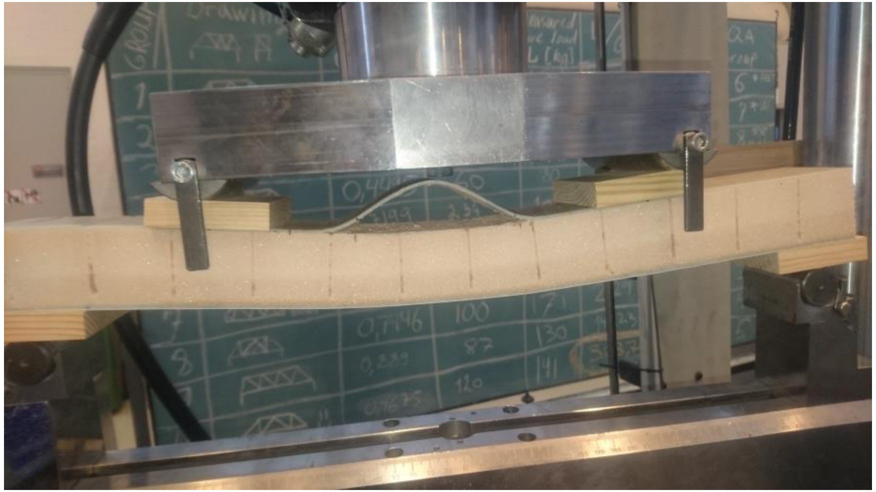
Transverse crack - 4-Point Bending Test

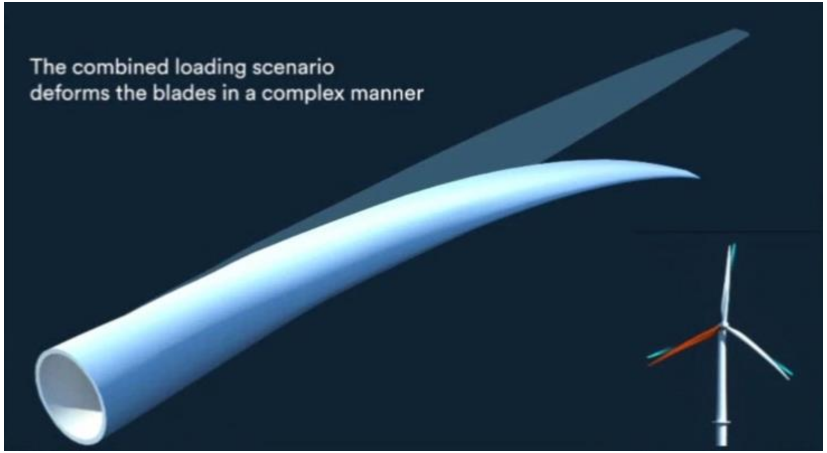
- The preliminary results validate the hypothesis:

  The bending of the panels will introduce crack groth for a panel with an initial sandwich core debond

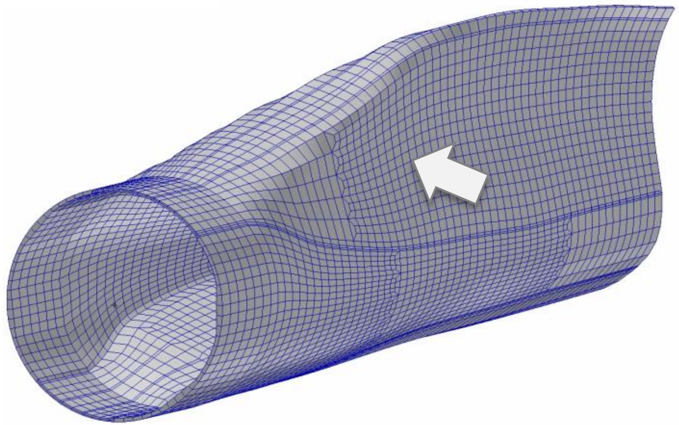


Root Cause

- The loads blade are subjected to induce a global bending behavior on both on flap and edge directions.
- The global blade bending leads to local trailing edge out-of-plane bending of the panels.



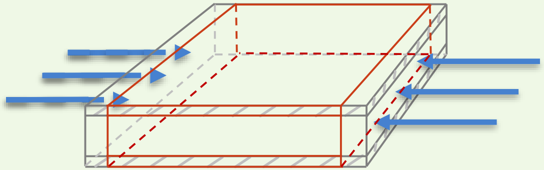
Global deformations



Local panel deformations

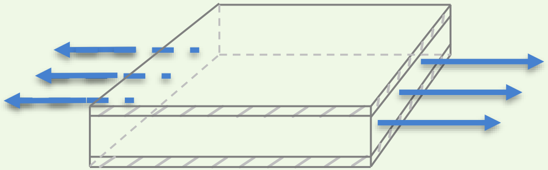
Bending of trailing edge panels

Case A: in plane bending

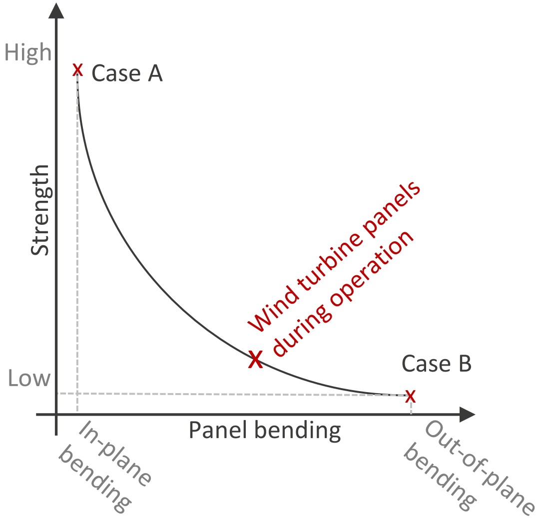


pure compression

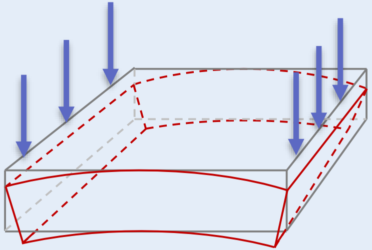
or



pure tension



Case B: out-of-plane bending



pure bending

Case A: *in plane bending* => max panel strength.
Case B: *out-of-plane bending* => min panel strength.

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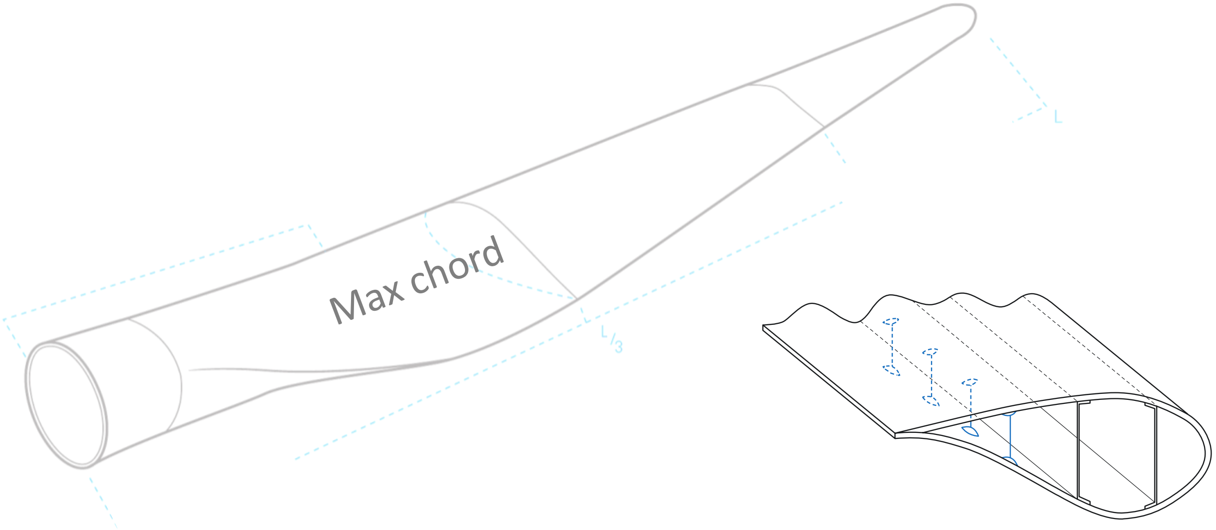
The solution

- Avoid local out-of-plane bending of the sandwich panels by connecting the two panels together.

- The root cause of damages is removed, hence the risk for damage reappearance is lowered, securing the AEP.



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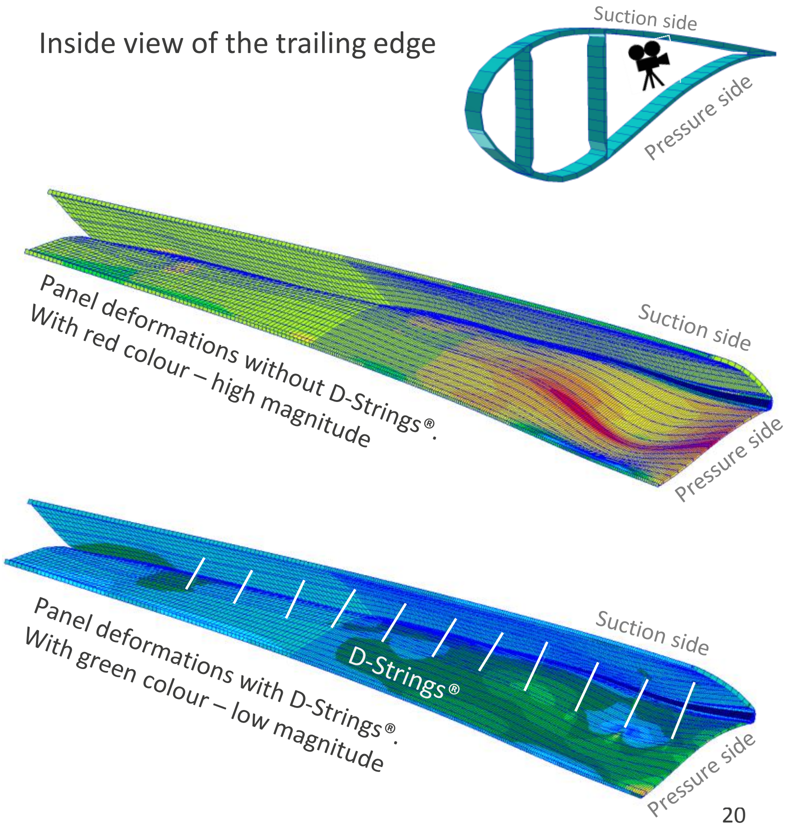
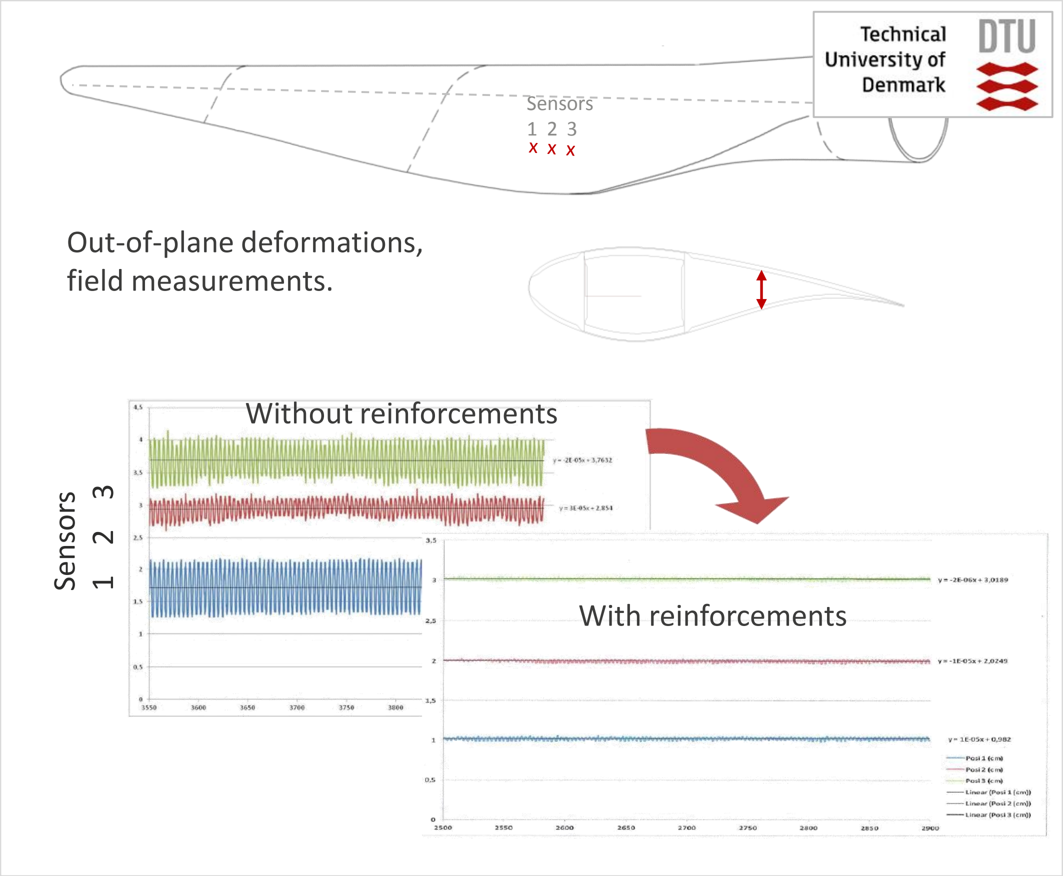
Out-of-plane bending removal

- Non-linear FEM simulations are used to study the influence of connecting the two panels together.
- The panel bending strain levels were evaluated and it was found the out-of-plane deformations are significantly reduced when a conenction of the two panels is made.



Field measurements



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Conclusion

Avoiding local out-of-plane bending deformations reduces the risk of cracks appearance.

Benefits:

- Increase the AEP from higher availability of the wind turbines.
- Reducing the maintenance costs for expensive recurring repairs.
- Improving the lifetime of the blades.
- Eliminate the risk of damage to the wind turbine.

Thank You

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